A SCIENTOMETRIC STUDY ON PORTRAIT OF NOBEL LAUREATES IN CHEMISTRY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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CERTIFICATE

This is to certify that the thesis entitled **"A Scientometric Study on Portrait of Nobel Laureates in Chemistry"** submitted by **Abhay Maurya** for the award of the Degree of Doctor of Philosophy in Library and Information is carried out under my supervision and incorporates the student bona-fide research and this has not been submitted for the award of any degree in this or any other university or institute of learning.

Place: Aizawl, Mizoram (Dr. Amit Kumar)

Date: Supervisor

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Month: February **Year: 2022**

DECLARATION

I, **Abhay Maurya**, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form the basis of the award of any previous degree to me or the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute

This is being submitted to Mizoram University for the degree of **Doctor of Philosophy in Library and Information Science.**

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(Prof. Pravakar Rath) (Dr. Amit Kumar)
Head of Department Supervisor

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Place: Aizawl (Abhay Maurya)

Date:

TABLE OF CONTENTS (SUMMARY)

TABLE OF CONTENTS (EXTENDED)

BS	Bachelor of Science
ct	carat
DNA	Deoxy Ribose Nucleic Acid
FRS	Fellow of the Royal Society
HCl	Hydrochloric Acid
h-Index	Hirsch Index
$KFe_2(CN)_6$	Potassium Ferrocyanide
kg	kilogram
KOH	Potassium Hydroxide
m	meters
MS	Master of Science
N_2O	Nitrous Oxide (laughing gas)
NaOH	Sodium Hydroxide
NH_3	Ammonia
NL	Nobel Laureates
PhD	Doctor of Philosophy
sec.	Second

The Nobel Prize *is a set of prizes that are awarded every year to academicians in recognition of their pioneering research work in the fields of academics, cultural, and scientific advancements by institutions in Sweden and Norway. The award was instituted as per the will of the Swedish chemist, industrialist, and engineer Alfred Nobel in 1895. The first set of five Nobel Prizes in chemistry, physics, literature, peace, and psychology was awarded in the year 1901 for outstanding work in these fields. To date, 184 academicians have been awarded the Nobel Prize in chemistry for their outstanding contribution to various branches of chemistry. This prize is regarded as the most prestigious award bestowed to an academician in his/her field of research.*

Scientometrics *is the study concerning analyzing and measuring scientific literature. It is a part of bibliometrics. This field of study concerns itself with measuring the impact of various research papers and academic journals, understanding the citations used, and the utilities of these measurements in the context of policy and management. This field of study assumes importance as there seems to be a high overlap between scientometrics and research areas in science which includes sociology of science, metascience, information science, information systems, and science policy.*

Scientometric portrait study refers to the quantitative analysis of all the publications of the scientist, either living or dead. It takes into consideration all the works of the scientist in his/her lifetime.

Key Words: *Nobel Prize, Chemistry, scientometrics, scientific literature, scientific citations, scientometric portrait*

CHAPTER - 1
INTRODUCTION

1.0 Introduction

Among all individuals who have dedicated their lives to the development of chemistry, literature, medicine, physics, and world peace, The Nobel Prize is the most coveted award that these individuals can receive. It is the distant dream of all researchers to be included in the list of Nobel Prize awardees. Nobel Prize awardees or Nobel Laureates, the term used to generally address them, are regarded as assets to the globe and the countries of their origin witness a steep rise in their prestige. The Nobel Prize has continued to receive much fanfare among all the global citizens, especially among the researchers. The Nobel Prizes chemistry, literature, medicine, physics, and world peace are awarded annually. As expressed by Alfred Nobel, which has been taken from his will, "the awards will be presented to individuals 'who have conferred the greatest benefit to humankind in the last 12 months". Nobel Prizes were first awarded in the year 1901, and the same has been going on till the present. However, these prizes were not conferred during the first and the second world wars. The prestige associated with the Nobel Prize can be gauged from the fact that this award has been compared with the "laurel wreath" that was conferred to various competitors in ancient Greece. The words "laurel wreath" has been modified as Laureate. Today, Nobel Prizes are awarded in six disciplines, with the inclusion of Nobel Prize in Economics which was added in the year 1968 by the central bank of Sweden from the grant that was given to it by the Nobel Foundation to commemorate the 300th anniversary of the bank. Economics was not included for the award in the will of 1895 left behind by Alfred Nobel. Several scholars have expressed their inability to regard prize in Economics as a Nobel Prize.

The process of awarding the Nobel Prize is long and arduous and commences with submitting of nominations by previous winners, professors from universities, and scientists. The process does not allow self-nomination. The process begins in the month of September every year and culminates on the 10th day of December, when the awards are finally presented to the rightful winners. While the awards under all the categories are awarded in Sweden, the Nobel Prize for peace is awarded in Norway. As per the doctrines in the will of Alfred Nobel and the conditions of nominations, the Nobel Prize can only be conferred to researchers and academicians during their lifespan and not after their death. Though the strictures in the will do not specify the number of researchers who are eligible to receive the prize in any category, the norm allows a maximum of three researchers to share the award in any category. The Nobel Prize is not a single award but includes a Diploma, a Medal, and a cash prize.

Nobel Prizes play a twin role. Besides recognizing the contributions made by any researcher for bringing betterment to the society, these prizes also help to motivate upcoming generations to follow further studies in these fields. R. P. Upadhye and others have suggested that all techniques are adopted that aid in projecting the entire lifetime accomplishments of all Nobel Prize winners who have become heroes after dedicating their lives to find the confirmable truth in the constrictive field in which he/she specializes (Upadhye, et al. 2004).

Almost every researcher who has spent his/her entire productive life in pursuing his/her research in such fields that have a positive effect on humanity receives recognition by receiving various awards and prizes during his/her lifetime. Despite being the recipient of several awards and recognition, they yearn for the Nobel Prize. The Nobel Prize exceeds all other prizes considering the magnificence and the status that is inherent to the prize. Several writers have written about the Nobel Prize: its history, its founder, the complicate and lengthy procedure involved in the process of electing the winners, and also their accomplishments. The reputation of the Nobel Prize has reached such heights that one can find 1500 journals with the words "Nobel" and "Nobel Prize" in the title in the database of 'Web of Science' (Karazija & Momkauskaite, 2004). A majority of these publications had been published to commemorate the 100^{th} anniversary of the foundation of this prize. For the benefit of interested students of science who wanted to have a glimpse of the Nobel Prizes, the materials concerning the Nobel Prize that are present in the Nobel archive and belonging to the first half of the 20^{th} century were made public during 2002. This development started a series of investigations on the process of nominations for the Nobel Prize, or "Nobel population". The investigators observed that several aspects went into the decision-making process of selecting the awardees: distribution of nominees according to country, national and international character in the nominations, winners or losers, most nominated scientists, the predominance of the male nominees, etc.

The Nobel Foundation has been given the responsibility of awarding the Nobel Prize. The Foundation is a private organization that was established on 29th June 1900 to fulfil the wishes of Alfred Nobel as mentioned in his will. The principal function of the Foundation lies in managing the finances left behind by Alfred Nobel and guarantying a constant financial resource for the Nobel Prize. The Foundation also guarantees freedom in the work of the recipients. Nobel Foundation has representatives from all the Nobel organizations. The will of Alfred Nobel restricts the Nobel Foundation from having any role in selecting the nominees or in choosing the winners. The high level of secrecy can be understood from the fact that the nominated individuals are even not aware of their nominations. The final selection of the individuals is made by the Prize Awarding Institutions who are independent entities and do not have any affiliation with any government agencies and organizations. These institutions are also not liable to the Nobel Foundation. The independence of the Prize Awarding Institutions is important as it helps maintain the purposes of the Nobel Prize and also to see that the best individual in the respective fields receive the awards.

Alfred Nobel died on 10th December 1896, leaving behind a will dated 1895. All the Nobel Prizes are being awarded as per his will. The first set of Nobel Prizes, barring the Nobel Prize in Economics, was presented in 1901 and has a close correlation with the history of modern science, arts, and political developments taking place throughout the entire 20th century. The provisions mentioned in the will left behind by Alfred Nobel had managed to attract global attention and led to severe unfavourable judgment and disbelief. The fact that the Nobel Prizes can be awarded to extraordinary people from across the globe did not go down well with the general population, who also criticized Alfred Nobel for internationalizing the awards. The Nobel foundation was established after skirting or overpowering several unending hindrances and difficulties and after several years of discussions which led to hostile conflicts. The covenants of the will were approved by the Norwegian Parliament (Storting) on the 26th day of April 1897. This paved the way for the foundation of the prize-awarding Norwegian Nobel Committee of the Storting and had elected representatives as its members. The other prize-awarding bodies were founded during 1898 as per the will through arbitration. These bodies include the Karolinska Institute, which was formed on 7th June, the Swedish Academy which was formed on

9th June, and the Royal Swedish Academy of Sciences which was formed on the 11th day of June.

1.1 Classical Methods

Dr. Shiyali Ramamrita Ranganathan, the mathematician, and librarian from India had, in the course of his presentation in 1948 at the ASLIB conference that was held at Lemington Spa, suggested that "there is a need to develop the subject of librametry on the same lines as biometry, psychometry, econometry, etc. considering that certain matters related to library science involve large numbers" (Rao, 1998). The term 'librametry' or 'librametrics' is formed by merging two words 'library' and 'metrics' and is used to include using mathematical models and statistical methods to evaluate library services. Though the opportunities of librametry had been defined in 1948, the subject did not receive appreciation prior to 1970 (Rao, 1998). Meanwhile, 1969 saw the coining of a new word, 'bibliometrics' that could be used to describe the process of enumerating all written communications (Pritchard, 1969). The scope of bibliometrics includes understanding the nature of written communication by way of analysing the different characters of written communication. There are different opinions on the ownership of the word 'bibliometrics'. While some scholars regard Pritchard as the founder of the word, other scholars mention the French origin and previous use of the word in French literature (Wilson, 1995; Fonesca, 1973; Otlet, 1934).

The basis of modern day scientometrics lies in the works of Derek J. de Solla Price and Eugene Garfield. Eugene Garfield has also created The Science Citation Index (Leydesdorff, L. & Milojevic, S., 2013) and has founded the Institute for Scientific Information which details the development of inter-correlated subject-disciplines. The term gained importance in 1977 after the journal "Scientometrics" was published by T. Braun in Hungary. This journal is presently being published from Amsterdam. The last few decades have seen huge industrialization of science which has led to a surge in the number of scientific publications and results. This has also increased the analysis of the data (de Solla Price, 1978). While the scope of sociology of science is limited to studying the behaviour of scientists, the scope of scientometrics is restricted to analysing the publications (Leydesdorff, L. & Milojevic, S., 2013). Based on what has been previously mentioned, scientometrics can also be defined to include the eperimental study of science and the results (Lowry, et al., 2004; Lowry, et al., 2013).

B. S. Kademani & V. L. Kalyane were the first to use the phrase "Scientometric portrait" to mean the process of biographical and bibliometric studies of prominent scientists, including the Nobel Laureates (Kademani, Kalyane & Kumar, 2001). A scientometric portrait can be defined as the study of those characters of the biography of researchers and scientists that include their careers to derive a relationship between the publications of their research and their accomplishments. The current study aims to look into Nobel Laureates' scientific efforts in the field of chemistry from its inception till 2019 and the roles they have played in the growth of chemistry.

1.2 Scientometrics Explained

The term'scientometrics dimensions' has been used to refer to the communication process and is considered a science of science that emphasises the quantitative parts of research. The term 'scientometrics dimensions' is used to represent a system of knowledge that are available in the field of science and technology and attempts to investigate the system of science and technology utilising a variety of approaches in a broad sense. As an integral part of the sociology of science, scientometrics has numerous applications, one of them being the formulation of scientific policies. The term "scientometrics" is the English version of the Russian term that is used to define the process of applying quantitative methods to the chronicle of science. The term "scientometrics" was coined in the magazine "Scientometrics," edited by T. Braun moved to the United States from Hungary in 1977 and quickly rose to fame. The journal is currently published in Amsterdam. The term'scientometrics' refers to the quantitative parts of scientific communication, as well as those aspects of society and culture that have grown associated with science over time. Some scholars believe that scientometrics is a field of sociology that may be used to make scientific policy. This viewpoint is based on the term's broad definition, which envisions a system of knowledge that aims to investigate many scientific and technical systems utilising a range of scientifically supported methodologies.

Several scholars which included J. Tague-Sutcliffe have defined scientometry as the study of the quantitative facets of science, either to enrich the subject or as a profitable business venture As a result, scientometrics is a multi-disciplinary study that includes the study of scientific behaviour, the history of science, the development of science and scientific institutions, the behaviour of science and scientists, and the formulation of policies and decisions that promote the growth of science and scientific temperament. Scientometrics is also known as the science of measuring and analysing. Bibliometrics, which is defined as the measurement of (scientific) publications, is used in scientometrics in practise. (Tague-Sutcliffe, 1992).

1.3 Scientometric Portrait

Bio-bibliometric analysis is the art of generating information about individual scientists in order to increase the odds of visibility for a good scientist who would otherwise be hidden from public view. This research has shown to be extremely valuable to anyone interested in the advancement of science and technology. A bio-bibliometric study, also known as biographical bibliometrics, scientometric portrait, or bio-bibliometrics, is the process of examining individual authors, scientists, or groups of authors/scientists' contributions to the advancement of science and scientific thinking over the course of their lives.

The mathematical and statistical study of a scientist's or researcher's career in order to associate their bibliographical analysis of publications with academic and scientific achievements is known as scientometric portrait research. The study of the scientometric portrait has recently gotten a lot of interest because of how useful it is to scientists in terms of highlighting many aspects of their careers, such as productivity based on biological age, collaboration patterns, authorship, and other factors (Sangam et al. 2006). S.K. Sen and S.K. Gan coined the term "bio-bibliometrics" to describe the quantitative and analytical methodologies used for the discovery and development of diverse structural correlations between the elements comprising biographical data and bibliographic data (Sen & Gan, 1990). The term ‘scientometric portrait’ was used for the first time in 1993 and was meant to include bio-bibliometric studies of scientists (Kalyane & Kalyane, 1993). Several scholars have, however, preferred to use the word ‘Information profile’ to describe such studies (Sinha & Bhatnagar, 1980; Sinha & Ullah, 1994). S.K. Sen used the term 'Micro-bibliometrics' to encompass research on respective scientists when presenting his paper on the theme 'Networking of libraries issues and possibilities' at the IASLIC Conference held at the famous Indian Institute of Technology, Bombay in 1994. (Sen, 1995).

Despite the fact that the word bio-bibliometrics is used to refer to both quantitative and analytical approaches for locating and analysing information, setting up a structural correlation between the elements that constitute biographical data and bibliometric data. Many studies on bio-bibliometrics haven't used the term in the title of their articles, despite the fact that it exists. Bio-bibliometrics is a word that has lately gained popularity as a tool for determining gene naming co-occurrence, words to retrieve and visualize genetic information medical science to create linguistic links between different genes (Stapley & Benoit 2000). It has, therefore, been recommended that both ‘scientometric portrait’ and ‘informetric portrait’ are befitting phrases that correctly define all studies that are conducted on scientists, as well studies concerning researchers who have enriched our knowledge of other subjects like Arts, Humanities, and Social Sciences.

1.4 Study of Chemistry as a Subject

Chemistry is the study of atoms, molecules, ions, elements, and compounds, as well as their structure, composition, characteristics, behaviour, and reactions. Chemistry is a branch of science that sits between physics and biology in terms of scope. The word chemistry comes from the Greek word alchemy, which refers to a collection of intuitive but non-scientific disciplines that include chemistry, metallurgy, philosophy, astrology, astronomy, mysticism, and medicine. Organic chemistry, inorganic chemistry, and physical chemistry are some of the sub-disciplines of chemistry. Analytical chemistry, biochemistry, surface chemistry, fuel chemistry, neuro chemistry, nuclear chemistry, and so on are some of the different fields of chemistry (Wikipedia, n.d.)

1.5 Significance of the Study

Due to its utility in comprehending the growth of literature or trends in related subjects or within a specific geographical area, the usage of scientometric research has increased in recent years. Several scientometric studies have been undertaken at both the micro and macro levels to analyse research in certain disciplines. Aside from that, scientometric research focusing on Nobel Laureates has also been carried out. Although there are fewer field-specific scientometric studies, none have been undertaken to date that cater to the scientometric portrait of Nobel Laureates in Chemistry. This research aims to fill the hole that has been created in the literary world. Since the award's establishment in 1901, the current study will provide a scientometric portrait of all Nobel Laureates in Chemistry. The total number of research articles published in various journals, as well as the total number of citations obtained, are used to determine all scientometric indices. Other indicators like as the h-index, SJR index, g-index, and citations are now used to determine the quality of research, and these characteristics also help to boost the reputation of Nobel Laureates and the fields in which they operate. This piece of research helps scientists and individual researchers to understand and build an interest in developing equivalent measures for other areas, as well as provide an overview of the field's strengths and flaws. Furthermore, future LIS scholars may be enticed to do similar studies in order to better understand different subject domains. This study's findings are also likely to yield some significant findings. Apart from what has already been stated, the current research will aid in the creation of a scientometrics portrait of Nobel Laureates in Chemistry by analysing author-by-author research productivity, domain-by-domain contributions, domain-by-domain authorships, prominent collaborators, document type research productivity, total research documents, total citations, co-author network, international collaboration, channels of communication, keywords analysis, and so on.

1.6 Scope of the Study

The focus of this research is limited to examining the scientometrics portraits of all Nobel Laureates in Chemistry from 2014 to 2018. The study's goals include:

a) Determining the number of scientific communications contributed by Nobel Laureates;

b) Determining the number of scientific communications contributed by Nobel Laureates.

c) A study of Nobel Laureates' domain-specific scientific communication, authorship patterns, and communication routes;

d) An examination of the authorship credits of Nobel Laureates' collaborators; and

e) Discovering the Nobel Laureates' citation network.

The names of scientists who have won the Nobel Prize in chemistry and who fall within the scope of this study have been compiled for reference.

Table 1: List of Nobel Laureates in chemistry from 2014 to 2018

S. No.	Year	Name	Rationale
01	2014	Eric Betzig	For the development of super-resolved fluorescence microscopy.
02		Stefan W. Hell	
03		William E. Moerner	

04	2015	Tomas Lindahl	For mechanistic studies of DNA repair.
05		Paul L. Modrich	
06		Aziz Sancar	
07	2016	Jean-Pierre Sauvage	For the design and synthesis of molecular machines.
08		Sir J. Fraser Stoddart	
09		Bernard L. Feringa	
10	2017	Jacques Dubochet	For developing cryo-electron microscopy for the high-resolution structure determination of biomolecules in solution.
11		Joachim Frank	
12		Richard Henderson	
13	2018	Frances Arnold	For the directed evolution of enzymes.
14		George P. Smith	For the phage display of peptides and antibodies.
15		Sir Gregory P. Winter	

1.7 Review of Literature

Without a review of the existing literature on the issue, no research project is complete. Such reviews can help any researcher define the scope of their research by incorporating new ideas, concepts, approaches, methods, and procedures. A survey of the literature reveals the numerous approaches to solving each given problem. During the course of this research, an attempt was made to give a thorough evaluation of related literature on the subject, which is listed below:

(a) Scientometric Portrait of James Allison: James Allison and Tasuku Honjo received the Nobel Prize for Physiology or Medicine in 2018. James Allison was an immunologist who was born on August 7, 1948, in the United States. Allison's articles have been subjected to a scientometric study. Allison has received various honours and medals in the field of biochemistry, culminating with the Nobel Prize. During his 47-year publishing career, from 1971 to 2018, he published 439 papers, which were retrieved for the study from Clarivate Analytics Web of Science. At the age of 22 years and 7 months, he had his first manuscript published in a journal. 238 papers have been published in the last 18 years with effect from 2001 up to 2018 from a total of 439 papers. From 1981 through 1990, he had an annual publication growth rate of 13.03 percent, with an average publishing growth rate of 4.39 percent. Allison's work has been mentioned 45904 times as of January 7th, 2019. For publicising his research papers, James Allison had 111 routes of contact. The Journal of Immunology, which has 51 publications, and the Proceedings of the National Academy of Sciences of the United States of America, which has 31 publications, are only two of the outlets that have published the majority of his work. Allison worked on his studies with 31 different countries. P. Sharma (64 publications) and J. Walchok (36 articles) are two of his most notable co-authors. J Yuan was a co-author on 24 papers, followed by A. Hurwitz with 22 papers, and M. Pellegrino and X. Zang with 19 papers each (Mohan & Kumbar, 2019).

(b) Scientometric Portrait of Amartya Kumar Sen: Amartya Kumar Sen is an Indian economist and the first Asian who received the Nobel Prize in Economics in 1998. He was born in the year 1933. In addition, Dr. Sen has received various national and international honours, including the Bharat Ratan, the country's highest civilian honour. Amartya Sen's scientometrics portrait has been the subject of investigation by a number of academics. In the framework of this research, I looked into Nilaranjan Barik and Puspanjali Jena's findings. Their research covered publications from 1969 to the 31st of December 2015. During this time (46 years), Dr. Sen produced 111 research articles, averaging 2 to 3 each year, with the exception of 1970, 1971, 1972, 1979, 1982, 1994, and 2006, when he published no articles. His first publication, however, was published in 1969 when he was 36 years old. Dr. Sen got the Nobel Prize for Physics at the age of 65, with 44 research papers to his credit, and the Bharat Ratna at the age of 66, with 48 research publications. Dr. Amartya Sen disliked collaborations and preferred to publish his works as single-authorship papers, according to the study. The authors discovered that 100 of the 111 articles studied were single-authored, with the other 11 papers being co-authored. Needless to say, Dr. Sen's collaboration coefficient was abysmally low at 0.09, according to the study. Two authors (6 articles), three authors (4 papers), and four authors (4 papers) are among the publications published in collaboration with other authors (1 paper). With two papers apiece, K. Arrow and K. Suzumura stand out among the co-authors. In terms of citations, which are regarded as a critical metric for determining the efficacy of any research, the study found that 89 papers (80.1 percent) were cited by different writers out of the 111 included in the study. Twenty-one other works (18.9%) were mentioned more than 100 times. Though Amartya Sen is a proponent of theoretical economics, his research encompasses a wide range of topics, including practical economics. The survey found that econometrics and finance accounted for 62 (55.86 percent) of the research, while social sciences accounted for 61 (54.95). Arts and humanities (19.12 percent) and medicine (17.32 percent) are two additional prominent areas (Barik & Jena, 2016).

(c) Scientometric Portrait of Prof. Rudovik R. Kazwala: Prof. Rudovik R. Kazwala is a renowned Professor of Veterinary Medicine and Public Health at the University of Florida's Faculty of Veterinary Medicine. A scientometrics analysis of his works shows that he began publishing at the age of 32 in 1990 and has continued to this day, with the exception of 1991 and 2002. 83 journal articles, 26 conference papers, and two book chapters were among the 111 publications recovered from the web using the Publish or Perish software between 1990 and 2015. Prof. Kazwala has a 26-year publishing career that may be separated into five quinquennial eras. His most productive times were the fourth and fifth quinquennial periods, when he authored 30 pieces each. The 2nd quinquennial era has 21 papers before to this one. With only 8 publications, the first quinquennial period was the least productive. Beginning in 2008, 54 publications, or over half of his total published articles, were published in the later portion of his active life. These findings indicate that his publication production has increased significantly in the second half of his professional career. Prof. Kazwala's writings are almost entirely collaborative. Six or more writers contributed to 70 articles, with the largest number of authors in a single work being 103. Prof. Kazwla is also the lead author in 20 publications, the second author in 17 papers, and the third author in 21 papers, according to the study. Prof. Kazwala has collaborated with 475 other researchers, the most notable of them are D. M. Kambaage (25 papers), S. Cleaveland (17 papers), and J. M. Sharp (16 papers). All of Prof. Kazwala's papers have been published in 38 journals that follow Bradford's Law of Scattering. The publication density and concentration are calculated to be 2.18 and 23.68, respectively, in the study. Kazwala's works have received 2057 citations, despite the fact that 26 of them have yet to be cited. The average number of citations per manuscript and the average number of citations per year are 82.64 and 18.95, respectively. An h-index of 29, a g-index of 43 make Prof. Kazwala a role model for the younger generation (Sife & Bernard, 2019).

(d) Scientometric Portrait of Eugene Garfield: Eugene Garfield, an American scientist who is widely regarded as one of the founders of scientometrics and bibliometrics, was born in New York City on September 16, 1925. The Web of Science database contains a complete list of his publications from 1954 to 2009.

Garfield has published 1501 publications, according to a review of his work. The majority of his publications are scientific research articles, journal editorials, talks, letters, abstracts, book reviews, research notes, and reviews. 1443 papers, or 96.12 percent of all publications, were single-authored, while 58 papers, or 3.87 percent, were co-authored by multiple authors. The papers having more than one author have been further subdivided into 35 papers having two authors, 14 papers having three authors, 3 papers having six authors, 2 papers each having five and nine authors, and I paper each by seven and eight authors. Garfield's first work was published in 1954, when he was 29 years old. His scientific productivity increased as he grew older, peaking between the ages of 47 and 65, when he authored 50 to 70 publications per year. The study also demonstrates that productivity has been steady from 1954 to 2009. Garfield had a great number of foreign partnerships, with the highest cooperation rate of 0.26 between 1964 and 1968, accounting for 3.86 percent of his works. From 1963 to 1967, he collaborated with I. H. Sher on eight occasions, followed by A. Welljamsdoraf on seven occasions from 1990 to 1992. A.I. Pudovkin (6 partnerships from 2002 to 2004) and G. S. Revesz were the other contributors (1967 to 1973 with 5 collaborations). Garfield's writings were also published in 86 distinct channels of communication, according to the study. Current Contents (1154 papers), The Scientist (146 papers), Journal of Chemical Documentation (12 papers), Nature (12 papers), American Chemical Society Abstracts of Papers (10 articles), and Science Magazine (10 papers) are among them (10 papers). Garfield's h-index was calculated to be 30, indicating that his works had earned the most citations (Sangam &Shivappa, 2010).

(e) Scientometric Portrait of G. Thanikaimoni: G. Thanikamoni (1938–1986), lovingly known as Thani, was an eminent Indian palynologist who was born on January 1, 1938, in Madras (formerly Chennai) and received the prestigious Fyson Prize in Natural Science. Thanikamoni published 56 papers between 1965 and 1991, five of which were published posthumously between 1986 and 1991. During the years 1967, 1971, 1982, 1989, and 1990, no publications were found. He published 56 works between 1965 and 1991, including 21 journals, 14 books, 10 chapters, 9 conference papers, and one thesis and one set of notes. Thanikamoni's works on palynology account for 51.79 percent of her output (29 out of 56 papers), with 35 of them being self-authored. The collaboration coefficient and the number of authors per publication were calculated to be 0.36 and 2.22, respectively, in the study. The author's productive life began when he was 27 years old and lasted 27 years. During that time, he published 50 papers on his own and 6 papers in collaboration with others. Thanikmoni published 56 papers through 14 channels of communication, with Pollen et Spores publishing a maximum of 7 pieces. The productive years of each individual were limited to the first, second, and third years, with 12 papers published in each. Till 1988, Thanikmoni collaborated with 25 researchers, with C. Cartini serving as the primary collaborator from 1973 to 1988, resulting in eight publications. Thanikmoni is responsible for 58.94 percent (56 of 95) of the authorship credits (Saravanan & Prasad, 2012).

(f) Scientometric Portrait of Michael Arijan Thelwall: Thelwall, who was born on February 5, 1965, is a Professor of Information Science at the University of Wolverhampton and the leader of the Statistical Cybermetrics Research Group. The study looked at 297 of Thelwall's papers from 2000 to 2015 that were found in the Scopus International Database. The 297 publications included 213 articles, 56 conference papers, 21 reviews, 5 chapters, and 1 erratum, according to the study's findings. The papers were divided into 57 single-authored publications, 136 publications with two authors, 63 publications with three authors, 21 publications with four authors, 7 publications with five authors, 8 publications with six authors, and 2 publications with seven authors, based on authorship. Each of the eight, ten, and twenty-eight authored pieces received one publication. 123 papers feature Thelwall as the only author, while 174 have co-authors. According to the study, there are 745 co-authors, divided into two and three-authored (67 percent) and single-authored (33 percent) (19 percent). In terms of paper publication dates, the investigation discovered that Thelwall published his first two papers in 1991, when he was 26 years old. These studies, however, were not included in the research. 66 papers were published in the five years from 2000 to 2004, followed by 1012 papers from 2005 to 2009 and 130 papers from 2009 to 2015. In the study, a joint effort in publications was seen in varied degrees. While single-authored papers were the most common in 2000, 2001, and 2003, multi-authored papers were more common from 2003 to 2012. In 2013 and 2014, however, there were no single-authored publications, bringing the percentage of single-authored and multi-authored papers to 19.19 percent and 80.81 percent, respectively. In terms of the degree of collaboration, the study found values of 0.11 in 2001, 0.95 in 2007, and 1 in 2013 and 2014. The degree of collaboration was calculated to be 0.74 on average, suggesting his inclination for collaborative work. The collaboration coefficient followed a similar pattern, with readings of 0.07 in 2007 and 0.59 in 2014. The investigation also reveals that Thelwall collaborated with 158 others, the most notable of whom were K. Kousha (27 papers) and D. Wilkinson (20 papers). 213 papers were published in 47 different channels of communication, out of the 297 papers that were studied. The Journal of the American Society for Information Science and Technology published 46 papers, followed by 26 papers in Scientometrics, 17 papers in Journal of Informetrics, 13 papers in Journal of Information Science, and 11 papers in the Journal of Documentation and the Journal of the Association for Information Science and Technology, respectively (Vellaichamy & Amsan, 2016).

(g) Scientometric Portrait of S. Chandrasekhar: Subrahmanyan Chandrasekhar was born in Lahore on October 19, 1910 and is regarded as one of the world's premier astrophysicists. He was the recipient of numerous medals and honours, including the Nobel Prize, which he received in 1983. Throughout his life, Dr. Chandrasekhar held a number of prestigious positions. Dr. Chandrasekhar began publishing his writings, either alone or in collaboration, when he was 18 years old in 1928 and continued until 1990. During this time, he published 380 papers in various journals, book chapters, research papers, and conference proceedings on diverse physics issues. He has also written a couple astrophysical books. Chandrasekhar worked with 48 co-authors on 421 publications over his publishing career, with N.R. Lebovitz (22 papers) and D. D. Elbert among the most notable (15 papers). In 1953, he also collaborated on two publications with Nobel Laureate Enrico Fermi. There are 267 single-authored works, 105 two-authored works, and 8 three-authored works among his publications. From 1983 to 1987, Subrahmanyan Chandrasekhar had the greatest collaboration coefficient of 0.5, while his production coefficient was 0.46. According to the analysis, Subrahmanyan Chandrasekhar's production was at its peak in the first 29 years of his publishing career. Chandrasekhar's writings were published across a total of 46 avenues of communication. Astrophysical Journal published 139 papers, Proceedings of the Royal Society A published 59 papers, Monthly Notices of the Royal Astronomical Society published 31 papers, Proceedings of the National Academy of Sciences published 14 papers, and Observatory published 10 papers. All of the bibliometric measures show a high degree of efficiency that would be difficult to achieve, according to the study's conclusion. The writers went on to say that Subrahmanyan Chandrasekhar's work can serve as a model for future generations (Kademani, Kalyane, & Kademani, 1996).

1.7.1 Research Gap

The retrospective search of the literature was carried out and relevant literature has been discussed and reviewed year wise on different aspects. There is a number of studies available on the scientometric portrait of individual scientists viz. Biologists; Information Scientists; Physicists; Chemists; Nobel laureates in the field of Medicine and Physics; Physiology; Mathematics; etc. It is evident from the study that few studies have been conducted on subject domains at a small level. More specifically the study of scientometric portraits of Nobel Laureates in the field of Chemistry is not carried out so far. So, the present study an attempt to fill up the gap in the proposed area.

1.8 Research Design

1.8.1 Statement of the Problem

The exponential growth of literature and rapid development of libraries generated several evolutionary studies about the effectiveness and efficiency of information services. These studies led to the identification and application of appropriate quantitative measuring techniques known as Scientometrics. Scientometric assessment of research is a kind of process to identify the growth and development of published research output in a specific subject domain with the help of various scientometric indicators. Library and Information professionals throughout the world began to use scientometric studies to throw light on the pattern of growth of literature, collaborative research, the ranking of journals, inter-relationship among different branches of knowledge, productivity and influence of authors, the pattern of the collection built up, their use, etc.

An exhaustive literature survey was made to know whether the study on the scientometric portrait of scientists in the field of science & technology, and social sciences has been done or not; and found number of studies on the scientometric portrait of scientists in the field of science & technology as well as social sciences. Researchers have conducted numbers of studies in certain fields of specific subject domains but observed rare studies in the field of Chemistry itself and particularly the scientometric portrait of Nobel Laureates in Chemistry has not been found from any corner of the world till today. Due to lack of such research in the field of Chemistry and personal interest towards conducting the study on Chemistry, need arises to draw the scientometric portrait of Nobel Laureates in Chemistry. Therefore, the study is an attempt to fill up the gap created in the field of Chemistry especially with contribution of Nobel Laureates.

1.8.2 Objectives of the Study

The objectives of the study area to:

i. Assess the number of scientific communications contributed by Nobel Laurates;
ii. Analyze the domain-wise scientific communication of Nobel Laureates;
iii. Analyze the domain-wise authorship patterns of Nobel Laureates;
iv. Analyze the year-wise authorship patterns of Nobel Laureates;
v. Find out the channels of communication used by Nobel Laureates;
vi. Author performance based on available metrics indicator;
vii. Aanalyze the scientific collaborations; and
viii. Find out the research network of Nobel Laureate.

1.8.3 Research Methodology

The project is self-exploratory, and its goal is to use scientometrics indicators to create a portrait of Nobel Laureates who received the coveted prize in Chemistry between 2014 and 2018. Since its introduction in 2014, the Nobel Prize in Chemistry has been awarded to 15 Nobel Laureates. The study includes all 15 Nobel Laureates. Various factors used to measure research are included in the scientometrics portraits of Nobel Laureates. The study looks at author-by-author research productivity, domain-by-domain contributions, domain-by-domain authorships, notable collaborators, document-type research productivity, total research documents, total citations, co-author network, international collaboration, communication channels, and keyword analysis, among other things. And further, to maintain the uniformity in references and text citation, the latest version of APA 7th ed. has been used.

1.8.4 Parameters of Study

Various factors to measure the research are included in the scientometrics portrait of Nobel Laureates. The research looked at author-by-author research productivity, domain-by-domain contributions, domain-by-domain authorships, prominent collaborators, document-type research productivity, total research documents, total citations, co-author network, international collaboration, communication channels, and keyword analysis, among other things.

1.8.5 Time Frame of Study

The study coveres the Nobel Laureates in Chemistry awarded during 2014-2018. Due to the selection of broad parameters for the study, huge contributions of individual Nobel Laureates in the field, qualitative indicators of the study, and timely completion of the work it was decided to choose the 5-year time frame for the study i.e., 2014-2018.

1.8.6 Population of Study

There are 15 Nobel Laureates awarded Nobel Prize in the field of Chemistry during 2014-2018. All the 15 Nobel Laureates were selected as sample of the study. The scientific communications produced by the 15 Nobel Laureates of Chemistry have been analyzed in the present study.

1.8.7 Data Collection and Analysis

The raw data have been gathered from a variety of databases, including Scopus, Web of Science, and others, because these databases are the most well-known, widely used, and largest of all bibliographic, abstract, and full-text databases worldwide. After that, the raw data was tabulated in an MS-Excel/CSV file. A considerable number of Nobel Laureates' works can be found in the scholarly journals indexed in these databases. All of these databases include a huge number of journals from a variety of international publishers covering a wide range of topics. Furthermore, both Web of Science and Scopus are citation databases of peer-reviewed literature that provide the most comprehensive perspective of the world's research output in all sectors of academic disciplines. Web of Science and Scopus databases were chosen for the collection of data to display broader perspectives on research in chemistry for Nobel Laureates because they cover the most research in numerous disciplines. Furthermore, using appropriate scientometrics methods, all bibliographic/scientometrics details are evaluated and analysed. The raw data is evaluated to ensure that the study's goals and objectives are met.

1.8.8 Chapterization

The present study consists of the following chapters:

Chapter 1: Introduction explains about about the basics of chemistry discipline and scientometric followed by review of literature related area, research gap, significance of the study, scope of the study, research design. In short, the chapter provides a brief introduction about the research conducted.

Chapter 2: Chemistry: History, Scope, Philosophy, and Relationship explains about history of chemistry, division of chemistry, scope of chemistry and relation of chemistry with other science.

Chapter 3: Nobel Prize: History discusses about the history of Nobel Prize, Nobel foundation and its functions, and Nobel statistics.

Chapter 4: Profile of Nobel Laureates in Chemistry (2014-2018) highlights the biographical detail of Nobel laureates who won Nobel Prize during 2014 to 2018.

Chapter 5: The Science behind Scientometry gives a quick view of history of Scientometric and scientometric theory which included citation analysis, scattering, bibliomerics laws, metrics indicator (Journal, author, and article).

Chapter 6: Data Analysis and Interpretation explains research methodology in beginning mentioning database and software used for the result output. It also explains scientists' performance with the help of bibliometrics and scientometrics indicator.

Chapter 7: Findings and Conclusion puts forward the research finding followed by conclusion and suggestion for further studies based upon previous chapter.

Bibliography

1.9 Conclusion

The scope of the present chapter lies in introducing the subject to the readers. While the historical aspect of scientometrics has been mentioned in detail, the study of chemistry as a subject has also been included. As a prelude to the future chapters, this chapter contains the scientometrics portraits of researchers in various fields. The chapter ends with explaining the rationale behind the study and also the methodology adopted for extracting data in respect of Nobel Laureates in Chemistry. The chapter finally ends with outlining the arrangement of future chapters in the thesis.

After discussing a brief introduction about the present research problem, its objective & significance, review of literature, research design and chapterization, the next chapter namely "Chemistry: History, Scope, Philosophy, and Relationship", shall be dealing with the concept of chemistry and sub-domain & relationship with other domain.

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CHEMISTRY: HISTORY, SCOPE, PHILOSOPHY & RELATIONSHIP

2.0 Introduction

"I never knew that chemistry is applied to so many things in everyday life! I knew that there would be a lot of math involved and just thought that we would be studying science more in-depth. Now that I've read this, I am more interested in studying chemistry at school." – Jonathan Liu, Professor of Global Business Management, Regent's University, London

From a beginner's perspective, science is a conglomeration of different disciplines that include, inter alia mathematics, physics, chemistry, and biology. When one speaks about chemistry, certain terms like elements and compounds comprising atoms, molecules, and ions come to our minds. The basic purpose of studying chemistry is to have a clear understanding of the composition, properties, behavior, structure, etc., of the terms stated above and the changes these undergo during a chemical reaction (Chemweb; Merriam-Webster; Dictionary.com).

Some intellectuals regard Chemistry as the central science due to its ability to impart an understanding of both the basic and applied scientific disciplines at a rudimentary level (Theodore et. al., 1999). No doubt, chemistry has been given a position between physics and biology (Reinhardt, 2001). Knowledge of chemistry is essential to have a clear understanding of other branches of science be it botany, geology, pharmacology, forensics, etc. The study of chemistry bestows an in-depth knowledge of how elements change into compounds and vice-versa. To understand both the behavior of substances around us and how this behavior could be adjusted to help humankind comes under the ambit of chemistry as a subject under scientific discipline.

The United Nations has declared 2011 as the International Year of Chemistry. This is an initiative by the International Union of Pure and Applied Chemistry (IUPAC) and the United Nations Educational, Scientific, and Cultural Organization (UNESCO) to encourage chemical societies and global academics and institutions for organizing local and regional level activities promoting interest in the field of chemistry.

2.1 Origin of the Word

The word chemistry is derived from the word *alchemy,* a word that is used in many forms all over Europe. The word *alchemy* finds its origin in the Arabic word *kimiya* or *al-kimiya* whose origin can be further traced to the Coptic *khemeia* (Simpson & Weiner, 1999; Anawati, 1996). However, the ultimate origin of the word has baffled academics to date (Encylopedia Britannica, 2002). The Oxford English Dictionary, however, traces the origin of the word *al-kimiya* to the Egyptian word for 'blackness'. Certain linguists use the term *al-kimiya* to mean 'cast together' (Weekley, 1967).

Two different concepts regarding the origin of the word 'chemistry' emerge as one dives into the depth of the knowledge of the same. As per the understanding of renowned Egyptologist Wallis Budge, the word chemistry finds its origin in the ancient Egyptian word *khemia* which can be interpreted as 'transmutation of the earth' encompassing science of matter at an elementary level and dealing with metals, crystals, and molecules. From the writings of Diocletian, which is written in Greek during 300 A.D., the resistance to the Egyptian interpretation of transmuting gold and silver is evident (Oxford English Dictionary Online). For the propounders of the Greek origin, the Arabic word *al-kimiya* is derived from the Greek word khymeia, which translates into English as the art of alloying metals. According to Mahn, the Greek word has been traditionally used to mean pouring together, casting together, etc (Douglas). If the Greek origin is agreed upon, origins of the term chemistry can be retraced to 'cast together' or 'pour together' and defined as the science of matter at a minute scale and dealing with the collection of atoms.

2.2 Transition from Alchemy to Chemistry

In the medieval ages, the dictionary of Latin terms included words like *alchimia* or *alchymia*, *alchimicus*, *alchimista* et. al. Georg Agricola, mineralogist, and humanist had dropped the words *al* from these words in his writings in Latin from 1530 and onwards. In his works, Agricola deliberately used the words *chymia* and *chymista* to mean 'chemical' or 'alchemical' (Rocke, 1985). The sixteenth century witnessed the wide acceptance of the terms coined by Agricola especially after the adoption of the words by Conrad Gessner who was popular among the readers in his pseudonym. Gessner's work received wide re-publication in many European languages with *al* missing from the original Latin words (Rocke, 1985).

The later part of the sixteenth century and the early part of the seventeenth century witnessed synonymity and interchangeability in the usage of the terms *alchimia* and *chimia.* The early eighteenth century was privy to differentiating between *chimia* and *alchimia* (Newman & Principe, 1998). The spelling of the term was ultimately changed to *alchemia* in the latter part of the eighteenth century which was eventually transformed to *alchemy,* which has been considered as the root word from *chemistry.*

2.3 History

The knowledge of chemistry had been in existence since times immemorial. Discovery of fire, extraction of metals, making of alloys, fermenting of beer and wine, pottery making, extracting perfumes and medicines from plants, glass making are examples of usage of chemistry that humans have known and used since their advent on the face of this planet. Excavation of certain items used during the pre-historic times bears testimony to the knowledge of chemistry that our ancestors had. These items include:

- ♣ A 100,000-year-old ochre processing workshop excavated from Blombos cave in South Africa;
- ♣ A small amount of gold dating 40,000 BC was found in caves in Spain;
- ♣ Meteoric iron weapons from 3,000 BC excavated in Egypt;
- ♣ Copper axe from 5,500 BC excavated from Belovode; and
- ♣ Bronze articles from 3,500 BC were found at various sites in India.

Even though alchemy was unable to explain the nature and behavior of matter around us, the experiments carried out by the alchemists paved the way for modern-day chemistry. *The Sceptical Chymist* authored by Robert Boyle in 1661 distinguished between alchemy and chemistry. One point that distinguishes the alchemy from chemistry is the usage of the scientific method by the latter. The works of Willard Gibbs intertwines the history of chemistry with the history of thermodynamics (History of Chemistry).

2.3.1 Ancient History

The commencement of chemistry as a subject of learning and investigation finds its roots when philosophers wondered about the difference in behavior and state of various objects, they saw around them. Such thoughts were not particular to any civilization but spread throughout all the earlier civilizations. These early investigations culminated in trying to establish the existence of certain primary elements that constituted all matter around them. The Greek philosopher Empedocles had resolved all matter into four different elementary constituents: earth, fire, air, and water around 420 BC. Though all the earlier civilizations worked on developing theories regarding the difference in states and properties of matter, the most noteworthy contribution is traced back to ancient Greece and India (Durant, 1935). The foundation of the Greek theory was laid at around 380 BC by the Greek philosopher Democritus, who defined matter as being composed of indivisible and indestructible particles, which he called "atomos". His theory was followed by Leucippus with the declaration that atoms were the most indivisible and fundamental part of the matter. These theories are similar in content with the theories proposed by various Indian philosophers. In his book titled Vaisheshika Sutras which was written around 380 BC, Indian philosopher Kanada echoes the same sentiments as recorded by Democritus together with the existence of gases. Declarations by both Kanada and Democritus lacked the backing of empirical data, thereby rendering the theory of the existence of atoms very easy to deny. This theory received much opposition including by the famous Greek philosopher, Aristotle who had in 330 BC opposed the existence of atoms. Preceding that, in 380 BC, a Greek text whose authorship is credited to Polybus declared the composition of the human body due to four humors. Further, Epicurus had around 300 BC, postulated a universe of indestructible atoms rendering humans responsible for a balanced life.

In 50 BC, *Lucretius*, (Simpson, 2005) the famous Roman philosopher cum poet wrote *De rerum natura* wherein he had presented the principles of atomism (Lucretius, 50 BCE). The early development of methods of purification can be attributed to *Pliny the Elder* when he descriptively explained the methods of purification in his book *Naturalis Historia.*

2.3.2 Early Medieval History

The early medieval period has been called the age of metals. This period witnessed the widespread use of metals in day-to-day life and also in warfare. This required refining of metal ores and extraction of metals which was rampant during the period. Certain practical attempts had been made to successfully extract the metals from their respective ores. These attempts provide clues regarding the history of the development of chemistry during the period. The earliest recorded source of information can be found in *De re metallica* which was authored by Georg Agricola and published in 1556 (Rocke, 1985). This book bears testimony to the highly complex and developed process utilized for mining and extraction of metals during the early medieval period. Besides redressing the mysticism associated with the process of extraction and mining, the approach adopted in the book laid a solid foundation for future metallurgists to emulate. The book had proved a treasure trove for future mineralogists on account of the detailed and vivid description provided regarding the nuances associated with the process including types of furnaces used, adjusting the process based on the composition of the ores, etc. The book gives due credit to the previous authors especially *Pliny the Elder* by occasionally drawing reference from his book *Naturalis Historia*. No doubt Agricola is aptly described as the "father of metallurgy" (von Zittel, 1901).

The early 1600s witnessed numerous publications in the field of chemistry and the methods involved. Sir Francis Bacon published *The Proficience and Advancement o Learning* in 1605 which was a treatise on scientific methods which in later years came to be known as the scientific method (Asarnow, 2005). The year also saw Michal Sedziwoj proposing the presence of oxygen which he referred to 'food for life present in the air' in his alchemical masterpiece *A New Light of Alchemy*. The next significant development came in the year 1615 with Jean Beguin publishing a textbook solely dedicated to chemistry titled *Tyrocinium Chymicum*. The book is credited for recording the first-ever chemical equation (Crosland, 1959). An outline of the scientific method makes an appearance in a 1637 book published by Rene Descartes titled *Discours de la methode.*

The transition from alchemy to chemistry has been outlined in 1648 when Jan Baptist van Helmont's book *Ortus medicinae* was published posthumously. The book which was a collection of the results of numerous experiments thereby laying the foundation for the *law of conservation of mass* was very powerful and had influenced Robert Boyle. Helmont is also credited with suggesting the presence of insubstantial matter other than air which was termed 'gas' derived from the Greek word *chaos.* Helmont had later conducted numerous experiments involving gases. Students of chemistry also remember Jan Baptist van Helmont for his pioneering ideas on spontaneous generation and 5-year tree experiment besides being considered as the founder of pneumatic chemistry.

2.3.3 Middle Medieval History

The field of chemistry has witnessed numerous developments in the eighteenth century. It all began in 1702 when German chemist Georg Stahl used the term *phlongiston* to represent those classes of compounds that are released during burning. Georg Brandt had in 1735 analyzed the dark blue pigment present in the ore of copper and identified the same as cobalt. In 1751, Axel Fredrik Cronstedt identified nickel as an impurity in copper ore. Cronstedt's works had made him among the founding fathers of mineralogy. The middle medieval period also witnessed the discovery of scheelite in 1751 by Nordisk Crostedt. Scheelite is the Swedish equivalent of tungsten meaning 'heavy stone'. The period is also credited with discovery of several elements and compounds. While the Scottish chemist Joseph Black isolated carbon-dioxide in 1754 (Cooper, 1999), Louis Claud Cadet de Gassicourt's accidental discovery of cacodyl oxide in 1757 led to a new age in chemistry with the introduction of organometallic compounds (Sevferth, 2001).

The eighteenth-century also witnessed certain epoch-making discoveries beginning formulation of the theory of latent heat by Joseph Black in 1758 which aids the explanation of thermochemistry (Partington, 1989). Isolation of hydrogen by Henry Cavendish in 1766 and thereafter discovering its properties as a colourless, odourless and tasteless gas that is inflammable but does not support combustion leading to the discovery of oxygen is yet another epoch-making event in the field of chemistry that had taken place in the eighteenth century. Cavendish's discovery of hydrogen and his proposal of the presence of yet another gas culminated in 1773 when the Swedish chemist Carl Wilhelm Scheele established the presence of oxygen (Kuhn, 2004). The discovery of oxygen, however, rests upon Joseph Priestley as he had published the same before Scheele (Kuhn, 2004; Bowden,2005; Creighton University. 2005). Priestley gained in reputation due to his discovery of soda water and his knowledge regarding electricity. However, his decision to defend the theory of phlogiston thereby denouncing the revolution in chemistry left him isolated within the scientific community. The year 1781, saw Wilhelm Scheele discovering tungstic acid which prompted both Scheele and Torbern Bergman to obtain new metals by reducing this acid (Saunders, 2004). Jose and Fausto Elhuyar were successful in making tungstic acid in 1783 leading to the discovery of tungsten (ITIA Newsletter).

The important names during this period include Alessandro Volta credited with constructing a device that could accumulate charges using a series of groundings and inductions. Volta is regarded as the father of electrochemistry and Antoine – Laurent de Lavoisier who established the *Law of Conservation of Mass* in 1789 (Lavoisier). Lavoisier in association with Claude Louis Berlhollet devised the system of the naming of elements and compounds. *Traite Elementaire de Chimie* authored by Lavoisier is considered the first chemistry textbook which denied the existence of phlogiston and incorporated the new theories of chemistry.

2.3.4 Late Medieval History

The nineteenth century brought in a divide between followers of the atomic theory as proposed by John Dalton and the nonfollowers. The nonfollowers included chemists like Wilhelm Ostwald and Ernst Mach (Pullman, 2004). Followers of the atomic theory which included Amedeo Avagadro and Ludwig Boltzmann made significant contributions during the period by explaining the properties of gases. The matter was put to rest in the first decade of the twentieth century when John Perrin investigated Einstein's explanation of the Brownian Motion. This period also saw Svante Arrhenius putting forward the theory of ions, Michael Faraday's contribution to electrochemistry among others. In 1801, John Dalton, an English chemist published his works corroborating the pressure that individual components of a gaseous mixture exert, which is known to us today as *Dalton's Law of Partial Pressures.* John Dalton proposed the atomic theory in 1803. This era also saw Joseph Proust proposing the law of definite proportions. In 1828, Jons Jacob Berzelius compiled a table of relative atomic mass with oxygen as the standard. Berzelius also proposed the radical theory of chemical combination.

English chemist Humpy Davy electrolyzed salts and discovered many new metals like sodium, potassium besides alkali metals. Potassium was discovered through the process of electrolysis in 1807 from KOH. Sodium was also isolated in the same year by the electrolysis of NaOH. In 1808, Davy discovered calcium by reacting lime and mercuric oxide (Enghag, 2004; Davy, 1808), followed by the isolation of magnesium, strontium (Weeks, 1933), and barium (Robert, 2006). N_2O or laughing gas was also discovered by Davy. During this period, Scheele investigated the properties of chlorine such as bleaching, the effect on insects, and the similarity of odour with aqua regia. Chlorine has been given its name by Davy who argued its elemental nature (Davy, 1811) besides demonstrating that oxygen could not be obtained from a solution of HCl. During the period, several chemical laws were promulgated: Charle's Law after Jacques Charles (Gay-Lussac, 1802), and Gay-Lssac's Law by Joseph Louis Gay-Lussac (Dalton, 1802; Joseph Louis Gay-Lussac). A French chemist Bernard Courtois discovered iodine in 1811 (Courtois, 1813; Swain, 2005). The middle of the nineteenth century witnessed a resurgence in the field of theoretical chemistry with several young chemists including Alexander Williamson from England, Charles Adolphe Wurtz, and Charles Gerhardt from France, and August Kekule from Germany advocating changes in consonance with Avagadro's hypothesis.

During 1825 Friedrich Wohler and Justus von Liebig worked with cyanic acid and fulminic acid and explained the concept of isomers. William Prout classified biomolecules into carbohydrates, proteins, and lipids in 1827 while Fredrich Wohler produced urea in 1828. Friedrich Wohler and Justus von Liebig also worked in the field of organic chemistry and explained the concept of functional groups and radicals in 1832 with the synthesis of benzaldehyde. The credit of discovering nitrogen is also bestowed upon Liebig.

The mid-1800s also contributed to the development of chemistry as a subject of study and research. In 1840, Germain Hess proposed Hess's Law which is considered as the first stage leading to establishing the law of conservation of energy. The other major achievements that aided the development of chemistry during the period included the synthesis of acetic acid from inorganic sources in 1847 by Hermann Kolbe, defining the concept of absolute zero by William Thomson in 1848. Absolute zero, in the Kelvin scale, is the temperature that causes a cessation in molecular movements. Advancement in the field of stereochemistry has been witnessed during this period in 1849 with the understanding of optical rotation when Louis Pasteur discovered that tartaric acid can simultaneously exist in levorotatory and dextrotatory forms (History of Chirality, 2006). In continuation of the works of Pierre Bourger and Johann Heinrich Lambert, August Beer in 1852 proposed Beer's Law leading to the development of spectrophotometry (Sigrist-Photometer, 2007). The petroleum industry witnessed major changes in 1855 with Benjamin Silliman Jr's pioneering work on the cracking of petroleum (Benjamin Silliman, 2003).

The late 19th century saw certain developments in the field of chemistry that laid the foundation for its upsurge in the twentieth century which will be discussed in the future section. The period from 1874 to 1876 saw huge development in the scope of refrigeration which has revolutionized our life. German engineer Carl von Linde conducted experiments on liquefying gases paving the way for conducting experiments at very low temperatures and also in vacuum. von Linde has also been credited with developing dimethyl ether refrigerator and ammonia refrigerator. In 1882, von Linde was successful in developing a process for separating liquid oxygen from liquid air which is used in the manufacture of steel till today.

The ion theory explaining the electrical conductivity through electrolytes was developed by Svante Arrhenius in 1883 (Svante August Arrhenius, 2005). A groundbreaking study of chemical kinetics was published by Jacobus Henricus van't Hoff in 1884 in his book *Études de Dynamique chimique* (Jacobus H. van 't Hoff, 1966). Henry Louis Le Chatelier's efforts in putting the principle of mobile equilibrium in a generalized form were completed in 1885 propounding the van't Hoff-Le Chatelier principle or Le Chatelier principle that explains how a dynamic chemical equilibrium influences the external stress of a system (Gale, 2005).

The structure of purine considered an essential ingredient of many biomolecules was proposed by Hermann Emil Fischer in 1884 and produced the same artificially in 1898. Cathode rays, which were composed of electrons were discovered by Eugene Goldstein in 1885. J H van't Hoff also published his colossal work on the theory of dilute solutions in L'Équilibre *chimique dans les Systèmes gazeux ou dissous à I'État dilué* in the same year. 1893 also witnessed the discovery of the octahedral structure of complex compounds of cobalt by Alfred Werner laying the foundation for the development of co-ordination chemistry (Alfred Werner, 1966).

2.3.5 Modern History

The twentieth century saw certain major developments in the field of chemistry. These include the invention of chromatography, an important technique in chemical analysis by Mikhail Tsvet in 1903, followed by Hantaro Nagaoka proposing the nuclear model of the atom in 1904 wherein the electrons are shown as orbiting a dense nucleus. Another milestone in chemistry that proved a boon in the field of agricultural science was seen in 1905 when Fritz Haber and Carl Bosch developed the Haber Process or the Bosch-Haber Process for the manufacture of NH_3 from nitrogen and hydrogen. This NH_3 proved an excellent ingredient for the manufacture of artificial fertilizers and explosives. The period also saw the association of Max Born and Fritz Haber to develop the Born-Haber cycle which is regarded as the process of assessing the lattice energy of ionic solids. The development of various poisonous gases used during World War I earned Fritz Haber the title ‘father of chemical warfare’.

Explanation of the Brownian Motion by Albert Einstein in 1905 firmly established the atomic theory. Bakelite considered one of the earliest plastics that had been commercially successful was invented by Leo Baekeland during this period. The year 1909 was phenomenal for the development of chemistry with the discovery of quantization of charge and the fact that all the electrons have the same mass and charge. This discovery follows Robert Andrew Millikan’s oil drop experiment when he calculated the charge on an electron with utmost precision. Millikan is also credited with providing support to Planck’s constant through photoelectricity when he proved Einstein’s theory of the relationship between frequency and energy in 1912.

The identification of acids and bases from other chemical compounds is vital in chemistry. This is done using a concept called pH. pH also measures the strengths of acids and bases. The concept of pH was developed in 1909 by S.P.L. Sorensen who had also devised ways of gauging the level of acidity. The other major development during the period was the introduction of the idea to change the basis of the arrangement of various elements in the periodic table from atomic mass to the positive charge in the nucleus. This concept was put forth in the year 1911 by Antonius Van den Broek. The year 1911 also saw Brussels host the first Solvay Conference which resulted in the coming together of a majority of the prominent scientists of the era. Previously scientists were conducting research in seclusion. This conference helped in the diffusion of information among scientists. The scope of X-ray crystallography which is regarded as a pioneering technique to understand the crystal nature of substances was enhanced during this period with the Bragg brothers; William Henry Bragg and William Lawrence Bragg proposing Bragg’s Law in 1912. The asymmetric distribution of charges in certain molecules was also explained in 1912 when Peter Debye proposed the idea of a molecular dipole.

The relation between chemistry and mathematics was strengthened in the latter half of the twentieth century with the easing of chemical calculations. It is also an era that witnessed the growth of industrial chemistry with the discovery of newer materials. John Pople reduced the volume of chemical calculations in 1970 by developing the Gaussian programme thereby easing chemical calculations to a great extent (Hehre et.al., 1970). The mechanisms of olefin metathesis reactions that had baffled chemists were put forward in 1971 by Yves Chauvin (Jean-Louis, 1971). One of the important discoveries during the late twentieth century is the discovery of stereoselective oxidation reactions by Karl Berry Sharpless in 1975 which included sharpless epoxidation (Katusi, 1980; Hill, et. al., 1985), sharpless asymmetric di-hydroxylation (Jacobsen, 1988; Kolb, 1994; Gonzalez, Aurigemma & Tuesdale, 2002), and sharpless oxyamination (Sharpless, 1975; Herranz, 1978; Herranz & Sharpless, 1990). Studies relating to certain peculiarities in the properties of carbon was also the topic of research during the late twentieth century, especially its ability to form long bonds. During this study, Harold Kroto, Robert Curl, and Richard Smalley discovered fullerenes, a class of carbon compounds having long chains, and named in the honor of the architect R. Buckminster Fuller as the structure resembled the geodesic dome designed by him. Carbon chemistry received another major boost in 1991 with Sumio Iijima discovering another class of cylindrical fullerene called carbon nanotube. Besides developing the scope of chemistry, the discovery of carbon nanotube also played a pivotal role in the development of nanotechnology (NIAIST, 2002). This period is also vital for the development of taxol which is a medicine for the treatment of breast cancer. Taxol was synthesized in 1994 by several teams which included a team led by K.C. Nikolaou (Borman, 1994; Blakeslee, 1994) and another team led by Robert A. Holton (Holton et.al., 1988, 1994, 1994). 1995 also saw the production of the Bose-Einstein condensate, a previously unknown state of matter capable of displaying quantum mechanical properties on a macroscopic level (NIST News Release, 2001).

2.4 Philosophies of Chemistry

The philosophy of chemistry lies in understanding the underlying assumptions in chemistry. This has attracted various philosophers over the ages, but unfortunately, the scope revolved around physics. Philosophical questions in chemistry gained importance only in the latter part of the 20th century (Weisberg, 2001; Scerri & Mcintyre, 1997). The term philosophy of chemistry was first used by Friedrich Wilhelm Joseph Schelling (Schelling, 1797).

Any student of chemistry, wishing to understand the scope of the subject is confronted with various philosophical questions. Although both atoms and molecules are regarded as the primary building blocks of all matter (Schummer, 2006), traditional concepts of the structure of compounds do not correspond to our understanding especially in the case of metal complexes (Ebbing & Gammon, 2005) and aromaticity (Pavia, Lampman & Kritz, 2004). Certain issues pertaining to chirality and symmetry are the topics of discussion for the philosophers with the biologists, the biochemists, and the chemists debating the origin of chirality. The other debatable issue among the philosophers is the origin of the phenomenon with one group claiming the same to be from a lifeless atmosphere and the other group denying the same. Some philosophers also tend to believe our bias towards considering nature as symmetrical neglecting the contrary evidence.

As mentioned above, philosophical aspects of chemistry gained importance in the latter part of the twentieth century. Several articles appeared during the period which inter-alia included *The Philosophy of Chemistry* by the Dutch philosopher Jaap van Brakel in 2000 followed by the publication of *Normative and Descriptive Philosophy of Science and the Role of Chemistry in Philosophy of Chemistry* Maltese chemist-cum-philosopher Erci Scerri in 2004. Scerri believed in the association of chemistry and physics and the fact that the periodic table is based on certain philosophical considerations and as such cannot be treated as a matter of scientific research alone.

Unlike in other sciences, research in the field of chemistry, particularly synthetic organic chemistry warrants research based on intellectual methods upon a philosophical foundation. In his book, ‘The logic of Chemical Synthesis’, Elias James Corey speaks about *‘retrosynthesis’* speculating synthesis based on computer programmes. Other prominent chemists like K.C. Nikolau also follow suit.

2.5 Sub-Disciplines in Chemistry

In a bid to ease the scope of the research, chemistry has been divided into various sub-disciplines which include certain highly specialized fields (Laidlaw et.al., 1986).

2.5.1 Physical Chemistry- This branch of chemistry deals with the fundamental basis of all chemical processes. The main areas of study under this branch include electrochemistry, chemical kinetics, chemical thermodynamics, and statistical mechanics. In 1752, during the course of a lecture in Petersburg University captioned ‘A Course in True Physical Chemistry’, Mikhail Lomonosov introduced the word Physical Chemistry to define his version of the scope of the sub discipline. To quote Lomonosov, ‘Physical chemistry is the science that must explain under provisions of physical experiments the reason for what is happening in complex bodies through chemical operations. Modern physical chemistry traces its root to the middle of the nineteenth century with works on chemical kinetics, chemical thermodynamics, and electrolysis. The scope of physical chemistry has been enhanced with the association of statistical mechanics to the study of colloids and surface chemistry. The developments in the twentieth century were vital for the development of physical chemistry with the introduction of experimental methods with theoretical developments. Various fields of spectroscopy like electron paramagnetic resonance spectography, infrared spectroscopy, microwave spectroscopy, and nuclear magnetic resonance spectography developed during the twentieth century also lended credibility to the development of physical chemistry. Physical chemistry is further subdivided into the following domains:

i. **Chemical Kinetics**: Study of the rate of a chemical reaction comes under the scope of chemical kinetics.
ii. **Chemical Physics**: This topic is based on the investigation of physicochemical phenomenon using techniques from atomic physics, condensed matter physics, and molecular physics.
iii. **Electrochemistry**: Under this topic one studies the chemical reactions taking place in a solution involving transfer of electrons between the electrolytes and the electrodes.
iv. **Femtochemistry**: This branch of physical chemistry discusses the chemical reactions on a very small timescale i.e., study of very fast chemical reactions.
v. **Geochemistry**: This scope of this branch is to study the mechanism behind all the major geological systems.
vi. **Photochemistry**: Photochemistry is that branch of physical chemistry that deals with the study of those chemical reactions which occur due to absorption of light by atoms and molecules.
vii. **Quantum Chemistry**: That branch of physical chemistry whose focus lies in the utilization of quantum mechanics in understanding the chemical processes.
viii. **Solid State Chemistry**: This branch studies the structure, preparation and properties of those materials which exist in solid state.

ix. **Spectroscopy**: The study under this branch is restricted to understanding the relation between matter and the energy radiated by it.

x. **Stereochemistry**: The structure of any matter is dependent upon the structure of molecules which are in turn dependent upon the spatial arrangement of atoms. Stereochemistry is defined as the study of the spatial arrangement of atoms that make up the molecule.

xi. **Surface Chemistry**: Study of all interactions that occur at the interface between two phases is the subject of surface chemistry. The interface may be between solid-liquid, solid-gas, gas-liquid, solid-vacuum among others.

xii. **Thermochemistry**: That branch of physical chemistry that studies the relation between any chemical reaction and the amount of heat evolved or absorbed is called thermochemistry. It also includes the study of calorimetry that measures the heat changes during any chemical reaction.

2.5.2 Inorganic Chemistry- The scope of inorganic chemistry includes the study of the properties and the reactions that inorganic compounds undertake. Metals have been in use since times immemorial and have defined the ages in the history of mankind, be it Bronze Age, Iron Age, Copper Age, etc. Metals have been and still are used for various reasons which inter alia include pottery making, making of arms and also in jewellery. The importance of inorganic chemistry can be understood from the fact that it has been able to extract and purify gold which has been considered a valuable commodity in history. The knowledge of inorganic chemistry has been instrumental in the discovery of various acids, bases besides the manufacture of glass. Metallurgy which is defined as the process of extraction of the ore till its refining is also the result of inorganic chemistry. Inorganic chemistry has been known to men since long and a prime example of the same lies in the discovery of Prussian blue ($KFe_2(CN)_6$). Understanding the nature of various compounds, especially the coordination compounds is also due to the development of inorganic chemistry. The end of the second world war witnessed an increase in the requirement of food grains which had been possible thanks to inorganic chemistry which helped in the production of chemical fertilizers. From a theoretical perspective, inorganic chemistry has enhanced our understanding of a variety of substances and has made studies of the same easier. Examples of these can be seen in the development of the periodic table which led to the arrangement of elements based on certain conditions, understanding the structure and properties of the atom and the sub-atomic particles, etc. The major divisions under inorganic chemistry are

i. **Bioinorganic Chemistry**: Bioinorganic chemistry studies the role of metals in biology. It includes the study of both naturally occurring metals like metalloproteins and artificially introduced metals through the intake of medicines or toxicology.

ii. **Cluster Chemistry**: It is a relatively new topic in inorganic chemistry. A cluster is that class of chemical compounds that have a triangular or a closed polyhedral structure where the size of the individual atoms range between that of a simple molecule and a nanoparticle. Study of the preparation, properties, and structure of such clusters comes under the scope of this branch.

2.5.3 Organic Chemistry- In organic chemistry, the scope of the study is restricted to understanding the structure, properties, composition, reactions, et.al., of compounds which are based on carbon skeleton or organic compounds. These molecules are necessary for the survival and growth of all life forms on earth. Traditionally, organic chemistry limited its scope to synthesizing new molecules and developing reactions that had the potential of increasing the efficacies of the synthesization reactions. These new molecules were the foundation block of a wide variety of substances ranging from drugs, preservatives, artificial flavours, chemical fertilizers and insecticides, plastics or polymers, and also included certain unusual natural substances and those substances that were considered difficult to prepare artificially. Understanding organic chemistry is essential for students or researchers wishing to contribute to the fields of biochemistry or molecular biology as the basic building block of life like nucleic acids (RNA and DNA), proteins, sugars, and fats are organic compounds though structurally very large. The ability of carbon to form long chains with itself is the reason why nature has chosen carbon as the basis of all life forms. Compounds containing a moderate number of carbon atoms in the chain is either crystalline in nature or develops a crystalline character over a period of time. Such crystalline structures are found inefficient and hence not made a part of the living forms. Higher derivatives of carbon, however, have a jelly like or colloidal structure making these a vital part of life forms. Unless these aspects are clearly comprehended, it is difficult to get an insight into the formation of complex compounds of carbon. There is no clear distinction between inorganic and organic chemistry due to the overlap between the disciplines that can be witnessed especially among the organometallic compounds. The sub-branches within organic chemistry include:

i **Organometallic Chemistry**: Organometallic compounds are those classes of compounds containing a minimum of one bond between a metal and carbon which belongs to any organic molecule. Study of the structure, synthesis, properties, preparation, and used of such compounds is included within organometallic chemistry.

ii **Physical Organic Chemistry**: The reactivity of organic molecules are related to their structure. The relation between the structure of an organic compound and its reactivity is studied in this sub-branch of organic chemistry.

2.5.4 Polymer Chemistry: This is a multi-disciplinary science related to the study of structure, synthesis, and properties of polymers. Polymers have assumed huge importance in the recent times with the discovery of plastics and in the apparel industry. Efforts to make both the products more durable and ecologically friendly require an understanding of the subject.

2.5.5 Nuclear Chemistry- Study of subatomic particles and their association to form the nuclei falls within the ambit of this discipline. Molecular transmutation is an important topic in this discipline and the use of the table of nuclides aids in the process. Studies relating to radioactivity, various nuclear processes and transformation of atoms are associated with this sub-topic. In the field of radioactivity, the studies include understanding the properties of certain elements like uranium, thorium, actinides, radon and the chemistry behind the equipment which primarily includes the nuclear reactors. An important area of study is the effect of materials exposed to nuclear wastes and disposal of the wastes. Nuclear chemistry also studies the impact of nuclear radiation on living matter. Since radiation affects living beings at a molecular level by changing the biomolecules which alters the chemistry within the life forms, nuclear chemistry is an integral part of radiation biology. Nuclear chemistry also helps in medical treatment particularly the treatment of diseases like cancer and enables improvement in these treatments. Nuclear chemistry is also the basis of nuclear magnetic resonance spectrography which finds application in organic chemistry and physical chemistry. Nuclear chemistry is basically divided into two parts which are discussed below:

i. **Radiation Chemistry**: This sub-division of nuclear chemistry deals with the study of the effect of radiation on living matter.

ii. **Radiochemistry**: Radiochemistry is the study of chemistry of radioactive materials, especially the chemical reaction of non-radioactive isotopes using radioactive isotopes of elements. A major portion of radiochemistry studies chemical reactions using radioactive substances.

2.5.6 Biochemistry- Biochemistry deals with the composition, reactions, and interactions among the various chemicals present inside a living organism. Biochemistry is also closely related to genetics and molecular biology. The composition and the processes of life were topics of interest among the ancient Greeks though biochemistry as a sub-topic of chemistry developed around the early part of the nineteenth century. The word biochemistry was used by the German chemist Carl Neuber in 1903 and the disciplines associated with this has continued to be accordingly named. The word biochemistry is a combination of two English words *bio* meaning *life* and *chemistry*. In 1877, Felix Hoppe Seyler used the term *biochemie* as a synonym for physiological chemistry and argued in favor of instituting a separate field dedicated to such studies. Basically, biochemistry deals with the chemical processes inside living organisms through the study of the structure and functions of the cellular components. The last 4 decades has increased our understanding of the different life processes and all areas of life science is dedicated to biochemistry. Biochemistry also studies the chemical characteristics of biomolecules and spreads its ambit to diverse fields like transportation within the cell membrane, genetic coding, synthesis of proteins, and signal transduction, which is a method of transferring the genetic material from one life form to the other through a virus. Biochemistry can be further subdivided into the following divisions:

i. **Bioorganic Chemistry**: This branch is a rapidly growing discipline in science that combines both biochemistry and organic chemistry. The scope of this discipline lies in the study of biological processes using chemical methods. Studies regarding the function of protein and enzymes comes under its ambit.

ii. **Biophysical Chemistry**: It is that discipline that uses the concept of physics and physical chemistry to understand various biological systems. It also studies the physical properties of biological macromolecules.

iii. **Medicinal Chemistry**: It is the amalgamation of both organic chemistry, pharmacology, and other biological sciences that includes the study of synthetic organic compounds. Such studies assume importance due to development of newer drugs used in the treatment of various diseases.

2.5.7 Materials Chemistry- It is a new sub-discipline within the subject and primarily includes understanding the materials that are considered useful. The list of useful materials includes solids, liquids, polymers, and materials lying between the phases. Materials have been of immense importance in the history of mankind and the same is reflected by the fact that ages in history have been named by the most prominent material used during the period. Spread out of the human civilization has been possible due to better materials used in tools and weapons. Advancements in the fields of material processing like aluminium and steel continue to have an impact in our daily lives even to this day. In earlier days, alchemy or empirical methods were used to control the materials. Development of both physics and chemistry helped in a better understanding of the materials around us and has also helped in harnessing the same to our advantage. It also encompasses the relationship between structure, properties, processing, and performance of materials under the ambit of study. This sub-discipline has a direct relation with both physical and inorganic chemistry as an understanding of the concepts under these sub-disciplines are necessary for proficiency in material chemistry.

2.5.8 Analytical Chemistry- Analysis of a given material to understand its structure and composition is the scope of this discipline. The scope of analytical chemistry lies in studying the methods used in separation, identification, and quantification of matter. The processes of separation, identification, and quantification form the basis of any analysis. While the process of separation isolates the anylates, identification analysis is concerned with identification of the anylates, and quantification analysis is the process of calculating the concentration of the analyte. Analytical chemists use both the wet method and the modern methods for separation. While processes like distillation, extraction, and precipitation are used in the wet method, modern methods use chromatography and electrophoresis as a separating procedure. In case of wet method of analysis, identification analysis is achieved through odour, colour and other physical properties besides certain other chemical properties including radioactivity, quantitative analysis is done by measuring the changes in mass or volume. In modern methods of analysis, both the identification and the quantitative analysis can be carried out using light or heat interaction, electrical or magnetic fields. Analytical chemistry finds application in all branches of chemistry in the fields of engineering, and medicines except theoretical chemistry.

2.5.9 Neuro Chemistry- In this discipline of chemistry, one studies the role played by the neurochemicals which include nucleic acids, lipids, sugars, peptides, proteins, etc., in the formation, maintenance, and modification of the nervous system. Neurochemistry has been the topic of study since the eighteenth century, though it has been recognized as a science recently. The human brain has traditionally been regarded as a separate organ from the nervous system. Later studies found the chemical build of the brain as being identical to the outer nervous system which led them to consider the brain as a part of the nervous system. Neurochemistry received an impetus through the works of Johann Ludwig Wilhelm Thudichum who proposed that many neurological illnesses are caused by imbalance in the chemicals present in the brain and suggested that the same could be arrested through chemical means. No doubt, Thudichum is regarded as the father of brain chemistry, the term used to represent neurochemistry in the early days. The 1950s saw neurochemistry as a separate discipline for research. The development of neurochemistry finds its origin in the various international neurochemistry symposia which led to the formation of many societies on neurochemistry. The topic of discussion in these societies revolved around understanding the nature of neorotransmitting substances. The ideas related to the subject received a more concrete form in 1972. The major success in altering the functions of the brain using chemicals was witnessed in 1961 with the L-DOPA experiment when Walter Burkmayer injected L-DOPA into the body of a patient suffering from Parkinson’s syndrome. The number of tremors experienced by the patient reduced considerably shortly after injecting the L-DOPA and control of the muscles also saw major improvement after the treatment.

2.5.10 Theoretical Chemistry- The study of chemistry backed by sound theoretical reasoning is called theoretical chemistry. It is that branch of chemistry that deals with generalizing the theoretical concepts regarding the scopes of chemistry. It acts as a unifying agent that amalgamates the common concepts from all sub-divisions of chemistry. The job of a theoretical chemist is to systematize, refine and detail the concepts, laws, and principles that govern chemistry. The central theme of theoretical chemistry lies in the presence of an interconnection between the structure and properties of molecules and molecular systems. It uses both physical and mathematical methods to define the structure and dynamics of various chemical systems and thereby draw a relation to understand and accurately predict their properties, both thermodynamic and kinetic. Generally, theoretical chemistry tries to explain chemical processes using the methods of theoretical physics, though there is a sharp difference between the two disciplines. In the explanation of chemical systems having a high level of complexity, theoretical physics uses mathematical methods, whereas theoretical chemistry combines semi-empirical and empirical methods with the mathematical methods. In the recent years, theoretical chemistry concentrated on quantum chemistry besides other components which includes molecular dynamics, statistical thermodynamics, etc. Modern theoretical chemistry can be divided into two components: the study of chemical structure, and the study of chemical dynamics. While the study of chemical structure includes electronic structure, equilibrium properties of the system of condensed phase and macro-molecules, force fields, potential energy surfaces, and vibrational motion, the study of chemical dynamics include bimolecular kinetics, collision theory, condensed phases of dynamics, energy transfer, molecular aspect of dynamics, metastable states, and unimolecular rate theory. Theoretical chemistry is further subdivided into

i. **Cheminformatics**: The use of computers and information technology to understand chemical processes.

ii. **Computational Chemistry**: It involves the use of scientific computing in the field of chemistry using the processes of approximation like density functional theory, force field method, semiempirical method, or Hartree Fock. The scope of the study includes prediction of the shape and properties of molecules using approximation techniques.

iii. **Mathematical Chemistry**: This is that branch of theoretical chemistry that predicts the structure of molecules purely by mathematical procedures without using quantum mechanics. Researchers in chemistry tend to use topology, which is a branch of mathematics to predict the structure and the properties of the compounds.

iv. **Molecular Dynamics**: The molecules within any substances are packed together due to Van der Waal's forces and are prone to distortions due to temperature. Molecular dynamics uses classical mechanics to stimulate the movement of nuclei in a group of atoms and molecules.

v. **Molecular Modelling**: Study of making models of molecules without referring to quantum mechanics like molecular docking, drug design. Electric potential and fitting of shape are the main items of study in this branch.

vi. **Molecular Mechanics**: Study of the intra and inter molecular attraction using the concept of potential energy relates to molecular mechanics. The potential energy is calculated as per certain theoretical considerations.

vii. **Quantum Chemistry**: Study of the application of quantum mechanics to chemical and physic-chemical reactions is defined as quantum chemistry.

viii. **Theoretical Chemical Kinetics**: Theoretical chemical kinetics refer to the study of dynamic systems related to activated complexes, reactive chemicals, and the respective differential equations.

Besides the major sub-disciplines of chemistry that have been discussed above, there are several other sub-disciplines which have been outlined below:

2.5.11 Astrochemistry- Study of chemical reactions in the universe.

2.5.12 Environmental Chemistry- The study of those chemical reactions that have an adverse impact on the ecosystem.

2.5.13 Green Chemistry: A philosophy of chemical research that encourages development of environmental chemicals and processes.

2.5.14 Agrochemistry- The study of those chemicals which can lead to a better agricultural production without leaving negative impact on the environment.

2.5.15 Atmospheric Chemistry- That branch of chemistry that studies the composition of the atmosphere of earth and other planets.

2.2.16 Chemical Engineering- The use of chemical sciences, life sciences, mathematics, and economics in the process of converting raw materials and chemicals into useful forms.

2.5.17 Chemical Biology- It is a combination of both chemistry and biology and tries to understand the effect of chemicals on life forms.

2.5.18 Chemical Informatics- Application of information technology in the field of chemistry.

2.5.19 Petrochemistry- Study of the conversion process of petroleum and natural gas into items of utility.

2.5.20 Pharmacology- Study of the effects of drugs on human bodies.

2.5.21 Synthetic Chemistry- The study of synthetic material in a bid to discover new material having better properties.

The various major sub-disciplines of chemistry have been the subject of research over the years. The list of articles published in various languages, across several journals and repositories from the period 2001 till 2020 is tabulated below:

Table 2: Number of Research Papers published on various sub-disciplines of chemistry from 2001 to 2020 (Source: https://core.ac.uk/search?)

Sl. No.	Sub-Disciplines	No. of Articles
1	Physical Chemistry	9,477,605
2	Inorganic Chemistry	2,818,364
3	Organic Chemistry	4,126,514
4	Nuclear Chemistry	4,889,281
5	Biochemistry	4,148,104
6	Materials Chemistry	8,288,060
7	Analytical Chemistry	4,969,840
8	Neuro Chemistry	2,927,027
9	Theoretical Chemistry	8,008,789

Considering the languages in which the articles were published and restricting ourselves to the first five languages in the decreasing order of the number of publications, our result is tabulated below:

Table 3: Number of Research Papers published in various languages

Sub-Discipline	**Languages**				
	English	Portuguese	Indonesian	Spanish	German
Physical Chemistry	3134581	52943	43565	40285	15771
Inorganic Chemistry	857487	18322	16607	13788	8086
Organic Chemistry	1119548	25540	24852	20003	12112

Nuclear Chemistry	1428346	41608	18142	40060	12528
Biochemistry	11158180	36381	25199	53624	23324
Materials Chemistry	2519595	35938	40032	32853	24001
Analytical Chemistry	1593954	28093	27984	23752	11169
Neuro Chemistry	898246	24067	16839	18377	10733
Theoretical Chemistry	2567324	58568	21881	43820	16934

(Source: https://core.ac.uk/search?)

These tables indicate the fact that the maximum numbers of research papers have been published in the field of physical chemistry followed by materials chemistry and theoretical chemistry. The lowest numbers of research papers have been published under the sub-discipline inorganic chemistry. As compared to other sub-disciplines, neuro chemistry also has lesser number of research papers. This can be understood from the fact that the neuro chemistry as a separate sub-discipline of chemistry has received recognition only recently.

Most of the research articles have been published in English. Though research papers have been published in almost all the major languages, the number of such works in English surpasses those in other languages by a wide margin. In order of decreasing number of published articles, the second highest number of research papers are published in Portuguese except in the case of biochemistry where articles in Spanish surpass those in Portuguese.

2.6 Scope of Chemistry

The study of chemistry has been put to much diverse use since long that has helped mankind in several ways thereby increasing its scope. A few of the areas of usage have been outlined below:

2.6.1 Supply of food- With the abnormal growth in the level of the population both at the regional and the global levels, the demand for food has witnessed an upsurge. To cater to the ever-growing needs for food in the light of diminishing farmlands, chemistry has helped by developing fertilizers, better seeds, insecticides, and pesticides. These discoveries have resulted in an abundance in the supply of food grains feeding the multitudes of population. Chemistry has also helped in the discovery of preservatives that help in maintaining a steady and perennial flow of food decreasing the financial loss to the growers.

2.6.2 Health and sanitary- The health industry has been greatly benefited from the discovery of various medicines that have enhanced the lifespan of individuals besides relieving them of normal bodily discomforts that one may experience. Such discoveries are boons of chemistry. Further, anesthetics have also lessened the pains suffered by patients during surgery making the procedure successful.

2.6.3 Saving the environment- Chemistry has also helped in the development of certain eco-friendly chemicals that have helped in environmental conservation. E.g., the replacement of CFC with newer environment-friendly chemicals as a cooling agent.

2.6.4 Ease of life- Various discoveries in the field of chemistry has eased human life to a large extent. Discovery of comfortable, durable, and attractive fibres is one of the major steps in this regard besides the use of metals, natural gas instead of wood or animal dung resulting in a lesser smoke formation, etc.

2.6.5 Industrial use- The growth of industries has been facilitated due to the development in the field of chemistry. A lot of industries rely upon chemicals as their main input. The global chemical industry plays an important role in economic development. The top 50 global chemical industries had reported a sales figure of US 980.5 billion$ and a profit margin of 10.3% in 2013 making this industry a highly lucrative business proposition (Tullo, 2014).

2.6.6 Warfare- Chemistry has changed the face of warfare with the transition from close range weapons to long-range weapons by the discovery of explosives. Explosives and other poisonous gases have also led to mass destruction.

2.7 Relation of Chemistry with other Sciences

2.7.1 Biology and Chemistry: All living objects are composed of various chemical substances that interact with one another through the process of chemical reactions for undertaking the various metabolic activities required for sustenance of life. Plants also produce various chemicals which find applications in making medicines. Understanding chemistry is, therefore, central to biology.

2.7.2 Medicine and Chemistry: An understanding of chemistry is essential to acquire knowledge of medicines. The mode of treatment depends upon the knowledge of occurrences within the body. From rudimentary treatment procedures to complex processes, chemistry plays a central role in the field of chemistry.

2.7.3 Physics and Chemistry: Both physics and chemistry are inter-dependable, and either cannot be completely understood without the other. Understanding the composition of the atoms or certain other concepts in the realm of physical chemistry require the aid of physics as these studies require mathematical calculations based on methods which are considered to be under the domain knowledge of physics. The physical properties of subatomic particles can be understood only with a detailed understanding of the various concepts of physics. Further, topics like spectroscopy are studied both in physics and chemistry though with a different perspective. Similarly, nuclear chemistry and theoretical chemistry are also a combination of both physics and chemistry and understanding both physics and chemistry is essential to understand the same.

2.7.4 Mathematics and Chemistry: Before the 20th century, chemistry was regarded as a classical science with many chemists being reluctant to use mathematical concepts in the subject. This reluctance is evident from the writings of Auguste Comte which appeared in 1830 and is quoted below:

"Every attempt to employ mathematical methods in the study of chemical questions must be considered profoundly irrational and contrary to the spirit of chemistry.... if mathematical analysis should ever hold a prominent place in chemistry -- an aberration which is happily almost impossible -- it would occasion a rapid and widespread degeneration of that science."

The second part of the 19th century saw a paradigm shift in the thought process when August Kekule opined in 1867 as under:

"I rather expect that we shall someday find a mathematico-mechanical explanation for what we now call atoms which will render an account of their properties."

This shift in thinking ultimately led to the amalgamation of mathematical processes in the field of chemistry.

2.7.5 Material Sciences and Chemistry: Every material is composed of atoms and their properties are determined by the mutual interaction between the atoms. Hence both material science and engineering are directly dependent upon the knowledge of chemistry.

2.7.6 Geology and Chemistry: Both geology and archaeology depend upon chemistry as a successful branch of study and research. Rocks are made of atoms and the associated properties are dependent upon its chemical composition. The knowledge of chemistry which has led to an understanding of radioactivity has revolutionized the scope of geology and archaeology.

2.7.7 Astronomy and Chemistry: Astronomical spectroscopy is credited with bestowing an understanding of the universe. Astronomical spectroscopy analyzes the spectrum obtained from various celestial bodies and compares the same with the spectrum generated from known elements giving an idea of the composition of various celestial bodies. Astronomical spectroscopy is regarded as a topic of chemistry.

2.8 Conclusion

Chemistry is among the oldest sciences and has its roots in the early medieval age when humans began to use metals for hunting, agriculture, and other uses. The discovery of fire has added a new dimension to the scope of chemistry. This chapter is dedicated to understanding the scope of chemistry. Chemistry has developed over the years and is continuing to do so, thanks to the painstaking efforts of the researchers. What started as alchemy has now grown into a major subject of science and its contents has baffled researchers since times immemorial. The development of the scope of chemistry into what it is today has not occurred overnight. This thesis has tried to understand the history of the development of the subject over the years by breaking the period into several ages and discussing the events that have occurred during those periods. Due credit has been bestowed to the researchers whose discoveries have enriched our knowledge of the subject. Chemistry is also a philosophy in itself. The structure of atoms, with its wide variations, justifies the philosophical significance of the subject. The subject has witnessed tremendous growth over the years, both in its variation and its scope. This chapter has discussed both the sub-disciplines and scope of the subject in great details. The scope of chemistry is unlimited, and it has helped in increasing the convenience of our livelihood. As a science, chemistry has a relation with other sciences. Its relationship with other sciences and mathematics has led to the creation of several sub-disciplines of chemistry. Chemistry holds relation with physics, mathematics, biology, medicine, geology, and astronomy. All these relationships with its benefits to humanity have been discussed in this chapter.

After having an overview on the concept of chemistry, sub domain and relation with other domain, the next chapter i.e. chapter 3, shall be dealing exclusively with "History of Nobel prize" history and function.

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CHAPTER – 3
HISTORY OF THE NOBEL PRIZE

3.0 Introduction

The Nobel Prize is a set of five separate prizes that is awarded to individuals who have undertaken studies that have been regarded as a benefit to humanity during the previous year. This prize is awarded as per the covenants of the will relinquished by Sir Alfred Nobel in 1895. The Nobel Prizes are awarded to outstanding researchers and scientists for their contributions in the field of physics, chemistry, physiology, literature and peace (Nobel Prize Outreach, 2021). To commemorate the memory of Sir Alfred Nobel, the Central Bank of Sweden started awarding the Nobel Prize in Economic Sciences from 1968. The first Nobel Prize in Economic Sciences was awarded in 1969 (Nobel Prize Outreach, 2021). Till date, Nobel Prizes are the most sought-after prizes due to the prestige associated with the prize (Shalev, 2005).

Alfred Nobel was a Swedish chemist who had risen to fame after inventing the dynamite. Besides being a chemist, Nobel was also an established engineer and an industrialist. Alfred Nobel died in 1896, leaving behind a will where he had stated that all his assets be used to sponsor the five Nobel Prizes, the first of which was awarded in the year 1901 (Nobel Prize Outreach, 2021). The Nobel Prizes are awarded every year in a glittering ceremony. The individuals winning the Nobel Prizes are referred to as Nobel Laureates and are given a gold medal, accompanied by a diploma and a cash award. As per the monetary values of 2020, the cash award amounts to US$ 1,145,000 (Nobel Foundation, 2020). The will left behind by Alfred Nobel states that a maximum of three individuals can share the Nobel Prizes, though the prizes can be awarded to organizations having a greater number of people (Schmidhuber, 2010). The Nobel Prizes are not awarded after the demise of the concerned individuals. In case an individual dies in the days that follow the announcement of the award and prior to the date of actual receipt, the prize is presented to the relatives of the deceased recipient or the affiliated organization (CBC News, 2011).

The first Nobel Prize was awarded in 1901 as per the will of Alfred Nobel, while the first Nobel Memorial Prize in Economic Sciences was awarded in 1969. Since then, the Nobel Prize has been awarded 603 times to 962 individuals and 25 organizations. This includes four individuals who have been awarded more than one

Nobel Prize (Nobel Prize Outreach, 2021). Table 3.1 provides details of the number of Nobel Prizes awarded since 1901 till 2020.

Table 4: Details of Nobel Prizes

Nobel Prizes	No. of Prizes	No. of Laureates	Single Nobel Laureate	Shared by two Nobel Laureates	Shared by three Nobel Laureates
Physics	114	216	47	32	35
Chemistry	112	186	63	24	25
Physiology	111	222	39	33	39
Literature	113	117	109	4	0
Peace	101	135	69	30	2
Economic Sciences	52	86	25	20	7
Total	*603*	*962*	*352*	*143*	*108*

Though Nobel Prizes are scheduled to be awarded annually, there have been 49 occasions when these prizes had not been awarded. The years during which the Nobel Prizes have not been awarded lie during the first and the second World Wars. Table 3.2 shows the years during which the Nobel Prizes were not awarded.

Table 5: Years during which Nobel Prizes were not awarded

Domain	**Years**	**Number**
Physics	1916, 1931, 1934, 1940, 1941, 1942	6
Chemistry	1916, 1917, 1919, 1924, 1933, 1940, 1941, 1942	8
Physiology	1915, 1916, 1917, 1918, 1921, 1925, 1940, 1941, 1942	9
Literature	1914, 1918, 1935, 1940, 1941, 1942, 1943	7
Peace	1914, 1915, 1916, 1918, 1923, 1924, 1928, 1932, 1939, 1940, 1941, 1942, 1943, 1948, 1955, 1956, 1966, 1967, 1972	19

3.1 History

Alfred Nobel was born into a family of engineers in Stockholm on the 21st day of October 1833. Alfred Nobel had been gifted with several skills. He was an engineer, a chemist, and also an inventor. His acumen as an industrialist came into light in the year 1894 when Alfred Nobel purchased the Bofors Iron and Steel Mill and started manufacturing armaments (Levinovitz & Ringertz, 2007). Alfred Nobel is also credited with inventing ballistite which is the main ingredient of many smokeless explosives. Ballistite was a prime opponent of cordite which was another smokeless powder invented by the British. During his lifetime, Alfred Nobel made 355 inventions which led to amassing huge wealth. Of the 355 inventions of Alfred Nobel, dynamite is the most famous (Levinovitz & Ringertz, 2007).

The turning point in Alfred Nobel's life came in 1888, when a French newspaper accidentally mentioned his name in the obituary titled *The Merchant of Death is Dead* which they had published in memory of his dead brother Ludvig Nobel. The article discombobulated Alfred and made him worried as to how the world would remember him after his death. The agony caused by the article can be understood from the fact that Alfred Nobel was forced to change his will after reading the article (Golden, 2000). Alfred Nobel died at the age of 63 years on the 10th day of December 1896 from cerebral haemorrhage at his home at San Remo in Italy (Ragnar, 1983).

Alfred Nobel was sceptical about his life, a fact that can be understood by the several wills that he had written during his lifetime. His last will was, however, written on the 27th day of November 1895, approximately one year before his death, and signed to the Swedish-Norwegian Club located in Paris (von Euler, 1981). In the will, Alfred Nobel had desired that his assets should be used to create a series of prizes that would be awarded to individuals who have benefited mankind to the highest degree. This caused tremendous astonishment among the general populace. Alfred Nobel desired that prizes should be given in five different subjects which included physics, chemistry, physiology (medicine), literature and peace (Nobel Prize Outreach, 2021).

According to the last will of Alfred Nobel, 94 percent of his total assets which amounted to 31 million SEK in 2008, was earmarked for the five prizes (Nobel Prize Outreach, 2021). Such was the scepticism regarding the will that the will did not receive approval from the Sorting in Norway till the 26th day of April 1897 (Levinovitz & Ringertz, 2007). To execute the provisions of the will, Ragnar Sohlman and Rudolf Lilljequist who were appointed executors of the will, established the Nobel Foundation to take care of the money and arrange for awarding the prizes (Abrams, 2012).

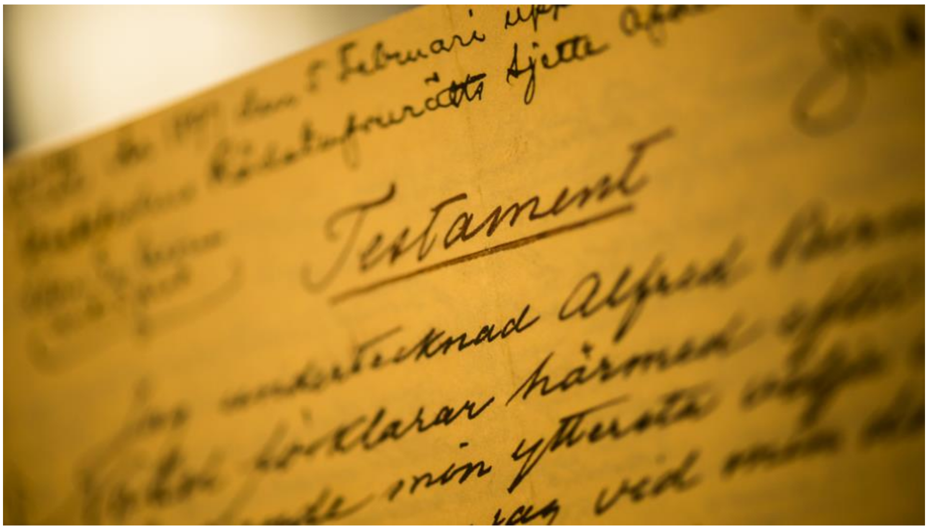

Figure 1: The last will of Alfred Nobel

As per the will of Alfred Nobel, the peace prize had to be awarded by the Norwegian Nobel Committee. The said Committee was formed in April 1897 after the will received approval and the members were appointed thereafter. This was followed by forming committees for awarding the other prizes. The newly formed committees included the Karolinska Institute which was established on the 7^{th} day of June 1897, the Swedish Academy which was established on the 9^{th} day of June 1897, and the Royal Swedish Academy of Sciences which was established on the 11^{th} day of June 1897 (Levinovitz & Ringertz, 2007). The Nobel Foundation formulated the guidelines based on which the prizes would be awarded. In the year 1900, the Foundation formulated certain rules which were promulgated by King Oscar the Second (Nobel Prize Outreach, 2021). The personal union between Sweden and Norway finally ended in 1905.

3.2 Nobel Foundation

As per the will left behind by Alfred Nobel, which was read in Stockholm on the 30^{th} day of December 1896, Alfred Nobel had earmarked 94% of his personal fortune to the Nobel Foundation for instituting five awards to be conferred to individuals who have served humanity. This asset has been the foundation upon which the Nobel Prizes are awarded each year. Founded as a private entity on the 29^{th} day of June 1900, the function of the Nobel Foundation laid in managing the administration and the finances of the Nobel Prizes which was the primary duty of the foundation as per the covenants of the will (Levinovitz & Ringertz, 2007). E. Bargengren, a Swedish historian who had access to the archives of the Nobel family mentions that the other two brothers of Alfred Nobel, Robert and Ludvig Nobel were involved in managing the family oil business in Azerbaijan. Bargengren has further added that the huge amount of money that was necessary to institute the Nobel Prizes was obtained after Alfred Nobel sold his stake of the oil field at Baku (O'Day, 1966). Besides engaging themselves in managing the affairs of awarding the prizes, the Nobel Foundation was required to internationalize the prizes and oversee its administration. The will of Alfred Nobel does not allow the Nobel Foundation to select the Nobel Laureates (Feldman, 2013), but to work as an advertising agency. The will clearly states that the primary responsibilities of the Nobel Foundation would lie in investing Nobel's money in a manner that prizes can be awarded annually and oversee the administration of the prizes. Despite the fact that the money earns interest by way of investments, the Swedish government has exempted the amount earned as interest upon investment from the provisions of income tax since 1946. Further, all money invested in the United States is also exempted from investment tax since 1953 (Levinovitz & Ringertz, 2007). With the investment scenario witnessing a rise since the 1980s, the investments made by the Nobel Foundation became more lucrative. (Levinovitz & Ringertz, 2007) have approximated the assets controlled by the Nobel Foundation at US$ 560 million as on the 31st day of December 2007.

As per the will of Alfred Nobel, the Nobel Foundation would have five members, including the Chairman from amongst Norwegian or Swedish citizens, with its head office being based at Stockholm. The designation of the members and the mode of their selection is tabulated in Table 3.3.

Table 6: Members of the Nobel Foundation

Sl. No.	Designation	Elected/Appointed by
1	Chairman	Appointed by the King of Sweden after consulting with the members of the foundation.
2	Executive Director	Appointed by the fiduciaries of the institutions that award the prizes.
3	Deputy Director	Appointed by the King of Sweden after consulting with

		the members of the foundation.
4	Deputy	Appointed by the fiduciaries of the institutions that award the prizes.
5	Deputy	Appointed by the fiduciaries of the institutions that award the prizes.

Since 1995, however, all the five members of the Nobel Foundation are being chosen by the trustees of the institutions awarding the prizes, with the Executive and the Deputy Directors being appointed from amongst the members of the board. The hierarchical set up of the Nobel Foundation has also undergone a change post 1995, and presently it consists of the institutions that award the prizes which include The Royal Swedish Academy of Sciences, The Nobel Assembly at the Karolinska Institute, The Swedish Academy, the Norwegian Nobel Committee, the trustees of these institutions, and the Auditors (Levinovitz & Ringertz, 2007).

Regarding the nature of investments, an article published in the (Nyheter, 2012) suggest that the Nobel Foundation had invested 50% of the total money in shares, 20% in bonds, while the balance 30% was invested in hedge funds or real estate. The early part of 2008 witnessed major shift in the nature of investment when 64% of the total assets were invested in European and American stocks, 20% in bonds, and 12% in hedge funds or real estate (von Helmut Steuer, 2008). The Nobel Foundation spent a whopping sum of approximately 120 million kronor in 2011. While 50 million krona was spent as prize money, 27.4 million krona was spent on engaging persons to confer the prizes and to pay the institutions. The cost of organizing the events in Stockholm and Oslo during the Nobel week cost 20.2 million krona and cost of administration, expenditure on organizing Nobel symposium and miscellaneous expenses amounted to 224 million kronor. The expenditure on awarding the Nobel Memorial Prize for Economic Sciences which was estimated at 16.56 million kronor has been paid by the Sveriges Riksbank (Sjöholm & Gustav, 2012).

3.3 The First Nobel Prize

After the guidelines for awarding the prizes had been formulated, the Nobel Foundation started the process of collecting nominations for the first Nobel Prize. The nominations that have been received by the Nobel Foundation were forwarded to the award giving institutions for their approval. From amongst the several nominations received from various institutions for the Nobel Prize for Physics, the Nobel Foundation shortlisted Wilhelm Rontgen for his discovery of X-rays and Philipp Leonard for his works on cathode rays. Based upon the selection made by The Academy of Sciences, the first Nobel Prize for Physics was awarded to Wilhelm Rontgen for discovering the X-rays (Leroy, 2003). The last decade of the nineteenth century witnessed several significant contributions in the field of Chemistry forcing the Nobel Foundation to decide the chronology of awarding the Nobel Prize for Chemistry (Levinovitz & Ringertz, 2007). Of the twenty nominations that had been received by the academy for Nobel Prize in Chemistry, eleven were in favour of Jacobus Henricus van't Hoff (Crawford, 1984). The academy decided to confer the first Nobel Prize for Chemistry to Jacobus Henricus van't Hoff for his works on chemical thermodynamics (Feldman, 2013).

The first Nobel Prize in literature was awarded to Sully Prudhomme despite the fact that the choice was protested by many which also included 42 writers, artists, and critics of Sweden. The critics of the award wanted the award to be conferred to Leo Tolstoy (Levinovitz & Ringertz, 2007). Some writers including Burton Feldman who had criticized the selection of Prudhomme felt that the selection of a Victorian poet for the Nobel Prize was prompted by the fact that the members of the academy had a liking for Victorian literature (Feldman, 2013). German physiologist and microbiologist, Emil von Behring, who is credited with developing antitoxin as a treatment of diphtheria which was the cause of numerous deaths was awarded the first Nobel Prize for Medicine (Leroy, 2003). The first Nobel Prize for Peace was jointly awarded to a Swiss national, Jean Henri Dunant and a French national, Frederic Passy. While Jean Henri Dunant is credited with founding the International Red Cross Organization and starting the Geneva Convention, Frederic Passy founded the Peace League and was associated with Jean Henri Dunant in forming the Alliance for Order and Civilization.

During the period of the second world was i.e., during the years 1938 and 1939, Adolf Hitler did not allow three German nationals Richard Kuhn, Adolf Friedrich Johann Butenandt, and Gerhard Domagk to receive the Nobel Prize (Levinovitz & Ringertz, 2007), though the three Nobel Laureates were allowed to receive the diploma and the medal (Wilhelm, 1983). Despite the neutral stand adopted by Sweden during the Second World War, Nobel Prizes were not awarded regularly during the period of the war. The Nobel Prize for peace was not awarded during 1939 and the years 1940 till 1942 saw no Nobel Prizes being awarded as Germany had occupied Norway. Nobel Prizes in all categories except peace and literature were awarded in 1943 (Nobel Prize Outreach, 2021).

The period of the Second World War was difficult for the members of the Norwegian Nobel Committee due to the occupation of Norway by the German military. While three members of the Norwegian Nobel Committee went into hiding, the other members were saved from being persecuted by the German military due to the declaration by the Nobel Foundation that the head office in Oslo was the property of Sweden (Feldman, 2013). While the remaining members of the Nobel Committee managed the day-to-day affairs of the committee, Nobel Prizes were not presented during this period. The year 1944 witnessed the coming together of the members of the Nobel Foundation and the three members who had gone into exile to facilitate accepting nominations for the Nobel Peace Prize and start awarding the Nobel Prize for peace (Levinovitz & Ringertz, 2007).

3.4 Nobel Memorial Prize in Economic Sciences

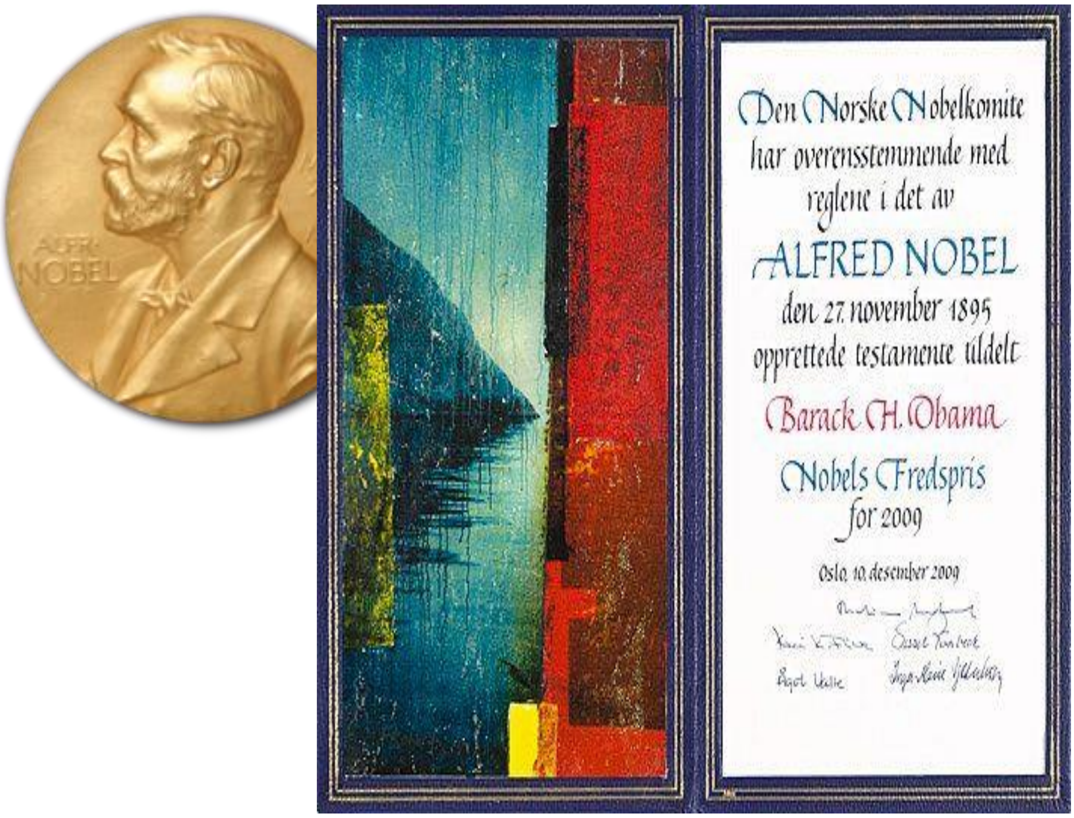

Figure 2: The Medal and the Certificate

While celebrating their 300th Foundation Day in 1968, the central bank of Sweden christened Sveriges Riksbank donated an immensely large sum of monetary funding to the Nobel Foundation to establish an award in honor of Late Alfred

Nobel. The first Alfred Nobel Memorial Prize in Economic Sciences named after the donor Sveriges Riksbank was awarded to Jan Tinbergen and Ragnar Frisch in 1969 for their work on developing applied dynamics model to analyze economic processes. The Royal Swedish Academy of Sciences was bestowed the duty of selecting economists and researchers in the field of economics who could be awarded the Alfred Nobel Memorial Prize in Economic Sciences. After the addition of the prize for economic sciences, the Nobel Foundation has decided not to increase the number of Nobel Prizes (Levinovitz & Ringertz, 2007).

3.5 Understanding the Process

The process of awarding the Nobel Prize begins with collection of nominations and ends with the Nobel Lecture. While the process involved is similar for all categories, the differences lie in the ability to nominate members. The following paragraphs detail the processes involved in each step of the ceremony (Feldman, 2013).

3.5.1 Nominations

This is the first step in the process of awarding the Nobel Prize. The process begins in the month of September of the previous year with the Nobel Committee sending nomination forms to 3000 distinguished personalities, which includes well-known academics who have been working in the relevant areas. Nominations for the Peace Prize are sought from the respective governments, former Laureates who have been awarded the Nobel Prize for Peace, and members of the Norwegian Nobel Committee (both current as well as former). The final date for receiving the completed nomination forms has been fixed as on the 31^{st} day of January in the next year that is the year in which the prizes are to be awarded (Feldman, 2013; Levinovitz & Ringertz, 2007). Based on the nominations, the Nobel Committee selects 300 nominations and also includes some additional names (Abrams, 2012). The nominations are not made public, and the level of secrecy can be understood from the fact that the nominated persons are not intimated about their nomination. All records of nominations are preserved in a sealed cover for 50 years after the distribution of the prizes (Feldman, 2013).

3.5.2 Selections

Selection is the second step in the process. This step commences with the Nobel Committee preparing a report citing the reasons for selecting certain nominations while rejecting the others. The report contains the advice received from the experts. This report and the selected list of nominations is then forwarded to the institutions that award the prizes for their approval (Feldman, 2013). The choice of the laureates in each field is made by these institutions by voting. The nomination receiving the highest number of votes is awarded the Nobel Prize in each category. The decision of the institutions is announced publicly after the voting and cannot be challenged or appealed (Levinovitz & Ringertz, 2007). The principle that guides the selection procedure is the fact that not more than three persons can be selected in any category, besides restricting the number of works to two. Further, all Nobel Prizes, other than the Nobel Prize for peace, is awarded to individuals. Nobel Prize for Peace can be awarded to institutions also (Abrams, 2012).

3.5.3 Posthumous Nominations

Dead individuals are not nominated for receiving the Nobel Prize. However, individuals who die in the days after their nominations have been accepted but before they actually receive the awards are eligible to be awarded the Nobel Prizes. In the history of the Nobel Prize, dead individuals have been awarded the Nobel Prize only twice. The first time any dead individual was awarded the Nobel Prize was in 1931 when Erik Axel Karlfeldt was awarded the Nobel Prize in Literature, while the second such occurence was in 1961 when the Nobel Peace Prize was awarded to United Nations Secretary General Dag Hammarskjold. Since 1974, the process of posthumously awarding the Nobel Prize has been stopped. It has to be ensured that the individual is alive *du*ring the announcement of the selection for the Nobel Prize. In 1996, William Vickrey was awarded the Alfred Nobel Memorial Prize in Economic Sciences posthumously after he died post announcement of the award but before receiving it (Abrams, 2012). The 2011 Nobel Prize for Medicine also witnessed a controversy when it was known that Ralph M. Steinman, one of the two persons who were selected for being awarded the Nobel Prize, had died three days prior to the announcement of the award. The fact that Nobel Prizes cannot be awarded posthumously led to an intense debate among the members of the committee regarding awarding the prize to Ralph M. Steinman. The Committee unanimously decided that nomination of Ralph M. Steinman for the prize was made in good faith and retained the nomination, leading to him being awarded the Nobel Prize in Medicine.

3.5.4 Recognizing a Laureate

As per the will of Alfred Nobel, the Nobel Prizes have to be awarded based on discoveries made during the previous year. The early days of the Nobel Prize saw individuals being considered for getting the award based on discoveries that were made beyond the preceding year (Nobel Foundation, 1999). This has caused serious embarrassment to the Nobel Committee and decreased the prestige associated with the Prize. An example of this can be understood from the fact that the 1926 Nobel Prize for Medicine was awarded to Johannes Fibiger for his supposed discovery of the parasite that caused cancer (Levinovitz & Ringertz, 2007). In its attempt at damage control and enhancing the prestige associated with the Nobel Prize, the Nobel Committee decided to recognize only those discoveries that stood over time (Levinovitz & Ringertz, 2007; Abrams, 2012; Breithaupt, 2001). According to Ralf Pettersson, who was the erstwhile Chairman of the Nobel Prize Committee for Medicine, the Nobel Assembly interprets the term 'previous year' as that year in which the full effect of the discovery has come into light. In other words, the entire effect of the discovery has been understood. (Liu, 2009).

There is no uniform policy regarding the interval between the date of the accomplishment and the date of receiving the award. The Nobel Prize in Literature, for example is not awarded based upon a single achievement but considers the lifetime achievement of the Nobel Laureate (Nobel Prize Outreach, 2021). The Nobel Prize for Peace can be awarded for lifetime achievement and also for individual accomplishments. While Martti Ahtisaari was awarded the Nobel Prize for Peace in 2008 for his involvement in resolving international conflicts (Bryant, 2008), Kofi Annan received the Nobel Peace Prize in 2001, just four years after being sworn in as the Secretary General of the United Nations (Abrams, 2012). Similarly, both Yaseer Arafat, Yitzhak Rabin, and Shimon Perez were awarded the Nobel Prize for Peace in 1994 one year after they signed the Oslo Accords (Vishveshwara, 2000).

Nobel Prizes in Physics, Chemistry, and Medicine is generally awarded after the discovery has gained global recognition. This may take several years as observed in the case of Subrahmanyan Chandrasekhar who shared the 1983 Nobel Prize in Physics for discovering the evolution and structure of stars which was completed in the 1930s (Vishveshwara, 2000). It can be appreciated that many scientists die years before their discoveries get global recognition, making them eligible to be nominated for the Nobel Prize. Discoveries which receive recognition after the scientist has died are never considered for the Nobel Prize (Nobel Foundation, 2004; Gingras & Wallace, 2008; Editorial, 2009).

3.5.5 The Nobel Prize Award Ceremony

The Nobel Prizes in all categories, except for peace are awarded in Stockholm, Sweden on the 10th day of December every year to mark the death anniversary of Alfred Nobel. The award ceremonies are preceded by Nobel Lectures where the individual Nobel Laureates deliver lectures thanking the Nobel Committee at finding them eligible for the prestigious award and also on their field of research. The award ceremony for awarding the Nobel Prize for peace is also held on the same day but at Oslo in Norway. The Nobel Lecture, the award ceremony, and the Nobel Banquet hosted in honour of the newly inducted Nobel Laureates are among the major international events (The Editor, 2009). The award ceremony that is organized in Sweden is held at the Stockholm Concert Hall. This is followed by the Nobel Banquet at the Stockholm Hall. The Nobel Prize for Peace, however, has been held at different locations. The period from 1905 till 1946 saw the ceremony being organized at the Norwegian Nobel Institute, while the award ceremonies during 1947 till 1989 were held at the University of Oslo. Since 1990, the award ceremonies for Nobel Prize for Peace are regularly being held at the Oslo City Hall (Levinovitz & Ringertz, 2007).

The highlight of the Nobel Prize Award presentation ceremony that is held in Stockholm lies in receiving the Nobel Prize from the royal hands of the King of Sweden. The Nobel Peace Prize is presented not by the royal family but by the Chairman of the Norwegian Nobel Committee in the presence of the King of Norway (Froman, 2007).

3.5.6 Nobel Banquet

Nobel Banquets are held immediately after the Nobel Prize Award Ceremony both in Stockholm and in Oslo. In Stockholm, the Nobel Banquets are organized in the Blue Hall at the Stockholm City Hall. The banquet has in its attendance 1300 guests which include the members of the Swedish Royal Family, the Nobel Laureates, and prominent personalities. The Nobel Banquet at Oslo is held at the Oslo Grand Hotel and has in its attendance 250 guests including the Nobel Laureates, the President of the Storting, the Prime Minister of Sweden, and selected members of the royal family of Norway.

3.5.7 Nobel Lectures

As per the rules that have been framed by the Nobel Committee, every Nobel Laureate is required to deliver a lecture on the subject of his research. These Nobel Lectures are organized by the institutions which have selected the Nobel Laureates. The style and more of delivering the lecture has been perfected over decades (Salazar, 2009). Though the Nobel Lectures are generally organized during the week that leads to the award ceremony, which commences from the date on which the Nobel Laureates reach Stockholm and culminates with the Nobel Banquet, this practice is not obligatory. Though it is obligatory for the Nobel Laureate to deliver the Nobel Lecture within six months of receiving the Nobel Prize, some have delivered their lectures much beyond the stipulated date. The President of the United States, Theodore Roosevelt who had been awarded the Nobel Prize for Peace in 1906, delivered his lecture in 1910 after he demitted the office of the President of the United States (Abrams, 2012).

3.6 The Nobel Prize

The Nobel Prize comprises a medal, a diploma, a cash award. The succeeding sections discuss each component of the prize in detail. Every Nobel Laureate receives a gold medal, a heavily decorated diploma, and prize money.

3.6.1 Medal

Every medal has the image depicting the left profile of Alfred Nobel in the obverse. While the front face of the medals that are awarded to Nobel Laureates in Physics, Chemistry, Literature, and Medicine depict the left side of the face of Alfred Nobel and the year of his birth and demise, the medals that are awarded to Nobel Laureates in Peace and Economic Sciences have a slightly different design in the picture of Alfred Nobel. The medal that is awarded to Nobel Laureates in Economic Sciences, for example, have their names etched on the rim of the medal (Feldman, 2013). The image on the reverse depends upon the institutions who award the prizes. The images in the medal that are awarded to Nobel Laureates in Physics and Chemistry are identical.

Prior to 1980, all medals were made using 23 carat (ct) gold. Post 1980, all medals are made using 18 ct green gold and plated with 24 ct gold. The weight of the medals depends upon the economic value of gold, the average weight of the medals measures 175 grams. The diameter of the medal is 66 millimetres and thickness vary between 2.4 millimetres and 5.2 millimetres. The amount of gold used in making the medals and the fact that these medals are kept open for public view makes it vulnerable to theft (Levinovitz & Ringertz, 2007). The second world war witnessed the transportation of the medals of German scientists Max von Laue and James Frank to Copenhagen following safety considerations. The matter went to such an extent that Hungarian chemist and Nobel Laureate George de Havesy was forced to dissolve his medal in aqua-regia when the German army invaded Denmark fearing confiscation and legal problems. The gold was recovered from the solution after the war, and the medal had been recast (Lemmel, 2021).

Traditionally, the medals for the Nobel Prize were made by the Swedish mint (Myntverket), which was also the oldest company in Sweden. As the company closed down its operation after serving for 107 years in 2011, the medals had to be prepared by a new company. The medals for the year 2011 were made in the Mint of Norway which is located at Kongsberg. Since 2012, all the five Nobel Prize medals are being made at Svenska Medalj AB. The Nobel Prize medals bear the trademark of the Nobel Foundation (Feldman, 2013).

3.6.2 Diplomas

Besides the Nobel Prize medal, all Nobel Laureates also receive a diploma. While the Nobel Laureates for Peace receive their diplomas from the Chairman of the Nobel Committee, the other Nobel Laureates receive their diplomas from the King of Sweden. Each diploma is finely crafted by the institutions that award the prizes and are unique in itself. The diploma contains a picture and a text in Swedish that bears the name of the Nobel Laureate and a citation showing the reason for being selected for the Nobel Prize. The diploma given as a part of the Nobel Peace Prize, do not contain any such citations.

3.6.3 Monetary Award

Besides the medal and the diploma, the Nobel Laureates also receive money in the form of a document that confirms the amount that the Nobel Laureate has received. There is no uniformity in the amount of the award, and it generally depends upon the ability of the Nobel Committee. During the 1980s, the prize money was 880,000 SEK per prize, which was enhanced to 10 million SEK in 2009. The amount of prize money was subsequently reduced to 8 million SEK in 2012 (Abrams, 2012). In case the Nobel Prize is shared by two individuals, the prize money is divided equally among the Nobel Laureates. Further, if three persons share the Nobel Prize, the award presenting institution can either divide the amount equally among the

Nobel Laureates or give one-half to one Nobel Laureate and divide the remaining among the other two Laureates (Sample, 2008; Sample, 2009).

3.7 Noble Prize statistics

Youngest person to be awarded the Nobel Prize: Malala Yousafzai is the youngest Nobel Laureate having received the Nobel Peace Prize in 2014 at the age of 17 years.

Oldest person to be awarded the Nobel Prize: John B. Goodenough is the oldest person to be awarded the Nobel Prize when he was awarded the Nobel Prize in Chemistry in 2019 at the age of 97 years.

Person receiving more than one unshared Nobel Prize: Linus Pauling received the Nobel Prize twice, once in 1954 for Chemistry and second in 1962 for Peace.

Laureates receiving several Nobel Prizes:

1. Marie Curie received the prize twice. In 1903 for Physics and in 1911 for Chemistry.
2. Linus Pauling received the prize twice. In 1954 for Chemistry and in 1962 for Peace.
3. John Bardeen received the Nobel Prize in Physics twice. The first in 1956, and the second in 1972.
4. Frederick Sanger received the Nobel Prize in Chemistry twice. The first in 1958 and the second in 1980.
5. International Committee of the Red Cross received the Nobel Peace Prize three times in 1917, 1944, and in 1963.
6. United Nations High Commissioner for Refugees received the Nobel Peace Prize twice in 1954 and in 1981.

Posthumous Nobel Laureates:

1. Erik Axel Karlfeldt received the Nobel Prize in Literature in 1931.
2. Dag Hammarskjöld received the Nobel Peace Prize in 1961.
3. Ralph M. Steinman received the Nobel Prize in Medicine in 2011.

Married couples who have received the Nobel Prizes:

1. Marie Curie and Pierre Curie received the Nobel Prize in Physics in 1903.
2. Irène Joliot-Curie and Frédéric Joliot received the Nobel Prize in Chemistry in 1935.
3. Gerty Cori and Carl Cori received the Nobel Prize in Medicine in 1947.

4. May-Britt Moser and Edvard I. Moser received the Nobel Prize in Medicine in 2014.
5. Alva Myrdal received the Nobel Peace Prize in 1982, while Gunnar Myrdal received the Nobel Prize in Economics Sciences in 1974.
6. Esther Duflo and Abhijit Banerjee received the Nobel Prize in Economics Sciences in 2019.

3.8 Conclusion

The chapter commences with discussing the history of the Nobel Prize. The life of Alfred Nobel has also been discussed in sufficient details in this chapter. The transformation of an engineer, and an industrialist to sponsoring the most prestigious awards in science to recognize researchers for their works due to reading a accidental obituary that had appeared in a local paper has also received description. Statistics regarding the aspects of the Nobel Prize has also been mentioned in this chapter. As per the will left behind by Alfred Nobel, which was read in Stockholm on the 30th day of December 1896, Alfred Nobel had earmarked 94% of his personal fortune to the Nobel Foundation for instituting five awards to be conferred to individuals who have served humanity. This asset has been the foundation upon which the Nobel Prizes are awarded each year. Founded as a private entity on the 29th day of June 1900, the function of the Nobel Foundation laid in managing the administration and the finances of the Nobel Prizes which was the primary duty of the foundation as per the covenants of the will. The will of Alfred Nobel does not allow the Nobel Foundation to select the Nobel Laureates, but to work as an advertising agency. The will clearly states that the primary responsibilities of the Nobel Foundation would lie in investing Nobel’s money in a manner that prizes can be awarded annually and oversee the administration of the prizes. Despite the fact that the money earns interest by way of investments, the Swedish government has exempted the amount earned as interest upon investment from the provisions of income tax since 1946. Further, all money invested in the United States is also exempted from investment tax since 1953. With the investment scenario witnessing a rise since the 1980s, the investments made by the Nobel Foundation became more lucrative. Studies have approximated the assets controlled by the Nobel Foundation at US$ 560 million as on the 31st day of December 2007. The will of Alfred Nobel, the Nobel Foundation would have five members, including the Chairman from amongst Norwegian or Swedish citizens, with its head office being based at Stockholm. The award of the prize since the inception has also been discussed together with introduction of the Nobel Prize in Economic Sciences. The process of the award has also been described in detail along with the contents of the Prize.

After discussing about the History of Nobel prize, next chapter deals with profile of Nobel laureates in chemistry (Chapter – 4).

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CHAPTER – 4

PROFILES OF NOBEL LAUREATES IN CHEMISTRY

Since the commencement of awarding the Nobel Prize, the Nobel Prize in Chemistry has been presented on 111 occasions to 194 Nobel Laureates between 1901 and 2019. Frederick Sanger is the only Nobel Laureate who has been awarded the Nobel Prize in Chemistry twice, once in 1958 and the other in 1980.

The succeeding pages show the profiles of the Nobel Laureates in Chemistry since the inception of the Nobel Prize till 2018. The tabulated form contains the year in which the Prize has been conferred, the names of the Nobel Laureates, their date and place of birth, age at which they became Nobel Laureates, the motivation for being awarded the Prizes, and the nature of distribution of the prize money.

4.1 Eric Betzig

Eric Betzig was born on 13th January 1960 at Ann Abor, Michigan of Helen Betzig and Robert Betzig, who was an engineer by profession. Betzig aspired to be an astronaut and work in the aerospace industry. He would often tell his parents of winning the Nobel Prize by the time he reaches 40 years. Though his dream of reaching space could not be materialized, Betzig succeeded in winning the Nobel Prize 14 years later than he had predicted. Eric Betzig was born on 13th January 1960 at Ann Abor, Michigan of Helen Betzig and Robert Betzig, who was an engineer by profession. Betzig aspired to be an astronaut and work in the aerospace industry. He would often tell his parents of winning the Nobel Prize by the time he reaches 40 years. Though his dream of reaching space could not be materialized, Betzig succeeded in winning the Nobel Prize 14 years later than he had predicted.

In 1873, Ernst Abbe stated that the maximum resolution of any optical microscope could never exceed 0.2 micrometers. Betzig worked on the development of super-resolved fluorescence to exceed the accepted limits of traditional optical microscopy as laid down by Ernst Abbe in 1873. He was awarded the Nobel Prize in

Chemistry in 2014 for his works which he shared with William E. Moerner and Stefan W. Hell. While William E. Moerner hails from the United States of America, Stefan W Hell is a Romanian-German chemist.

Eric Betzig is the brother of Laura Betzig, a social historian. In his younger days, Eric Betzig was enrolled in Ann Arbor Pioneer School and went on to study physics at the California Institute of Technology and obtained his graduation in 1983. He then went on to study Applied and Engineering Physics at Cornell University from where he obtained his doctorate in 1988.

Betzig began his professional life after obtaining his doctorate when he joined AT&T Bell Laboratories located in New Jersey. During his stay at AT & T Bell Laboratories, Betzig worked on near-field microscopy using a ray of light having wavelength of dew nanometres from the sample. Though the results of his experiments were better ta those obtained by Abbe, but the wavelength was too small to enable seeing the structures that lie beneath the surface of the cell. In the summer of 1989, Prof. (Dr.) William Moerner detected the phenomenon of light absorption by single molecules while conducting the experiment at absolute zero temperature, becoming the first researcher to accomplish such a feat. This accomplishment motivated Betzig to replicate the experiment at room temperature, as this is the temperature at which all practical studies would be conducted. The rationale behind Betzig's experiment lay in the fact that in case the molecules emit different colours, a microscope would be able to capture the colours and produce images that are unique to the colour. The pictures would then be superimposed to produce an image that would surpass Abbe's limit. It requires mention that generation of molecular orbital properties was unthought of at this period.

The year 1995 saw a twist in the life of Betzig when he had the feeling that he had accomplished all that he could. This led him to resign from the post and join the family engineering company where he developed the Flexible Adaptive Servo Hydraulic Technology, that would usher in a new era in production line machinery. The fascination to crack Abbe's limit compelled Betzig to collaborate with Harald Hess, his previous colleague at AT &T Bell Corporation, to implement the idea used by Mike Davidson at the Florida State University regarding photoactivated fluorescent proteins. The duo used stochastic photoactivation in place of colour to separate the molecules. Betzig and Hess built a microscope to help them in their quest in the living room of Herald Hess, and after completion shifted the instrument to the laboratory at the National Institutes of Health belonging to Jennifer Lippincott-Schwartz. Unlike electron microscopy which kills the cells, the newly developed microscope used weak pulses of light to activate fluorescence, a few proteins at a time, without killing the cells. The new instrument has other advantages in the form of being able to retain the different biological processes. After several attempts to activate and capture the image, the microscope was able to measure the position of all the molecules and build an image having high resolution as anticipated by Betzig.

After their spectacular achievement, both Betzig and Hess were hired by the Janelia Research Campus maintained by the Howard Hughes Medical Institute in Virginia. Here, Betzig succeeded in developing lattice light sheet microscopy to capture the three-dimensional, high-resolution images of the life processes occurring inside a living cell using adaptive optical microscopes. His efforts enabled high resolution imaging inside aberrating multicellular organisms. Both Eric Betzig and his wife Na Ji were appointed professors at the University of California, Berkeley Campus. The couple has three young children and reside within the walls of the university campus.

Quick Fact

Name	Robert Eric Betzig
Born	13 January 1960, Ann Arbor, MI, USA
Nationality	American
Father	Robert Betzig
Mother	Helen Betzig
Fields	Applied physics
Alma mater	California Institute of Technology (BS) Cornell University (MS, Ph. D.)
Known for	Nanoscopy, fluorescence microscopy
Institutions	Howard Hughes Medical Institute University of California, Berkeley
Notable awards and affiliations	Member of the National Academy of Sciences (2015)

	Nobel Prize in Chemistry (2014)
Affiliation at the time of the award	Janelia Research Campus, Howard Hughes Medical Institute, Ashburn, VA, USA
Age of becoming Nobel Laureate	54
Prize motivation	For the development of super-resolved fluorescence microscopy
Prize share	1/3

4.2 Stefan Walter Hell

Since the invention of optical microscopes in the later part of the fifteenth century, the instrument has witnessed massive development in its design and utility. In the last part of the nineteenth century, based upon the works of the German microscopist Ernst Abbe, it was believed that the optical microscopes had reached the ultimate limits of their abilities. The Nobel Prize in Chemistry for 2014 was presented to three scientists for their works on overcoming the limits set by Abbe.

Stefan Walter Hell was born on 23rd December 1962 in Arad district of Romania. Hell's family migrated from Santana, a larger rural community in the nearby district founded by German immigrants in the 18th century. Stefan Walter Hell received his secondary education at Nikolaus Lenau High School in Timisoara before he persuades his parents to migrate to West Germany in 1978. In West Germany, the family settled in Ludwigshafen in the south-western part. Stefan Walter Hell was enrolled at Heidelberg University in 1981 and completed his doctorate in 1990 in physics while studying confocal microscopy.

At Heidelberg University, Hell worked independently and persued his ideas regarding improvement of the depth resolution in confocal laser microscopy. Thereafter, Hell joined the European Molecular Biology Laboratory located in Heidelberg and remained there for more than two years commencing 1991. At the

European Molecular Biology Laboratory, Stefan Hell worked on his ideas and developed what we now know as 4Pi microscopy. This form of microscopy helps in capturing images that have resolutions up to seven times higher than the previously developed models.

After his brief stint at the European Molecular Biology Laboratory, Stefan Hell went to the University of Turku in Finland. Stefan Hell worked in this university from 1993 till 1996 which included a brief six-month stay at Oxford University in the United Kingdom as a visiting scientist. Upon arrival at Turku, Stefan came to know the principle of stimulated emission depletion microscopy. He, along with Jan Wichmann worked on the principle and published a paper jointly. This instrument was regarded as the first microscope to cross Abbe's limit and later became the motivation behind Stean Hell being awarded the Nobel Prize in Chemistry. However, this design met with initial scepticism both in Germany and among global scientists.

During 1996, some senior scientists at the Max Planck Institute of Biophysical Chemistry located at Gottingen in Germany realized the immense potential of the work of Stefan Hell. Hell joined the Max Planck Institute of Biophysical Chemistry in December 1996, and in 2002 he was appointed the Director of the institute.

In 1999, during his stay at the Max Planck Institute of Biophysical Chemistry, Hell and Thomas Klar built a working model of the stimulated emission depletion microscope and demonstrated its efficacy. The rationale behind working of this microscope lay in illuminating certain molecules by a beam of non-fluorescent light. The modus operandi employed by Stefan Hell lay in focusing laser light to stimulate fluorescent molecules by focusing a ring-shaped beam of light.

Fluorescent photons are released only from molecules that reside at the centre of the ring-shaped beam. Since this region can be made smaller than a diffracted beam, scanning beams jointly across the sample can induce consecutive emission by features that reside within the proximity of sub-diffraction. This enables capturing images of features that have a diameter of 20 nanometres enabling high-speed recordings of active biological processes. In theory, the region where the molecules produce fluorescence can be tuned down to the size covered by a single molecule, which provides resolution at a molecular scale.

The stimulated emission depletion microscope has proved useful in the investigation of various diseases and cells. This development has made Stefan Hell the head of the department Optical Nanos copy at the German Cancer Research Centre located in Heidelberg. Stefan Hell is also the adjunct professor of physics at the universities of Heidelberg and Göttingen.

Stefan Walter Hell has received many major awards since 2000, culminating in the Nobel Prize, which he shares with the Americans Eric Betzig and William Moerner.

Quick Fact

Name	Stefan Walter Hell
Born	23 December 1962 Arad, Romania
Nationality	German
Fields	Physical chemistry
Alma mater	Heidelberg University
Doctoral advisor	Siegfried Hunklinger
Thesis	'Imaging of transparent microstructures in a confocal microscope' (1990)
Known for	STED microscopy
Institutions	European Molecular Biology Laboratory Max Planck Institute for Biophysical Chemistry German Cancer Research Center
Notable awards and affiliations	• Prize of the International Commission for Optics, 2000 • Helmholtz-Award for metrology, Co-Recipient, 2001 • Berthold Leibinger Innovationspreis, 2002 • Carl-Zeiss Research Award, 2002 • Karl-Heinz-Beckurts-award, 2002 • C. Benz u. G. Daimler-Award of Berlin-Brandenburgisch academy, 2004 • Robert B. Woodward Scholar, Harvard University, Cambridge, MA, USA, 2006 • "Innovation Award of the German Federal President", 2006 • Julius Springer Prize for Applied Physics

2007

- Member of the Akademie der Wissenschaften zu Göttingen 2007
- Gottfried Wilhelm Leibniz Prize, 2008
- Lower Saxony State Prize 2008
- Nomination for European Inventor of the Year of the European Patent Office, 2008
- Method of the year 2008 in Nature Methods
- Otto-Hahn-Preis, 2009
- Ernst-Hellmut-Vits-Prize, 2010
- Hansen Family Award, 2011
- Körber European Science Prize, 2011
- The Gothenburg Lise Meitner prize, 2010/11
- Meyenburg Prize,[16] 2011
- Science Prize of the Fritz Behrens Foundation 2012
- Doctor Honoris Causa of „Vasile Goldiș” Western University of Arad, 2012/05
- Romanian Academy, Honorary Member, 2012
- Paul Karrer Gold Medal, University of Zürich, 2013
- Member of Leopoldina, German National Academy, 2013
- Carus Medal of the Leopoldina, 2013
- Kavli Prize, 2014
- Nobel Prize in Chemistry, 2014
- Romanian Royal Family: Knight Commander of the Order of the Crown
- Romania: Grand Cross of the Order of the Star of Romania, 2015

	• Glenn T. Seaborg Medal, 2015 • Wilhelm Exner Medal, 2016 • Foreign associate of the National Academy of Sciences, 2016 • Honorary Fellow of the Royal Microscopical Society (HonFRMS), 2017 for his contributions to microscopy. • Fellow of the Norwegian Academy of Science and Letters.
Affiliation at the time of the award	Max Planck Institute for Biophysical Chemistry, Göttingen, Germany, German Cancer Research Center, Heidelberg, Germany
Age of becoming Nobel Laureate	52
Prize motivation	For the development of super-resolved fluorescence microscopy
Prize share	2/3

4.3 William Esco Morener

Since the later part of the nineteenth century, the domain of optical microscopy was heavily dependent upon the works of the German microscopist Ernst Abbe, who had prescribed a natural limit of less than 200 nanometers. The proposal by Abbe relied upon his theory that no optical microscope could distinguish between objects if these are kept less than at a distance of 200 nanometres (half the wavelength of visible light).

Though this problem can be solved using electron microscopy which can distinguish between objects placed few nanometres apart, this technique suffers from the demerit that it cannot be used on living tissues. The Nobel Prize in Chemistry for

2014 was awarded to three researchers for their works on breaking the Abbe's limit by using moleules and their fluorescence. While Stefan Walter Hell, a German researcher, used lasers to stimulate fluorescent molecules in small molecules to make compound images, Eric Betzig relied upon the works done by William Esco Moerner to use single-molecule microscopy in the United States. William Esco Moerner had done his research in the later-half of the 1980s.

Moerner based his works on switching the fluorescence of all molecules on and off and watching the same molecules over a period of time while allowing a few molecules to glow at any particular time. By merging all these images, scientists are able to produce super images which are resolved at the nano level. Though Eric Betzig demonstrated a working microscope capable of such a feat in 2006, the credit of isolating individual molecules with the help of light for undertaking spectroscopy analysis goes to William Esco Meorner who had attempted to conduct such an experiment many years prior to Betzig.

William Esco Moerner was born on the 24th day of June 1953 in Pleasenton in California and spent his early years in San Antonio in Texas. He studied physics, mathematics and electrical engineering and graduated in the year 1975 from Washington University I St Louis. Thereafter, Moerner moved to Cornell University and completed his master's in 1978 and his doctorate in physics in 1982.

Armed with a doctorate degree in physics, Moerner began his professional life at the research centre of IBM housed at San Jose in California. Here, Moerner rose to the position of project leader and remained in this position for six years commencing from 1989. During his tenure at IBM in 1989, Moerner measured the capacity of absorption of light using a single molecule. By doing so, Moerner became the first person to achieve this amazing feat.

Prior to Moerne's epoch making attempt, researchers relied on taking average imprint of several molecules present in a sample. Moerner conducted absorption spectroscopy on an organic crystal sample containing small quantity of pentacene hydrocarbon molecule maintained at a temperature which equalled absolute zero. This technique helped Moerner to distinguish between individual molecules using finely tuned laser. The observations led Moerner to conclude the fact that the single molecules have the ability of optically switching.

Moerner was appointed Distinguished Chair in Physical Chemistry at the

University of California, San Diego campus in 1995, where he me Roger Tsein who was working on a project on isolating green fluorescent proteins from jellyfish, that would win him the Nobel Prize. The results of this project could be extended to other proteins and the position of these proteins inside the cell could be determined. Moerner mixed these proteins in a gel solution and was able to observe individual glow using an optical microscope. During conduct of the experiment, Moerner observed that the green fluorescent proteins could turn off and on by exciting them with lights of certain wavelength and other certain conditions behaved like a firefly.

This property was used by future scientists like Eric Betzig and others and shows how certain scientific discoveries have the ability to open new vistas capable of motivating future researchers. Moerner moved to Stanford University in California in 1998 as a Harry S Mosher Chair in physical chemistry and applied physics with single molecule. He resides in California with his wife Sharon and their son.

Quick Fact

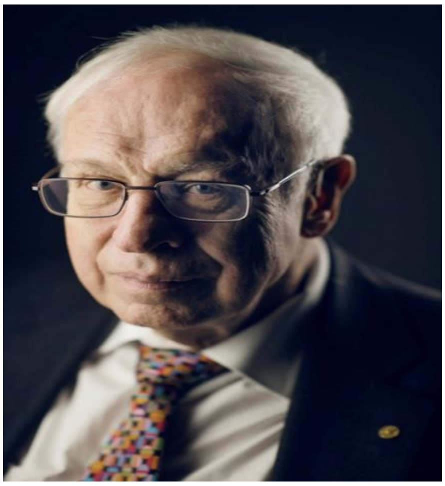
Name	William Esco Moerner
Born	24 June 1953, Pleasanton, CA, USA
Nationality	American
Father	William Alfred Moerner
Mother	Bertha Frances (Robinson)
Fields	Chemistry, applied physics, biophysics
Alma mater	Washington University in St. Louis, Cornell University
Doctoral advisor	Albert J. Sievers
Thesis	Vibrational relaxation dynamics of an IR-laser-excited molecular impurity mode in alkali halide lattices (1982)
Other academic advisors	James Gegan Miller
Institutions	Stanford University, UC San Diego
Notable awards and honor	• National Winner of the Outstanding Young Professional Award for 1984 • The electrical engineering honorary society, Eta Kappa Nu, April 22, 1985 • IBM Outstanding Technical

Achievement Award for Photon-Gated Spectral Hole-Burning, July 11, 1988

- IBM Outstanding Technical Achievement Award for Single-Molecule Detection and Spectroscopy, November 22, 1992
- Earle K. Plyler Prize for Molecular Spectroscopy, American Physical Society, 2001
- Wolf Prize in Chemistry, 2008
- Irving Langmuir Award in Chemical Physics, American Physical Society, 2009
- Pittsburgh Spectroscopy Award, 2012
- Peter Debye Award in Physical Chemistry, American Chemical Society, 2013
- the Engineering Alumni Achievement Award, Washington University, 2013
- the Nobel Prize in Chemistry, 2014
- Moerner also holds more than a dozen patents.
- His honorary memberships include Senior Member, IEEE, June 17, 1988
- National Academy of Sciences, 2007
- He is also a Fellow of the Optical Society of America, May 28, 1992
- the American Physical Society, November 16, 1992
- the American Academy of Arts and Sciences, 2001
- the American Association for the Advancement of Science, 2004

Affiliation at the time of the award	Stanford University, Stanford, CA, USA
Age of becoming Nobel Laureate	61
Prize motivation	For the development of super-resolved fluorescence microscopy
Prize share	3/3

4.4 Tomas Lindahl



Right from their birth to attaining the state of adulthppd, all living organisms grow by the process of cell division. The process of cell division is also associated with severe damage in the cell. To decrease the effect of the damage, all cells have an inherent repair mechanism that is unique to the individual. The growth of the cells is due to the presence of proteins inside the cell, while the deoxy ribose nucleic acid (DNA) acts as the blue print of the organism.

The early researchers believed that DNA was stable but recent research has contradicted the validity of the earlier findings. It is now known that DNA is susceptible to damage and erodes over time. The reasons for this phenomenon have been partly attributed to the process of constant splitting and recombination during the process of growth, and partly attributed to the environment. The damage to the DNA has been found to be fatal as it leads to the growth of cancer cells. However, there are certain proteins that repair the damaged cells either by repairing the errors in the process of DNA strands or, by producing cells for destruction before the onset of cancer. As per estimates, these repair proteins are able to repair 99.9% of these potentially fatal damages.

Through his studies of biochemistry conducted in the 1970s, Tomas Lindahl found that strands of DNA were being subject to several potentially fatal damages each day. Though most of these damages were harmless, yet frequent failure of the DNA strands had the potential to thwart the development of all forms of life in the planet. This is indeed a frightening thought that led Lindahl to discover base excision repair, a process by which certain proteins, called the DNA repair enzymes constantly repair and replace the damaged parts of DNA. This study was of such importance that it motivated the Nobel Committee to confer the 2015 Nobel Prize in Chemistry to Tomas Lindahl, together with Paul Modrich and Aziz Sancar for their work that aims to increase our knowledge of the working of cells, and the causes that lead to cancer and ageing.

Lindahl received his education at the Karolinska Institute in Stockholm which is the Medical School affiliated to Stockholm University. He obtained his doctorate degree in 1967 and MD degree in 1970. At the Karolinska Institute, Lindahl demonstrated that unstable nature of DNA and the requirement of maintenance. Lindahl got his postdoctoral research at Princeton and Rockefeller Universities in the United States before returning to Sweden as Professor of Medical Chemistry at the University of Gothenburg in 1978. While at the University of Gothenburg, Lindahl made some discoveries regarding how Epstein Barr virus DNA causes cancer. Lindahl met virologist Beverly Griffin at a conference and returned with her to London where he joined the Imperial Cancer Research Fund as a researcher in 1982. The couple remained together until Beverly's death in 2016.

Lindahl set up CRUK’s Mutagenesis Research Laboratory at Clare Hall in Hertfordshire in 1986 to change the working atmosphere on his alma mater in Stockholm. He remained as the director till 2005, and continued his research aimed at characterising previously unknown DNA repair systems, that have provided a greater understanding of the mechanisms of defence systems of the cells.

Tomas Lindahl is a member of the Swedish and Norwegian Academies of Science, a Fellow of the UK Academy of Medical Sciences, and the Royal Society. He was awarded the Royal Medal in 2007, and the prestigious Copley Medal in 2010. Lindahl also chairs the Scientific Advisory Board of IFOM, the Italian Research Institute for Molecular Oncology, and regularly visits IFOM in Milan. In 2018, Lindahl was appointed a Foreign Member of the US National Academy of Sciences.

Quick Fact

Name	Tomas Robert Lindahl
Born	28 January 1938, Stockholm, Sweden
Nationality	Swedish, British (dual nationality)
Father	Folke Robert Lindahl

Mother	Ethel Hulda Hultberg
Fields	Cancer research, DNA repair
Alma mater	Karolinska Institutet (MD, PhD)
Thesis	On the structure and stability of nucleic acids in solution (1967)
Known for	Clarification of cellular resistance to carcinogens
Institutions	Francis Crick Institute London Research Institute University of Gothenburg Princeton University Rockefeller University
Notable awards and affiliations	EMBO Membership (1974) FRS (1988) FMedSci (1998) Royal Medal (2007) Copley Medal (2010) Nobel Prize in Chemistry (2015)
Affiliation at the time of the award	Francis Crick Institute, Hertfordshire, United Kingdom, Clare Hall Laboratory, Hertfordshire, United Kingdom
Age of becoming Nobel Laureate	77
Prize motivation	For mechanistic studies of DNA repair
Prize share	1/3

4.5 Paul Modrich

All living organisms from the unicellular to the multicellular are highly complex, with each cell being capable of sustaining life. Besides what has been stated, each cell contains proteins that help in cell division and DNA which contain genetic information. Contrary to what has been previously thought, DNA is not entirely stable. It is susceptible to damage and decay which results due to age or due to natural processes of cell division and replication.

The Nobel Prize in Chemistry for 2015 was awarded to Paul Modrich, along with Tomas Lindahl and Aziz Sancar, for their independent study on how cells repair damaged DNA and preserve the genetic information. Their study has not only increased our knowledge of the functions of te cell and genetics, but also has severe implications for treatment of cancer.

While Lindahl showed the unstable nature of DNA and discovered base excision repair which is a molecular process by which damaged or decayed strands of DNA are constantly rebuilt repaired, Aziz Sancar mapped nucleotide excision repair, a process that repairs UV damage to strands of DNA and corrects the damages caused by mutagenic substances. Paul Modrich established the nature of mismatch repair. Mismatch repair is defined as the process by which cells correct damages that tak place when DNA is replicated during the process of cell division. While this damage can cause a hereditary variant of colon cancer, a effective mismatch repair can drastically reduce this risk.

The process of mismatch repair helps in stabilizing the genome by correcting the damages caused during cell division, blocking recombination between diverged strands of DNA, and also by triggering the arrest of cell cycle and cell death as an after effect of damage caused to DNA due to administration of certain anti-cancer drugs. Among the earliest works related to providing evidence relating to strand directed mismatch repair is the work done by Matthew Meselson on Escherichia coli. Modrich was instrumental in identifying proteins and enzymes that are responsible for the reaction, including MutH, MutL, MutS, and MutU proteins, and also proposed the mechanism of the occurrence.

In humans, mismatch repair works in an identical fashion, using homologs of the MutS and MutL proteins. Genetic defects in human MutS or MutL proteins is considered to be the cause of the most common form of hereditary colon cancer, and also a substantial part of sporadic cancers. Paul Modrich and his team observed that inactivation of human Mut proteins causes the cancer cells to be resistant to killing by certain chemotherapeutic drugs. In 1996, Modrich showed the process regarding recognition of the lesions produced by these drugs on the DNA by the human mismatch repair system. This led Paul Mudroch to conclude that this is the first step in the chain of events that leads to killing the cancer causing cells. Paul Mudroch has also established the mechanism of the occurrence of human mismatch repair, and continues to study the molecular nature of this pathway and its role in the cellular response to DNA damage.

Paul Modrich was born in 1946 in Raton, New Mexico after his paternal grandparents had migrated to the United States from Croatia. Modrich showed an interest in biology from an early age due to the huge biological diversity that he had observed around his small town. When he was not busy playing baseball or basketball, he would go to the Rocky Mountains and look for fossils. "Within five miles, the ecology can change dramatically," he says. "It was very thought provoking."

Modrich’s curiosity for the natural world received further encouragement from his parents. His father who was a teacher of biology at the local high school. Modrich has credited his father for setting him on the path to success. After Francis Crick, James Watson and Maurice Wilkins received the 1962 Nobel for the discovery of the DNA double helix, Modrich remembers his father giving him the advice: "You should learn about this DNA stuff."

Modrich studied biology at the Massachusetts Institute of Technology (MIT) and received his bachelor's degree in 1968. He then went on to Stanford University in California, where he earned his doctorate degree in biochemistry in 1973. During that period, researchers thought that DNA was stable, but Modrich first investigated the ligase enzyme as a calatyst that repairs break in the DNA of E. coli. Modrich began his work on mismatch repair in E. coli in the latter half of the 1970s.

Pau Modrich married fellow Duke biochemist Vickers Burdett and had two adult children from his previous marriage.

Quick Fact

Name	Paul Lawrence Modrich
Born	13 June 1946, Raton, NM, USA
Nationality	American
Father	Laurence Modrich
Mother	Margaret McTurk
Fields	DNA mismatch repair
Alma mater	MIT (BS), Stanford University (PhD)
Doctoral advisor	Robert Lehman
Thesis	Structure, mechanism and biological role of E. coli DNA ligase (1973)
Known for	Clarification of cellular resistance to carcinogens
Institutions	Duke University Howard Hughes Medical Institute University of California, Berkeley
Notable awards and affiliations	• 1983: Pfizer Award in Enzyme Chemistry • 1996: General Motors Charles S. Mott Prize in Cancer Research • 1998: Robert J. and Claire Pasarow Foundation Medical Research Award for cancer research • 2000 Feodor Lynen Medal • 2005: American Cancer Society Medal of Honor • 2015: Nobel Prize in Chemistry • 2016: Arthur Kornberg and Paul Berg Lifetime Achievement Award in Biomedical Sciences • He is a fellow of the American Academy of Arts and Sciences and a member of the National Academy of Medicine and the

	National Academy of Sciences.
Affiliation at the time of the award	Howard Hughes Medical Institute, Durham, NC, USA, Duke University School of Medicine, Durham, NC, USA
Age of becoming Nobel Laureate	69
Prize motivation	For mechanistic studies of DNA repair
Prize share	2/3

4.6 Aziz Sancar

Aziz Sancar is a Turkish-American biochemist who was (born on 8th September 1946 at Savur, Mardin in Turkey. Sancar is credited for his contribution to mechanistic discoveries that underlie a cellular process which is known as nucleotide exision repair by which cells are able to rectify the defects in DNA that may be caused due to excess exposure to ultraviolet light or due to the administration of certain chemicals that induce mutation.

Aziz Sancar received the Nobel Prize in Chemistry for 2015 for his works on the mechanisms of DNA repair. Sancar shared the Nobel Prize with two other researchers which included Tomas Lindahl, a Swedish biochemist and Paul Modrich, an American biochemist.

Sancar completed his M.D. degree in 1969 from the Istanbul Medical School and started working as a local physician near Savur. In 1973, Sancar went to the United States to study molecular biology in the University of Texas in Dallas and was awarded his doctorate degree. On completion of his doctorate, Sancar joined Yale University as a research associate and in 1982 he joined the University of North Carolina School of Medicine as a faculty. Sancar was later named the Sarah Graham Kenan Professor of Biochemistry and Biophysics in the University of North Carolina School of Medicine.

As a student pursuing his bachelor's degree, Sancar studied an enzyme known as DNA photolyase in the bacterium Escherichia coli. This was a newly discovered enzyme capable mediating the process of photo-reactivation, wherein light within the visible spectrum is able to induce enzymatic reactions that are able to repair DNA which have been damaged by ultraviolet irradiation. After moving to Yale University, Sancar turned his attention to several other DNA repair factors in *E. coli*, like the genes *uvrA*, *uvrB*, and *uvrC*. Sancar went on to purify the genes and reconstituted them in vitro. These efforts led to the discovery of the excision repair function of an enzyme known as uvrABC nuclease in *E. coli*. The modus operandi of the enzyme lies in its ability to specifically target DNA that have been damaged by exposure to ultraviolet radiation or due to exposure to chemical, by cutting the affected strand of DNA at each end of the damaged region and helping in removing the damaged nucleotides.

During the later stages, Sancar succeeded in reconstituting a human excision nuclease, and identifying components that are necessary for nucleotide excision repair in human cells. This led him to propose that human cells employed extra enzymes to remove the excised portion of DNA. Sancar also instrumental in identifying the role for defective nucleotide excision repair in the production of neurological abnormalities that are associated with xeroderma pigmentosum, which has been defined as a neurodegenerative condition that disposes individuals to having cancer of the epithelial cells. Abnormalities in nucleotide excision repair were also found to cause other rare hereditary disorders, which include cockayne syndrome and photosensitive trichothiodystrophy.

The early 1980s saw Sancar continue to investigate photolyase in *E. coli*, and later he began to explore the checkpoints of DNA damage. He also discovered two light-harvesting chromophores in photolyase, which he proposed were key components of the mechanism of photolyase reaction and its activity at the blue end of the visible light spectrum. In the early 2000s Sancar was able to directly observe the mechanism of DNA repair by photolyase. Sancar also investigated human photolyase orthologs known as cryptochrome 1 and 2. He found that the cryptochromes, which are located in the eye, function as photoreceptive components of the mammalian circadian clock.

Sancar was an elected member of multiple academic institutions which included the American Academy of Ars and Science, the US National Academy of Sciences, and the Turkish Academy of Sciences.

Quick Fact

Name	Aziz Sancar
Born	8 September 1946 Savur, Mardin, Turkey
Nationality	Turkish, American
Father	Abdulgani Sancar
Mother	Meryem Sancar
Fields	Biochemistry DNA repair Molecular biology Molecular biophysics Cancer research
Alma mater	Istanbul University (MD, 1969) UT Dallas (PhD, 1977)
Doctoral advisor	Claud Stan Rupert
Thesis	A study on photoreactivating enzyme (DNA photolyase) of Escherichia coli (1977)
Institutions	UNC School of Medicine UNC Lineberger Comprehensive Cancer Center Yale School of Medicine
Notable awards and affiliations	• Presidential Young Investigator Award (1984) • TÜBİTAK Science Award (1995) • Member of the National Academy of Sciences (2005) • Vehbi Koç Award (2007) • Nobel Prize in Chemistry (2015)
Affiliation at the time of the award	University of North Carolina, Chapel Hill, NC, USA
Prize motivation	For mechanistic studies of DNA repair
Age of becoming Nobel Laureate	69
Prize share	3/3

4.7 Jean-Pierre Sauvage

Motivated by their works on designing and synthesizing molecular machines, the Nobel Committee decided to award the Nobel Prize in Chemistry for 2016 to Jean-Pierre Sauvage, James Fraser Stoddart, and Bernard Lucas Feringa.This study laid the foundation for discovering smart materials that have the ability to acclimatise with the environment and development of medical delivery systems by which drugs are released upon arriving at the target site.

Though the discovery may seem incredible, the human body does this naturally and regularly. In fact, the works have replicated the natural abilities of the human body. Every cell present in any living organism is a storehouse of biological and mechanical activities. Researchers are using synthetic molecules to convert chemical energy to mechanical movements.

Jean-Pierre Sauvage was among the first researchers who can be credited for making sufficient progress in the field of producing synthetic molecules. He was instrumental in finding a method of creating catenane, which are two interlocking rings that looks like links in a chain. Though the first catenane was created independently by Edel Wasserman, a chemist from the United States and his German counterpart Professor Gotfrie Schill in the early 1960s, the process employed by the two researchers were both inefficient and difficult to copy. Despite the intellectually active nature of the discovery, the process did not attract much enthusiasm among the researchers. Jean-Pierre Sauvage improved upon the efficacy of the process by mixing copper to the phenanthroline mix. The basis for adding copper lies in the act that the phenanthroline mix binds to the metal and creates a template. When the phenanthroline mix hardens, the copper atom is removed. Since the time Jean-Pierre Sauvage proposed this method, the template-directed synthesis has been used as a standard procedure in this field.

Sauvage observed the cartanene and realised that the ability of the hoops presents in the catenane ring to rotate independtly and freely. This discovery prompted him to try assembling the chains into small machines. In 1994, Jean-Pierre Sauvage and his colleagues made a catanene where one ring was able to move around the other and in 1997 succeeded in controlling the pirouetting in a catenane using a mix of electrochemical and photochemical methods. In 2000, Jean-Pierre Sauvage and his colleagues succeeded in producing a rotaxan structure capable of extending and contracting like any filament in the muscle.

The Nobel Prize was the best birthday gift that Sauvage could ever receive. The awards were announced on the day of his birth. Jean-Pierre Sauvage was born on the 21st day of October 1944 in Paris. He completed his doctorate under the guidance of Nobel Laureate Jean-Marie Lehn at the Universite Louis-Pasteur in Alsace. During his doctorate, Sauvage worked on synthesizing cryptand ligands-synthetic bi- and polycyclic molecules that attach themslves to central metal atoms. After graduating from college, Sauvage joined the National Center for Scientific Research in Strasbourg as a research fellow. He had a postdoctoral fellowship with Malcolm LH Green in Oxford, after which he returned to the National Center for Scientific Research and was appointed professor at Strasbourg from 1981-84 and a director of research at the National Center for Scientific Research from 1979 to 2009. Thereafter, Sauvage became a professor emeritus of Strasbourg University.

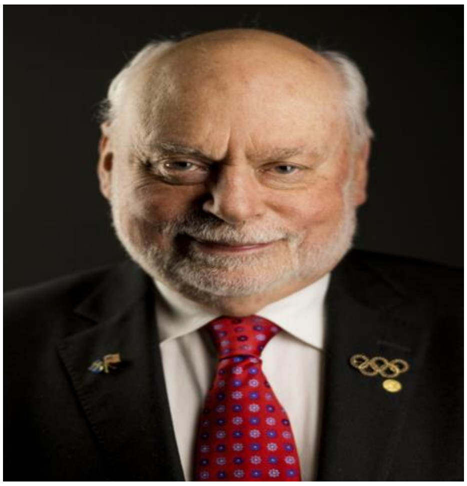
Besides the studies which have won him the Nobel Prize in Chemistry in 2016, Jean-Pierre Sauvage has also shown interest in molecular topology. Among the studies in molecular topology include describing the syntheses of complexely tied molecules and other complex catananes which are based on co-ordination complexes. Among the other research conducted by Jean-Pierre Sauvage include modelling the reaction centre of the reactions involved in photosynthesis and ways to reduce carbon dioxide by electro-chemical methods.

Jean-Pierre Sauvage is a very private person and has not divulged information about his family. He is married and has been elected correspondent member of the French Academy of Sciences. Later he was elevated to the post of a full-time member. Sauvage has several awards to his credit, but the Nobel Prize in Chemistry is the most coveted. During the course of the Nobel Lecture, Sauvage commented, “The Nobel is very special, it’s the prize most scientists don’t even dare to dream of in their wildest dreams.”

Quick Fact

Name	Jean-Pierre Sauvage
Born	21 October 1944, Paris, France
Nationality	French
Father	Camille André Sauvage
Mother	Lydie Angèle Arcelin
Fields	coordination chemistry, supramolecular chemistry
Alma mater	ECPM Strasbourg (engineering diploma, 1967) Université Louis-Pasteur (PhD)
Doctoral advisor	Jean-Marie Lehn
Thesis	Les Diaza-polyoxa-macrobicycles et leur cryptates (1971)
Institutions	Strasbourg University
Notable awards and affiliations	French Academy of Sciences (1990) Nobel Prize in Chemistry (2016) US National Academy of Sciences (April 2019)
Affiliation at the time of the award	University of Strasbourg, Strasbourg, France
Age of becoming Nobel Laureate	72
Prize motivation	For the design and synthesis of molecular machines
Prize share	1/3

4.8 James Fraser Stoddart



In the words of nanoscientist Dr Eric Drexler, self-replicating nano-bots had the ability to convert the earth into hell, a statement brought to public knowledge by Prince Charles. What Prince Charles meant while quoting the nanoscientist was that any new technology should be used wisely and appropriately. Though the prince compared nanotechnology with "triumph of human ingenuity', Prince Charles ended commenting that: "Some of the work may have fundamental benefits to society, such as enabling the construction of much cheaper fuel-cells, or new ways of combating ill-health."

Though the statement seems to come out of a science-fiction film, the idea has the ability to provide incredible ingenuity in creating miniature mechanical devices at an atomic scale. This idea materialized in 1981, the scanning tunneling microscope was developed that could visualize individual atoms. This led to the development of a new science called nanotechnology. The Nobel Prize in Chemistry for 2016 was awarded to three researchers: Jean-Pierre Sauvage, Sir Fraser Stoddart and Ben Feringa for their works on designing and producing molecular machines capable of performing controlled tasks when energy is supplied.

Jean-Pierre Sauvage, a French researcher was among the first researchers to refine techniques that help in the production of molecular hoops in a chain, with each link capable of moving independently. This finding formed the foundation for more advanced nano engines.

Fraser Stoddart is credited with developing an innovative system called a rotaxane. He threaded a molecular ring onto the thin axle of a dumbbell and showed that the ring had the capability of controlled movement along the axle. This led to the development of molecular devices like pump, molecular muscle, valve capable of opening and closing, and molecule-based computer chip.

Stoddart conducted his research at the University of California, Los Angeles campus where he produced a large 'ultra-dense' memory device that could store information by using controllable molecular switches. This proved to be an important step in the creation of molecular computers that are smaller and more powerful than the models based on silicon. In the words of Stoddart, “This research is the culmination of a long-standing dream that these molecules could be used for information storage.”

Stoddart is also credited for developing interlocked, self-assembling molecules called ‘suitanes’. “Discovering the way to dress a molecule with another one is a prelude to constructing artificial systems reminiscent of living cells”, opined Stoddart.

James Fraser Stoddart was born in Edinburgh in Scotland, in May 1942 and spent his childhood on a farm near Carrington, Midlothian. Here he attended the local school before going on to Melville College in Edinburgh. At the University of Edinburgh, he earned his graduate degree and his doctorate degree. Thereafter, he moved to Queen’s University in Kingston, Canada as a post-doctoral fellow, and returned to Britain in 1970 as a research fellow at the University of Sheffield. He was appointed a lecturer, and later a reader in chemistry. Meanwhile he worked as a visiting fellow at UCLA and spent three years at the ICI Corporate Laboratory in Runcorn, Cheshire. His research into stereochemistry beyond the molecule, also earned him the DSc degree. In 1990, Stoddart was made chair of organic chemistry at the University of Birmingham, and in 1997 moved to UCLA the Winstein Professor. In 2002, he joined the California NanoSystems Institute, and rose to the post of director. Later Stoddart joined Northwestern University as a Board of Trustees Professor, and established a Mechanostereochemistry Group in Evanston, Illinois.

The awards conferred to Stoddart include the Albert Einstein World of Science Award. He was also appointed a Knight Bachelor. In 1968, Stoddar married fellow Scottish chemist Norma Scholan, who later worked with him and with whom he has two children – daughter Alison is also a chemist and Chief Editor of the journal Nature Reviews: Materials. After Norma’s death in 2004 the family set up an annual award in her name for Academic Excellence and Outstanding Citizenship at UCLA.

In the words of Royal Society Research Professor David Leigh, "The credit for making molecular machines attractive to chemists goes to Fraser Stoddart. He had the vision to realise that these architectures gave you the possibility of large amplitude-controlled motions, and that that could be the basis of molecular machines."

Quick Fact	
Name	Sir James Fraser Stoddart
Born	24 May 1942, Edinburgh, Scotland, UK
Nationality	British
Father	Thomas Fraser Stoddart
Mother	Jane Spalding Hislop Fortune
Fields	Supramolecular chemistry Unnatural Product Chemistry Molecular Nanotechnology
Alma mater	Melville College, Edinburgh (BS, 1964) University of Edinburgh (Phd, 1967)
Doctoral advisor	Edmund Langley Hirst D M W Anderson
Thesis	Studies on plant gums of the Acacia group (1967) Some adventures in stereochemistry (1980)
Known for	• Mechanically interlocked molecular architectures (MIMAs) • Mechanical Bond in Chemistry • Molecular Shuttles and Switches • Artificial Molecular Machines • Template-Directed Synthesis • Chemical Topology • Stereochemistry • Metal-Organic Frameworks • Cyclodextrin Chemistry
Institutions	• Queen's University (1967–70) • University of Sheffield (1970–1990) • ICI Corporate Laboratory, Runcorn (1978-1981) • University of Birmingham (1990–1997) • University of California, Los Angeles

	(1997–2008) • Northwestern University (2008–) • Tianjin University (2014–) • University of New South Wales (2018–)
Doctoral students	David Leigh Douglas Philp Stuart Cantrill
Notable awards and affiliations	**Memberships** • 2014 Membership, National Academy of Sciences, USA • 2012 Fellowship, American Academy of Arts and Sciences, USA • 2011 Honorary Fellowship, Royal Society of Chemistry, UK • 2008 Honorary Fellowship, Royal Society of Edinburgh, UK • 2006 Appointed Knight Bachelor by HM Queen Elizabeth II, UK • 2006 Foreign membership, Science Division of the Royal Netherlands Academy of Arts and Sciences • 2005 Fellowship, American Association for the Advancement of Science, USA • 1999 Fellowship, Academy of Natural Sciences (Leopoldina), Germany • 1994 Elected a Fellow of the Royal Society of London, UK **Awards and Honours** • 2016 Nobel Prize in Chemistry • 2016 Haworth Memorial Lectureship, Royal Society of Chemistry • 2014 Centenary Prize Winner, Royal Society of Chemistry

	• 2012 Distinguished Citizen Award, Illinois Saint Andrew Society, Chicago, USA • 2010 Royal Medal of the Royal Society of Edinburgh presented by Duke of Edinburgh • 2008 Davy Medal of the Royal Society of London • 2008 American Chemical Society Arthur C. Cope Award • 2007 Feynman Prize in Nanotechnology (Experimental) • 2007 Albert Einstein World Award of Science • 2007 Tetrahedron Prize for Creativity in Organic Chemistry • 2007 King Faisal International Prize in Science • 2007 Jabir Ibn Hayyan (Geber) Medal (Saudi Chemical Society) • 2005 University of Edinburgh Alumnus of the Year 2005 Award • 2004 Nagoya Gold Medal in Organic Chemistry • 1999 American Chemical Society Arthur C Cope Scholar Award • 1993 International Izatt-Christensen Award in Macrocyclic Chemistry
Affiliation at the time of the award	Northwestern University, Evanston, IL, USA
Prize motivation	For the design and synthesis of molecular machines
Age of becoming Nobel Laureate	74

Prize share 2/3

4.9 Bernard Lucas Feringa

The cells of all living organisms, be it flora or fauna, contain microscopic machinery capable of producing new proteins and destroying old ones to maintain the organs and regulate the bodily systems. The fact that such machines could be artificially produced was proposed by physicist Richard Feynman way back in 1959. The idea saw light in 1981, when scanning tunneling microscope was developed that could visualize individual atoms. This disc--overy made the science of nanotechnology a possibility.

Though the problem was one of scale, the winners of the 2016 Nobel Prize in Chemistry were not only able to see the atoms but were among the first to use chemical energy to produce mechanical motion and arrange these into structures and devices. This led to the creation of molecular devices which were a thousand times smaller than the width of a human hair. Their work provided the foundation for producing self-healing materials, targeted delivery systems for medications and potentially a new generation of nano-computers.

While Jean-Pierre Sauvage is credited with perfecting the art of interlocking rings to make a molecular chain James Fraser Stoddart is known for developing rotaxane, a wheel that could not only rotate but slide along the axle in a controlled manner.

Bernard Lucas Feringa is an expert in stereochemistry and photochemistry and fitted the new world of nanotechnology perfectly. He developed molecular motors and also succeeded in getting a molecular rotor blade to spin continuously in the same direction. Using four of these blades as wheels, Feringa made a car smaller than the width of a human hair that could drive across a surface after receiving an electrical charge. The Chinese Academy of Sciences regarded the nanocar as being one of the ten major discoveries in sciences globally. Feringa also created a range of other devices, which included a nanowindmill powered by light and a which enabled him to rotate a glass cylinder 10,000 times bigger than the motor.

Born in May 1951, Bernard Lucas Feringa is the second of ten children born to a Catholic couple and was raised on the family farm in Barger-Compascuum on the Dutch-German border. He studied at the University of Groningen and earned his master's degree and his doctorate. After serving as a research scientist for the Shell Oil Company in Amsterdam and England, Feringa joined the faculty at Groningen, rising from lecturer and being promoted as a professor in 1988. Feringa is also the Jacobus van't Hoff Distinguished Professor of Molecular Sciences at the university's Stratingh Institute for Chemistry as well as chair of the science division of the Royal Netherlands Academy of Arts and Sciences.

The Feringa group studies aspects of molecular nanoscience, responsive materials, molecular switches and motors and photopharmacology, which uses light-sensitive molecular, switches to control bioactive molecules. The aim of this group lies in delivering drugs with exact accuracy, thereby reducing systemic toxicity and resistance to drug.

Together with his main career, Feringa has served as a visiting professor at leading universities including Leuven, Santiago de Compostela and Potenza, and is also the co-founder of the research company Selact. Feringa is also the founding scientific editor of the RSC journal Organic and Biomolecular Chemistry. Feringa has also received numerous honours and awards and is a member of many chemical and scientific related societies including the Royal Society of Chemistry in the United Kingdom, the American Academy of Arts and Sciences, the Royal Netherlands Academy of Arts and Sciences and the Royal Netherlands Chemical Society. His homeland has also awarded him the prestigious NWO Spinoza Prize in 2004, and in 2008 he was appointed a Knight of the Order of the Netherlands Lion. After he was awarded the Nobel Prize, the honour was upgraded to the rank of Commander.

Professor Feringa lives near Groningen with his wife Betty, with whom he has three daughters.

Quick Fact

Name	Bernard Lucas "Ben" Feringa
Born	18 May 1951 Barger-Compascuum,

	Netherlands
Nationality	Dutch
Father	Geert Feringa (1918–1993)
Mother	Lies Feringa née Hake (1924–2013)
Fields	Organic Chemistry Materials Science Nanotechnology Photochemistry
Alma mater	University of Groningen (MSc, PhD)
Doctoral advisor	Hans Wijnberg
Thesis	Asymmetric oxidation of phenols. Atropisomerism and optical activity (1978)
Known for	Molecular switches/motors, Homogeneous catalysis, stereochemistry, photochemistry
Institutions	University of Groningen, 1984–present Royal Dutch Shell, 1979–1984
Notable students	Nathalie Katsonis
Notable awards and affiliations	• Feringa is member of many chemical and scientific related societies: • In 1998, Feringa was elected as a Fellow of the Royal Society of Chemistry (FRSC). • In 2004, he was elected Foreign Honorary Member of the American Academy of Arts and Sciences. • Feringa is an elected Member, since 2006, • Academy Professor, since 2008 of the Royal Netherlands Academy of Sciences. • In addition, Feringa is a former President of the Bürgenstock Conference in 2009, Switzerland,

- elected Member of the Academia Europaea since 2010.
- In 2013, he was appointed as Council Member of the Royal Society of Chemistry.
- On 13 October 2016, Feringa was elected an Honorary Member of the Royal Netherlands Chemical Society.
- In recognition to his contributions to synthetic methodologies and catalysis, Feringa was given the Novartis Chemistry Lectureship Award 2000-2001.
- A large part of Feringa's research career has focused on molecular nanotechnology and especially molecular photochemistry and stereochemistry.
- His contributions in these areas have been recognised in research awards including Körber European Science Prize in 2003,
- the Spinoza Prize in 2004,
- the Prelog Gold Medal in 2005 (ETH-Zürich), Switzerland
- He won the James Flack Norris Award in Physical Organic Chemistry of the American Chemical Society in 2007, USA,
- the European Research Council Advanced Grant in 2008,
- the Paracelsus Award of the Swiss Chemical Society, in 2008

- Feringa furthermore was awarded the Chirality Medal for distinguished contributions to all aspects of stereochemistry in 2010,
- the Solvias Ligand Contest Award Yale University (USA),
- the Organic Stereochemistry Award in 2011 of the Royal Society of Chemistry, UK, and
- the Decennial Van‘t Hoff Medal in 2011 of the Genootschap ter Bevordering van de Natuur-, Genees-, en Heelkunde, in the Netherlands.
- Feringa's contributions to the molecular sciences have been recognized with the Arthur C. Cope Scholar Award
- the Nagoya Medal of Organic Chemistry
- the 2012 Grand Prix Scientifique Cino del Duca
- the Humboldt award of the Alexander von Humboldt Foundation in 2012, Germany.
- In 2013, he won subsequently the Lily European Distinguished Science Award,
- the Nagoya Gold Medal in Nagoya, Japan, the Yamada-Koga Award in Tokyo, Japan,
- the Royal Society of Chemistry Award for distinguished service, and
- the Marie Sklodowska-Curie Medal of the Polish Chemical Society.

- Theodor Föster Award of the German Chemical Society (GDCh)
- Bunsen-Society for Physical Chemistry in 2014, Germany
- the Arthur C. Cope Late Career Scholars Award of the American Chemical Society in 2015.
- In November 2015, he was the recipient of the "Chemistry for the future Solvay prize”
- On 20 December 2016, Feringa jointly received the Nobel Prize in Chemistry
- In 2008, he was appointed a Knight of the Order of the Netherlands Lion by Queen Beatrix of the Netherlands, on 23 November 2016 he was promoted to Commander of the same Order by King Willem-Alexander of the Netherlands.
- On 1 December 2016 Feringa was made an Honorary Citizen of Groningen.
- On 6 April 2017 a street in his birthplace Barger-Compascuum was named Prof. Dr. B. L. Feringadam
- In 1997, he completed the 200 km Elfstedentocht in 12 hours.
- He was elected a foreign member of the US National Academy of Sciences in April 2019.

Affiliation at the time of the award University of Groningen, Groningen, the Netherlands

Prize motivation For the design and synthesis of molecular machines

Age of becoming Nobel Laureate 65

Prize share 3/3

4.10 Jacques Dubochet

The latter part of the 20th century has been witnessing to rapid advances in the area of science and technology and has been successful in increasing our knowledge of the functioning of the human body. Efforts made by researchers like Jacques Dubochet, Joachim Frank and Richard Henderson have taken technology to an entirely new level. The three researchers have shared the Nobel Prie in Chemistry in 2017 for their works on developing cryo-electron microscopy to define the high-resolution structures of biomolecules in their solutions. This study has allowed the use of microscopes to study organic processes at an atomic level.

The idea of studying life processes at an atomic level was previously impossible due to the absence of suitable microscopes to help in the process. While the ordinary optical microscopes lacked the power of magnification, the electron microscopes, by their use of electrons of short wavelength suffered from the defect of destroying the biological specimens. This problem can be solved by protecting the sample from the powerful beam of the electron microscope and the effect of the vacuum which evaporates the essential liquid in biological matter.

Henderson countered the problem by building an existing X-ray crystallography technique that replicates the structure of proteins in the plant membrane. While Frank Henderson made the technology available globally, Dubochet was instrumental in finding a way of freezing water very fast to vetrify it. This forms a smooth glassy protective layer around the sample and protecting it from internal damages.

Jacques Dubochet was born on 8th day of June 1942 in Aigle in Switzerland. He developed an interest in science from a very young age. His lack of interest in literature was instrumental in diagnosing him as dyslexic. In spite of his weak mental condition, Dubochet was admitted into the Ecole polytechnique de I'Universite de Lausanne where he obtained his bachelor's degree in physical engineering.

Thereafter he went to the University of Geneva for a Certificate of Molecular Biology. Dubochet began his research in electron microscopy at the University of Geneva and earned his doctorate in biophysics at Geneva and Basel.

After spending a few years in research, Dubochet was elected leader of the group at the European Molecular Biology Laboratory in Heidelberg where he researched the possibility of vitrifying water that would help in preserving samples in electron microscopes. Alasdair McDowall, while changing the cooling device replaced liquid nitrogen with liquid ethane and observed an amorphous frozen droplet that was devoid of ice crystals. The team warmed it to 135 Kelvin when the crystals developed. They had accidentally found the way to vitrify water.

In 1987 Dubochet was appointed Professor in the Department of Ultra-structural Analysis at the University of Lausanne and was elevated to the post of President of the Biology section in 1998. According to Dubochet, this represented an era in which, "interesting things were happening in biology". At the University of Lausanne, Dubochet introduced mandatory courses on ethics and philosophy. This was necessary to increase the level of awareness among young researchers regarding the link between the creation of science and its applications for the welfare of the society.

After retiring from the University of Lausanne, Dubochet became an honorary professor. Dubochet is married and has two grown children in the form of a son and a daughter.

Quick Fact

Name	Jacques Dubochet
Born	8 June 1942, Aigle, Switzerland
Nationality	Swiss
Fields	Structural biology Cryo-electron microscopy
Alma mater	École polytechnique fédérale de Lausanne (BS) University of Geneva (MS) University of Geneva (PhD) University of Basel (PhD)
Doctoral advisor	Eduard Kellenberger

Thesis	Contribution to the use of dark-field electron microscopy in biology (1974)
Known for	Cryo-electron microscopy
Institutions	European Molecular Biology Laboratory (1978-1987) University of Lausanne (since 1987)
Notable awards and affiliations	Nobel Prize in Chemistry (2017)
Affiliation at the time of the award	University of Lausanne, Lausanne, Switzerland
Age of becoming Nobel Laureate	75
Prize motivation	Development of cryo-electron microscopy to ascertain the high-resolution structure of biomolecules in their solutions
Prize share	1/3

4.11 Joachim Frank

Any picture speaks a thousand words. This statement is true in the field of biochemistry. This field of knowledge allows for freezing the activities witi any living cell an recording the activities. The art of capturing the images of the activities that occur within the cell using an electron microscope and merging these into a three-dimensional image is called cryo-electron microscopy. The development of cryo-electron microscopy was the motivation that led the Nobel Committee to award the Nobel Prize in Chemistry for 2017 to Joachim Frank, Richard Henderson, and Jacques Dubochet. The benefits of electron microscopes lies in getting images that have higher magnification and resolution compared to the conventional optical microscopes. These microscopes direct a beam of electrons on the sample to achieve such amazing results. Electron microscopes can be used only if the sample are kept in vacuum. Here the samples decay due to evaporation of the water present in the sample.

The research on cryo-electron microscopy began in the 1970s. While Henderson used electron microscope to photograph the structure of proteins that form highly ordered crystals in a membrane, Frank developed computational methods to determine the structures of unordered, single molecules. Dubochet developed a way of protecting the sample by freezing water into a smooth glaze, rather than using crystal ice.

Joachim Frank was born in 1940 in Siegen, Germany. He studied physics at the University of Freiburg, and then went to the University of Munich to study the possibility of using electrons to study molecules. Frank completed his graduation at the Max Planck Institute in Munich. At the Max Planck Institute, Joachim Frank got the clue of jogging the electron microscope, and creating blurred images of carbon films. While viewing the images by optical diffraction, Frank observed striped patterns that indicated the high level of precision with which images of molecules could be aligned in the computer by cross-correlation.

After receiving his doctorate degree from the Technical University of Munich, Frank obtained a Harkness fellowship that allowed him to visit laboratories of his choice in the United States. There Frank picked the Jet Propulsion lab at Caltech before joining Bob Glaeser, which was one of the cryo-EM pioneers, at the University of California, Berkeley campus, and completed his US tour at Cornell University. In 1973 Frank moved to the Cavendish Lab, Cambridge, where he continued his work on image analysis and calculated the minimum electron dose to ensure accuracy of alignment without damaging the molecule.

In 1975, Frank was invited to join the Wadsworth Laboratory in Albany, New York, where he and his students' combined images captured using electron microscopes into three-dimensional reconstructions, by using the ribosome to test the procedures. Frank joined the University of Albany in 1985 and the following year was appointed as Professor of Biomedical Sciences. During a sabbatical in 1987, Frank returned briefly to Cambridge to work with Richard Henderson at the Laboratory for Molecular Biology of the MRC.

As the ribosome images became sharper with improved programmes, Frank decided to study the mechanism of protein synthesis. His efforts received a boost during conducting research at the Max Planck Institute for Medical Research in Heidelberg, Germany. Frank has been able to create frame-by-frame representations of how mRNA and tRNA interact with the ribosome. From 1998 until recently, Frank has been a Howard Hughes Medical Institute Investigator. In 2008, he joined Columbia University as Professor of Biochemistry, Molecular Biophysics, and Biological Sciences. Apart from his research, Frank is a poet, a writer of fiction and a successful photographer.

Quick Fact

Born	12 September 1940, Siegen, Germany
Nationality	German, American
Fields	Structural biology Cryo-electron microscopy
Alma mater	University of Freiburg (BS) University of Munich (MS) Max Planck Society Technical University of Munich (PhD)
Doctoral advisor	Walter Hoppe
Other academic advisors	Robert M. Glaeser, Robert Nathan
Thesis	Untersuchungen von elektronenmikroskopischen Aufnahmen hoher Auflösung mit Bilddifferenz- und Rekonstruktionsverfahren (1970)
Known for	Single-particle cryo-electron microscopy Ribosome structure and dynamics
Institutions	• University at Albany, • Department of Biomedical Sciences • Columbia University College of Physicians and Surgeons, • Department of Biochemistry and Molecular Biophysics
Notable awards and affiliations	• 1994 Humboldt Research Award of the Alexander von Humboldt Foundation • 2006 Fellow of the American Academy of Arts and Sciences

	• 2006 Member of the National Academy of Sciences • 2014 Benjamin Franklin Medal in Life Science of the Franklin Institute • 2017 Wiley Prize in Biomedical Sciences • 2017 Nobel Prize in Chemistry • 2018 Honorary Doctorate, University of Siegen (Germany) • 2018 Honorary Fellow of the Royal Microscopical Society
Affiliation at the time of the award	Columbia University, New York, NY, USA
Age of becoming Nobel Laureate	77
Prize motivation	For developing cryo-electron microscopy for the high-resolution structure determination of biomolecules in solution
Prize share	2/3

4.12 Richard Henderson

A cell is the building block of any living organism. These cells can be considered to be factories at a microscopic level, each working relentlessly to ensure smooth running of the individual. Though we had known this since time immemorial, the recent advances in science and technology have made visualization of these activities a possibility. The key to observing the functions taking place within any living cell lies in using the electron microscope.

These microscopes direct a beam of electrons, having wavelengths much smaller than visible light, and make detection of individual atoms a possibility. But the intensity of the beam of electrons damages the freshness of the sample, and to avoid any interference by air particles, the entire experiment has to be conducted in vacuum. This causes the water present in the cell to evaporate and damages the biological sample.

Efforts have been on to overcome these problems and use the electron microscope to capture hig-resolution images. Research conducted by Richard Henderson, Jacques Dubochet, and Joachim Frank on using the electron microscope to capture high-resolution images of biological samples in their solution had been the motivation for the Nobel Committee to award them the Nobel Prize in Chemistry for 2017.

While Henderson developed the electron microscope to capture the photograph of the structure of membrane proteins, Frank was instrumental in generalizing the system. Dubochet worked on trying to protect the sample with a smooth glaze of water rather than using ice crystals. Their efforts have ushered in a new field of study called cryo-electron microscopy. Using this technique, researchers can observe the atomic structures of virus and proteins and are also able to see the life processes in a step-by-step manner.

Richard Henderson was born in Edinburgh, Scotland, in July 1945 and was admitted to Hawick High School and Boroughmuir Secondary School before being admitted to Edinburgh University. He earned his graduate in physics and went to Cambridge to study the digestive enzyme chymotrypsin at the Medical Research Council Laboratory of Molecular Biology. There, Henderson earned his doctorate degree and worked as a researcher for one year before moving to Yale University in the United States. In the United States, Henderson spent three years pursuing his interest in membrane proteins. In 1973 Henderson returned to the Medical Research Council Laboratory of Molecular Biology and has remained there. He worked his way up from researcher to group leader, and then became the director of the laboratory in 1996. Thereafter Henderson returned to being a research scientist.

In the 1970s Cambridge was famous for the use of X-ray crystallography. The technique has its limitations in the form of requiring the sample to be in crystalline form, and also the fact that diffracting X-rays are 'reverse-calculated' to map the atomic structure. With collaboration from Nigel Unwin, Henderson decided to try electron microscopy. Electron microscopy had been used since the 1930s but was of little use for his delicate subject of proteins, especially bacteriorhodopsin, a membrane protein responsible for photo-synthesizing bacterium. Membrane proteins perform poorly when removed from their natural home but, undeterred, Henderson could record images and diffraction patterns from whole membranes, coated in a glucose solution for protection in the vacuum. Surrounded by the glucose solution, the protein retained its structure. By reducing the electron beam's power, Henderson sacrificed clarity for the survival of the sample but, because the proteins were packed in regular order, he could calculate a more precise image using the same mathematical method as X-ray crystallography. By viewing the membranes at different angles, he built up a 3D model of the protein's structure. Henderson toured the world seeking better electron microscopes and, as technology improved, so his images became sharper until in 1990 he was finally able to create a model of the protein at atomic resolution.

Henderson is a Fellow of the Royal Society, and among the awards conferred upon hin in the recent years include the RS Copley Medal, the Hollaender Award, Wiley Prize and an honorary DSc from his alma mater, Edinburgh University. Receiving the Nobel Prize, he thanked other contributors, especially fellow Laureate Jacques Dubochet for his breakthrough work.

Quick Fact

Name	Richard Henderson
Born	19 July 1945 Edinburgh, Scotland
Nationality	British
Fields	Structural biology Cryo-electron microscopy Electron crystallography
Alma mater	University of Edinburgh (BSc) Corpus Christi College, Cambridge University of Cambridge (PhD)
Doctoral advisor	David Mervyn Blow
Thesis	X-Ray Analysis of α-chymotrysin: Substrate and Inhibitor Binding (1970)
Known for	Cryo-electron microscopy
Institutions	Laboratory of Molecular Biology

Yale University

Post-docs

- David Agard, since 1983 at UCSF
- Per Bullough, since 1994 at the University of Sheffield
- Nikolaus Grigorieff, since 2013 at HHMI Janelia Research Campus
- Reinhard Grisshammer, since 2017 at the National Cancer Institute
- Edmund Kunji, since 2000 at MRC Mitochondrial Biology Unit, University of Cambridge
- Peter Rosenthal, since 2015 at the Francis Crick Institute
- John Rubinstein, since 2006 at The Hospital for Sick Children, Toronto
- Gebhard Schertler, since 2010 at ETH Paul Scherrer Institute
- Christopher Tate, since 1992 at MRC Laboratory of Molecular Biology
- Vinzenz Unger, since 2010 at Northwestern University

Notable awards and affiliations

- 1978 William Bate Hardy Prize
- 1983 Fellow of the Royal Society (FRS)
- 1984 Sir Hans Krebs Medal by the Federation of European Biochemical Societies
- 1998 Foreign Associate of the US National Academy of Sciences
- 1981 Ernst-Ruska Prize for Electron Microscopy
- 1991 Lewis S. Rosenstiel Award
- 1993 Louis-Jeantet Prize for

	Medicine • 1998 Fellow of the Academy of Medical Sciences (FMedSci) • 1999 Gregori Aminoff prize (together with Nigel Unwin) • 2003 Corpus Christi College, Cambridge • 2003 British Biophysical Society • 2005 Microscopy Society of America • 2008 University of Edinburgh • 2016 The Copley Medal of the Royal Society • 2016 Alexander Hollaender Award in Biophysics • 2017 Wiley Prize • 2017 Fellow of the Royal Society of Chemistry (HonFRSC) • 2017 Nobel Prize in Chemistry • 2018 The Order of the Companions of Honour (CH) in the Queen's Birthday Honours for services to electron microscopy of biological molecules • 2018 The Royal Medal of the Royal Society of Edinburgh • 2019 Honorary Doctor of Science degree from the University of Leeds
Affiliation at the time of the award	MRC Laboratory of Molecular Biology, Cambridge, United Kingdom
Age of becoming Nobel Laureate	72
Prize motivation	For developing cryo-electron microscopy for the high-resolution structure determination of biomolecules in solution
Prize share	3/3

4.13 Frances Hamilton Arnold

Frances Hamilton Arnold is a woman of many talents. Her life has constantly evolved, and she has adapted herself to the emerging challenges. From studying nuclear power, Arnold switched to solar energy and finally ended her quest using nature as her laboratory to create special enzymes that could benefit humanity. Arnold believes that nature has learnt to adjust itself to human waste and has the ability to develop enzymes that can disintegrate chemical wastes and plastic wastes.

Disintegration of these human wastes is a long procedure which has to be quickened considering the vast amount of wastes generated annually. The panacea to this problem lay in nudging the evolution in the right direction. Arnold began her research in the early part of the twentieth century when she tried to build mutant enzymes by inserting random mutations to genes encoding proteins into bacteria. After a few generations of mutations and observing their performances, Arnold was successful in making an enzyme that could work in hostile and un-natural environments. Arnold and her team were able to develop thermo stable enzymes that had the ability to break down cellulose present in the cell walls of plants to produce biofuels. She was also successful in creating enzymes that helped in the formation of carbon-silicon bonds. Her works in directed evolution have helped in the manufacture of pharmaceutical products, chemicals used in agriculture, detergents and several other products that cause less damage to the environment.

Arnold's efforts in demonstrating the power of evolution for enzyme engineering earned her a half share of the Nobel Prize, while the other half was shared between George Smith of the University of Missouri, and Sir Gregory Winter of the MRC Laboratory in Cambridge, United Kingdom.

Frances Hamilton Arnold was born in Pittsburgh, Pennsylvania in July 1956 and was admitted to Taylor Allderdice High School. She was something of a rebel, despite growing up in Cold War USA with a nuclear physicist father and a Lt General grandfather. She left home at the age of 15, hitch-hiked her way to

Washington DC to protest the Vietnam War, and earned a living as a waitress and taxi driver.

At Princeton University, Arnold studied mechanical engineering and aerospace engineering, but also took courses in Russian, Italian, economics and international affairs, and spent a year in Italy making nuclear reactor components. But her real interest was in renewable energy. After graduating, she worked in Brazil and at the Solar Energy Research Institute in Colorado, designing solar energy facilities and helping to write policy papers for the United Nations. Responding to the Reagan's lack of interest in renewable energy projects and investment, Arnold returned to academics at the University of California, Berkeley campus, where she earned a doctorate in chemical engineering, she then joined the faculty at California Institute of Technology, and began her quest to design new enzymes, using rational engineering techniques. Though the early techniques were "terrifyingly unproductive", she had an epiphany in the early 1990s and let evolution teach her the rules.

Arnold is the Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry at Caltech, she is still in active reearch, persuading enzymes to catalyse reactions not known in biology and developing new machine-learning-guided protein evolution methods.

Quick Fact

Name	Frances Hamilton Arnold
Born	25 July 1956, Pittsburgh, PA, USA
Nationality	American
Father	William Howard Arnold
Mother	Josephine Inman (née Routheau)
Fields	Chemical engineering Bioengineering Biochemistry
Alma mater	Princeton University (BS) University of California, Berkeley (MS, PhD)
Doctoral advisor	Harvey Blanch
Thesis	Design and Scale-Up of Affinity

	Separations (1985)
Known for	Directed evolution of enzymes
Institutions	California Institute of Technology
Doctoral students	Christopher Voigt Huimin Zhao
Notable awards and affiliations	• Draper Prize (the first woman to receive it), • Honorary Doctorate, Technical University of Denmark (2019) • Nobel Prize in Chemistry (2018) • Elected an International Fellow of the Royal Academy of Engineering (2018) • Raymond and Beverly Sackler Prize in Convergence Research (2017) • Spiegelman Lecture, University of Illinois (2017) • Society of Women Engineers' 2017 Achievement Award • Honorary Degree of Doctor of Science from Dartmouth College (2017) • Honorary Doctorate, University of Chicago (2016) • Millennium Technology Prize (2016) • Honorary Degree of Doctor of Science from the ETH Zurich (2015) • Elmer Gaden Award, Biotechnology and Bioengineering (2015) • Inducted into the National Inventors Hall of Fame (2014) • Golden Plate Award, American Academy of Achievement (2014) • Emanuel Merck Lecture of the Technische Universität Darmstadt,

Germany (2013)

- ENI Prize in Renewable and Nonconventional Energy (2013)
- Honorary Degree of Doctor of Science from Stockholm University (2013)
- Honorary Degree of Doctor of Science from the Stockholm University (2013)
- Charles Stark Draper Prize (2011)
- National Academy of Engineering (NAE) (2011)
- National Medal of Technology and Innovation (2011)
- American Academy of Arts and Sciences (2011)
- Elected fellow of the American Association for the Advancement of Science (2010)
- American Academy of Microbiology (2009)
- National Academy of Sciences (2008)
- FASEB Excellence in Science Award (2007)
- Enzyme Engineering Award from Engineering Conferences International and Genencor (2007)
- Francis P. Garvan–John M. Olin Medal, American Chemical Society (2005)
- Elected fellow of American Institute for Medical and Biological Engineering (2001)
- National Academy of Engineering (2000)

Affiliation at the time of the award	California Institute of Technology (Caltech), Pasadena, CA, USA
Age of becoming Nobel Laureate	62
Prize motivation	For the directed evolution of enzymes
Prize share	1/2

4.14 George Pearson Smith

George Pearson Smith, a researcher who was able to harness the power of evolution, conducted his research on bacteriophages, viruses that could possibly infect bacteria, and in the discovery of proteins that had new functions. Smith shared one half of the Nobel Prize in Chemistry for 2018 with Sir Gregory Winter, for their work on phage display, while the other half was awarded to Frances Arnold for her studies in the directed evolution of enzymes.

Phages are a class of virus that reproduce in bacteria and infect them. Smith began his work on phages in 1984 and realized that the filamentous family of phages had the ability to tolerate a variety of guest peptides that are genetically combined to the proteins present on the outer surface of the phage particle. Using different but currently used methodologies in molecular biology, construction of large libraries containing millions of phage clones, each attaching itself to unique guest peptide on the surface of the phage was possible.

The fact that guest peptides display themselves on the outer surface of the phage, they have the ability to react with biomolecules like antibodies that are dissolved in the surrounding medium. If any such biomolecule is restrained on the solid surface, and the surface is exposed to a large library of phage clones displaying different guest peptides, phages whose displayed guest peptides are binded to the restrained biomolecule are captured on the surface while all other phages can be removed. This process of retaining certain guest peptides while removing the others is, called affinity selection and the process allows binding peptides to be specifically selected. This process applies to small guest peptides in the starting library. In this artificial ecosystem, only the fittest guest peptides are able to survive. It has been found that the guest peptides having affinity towards the restrained biomolecule are able to survive. In this context, fitness is defined by the researchers in his or her unique ways depending upon the nature of the research.

Since the publication of the results of the initial research, several laboratories, which also included the laboratory where George Pearson Smith worked, began their works that would validate and expand the idea of phage display. The idea has attracted the interest of several researchers who have enriched this domain of knowledge using creative techniques. Among the research who have enriched phage display include Gregory Winter who shared the Nobel Prize in Chemistry in 2018. According to Smith, phage display is an exemplification of how scientific discoveries and innovations is a result of the efforts put by the global scientific communities, and not by individuals.

George Pearson Smith was born in Norwalk, Connecticut in March 1941, and displayed a fascination for animals, particularly reptiles such as alligators and snakes. He attended preparatory school at Andover, Massachusetts, and spent a year as an exchange student in England, where he learnt to play rugby and cricket. He returned to study herpetology at Haverford College in Pennsylvania. While Haverford did not offer herpetology, the department of biology focused on molecular biology, which Smith says was a much better fit to his abilities. After graduating in biology in 1963, and a year as a teacher and laboratory technician, Smith joined graduate school at Harvard University, where he earned his doctorate in bacteriology and immunology in 1970.

Smith served as a postdoc at the University of Wisconsin in Madison before joining the faculty at University of Missouri. It was during a sabbatical with Robert Webster at Duke University in Durham, North Carolina, that Smith began the work that won him the Nobel Prize. He was named Curators' Distinguished Professor in 2000 and became a professor emeritus in 2015. Other than the Nobel Prize. Smith received the Promega Biotechnology Research Award by the American Society for Microbiology in 2007 and is an elected Fellow of the American Association for the Advancement of Science and of the U.S. National Academy of Sciences.

Smith lives in Columbia, Missouri, with his wife, Marjorie Sable, professor emerita of the MU School of Social Work. The couple have two sons and are vocal advocates of social justice and human rights. Despite being a non-Jewish member of the Jewish community (Marjorie and the children are Jewish), Smith is active in the movement to boycott Israel until it ends its subjugation and dispossession of the Palestinian people. Smith is a founding member of the 60-strong Columbia Chorale choir.

Quick Fact

Name	George Pearson Smith
Born	10 March 1941, Norwalk, CT, USA
Nationality	American
Fields	Biochemistry, Biology
Alma mater	Haverford College (AB) Harvard University (PhD)
Doctoral advisor	Edgar Haber
Thesis	The variation and adaptive expression of antibodies. (1970)
Known for	Phage displays
Institutions	Postdoctoral Scholar, University of Wisconsin–Madison Professor, University of Missouri Visiting Professor, Duke University
Notable awards and affiliations	2000 University of Missouri Curators' Professor 2001 Elected Fellow – American Association for the Advancement of Science (AAAS) 2007 American Society for Microbiology Promega Biotechnology Research Award 2018 Nobel Prize in Chemistry together with Greg Winter and Frances Arnold
Affiliation at the time of the award	University of Missouri, Columbia, USA
Prize motivation	For the phage display of peptides and antibodies

Age of becoming Nobel Laureate 77

Prize share 1/4

4.15 Sir Gregory Paul Winter

The life of Sir Gregory Paul Winter is one of happiness and sorrow. He was a research fellow at the Medical Research Council Laboratory of Molecular Biology in Cambridge. One day in 1984, when he was cycling his way to his laboratory, he met with a tragic accident which rendered him incapable of conducting his experiments with one hand. While recuperating from the accident, Winter started to examine the structures of antibodies using computer graphics and observed that the basic Y-shaped structure were identical between different species, with the difference in the tips of the arms. This observation gave Winter the idea that merging the tip of the antibodies present in mouse into the human antibodies could create a humanized antibody.

Such antibodies opened new vistas in the war against cancers. Rodent antibodies have previously been used to cure human cancers, but these were rejected by the human immune system. By splicing the mouse's cancer-detecting component to a human antibody, Winter hoped that the humanised antibody would evade the surveillance of the human immune system long enough to kill the cancer.

After just 18 months of developing the antibody, the treatment was tested on a test patient, a female who was diagnosed having a large tumor on her spleen. Within a few days of the therapy the tumor had reduced, with no real side effects except one. Winter had a profound effect on meeting the woman patient and has admitted that his interest in the matter was purely from an academic perspective. After his initial success, Winter was determined to help patients, and although he had been required to patent his technique, he negotiated with his employers the Medical Research Council Laboratory of Molecular Biology to make the process widely accessible in a bid to encourage pharmaceutical companies develop new antibody medications.

Thinking that the hybrid antibody might not provide a perfect cure, Winter began researching on producing perfect human antibodies. He received encouragement from the biotechnology company owned by Geoffrey Grigg, an Australian, and went on to establish the Cambridge Antibody Technology, a firm that would produce a variety of human antibodies. Winter used the phage display process popularized by George Pearson Smith to test the binding abilities including those proteins that are characteristics of cancer-causing cells.

These monoclonal antibodies, or mAbs, have aided production of new varieties of therapeutic drugs, and have included top selling brands like the human antibody Humira, the humanized antibodies Herceptin and Avastin. Gregory Paul Winter was born in April 1951 in Leicester and spent his childhood in Ghana, where his father moved from academia to administration. He studied at the Royal Grammar School, Newcastle upon Tyne, and then studied natural sciences at Trinity College, Cambridge, graduating in 1973 and going on to earn his doctorate, for research into protein sequencing, from the Medical Research Council Laboratory of Molecular Biology in 1977. He remained at the Medical Research Council Laboratory of Molecular Biology and specialized in sequencing nucleic acid and recombinant DNA technology and was elevated to the post of deputy director and then Master of Trinity College.

Winter shared one half of the Nobel Prize in Chemistry for 2018 with George Smith, for his work on phage display, while the other half was received by Frances Arnold for her breakthrough in directed evolution of enzymes.

Quick Fact

Name	Sir Gregory Paul Winter
Born	14 April 1951, Leicester, UK
Nationality	British
Fields	Biochemistry
Alma mater	Trinity College, Cambridge (MA, PhD)
Doctoral advisor	Brian S. Hartley
Thesis	The amino acid sequence of tryptophanyl tRNA synthetase from Bacillus stearothermophilus (1977)
Known for	Cambridge Antibody Technology Domantis

	Bicycle Therapeutics
	Antibody engineering
Institutions	University of Cambridge
	Laboratory of Molecular Biology
	Imperial College London
Notable awards and affiliations	• Colworth Medal (1986) • EMBO Member (1987) • Louis-Jeantet Prize for Medicine (1989) • Fellow of the Royal Society (FRS) in 1990 • Scheele Award (1994) • King Faisal International Prize (1995) • William B. Coley Award (1999) • Knight Bachelor (2004) • Royal Medal (2011) • Prince Mahidol Award (2016) • Nobel Prize in Chemistry (2018)
Affiliation at the time of the award	MRC Laboratory of Molecular Biology, Cambridge, United Kingdom
Prize motivation	For the phage display of peptides and antibodies
Age of becoming Nobel Laureate	67
Prize share	1/4

After discussing about profile of Nobel laureates in chemistry, next chapter deals with “The science behind scientometry” (Chapter – 5).

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THE SCIENCE BEHIND SCIENTOMETRY

5.0 Introduction

Scientometry is defined as the quantitative study of science. Among its scope lies the analysis and the evaluation of the various topics covered under science, technology, and innovation. The scientometric analysis is defined as the measurement of the impact that authors have on their institutes and countries through their publications, journals, and other scientific publications which include articles and patents. The scope of scientometric analysis lies in assessing the behavioral pattern of citations towards understanding scholarly communication and devising a relationship between various intellectual abilities of science. The modes of operation lay focus on the culmination of various indicators that are used in the assessment of performance and productivity (Leydesdorff & Milojević, 2015). Scientometrics shares common boundaries with its predecessors which features bibliometrics, cyber metrics, informatics, and webometrics. While bibliometrics, which is one of the acknowledged areas of research in the library and information science, bases itself on understanding the quantitative aspects of written publications, informatics studies the quantitative aspects of all information which also includes those items that are covered under the ambit of the other domains of research (Wolfram, 2003). Various scholars have outlined the relationship between the various domains and the same have been produced below in a pictorial form as Figure **A** (Björneborn & Ingwersen, 2004).

The last few decades have witnessed an exponential growth in the volume of published literature primarily due to the enhancement in the diversity among the research community and also the growth of the internet. These ever-increasing publications which vary directly with the nature of diversities require a thorough and systematic investigation of the intellectual assembly in a bid to assess not only the trend and change in developments but also the realms of innovation and the challenges faced. The next few pages try to bring out the intellectual arrangement of scientometrics in a phased and a proper manner.

To achieve the required objectives, we adhere to the modus operandii wherein we try to understand the epistemological characters, emerging trends, and thematic patterns using the Scientometric approach. Our study regards scientometrics to encompass bibliometrics, cyber metrics, informatics, and webometrics. The knowledge of scientometrics aids the scientometrics community in a variety of ways: having an in-depth publication profile helps the community in becoming more self-explanatory, identification of emerging technologies can help researchers in expanding the domain of their research, and it acts as a guiding light to interested researchers.

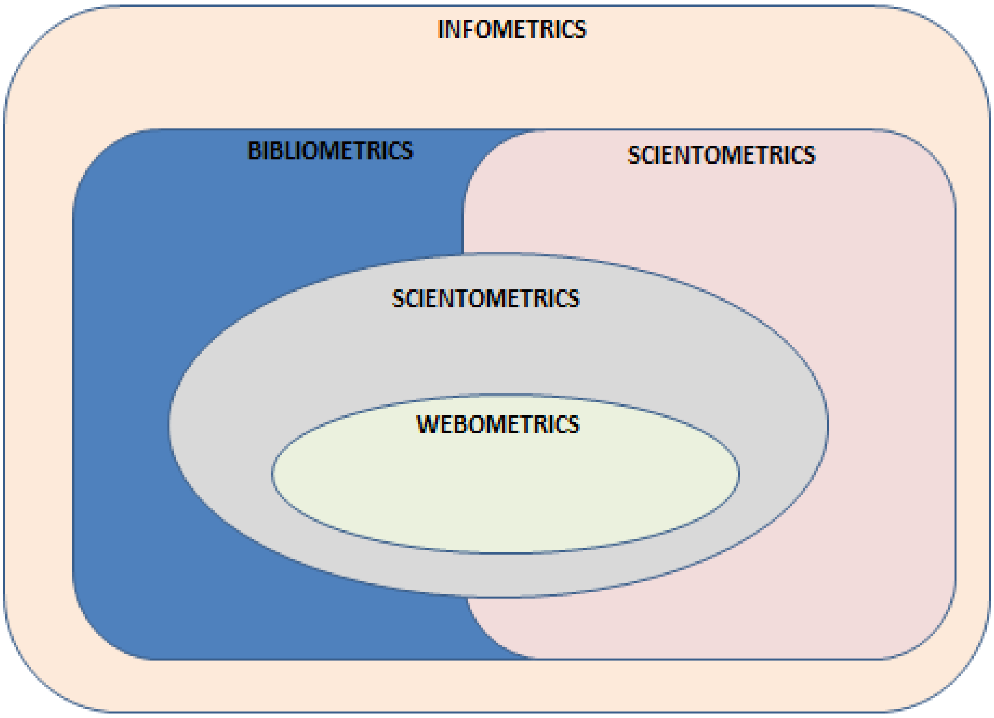


Figure 3: Relationship between the science of metrics (adapted from Björneborn and Ingwersen, Björneborn & Ingwersen, 2004)

5.1 History

The word *'metric'* is the English derivation of the Latin word *'metricus'* (Metric, 2014) and the French word *'metrique'* (Metrics, 2014) and is used to signify measurement of something or deriving quantitative measurement or approximation. Initially used in 1864 (Metrics, 2014), the term encompasses a large number of knowledge domains ranging from physics to chemistry to mathematics culminating in the more recent software development and analysis. Among the most prominent usage of the word is it's being regarded as a unit of measurement of various knowledge areas and LIS. All systems of measurements involve methods that correspond to statistical analysis. Shri Prashanta Chandra Mahalanobis, a key propounder of statistics in modern India regarded statistics as a vital technical tool due to the varied usage which includes various developmental and forecast studies. The knowledge of statistics finds applicability in almost all the subjects be it medical science, engineering science, physical science, agricultural science, social science, cognitive science, behavioral science, and the like. Further, statistical techniques amalgamated with other known areas of knowledge give birth to new and modern areas of knowledge. Scientometry is a classic example of this fact. Along the same lines are subjects like educametry, econometry, psychometry, etc. In the context of library and information sciences, quantitative techniques have gained popularity with the usage reaching levels of unprecedence. These quantitative techniques have come a long way from being treated as a classification tool used by the librarian to ease the process of cataloging to being considered as a specialized science that provides a scope for detailed study and research. In the lines of other major subjects like management, philosophy, sociology, history, and the like, these quantitative techniques also find presence in the Auxiliary Tables of all the foremost classification theories (Creative Commons, Dewey Decimal Classification, or Universal Decimal Classification). On tracing back in the annals of time, the applicability of measuring techniques commenced in the mid-1920s with the introduction of statistical bibliography which involved the application of quantitative techniques in bibliographical works. The history of the statistical bibliography, which is regarded as an application of statistical methods to the library and bibliographical works, has been studied in detail (Wittig, 1978) and traces back to 1917 (Cole & Eales, 1917) and thereafter in 1922 (Hulme, 1923). The term statistical bibliography also finds mention in C.F.Gosnell's Ph.D. thesis titled 'The Rate of Obsolescence in College Library Book Collection', submitted to the New York University in 1943 (Gosnell, 1943). Gosnell emphasized upon the quantitative aspects of the bibliography rather than upon the qualitative aspects associated with the subject. Similar studies have also been conducted that point to the fact that statistical bibliography finds a gamut of applications in the analysis of information falling under the umbrella of medical sciences (Raisig, 1962). Regarding the genealogy of the word, statistical bibliography is derived from two distinct English words, viz., statistics and bibliography. Under the ambit of statistics lies all numerical data that has the ability to provide information about any subject by way of analysis through the process of assembly, classification, and tabulation of the data (Friend & Guralnik, 1964) while bibliography is the combination of two Latin words:

‘*biblion’* and *’graphos’* (Friend & Guralnik, 1964). While ‘*biblion’* means to read, *’graphos’* is indicative of the writing skills. As such, the word bibliography is used to signify the writings by various authors on varied subjects, which may also include sub-topics within any broad subject. Various scholars like E. Hulme have defined bibliography to mean the science of classification of knowledge or information (Hulme, 1923). The amalgamation of the two distinct words *‘bibliography’* and *‘statistics’* gives birth to the term *‘statistical bibliography’*, which encompasses the application of quantitative methods of statistical applications to library science.

The term *‘librametry’* was coined by Dr. S. R. Ranganathan and he used it for the first time in 1948 at the ASLIB Conference held at Leamington Spa where going by the increase in the numbers of works and services connected with library science, he advocated the use of librametry by the librarians on similar lines as that of psychometry, biometry, and econometry (Rao, 1998). Librametry or librametrics, by which it is also known, is formed as a combination of two words ‘library’ and ‘metrics. While the former is used to include the systems and services associated with library sciences, the latter refers to the mathematical models and techniques for evaluation. Being a mathematical science, the use of techniques of statistics simplifies the preparation of any report and renders it comprehensive and understandable. Despite being coined and used for the first time in 1948, librametry failed to develop as a science requiring further study until the early 1970s. To lament this delay, various scholars demonstrated their utter dissatisfaction as per the comments of Prof. I K Ramachandra Rao, “In spite of his (Ranganathan) early attempt to define the scope of librametry, the subject hardly developed until the early 1970s” (Rao, 1998). The term bibliometrics was first used by A. Pritchard in 1969 (Pritchard, 1969) and was used to include all studies that quantify the process of communication in the written form. Pritchard defined the term as “*the definition and purpose of bibliometrics is to shed light on the process of written communication and of the nature and course of a discipline (in so far as this is displayed through written communication) by means of counting and analyzing the various facets of written communication”* (Pritchard, 1969). Though the term bibliometrics is credited to Pritchard, scholars like C S Wilson and E N D A Fonesca have pointed to its French origin (Wilson, 1995; Fonesca, 1973). To prove his statement, Fonesca quoted Paul Otlet (Otlet, 1934) who had used the term *‘biblometrie’* in his treatise *Traitée de Documentation. Le livre sur le livre. Theorie et Pratique* covering Section 124 (pages 13 to 22) of his book *Le livre et la Mesure.* In the words of I N Sengupta (Sengupta, 1992), the first bibliometric study was produced by F B F Campbell (Campbell, 1896) where he studied the scattering of subjects in various publications using statistical methods. Various sources and scholars have defined bibliometrics using unique paradigms. The term bibliometrics has been defined by the British Standard Glossary of Documentation as the study of the applicability of mathematical and statistical methods to written documents and other types of publications (British Standard Institution, 1916). W. G. Potter defines bibliometrics as the study and the measurement of patterns of publication of all written communication including their authors (Potter, 1981). According to I N Sengupta, bibliometrics involves classification, organization, and quantitative evaluation of patterns of publications pertaining to both micro and macro communications together with their authors using mathematical calculus and statistical calculus (Sengupta, 1985). Towards defining bibliometrics, D L Hertzel used the words "*the science of recorded discourses, which uses specific methodologies, both mathematical and scientific, in its research, is a controlled study of communication. It is the body of literature, a bibliography quantitatively or numerically or statistically analyzed – a statistical bibliography; a bibliography in which measurements are used to document and explain the regularity of communication phenomenon"* (Hertzel, 1987). The study of bibliometrics has been classified into two general categories: descriptive bibliometrics, and evaluative bibliometrics. While descriptive bibliometrics concerns itself with geographical or temporal distribution of the count of productivity, evaluative bibliometrics includes literature usage count which is a measure of the number of citations and references of the communication. Several scholars opine that bibliometrics should also contain information regarding the structure of knowledge and the forms of communication (Nichols & Ritchie, 1978). Their study provided a clear distinction between the two categories of bibliometrics. That branch of bibliometrics that describes the characters and features of any literature is regarded as descriptive bibliography while the branch that restricts itself to the examination of the relationships between the components of any literature is termed as behavioral bibliometrics. Bibliometrics has a wide scope encompassing various items which, inter-alia, include studying or describing literature, laying focus on consistent patterns among authors, and modes of communication. Bibliometrics has also been defined by various authors as the quantitative treatment of the characteristics and behavior of recorded discourses (Fairthorne, 1969).

In the early seventies, bibliometrics was called scientometrics in the countries of Eastern Europe (Rao, 1998). In a study conducted in 1969, research scholars (Hood & Wilson, 2001) mention the use of the *naukometriya* (Namimav & Mulchenko, 1969b) which is the Russian equivalent of scientometrics (Namimav & Mulchenko, 1969a). As the name suggests, scientometry is used to refer to studies related to all facets of scientific and technological literature. The popularity of the term has witnessed an upward spike in 1978 with the publication of *The Journal of Scientometrics* by Tibor Braun in Hungary. The preface of the journal which presents the contents of the journal indicates that the subject embraces a wide gamut of chapters including the science behind science, scientific communication, and policy (Wilson, 2001). Several scholars have also outlined the scope and the objectives of scientometrics to include the quantitative aspects of entire matters related to all disciplines and sub-disciplines of science including policy, administration, and output (Nalimov, 1970; Nalimov, Kordon & Korneeva, 1971). Going by the scope of both bibliometrics and scientometrics, it is observed that scientometrics has a wider scope as compared to bibliometrics. In the words of T N Rajan and B K Sen (Rajan & Sen, 1986), *"Etymologically scientometrics means the study relating to the measurement of science. Science can be measured from several points of view like the production of graduates, post-graduates or Ph. Ds of science; the establishment of research institutions, the institutions of study and teaching of science; the deployment of scientific manpower, brain drain; expenditure of R & D; founding of the media of scientific communication, e.g., primary and secondary scientific periodicals; scientific literature and scientific information system, services and products. The metric studies of all these aspects fall within the ambit of scientometrics. The area of scientometrics which deal with scientific information is also covered by informetrics. It is to be noted that a very large share of the literature of informetrics pertains to scientometrics".* J M Tague-Sutcliffe, however, defines scientometry as "*the study of quantitative aspects of science as a discipline or economic activity. It is part of the sociology of science and has application to science policymaking. It involves quantitative studies of scientific activities, including among others, publication, and so overlaps bibliometrics to some extent"* (Tague-Sutcliffe, 1992). Going by the definition of the subjects, it can be appreciated that while scientometrics is concerned with science and scientific literature including the authors, informetrics has a far wider scope as it encompasses knowledge from all domains and sub-domains. The scope of scientometrics has grown over the years from the analysis of simple data to a specific subject which involves statistical modeling, simulation, cluster analysis among others (Lancaster, 1991). Information is the building block of all knowledge and without the flow of information, knowledge ceases to survive. In the case of bibliometrics, librametrics, and scientometrics, the three basic words are bibliography, library, and science respectively which are not as fundamental as information. Going by the meanings of the three words, bibliography is meant to imply a chronological arrangement of entries, while library is an establishment that houses information. Science, however, is a subject of study and research. While librametrics found its first usage in 1948, followed by scientometrics and bibliometrics in 1969, the term informetrics was first used by Otto Nacke in 1979 (Tague-Sutcliffe, 1992). Despite this fact, informetrics can be considered more fundamental than its predecessors.

The All-Union Institute for Scientific Information, in 1984 formed a committee named Federation Internationale de la Documentation Committee under the chairmanship of O' Nacke. The committee, after due deliberations, arrived at the consensus that informetrics is a generic term encompassing both bibliometrics and scientometrics. The usage of the Russian version of this term *Informetritya* was accepted in the monogram of the Federation Internationale de la Documentation in 1988. The first conference on *Bibliometrics and Theoretical Aspects of Information* held in 1988 resolved that informetrics used to imply both bibliometrics and scientometrics could find wide utility and become a topic of research in the future (Hood & Wislon, 2001). To mark the belief, the proceedings of the conference were named *Informetrics 87/88.* In this context, the editors voiced the fact that during the process of proposing a new nomenclature, the new name should be used with the old one (Egghe & Rousseau, 1988). In the second conference on *Bibliometrics and Theoretical Aspects of Information* held in 1990, the decision regarding the use of informetrics as a generic term received endorsement (Egghe & Rousseau, 1990). The fourth conference was purposefully named *International Conference on Bibliometrics, Informetrics, and Scientometrics* to show that all the three terms are treated with equality and laid equal emphasis on these. The proceedings of this conference were published in four volumes, of which three were published in various English journals (Glänzel & Kretschmer, 1992, 1994, 1994).

Eugene Garfield, who is regarded as one of the most prominent proponents of classical metrics was an American scientist who was born in New York City in 1925 (Cybernetics, 2014). After receiving his Ph.D. in Structural Linguistics from the University of Pennsylvania in 1961, Garfield established the Institute of Scientific Information at Philadelphia in Pennsylvania, which is, at present, the scientific division of The Thomas Reuters Company. Garfield has been credited for his innovative bibliography which includes *the Scientific Citation Index, Current Contents, the Journal Citation Reports, Index Chemicus,* etc. Garfield is also the founder-publisher of *The Scientist* which specialized in covering the lives of scientists. Garfield has also launched a software package for bibliometric analysis and visualization in 2007 named HistCite, besides developing the comprehensive citation index to study the propagation of scientific thought. The *Scientific Citation Index* helps in calculating the cited half-life, the citing half-life, impact factor, and immediacy index besides a host of other features ultimately leading to the publication of journals like *Nature* and *Science*.

5.2 Citation Analysis

Garfield and Rubin define citation analysis as the art of thorough investigation of the frequency, graphs, and the patterns of citations of works of an author in articles and books (Garfield, 1983; Rubin, 2010). Citation analysis is among the most extensively used methods in bibliometrics and establishes a relationship among various research works using the citations in scholarly works. Bibliographic coupling and cocitation are examples of associations which find their base in citation analysis. At present, automated citation indexing (Giles, Bollacker & Lawrence, 1998) like Cite Seer and Google Scholar have gathered storm with its ability to analyze a large number of citations allowing pattern and knowledge discovery at an unprecedented level. With the advent of automated citation index, computation of impact measures of scholars based upon the data collected from various citation index has been made easier. The embedded applications include a host of features from expert referees to granting proposals and providing transparent data to support academic merits thereby promoting decisions.

Among the earliest recorded use of citation analysis is the work done by P L K Gross and E M Gross in 1927 where they have analyzed citations based on counting

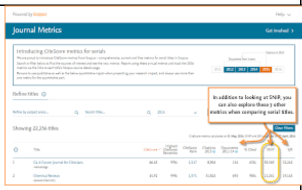
(Gross & Gross, 1927). In their work, the authors produced a list of journals containing chemical equations by counting and analyzing articles from journals of chemistry and ranking them based on citations received. Cole and Eales also worked on similar lines but their scope was restricted to bibliography and not to citations. Over time, citation analysis became an irreplaceable component of bibliometrics with wide-scale ramifications.

The reasons for conducting citation analysis are numerous, including

- Establishment of the impact of a particular work by way of identifying other authors who have based their work upon it or cited it within their papers;
- Learning more about a subject by identification of inspiring works in that domain;
- Determination of the impact a particular author has in his/her discipline and beyond by considering the total number of citations based on discipline and country; and
- Promoting and tenuring purposes by understanding the quality of sources where a scholar's work has been published and cited.

Several tools are available for citation analysis, both subscription-based and free. Each tool has unique strengths and weaknesses and none of them cover the entire gamut of scholarly publications. Therefore, it is pertinent that more than one tool is used to arrive at a fuller picture of the scholarly impact of an author or a journal.

Table 7 provides an insight into the characteristics of three major and widely used citation analysis tools, Web of Science, Scopus, and Google Scholar:

	Web of Science	**Scopus**	**Google Scholar**
			
Subject	Arts, Humanities, Science, Social Science, and Technology	Arts, Humanities, Medical, Science, Social Science, and Technology	Arts, Business, Humanities, Medical, Science, Social Science, and Technology

Components	Arts & Humanities Citation Index Science Citation Index Social Science Citation Index Conference Proceedings	Life Science Health Sciences Physical Sciences Social Sciences	PubMed, IEEE, American Institute of Physics, Nature.com, Springer, Wiley, Sage Open-Source Journals Online thesis
Coverage	Over 10000	16500	Not known
Periodicity	Some journals are pre-1900s	Some journals date back to 1823	As and when available on the web
Update	Weekly	1 to 2 times every week	Every month
Strengths	Citation reports, h-factors, and impact factors are the most widely used.	User friendly Broad coverage Downloadable citation	Provides a more comprehensive picture of scholarly works. Includes peer-reviewed papers. Better coverage of newer papers.
Weaknesses	The difference in citation patterns and errors often leads to low citation counts.	Citation tracking is limited to new papers.	Limited search. Limited citation count. Exporting citations hard.

Table 7: Sources for citation analysis

The co-citation analysis of journals would resemble Figure 4 as depicted herein under.

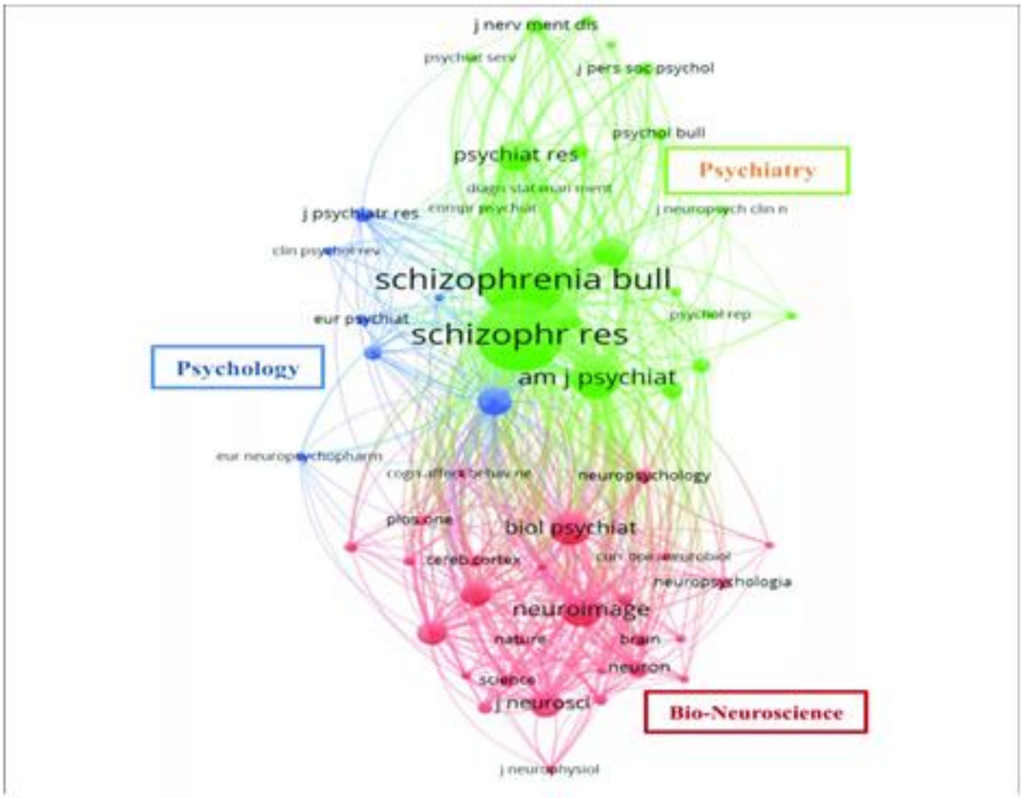


Figure 4: Co-citation analysis of journals

5.3 Scattering Phenomenon

The components of the bibliography which include authors and sources like books, journals, research papers, Ph.D. thesis, etc are scattered within a large number of items for any subject. To cite an example, articles are printed in various journals, authors publish their papers in several journals as part of several articles among others. The availability of articles across several journals is referred to as bibliographic scattering. The classical metrics which include scientometrics measure these scatterings. The set of data that are generally handled by classical metrics conform to a large number of mathematical laws and distribution. These laws include Bradford's Law, Lotka's Law, and Zipf's Law. These laws with their varied mathematical forms have been a subject of review by various authors including Bookstein (Bookstein, 1976), Brookes (Brookes, 1969), Fairthorne (Fairthorne, 1969), Leimkuhler (Leimkhuler, 1967), and Price (Price, 1976). Some of the authors have used these statistical laws in their original forms while others have used them with necessary changes. Some researchers like D J S Price regard the three laws mentioned above as special cases of basic unique distribution. D J S Price (Price, 1976) had also proposed a cumulative advantage distribution where success breeds success. According to Price, this distribution is "*an appropriate underlying probabilistic theory for the Bradford Law, the Lotka Law, the Pareto Law, the Zipf law, and for all the empirical results of citation frequency analysis*".

5.3.1 Bradford's Law

Bradford's Law is regarded as the law of scattering and diminishing returns. Formulated in 1948, the law states that for a given subject domain *there exist a few very productive periodicals, a larger number of less productive producers, and a still larger number of repeatedly diminishing productivity* (Bradford, Egan & Shera, 1953). Bradford's Law divides any literature into three zones: Zone 1 or core at the top, Zone 2 or the middle zone, and Zone 3 or the tail at the bottom. Zone 1 contains the most cited journals in any literature of any subject, Zone 2 includes all journals having an average number of citations while Zone 3 contains journals that are hardly cited and are hence considered of limited importance (Potter, 2010). While some researchers classify subjects in terms of lexical, subject scattering, and semantic (Hjørland & Nicolaisen, 2005), others believe in the fact that defining a subject is of no consequence as long as it is being applied consistently (Heine, 1998).

In mathematical terms, Bradford's Law states that the number of journals in Zone 2 and Zone 3 will be more than Zone 1 by n and n^2 respectively (Fairthorne, 2005; Garfield, 1980). Knowing the number of journals in the core or the middle region, the total number of journals in any subject can be predicted accurately. With the total number of journals known, the amount of relevant information that is found missing can be calculated. The concept of Bradford's Law can be understood from Figure 5 which depicts the pictorial representation of Bradford's Law of Scattering.

For empirical testing of Bradford's Law, a large and complete bibliography is necessary with a well-defined scope of the subject and a limited time frame (Fairthorne, 2005; Naranan, 1970). A successful application of Bradford's Law can be seen in the field of crystallography (Behren & Luksch, 2006), nursing (Bradford, 1953), science (Brookes, 1969), and occupational therapy (Potter, 2010). Besides the areas of application as mentioned above, Bradford's Law also finds application in *Eugene Garfield's Science Citation Index* (Bensmen, 2007). Bradford's Law, however, suffers from certain drawbacks. In an analysis of the randomized controlled trials in the MIDLINE database, the journal distribution deviated from the standard Bradford's Law (Tsay & Yang, 2005). Studies to establish the efficacy of Bradford's

Law in the prediction of the size of literature in systematic reviews are lacking. However, the use of other methods of estimation like the Horizn Estimates has met with a varying degree of success (Kastner, Straus, McKibbon & Goldsmith, 2009).

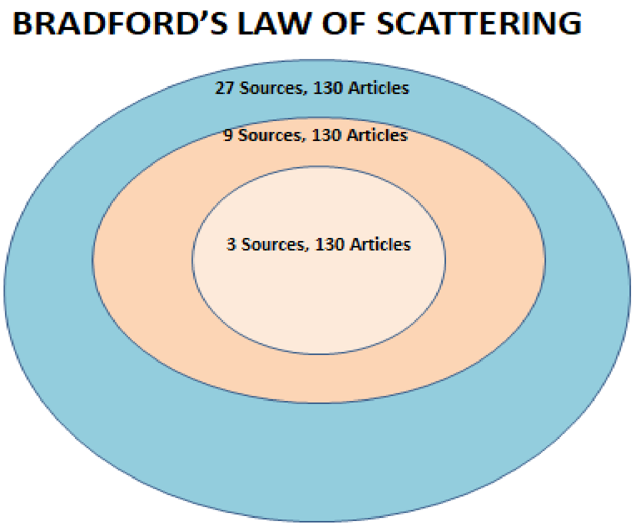


Figure 5: Pictorial representation of Bradford's Law of Scattering

5.3.2 Zipf's Law

Zipf's Law is an empirical law framed using mathematical statistics that proposes that data pertaining to social and physical sciences can be approximated using Zipfian distribution. Originally proposed for quantitative semantics, Zipf's Law states that the frequency of the occurrence of any word varies inversely to its rank in the frequency table. In other words, the word having the highest frequency will have an occurrence that will be approximately twice as much as the word with the second-highest frequency, thrice as much as the word having third highest frequency, and onwards depicting the inverse relation between ranking and frequency. To cite an example, in the American English text, Brown Corpus, the word *'the'* has the highest frequency of occurrence and with 69,971 words out of a total of over 1 million words accounting for 7% of the total words in the text. The word with the second-highest frequency is *'of'* which occurs 36,411 times and accounts for 3.5% of the total words, which corresponds to Zipf's Law. The word with the third-highest occurrence is *'and'* appearing 28,852 times in the text. Half of the Brown Corpus has been filled in with 135 items of the English vocabulary (Fagan & Gencay, 2010).

Zipf's Law can also be used in the ranking of systems created through human intervention (Piantadosi, 2014) like music (Zanette, 2004), mathematical expressions

(Greiner et al., 2020), and also in uncontrolled environments like sizes of corporations, population, etc. For the ranking of cities, Zipf's Law is a better fit with the value of the exponent at 1.07.

Zipf's Law can be easily understood by plotting a graph with the log of the rank order and log of the frequency as its axes. The graph of the words presents in the book 'Brown Corpus' has been shown below in Figure 6.

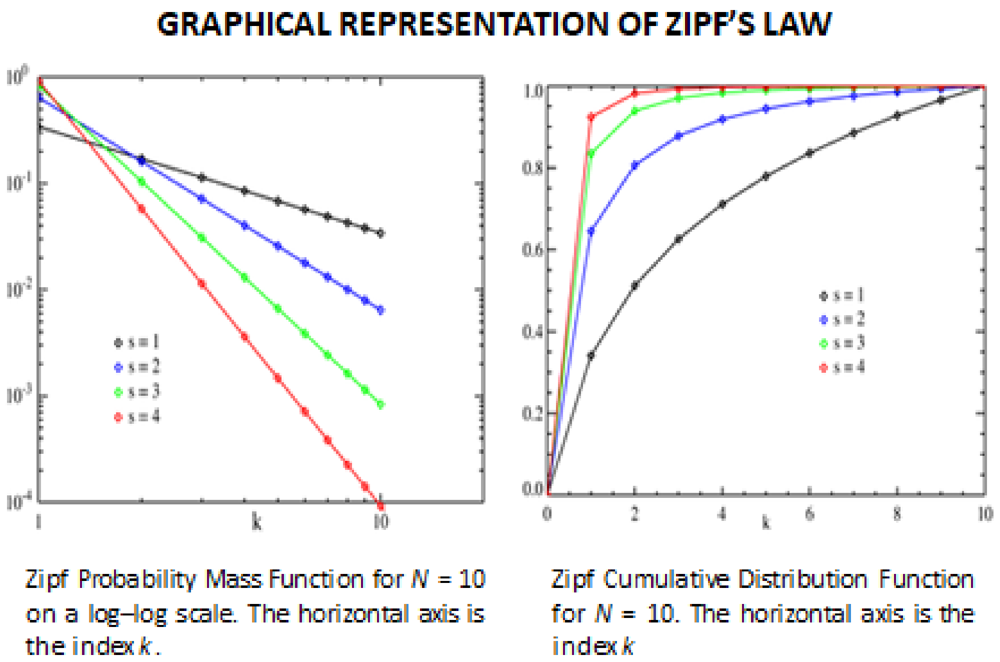


Figure 6: Graphical representation of Zipf's Law of Scattering

The graph for probability mass function is in agreement with Zipf's Law as far as linearity is concerned.

To state Zipf's Law in a mathematical form, if *N*, *k*, and *s* represent the number of elements, their rank, and the value of the exponent characterizing the distribution respectively, then the normalized frequency of the element having rank *k* depicted by *f(k, s, N)* is given by

$$f(k, s, N) = \frac{1/k^s}{\sum_{n=1}^{N}(1/n^s)}$$

Zipf's Law holds good if the number of elements with a particular frequency is a random variable with a power-law distribution given by (Adamic, 2000)

$$p(f) = \alpha f^{-1-1/s}$$

The other mathematical version of Zipf's Law is given by

$$f(k, s, N) = \frac{1}{k^s H_{N,s}}$$

Where H represents N^{th} generalized harmonic number.

Zipf's Law holds good for infinitely many words for s>1 when

$$\zeta(s) = \sum_{n=1}^{\infty} \frac{1}{n^s} < \infty$$

where ζ is called Riemann's zeta function.

5.3.3 Lotka's Law

Lotka's Law (Lotka, 1926), named after Alfred J Lotka is one of the special applications of Zipf's Law and is used to calculate the frequency of publications by different authors in any subject. According to the law, if 'x' denotes the number of contributions made by various authors in any subject in a particular period, then it is a fraction of the number of authors making a single contribution over that period, following the formula $1/_{x^a}$ where *'a'* has a value that is very close to two (a ≈ 2). Due to the value of *'a',* this law is also called the approximate inverse square law. The law states that the number of authors publishing a certain number of articles is a fixed ratio to the number of authors publishing a single article. The law can also be stated as with an increase in the number of publications, the frequency of the number of authors producing publications varies inversely with the number of articles published. It has been observed that there are 1/4 as many researchers publishing two articles within a specified period as there are single-publication authors, 1/9 as many publishing three articles, 1/16 as many publishing four articles, etc. Though the law covers many disciplines, the actual ratios involved (as a function of 'a') are specific to every discipline.

Mathematically, the law can be represented as

$$x^n Y = C$$

Or $$Y = {^C}/_{x^n}$$

Where x represents the number of publications, Y represents the relative frequency of authors, and n and C are constants that are subject-specific. The value of n is approximately equal to 2 (n ≈ 2). The graphical representation of Lotka's Law is shown in Figure 7**.**

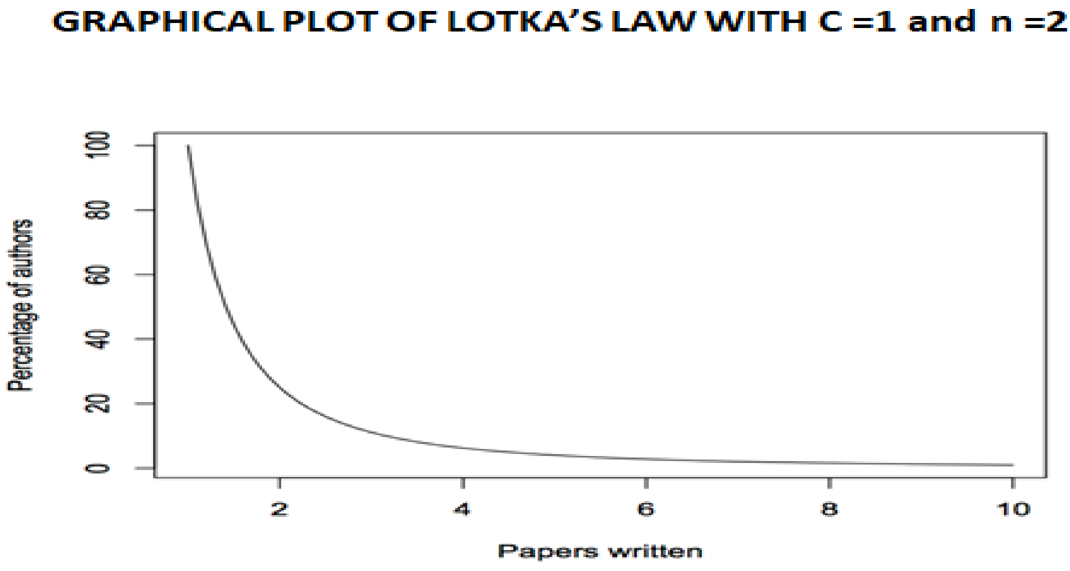


Figure 7: Graphical representation of Lotka's Law of Scattering

5.3.4 Journal Metrics

Among the earliest known journal metrics is the *Impact Factor* which was proposed by Eugene Garfield in 1975 for indexing journals in the Journal Citation Reports. Because of the speed at which papers get cited, the journal matrix is dependent upon various academic disciplines. The numbers of citations also vary among various subjects. Studies have pointed to the fact that during the first two years of the publication the percentages of total citations vary between 1% to 3% for mathematical and physical sciences to between 5% and 8% for biological sciences (Nierop, 2009). The impact factor suffers from certain drawbacks like its inability to compare journals of varied subjects. Though the impact factor is measured as the arithmetic mean of the number of citations per paper, it is a matter of common observation that the citation count follows Bradford's distribution law, making arithmetic mean a statistically unsuitable mode of measurement. As an example, a large proportion of the impact factor of *Nature* magazine (approximately 90%) was on account of a quarter of its publications making the importance of any of its publications different from the overall figures (Not so deep Impact, 2005). Further, with the increase in the number of the digital version of articles, the strength of the relationship between citation rates of various papers and impact factor has been decreasing steadily (Lozano, Larivière & Gingras, 2012). Many metrics are being used to gauge the quality of journals, a few of which are mentioned as under along with their definitions:

1. Immediacy Index – the ratio of the number of articles cited during a particular year to the number of articles published during that particular year.
2. Cited Half Year – the median age of the articles that have been cited.
3. Aggregate Impact Factor – the impact factor of the total subject.
4. Eigenfactor Score (Bergstrom, 2007; Bergstrom, West & Wiseman, 2008) – developed by Jevin West and Carl Bergstrom in 2008 at the University of Washington, the Eigen factor Score is defined as the process of rating the overall importance of any scientific journal. The procedure of ranking of journals is based on the number of citations, citations from highly ranked journals having a higher weight than the poorly ranked ones lending a higher contribution to the eigenfactor. As such, eigenfactor scales newer heights depending upon the impact of the journals with journals having a higher impact factor having higher Eigenfactor scores. High impact factor is defined as the number of times articles published in any journal which are more than 5 years old are cited in any year, neglecting citations in articles published in the same journal. According to C T Bergstrom and J D West (Bergstrom, 2007; Bergstrom, West & Wiseman, 2008), this feature can be interpreted as a modified form of the 5-year Impact Factor. According to the Journal for Critical Reviews, the eigenfactor algorithm ranks journals on parameters like the number of citations and the time the researchers spend on the journal's website.
5. Article Influence Score: article influence score is defined as the evaluation of a journal's relative relevance on an individual basis. It is derived by multiplying a journal's eigenfactor score by the number of articles published in that journal. Any fraction acquired is normalised to one, resulting in the total number of articles from all articles at one. The influence of the journals can be gauged by article influence score. Scores higher than 1 show influence higher than the average and lesser than 1 is indicative of influence that is lower than the average. For any Journal Citation Reports year, the influence of an article in any International Scientific Indexing (ISI) journal is defined as the value obtained by dividing the eigenfactor score by the fraction of all ISI articles published in all ISI journals. In 2019, for instance, the *Annual Reviews of Immunology* was the most influential journal with an article influence score of 27,454 meaning thereby that any article in the said journal has an influence that

is twenty-seven times more than any journals in the Journal Citation Reports (ox.libguides.com, 2019).

6. h5-Index – defined as the largest number *'h'* such that a minimum of *'h'* articles has been cited *'h'* times at the least. A journal having an h5 index of 5 indicates the fact that a minimum of 8 articles has been cited 8 times over a period of 5 years (Refer to details in future sections).
7. SJR Indicator – Scimago Journal Ranking – number of citations received by articles, weighted upon a variety of factors like prestige and influence. It measures the influence of scholarly journals depending upon the importance of the journals that have been cited.
8. Source Normalized Impact per Paper (SNIP) – measures the contextual citation of any source by weighing citations based upon the citations from specific fields. SNIP makes a comparison between journals of various subjects taking into account the properties of the subjects. The subjects are sets of documents citing any particular journal. SNIP considers, inter-alia, the frequency of citation from other research papers in the list of reference, the extent of the assessment of the database in covering literature in the specific domain, and the speed of maturity of the impact of the citation. SNIP is defined as the ratio between the average citation count of any source and the potential of citation in the specific field. The potential of citation or citation potential as it is popularly called is the mean of the number of references of documents citing a source. It is a measure of the probability of any reference being cited by any future paper in any specified field. Citation potential finds importance due to the wide variation in the citation counts between research disciplines. Life sciences, for example, have a citation index higher than physical or mathematical sciences. The concept of citation potential can be understood by the following example. If any research paper has 40 cited references on an average as against another paper having 10 cited references, then the former paper has a citation potential that is 4 times more than the latter. Citation potential also varies across sub-domains within any subject. Basic journals, for example, ha the tendency to have citation potential higher than clinical journals. Along the same lines, journals on emerging topics have a higher citation potential more than periodicals in classical topics (scopus.com, 2014).

5.3.5 Author Metrics

Author metrics is a measurement of the research impact of scholarly publications by individual authors. The limitations experienced by different authors emphasize the exact parameter that is required to be measured. Since different subject domains have different publishing patterns, the impact of research by authors belonging to various disciplines cannot be measured using the same yardstick. According to J Kaur (Kaur, Radicchi & Menczer, 2013), the analysis of author impact plays a crucial role in evaluation, hiring, and tenure decisions. The central objective of the metrics is restricted to assessing both the scholarly and social visibility of the authors. The major author metrics are detailed below (wiki.lib.sun.ac.za, 2014):

1. Captures – defined as the number of times any research article has been shared or bookmarked.
2. Citations – indicates the number of times a particular research work is cited in future literature.
3. g-index – calculated on the basis of the distribution of citations received by the research works of researchers in such a way that arranging the articles in the descending order of their rankings. The g-index is the largest number such that the top g-articles receive g^2 citations at the least. This concept was proposed by Leo Egghe in 2005.
4. h-core – h-core of any publication refers to the set of those *'h'* articles which are the most cited and form a part of that publication.
5. h-index – Proposed by J E Hirsch in 2005, this is a measure of the citations received by a scientist.
6. h-median – defined as the median of the citation count in h-core.
7. h5-index, h5-core, h5-median – includes h-index, h-core, and h-median respectively of those publications that have been published in the previous 5 calendar years.
8. i-10 index – indicative of the number of academic works published by individual authors that have received at least 10 citations.
9. Mentions – the number of times any research paper finds mention in Wikipedia and others.
10. Social Media – includes shares in Facebook, LinkedIn, and in tweeter

11. Usage – represents the times any research article is viewed on the website of the publisher. Other definitions include the number of times any article or supplementary data is downloaded.

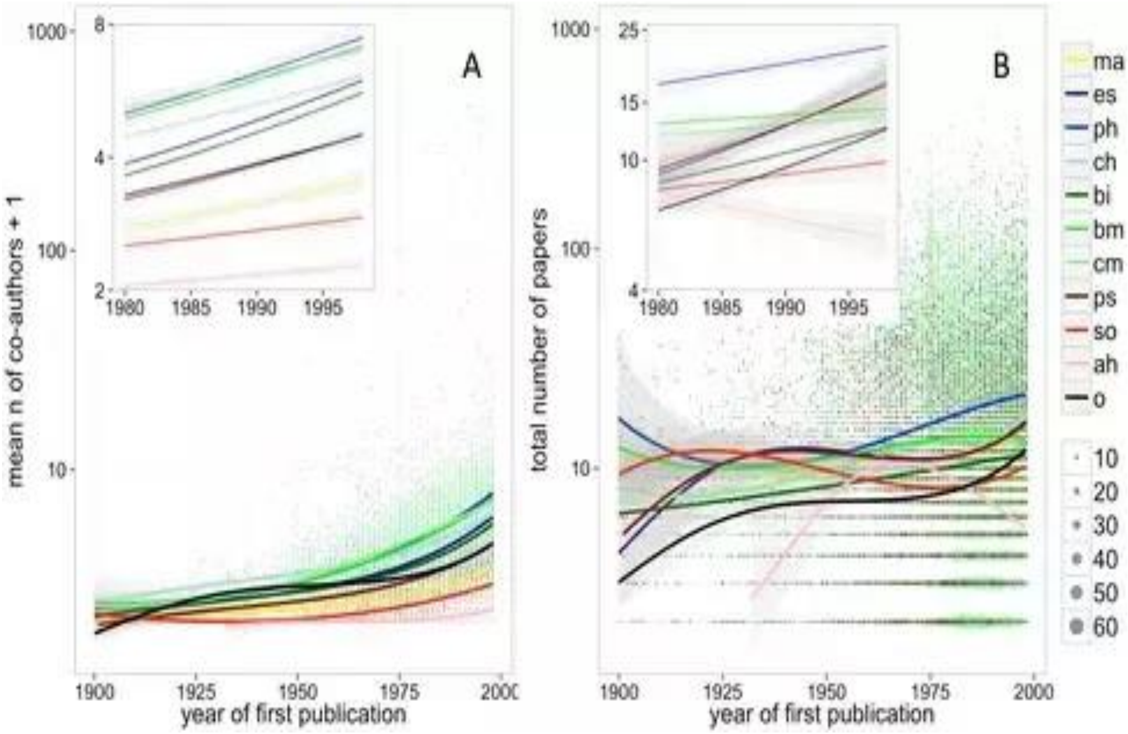


Figure 8: **Author level metrics**

The pictorial form of author level metrics is represented in Figure 8 above.

5.3.6 Article Level Metrics

Article level metrics refer to those metrics that are used for measuring the impact and the usage of the research articles published by individual authors. Classically, both impact and usage of the articles of research were evaluated using bibliometrics or informetrics though both these procedures suffered due to low scope resulting from their primary focus only on journals, which included immediacy index or impact factor. Certain metrics at the level of the researcher including the g-index, h-index, or the i-index had been developed in the last decades. Unlike author metrics or journal metrics, article-level metrics base their focus on individual articles rather than on authors or journals. Though this procedure is related to altmetrics, there exist several differences. PLOS, which is regarded as an open-access publisher provides article-level metrics to all its academic journals which also include altmetrics, citations, and downloads.

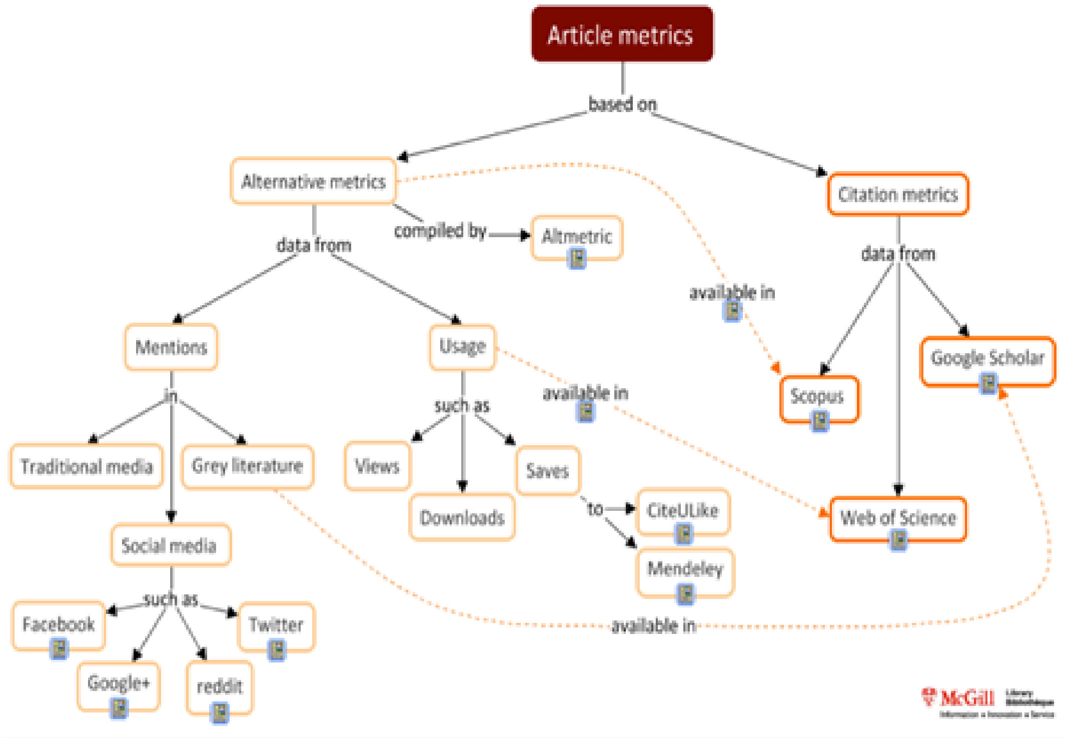


Figure 9: Article level metrics

5.3.7 Hirsch Index (h-Index)

The h-index is an author level metrics used to measure the citation impact and productivity of the publications by any research scholar or scientist. The h-index has a bearing with various positive factors like being accepted for research fellowships, being selected for top positions in elite universities, and winning the most coveted Nobel Prize, among others (Bornmann & Daniel, 2007). The basis of arriving at this index lies in calculating the most cited work of any author and also the number of times these have been cited in other publications. Besides this, the h-index also finds application in assessing the impact and the productivity of any journal having scholarly values (Suzuki, 2012) and a group of scientists as well from any department, or any university, or any nation (Jones, Huggett & Kamalski, 2011). This index was proposed by a physicist Jorge E Hirsch in 2005 at a presentation held at the University of California, San Diego as a way of defining the relative quality of theoretical physicists (Hirsch, 2005). Due to this h-index is also known as Hirsch Index or Hirsch Number.

The h-index is the maximum value of h based on the condition that certain authors or journals have published h number of research papers that have been cited h number of times individually (MacDonald, 2005). The h-index is an improvement upon the previously used simple methods that calculated the total number of citations or the number of publications. With citation conventions witnessing severe differences among different fields, h-index has an optimized efficacy while comparing scholars in the same knowledge domain (Key Measures of Academic Influence). Figure 10 shows the graphical plot of the h-index.

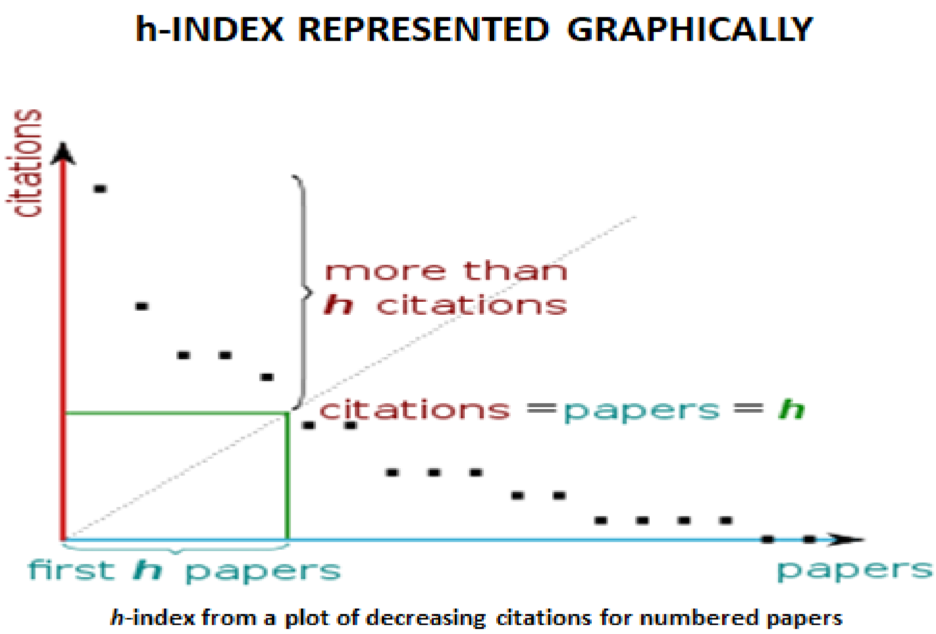


Figure 10: Graphical representation of h-index

If f represents the function corresponding to the number of citations for the individual publication, we calculate the h-index using the following method.

Firstly, the values of *f* are arranged in descending order (i.e., from the highest value to the lowest value)

Secondly, we obtain the ultimate position at which the value of *f* is greater than or equal to the number of that position.

This position is referred to as the *h*- position and h-index in the number of that position.

The calculation is depicted in a tabular form in Table 8 below for an easy understanding.

Position	Name of the publication	Number of citations (f) (Case 1)	Number of citations (f) (Case 2)
1	A	10	28
2	B	8	8
3	C	5	5

4	D	4	3
5	E	3	3
h-index		**4**	**3**

Table 8: **Calculation of h-index**

In the first case, the h-index has been calculated at 4 because the number of citations in the fourth position is found to be 4. In the second case, however, the h-index has been calculated as 3 as the paper in the fourth position has only 3 citations which is lower than the position number. Numerically,

If the function f is arranged in descending order, the h-index is calculated as

$$h - index(f) = \max\{i \in N: f(i) \geq i\}$$

The Hirsch index can be compared to the Eddington number which is an old metric used in the evaluation of cyclists. In assessing the impact of any researcher's work, the h-index can be used as an alternative to more traditional journal impact factor metrics. The calculation of the h-index is simple because highly cited articles contribute to it. Hirsch showed that h has a high predictive value for whether a scientist has received prestigious awards such as membership in the National Academy of Sciences or the Nobel Prize. The h-index rises as citations increase, so it is a function of a researcher's academic age. Manual calculation of the h-index is also possible either by using certain citation databases or through automated methods. Paid or subscription-based databases which include Scopus and Web of Science also have automated calculators. This feature has also been incorporated by Google Scholar from July 2011 by providing an automatic h-index and i10-index calculator within their profile (Google Scholar Citation Help). Besides, certain specific databases like INSPIRE-HEP have the facility of automatic calculation of the h-index of researchers working in the domain of high energy physics.

The h-index is also dependent upon coverage areas with each database producing a different h-index for the same scholar (Bar-IIan, 2007). There have been numerous studies to test the dependence of h-factors from databases on coverage areas. It has been observed that Web of Science covers journal publications more strongly than high impact conferences. Scopus, on the other hand, covers conferences better than publications. Google Scholar, however, covers both with equal intensity (Meho & Yang, 2007; Meho & Yang, 2006). The scholars in the field of computer science face the problem regarding the exclusion of conference proceedings papers as these are a vital part of their literature (Meyer et. al., 2009).

Similarly, Google Scholar has received criticism from scholars regarding their inability to adhere to the theories of Boolean logic while combining search terms and producing invisible citations including gray literature to enhance their citation counts (Jacso, 2006). In their study of the citation counts of various databases, Meho and Yang found that Google Scholar had identified 53% more citations than Scopus and Web of Science combined, by way of reporting citations from journals or conference proceedings having a low impact. To counter such malpractices, it has been advised to take the maximum h-index measured from any academic as false negatives are more dangerous than false positives (Sanderson, 2008).

Studies concerning the variance of the h-index with variation in subjects, nations, institutions, times, etc. have been few and far between. Hirsch believed that for any physicist (i) an h-index of 12 could result in securing the post of Associate Professor in any of the major US Universities, (ii) an h-score of 18 could make him a full-time professor, (iii) an h-score between 15 and 20 could result in getting a fellowship from the American Physical Society, while (iv) an h-index of 45 or higher could mean a membership to the United States National Academy of Sciences (Peterson, 2005). Hirsch further suggested that after a tenure of 20 years as a scientist, h-scores of 20, 40, and 60 would mean being regarded as a successful scientist, an outstanding scientist, and a truly unique scientist respectively (Hirsch, 2005).

Using this concept, Hirsch was able to rank various scientists from 1983 to 2002. The names of 10 scientists in the decreasing order of their h-scores are Solomon H Snyder (h-score = 191), David Baltimore (h-score = 160), Robert C Gallo (h-score = 154), Pierre Chambon (h-score = 153), Bert Vogelstein (h-score = 151), Salvador Moncada (h-score = 143), Charles A Dinarello (h-score = 138), Tadamitsu Kishimoto (h-score = 134), Ronald M Evans (h-score = 127), Axel Ullrich, and Ralph L Brinster (h-score = 120) (Hirsch, 2005). The 36 new entrants in the fields of biological and biomedical sciences in the American Academy of Sciences had an average h-score of 57. Hirsch, however, believed that this h-score would vary across different fields of knowledge (Hirsch, 2005).

The h-index was intended to act as the panacea for the disadvantages that previous bibliometric indicators had which included basing upon the number of papers, citations, etc. The number of papers published is a quantitative aspect and does not depict the qualitative aspect of the authors while citations show variance depending upon the type of publication. The h-index has been intended to measure both the qualitative and the quantitative aspects of any scientific publication.

There are several criticisms of the concept of h-index. Among the criticisms include (Wendl, 2007): nonadherence to the number of citations, disregarding the information in the author's placement, less predictive as per the results of some studies, ability to be manipulated through self-citations, etc.

5.3.8 g - Index

The g-index has been developed in 2006 by Leo Egghe as an author level metrics (Egghe, 2006). The g-index is calculated on the distribution of the citations received by the publications of any researcher, in such a way that ranking these publications in the diminishing order of the number of citations received, the g-index is that unique largest number such that the topmost g articles receive a minimum of g^2 citations. Mathematically, g-index can be expressed using the formula given below:

$$g^2 \leq \sum_{i \leq g} c_i$$

The graph of the g-index is shown in Figure 11 below.

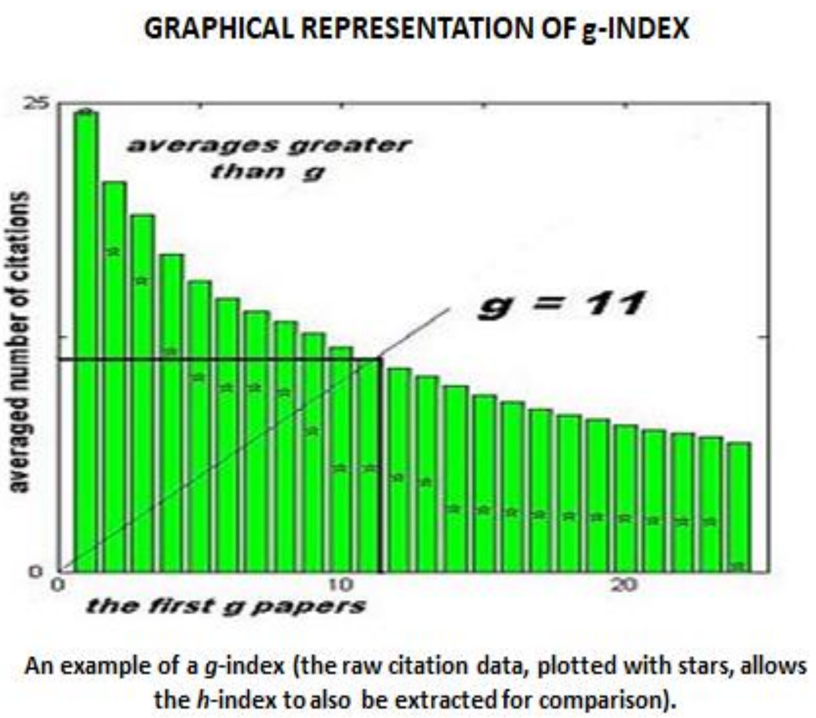


Figure 11: Graphical representation of g-index

Alternatively, g-index can be defined as the highest number of *n* articles having a high number of citations for which the arithmetic mean of the citations is *n*. Mathematically,

$$g \leq \frac{1}{g}\sum_{i \leq g} c_i$$

Statistically, it can be proved that for any set of publications, the g-index exists and is unique.

$$g = \left(\frac{\alpha - 1}{\alpha - 2}\right)^{\frac{\alpha-1}{\alpha}} \frac{1}{T^{\alpha}}$$

Where α is the Lotkaian coefficient, and T denotes the total number of sources.

Since $h = T^{\frac{1}{\alpha}}$, the above equation can be written as

$$g = \left(\frac{\alpha - 1}{\alpha - 2}\right)^{\frac{\alpha-1}{\alpha}} h > h$$

The g-index replaces the more mature h-index in the fact that the h-index does not calculate the arithmetic mean of the number of citations. The h-index needs at least n citations for the least-cited articles neglecting the highly cited papers. Also, in contrast to the h-index, the g-index shows saturation when the arithmetic mean of citations in all published works exceeds the number of published works.

The g-index has been characterized using three axioms (Woeginger, 2008), the simplest among which states that the research index of any author should not portray a downward trend on moving the citations from weaker articles to stronger ones. Like its predecessor the h-index, the g-index is a natural number and, therefore lacks the power of discrimination. To overcome this deficiency, a more rational generalization has been recommended (Tol, 2008). The recommendation called the collective g-index states that *for a set of researchers who have been ranked in the decreasing order of their g-index, the* g_1 *index is the largest number such that the topmost* g_1 *researchers have an average g-index of* g_1 *at the minimum.*

5.3.9 m – Index or m – Quotient

The concept of m-quotient or m-index has been proposed to enable even the junior scientists to receive the credit that they deserve. The m-index handles these propositions by weighing the period of academic pursuit, unlike its predecessors that showed scant regard towards the academic career of any scientist.

m-index is calculated by dividing the h-index by the number of years. If n represents the time (measured in years) since the publication of the first research paper by any scientist, then

$$m - index = \frac{h - index}{n}$$

The stability of the m-index is a matter of concern in the early part of a scientist's career as a minor change in the h-index can alter the m-index by a wide margin. Hirsch opines regarding the appropriateness of choosing the first published scholarly work as the starting point. Despite adding the weighting factor, the m-quotient does not contribute heavily to the list of disadvantages including the qualitative and the quantitative aspects of the h-index.

5.3.10 i - Index

The i-index has originally been designed as a method of conveying the impact of the patents to the prospective investors. The methodology of calculating the i-index has been borrowed from the methodology that had been utilized to calculate the h-index which was being used by various research scholars to calculate the impact that their published works had upon other researchers. The h-index has a direct correlation to the number of times any written research publication is cited. On similar lines, patent citations are used as a representation to assess the forward impact of the patents of investors.

While computing the i-index, the stage of filing the patent is vital and taken into consideration as those patent applications that have not been considered due to being less than one document are not taken into account. Citations by either the author himself or the assignee of the patent or by both the author and the assignee are considered as partial citations and discounted appropriately. The calculation of the h-index has thus been modified and has adapted for patent documents.

Based on what has been stated above and along similar lines as the h-index, the i-index of 17.25 can be used to imply that any individual has a minimum of 17 patent rights with a minimum of 17 forward citations each. The i-index is not calculated from a fixed minimum scale and cannot exceed the total citations filed by the inventors. The value of the i-index is not time-independent but grows with time depending upon the number of patents filed and the number of patents that are granted besides the number of citations. Citations are calculated based upon both the number and type of citation, be itself cited or otherwise. These features make the i-index an evolutionary metric that has the ability to track the trajectory of the impact of an inventor over time.

For the best comparison of inventors using the i-index, the best result is obtained by comparing the i-index of patents filed in the same technologies within the same period of time. The relevance of the comparisons also increases if the mixture of the jurisdiction of the patents is the same for the two sets of patent applications for all the inventors. This is due to the variation in the pace of both the individual sectors and the number of patents filed in each area. The i-index also has a downstream effect on patent citations. These factors have an impact on the calculation of the i-index.

The following points have to be considered with the i-index. Comparisons between inventions pertaining to different periods of time should be avoided. Calculating the i-index of patent documents belonging to the age before the digital age can be tricky. The availability of patent data based on tracking of patents and the citation data is also a cause of concern.

Despite what has been mentioned above, the i-index finds use in quantification of the impact that an inventor has and is a way to compare and standardize the same.

5.3.11 Journal Impact Factor

The journal impact factor or impact factor of any scholarly journal is a scientometric index that indicates the arithmetic mean per annum of the number of citations received by those articles that have been published in the last two years. It finds frequent use as a substitute indicating the relative importance of a journal in any knowledge domain. Journals having a high impact factor are treated as better than those which have a low impact factor.

Eugene Garfield, who is the founder of the Institute for Scientific Information, is considered as the proposer of the concept of impact factor. The impact factor has been in use since 1975 for journals that have been listed in the Journal Citation Reports.

The two-year journal impact factor for any particular year is calculated as the ratio of the number of citations received during that year for publications in journals published during the two preceding years also referred to as the number of citable items published in those two preceding years (Web of Science, 2019; Garfield, 1994).

$$IF_y = \frac{Citations_y}{Publications_{y-1} + Publications_{y-2}}$$

Let a journal be cited 74090 times during the year 2020, and the number of journals published in 2019 and 2018 is 880 and 902 respectively, then the journal impact factor of the journal during 2020 would be calculated as:

$$IF_{2020} = \frac{Citations_{2020}}{Publications_{2019} + Publications_{2018}} = \frac{74090}{880+902} = 41.577$$

This indicates that, on an average, the papers published in the journal during 2018 and 2019 have individually received approximately 42 citations during 2020. It is also to be noted that the impact factor for 2020 can be calculated on completion of processing by the indexing agency and can only be reported by early 2021. As observed from the equation, the impact factor is dependent on citations and publications. Publications are also known as citeable items. The Institute for Scientific Information has clearly defined the terms 'citation' and 'publication'. Publications include items classified under article, proceedings, or reviews present in the Web of Science database, completely excluding corrections, discussions, editorials, notes, and retractions. The Web of Science database can be accessed by all the registered users, who are at liberty to check the citable items for any particular journal. The number of citations, on the other hand, is extracted from a more dedicated JCR database rather than from the Web of Science database. Since the JCR database is not accessible, the JCR Impact factor represents an exclusive value that has been defined by the Institute for Scientific Information and calculated by them without scope for external verification (Hubbard & McVeigh, 2011).

Fresh journals, that have been indexed immediately after the publication of the first issue will be eligible to receive an impact factor only after two years of indexing. During these years, these journals would be regarded as having null values for impact factor. For those journals that have been indexed with a volume that is different from the commencing volume, the impact factor can be calculated on the completion of three years of indexing. Certain agencies like the Journal Citation Reports, however, assign impact factors to journals that have not completed the requisite two years of indexing by the process of partial citation data (RSC Advances, 2013; news.cell.com, 2014). Since the calculation of the journal impact factor requires the knowledge of the item count of two years, the process adopted by the JCR treats one of these counts as zero. Further, the availability of annual publications and other such publications that are published on an irregular basis affect the item count. Though the impact factor is restricted to a certain time frame, it can be calculated for any period. For instance, the Journal Citation Reports have a five-year impact factor, which is computed by dividing the number of citations any journal has received in any particular year by the number of articles published in that journal in the previous five years (JCR with Eigenfactor; ISI-5year Impact Factor).

The impact factor finds usefulness in comparing various journals in any given domain of knowledge. The Web of Science, for instance, has indexed more than 11,500 journals in science and social science (Clarivate Analytics). Journal impact factors are also used to estimate the merit of both individual articles as well as individual researchers (McKiernan, et. al., 2019). Hoeffel summarized the use of impact factors as (Hoeffel, 1998)

"Impact Factor is not a perfect tool to measure the quality of articles but there is nothing better and it has the advantage of already being in existence and is, therefore, a good technique for scientific evaluation. Experience has shown that in each specialty the best journals are those in which it is most difficult to have an article accepted, and these are the journals that have a high impact factor. Most of these journals existed long before the impact factor was devised. The use of impact factor as a measure of quality is widespread because it fits well with the opinion we have in each field of the best journals in our specialty. In conclusion, prestigious journals publish papers of high level. Therefore, their impact factor is high, and not the contrary".

Since impact factors are a journal-level metric, rather than being an article-level or an individual-level metric, its use is controversial. Though Garfield agrees with Hoeffel in this regard (Garfield, 2006), but warns against the misuse since there exists a wide variation in the number of citations] among different articles within a single journal (Garfield, 1998). Figure 12 is a depiction of the graphical form of the journal impact factor.

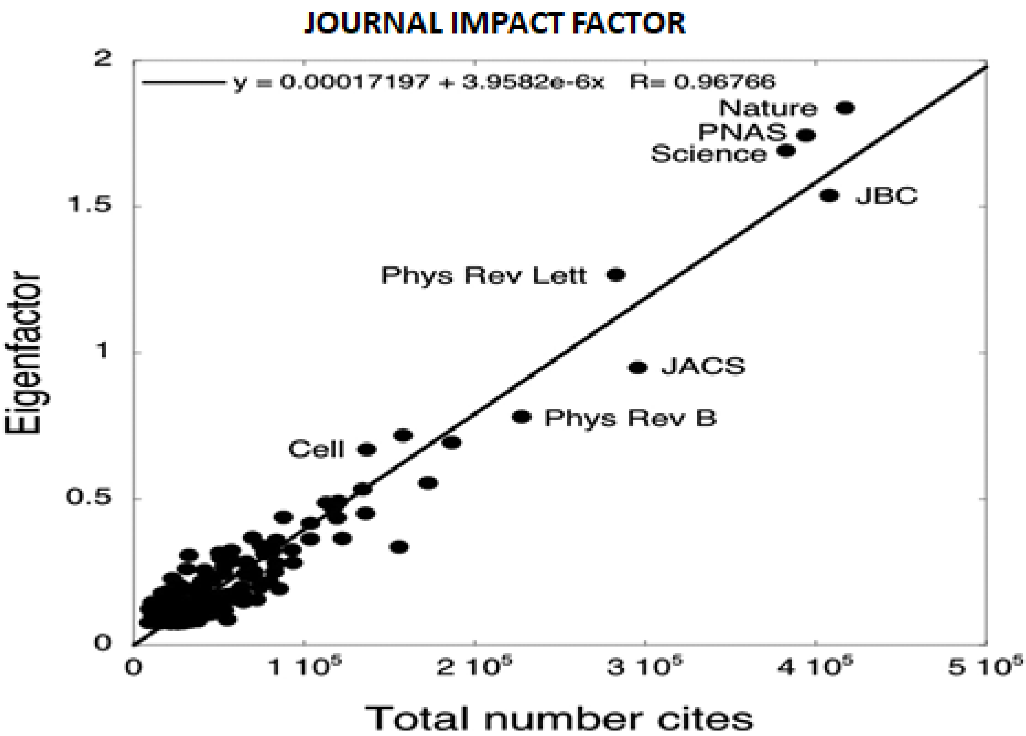


Figure 12: Graph of the Journal Impact Factor depicting the domain areas

The impact factor of the 10 most prominent journals during 2020 is tabulated in Table 9.

S.No.	Name of Journal	Impact Factor (2020)
1	Nature Materials	38.887
2	Nature Biotechnology	31.864
3	Advances in Physics	30.917
4	Advanced Materials	25.809
5	Materials Today	24.372
6	IEEE Communications, Surveys, and Tutorials	22.973
7	IEEE Transactions on Pattern Analysis and Machine Intelligence	17.730
8	Annual Review of Materials Research	16.816
9	Biotechnology Advances	12.831
10	Nature Communications	11.878

Table 9: Journals having the highest impact factor during 2020.

5.3.12 Science Citation Index

The Science Citation Index which was created by Eugene Garfield and launched in the year 1967 is a citation index that has been produced by the Institute for Scientific Information. After a change of hands, the Institute for Scientific Information is now owned by Clarivate Analytics which is the intellectual property and the scientific arm of Thomson Reuters (Garfield, 1955; Garfield, 1963; Garfield, 2011). The Science Citation Index Expanded which is the larger version of the science citation index covers more than 8,500 notable and significant journals, across 150 different domains, from the year 1900 till the present. The rigorous process adopted during the stage of selection makes those journals making it into the Science Citation Index being regarded as the leading journals of science and technology in the world (Ma, Fu & Ho, 2012).

5.3.13 Acknowledgement Index

An acknowledgement index or acknowledgment index (American variant) is a method that indexes and analyzes the acknowledgments present in scientific and technical literature by the process of quantification of the same (Leydesdorff & Milojević, 2015). Generally, all written publications, including research articles contain a section dedicated to acknowledging all the stake-holders involved in the success of the work by way of contributing ideas or materials and have an influence on the work like funding agencies, colleagues, technical staff, among others. Like the citation index, the acknowledgment index also gauges various factors that influence any scientific work, but the point of difference between the two is that the latter measures the influence of both formal and informal sources. While the formal sources of influence include economic and institutional sources, the informal sources comprise artifacts, ideas, individuals, and people. The acknowledgment index differs from the impact factor in the sense that while the latter produces an overall single metric, the former relies upon separate analysis of all the individual components. Since both the number of acknowledgments present in a paper and the number of times any paper has been cited are measurable, the ratio of the total number of citations to the total number of papers where the acknowledged entity appears can be regarded as the impact of the acknowledged entity (Councill, et. al., 2005; Giles & Councill, 2004).

5.4 Conclusion

Any analysis has to be backed by sound knowledge and understanding of the theories and the concepts associated with the analysis. The scope of this chapter is restricted but not limited to understanding the concepts and the theories that relate to scientometry. This chapter begins with the idea that scientometrics is a science and requires a thorough understanding of the terms associated with the subject. The chapter progresses to describing the history of scientometrics commencing from 1964 and how the indices have been used to describe the productivity of individual researchers. Laws associated with scientometrics like Bradford's Law, Lotka's Law, Zipf's Law have also been discussed in depth with their mathematical formulae. This chapter also explains the various scientometric indices that have been used to assess the performance of the Nobel Laureates in Chemistry.

After discussing about the science behind scientometry, next chapter deals with data analysis and interpretation (Chapter – 6).

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CHAPTER - 6

DATA ANALYSIS AND INTERPRETATION

6.0 Introduction

As mentioned in the previous chapters, the prestigious Nobel Prize is conferred upon individuals in certain disciplines in such a manner as decided as per the will of late Alfred Nobel, a renowned Swedish chemist, engineer, businessman, and philanthropist. Nobel Prize for Economic Sciences has, however, been added in 1968. The first Nobel Prize ceremony was held in 1901 when Nobel Prizes were awarded in five disciplines- Physics, Medicine, Chemistry, Peace, and Literature. The first Nobel laureate in the discipline of Chemistry was Jacobus H. van’t Hoff, who was awarded the prize for his commendable works on Osmotic Pressure and Chemical Equilibrium. Since then, Nobel Prizes in Chemistry has been awarded every year, baring certain years when the same could not be awarded. From its inception in 1901 till 2020, the Nobel Prize was awarded 112 times to 186 recipients, with Frederick Sanger being awarded the same twice, the first in 1958 and the second in 1980. As such, Chemistry can boast of having 185 Nobel Laureates.

The subsequent sections of this chapter deal with the scientometric portraits of all Nobel Laureates in Chemistry from 1901 till 2019. We have begun our analysis of the scientometric data of the Nobel Laureates who were awarded the Prize in 2019 and have progressed towards those who had been awarded the same in 1901.

6.1 Purpose of the Chapter

The scope of this chapter is restricted to quantitatively assessing the productivity of publications of all Nobel Laureates in a bid to analyze the medium of all scientific communications, and the domain-wise authorship patterns. Besides what has been mentioned in the previous lines, the chapter also tries to find the various channels of communication used by the Nobel Laureates, their production over time, and the citation network.

6.2 Modus Operandi (Methods Applied in Study)

My studies have been based on the papers that have been indexed in the Scopus database. Analyses of the data obtained were done using various parameters, which included, inter-alia, documents authored by the Nobel Laureates, the number of scientific communications, domain-wise scientific communications, and pattern of authorship, channels of communication, analysis of citations received, and their collaboration with other authors. The method adopted in this study in described in the subsequent sections:

(i) Data pertaining to all the Nobel Laureates have been extracted from the Scopus database (https:// www.scopus.com / search /form.uri ?display = authorLookup) by selecting the 'Author' radio button.

(ii) On the page, there were three search fields: 'Author last name,' 'Author first name,' and 'Affiliation.' The author's last name was put in the first search form, and the author's first name was entered in the second search field. The 'Affiliation' search field has since been confirmed.

(iii) I had selected all the files in the data files of the papers that had surfaced that had all permutations of the Nobel Laureates' names as one of the authors of the documents. Only those documents were chosen in which the name of the affiliating institute matched the name of the institute at the time the Nobel Prize was awarded.

(iv) All selected data were then downloaded in different formats: Text, Comma Separated Values (CSV), and Bibtex formats.

Subsequently, all the data were analyzed using Biblioshiny in R. The visualizations have been done using VOSviewer.

6.3 Data Analysis and Interpretations

For the convenience of data presentation, analysis and interpretation, results of the study are classified into five sections i.e., scientific communications, domain-wise scientific communication, domain-wise authorship patterns, year-wise authorship patterns, channels of communication, Author performance based on available metrics indicator, scientific collaborations and research network of Nobel Laureate.

2014

Nobel Prize in Chemistry was awarded to three researchers in 2014 for the development of super-resolved fluorescence microscopy. The Scientometric portraits of the Nobel Laureates have been detailed in the succeeding sections.

6.3.1 ROBERT ERIC BETZIG

Robert Eric Betzig was one of the three researchers who were awarded the Nobel Prize in Chemistry in 2014 for their work towards the development of super-resolved fluorescence microscopy. Born in 1960, Robert Eric Betzig published his first paper in 1981, when he had attained the biological age of 21 years. This reflects the early age of the commencement of publications. Robert Eric Betzig has published his works in numerous domains which include (a) Applied Physics, (b) Cell Biology, (c) Microscopy, and (d) Molecular Biology.

6.3.1.1 To assess the number of scientific communications contributed by Robert Eric Betzig

From table 10, it is indicated that highest no document produced by article (100) follow that conference paper (24) follow that Review (9) and so on.

Table 10: Scientific Communication

DOCUMENT TYPES	
Article	100
Conference Paper	24
Erratum	3
Note	1
Review	9

6.3.1.2 To analyze the domain-wise scientific communication of Robert Eric Betzig.

The domain wise pattern of scientific communication of Robert Eric Betzig is presented in Table 11. On scrutiny of the table, it is observed that Betzig's communication is in the domain of applied physics, cell biology, microscopy, and molecular biology. Table 11 shows that most of the scientific communication of Betzig is in the domain of applied physics (28.47%) followed by cell biology (27.74%). 21.90% of the total scientific communication of Robert Eric Betzig are in the fied of microscopy and molecular biology.

The table further shows that most of the scientific communication is in the form of articles (72.99%), followed by conference papers (17.52%). The author has also published his scientific works in the forms of reviews (6.57%), erratum (2.19%), and notes (0.73%).

Table 11: Number of Scientific Communication

Document	**Domain**				**Total Papers**	**%**
	A	B	C	D		

Article	26	31	17	26	**100**	**72.99**
Conference Papers	0	3	9	2	**24**	**17.52**
Erratum	2	0	0	1	**3**	**2.19**
Note	0	0	1	0	**1**	**0.73**
Review	1	4	3	1	**9**	**6.57**
%	**28.47**	**27.74**	**21.90**	**21.90**		

A: Applied Physics B: Cell Biology C: Microscopy D: Molecular Biology

Figure 13 represents the data in a graphical format.

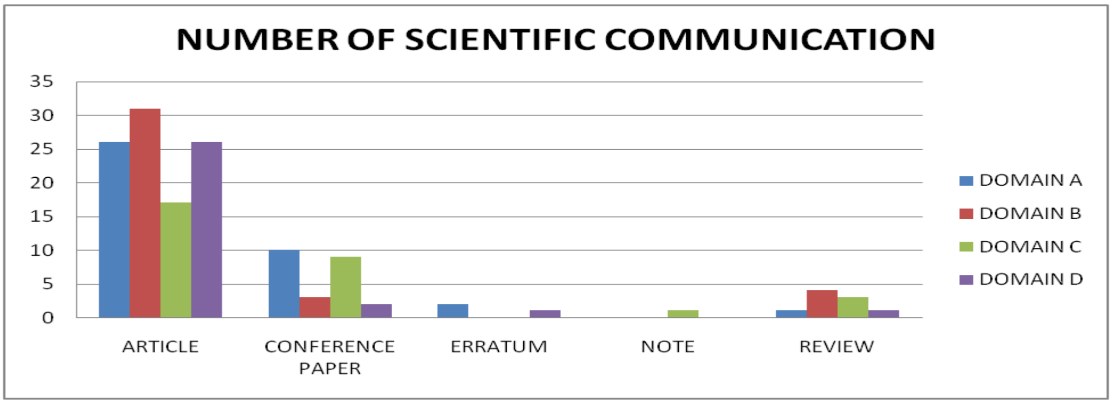


Fig 13: Number of Scientific Communication

6.3.1.3 To analyze the domain-wise authorship patterns of Robert Eric Betzig.

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Robert Eric Betzig are multi-authored having 5 or more authors. 14.60% of the total works are single-authored. The maximum communication of Robert Eric Betzig is with 4 to 10 authors.

Table 12: Domain-wise Authorship as per Collaboration

Domain	**Authors**						
	1	2	3	4 TO 10	11 TO 20	21 TO 30	31
A	8	2	5	23	1	0	0
B	4	1	1	19	11	1	1
C	8	3	3	14	0	1	0
D	0	1	3	18	8	1	0
Total	**20**	**7**	**12**	**74**	**20**	**3**	**1**
%	**14.60**	**5.11**	**8.76**	**54.01**	**14.60**	**2.19**	**0.73**

A: Applied Physics B: Cell Biology C: Microscopy D: Molecular Biology

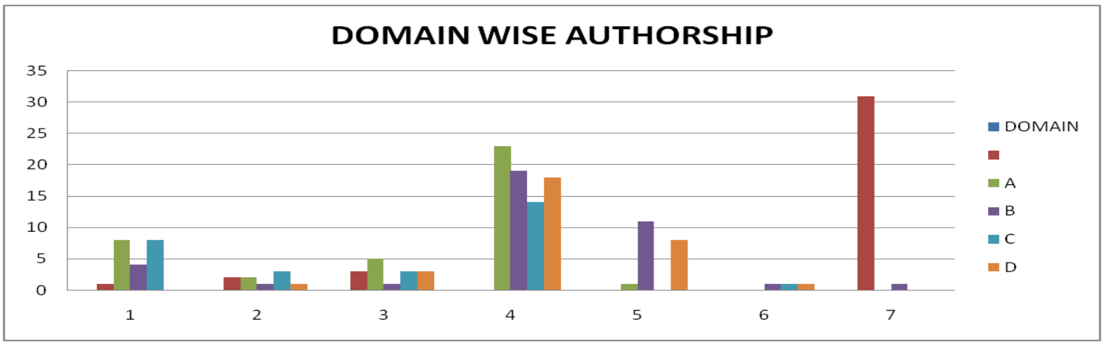


Fig 14: Domain-wise Authorship

6.3.1.4 To analyze the year-wise scientific communication of Robert Eric Betzig.

Table 13 and Figure 15 show the domain and year-wise authorship pattern of Robert Eric Betzig. Robert Eric Betzig has published the maximum number of works (57.66%) during the period 2011 till 2020. This is followed by 20.44% of his publications during 1991-2000 and 16.06% during 2001-2010. The maximum productivity of Robert Eric Betzig is in the field of Microscopy. The table also shows that Robert Eric Betzig's productivity has increased over time.

Table 13: Domain and Year-wise Authorship

Period	**Domain**				**Total Papers**	**%**
	A	**B**	**C**	**D**		
1981-1990	5	0	2	1	**8**	**5.84**
1991-2000	10	2	12	4	**28**	**20.44**
2001-2010	8	7	4	3	**22**	**16.06**
2010-2020	16	29	11	23	**79**	**57.66**
Total	**39**	**38**	**28**	**30**	**137**	**100**

A: Applied Physics B: Cell Biology C: Microscopy D: Molecular Biology

Table 14: Year Wise Productivity

Year	**Domain**				**Total Papers**	**%**
	A	**B**	**C**	**D**		
1981	2	0	0	0	2	1.46
1982	0	0	0	0	0	0
1983	1	0	0	0	1	0.73
1984	0	0	1	0	1	0.73
1985	2	0	0	1	3	2.19
1986	0	0	0	0	0	0

1987	0	0	0	0	0	0
1988	0	0	1	0	1	0.73
1989	0	0	0	0	0	0
1990	0	0	0	0	0	0
1991	1	0	0	0	1	0.73
1992	1	2	2	0	5	3.65
1993	0	0	5	0	5	3.65
1994	6	0	4	0	10	7.30
1995	0	0	1	1	2	1.46
1996	0	0	0	2	2	1.46
1997	0	0	0	0	0	0
1998	1	0	0	1	2	1.46
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
2003	0	0	0	0	0	0
2004	0	0	0	0	0	0
2005	7	0	0	0	7	5.11
2006	0	1	0	1	2	1.46
2007	1	0	0	1	2	1.46
2008	0	5	2	0	7	5.11
2009	0	1	1	0	2	1.46
2010	0	0	1	1	2	1.46
2011	2	1	2	1	6	4.38
2012	1	1	2	1	5	3.65
2013	1	1	0	3	5	3.65
2014	5	3	2	0	10	7.30
2015	4	11	2	0	17	12.41
2016	3	6	0	3	12	8.76
2017	0	3	3	2	8	5.84
2018	0	0	0	4	4	2.92
2019	0	3	0	6	9	6.57

2020	0	0	0	3	3	2.19

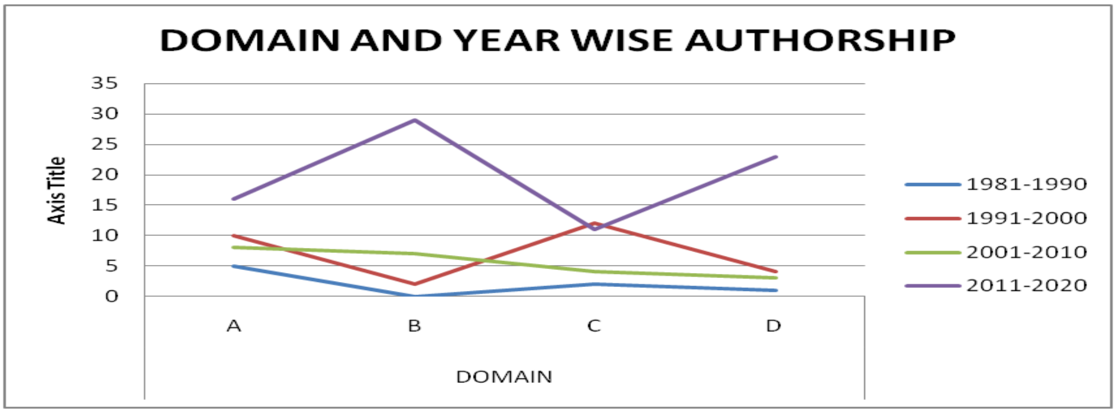


Figure 15: Year Wise Authorship

6.3.1.5 Authors' production over time of Robert Eric Betzig

The result of the analysis of the author's production over time can also be seen in Figure 16 which shows that the numbers of publications in various domains have increased over time.

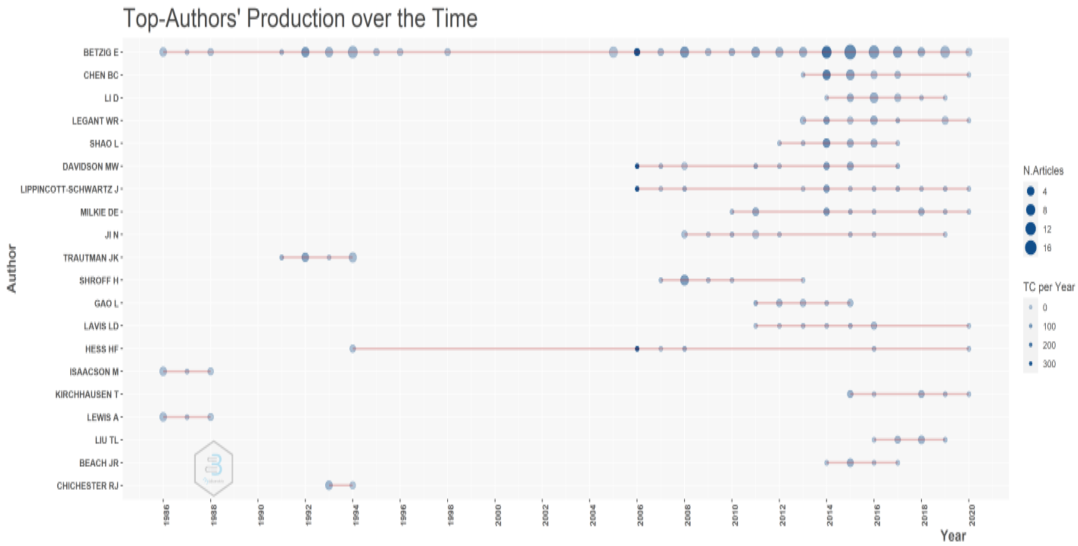


Fig 16: Authors' Production Over Time

6.3.1.6 To find out the channels of communication used by Robert Eric Betzig.

An analysis of Figure 17 shows that Robert Eric Betzig published his works in various journals. The highest number of publications has appeared in the journal *'Science'*.

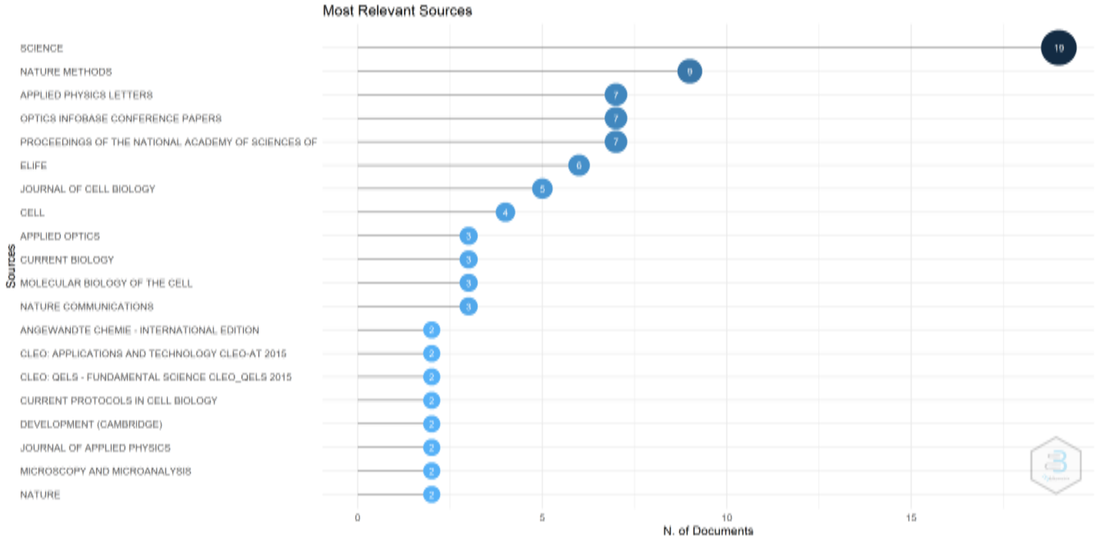


Fig 17: Most Relevant Sources

Table 15: Most Relevant Sources

Sources	**Articles**
Science	19
Nature Methods	9
Applied Physics Letters	7
Optics Infobase Conference Papers	7
Proceedings Of the National Academy of Sciences of The United States Of America	7
Elife	6
Cell	5
Journal Of Cell Biology	5
Applied Optics	3
Current Biology	3
Molecular Biology of The Cell	3
Nature Communications	3
Angewandte Chemie - International Edition	2
Cleo: Applications and Technology Cleo-At 2015	2
Cleo: Qels - Fundamental Science Cleo_Qels 2015	2
Current Protocols in Cell Biology	2
Development (Cambridge)	2
Journal Of Applied Physics	2
Microscopy And Microanalysis	2

Nature	2
Nature Cell Biology	2
Optics Letters	2
Proceedings - Annual Meeting Microscopy Society of America	2
Proceedings Of Spie - The International Society for Optical Engineering	2
Review Of Scientific Instruments	2
Ultramicroscopy	2
2007 4th Ieee International Symposium on Biomedical Imaging: From Nano to Macro - Proceedings	1
2008 Conference on Quantum Electronics and Laser Science Conference on Lasers and Electro-Optics Cleo/Qels	1
2016 Conference on Lasers and Electro-Optics Cleo 2016	1
Acs Chemical Biology	1
Aiaa Paper	1
Annals Of The New York Academy of Sciences	1
Bioimaging	1
Biophysical Journal	1
Cell Reports	1
Chemie In Unserer Zeit	1
Communications Biology	1
Conference On Optical Fiber Communication Technical Digest Series	1
Conference On Quantum Electronics and Laser Science (Qels) - Technical Digest Series	1
Current Opinion in Neurobiology	1
F1000research	1
Faseb Journal	1
Genes And Development	1
Ieee Leos Annual Meeting - Proceedings	1
Immunity	1
Journal Of Biomedical Optics	1
Molecular Cell	1
Nature Protocols	1
Neuron	1

Optics Express	1
Physical Review A - Atomic Molecular and Optical Physics	1
Plos Biology	1
Plos One	1
Proceedings - 2019 Ieee International Conference on Bioinformatics and Biomedicine Bibm 2019	1
Proceedings 2015 European Conference on Lasers and Electro-Optics - European Quantum Electronics Conference Cleo/Europe-Eqec 2015	1
Quantum Electronics and Laser Science Conference (Qels)	1
Reviews Of Modern Physics	1
Science Advances	1
Thin Solid Films	1

6.3.1.7 Author performance based on available metrics indicator (Robert Eric Betzig).

Table 16: Performance of the Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	25.21	01	i10-index (i10)	98
02	Total Citation	24415	02	h5-index (h5)	27
03	Audience Factor	21.27	03	g-Index	115
04	CiteScore (Maximum)	46.8	04	a-Index	380.11
05	ResearchGate Citations	1905	05	h(2)-index	17
06	Microsoft Academic Search Citations	35345	06	hg-index (hg)	83.76
07	Google Scholar Citations	13145	07	r-index	152.27
08	Eigenfactor	7.789	08	ar-index (ar)	429.39
09	Crown Indicator	14.928	09	k-index	0.10
10	Mean Citation Score	212.23	10	q2-index	13.31
11	Mean Normalized Citation Score (MNCS)	180.95	11	f-index	5.23
12	Mean Citation Rate Subfield (MCRS)	162.28	12	m-index	2.90

13	Scientific Talent Pool (STP)	89.82	13	m quotient (m-q)	2.90
14	Microsoft Academic Search Papers (MASP)	163	14	Contemporary-index (Ch)	1134.91
15	Google Scholar Papers (GSP)	219	15	Trendh h-index (Th)	0.14
16	Impact per Paper (IPP)	76.28	16	Dynamic h-Type index (Dh-T)	401.45
17	Citation per paper (CPP)	2.35	17	n-index	2.10
18	Citations per Paper self-citation not included (CPPex)	209.23	18	mean h-index	31
19	The average number of citations per publication (ANCP)	11.99	19	Normalized h-index	57
20	Total and the Average Number of Citations (TNCS)	24417/ 11.99	20	Specific-impact s-index (Sis)	47.35
21	Relative Activity Index (RAI)	64.19	21	Seniority independent Hirsch type index (Sih-T)	42
22	Relative Specialization index (RSI)	95.23	22	Hw-index	152.27
23	Relative Citation Rate (RCR)	85.80	23	Hm-index	20
24	Relative Database Citation Potential (RDCP)	87.85	24	Tapered h-index	0.09
25	Journal Acceptance Rate (JAR)	28.789	25	i20-index	54
26	% Self Citations (%SC)	1.34	26	v-index over h	3.44
27	Percentage of papers not cited (%Pnc)	16.06	27	e-index	139.52
28	PR Percentile Ranks (PR)	53	28	Multidimensional h-index	52
29	LogZ-score (LogZ)	12.556	29	Research Collaboration Index	97.26
30	Innovative Knowledge (IK)	56.23	30	Communities Collaboration	39.23

				Index	
31	Technological Impact (TI)	76.16	31	ch-index	72.86
32	Scientific Talent Pool (STP)	76.31	32	speed s-ICitationindex	75.5
33	Normalized position of publication journal (NPJ)	61.24	33	π-index	149.16
34	WorldCat Hold (WCH)	82	34	h5-median (h5-m)	22.5
35	Papers in Top 1 (PT1)	12	35	2nd generation citations h index	48
36	Papers in Top 10 (PT10)	25	36	Role basedh-maj-index (Rbhm)	32
37	Papers in Top 50 (PT50)	31	37	h2 lower (h2-l)	14
38	High Cited Papers (HCP)	12	38	h2-center (h2-c)	60
39	Papers in First Quartile (Q1)	21	39	h2-upper (h2-u)	108
40	Publications in Thomson Reuters indices (PWoS)	15	40	h3-index	24
41	Number of highly cited publications (NHCP)	9	41	p-index	17.62
42	Publications in top-ranked journals (PTRJ)	15	42	$\bar{h}$-index (Hbar)	61
43	Papers in Collaboration (PCol)	117	43	Mockhm-index (Mhm)	55.08
44	Share of articles coauthored with another unit (%CoA)	85.40	44	w-index	25.27
45	National Collaboration (NCol)	45	45	b-index	27.98
46	International Collaboration (ICol)	72	46	Generalizedh-index	58
47	Scientific Leadership (SL)		47	Single paperh-index	26
48	Average Authors per Paper	11.99	48	hint-index	42
49	Productivity per Paper	19.87	49	h_{rat}-index	61.98
50	RoG, CAGR, RGR and DT	1.18, (-	50	πv-index	48.39

		)0.96, 0.15, 1.05			

6.3.1.8 To analyze the scientific collaborations (Robert Eric Betzig).

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Robert Eric Betzig has collaborated with 453 different authors in the conduct and publication of his research work. The author has published only 20 single-authored documents.

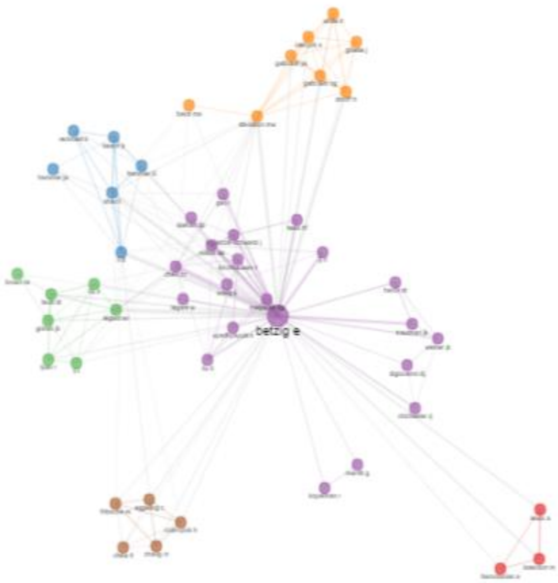


Fig 18: Collaboration Network

6.3.1.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{Total\ Authors\ in\ multi-authored\ articles}{Total\ multi-authored\ articles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Robert Eric Betzig, the collaboration index has been calculated at 3.99.

6.3.1.8.2 National and International Collaboration: Robert Eric Betzig has published his papers in collaboration with 459 authors hailing from different countries. Most of Betzig's papers have been co-authored by authors from the United Kingdom, Taiwan, and China. Figure 19 shows the collaboration worldmap of Robert Eric Betzig.

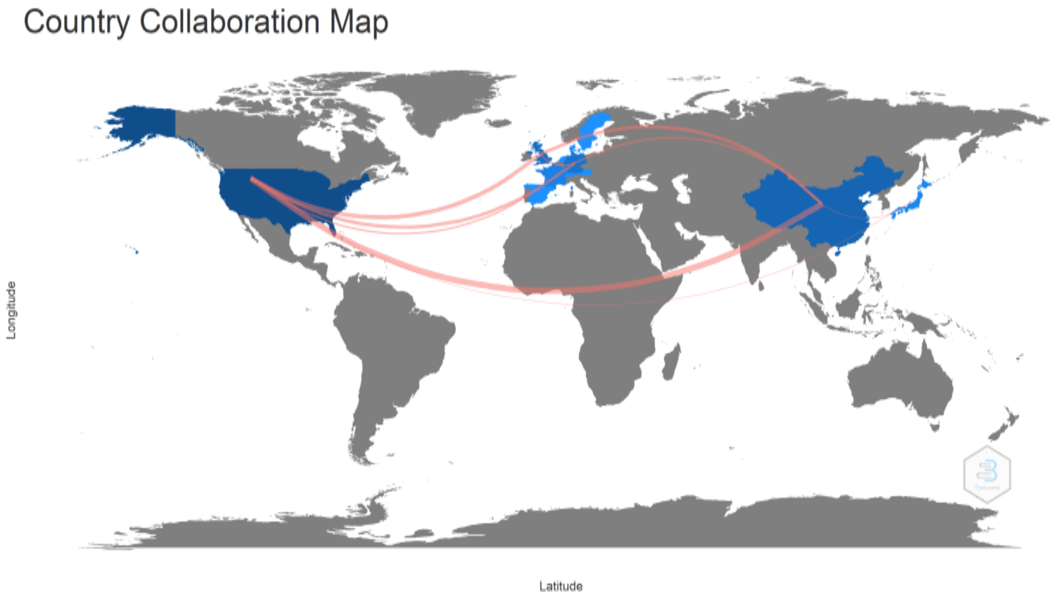


Fig 19: National and International Collaboration

An analysis of the above graph shows that Robert Eric Betzig had a strong collaboration with researchers from the United Kingdom, followed by researchers from Japan and China.

6.3.1.8.3 Co-authorship index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index $\leq$ co-authorship index. The co-authorship index of Robert Eric Betzig has been calculated at 6.87.

6.3.1.8.4 Invisible College: To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Robert Eric Betzig had close communication with 52 authors while publishing his documents.

6.3.1.9 To find out the research network of Robert Eric Betzig.

6.3.1.9.1. Co-authorship: Robert Eric Betzig had collaborated with 459 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with D Li, M W Davidson, C B Chen and W R Legant were the highest.

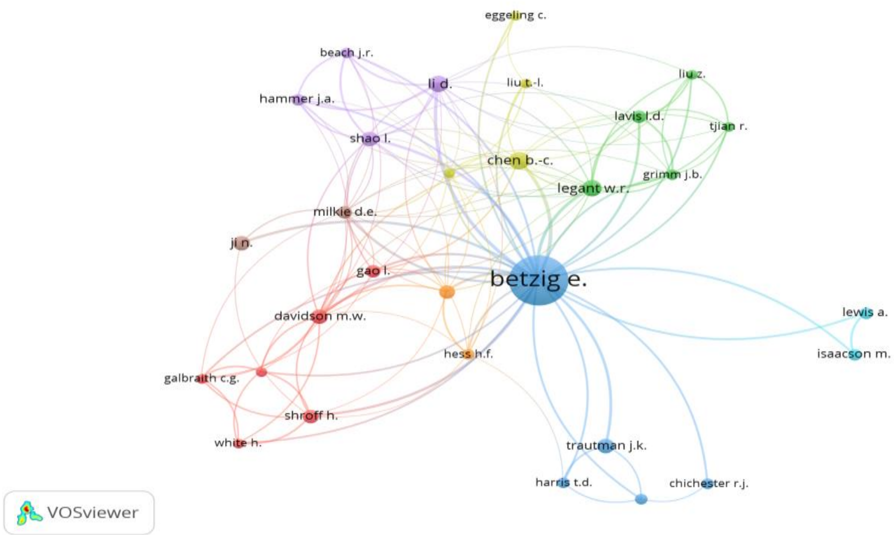


Fig 20: Co-authorship Pattern

6.3.1.9.2 Keyword Co-occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top four keywords on the decreasing order of their link strengths.

Table 17: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	62	1046
animals	48	926
priority journals	52	856
nonhuman	47	850

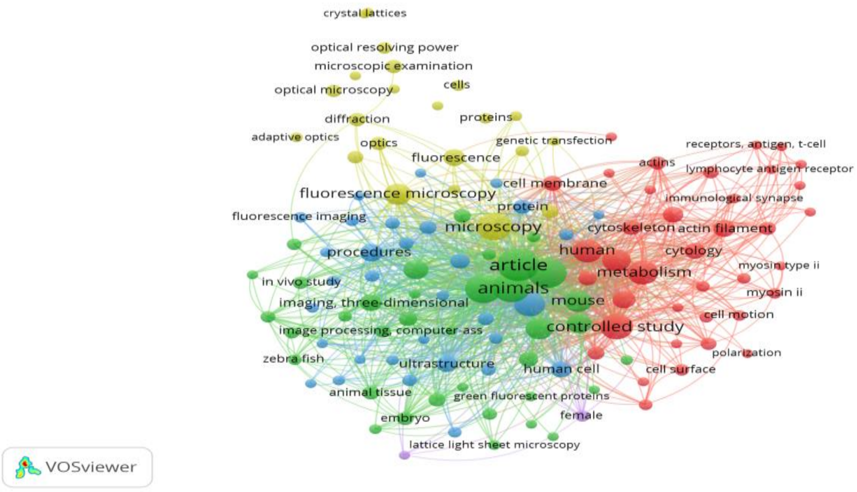


Fig 21: Keyword Co-occurrence authorship Pattern

6.3.1.9.3 Citation Analysis: Of the 137 papers published by Robert Eric Betzig, either as a single author or in collaboration, 116 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *Imaging Intracellular Fluorescent Proteins at Nanometer Resolution*, published in the journal *Science* during 2006 has been cited 5474 times followed by the article *Near Field Optics: Microscopy, Spectroscopy, and Surface Modification Beyond the Diffraction Limit* published in *Science* in 1992 received 1597 citations.

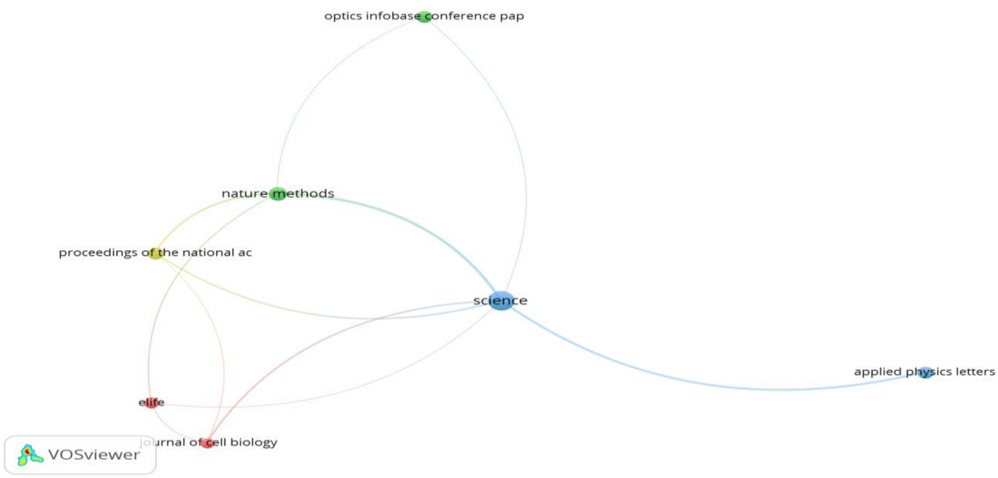


Fig 22: Citation Network

6.3.1.9.4 Bibliographic Coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Robert Eric Betzig is presented in figure 23.

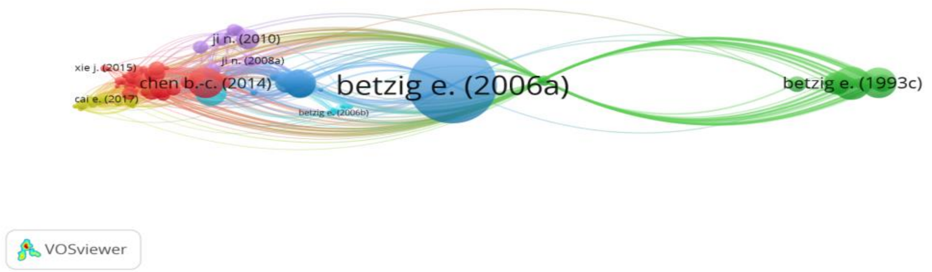


Fig 23: Bibliographic Coupling

6.3.1.9.5 Co-citation Analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme.

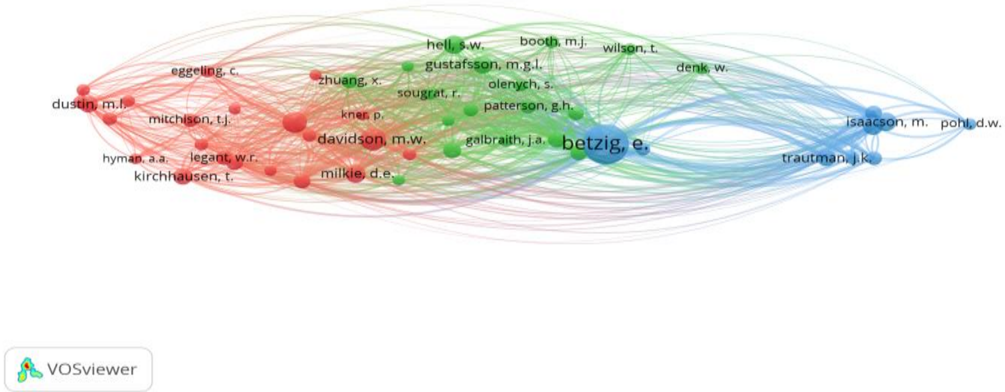


Fig 24: Co-citation Network

The co-citation network of Robert Eric Betzig is produced in Fig. 24. Analysis of the figure shows that 116 articles published by Robert Eric Betzig has been co-cited by 3 clusters. The first cluster has 22 items, second cluster has 18 items, while the third cluster has 9 items. There are a total of 890 links, with a total link strength of 26919.

6.3.1.10 Cluster Mapping

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 25 shows the coupling map of Robert Eric Betzig.

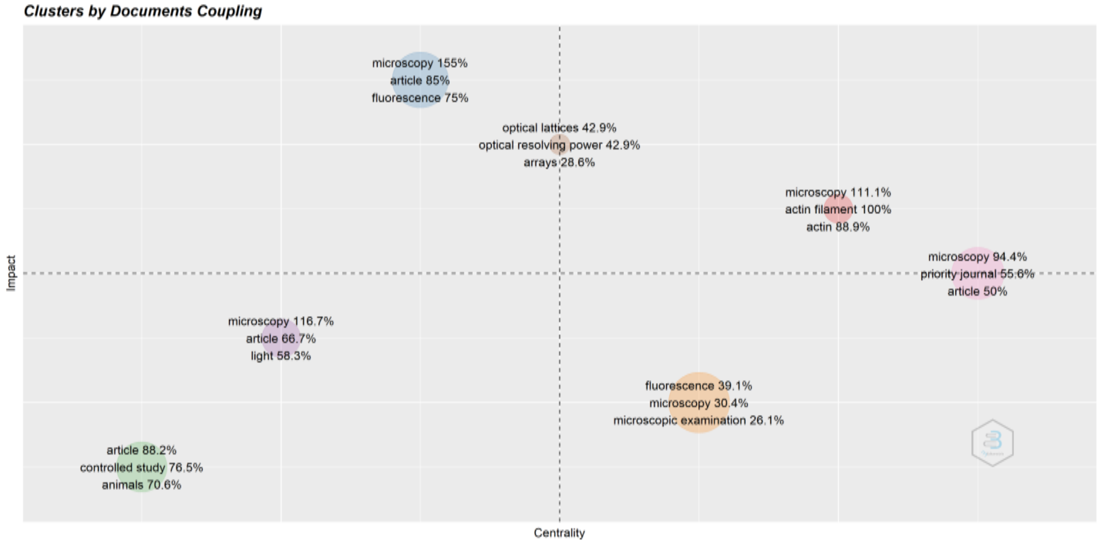


Fig 25: Document Coupling

6.3.1.11 Other Information (Robert Eric Betzig)

Table 18: Main Information

Description	**Results**
Timespan	1981:2020
Sources	
Journals, Books, Etc	59
Documents	137
Total	**196**
Average Years from Publication	13.1
Average Citations Per Documents	163.5
Average Citations Per Year Per Doc	11.99
References	3948
Document Contents	
Keywords Plus (Id)	1382
Author's Keywords (De)	98

Authors	
Authors	469
Author Appearances	941
Authors Of Single-Authored Documents	2
Authors Of Multi-Authored Documents	467
Authors Collaboration	
Single-Authored Documents	20
Documents Per Author	0.292
Authors Per Document	3.42
Co-Authors Per Documents	6.87
Collaboration Index	3.99
H-Index	61
Total Citation	24415 Citations By 16712 Documents

The publication productivity of Robert Eric Betzig was found to be consistent throughout the entire productive life and he has made outstanding contributions in the field of fluorescence microscopy. Robert Eric Betzig has been consistently active in research despite many administrative responsibilities. Robert Eric Betzig has a preference for working in collaboration and has a high degree of collaboration at institutional, national, and international levels. The high rate of citations received by his papers proves the usefulness and impact that his works have in the field of developing lithium-ion batteries. Robert Eric Betzig's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.2 STEFAN WALTER HELL

Stefan Walter Hell (dob: 23.12.1962) is a Romanian-German physicists and one of the directors of the max Plank Institute for Biophysical Chemistry in Gottigen, Germany. He is one of the recipients of the Nobel Prize in Chemistry in 2014 for the development of super-resolved fluorescence microscopy. The fields of knowledge in which Stefan Walter Hell published his works include (a) Applied Physics, (b) Biophysics, (c) Microscopy, and (d) Nanobiophotonics.

6.3.2.1 To assess the number of scientific communications contributed by Stefan Walter Hell.

Table 19: Scientific Communication

Document Types	
Article	371
Book Chapter	5
Conference Paper	43
Editorial	3
Erratum	3
Note	2
Review	13
Short Survey	5

6.3.2.2 To analyze the domain-wise scientific communication of Stefan Walter Hell.

A look into the nature of scientific communication reveals that 33.93% of his works are in the domain of nanobiophotonics followed by 24.94% in microscopy. Table 19 is the tabular form of the number of scientific communications of Stefan Walter Hell. Regarding the nature of the document, Table 20 shows that most of the papers were in the form of articles (83.37%), followed by conference papers (9.66%). With 0.67% of the total documents, editorials and erratum contribute the lowest to the list of total publications.

Table 20: Number of Scientific Communication

Document	Domain				Total Papers	%
	A	B	C	D		
Article	75	81	93	122	**371**	**83.37**
Book Chapters	0	2	3	0	**5**	**1.12**
Conference Papers	7	8	9	19	**43**	**9.66**
Editorial	1	1	0	1	**3**	**0.67**
Erratum	1	1	0	1	**3**	**0.67**
Note	1	0	0	1	**2**	**0.45**
Review	2	2	4	5	**13**	**2.92**
Short Survey	1	0	2	2	**5**	**1.12**

%	19.78	21.35	24.94	33.93	445	100

A: Applied Physics B: Biophysics C: Microscopy D: Nanobiophotonics

A graphical form of Table 20 is shown in Figure 26.

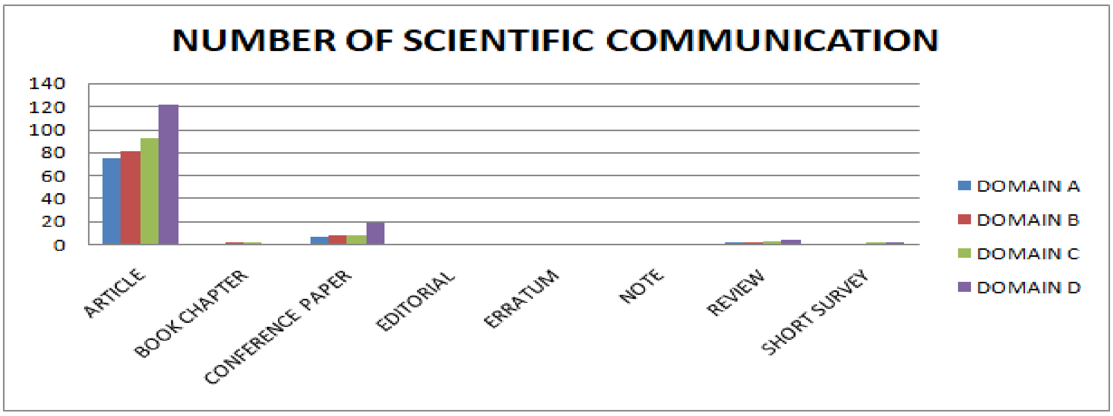


Fig 26: Number of Scientific Communication

6.3.2.3 To analyze the domain-wise authorship patterns of Stefan Walter Hell.

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Stefan Walter Hall are multi-authored having 5 to 10 authors. 28 documents representing 6.30% of the total works are single-authored, while 1 document is authored by 39 authors. Table 21 is a tabular form of the authorship pattern and Figure 27 presents a graphical view of the data.

Table 21: Domain-wise Authorship as per Collaboration

Domain	**Authors**						
	1	2	3	4 TO 10	11 TO 20	21 TO 30	39
A	2	10	12	29	35	0	0
B	3	12	30	50	0	0	0
C	10	13	08	80	0	0	0
D	13	15	12	97	8	5	1
Total	**28**	**50**	**62**	**256**	**43**	**5**	**1**
%	**6.30**	**11.24**	**13.94**	**57.53**	**9.67**	**1.13**	**0.23**

A: Applied Physics B: Biophysics C: Microscopy D: Nanobiophotonics

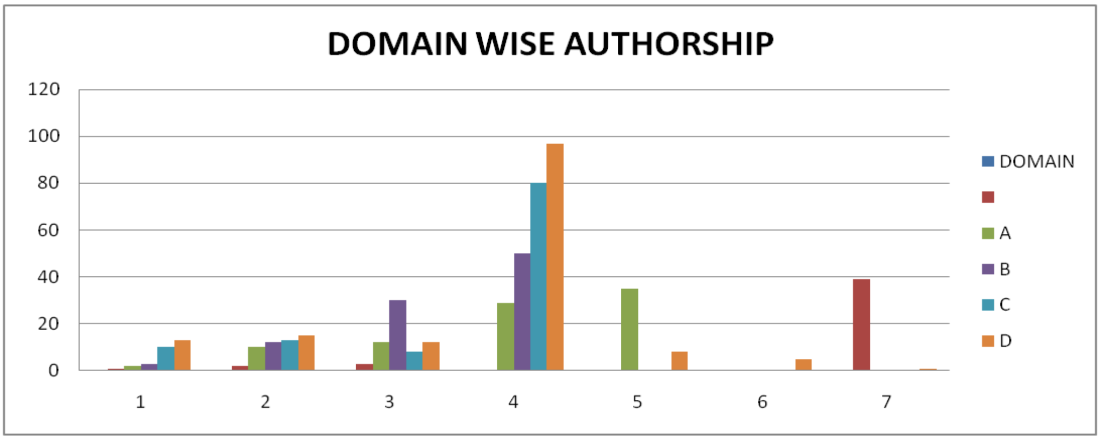


Fig 27: Domain-wise Authorship

6.3.2.4 To analyze the year-wise scientific communication of Stefan Walter Hell.

Table 22 and figure 28 show the domain and year-wise authorship pattern of Stefan Walter Hell. Stefan Walter Hell has published 445 documents on various subjects during the years 1989 till 2020. Table 23 also shows that the number of publications has continued to increase over time. This is indicative of the fact that the increase in biological age has contributed to the increase in the number of publications.

Table 22: Domain and Year-wise Authorship

Period	**Domain**				**Total Papers**	**%**
	A	**B**	**C**	**D**		
1981-1990	0	0	0	2	**2**	**0.45**
1991-2000	8	12	18	35	**73**	**16.41**
2001-2010	32	43	23	96	**194**	**43.60**
2010-2020	48	40	70	18	**176**	**39.56**
Total	**88**	**95**	**111**	**151**	**445**	**100**

A: Applied Physics B: Biophysics C: Microscopy D: Nanobiophotonics

Table 23: Year Wise Productivity

Period	**Domain**				**Total Papers**	**%**
	A	**B**	**C**	**D**		
1981	0	0	0	0	0	0
1982	0	0	0	0	0	0
1983	0	0	0	0	0	0
1984	0	0	0	0	0	0
1985	0	0	0	0	0	0
1986	0	0	0	0	0	0

1987	0	0	0	0	0	0
1988	0	0	0	0	0	0
1989	0	0	0	0	0	0
1990	0	0	0	2	2	0.45
1991	0	0	0	0	0	0
1992	0	0	0	0	0	0
1993	0	0	0	0	0	0
1994	2	3	4	1	10	2.25
1995	3	4	3	5	15	3.37
1996	1	1	4	2	8	1.80
1997	0	1	2	3	6	1.35
1998	1	2	5	5	13	2.92
1999	0	1	0	4	5	1.12
2000	1	0	0	10	11	2.47
2001	8	6	0	0	14	3.15
2002	5	8	0	0	13	2.92
2003	4	7	0	0	11	2.47
2004	3	3	0	0	6	1.35
2005	4	6	0	0	10	2.25
2006	7	13	2	0	22	4.94
2007	1	0	11	16	28	6.29
2008	0	0	10	17	27	6.07
2009	0	0	0	29	29	6.52
2010	0	0	0	31	31	6.77
2011	11	0	9	10	30	6.74
2012	8	11	0	0	19	4.27
2013	10	10	0	0	20	4.49
2014	5	12	0	0	17	3.82
2015	14	12	0	0	26	5.84
2016	0	2	12	0	14	3.15
2017	0	2	16	0	18	4.04
2018	0	0	13	0	13	2.92
2019	0	0	13	0	13	2.92

2020	0	0	0	3	3	0.67

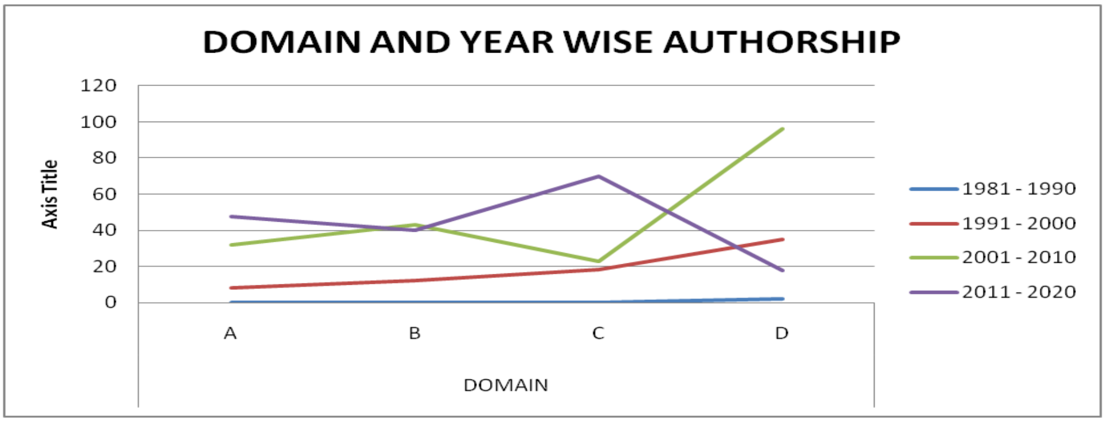


Fig 28: Domain wise and Year wise Authorship

6.3.2.5 Author production over time (Stefan Walter Hell)

The result of the analysis of the author's production over time can also be seen in Figure 29 which shows that the numbers of publications in various domains have increased over time.

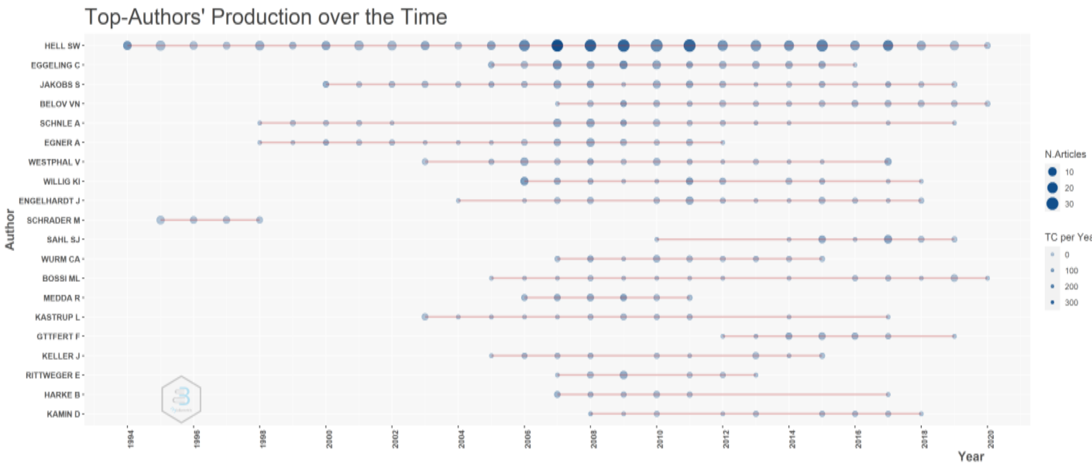


Fig 29: Authors' Production Over Time

6.3.2.6 To find out the channels of communication used by Stefan Walter Hell.

An analysis of figure 30 shows that Stefan Walter Hell published his works in various journals. The highest number of publications has appeared in the journal *'Optical Express'*.

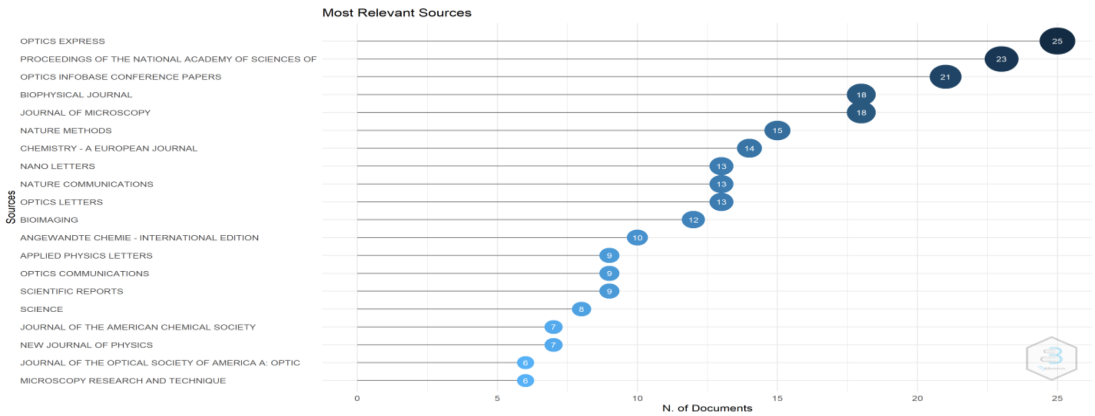


Fig 30: Most Relevant Sources

Table 24: Most Relevant Sources

Sources	Articles
Optics Express	25
Proceedings Of the National Academy of Sciences of The United States of America	25
Optics Infobase Conference Papers	21
Biophysical Journal	18
Journal Of Microscopy	18
Chemistry - A European Journal	16
Nature Methods	15
Nature Communications	14
Nano Letters	13
Optics Letters	13
Angewandte Chemie - International Edition	12
Bioimaging	12
Applied Physics Letters	9
Optics Communications	9
Scientific Reports	9
Journal Of the American Chemical Society	8
Science	8
New Journal of Physics	7
Journal Of the Optical Society of America A: Optics and Image Science and Vision	6
Microscopy Research and Technique	6

Proceedings Of Spie - The International Society for Optical Engineering	6
Applied Optics	5
Chemphyschem	5
European Journal of Organic Chemistry	5
Nature	5
Nature Biotechnology	5
Nature Photonics	5
Physical Review Letters	5
Acs Nano	4
Elife	4
Embo Journal	4
Handbook Of Biological Confocal Microscopy: Third Edition	4
Journal Of Biomedical Optics	4
Journal Of Neuroscience	4
Journal Of Structural Biology	4
Langmuir	4
Small	4
Applied Physics B: Lasers and Optics	3
Nature Neuroscience	3
Neuron	3
Plos One	3
Applied Physics A: Materials Science and Processing	2
Biochemistry	2
Cell Reports	2
Chemical Science	2
Cleo/Europe - Eqec 2009 - European Conference on Lasers And Electro-Optics And The European Quantum Electronics Conference	2
Conference Proceedings - Lasers and Electro-Optics Society Annual Meeting-Leos	2
Febs Letters	2
Journal Of Cell Science	2
Journal Of Organic Chemistry	2
Journal Of Physics D: Applied Physics	2

Nachrichten Aus Der Chemie	2
Optical Nanoscopy	2
Optics And Photonics News	2
Photochemical And Photobiological Sciences	2
Ultramicroscopy	2
2010 23rd Annual Meeting of The Ieee Photonics Society Photinics 2010	1
2011 Conference on Lasers and Electro-Optics: Laser Science to Photonic Applications Cleo 2011	1
2013 Conference on Lasers and Electro-Optics Europe and International Quantum Electronics Conference Cleo/Europe-Iqec 2013	1
Acs Chemical Biology	1
Acs Photonics	1
Advanced Materials	1
Advanced Optical Materials	1
Analytical Chemistry	1
Annalen Der Physik	1
Annalen Der Physik (Leipzig)	1
Applied Physics B Lasers and Optics	1
Beilstein Journal of Organic Chemistry	1
Bio-Optics: Design and Application Boda 2013	1
Biochemical Journal	1
Bioconjugate Chemistry	1
Biophysical Chemistry	1
Biospektrum	1
Cancer Research	1
Cardiovascular Research	1
Chemical Communications	1
Chemical Physics Letters	1
Chemie In Unserer Zeit	1
Circulation Research	1
Cleo: Applications and Technology Cleo-At 2015	1
Cleo: Qels - Fundamental Science Cleo_Qels 2015	1
Conference On Lasers and Electro-Optics Europe - Technical Digest	1

Conference On Quantum Electronics and Laser Science (Qels) - Technical Digest Series	1
Current Opinion in Neurobiology	1
Developmental Cell	1
Epl	1
European Journal of Cell Biology	1
Experimental Hematology	1
Faraday Discussions	1
Journal Of Applied Physics	1
Journal Of Biological Chemistry	1
Journal Of Biophotonics	1
Journal Of Cell Biology	1
Journal Of Modern Optics	1
Journal Of Molecular and Cellular Cardiology	1
Journal Of Physics B: Atomic Molecular and Optical Physics	1
Journal Of Physiology	1
Journal Of Quantitative Spectroscopy and Radiative Transfer	1
Macromolecules	1
Medical And Biological Engineering and Computing	1
Methods And Applications in Fluorescence	1
Microscopy And Microanalysis	1
Molecular And Cellular Biology	1
Molecular Systems Biology	1
Mutagenesis	1
Nanobiotechnology	1
Nature Physics	1
Nature Reviews Molecular Cell Biology	1
Nature Structural and Molecular Biology	1
Neuroscience	1
Optical Molecular Probes Imaging and Drug Delivery Omp 2013	1
Optical Trapping Applications Ota 2013	1
Optik (Jena)	1
Organic Letters	1

Pacific Rim Conference on Lasers and Electro-Optics Cleo - Technical Digest	1
Physical Review E - Statistical Nonlinear and Soft Matter Physics	1
Physical Review E - Statistical Physics Plasmas Fluids and Related Interdisciplinary Topics	1
Physics Letters Section A: General Atomic and Solid State Physics	1
Plant Direct	1
Plos Pathogens	1
Pmc Biophysics	1
Proceedings 2015 European Conference on Lasers and Electro-Optics - European Quantum Electronics Conference Cleo/Europe-Eqec 2015	1
Progress In Biomedical Optics and Imaging - Proceedings of Spie	1
Progress In Electromagnetics Research	1
Quarterly Reviews of Biophysics	1
Review Of Scientific Instruments	1
Reviews In Molecular Biotechnology	1
Reviews Of Modern Physics	1
Springer Handbooks	1
Springer Series in Chemical Physics	1
Technical Digest - Summaries of Papers Presented at The Quantum Electronics and Laser Science Conference Qels 2001	1
Thin Solid Films	1
Topics In Applied Physics	1
Traffic	1
Trends In Cell Biology	1

6.3.2.7 Author's performance based on available metrics indicators (Stefan Walter Hell)

Table 25: Performance of the Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	58.23	01	i10-index (i10)	348
02	Total Citation	255670	02	h5-index (h5)	42

03	Audience Factor	34.85	03	g-Index	136
04	CiteScore (Maximum)	95.8	04	a-Index	318.66
05	ResearchGate Citations	8323	05	h(2)-index	104.29
06	Microsoft Academic Search Citations	40525	06	hg-index (hg)	197.50
07	Google Scholar Citations	52	07	r-index	71.44
08	Eigenfactor	65.9	08	ar-index (ar)	18.10
09	Crown Indicator	2.803	09	k-index	39.06
10	Mean Citation Score	62.26	10	q^2-index	31.87
11	Mean Normalized Citation Score (MNCS)	87.25	11	f-index	1.55
12	Mean Citation Rate Subfield (MCRS)	62.27	12	m-index	3.65
13	Scientific Talent Pool (STP)	18.26	13	m quotient (m-q)	3.65
14	Microsoft Academic Search Papers (MASP)	119	14	Contemporary-index (Ch)	126.21
15	Google Scholar Papers (GSP)	231	15	Trendh h-index (Th)	0..38
16	Impact per Paper (IPP)	15.34	16	Dynamic h-Type index (Dh-T)	64.96
17	Citation per paper (CPP)	1.44	17	n-index	6.48
18	Citations per Paper self-citation not included (CPPex)	1.01	18	mean h-index	65.5
19	The average number of citations per publication (ANCP)	98.93	19	Normalized h-index	0.16
20	Total and the Average Number of Citations (TNCS)	255670 and 98.93	20	Specific-impact s-index (Sis)	21.08
21	Relative Activity Index (RAI)	36.29	21	Seniority independent Hirsch type index (Sih-T)	112
22	Relative Specialization index (RSI)	18.43	22	Hw-index	68.36

23	Relative Citation Rate (RCR)	25.45	23	Hm-index	54.28
24	Relative Database Citation Potential (RDCP)	19.89	24	Tapered h-index	0.45
25	Journal Acceptance Rate (JAR)	69.89	25	i20-index	313
26	% Self Citations (%SC)	52	26	v-index over h	0.15
27	Percentage of papers not cited (%Pnc)	23.4	27	e-index	185.09
28	PR Percentile Ranks (PR)	28	28	Multidimensional h-index	5
29	LogZ-score (LogZ)	26.29	29	Research Collaboration Index	26.31
30	Innovative Knowledge (IK)	15.36	30	Communities Collaboration Index	65.95
31	Technological Impact (TI)	23.39	31	ch-index	54.31
32	Scientific Talent Pool (STP)	31.67	32	speed s-iCitationndex	68.97
33	Normalized position of publication journal (NPJ)	10	33	π-index	3.65
34	WorldCat Hold (WCH)	218	34	h5-median (h5-m)	298
35	Papers in Top 1 (PT1)	73	35	2nd generation citations h index	98
36	Papers in Top 10 (PT10)	93	36	Role basedh-maj-index (Rbhm)	25
37	Papers in Top 50 (PT50)	189	37	h2 lower (h2-l)	72.35
38	High Cited Papers (HCP)	203	38	h2-center (h2-c)	230.65
39	Papers in First Quartile (Q1)	62	39	h2-upper (h2-u)	416.23
40	Publications in Thomson Reuters indices (PWoS)	25	40	h3-index	78.25
41	Number of highly cited publications (NHCP)	183	41	p-index	65.39
42	Publications in top-ranked journals (PTRJ)	195	42	$\bar{h}$-index (Hbar)	99
43	Papers in Collaboration (PCol)	417	43	Mockhm-index	29.89

				(Mhm)	
44	Share of articles coauthored with another unit (%CoA)	72	44	w-index	95.23
45	National Collaboration (NCol)	252	45	b-index	126.98
46	International Collaboration (ICol)	312	46	Generalizedh-index	96.35
47	Scientific Leadership (SL)	25.98	47	Single paperh-index	65
48	Average Authors per Paper	1.85	48	hint-index	76.85
49	Productivity per Paper	0.19	49	h_{rat}-index	95
50	RoG, CAGR, RGR and DT	0.35, (-)0.68, 0.25, 1.68	50	πv-index	68.26

6.3.2.8 Scientific collaboration of Stefan Walter Hell.

Stefan Walter Hell has collaborated with 816 different authors in the conduct and publication of his research work. The author has published only 28 single-authored documents.

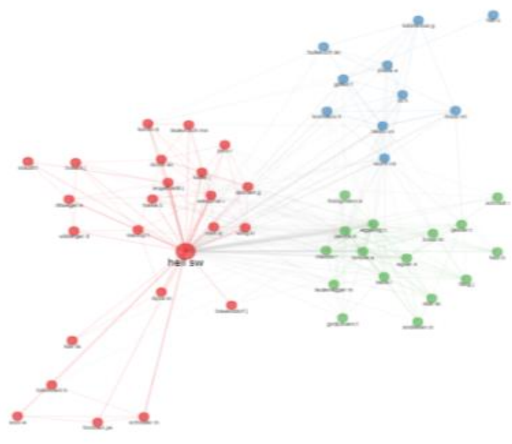


Fig 31: Collaboration Network

6.3.2.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{Total\ Authors\ in\ multi - authored\ articles}{Total\ multi - authored\ articles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Stefan Walter Hell, the collaboration index has been calculated at 1.97.

6.3.2.8.2 National and International Collaboration: Stefan Walter Hell has publis-

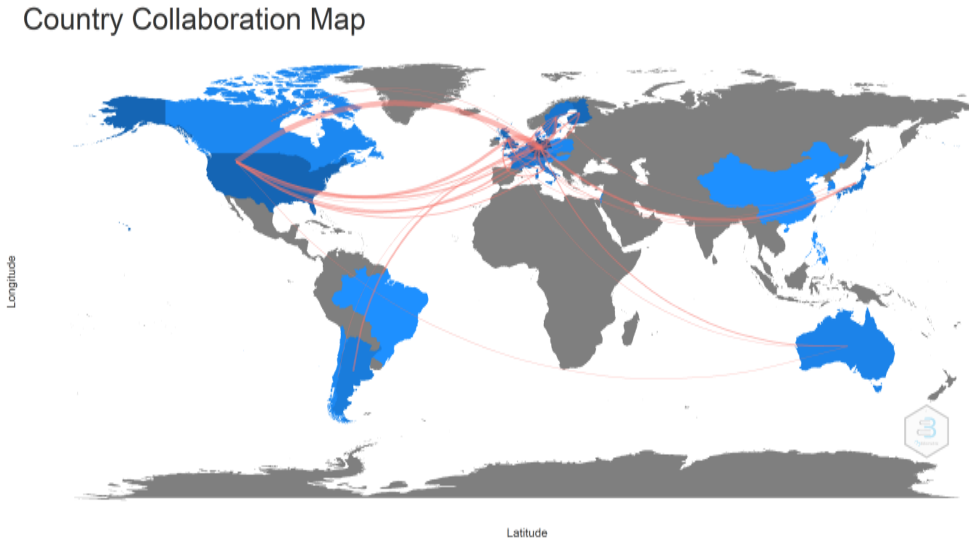


Fig. 32: National and International Collaboration

-hed his papers in collaboration with 816 co-authors hailing from different countries. Most of his papers have been co-authored by authors from Germany, the United States, the United Kingdom, and France.

6.3.2.8.3 Co-authorship index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Stefan Walter Hell has been calculated at 5.86.

6.3.2.8.4 Invisible College: Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Stefan Walter Hell had close communication with 650 authors while publishing his documents.

6.3.2.9 To find out the research network of Stefan Walter Hell.

6.3.2.9.1 Co-authorship: The co-authorship pattern of Stefan Walter Hell shows his strong linkage with 650 co-authors.

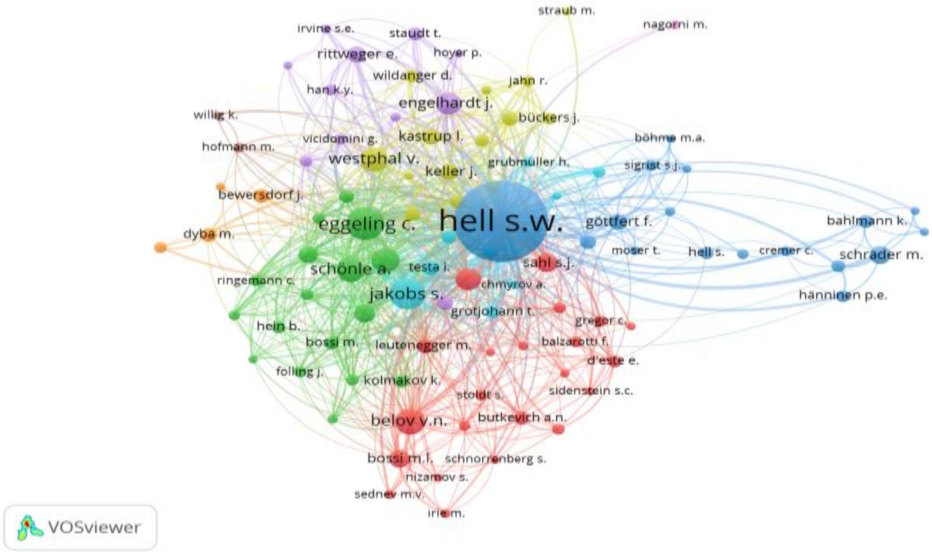


Fig 33: Co-authorship pattern of Stefan Walter Hell

6.3.2.9.2 Keyword occurrences: The four words that have occurred on numerous occasions in the documents have been tabulated below on the basis of their link strength.

Table 26: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	219	3801
mluorescence microscopy	157	2466
priority joural	127	2196
animals	100	2162

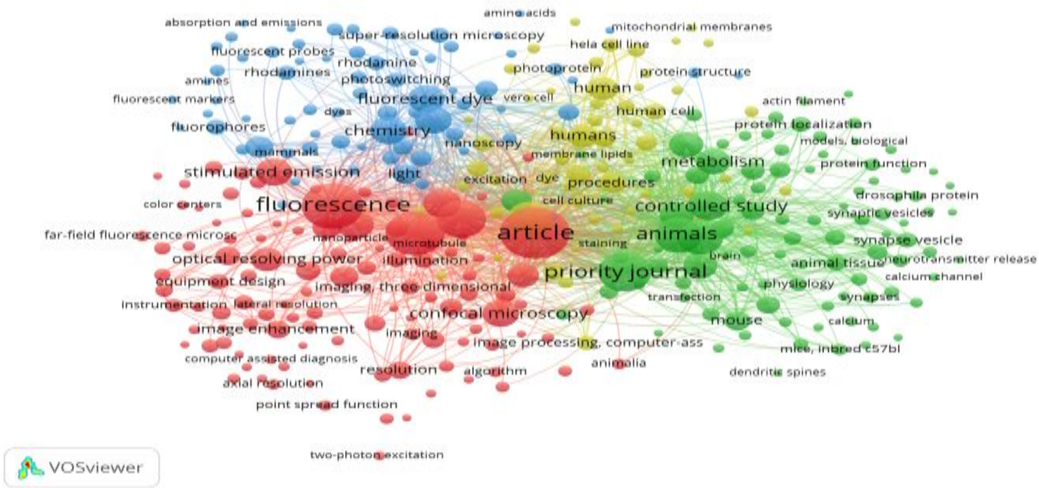


Fig 34: Keyword Co-occurrences Authorship Pattern

6.3.2.9.3 Citation Analysis: Of the 445 documents published by Stefan Walter Hell, either as a single author or in collaboration, 54 documents have not been cited, while some other documents have received very less citations.

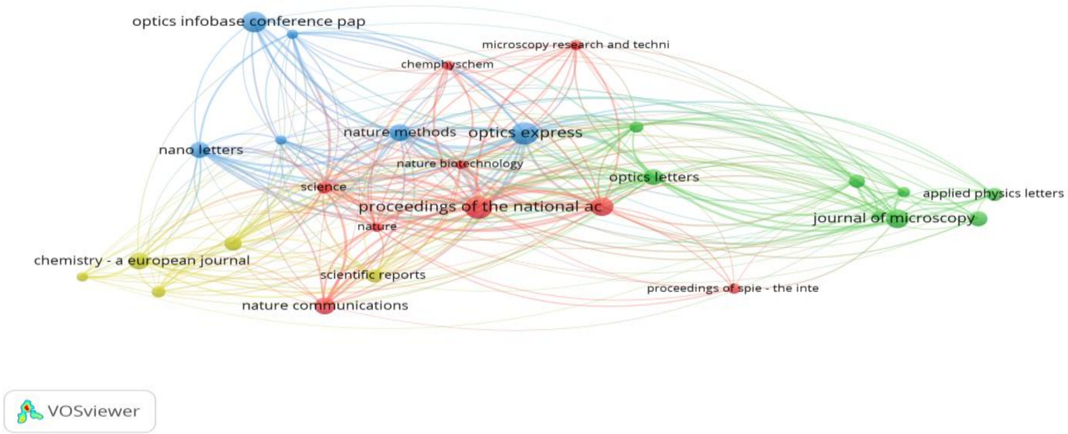


Fig. 35: Citation Analysis

6.3.2.9.4 Bibliographic Coupling: Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Stefan Walter Hell is presented in figure 36.

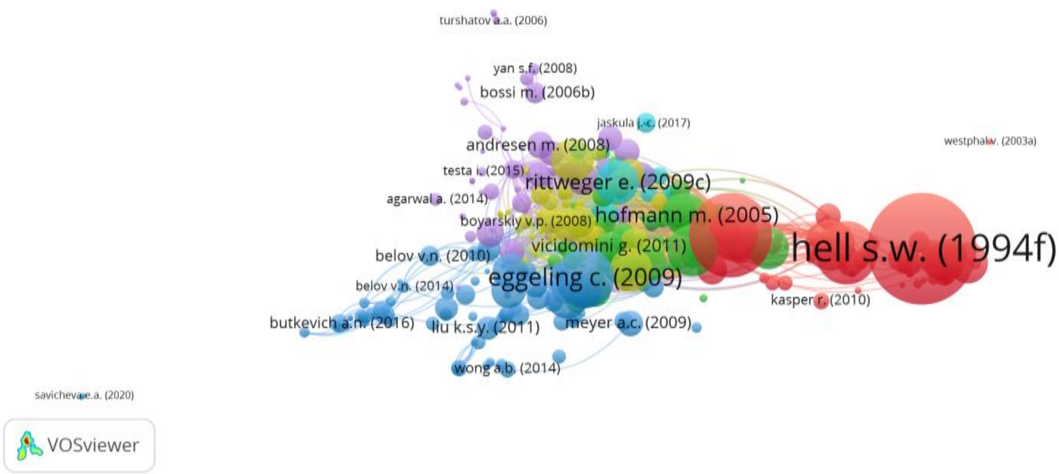


Fig 36: Bibliographic Coupling

6.3.2.9.5 Co-citation Analysis: The co-citation network of Stefan Walter Hell is produced in Fig. 37. Analysis of the figure shows that 409 articles published by Stefan Walter Hell have been co-cited by 8 clusters.

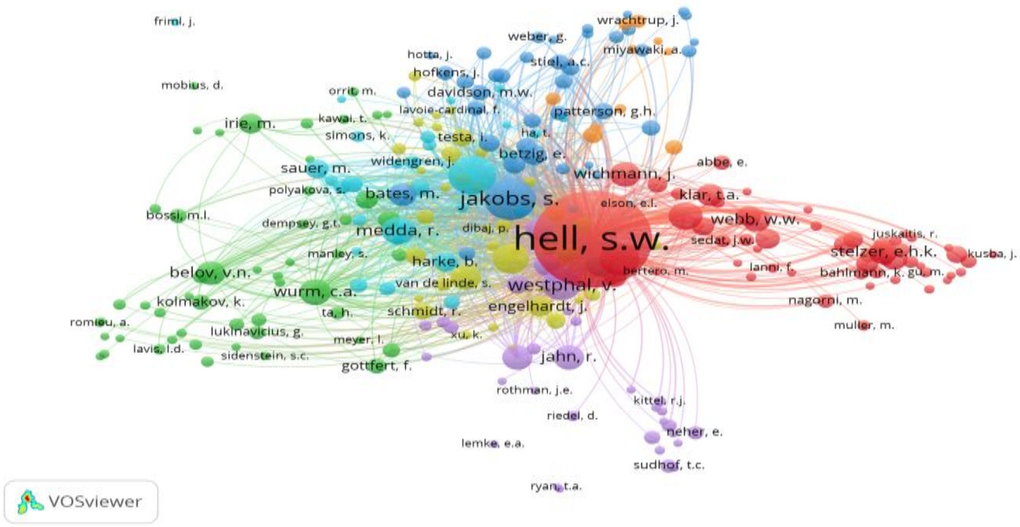


Fig 37: Co-citation Analysis

6.3.2.10 To Analyze Cluster Mapping (Stefan Walter Hell)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 38 shows the coupling map of Stefan Walter Hell.

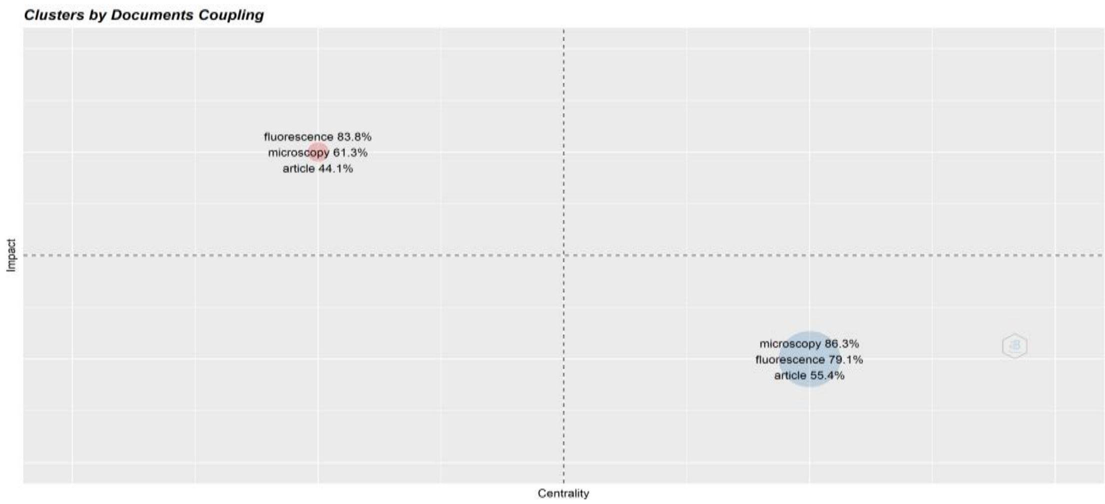


Fig 38: Document Coupling

6.3.2.11 Other Information (Stefan Walter Hell)

Table 27: Main Information

Description	**Results**
Timespan	1989:2020
Sources	

Journals, Books, Etc	131
Documents	445
Total	576
Average Years from Publication	13
Average Citations Per Documents	93.91
Average Citations Per Year Per Doc	7.005
References	10962
Document Types	
Article	371
Book Chapter	5
Conference Paper	43
Editorial	3
Erratum	3
Note	2
Review	13
Short Survey	5
Total	445
Document Contents	
Keywords Plus (Id)	2863
Author's Keywords (De)	421
Authors	
Authors	822
Author Appearances	2609
Authors Of Single-Authored Documents	2
Authors Of Multi-Authored Documents	820
Authors Collaboration	
Single-Authored Documents	28
Documents Per Author	0.541
Authors Per Document	1.85
Co-Authors Per Documents	5.86
Collaboration Index	1.97
H-Index	102
Total Citation	45131 Citations By 20306 Documents

The publication productivity of Stefan Walter Hell is consistent throughout the entire productive life, and he has made outstanding contributions in the field of chemistry and physics. Stefan Walter Hell has a preference for working in collaboration and has a high degree of collaboration at institutional, national, and international levels. Stefan Walter Hell's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.3 WILLIAM ESCO MOERNER

William Esco Moerner (dob: 24th June 1953) is an American physical chemist and chemical physicist who has experience in the field of biophysics and imaging of single molecules. William Esco Moerner is credited with being the first researcher to achieve the optical detection and spectroscopy of a single molecule in condensed particles. William Esco Moerner has published his works in the fields of (a) Applied Physics, (b) Biophysics, (c) Chemistry, and (d) Microscopy.

6.3.3.1 To assess the number of scientific communications contributed by William Esco Moerner.

Table 28: Scientific Communication

Document Types	
Article	270
Book	1
Book Chapter	4
Conference Paper	139
Editorial	2
Erratum	5
Letter	3
Note	5
Review	20
Short Survey	3

6.3.3.2 To analyze the domain-wise scientific communication of William Esco Moerner

A look into the nature of scientific communication reveals that most of his works are in the domain of chemistry followed by biophyscis, applied physics, and microscopy. Regarding the nature of the document, Table 27 shows that most of the papers were in the form of articles (59.68%, followed by conference papers (30.76%).

Table 29: Number of Scientific Communication

Document	Domain				Total Papers	%
	A	B	C	D		
Article	60	65	84	64	270	**59.68**
Book	0	0	1	0	1	**0.23**
Book Chapters	1	0	2	1	4	**0.89**
Conference Papers	37	40	28	34	139	**30.76**
Editorial	0	0	2	0	2	**0.45**
Erratum	1	0	2	2	5	**1.11**
Letter	2	1	0	0	3	**0.67**
Note	2	0	1	2	5	**1.11**
Review	5	7	6	2	20	**4.43**
Short Survey	1	1	1	0	3	**0.67**
%	**24.12**	**25.23**	**27.44**	**23.24**		

A: Applied Physics B: Biophysics C: Chemistry D: Microscopy

A graphical form of Table 27 is shown in Figure 39.

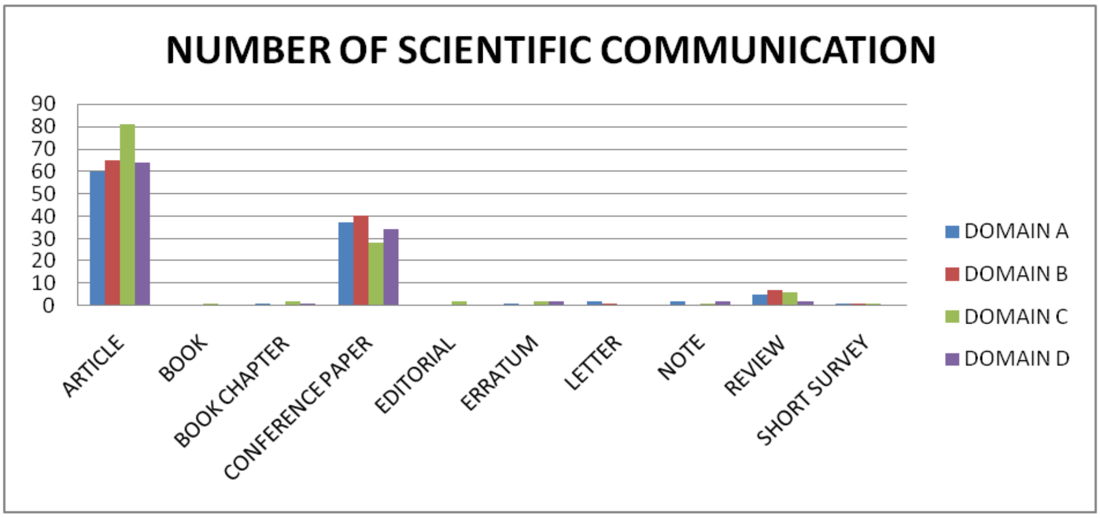


Fig 39: Number of Scientific Communication

6.3.3.3 To analyze the domain-wise authorship pattern of William Esco Moerner

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Moerner are multi-authored having 4 to 10 authored. The author has 38 single-authorted documents. Table 28 is a tabular form of the authorship pattern and Figure C.2 presents a graphical view of the data.

Table 30: Domain-wise Authorship as per Collaboration

Domain	Authors							
	1	**2**	**3**	**4 TO 10**	**11 TO 20**	**21 TO 30**	**33**	**384**
A	6	16	14	70	3	2	1	0
B	11	15	18	63	3	0	0	0
C	10	17	21	75	3	0	0	0
D	11	16	15	60	0	1	0	1
Total	**38**	**64**	**68**	**268**	**9**	**3**	**1**	**1**
%	**8.41**	**14.16**	**15.05**	**59.30**	**2.00**	**0.67**	**0.23**	**0.23**

A: Applied Physics B: Biophysics C: Chemistry D: Microscopy

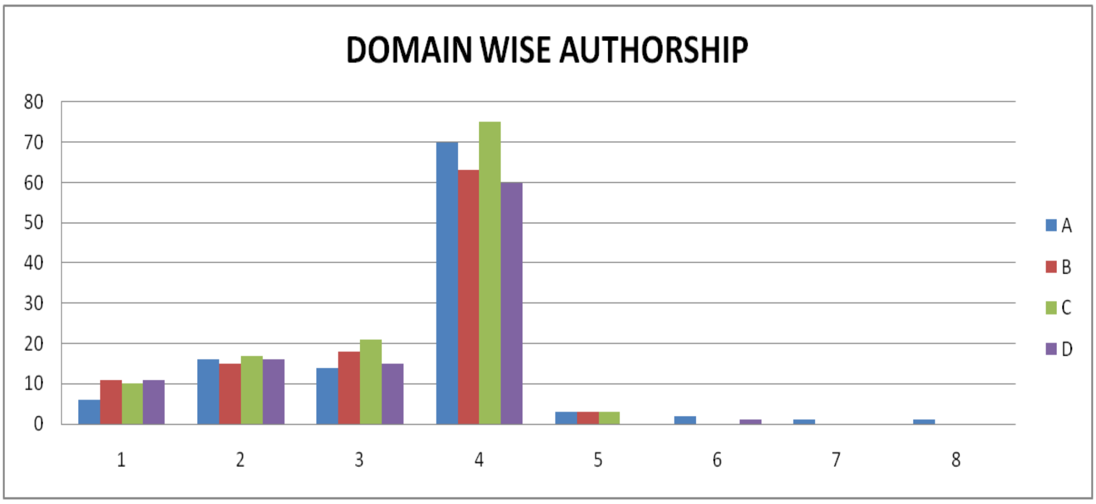


Fig 40: Domain-wise Authorship

6.3.3.4 To analyze the year-wise scientific communication of William Esco Moerner

Table 31 and figure 41 show the domain and year-wise authorship pattern of Moerner. William Esco Moerner has published 3 documents on applied physics during the years 1971 till 1980. This represents 0.67% of his total publications. Table 32 also shows that the number of publications has continued to increase. This is indicative of the fact that the increase in biological age has contributed to the increase in the number of publications. The maximum number of documents published by is during the period 2001 till 2010 when the author has published 33.19% of his total publication.

Table 31: Domain and Year-wise Authorship

Period	Domain				Total Papers	%
	A	B	C	D		
1971-1980	3	0	0	0	**3**	**0.67**
1981-1990	11	35	0	9	**55**	**12.17**
1991-2000	45	8	50	6	**109**	**24.12**
2001-2010	35	63	35	17	**150**	**33.19**
2011-2020	18	4	41	72	**135**	**29.85**
TOTAL	**112**	**110**	**126**	**104**	**452**	**100**

A: Applied Physics B: Biophysics C: Chemistry D: Microscopy

Table 32: Year-Wise Productivity

Year	Domain				Total Papers	%
	A	B	C	D		
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	3	0	0	0	3	0.66
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	0	0	0	0
1979	0	0	0	0	0	0
1980	0	0	0	0	0	0
1981	3	0	0	0	3	0.66
1982	3	0	0	0	3	0.66
1983	3	3	0	0	6	1.33
1984	2	7	0	0	9	1.99
1985	0	7	0	0	7	1.55
1986	0	3	0	0	3	0.66
1987	0	8	0	0	8	1.77

1988	0	3	0	0	3	0.66
1989	0	4	0	2	6	1.33
1990	0	0	0	7	7	1.55
1991	9	0	0	0	9	1.99
1992	8	0	0	0	8	1.77
1993	13	0	0	0	13	2.88
1994	15	0	0	0	22	4.87
1995	0	6	0	0	6	1.33
1996	0	2	7	0	9	1.99
1997	0	0	12	0	12	2.65
1998	0	0	13	0	13	2.88
1999	0	0	0	8	8	1.77
2000	0	0	0	8	8	1.77
2001	8	0	0	0	8	1.77
2002	12	0	0	0	12	2.65
2003	15	1	0	0	16	3.54
2004	0	13	0	0	13	2.88
2005	0	17	0	0	17	3.76
2006	0	11	0	0	11	2.43
2007	0	20	1	0	21	4.64
2008	0	0	10	0	10	2.21
2009	0	0	15	6	21	4.65
2010	0	0	9	9	18	3.98
2011	18	1	0	0	19	4.20
2012	0	1	14	0	15	3.32
2013	0	1	14	0	15	3.32
2014	0	1	13	6	20	4.24
2015	0	0	0	22	22	4.87
2016	0	0	0	6	6	1.33
2017	0	0	0	8	8	1.77
2018	0	0	0	7	7	1.55
2019	0	0	0	10	10	2.21
2020	0	0	0	9	9	1.99

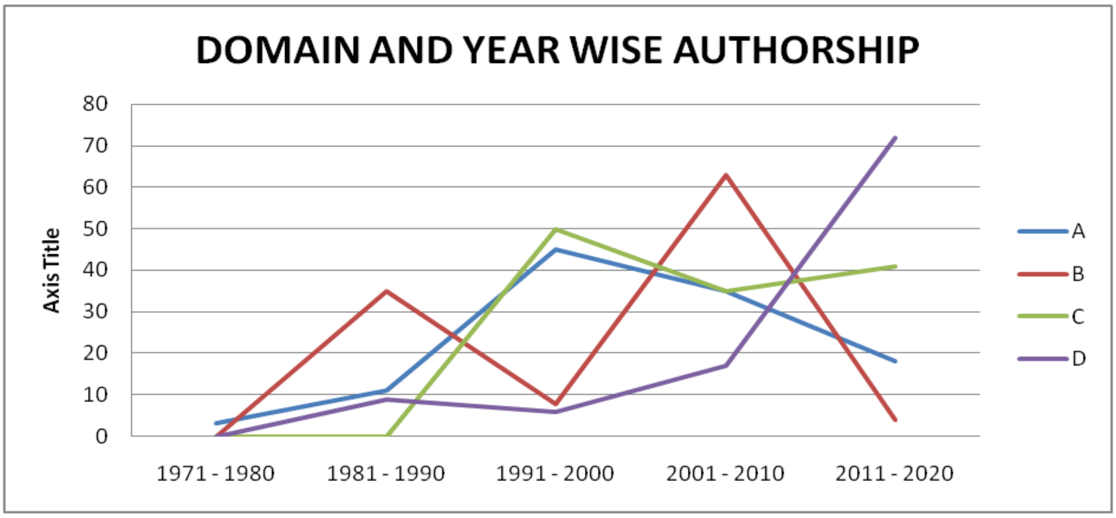


Fig 41: Domain wise and Year wise Authorship

6.3.3.5 Author's production over time (William Esco Moerner)

The result of the analysis of the author's production over time can also be seen in Figure 42 which shows that the numbers of publications in various domains have increased over time.

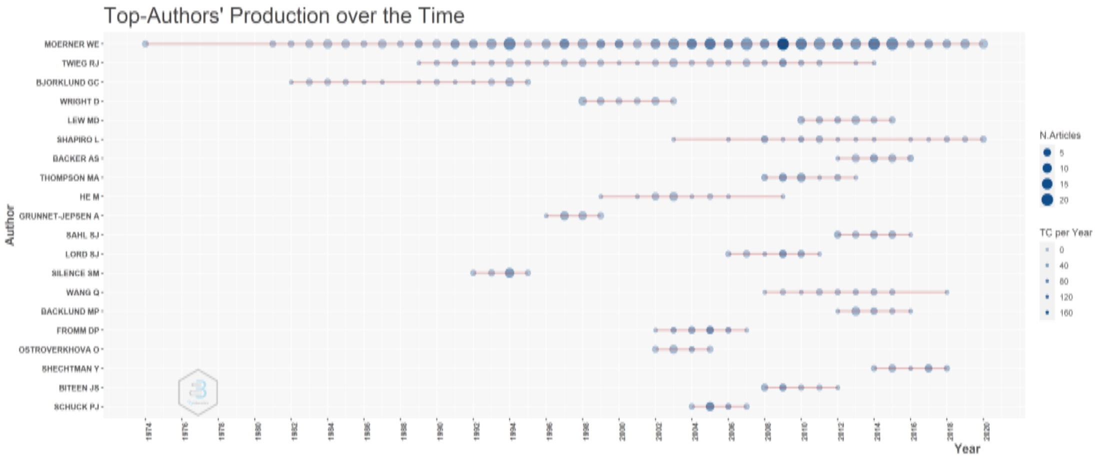


Fig 42: Authors' Production Over Time

6.3.3.6 To find out the channels of communication used by William Esco Moerner

An analysis of Figure 43 shows that Prof. William Esco Moerner published his works in various journals. The highest number of publications has appeared in the journal *'Optics Infobase Conference Paperes'*.

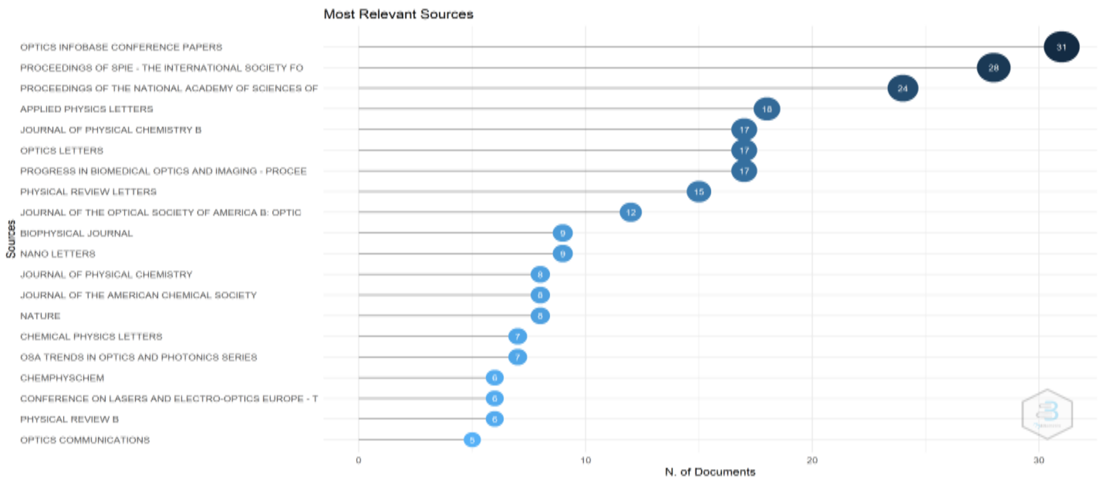


Fig 43: Most Relevant Sources

Table 33: Most Relevant Sources

Sources	**Articles**
Optics Infobase Conference Papers	31
Proceedings Of Spie - The International Society for Optical Engineering	28
Proceedings Of the National Academy of Sciences of The United States of America	27
Applied Physics Letters	18
Journal Of Physical Chemistry B	17
Optics Letters	17
Progress In Biomedical Optics and Imaging - Proceedings of Spie	17
Physical Review Letters	15
Journal Of the Optical Society of America B: Optical Physics	12
Nano Letters	10
Biophysical Journal	9
Journal Of the American Chemical Society	9
Journal Of Physical Chemistry	8
Nature	8
Chemical Physics Letters	7
Osa Trends in Optics and Photonics Series	7
Chemphyschem	6
Conference On Lasers and Electro-Optics Europe - Technical Digest	6
Physical Review B	6
Optics Communications	5

Science	5
Chemical Physics	4
Faraday Discussions	4
Journal Of Luminescence	4
Nature Communications	4
Nature Photonics	4
Optics Express	4
Accounts Of Chemical Research	3
Analytical Chemistry	3
Angewandte Chemie - International Edition	3
Chemical Reviews	3
Chemistry Of Materials	3
Conference Proceedings - Lasers and Electro-Optics Society Annual Meeting-Leos	3
Journal Of Chemical Physics	3
Journal Of Physical Chemistry A	3
Molecular Biology of The Cell	3
Nature Methods	3
Proceedings Of the International Quantum Electronics Conference (Iqec'94)	3
Single-Molecule Optical Detection Imaging and Spectroscopy	3
Single Molecules	3
2009 Conference on Lasers and Electro-Optics And 2009 Conference on Quantum Electronics and Laser Science Conference Cleo/Qels 2009	2
Acs Nano	2
Adaptive Optics: Analysis Methods and Systems Ao 2015	2
American Chemical Society Polymer Preprints Division of Polymer Chemistry	2
Annual Review of Physical Chemistry	2
Biomedical Optics Express	2
Cell	2
Chemical Science	2
Cleo: Science and Innovations Cleo-Si 2015	2

Conference On Quantum Electronics and Laser Science (Qels) - Technical Digest Series	2
Lasers And Electro-Optics/Quantum Electronics and Laser Science Conference: 2010 Laser Science to Photonic Applications Cleo/Qels 2010	2
Macromolecules	2
Materials Research Society Symposium - Proceedings	2
Methods In Molecular Biology	2
Molecular Crystals and Liquid Crystals Science and Technology Section B: Nonlinear Optics	2
Optica	2
Physical Review E - Statistical Nonlinear and Soft Matter Physics	2
Springer Series in Chemical Physics	2
Synthetic Metals	2
Tetrahedron Letters	2
The Journal of Chemical Physics	2
Xvii International Conference on Quantum Electronics. Digest Of	2
2008 Conference on Quantum Electronics and Laser Science Conference on Lasers and Electro-Optics Cleo/Qels	1
2013 Conference on Lasers and Electro-Optics Cleo 2013	1
2016 Conference on Lasers and Electro-Optics Cleo 2016	1
2017 Conference on Lasers and Electro-Optics Cleo 2017 - Proceedings	1
Acs Chemical Biology	1
Advanced Functional Materials	1
Advanced Materials	1
Advances In Atomic Molecular and Optical Physics	1
Angewandte Chemie International Edition in English	1
Annual Review of Biophysics	1
Annual Review of Materials Science	1
Applied Magnetic Resonance	1
Applied Optics	1
Applied Physics B Photophysics and Laser Chemistry	1
Applied Physics B: Lasers and Optics	1
Chemie In Unserer Zeit	1

Chemistry And Biology	1
Cleo: Applications and Technology Cleo-At 2015	1
Cleo: Qels - Fundamental Science Cleo_Qels 2015	1
Cleo: Science and Innovations Cleo_Si 2013	1
Cold Spring Harbor Perspectives in Biology	1
Conference Proceedings - Lasers and Electro-Optics Society Annual Meeting	1
Current Opinion in Structural Biology	1
Current Protocols in Cell Biology	1
Cytometry	1
Developmental Cell	1
Epj Web Of Conferences	1
Frontiers In Optics Fio 2014	1
Ieee Journal of Quantum Electronics	1
Iqec International Quantum Electronics Conference Proceedings	1
Japanese Journal of Applied Physics	1
Journal Of Applied Physics	1
Journal Of Bacteriology	1
Journal Of Microscopy	1
Journal Of Molecular Biology	1
Journal Of Organic Chemistry	1
Journal Of Physical Chemistry Letters	1
Journal Of Physics D: Applied Physics	1
Materials Science and Engineering B	1
Methods In Enzymology	1
Molecular Cell	1
Molecular Crystals and Liquid Crystals Science and Technology Section A: Molecular Crystals and Liquid Crystals	1
Nature Cell Biology	1
Nature Chemistry	1
Nature Microbiology	1
Nature Reviews Microbiology	1
Nature Structural Biology	1

New Journal of Physics	1
Nonlinear Optics Nlo 2015	1
Nonlinear Optics Quantum Optics	1
Novel Techniques in Microscopy Ntm 2015	1
Optical Materials	1
Optics And Photonics News	1
Photonics Spectra	1
Physical Review A - Atomic Molecular and Optical Physics	1
Physical Review B - Condensed Matter and Materials Physics	1
Physics And Chemistry at Low Temperatures	1
Plos One	1
Progress In Crystal Growth and Characterization of Materials	1
Pure And Applied Chemistry	1
Quantum Electronics and Laser Science Conference (Qels)	1
Quarterly Reviews of Biophysics	1
Review Of Scientific Instruments	1
Reviews Of Modern Physics	1
Scientific Reports	1
Sensors And Actuators B: Chemical	1
Small	1
Springer Series in Optical Sciences	1
Technical Digest - European Quantum Electronics Conference	1
Tetrahedron	1
Trac - Trends in Analytical Chemistry	1

6.3.3.7 Author's performance based on available metrics indicators (William Esco Moerner)

Table 34: Performance of the Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	76.86	01	i10-index (i10)	266
02	Total Citation	29150	02	h5-index (h5)	21
03	Audience Factor	182	03	g-Index	144

04	CiteScore (Maximum)	57.8	04	a-Index	216.03
05	ResearchGate Citations	5	05	h(2)-index	16
06	Microsoft Academic Search Citations	14590	06	hg-index (hg)	105.98
07	Google Scholar Citations	22350	07	r-index	129.81
08	Eigenfactor	5.78	08	ar-index (ar)	337
09	Crown Indicator	6.28	09	k-index	0.06
10	Mean Citation Score	71.19	10	q^2-index	17.02
11	Mean Normalized Citation Score (MNCS)	35.32	11	f-index	1.77
12	Mean Citation Rate Subfield (MCRS)	25.03	12	m-index	3.71
13	Scientific Talent Pool (STP)	19.36	13	m quotient (m-q)	3.71
14	Microsoft Academic Search Papers (MASP)	219	14	Contemporary-index (Ch)	420.78
15	Google Scholar Papers (GSP)	326	15	Trendh h-index (Th)	0.11
16	Impact per Paper (IPP)	17.25	16	Dynamic h-Type index (Dh-T)	59
17	Citation per paper (CPP)	2.32	17	n-index	3.90
18	Citations per Paper self-citation not included (CPPex)	66.20	18	mean h-index	41.50
19	The average number of citations per publication (ANCP)	3.74	19	Normalized h-index	52.17
20	Total and the Average Number of Citations (TNCS)	29150 and 3.74	20	Specific-impact s-index (Sis)	46.12
21	Relative Activity Index (RAI)	39.85	21	Seniority independent Hirsch type index (Sih-T)	5
22	Relative Specialization index (RSI)	16.91	22	Hw-index	129.81
23	Relative Citation Rate (RCR)	35.07	23	Hm-index	26
24	Relative Database Citation	25.01	24	Tapered h-index	0.12

	Potential (RDCP)				
25	Journal Acceptance Rate (JAR)	38.27	25	i20-index	221
26	% Self Citations (%SC)	99.73	26	v-index over h	3.44
27	Percentage of papers not cited (%Pnc)	24.06	27	e-index	103.76
28	PR Percentile Ranks (PR)	52.36	28	Multidimensional h-index	49.97
29	LogZ-score (LogZ)	13.67	29	Research Collaboration Index	39.14
30	Innovative Knowledge (IK)	26.94	30	Communities Collaboration Index	52.03
31	Technological Impact (TI)	38.93	31	ch-index	16.78
32	Scientific Talent Pool (STP)	19.30	32	speed s-iCitationndex	55.26
33	Normalized position of publication journal (NPJ)	27.07	33	π-index	70.15
34	WorldCat Hold (WCH)	55	34	h5-median (h5-m)	8
35	Papers in Top 1 (PT1)	3	35	2nd generation citations h index	62
36	Papers in Top 10 (PT10)	7	36	Role basedh-maj-index (Rbhm)	25.08
37	Papers in Top 50 (PT50)	17	37	h2 lower (h2-l)	17
38	High Cited Papers (HCP)	2	38	h2-center (h2-c)	79
39	Papers in First Quartile (Q1)	8	39	h2-upper (h2-u)	159
40	Publications in Thomson Reuters indices (PWoS)	0	40	h3-index	55.54
41	Number of highly cited publications (NHCP)	181	41	p-index	59.58
42	Publications in top-ranked journals (PTRJ)	204	42	$\bar{h}$-index (Hbar)	78
43	Papers in Collaboration (PCol)	414	43	Mockhm-index (Mhm)	37.36
44	Share of articles coauthored with	91.59	44	w-index	16.96

	another unit (%CoA)				
45	National Collaboration (NCol)	217	45	b-index	21.20
46	International Collaboration (ICol)	235	46	Generalizedh-index	59.19
47	Scientific Leadership (SL)	11.25	47	Single paperh-index	53
48	Average Authors per Paper	5.6	48	hint-index	89.28
49	Productivity per Paper	0.33	49	h_{rat}-index	78.99
50	RoG, CAGR, RGR and DT	0.34, (-)0.89, 0.12, 1.36	50	πv-index	12.05

6.3.3.8 To assess the scientific collaboration of William Esco Moerner

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works.

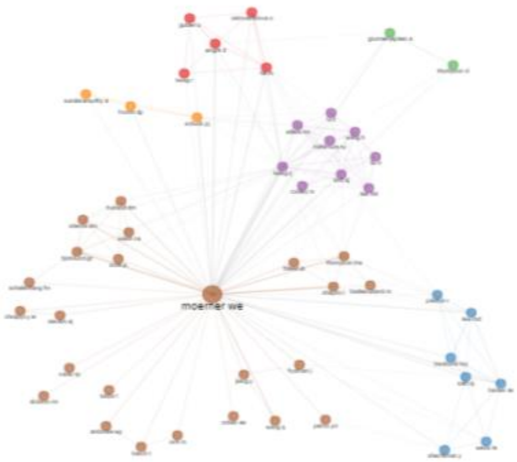


Fig 44: Collaboration Network

In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. William Esco Moerner has collaborated with 924 different authors in the conduct and publication of his research work. The author has published only 38 single-authored documents.

6.3.3.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{Total\ Authors\ in\ multi-authored\ articles}{Total\ multi-authored\ articles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of William Esco Moerner, the collaboration index has been calculated at 2.22.

6.3.3.8.2 National and International Collaboration: William Esco Moerner has published most of his papers in collaboration with co-authors from the United States, Germany, France, and Switzerland. The collaboration map of William Esco Moerner is produced in figure 45.

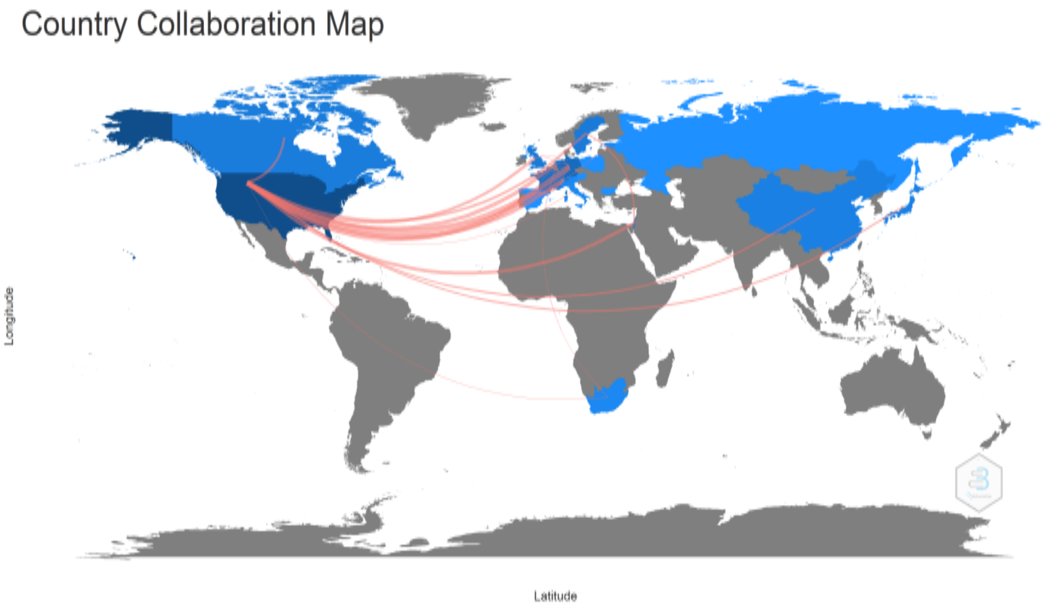


Fig. 45: National and International Collaboration

6.3.3.8.3 Co-authorship index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of William Esco Moerner has been calculated at 3.74.

6.3.3.8.4 Invisible College: Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Yoshino had close communication with 924 authors while publishing his documents.

6.3.3.9 To find out the research network of William Esco Moerner

6.3.3.9.1 Co-authorship: William Esco Moerner had collaborated with 924 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with R J Twieg, M He, and S J Lord were the highest. A graphical representation of the co-authorship pattern is shown in figure 46 below.

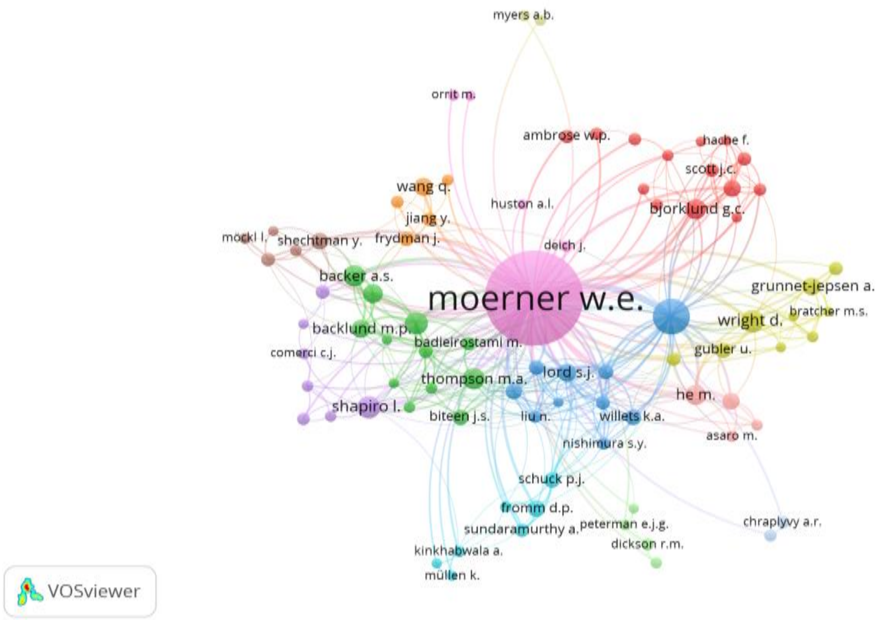
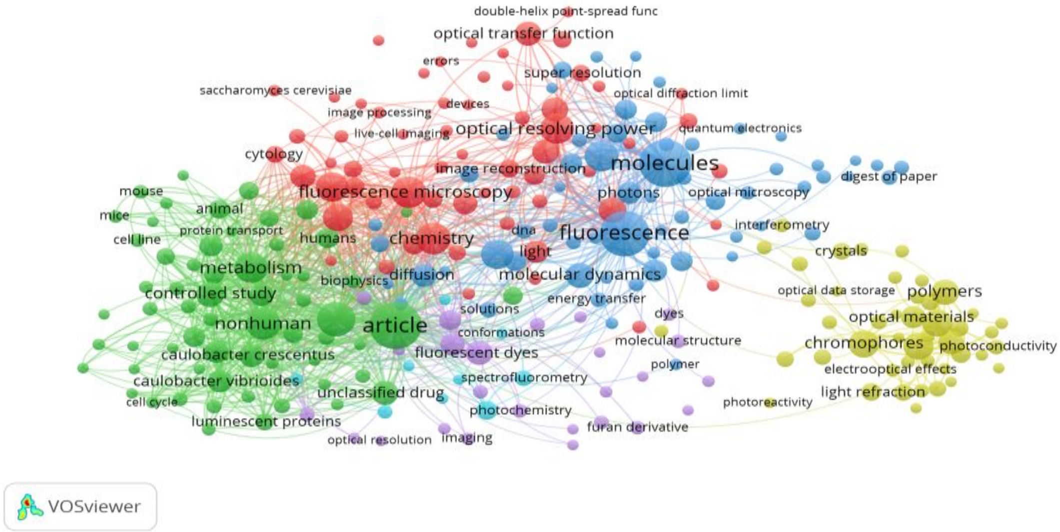


Fig. 46: Co-authorship pattern of William Esco Moerner

6.3.3.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top four keywords on the decreasing order of their link strengths.

Table 35: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	95	1301
nonhuman	44	773
fluorescence	86	766
priority journal	53	756



Fig, 47: Co-occurrence of Keywords

6.3.3.9.3 Citation analysis: Of the 452 papers published by William Esco Moerner, either as a single author or in collaboration, 344 have been cited by other researchers in their papers.

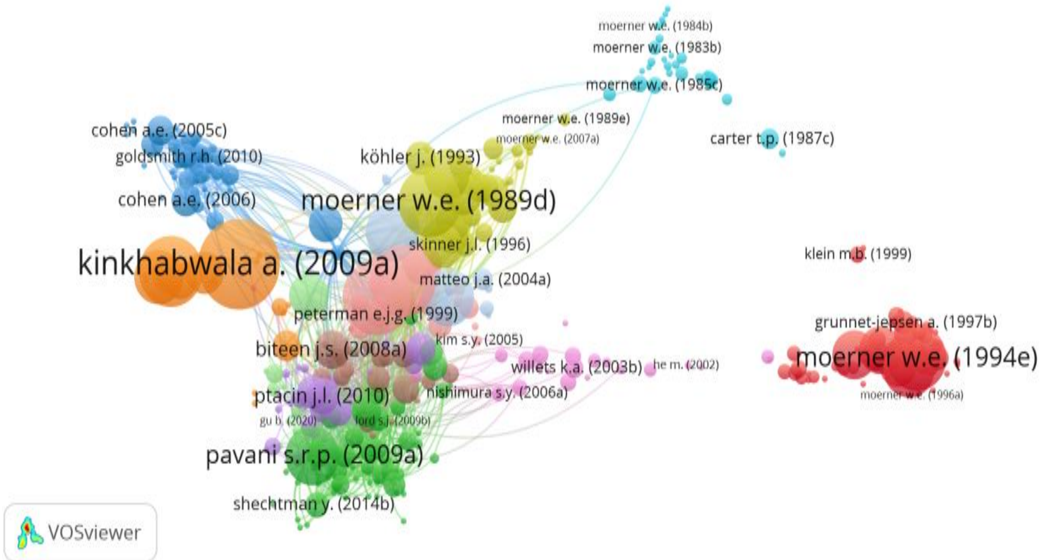


Fig. 48: Citation Analysis

6.3.3.9.4 Bibliographic coupling: Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Prof. William Esco Moerner is presented in figure 49.

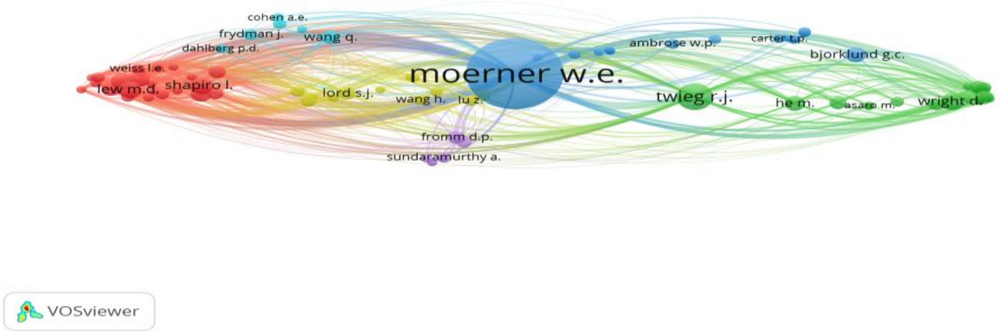


Fig. 49: Bibliographic Coupling

6.3.3.9.5 Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of William Esco Moerner is produced in Fig. 50. Analysis of the figure shows that the articles published by Moerner has been co-cited by 5 clusters, having 41837 links, with a total link strength of 1531791.

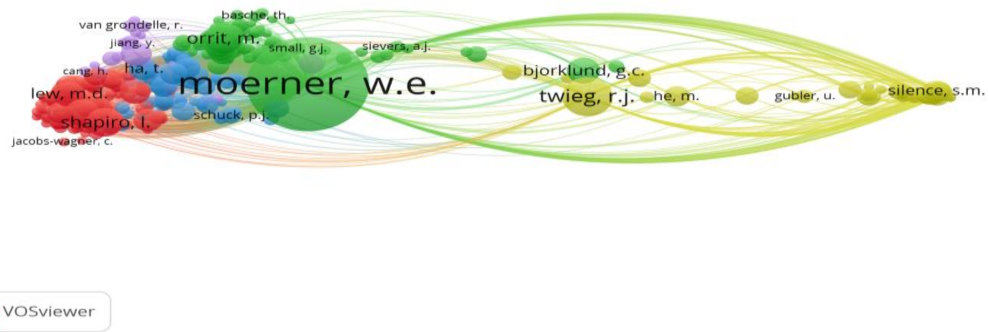


Fig. 50: Co-citation Analysis Pattern

6.3.3.10 To analyze cluster mapping (William Esco Moerner)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 51 shows the coupling map of William Esco Moerner.

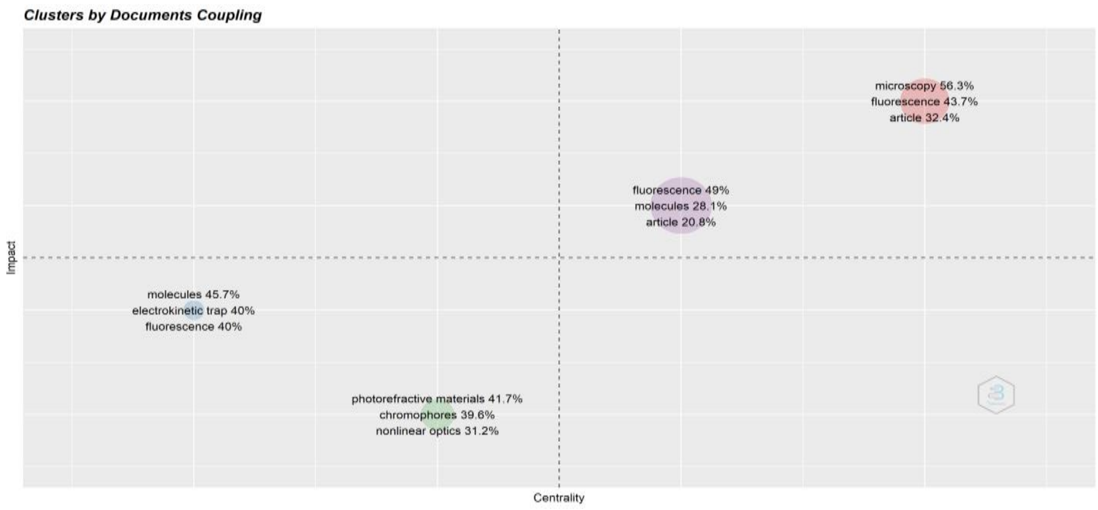


Fig 51: Document Coupling

6.3.3.11 Other information (William Esco Moerner)

Table 36: Main Information

Description	**Results**
Timespan	1974:2015
Sources	
Journals, Books, Etc	132
Documents	452
Total	584
Average Years from Publication	17.6
Average Citations Per Documents	61.72
Average Citations Per Year Per Doc	3.74
References	10525
Document Types	
Article	270
Book	1
Book Chapter	4
Conference Paper	139
Editorial	2
Erratum	5
Letter	3
Note	5
Review	20

Short Survey	3
Total	452
Document Contents	
Keywords Plus (Id)	2560
Author's Keywords (De)	295
Authors	
Authors	92
Author Appearances	2533
Authors Of Single-Authored Documents	2
Authors Of Multi-Authored Documents	919
Authors Collaboration	
Single-Authored Documents	38
Documents Per Author	0.491
Authors Per Document	2.04
Co-Authors Per Documents	5.6
Collaboration Index	2.22
H-Index	78

The publication productivity of William Esco Moerner is consistent throughout the entire productive life and he has made outstanding contributions in the field of Microscopy. Moerner has been consistently active in research despite many administrative responsibilities. He has preferred to work in collaboration and has a high degree of collaboration at institutional, national, and international levels. William Esco Moerner has an h-index of 78 and is regarded as one of the most successful scientists in the field of chemistry. William Esco Moerner's research efforts have largely been concentrated on developing microscopy which proves his strength in this field. William Esco Moerner's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

2015

The Chemistry Nobel Prize for 2015 was jointly awarded to three researchers for *mechanistic studies of DNA repair*. The award was shared by Paul L Modrich, Aziz Sancar, and Tomas Lindahl.

6.3.4 PAUL LAWRENCE MODRICH

Paul Lawrence Modrich (dob: 13^{th} June 1946) is an American biochemist who is also the James B. Duke Professor of Biochemistry at Duke University and Investigator at the Howard Hughes Medical Institute. Modrich is known for research on DNA mismatch repair. Paul L Modrich was one of the recipients of the Nobel Prize for Chemistry for 2015 with Aziz Sancar and Tomas Lindahl.

6.3.4.1 To assess the number of scientific communications contributed by Paul Lawrence Modrich.

The works of Paul L. Modrich has been in the form of articles, books, editorials, conference papers, editorials, erratum, letters, reviews, and short surveys. Table 37shows the number of such scientific communications contributed by the scientist.

Table 37: Scientific Communication

Document Types	
Article	170
Conference Papers	3
Erratum	1
Review	11
Short Survey	3

6.3.4.2 To analyze the domain-wise scientific communication of Paul Lawrence Modrich.

Among the different domains in which he has published his works include biochemistry, DNA Mismatch, DNA Repair, and microbiology. Table 38 shows the total number of documents published by Paul L Modrich in all documents. An analysis of the table shows that most of his studies are in the field of biochemistry followed by DNA repair. Among the documents, the maximum numbers of papers are in the form of articles, followed by reviews. Some of his research works have also been published in the form of conference papers, erratum and short survey.

Table 38: Number of Scientific Communication

Documents	Domain				Total Papers	%
	A	B	C	D		
Article	56	33	39	42	**170**	**90.43**
Conference Paper	1	0	1	1	**3**	**1.60**
Erratum	1	0	0	0	**1**	**0.53**
Review	2	5	4	0	**11**	**5.85**
Short Survey	1	0	2	0	**3**	**1.60**
Total	**61**	**38**	**46**	**43**	**188**	**100**
%	**32.45**	**20.21**	**24.47**	**22.87**		

A: Biochemistry B: DNA Mismatch C: DNA Repair D: Microbiology

A graphical representation of the above data can be observed in Figure 52 below.

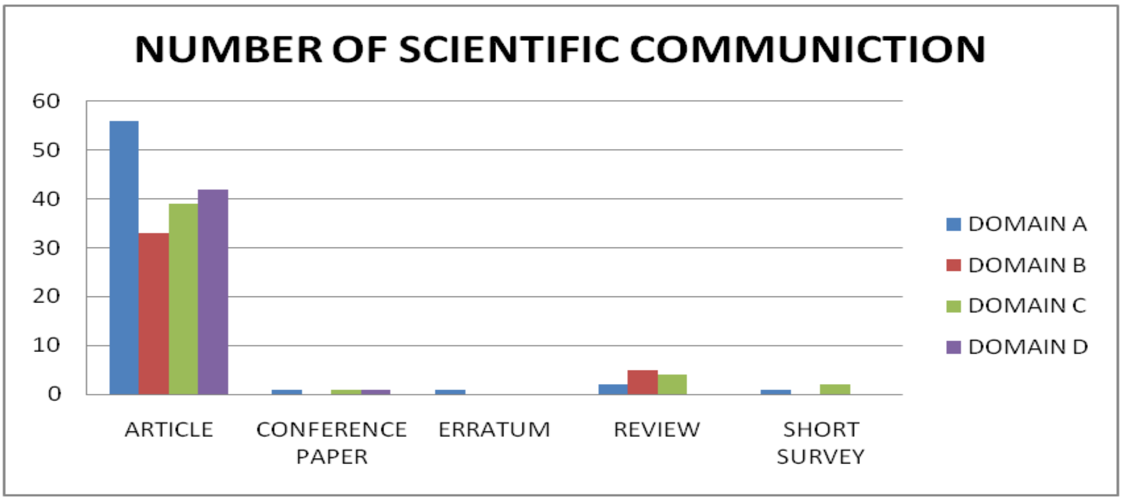


Fig 52: Number of Scientific Communication

6.3.4.3 To analyze the domain-wise authorship pattern of Paul Lawrence Modrich.

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Paul L Modrich are multi-authored having more than 3 authors. He has very few single authored publications with the percentage of such publications standing at 7.45%. The author has contributed with 21 co-authors for publication of his scientific communications. Table 39 is a tabular form of the authorship pattern and figure 53 presents a graphical view of the data.

Table 40 shows the domain-wise authorship pattern of Paul L Modrich. Modrich has authored 14 single-authored documents which represent 7.45% of his total publications. However, most of his publications have 5 to 10 authors. Paul L

Modrich has co-authored with a maximum of 21 authors for a single publication. A graphical view of the above information is provided in figure 53.

Table 39: Domain-wise Authorship as per Collaboration

Domain	Authors					
	1 - Author	2 - Author	3 - Author	4 - Author	5 – 10 Author	11 – 21 Author
A	2	10	18	12	19	0
B	4	6	7	4	11	6
C	6	13	8	6	10	3
D	2	5	8	5	18	5
Total	**14**	**34**	**41**	**27**	**58**	**14**
%	**7.45**	**18.09**	**21.81**	**14.36**	**30.85**	**7.45**

A: Biochemistry B: DNA Mismatch C: DNA Repair D: Microbiology

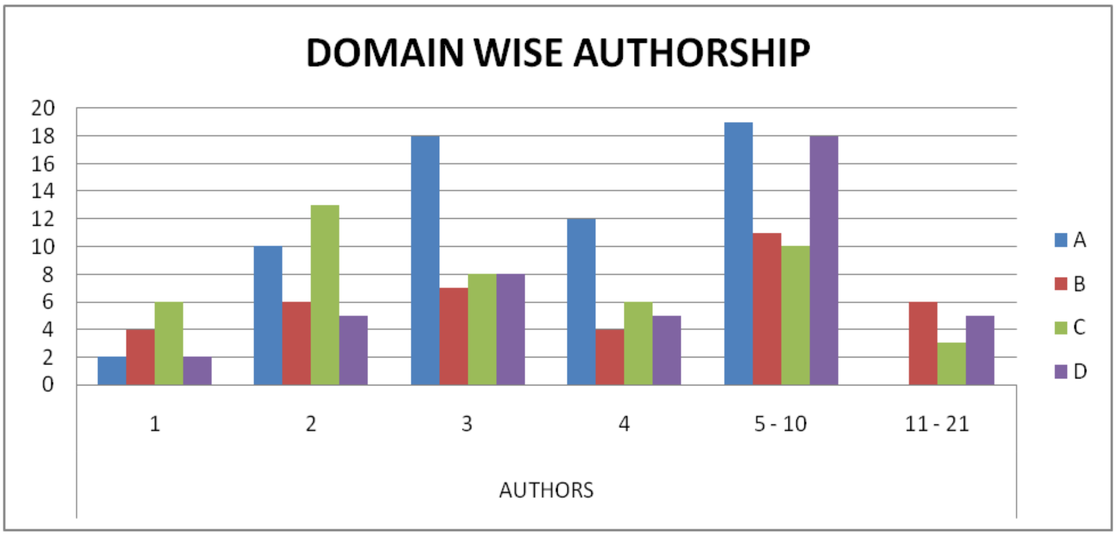


Fig 53: Domain-wise Authorship

6.3.4.4 To analyze the year-wise scientific communication of Paul Lawrence Modrich.

Paul Lawrence Modrich's publication life began in 1970, or when he had attained a biological age of 24 years. A look into his year-wise productivity reveals that the author has published the maximum number of works from 1991 till 2000 when he had published 61 papers in all domains at 32.45%. During the first 10 years of his productive life, Modrich has published 22 papers (11.70%) which is the lowest number of works published by the author. A tabular form of this information is provided in Table 40, while a graphical representation is given in figure 54.

Table 40: Domain and Year-wise Authorship

Year	Domain				Total Papers	%
	A	B	C	D		
1970-1980	8	3	6	5	**22**	**11.70**
1981-1990	13	4	20	9	**46**	**24.47**
1991-2000	16	21	10	14	**61**	**32.45**
2001-2010	18	7	6	14	**45**	**23.94**
2011-2020	6	3	4	1	**14**	**7.45**
Total	**61**	**38**	**46**	**43**	**188**	

A: Biochemistry B: DNA Mismatch C: DNA Repair D: Microbiology

Table 41: Year-wise Productivity

Period	Domain				Total Papers	%
	A	B	C	D		
1970	1	0	0	0	1	0.53
1971	1	0	0	0	1	0.53
1972	1	0	0	0	1	0.53
1973	1	2	0	0	3	1.59
1974	1	0	0	0	1	0.53
1975	1	0	0	0	2	1.06
1976	1	1	0	0	2	1.06
1977	1	1	0	0	2	1.06
1978	0	1	0	0	1	0.53
1979	0	3	0	0	3	1.59
1980	0	0	0	4	4	2.13
1981	7	0	0	0	7	3.72
1982	4	0	0	0	4	2.13
1983	2	4	1	0	7	3.72
1984	0	0	2	0	2	1.06
1985	0	0	3	0	3	1.59
1986	0	0	2	0	2	1.06
1987	0	0	5	0	5	2.66
1988	0	0	5	0	5	2.66
1989	0	0	2	5	7	3.72

1990	0	0	0	2	2	1.06
1991	1	0	0	0	1	0.53
1992	1	0	0	0	1	0.53
1993	9	0	0	0	9	4.79
1994	3	0	0	0	3	1.59
1995	2	6	0	0	8	4.26
1996	0	8	0	0	8	4.26
1997	0	7	3	0	10	5.32
1998	0	0	7	3	10	5.32
1999	0	0	0	7	7	3.72
2000	0	0	0	4	4	2.13
2001	5	0	0	0	5	2.66
2002	2	0	0	0	2	1.06
2003	4	0	0	0	4	2.13
2004	5	0	0	0	5	2.66
2005	2	3	0	0	5	2.66
2006	0	4	4	0	8	4.26
2007	0	0	2	1	3	1.59
2008	0	0	0	4	4	2.13
2009	0	0	0	4	4	2.13
2010	0	0	0	5	5	2.66
2011	4	0	0	0	4	2.13
2012	0	0	0	0	0	0
2013	2	0	0	0	2	1.06
2014	0	2	0	0	2	1.06
2015	0	1	0	0	1	0.53
2016	0	0	2	0	2	1.06
2017	0	0	1	0	1	0.53
2018	0	0	1	0	1	0.53
2019	0	0	0	0	0	0
2020	0	0	0	1	1	0.53

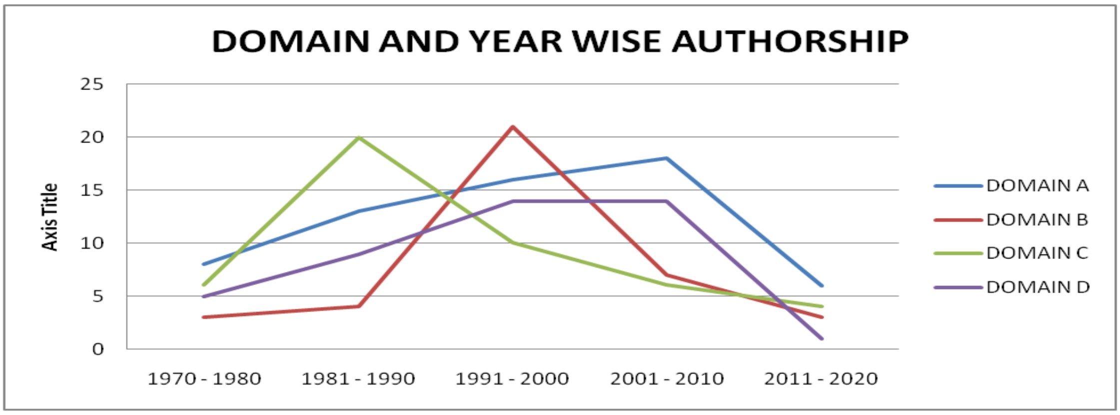


Fig 54: Domain wise and Year wise Authorship.

6.3.4.5 Author's production over time (Paul Lawrence Modrich)

The year-wise authorship pattern of Paul Lawrence Modrich is shown in Figure 55.

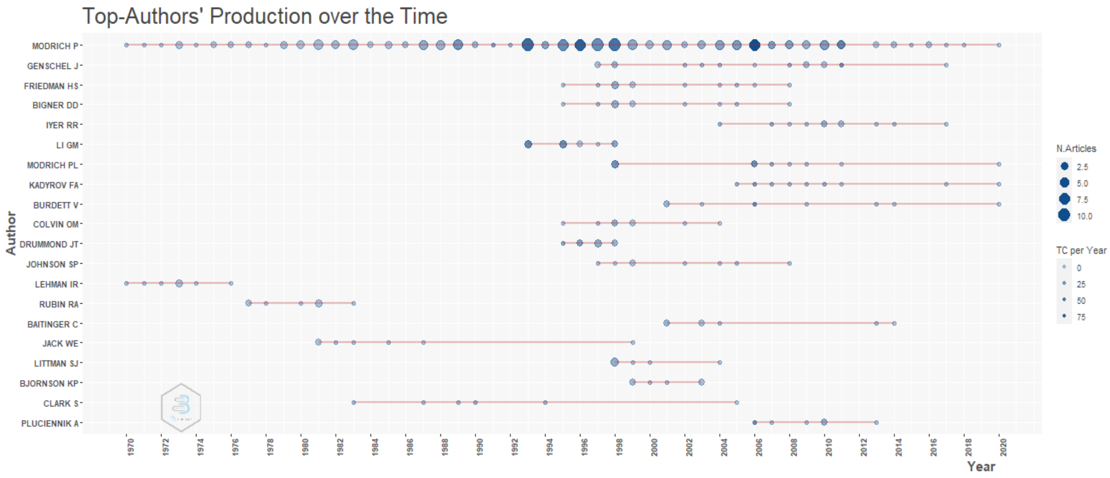


Fig 55: Authors' Production Over Time

6.3.4.6 To find out the channels of communication used by Paul Lawrence Modrich.

Paul Lawrence Modrich has published his works in various journals. Figure 56 is a graphical representation of the data, which indicates that the maximum number of papers (70) have appeared in the journal *'Journal of Biological Chemistry.*

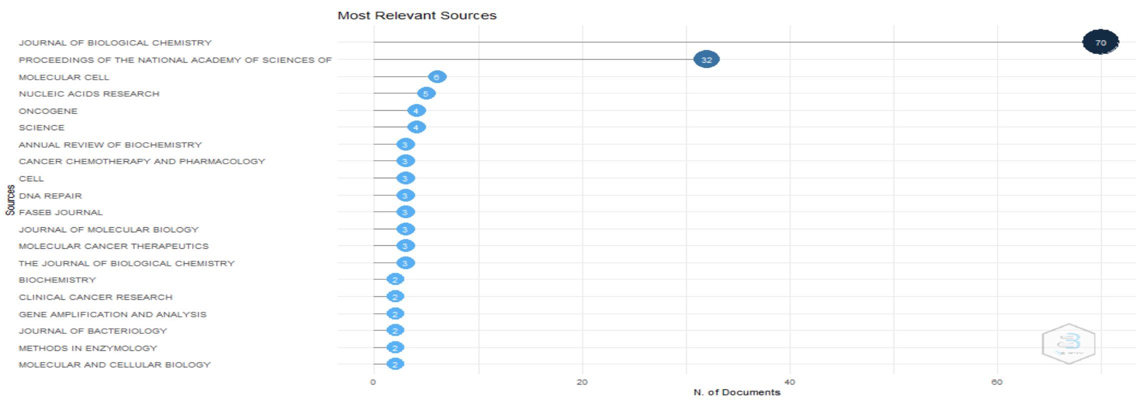


Fig 56: Most Relevant Sources

Table 42: Most Relevant Sources

Sources	Articles
Journal Of Biological Chemistry	71
Proceedings Of the National Academy of Sciences of The United States of America	32
Molecular Cell	6
Nucleic Acids Research	5
Oncogene	4
Science	4
Annual Review of Biochemistry	3
Cancer Chemotherapy and Pharmacology	3
Cell	3
Dna Repair	3
Faseb Journal	3
Journal Of Molecular Biology	3
Molecular Cancer Therapeutics	3
The Journal of Biological Chemistry	3
Biochemistry	2
Clinical Cancer Research	2
Gene Amplification and Analysis	2
Journal Of Bacteriology	2
Methods In Enzymology	2
Molecular And Cellular Biology	2
Acta Crystallographica Section F: Structural Biology and Crystallization Communications	1
Angewandte Chemie - International Edition	1
Annual Review of Genetics	1
Basic Life Sciences	1
Bba - Gene Structure and Expression	1
Cancer Research	1
Chemical Reviews	1
Chemistry And Biology	1
Cold Spring Harbor Symposia on Quantitative Biology	1

Critical Reviews in Biochemistry and Molecular Biology	1
Current Biology	1
Embo Journal	1
Gene	1
Genes And Development	1
Genetics	1
Genome	1
Genomics	1
Japanese Journal of Cancer Research	1
Japanese Journal of Cancer Research: Gann	1
Journal Of Clinical Oncology	1
Journal Of Neuro-Oncology	1
Journal Of Organic Chemistry	1
Mutation Research-Dna Repair	1
Mutation Research - Fundamental and Molecular Mechanisms of Mutagenesis	1
Nature Genetics	1
Philosophical Transactions of The Royal Society of London. Series B Biological Sciences	1
Proceedings Of Spie - The International Society for Optical Engineering	1
Progress In Clinical and Biological Research	1
Quarterly Reviews of Biophysics	1
Ultramicroscopy	1

6.3.4.7 Author's performance based on available metrics indicators (Paul Lawrence Modrich)

Table 43: Performance of Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	23.79	01	i10-index (i10)	168
02	Total Citation	22608	02	h5-index (h5)	0
03	Audience Factor	187	03	g-Index	149
04	CiteScore (Maximum)	50.1	04	a-Index	236.65

05	ResearchGate Citations	3786	05	h(2)-index	23
06	Microsoft Academic Search Citations	36508	06	hg-index (hg)	108.49
07	Google Scholar Citations	37859	07	r-index	136.73
08	Eigenfactor	82.6	08	ar-index (ar)	359.52
09	Crown Indicator	88.215	09	k-index	0.04
10	Mean Citation Score	122.51	10	q2-index	18.85
11	Mean Normalized Citation Score (MNCS)	98.99	11	f-index	1.64
12	Mean Citation Rate Subfield (MCRS)	88.19	12	m-index	3.29
13	Scientific Talent Pool (STP)	72.63	13	m quotient (m-q)	3.29
14	Microsoft Academic Search Papers (MASP)	206	14	Contemporary-index (Ch)	0.69
15	Google Scholar Papers (GSP)	257	15	Trendh h-index (Th)	0.01
16	Impact per Paper (IPP)	77.78	16	Dynamic h-Type index (Dh-T)	12.43
17	Citation per paper (CPP)	119.26	17	n-index	4.16
18	Citations per Paper self-citation not included (CPPex)	117.69	18	mean h-index	40
19	The average number of citations per publication (ANCP)	1.91	19	Normalized h-index	55
20	Total and the Average Number of Citations (TNCS)	22608 and 1.91	20	Specific-impact s-index (Sis)	26.78
21	Relative Activity Index (RAI)	7.43	21	Seniority independent Hirsch type index (Sih-T)	1
22	Relative Specialization index (RSI)	15.26	22	Hw-index	136.73
23	Relative Citation Rate (RCR)	1.56	23	Hm-index	34
24	Relative Database Citation	23.34	24	Tapered h-index	0.06

	Potential (RDCP)				
25	Journal Acceptance Rate (JAR)	22.53	25	i20-index	152
26	% Self Citations (%SC)	3.94	26	v-index over h	3.44
27	Percentage of papers not cited (%Pnc)	2.66	27	e-index	111.60
28	PR Percentile Ranks (PR)	72	28	Multidimensional h-index	45
29	LogZ-score (LogZ)	36.29	29	Research Collaboration Index	7.95
30	Innovative Knowledge (IK)	6.24	30	Communities Collaboration Index	99.42
31	Technological Impact (TI)	26.31	31	ch-index	52
32	Scientific Talent Pool (STP)	72.63	32	speed s-iCitationndex	36.87
33	Normalized position of publication journal (NPJ)	56	33	π-index	7.79
34	WorldCat Hold (WCH)	41	34	h5-median (h5-m)	0
35	Papers in Top 1 (PT1)	24	35	2nd generation citations h index	67.98
36	Papers in Top 10 (PT10)	54	36	Role basedh-maj-index (Rbhm)	12.03
37	Papers in Top 50 (PT50)	75	37	h2 lower (h2-l)	12
38	High Cited Papers (HCP)	8	38	h2-center (h2-c)	24.03
39	Papers in First Quartile (Q1)	26	39	h2-upper (h2-u)	34
40	Publications in Thomson Reuters indices (PwoS)	6	40	h3-index	14
41	Number of highly cited publications (NHCP)	4	41	p-index	2.79
42	Publications in top-ranked journals (PTRJ)	72	42	$\bar{h}$-index (Hbar)	79
43	Papers in Collaboration (Pcol)	174	43	Mockhm-index (Mhm)	32.28
44	Share of articles coauthored with another unit (%CoA)	27.98	44	w-index	1.39

45	National Collaboration (Ncol)	65.38	45	b-index	28.28
46	International Collaboration (Icol)	34.62	46	Generalizedh-index	62.13
47	Scientific Leadership (SL)		47	Single paperh-index	19.68
48	Average Authors per Paper	1.06	48	hint-index	26.35
49	Productivity per Paper	18.95	49	h_{rat}-index	79.99
50	RoG, CAGR, RGR and DT	0.72, (-)0.35, 0.12, 1.75	50	πv-index	62.28

6.3.4.8 To analyze the scientific collaboration of Paul Lawrence Modrich

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Paul L Modrich has collaborated with 367 different authors in the conduct and publication of his research work. The author has published only 18 single-authored documents.

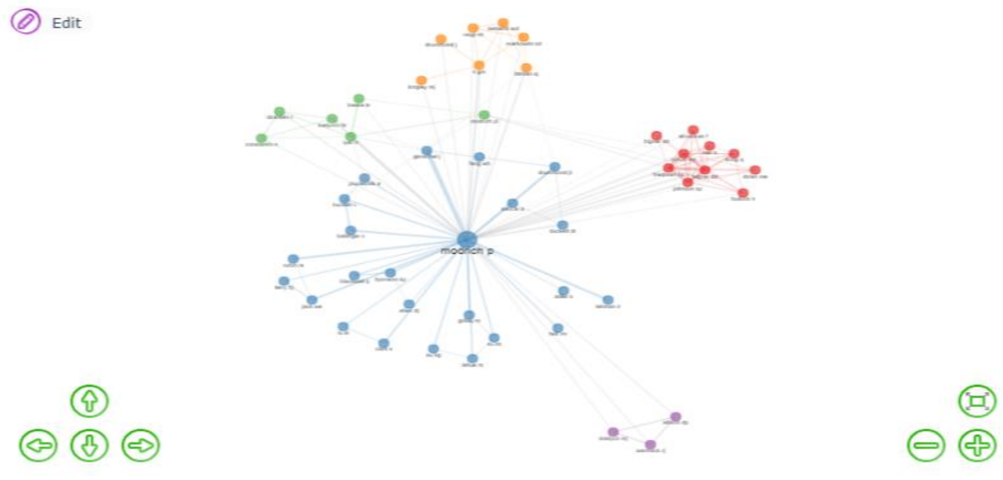


Fig 57: Collaboration Network

6.3.4.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Paul Lawrence Modrich, the collaboration index has been calculated at 2.26.

6.3.4.8.2 National and International Collaboration: Paul Lawrence Modrich has published his papers in collaboration with 367 co-authors of mostly hailing from the United States of America, the United Kingdom, Canada, and Taiwan. Of the 188 papers published in collaboration, 174 have been published along with national collaboration, while the others have been published with collaborative efforts from international researchers. The collaboration map of Modrich is produced in figure 58.

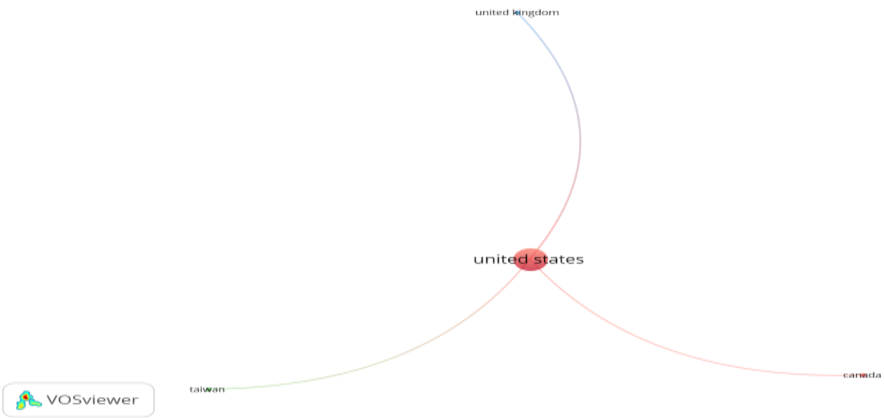


Fig. 58: National and International Collaboration

6.3.4.8.3 Co-authorship Index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Paul Lawrence Modrich has been calculated at 4.72.

6.3.4.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources have resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Paul Lawrence Modrich had close communication with 189 co-authors while publishing his documents.

6.3.4.9 To find out the research network of Paul Lawrence Modrich.

6.3.4.9.1 Co-authorship: Paul Lawrence Modrich had collaborated with 367 co-authors.

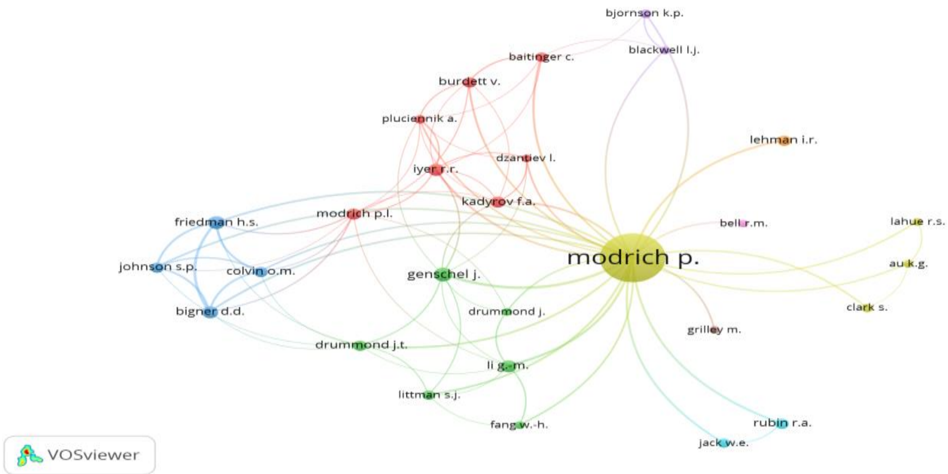


Fig. 59: Co-authorship Pattern of Paul Lawrence Modrich

On analysis of the co-authorship pattern, it is observed that the author's collaboration with H S Friedman, D D Bigner, O M Colvin, and S P Johnson were the highest. A graphical representation of the co-authorship pattern is shown in figure 59 below.

6.3.4.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top four keywords on the decreasing order of their link strengths.

Table 44: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	129	2561
priority journal	111	2220
dna repair	92	1907
human	68	1452

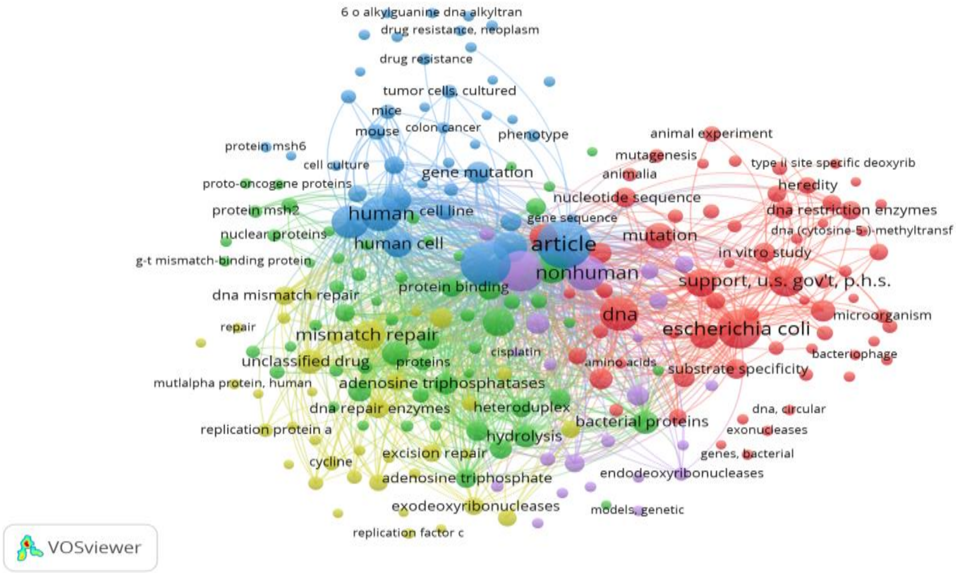


Fig. 60: Keyword Co-occurrences Authorship Pattern

6.3.4.9.3 Citation analysis: Of the 855 papers published by Paul Lawrence Modrich, either as a single author or in collaboration, 184 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *Mismatch repair in replication fidelity, genetic recombination, and cancer biology*, published in the journal *Annual Review of Biochemistry* during 1996 has been cited 1282 times followed by the article *Hypermutability and mismatch repair deficiency in RER tumor cells* published in *Annual Review of Genetics* in 1991 which received 749 citations. Another article, *DNA Mismatch Repair: Functions and Mechanisms* published in the journal *Chemical Reviews* during 2006 has been cited 621 times. A graphical representation of the above information is presented in Figure 61.

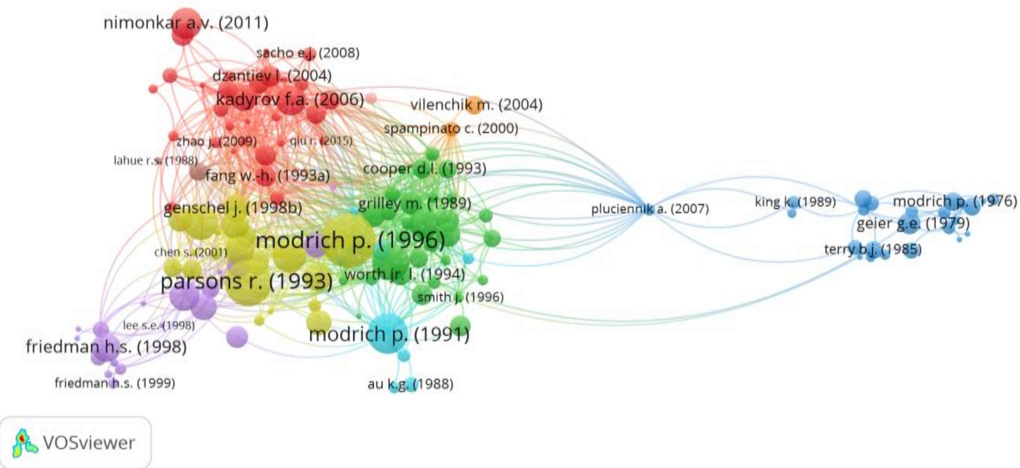


Fig. 61: Citation Analysis

6.3.4.9.4 Bibliographic Coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Paul Lawrence Modrich is presented in figure 62.

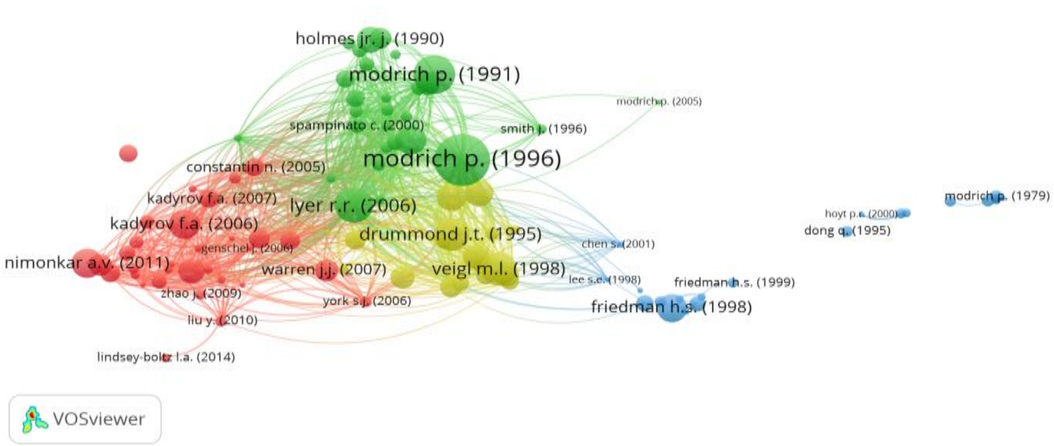


Fig. 62: Bibliographic Coupling

6.3.4.9.5 Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of Paul Lawrence Modrich is produced in Fig. 63. Analysis of the figure shows that the articles published by Paul Lawrence Modrich has been co-cited by 5 clusters, having 44, 32, 21, 20, and 11 items each. There are a total of 7110 links, with a total link strength of 382597.

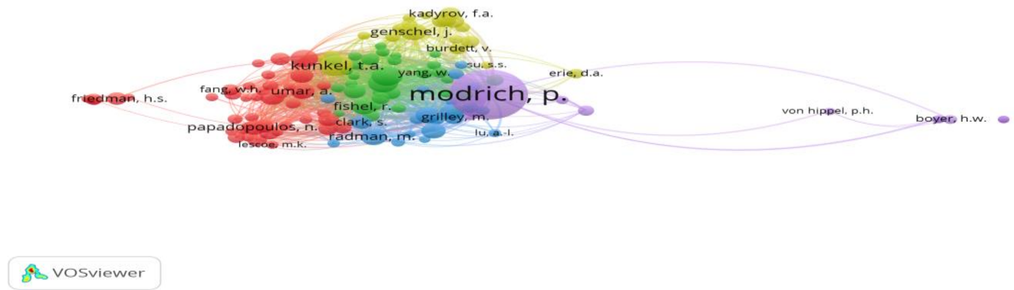


Fig. 63: Co-citation Analysis

6.3.4.10 To analyze cluster mapping (Paul Lawrence Modrich)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 64 shows the coupling map of Paul Lawrence Modrich.

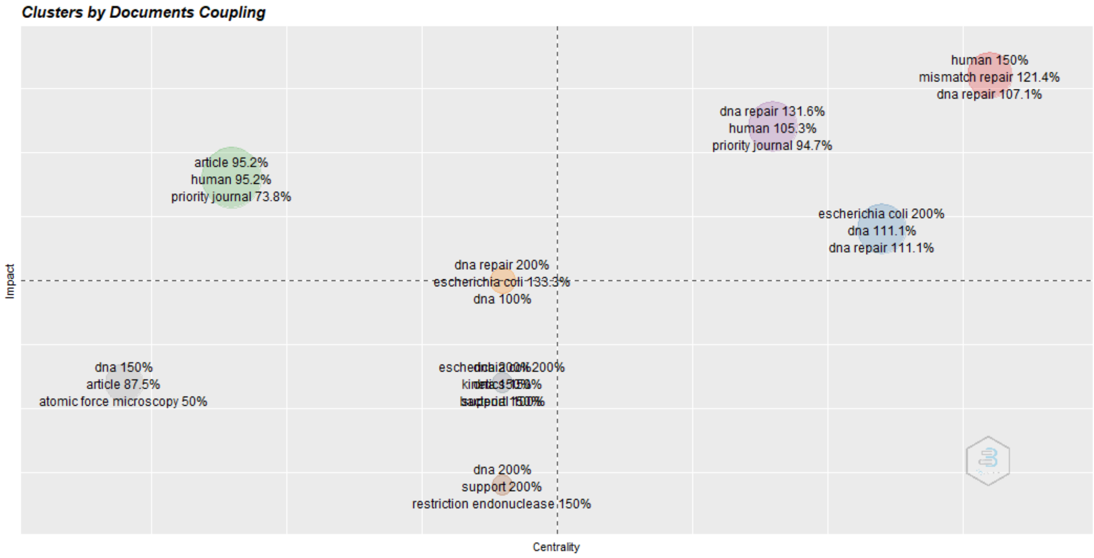


Fig 64: Document Coupling

6.3.4.11 Other information (Paul Lawrence Modrich)

Table 45: Main Information

Description	**Results**
Timespan	1970:2020
Sources	
Journals, Books, Etc	51
Documents	188
Total	239
Average Years from Publication	26.2
Average Citations Per Documents	117.2
Average Citations Per Year Per Doc	4.97
References	4206
Document Types	
Article	170
Conference Paper	3

Erratum	1
Review	11
Short Survey	3
Total	188
Document Contents	
Keywords Plus (Id)	1379
Author's Keywords (De)	120
Authors	
Authors	395
Author Appearances	887
Authors Of Single-Authored Documents	1
Authors Of Multi-Authored Documents	394
Authors Collaboration	
Single-Authored Documents	14
Documents Per Author	0.476
Authors Per Document	2.10
Co-Authors Per Documents	4.72
Collaboration Index	2.26
H-Index	79
Total Citation	22608 Citations By 11835 Documents

The publication productivity of Paul Lawrence Modrich is consistent throughout the entire productive life, and he has made outstanding contributions in the field of DNA Repair, DNA mismatch, microbiology, and biochemistry. His publication life commenced in 1970 after he had attained a biological age of 24 years. Paul Lawrence Modrich has been active in research despite many responsibilities. He has worked in collaboration and has a high degree of collaboration at institutional, national, and international levels. Paul Lawrence Modrich has an h-index of 79 and is regarded as one of the most successful scientists in the field of chemistry. Paul Lawrence Modrich's research efforts have largely been concentrated on DNA mismatch and DNA repair which proves his strength in this field. Paul Lawrence Modrich's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.5 AZIZ SANCAR

Aziz Sancar, a Turkish molecular biologist and a Nobel Laureate was born on 8th September 1946. Aziz Sancar specializes in DNA repair and cell cycle checkpoints and circadian clock. He received the Nobel Prize in Chemistry with Tomas Lindahl and Paul Lawrencve Modrich on 2015 for mechanistic studies of DNA repair. Aziz Sancar has also contributed to photolyase and nucleotide excision repair in bacteria. At present, Aziz Sancar is the Sarah Graham Kenan Professor of Biochemistry and Biophysics at the University of North Carolina School of Medicine and a member of the United Nations Council Lineberger Comprehensive Cancer Center. Aziz Sancar has also founded the Aziz and Gwen Sancar Foundation, a not-for-profit organization that supports Turkish students present in the United States of America.

6.3.5.1 To assess the number of scientific communications contributed by Aziz Sancar.

Aziz Sancar has used several media to publish his scientific works. While most of his scientific communication have been through articles that he has published himself or in collaboration with other co-authors, he has also authored books, presented conference papers, editorials, reviews, surveys, etc. Table 46 shows the number of scientific communications of the Nobel Laureate.

Table 46: Scientific Communication

Document Types	
Article	348
Book Chapter	4
Conference Paper	3
Editorial	2
Erratum	8
Letter	2
Note	6
Review	29
Short Survey	12

6.3.5.2 To analyze the domain wise scientific communication of Aziz Sancar.

The works of Aziz Sancar can be broadly classified into four categories or domains. These include biochemistry, molecular biophysics, DNA repair, and molecular biology. Translating the information in numerical and percentage terms, Aziz Sancar has published a total of 414 papers of which 154 papers are on DNA repair (37.20%), 93 papers on biochemistry (23.19%), and 82 papers on biophysics and microbiology (19.81%). Aziz Sancar has published his works using several modes. While most of his works, (348, 84.06%) are in the form of articles, he has also published his works in the form of Book Chapters, Conference Papers, Editorials, Errata, Letters, Notes, Reviews, and Short Surveys in varying proportions. Table 47 is a tabular form of the above information and figure 65 is a graphical form of the same.

Table 47: Number of Scientific Communication

Document	**Domain**				**Total Papers**	%
	A	B	C	D		
Article	79	72	133	64	**348**	**84.06**
Book Chapter	0	1	2	1	**4**	**0.97**
Conference Paper	1	0	1	1	**3**	**0.72**
Editorial	1	0	0	1	**2**	**0.48**
Erratum	3	1	1	3	**8**	**1.93**
Letter	0	0	2	0	**2**	**0.48**
Note	1	2	2	1	**6**	**1.45**
Review	6	6	10	7	**29**	**7**
Short Survey	5	0	3	4	**12**	**2.9**
%	**23.19**	**19.81**	**37.20**	**19.81**	**414**	**100**

A: Biochemistry B: Molecular Biophysics C: DNARepair D: Molecular Biology

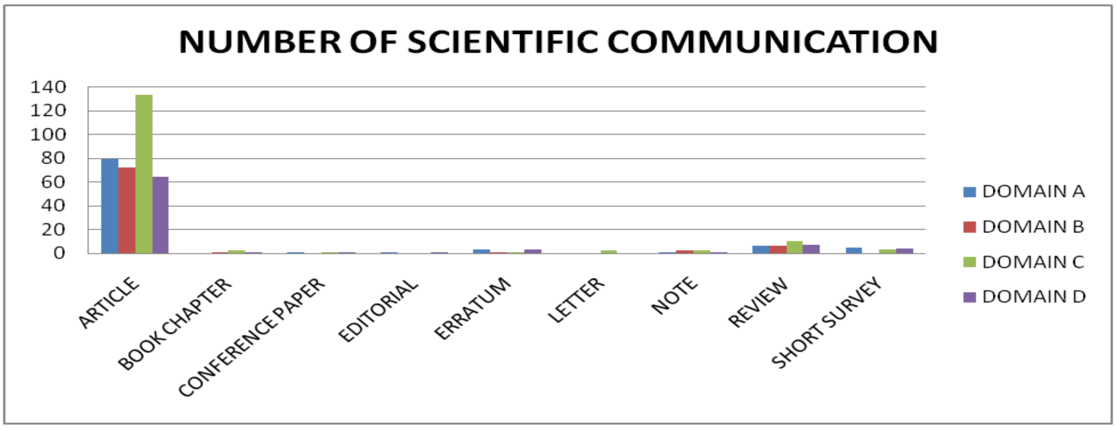


Fig. 65: Number of Scientific Communication

6.3.5.3 To analyze the domain-wise authorship pattern of Aziz Sancar.

Aziz Sancar had to work in collaboration with other authors due to his numerous responsibilities which is evident from the analysis of his works. While the author has 20 single-authored documents representing 4.83% of his total publications, 220 publications have been published with collaboration with 4 to 10 authors (53.14%). Two documents have been authored by 23 authors while one document has been authored by 93 authors.

Table 48: Domain-wise Authorship as per Collaboration

DOMAIN	AUTHORS						
	1 AUTHOR	2 AUTHOR	3 AUTHOR	4 -10 AUTHOR	11 - 20 AUTHOR	23 AUTHOR	93 AUTHOR
A	6	15	10	63	2	0	0
B	5	20	8	48	1	0	0
C	3	50	30	67	3	0	1
D	6	23	7	42	2	2	0
TOTAL PAPERS	**20**	**108**	**55**	**220**	**8**	**2**	**1**
%	**4.83**	**26.09**	**13.29**	**53.14**	**1.93**	**0.48**	**0.24**

A: Biochemistry B: Molecular Biophysics C: DNA Repair D: Molecular Biology

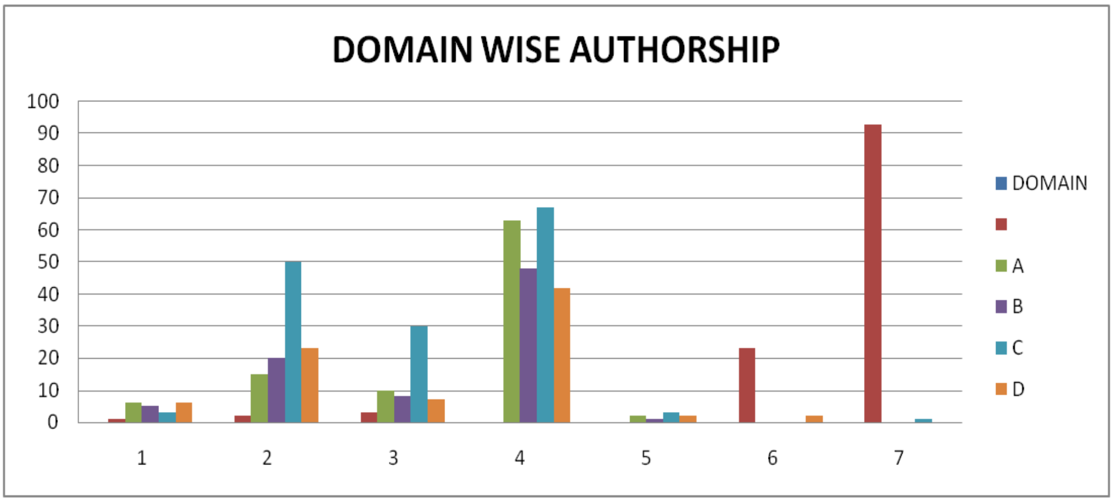


Fig. 66: Domain-wise Authorship Pattern

6.3.5.4 To analyze the year-wise scientific communication of Aziz Sancar.

Aziz Sancar's publication life began in 1971, 25 years after his birth. A look into his year-wise productivity reveals that the author has published the maximum number of works from 1991 till 2000 when he had published 141 papers in all domains at 34.06%. During the first 10 years of his productive life, Aziz Sancar published 10 papers (2.42%) which is the lowest number of works published by the author. A tabular form of this information is provided in Table 49, while a graphical representation is given in figure 67.

Table 49: Domain and Year-wise Authorship

Period	Domain				Total Papers	%
	A	B	C	D		
1971-1980	0	0	5	5	**10**	**2.42**
1981-1990	23	3	44	11	**81**	**19.57**
1991-2000	32	27	49	33	**141**	**34.06**
2001-2010	15	27	34	25	**101**	**24.40**
2011-2020	26	25	22	8	**81**	**19.57**
TOTAL	**96**	**82**	**154**	**82**	**414**	

A: Biochemistry B: Molecular Biophysics C: DNA Repair D: Molecular Biology

Table 50: Year-wise Productivity

Year	Domain				Total Papers	%
	A	B	C	D		
1971	0	0	1	0	1	0.24
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	0	0	0
1978	0	0	3	0	3	0.72
1979	0	0	1	3	4	0.97
1980	0	0	0	2	2	0.48
1981	5	0	0	0	5	1.21
1982	4	0	0	0	4	0.97
1983	3	0	0	0	3	0.72
1984	6	0	0	0	6	1.45
1985	5	2	0	0	7	1.69

1986	0	1	8	0	9	2.17
1987	0	0	11	0	11	2.66
1988	0	0	8	0	8	1.93
1989	0	0	12	0	12	2.90
1990	0	0	4	11	15	3.62
1991	15	0	0	0	15	3.62
1992	17	1	0	0	18	4.35
1993	0	17	0	0	17	4.11
1994	0	9	6	0	15	3.62
1995	0	0	19	0	19	4.59
1996	0	0	17	0	17	4.11
1997	0	0	9	7	16	3.86
1998	0	0	0	6	6	1.45
1999	0	0	0	11	11	2.66
2000	0	0	0	7	7	1.69
2001	4	0	0	0	4	0.97
2002	10	0	0	0	10	2.42
2003	1	11	0	0	12	2.90
2004	0	14	0	0	14	3.38
2005	0	2	11	0	13	3.14
2006	0	0	11	0	11	2.66
2007	0	0	9	0	9	2.17
2008	0	0	3	6	9	2.17
2009	0	0	0	10	10	2.42
2010	0	0	0	9	9	2.17
2011	12	0	0	0	12	2.90
2012	8	0	0	0	8	1.93
2013	6	2	0	0	8	1.93
2014	0	7	0	0	7	1.69
2015	0	8	0	0	8	1.93
2016	0	8	0	0	8	1.93
2017	0	0	13	0	13	3.14
2018	0	0	8	0	8	1.93

2019	0	0	1	7	8	1.93
2020	0	0	0	4	4	0.97

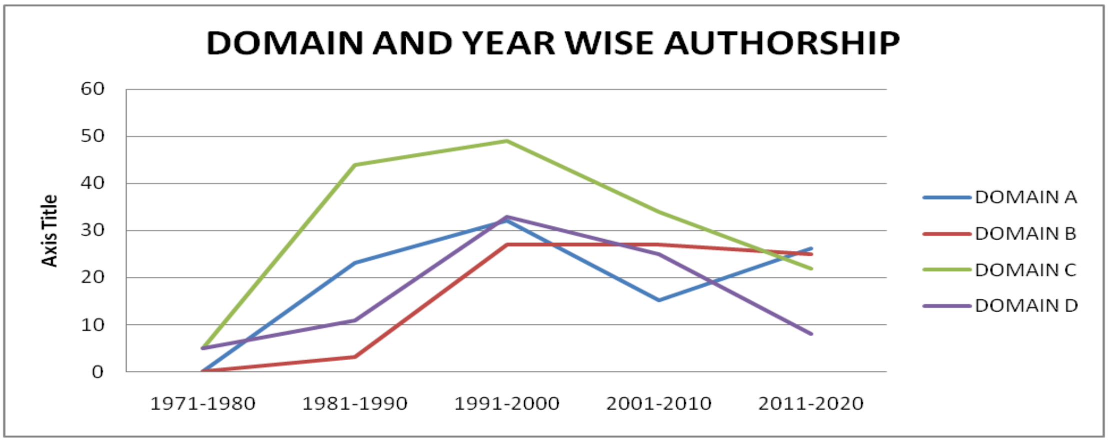


Fig. 67: Domain and Year-wise Authorship

6.3.5.5 Author's Production over time (Aziz Sancar)

The productivity of Aziz Sancar as a factor of time has been shown in Fig.68. The figure bears testimony to the fact that the productivity shown in the table above.

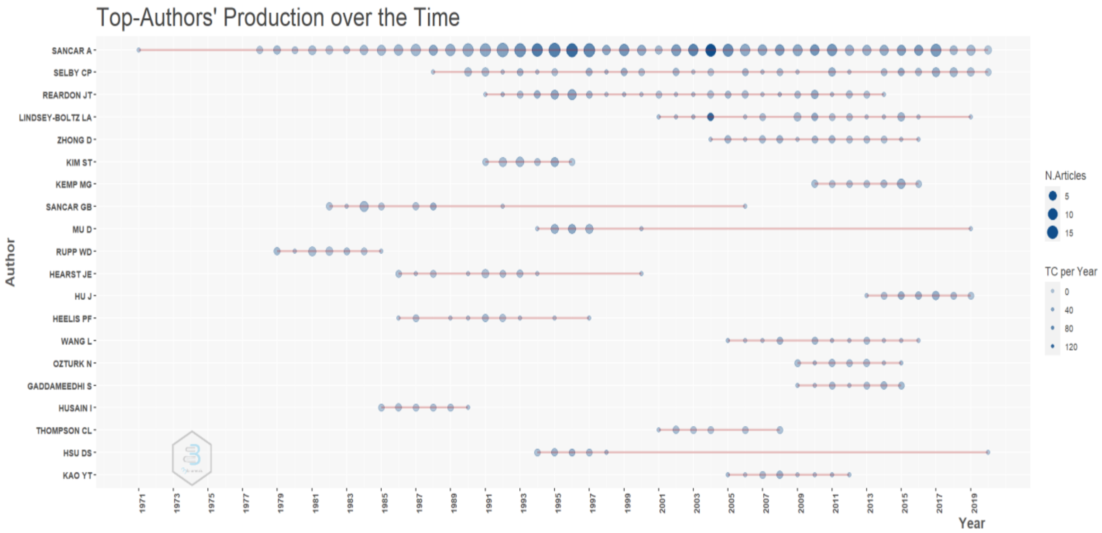


Fig. 68: Author's Production over Time

6.3.5.6 To find out the channels of communication used by Aziz Sancar.

Aziz Sancar published his scientific works using a variety of methods, be it articles, erratums, editorials, notes, book chapters, etc. The articles published by Aziz Sancar has been published in a number of journals. In the order of the decreasing number of articles, the top twenty journals publishing his articles have been shown in Fig 69. The figure shows that 92 articles have been published in *Journal of Biological*

Chemistry, followed by 71 articles in *Proceedings of the National Academy of Sciences in the United States of America*.

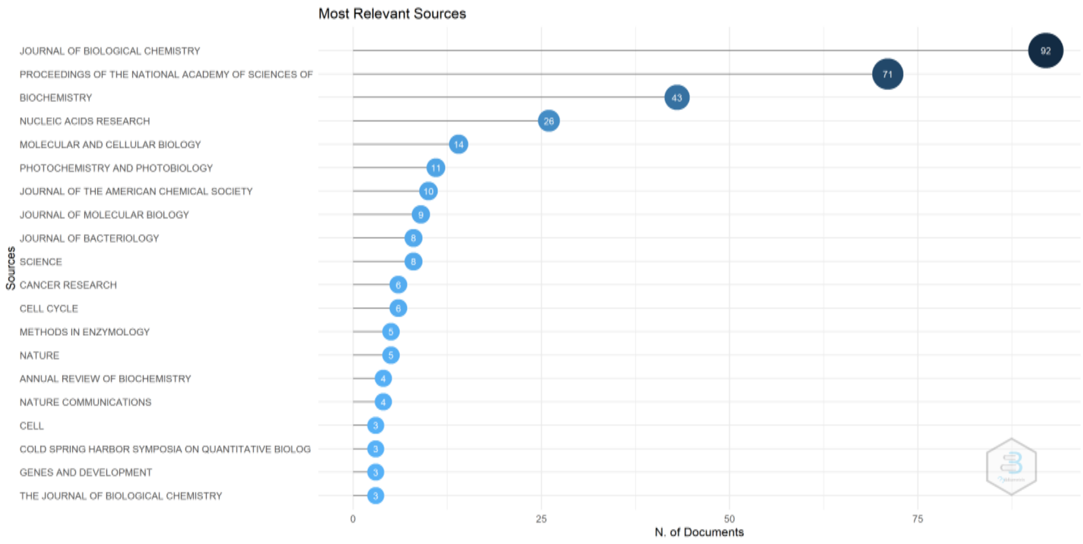


Fig. 69: Channels of Communication

Table 51: Most Relevant Sources

Sources	Articles
Journal Of Biological Chemistry	96
Proceedings Of the National Academy of Sciences of The United States of America	73
Biochemistry	43
Nucleic Acids Research	26
Molecular And Cellular Biology	14
Photochemistry And Photobiology	12
Journal Of the American Chemical Society	10
Journal Of Molecular Biology	9
Science	9
Journal Of Bacteriology	8
Cancer Research	6
Cell Cycle	6
Methods In Enzymology	5
Nature	5
Annual Review of Biochemistry	4
Nature Communications	4
Cell	3

Cold Spring Harbor Symposia on Quantitative Biology	3
Genes And Development	3
The Journal of Biological Chemistry	3
Advances In Protein Chemistry	2
Biochemical And Biophysical Research Communications	2
Biochimie	2
Cell Metabolism	2
Chemical Research in Toxicology	2
Current Biology	2
Faseb Journal	2
Journal Of Biological Rhythms	2
Journal Of Investigative Dermatology	2
Journal Of Neuroscience	2
Journal Of Photochemistry and Photobiology B: Biology	2
Journal Of Physical Chemistry B	2
Molecular Brain Research	2
Mutation Research-Dna Repair	2
Mutation Research - Dna Repair	2
Progress In Nucleic Acid Research and Molecular Biology	2
Analytical Biochemistry	1
Angewandte Chemie - International Edition	1
Annual Review of Genetics	1
Bmc Genomics	1
Bmc Neuroscience	1
Brenner's Encyclopedia of Genetics: Second Edition	1
Briefings In Bioinformatics	1
Cancer Reviews	1
Cell Biochemistry and Biophysics	1
Cell Cycle (Georgetown Tex.)	1
Cellular And Molecular Life Sciences	1
Chemical Reviews	1
Chemico-Biological Interactions	1
Clinical Cancer Research	1

Crc Handbook Of: Organic Photochemistry and Photobiology Second Edition	1
Embo Journal	1
Environmental And Molecular Mutagenesis	1
Febs Journal	1
Febs Letters	1
Femtochemistry Vii	1
Frontiers In Molecular Biosciences	1
Frontiers In Neuroscience	1
Gene	1
Genomics	1
Handbook Of Photosensory Receptors	1
Indian Journal of Biochemistry & Biophysics	1
International Journal of Radiation Biology	1
Investigative Ophthalmology and Visual Science	1
Journal Of Circadian Rhythms	1
Journal Of Experimental Biology	1
Journal Of Neurogenetics	1
Journal Of Physical Chemistry A	1
Journal Of the National Cancer Institute	1
Journal Of Theoretical Biology	1
Medecine/Sciences	1
Methods	1
Mgg Molecular & General Genetics	1
Microbiological Reviews	1
Molecular Interventions	1
Molecular Microbiology	1
Mutation Research - Fundamental and Molecular Mechanisms of Mutagenesis	1
Nature Genetics	1
Nature Protocols	1
Nature Structural and Molecular Biology	1
Novartis Foundation Symposium	1

Oncogene	1
Pigment Cell and Melanoma Research	1
Plos One	1
Progress In Clinical and Biological Research	1
Science (New York N.Y.)	1
Scientific Reports	1
Trends In Biochemical Sciences	1
Turk Tip Cemiyeti Mecmuasi	1

6.3.5.7 Author's performance based on available metrics indicators.

Table 52: Performance of Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	98.56	01	i10-index (i10)	365
02	Total Citation	38672	02	h5-index (h5)	22
03	Audience Factor	214.9	03	g-Index	177
04	CiteScore (Maximum)	50.1	04	a-Index	237.12
05	ResearchGate Citations	25298	05	h(2)-index	18
06	Microsoft Academic Search Citations	56659	06	hg-index (hg)	137.62
07	Google Scholar Citations	48972	07	r-index	159.29
08	Eigenfactor	52.09	08	ar-index (ar)	409.23
09	Crown Indicator	92.18	09	k-index	0.08
10	Mean Citation Score	95.50	10	q2-index	21.40
11	Mean Normalized Citation Score (MNCS)	86.24	11	f-index	1.64
12	Mean Citation Rate Subfield (MCRS)	72.14	12	m-index	4.28
13	Scientific Talent Pool (STP)	58.25	13	m quotient (m-q)	4.28
14	Microsoft Academic Search Papers (MASP)	452	14	Contemporary-index (Ch)	301.93
15	Google Scholar Papers (GSP)	355	15	Trendh h-index (Th)	0.07

16	Impact per Paper (IPP)	36.29	16	Dynamic h-Type index (Dh-T)	28.96
17	Citation per paper (CPP)	2.02	17	n-index	3.96
18	Citations per Paper self-citation not included (CPPex)	86.56	18	mean h-index	53.5
19	The average number of citations per publication (ANCP)	90.28	19	Normalized h-index	91.46
20	Total and the Average Number of Citations (TNCS)	38672, 90.28	20	Specific-impact s-index (Sis)	19.75
21	Relative Activity Index (RAI)	76.35	21	Seniority independent Hirsch type index (Sih-T)	1
22	Relative Specialization index (RSI)	90.28	22	Hw-index	159.29
23	Relative Citation Rate (RCR)	23.24	23	Hm-index	19
24	Relative Database Citation Potential (RDCP)	16.89	24	Tapered h-index	0.06
25	Journal Acceptance Rate (JAR)	67.20	25	i20-index	335
26	% Self Citations (%SC)	9.74	26	v-index over h	3.45
27	Percentage of papers not cited (%Pnc)	9.74	27	e-index	118
28	PR Percentile Ranks (PR)	76	28	Multidimensional h-index	56.32
29	LogZ-score (LogZ)	10.23	29	Research Collaboration Index	35.06
30	Innovative Knowledge (IK)	90.2	30	Communities Collaboration Index	9.95
31	Technological Impact (TI)	82.31	31	ch-index	55.55
32	Scientific Talent Pool (STP)	58.25	32	speed s-iCitationndex	48.53

33	Normalized position of publication journal (NPJ)	25	33	π-index	114.83
34	WorldCat Hold (WCH)	133.5	34	h5-median (h5-m)	15.38
35	Papers in Top 1 (PT1)	25	35	2nd generation citations h index	99
36	Papers in Top 10 (PT10)	52	36	Role basedh-maj-index (Rbhm)	75
37	Papers in Top 50 (PT50)	158	37	h2 lower (h2-l)	2
38	High Cited Papers (HCP)	17	38	h2-center (h2-c)	19
39	Papers in First Quartile (Q1)	123	39	h2-upper (h2-u)	36
40	Publications in Thomson Reuters indices (PWoS)	12	40	h3-index	12
41	Number of highly cited publications (NHCP)	7	41	p-index	11.05
42	Publications in top-ranked journals (PTRJ)	118	42	$\bar{h}$-index (Hbar)	107
43	Papers in Collaboration (PCol)	394	43	Mockhm-index (Mhm)	3.95
44	Share of articles coauthored with another unit (%CoA)	4.48	44	w-index	2.85
45	National Collaboration (NCol)	44.28	45	b-index	19.20
46	International Collaboration (ICol)	55.72	46	Generalizedh-index	92
47	Scientific Leadership (SL)	23.32	47	Single paperh-index	58
48	Average Authors per Paper	1.44	48	hint-index	78
49	Productivity per Paper	9.99	49	h_{rat}-index	108
50	RoG, CAGR, RGR and DT	0.67, (-)0.23, 0.48, 1.25	50	πv-index	0.26

6.3.5.8 To analyze the scientific collaboration of Aziz Sancar

Collaboration among researchers is an important aspect as it helps to share expertise

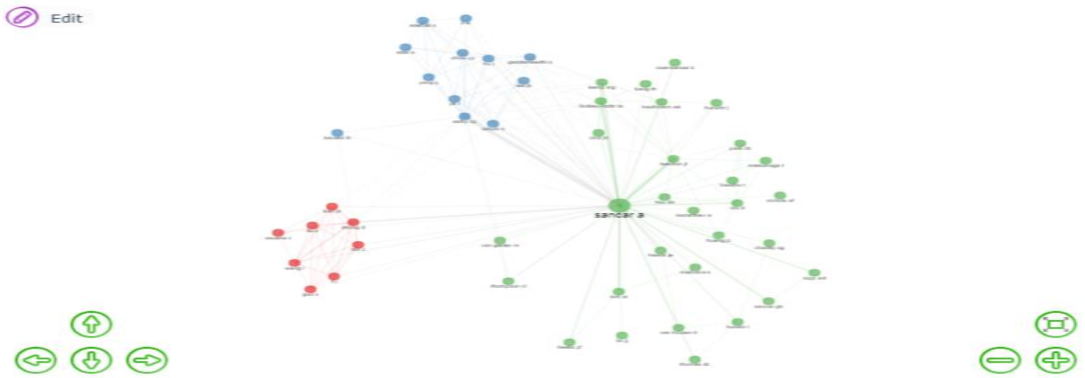


Fig 70: Collaboration Network

and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Aziz Sancar has collaborated with 614 different authors in the conduct and publication of his research work. The author has published 20 single-authored documents.

6.3.5.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{Total Authors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Aziz Sancar, the collaboration index has been calculated at 1.52.

6.3.5.8.2 National and International Collaboration: Aziz Sancar has published his papers in collaboration with more than 614 co-authors hailing mostly from the United States, the United Kingdom, Japan, Turkey, and China. The collaboration map of Aziz Sancar is produced in figure 71.

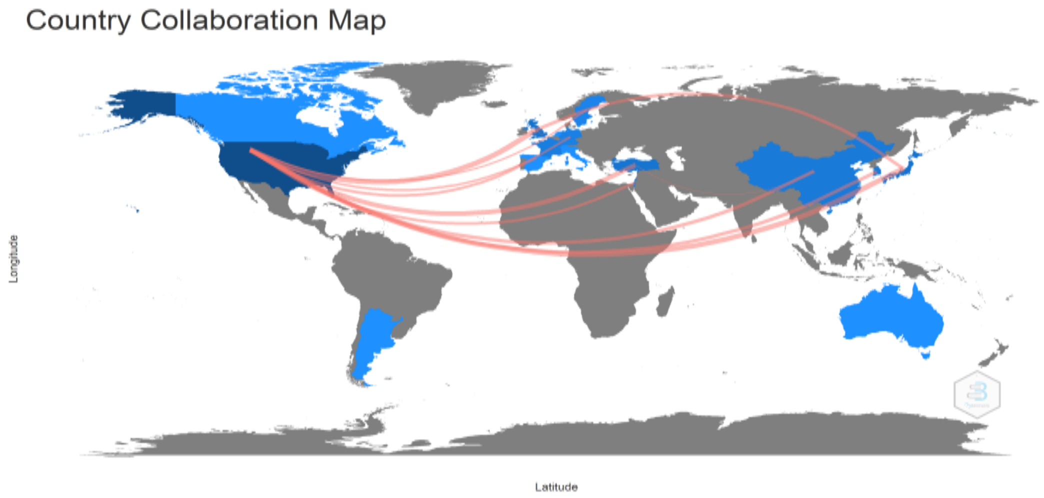


Fig. 71: National and International Collaboration

6.3.5.8.3 Co-authorship Index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Aziz Sancar has been calculated at 4.48.

6.3.5.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources has resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Aziz Sancar had close communication with 214 co-authors while publishing his documents.

6.3.5.9 To find out the research network of Aziz Sancar.

6.3.5.9.1 Co-authorship: Aziz Sancar had collaborated with 614 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with B P Selby, D Zhong, J T Reardom, and L A Lindsey-Boltz were the highest. A graphical representation of the co-authorship pattern is shown in figure 72.

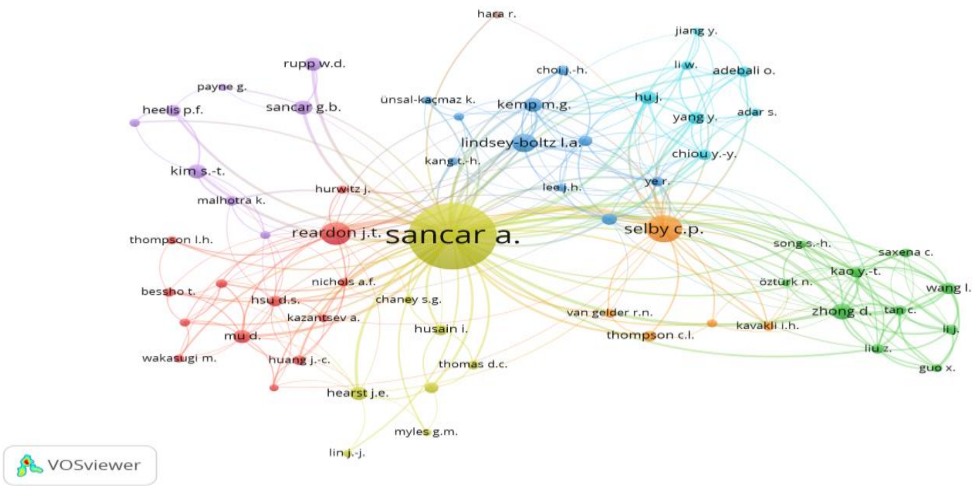


Fig. 72: Co-authorship Pattern of Aziz Sancar

6.3.5.9.2 Keyword Occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top five keywords on the decreasing order of their link strengths.

Table 53: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	290	7114
Priority journal	297	7036
DNA repair	242	5338
nonhuman	218	5170

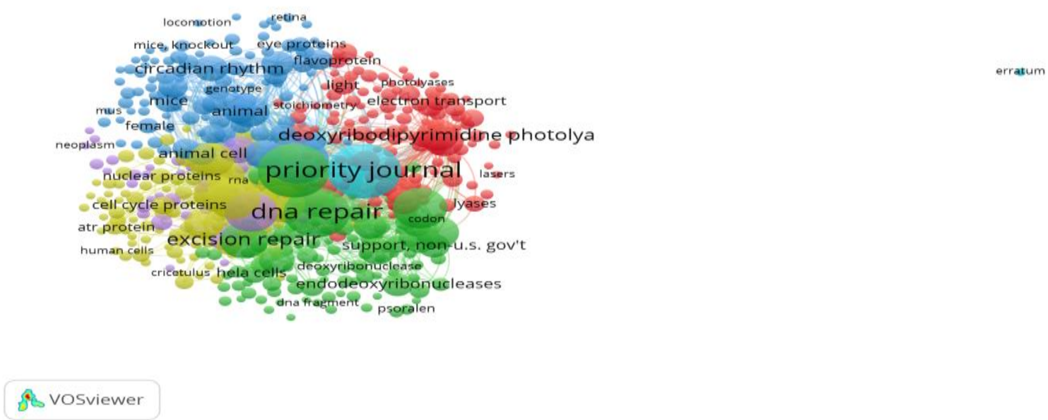


Fig. 73: Keyword Co-occurrences Authorship Pattern

6.3.5.9.3 Citation analysis: Of the 414 papers published by Aziz Sancar, either as a single author or in collaboration, 403 have been cited by other researchers in their papers. A graphical representation of the above information is presented in Figure 74.

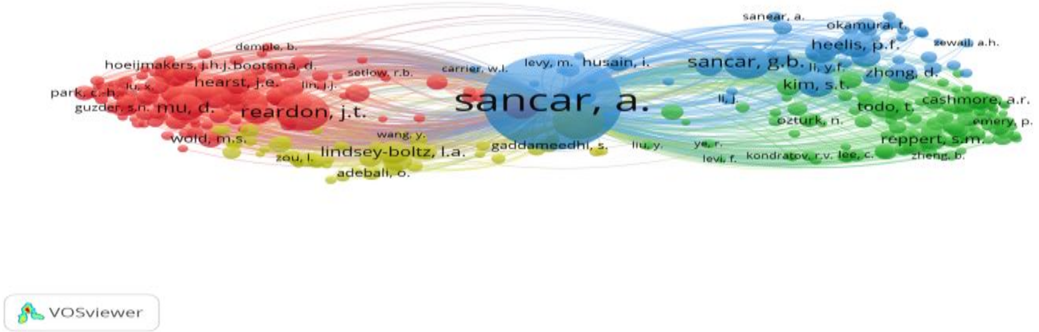


Fig. 74: Citation Analysis

6.3.5.9.4 Bibliographic Coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Aziz Sancar is presented in figure 75.

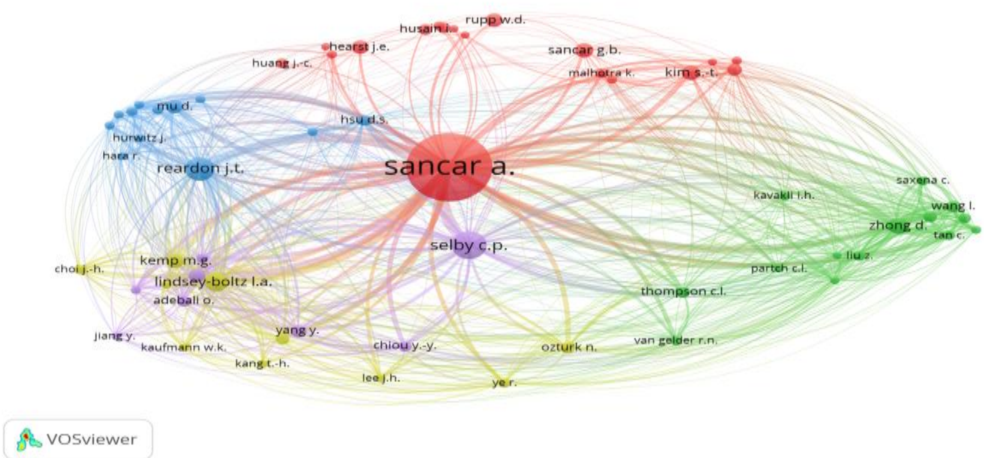


Fig. 75: Bibliographic Coupling

6.3.5.9.5 Co-citation analysis: Co-citation analysis is the process of tracking

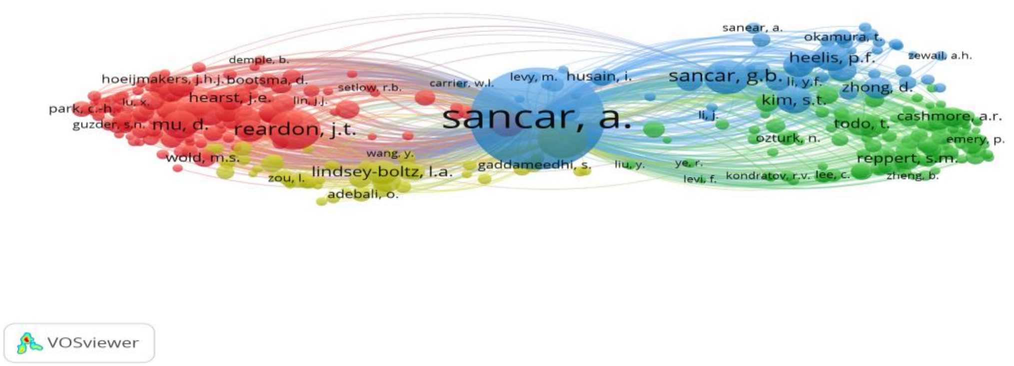


Fig. 76: Co-citation Analysis

documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of Aziz Sancar is produced in Fig. 76. Analysis of the figure shows that the articles published by Sir James Fraser Stoddart has been co-cited by 4 clusters, having 525, 282, 190, and 3 authors each. There are a total of 498742 links, with total link strength of 119054534.

6.3.5.10 To analyze cluster mapping (Aziz Sancar)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 77 shows the coupling map of Aziz Sancar.

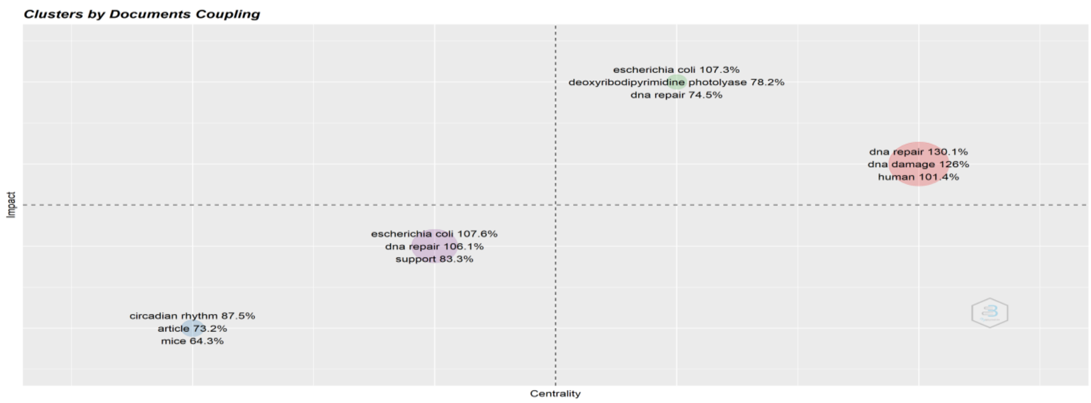


Fig 77: Document Coupling

6.3.5.11 Other Information (Aziz Sancar)

Table 54: Main Information

Description	Results
Timespan	1971:2020
Sources	
Journals, Books, Etc	84
Documents	414
Total	498
Average Years from Publication	21.6
Average Citations Per Documents	90.28
Average Citations Per Year Per Doc	4.321
References	11977
Document Types	
Article	348
Book Chapter	4
Conference Paper	3
Editorial	2
Erratum	8
Letter	2
Note	6
Review	29
Short Survey	12
Total	414
Document Contents	
Keywords Plus (Id)	2532
Author's Keywords (De)	295
Authors	
Authors	598
Author Appearances	1856
Authors Of Single-Authored Documents	1
Authors Of Multi-Authored Documents	597
Authors Collaboration	
Single-Authored Documents	20

Documents Per Author	0.692
Authors Per Document	1.44
Co-Authors Per Documents	4.48
Collaboration Index	1.52
H-Index	107
Total Citation	38672 Citations By 19164 Documents

The publication productivity of Aziz Sancar is consistent throughout the entire productive life and he has made outstanding contributions in the field of nanotechnology and supramolecular chemistry. His publication life commenced in 71 after he had attained a biological age of 25 years. Aziz Sancar has been active in research despite many administrative responsibilities. Aziz Sancar's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.6 TOMAS ROBERT LINDAHL

Tomas Robert Lindahl (dob: 28th January 1938) is a Swedish-British scientist who specializes in cancer research. He has done commendable works in the field of DNA repair and genetics of cancer. He is one of the recipients of the 2015 Chemistry Nobel Prize with Paul Lawrence and Aziz Sancar for mechanistic studies of DNA repair.

6.3.6.1 To assess the number of scientific communications contributed by Tomas Robert Lindahl.

Table 55: Scientific Communication

Document Types	
Articles	198
Conference Papers	9
Editorial	4
Erratum	1
Letter	3
Review	23
Short Survey	0

6.3.6.2 To analyze the domain-wise scientific communication of Tomas Robert Lindahl.

A look into the nature of scientific communication reveals that 33.47% of his works are in the domain of DNA repair followed by 33.05% in cancer research and 16.74% in biochemistry and organic chemistry. Table 55 is the tabular form of the number of scientific communications of Tomas Robert Lindahl. Regarding the nature of the document, Table 56 shows that most of the papers were in the form of articles (82.85%), followed by reviews (9.62%). With 0.42% of the total documents, erratum contributes the lowest to the list of total publications.

Table 56: Number of Scientific Communication

Document	Domain				Total Papers	%
	A	B	C	D		
Article	33	64	65	36	198	**82.85**
Conference Papers	2	3	3	1	9	**3.77**
Editorial	0	2	2	0	4	**1.67**
Erratum	1	0	0	0	1	**0.42**
Letter	1	1	1	0	3	**1.26**
Review	2	10	8	3	23	**9.62**
Short Survey	1	0	0	0	1	**0.42**
%	**16.74**	**33.47**	**33.05**	**16.74**	**239**	

A: Biochemistry B: DNA Repair C: Genetics of Cancer D: Organic Chemistry

A graphical form of Table 56 is shown in Figure 78.

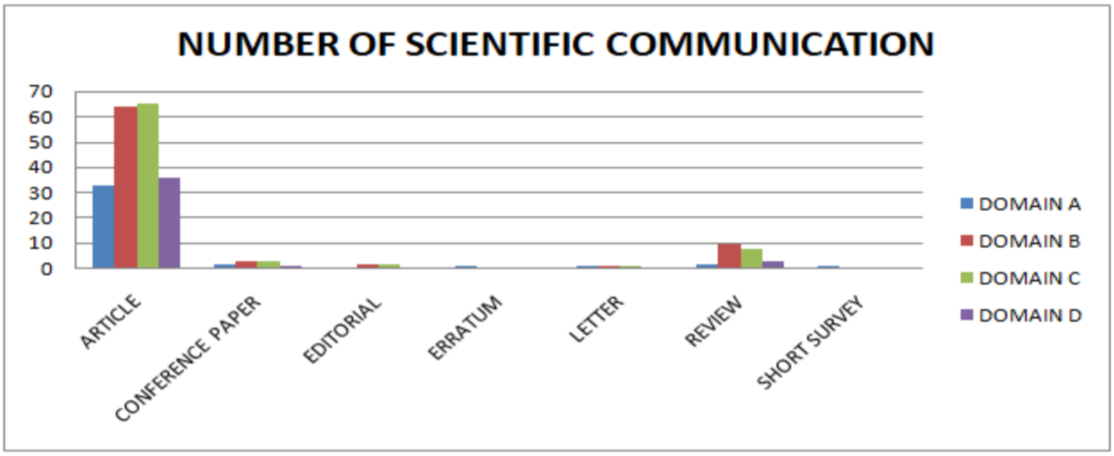


Fig 78: Number of Scientific Communication

6.3.6.3 To analyze the domain-wise authorship pattern of Tomas Robert Lindahl.

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Tomas Robert Lindahl are multi-authored. The highest numbers of documents are found to have 4 to 10 authors. This is followed by 2-authored documents. 35 documents representing 14.64% of the total works are single-authored. One document has 60 co-authors. Table 57 is a tabular form of the authorship pattern and Figure 79 presents a graphical view of the data.

Table 57: Domain-wise Authorship as per Collaboration

Domain	Authors						
	1 Author	2 Authors	3 Authors	4 – 10 Authors	11 – 20 Authors	21 - 30 Authors	60 Authors
A	4	14	8	9	4	1	0
B	13	21	13	33	0	0	0
C	12	12	15	36	2	1	1
D	6	9	11	13	1	0	0
Total	**35**	**56**	**47**	**91**	**7**	**2**	**1**
%	**14.64**	**23.43**	**19.67**	**38.08**	**2.93**	**0.84**	**0.42**

A: Biochemistry B: DNA Repair C: Genetics of Cancer D: Organic Chemistry

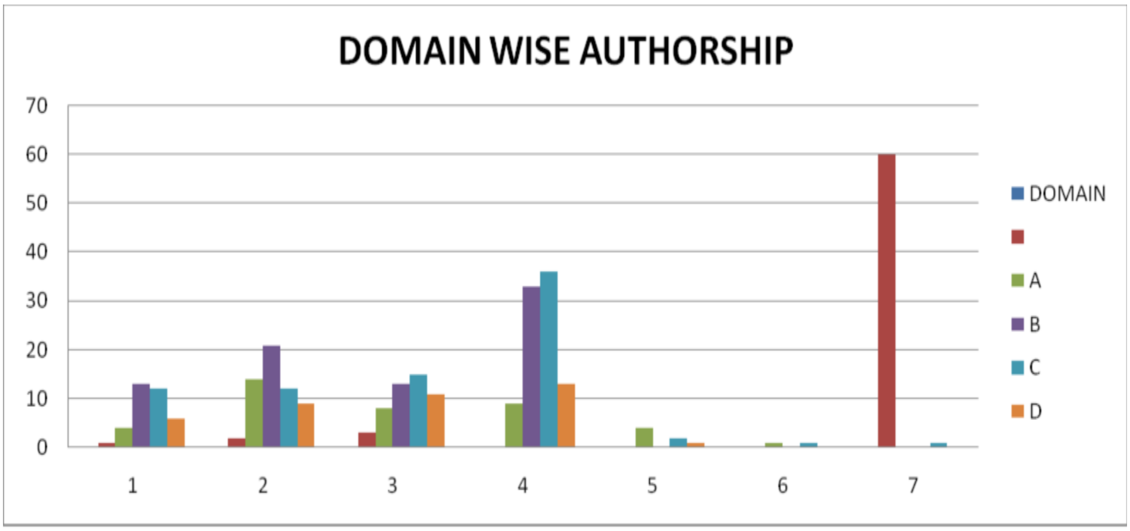


Fig 79: Domain-wise Authorship

6.3.6.4 To analyze the year-wise scientific communication of Tomas Robert Lindahl.

Table 58, table 59 and figure 80 show the domain and year-wise authorship pattern of Tomas Robert Lindahl. Tomas Robert Lindahl has published 239 documents on various subjects commencing from the years 1962.

Table 58: Domain and Year-wise Authorship

Period	**Domain**				**Total Papers**	**%**
	A	**B**	**C**	**D**		
1961 - 1970	5	4	4	4	**17**	**7.11**
1971 - 1980	13	17	18	8	**56**	**23.43**
1981 - 1990	6	18	14	9	**47**	**19.67**
1991 - 2000	9	24	26	9	**68**	**28.45**
2001 - 2010	6	13	14	8	**41**	**17.15**
2011 - 2017	1	4	3	2	**10**	**4.18**
Total	**40**	**80**	**79**	**40**	**239**	**100**

A: Biochemistry B: DNARepair C: Genetics of Cancer D: Organic Chemistry

Table 59: Domain and Year-wise Authorship

Year	**Domain**				**Total Papers**	**%**
	A	**B**	**C**	**D**		
1961	0	0	0	0	0	0
1962	1	0	0	0	1	0.42
1963	3	0	0	0	3	1.26
1964	0	0	0	0	0	0
1965	1	0	0	0	1	0.42
1966	0	4	0	0	4	1.67
1967	0	0	4	1	5	2.09
1968	0	0	0	1	1	0.42
1969	0	0	0	2	2	0.84
1970	0	0	0	0	0	0
1971	4	0	0	0	4	1.67
1972	4	0	0	0	4	1.67
1973	5	0	0	0	5	2.09
1974	0	7	0	0	7	2.93
1975	0	5	0	0	5	2.09
1976	0	5	1	0	6	2.51
1977	0	0	5	0	5	2.09
1978	0	0	8	0	8	3.35
1979	0	0	3	4	7	2.93

1980	0	0	0	5	5	2.09
1981	4	0	0	0	4	1.67
1982	2	7	0	0	9	3.76
1983	0	4	0	0	4	1.67
1984	0	4	0	0	4	1.67
1985	0	3	2	0	5	2.09
1986	0	0	3	0	3	1.26
1987	0	0	3	0	3	1.26
1988	0	0	5	0	5	2.09
1989	0	0	1	2	3	1.26
1990	0	0	0	7	7	2.93
1991	7	0	0	0	7	2.93
1992	2	6	0	0	8	3.35
1993	0	7	0	0	7	2.93
1994	0	8	0	0	8	3.35
1995	0	3	2	0	5	2.09
1996	0	0	7	0	7	2.93
1997	0	0	9	0	9	3.76
1998	0	0	4	0	4	1.67
1999	0	0	4	1	5	2.09
2000	0	0	0	8	8	3.35
2001	6	0	0	0	6	2.51
2002	0	6	0	0	6	2.51
2003	0	3	0	0	3	1.26
2004	0	4	6	0	10	4.18
2005	0	0	5	0	5	2.09
2006	0	0	3	0	3	1.26
2007	0	0	0	5	5	2.09
2008	0	0	0	0	0	0
2009	0	0	0	3	3	1.26
2010	0	0	0	0	0	0
2011	1	0	0	0	1	0.42
2012	0	3	0	0	3	1.26

2013	0	1	0	0	1	0.42
2014	0	0	0	0	0	0
2015	0	0	0	0	0	0
2016	0	0	3	1	4	1.67
2017	0	0	0	1	1	0.42
2018	0	0	0	0	0	0
2019	0	0	0	0	0	0
2020	0	0	0	0	0	0

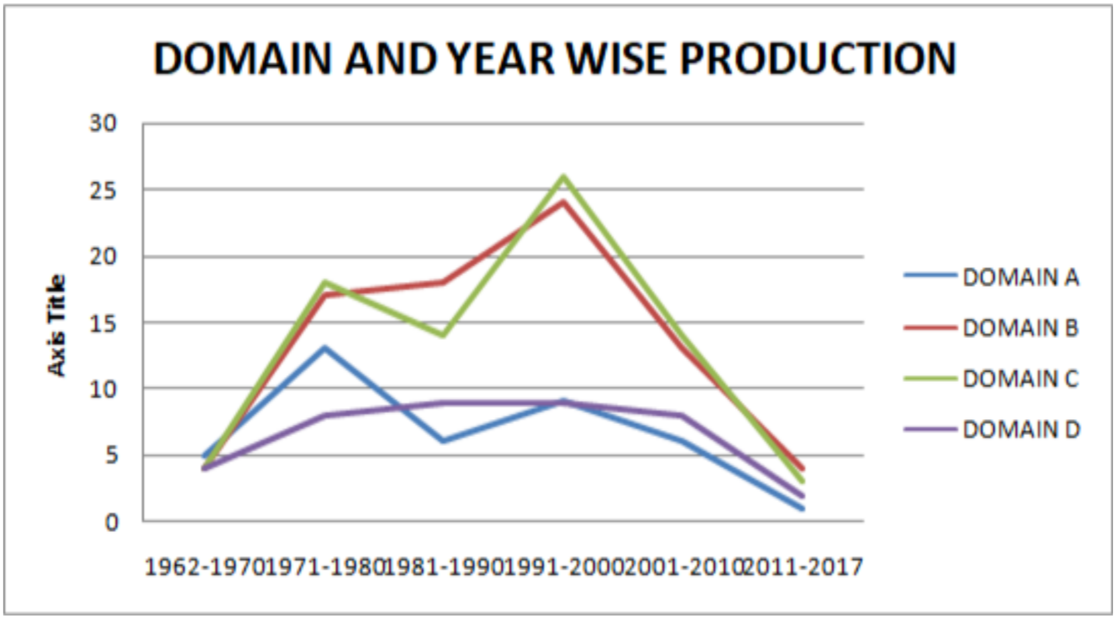


Fig 80: Domain wise and Year wise Authorship

6.3.6.5 Author's production over time (Tomas Robert Lindahl)

The result of the analysis of the author's production over time can also be seen in Figure 81 which shows that the numbers of publications in various domains have increased over time.

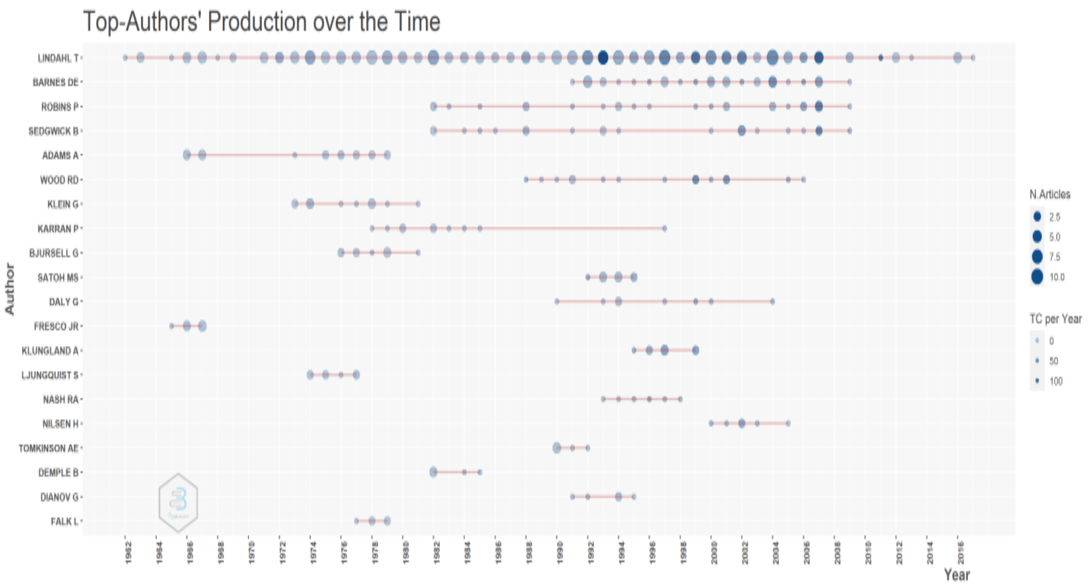


Fig 81: Authors' Production Over Time

6.3.6.6 To find out the channels of communication used by Tomas Robert Lindahl

An analysis of Figure 82 shows that Tomas Robert Lindahl published his works in various journals. The highest number of publications has appeared in the journal *'Journal of Biological Chemistry' followed* by *'Proceedings of the National Academy of Sciences of the United States of America'*.

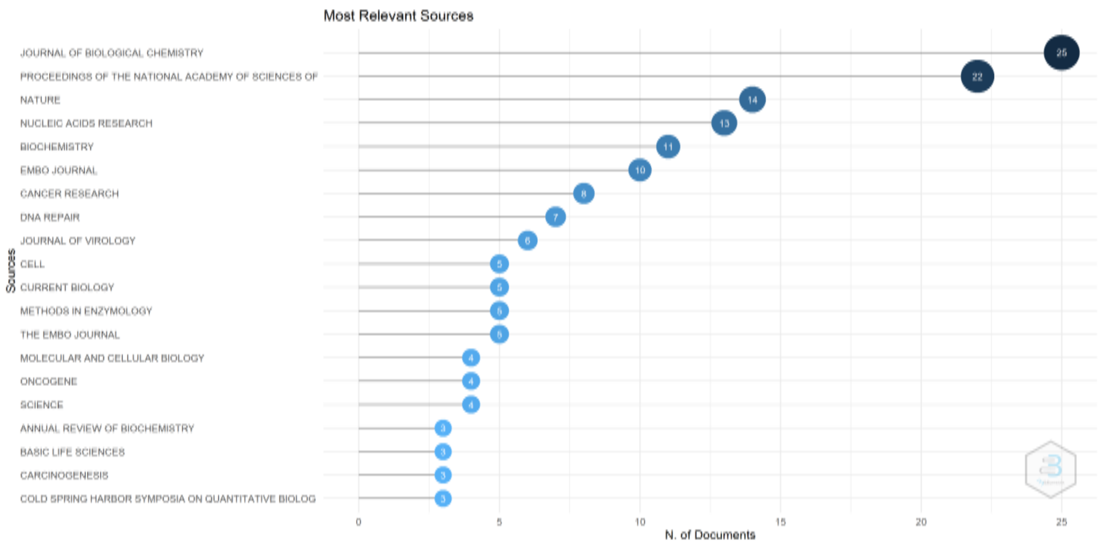


Fig 82: Most Relevant Sources

Table 60: Most Relevant Sources

Sources	Articles
Journal Of Biological Chemistry	25
Proceedings Of the National Academy of Sciences of The United States	22

of America	
Nature	14
Nucleic Acids Research	13
Biochemistry	11
Embo Journal	10
Cancer Research	7
Dna Repair	7
Journal Of Virology	6
Cell	5
Current Biology	5
Methods In Enzymology	5
The Embo Journal	5
Molecular And Cellular Biology	4
Oncogene	4
Science	4
Annual Review of Biochemistry	3
Basic Life Sciences	3
Carcinogenesis	3
Cold Spring Harbor Symposia on Quantitative Biology	3
Genes And Development	3
Iarc (International Agency for Research on Cancer) Scientific Publications	3
International Journal of Cancer	3
Journal Of Molecular Biology	3
Mutation Research-Dna Repair	3
Mutation Research - Fundamental and Molecular Mechanisms of Mutagenesis	3
American Journal of Human Genetics	2
Cancer Surveys	2
Current Opinion in Cell Biology	2
European Journal of Biochemistry	2
Febs Letters	2
Genomics Proteomics and Bioinformatics	2

Molecular Cell	2
Mutation Research	2
Nature Chemical Biology	2
Philosophical Transactions of The Royal Society B: Biological Sciences	2
Progress In Clinical and Biological Research	2
Progress In Nucleic Acid Research and Molecular Biology	2
Virology	2
Acta Pathologica Microbiologica Scandinavica	1
Angewandte Chemie - International Edition	1
Annual Review of Genetics	1
Bba - Biochimica Et Biophysica Acta	1
Bba Specialized Section on Nucleic Acids and Related Subjects	1
Biochemical And Biophysical Research Communications	1
Biochemical Society Transactions	1
Biochimie	1
Biological Chemistry Hoppe-Seyler	1
Biotechnology And Bioengineering	1
British Journal of Cancer	1
Ciba Foundation Symposia	1
Current Biology: Cb	1
Current Opinion in Genetics and Development	1
Esmo Open	1
European Journal of Cancer Part A	1
Faseb Journal	1
Free Radical Biology and Medicine	1
Genome Biology	1
Genomics	1
Johns Hopkins Medical Journal. Supplement	1
Journal Of Bacteriology	1
Journal Of Cell Science	1
Journal Of Immunology	1
Journal Of the American Chemical Society	1
Journal Of the National Cancer Institute	1

Mgg Molecular & General Genetics	1
Mutation Research - Reviews in Mutation Research	1
Mutation Research/Reviews in Genetic Toxicology	1
Nature Genetics	1
Nature Reviews Molecular Cell Biology	1
Philosophical Transactions of The Royal Society of London. Series B Biological Sciences	1
The Journal of General Virology	1
The Lancet	1
Trends In Biochemical Sciences	1

6.3.6.7 Author's performance based on available metrics indicators (Tomas Robert Lindahl)

Table 61: Performance of the Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	32.35	01	i10-index (i10)	200
02	Total Citation	38267	02	h5-index (h5)	4
03	Audience Factor	36.85	03	g-Index	195
04	CiteScore (Maximum)	56.9	04	a-Index	338.88
05	ResearchGate Citations	12349	05	h(2)-index	20
06	Microsoft Academic Search Citations	55130	06	hg-index (hg)	138.94
07	Google Scholar Citations	45160	07	r-index	183.16
08	Eigenfactor	12.93	08	ar-index (ar)	609.98
09	Crown Indicator	99.257	09	k-index	0.10
10	Mean Citation Score	169.24	10	q^2-index	20.21
11	Mean Normalized Citation Score (MNCS)	125.97	11	f-index	2.42
12	Mean Citation Rate Subfield (MCRS)	158.29	12	m-index	4.13
13	Scientific Talent Pool (STP)	80.28	13	m quotient (m-q)	4.13
14	Microsoft Academic Search	197	14	Contemporary-	0.22

	Papers (MASP)			index (Ch)	
15	Google Scholar Papers (GSP)	180	15	Trendh h-index (Th)	0.01
16	Impact per Paper (IPP)	69.23	16	Dynamic h-Type index (Dh-T)	33.30
17	Citation per paper (CPP)	1.62	17	n-index	3.30
18	Citations per Paper self-citation not included (CPPex)	153.18	18	mean h-index	51.50
19	The average number of citations per publication (ANCP)	5.985	19	Normalized h-index	78.61
20	Total and the Average Number of Citations (TNCS)	38267, 5.985	20	Specific-impact s-index (Sis)	17.35
21	Relative Activity Index (RAI)	25.31	21	Seniority independent Hirsch type index (Sih-T)	2
22	Relative Specialization index (RSI)	98.99	22	Hw-index	186.16
23	Relative Citation Rate (RCR)	72	23	Hm-index	19
24	Relative Database Citation Potential (RDCP)	52.01	24	Tapered h-index	0.05
25	Journal Acceptance Rate (JAR)	78	25	i20-index	179
26	% Self Citations (%SC)	4.29	26	v-index over h	3.45
27	Percentage of papers not cited (%Pnc)	5.44	27	e-index	154.10
28	PR Percentile Ranks (PR)	5.99	28	Multidimensional h-index	78.26
29	LogZ-score (LogZ)	15.993	29	Research Collaboration Index	85.37
30	Innovative Knowledge (IK)	78.24	30	Communities Collaboration Index	62.13

31	Technological Impact (TI)	89.84	31	ch-index	17.98
32	Scientific Talent Pool (STP)	80.28	32	speed s-iCitationndex	5.91
33	Normalized position of publication journal (NPJ)	23	33	π-index	155.95
34	WorldCat Hold (WCH)	210.4	34	h5-median (h5-m)	4
35	Papers in Top 1 (PT1)	4	35	2nd generation citations h index	76
36	Papers in Top 10 (PT10)	14	36	Role basedh-maj-index (Rbhm)	22.22
37	Papers in Top 50 (PT50)	35	37	h2 lower (h2-l)	6
38	High Cited Papers (HCP)	3	38	h2-center (h2-c)	18
39	Papers in First Quartile (Q1)	35	39	h2-upper (h2-u)	34
40	Publications in Thomson Reuters indices (PWoS)	1	40	h3-index	17
41	Number of highly cited publications (NHCP)	48	41	p-index	86.2
42	Publications in top-ranked journals (PTRJ)	172	42	$\bar{h}$-index (Hbar)	88.99
43	Papers in Collaboration (PCol)	204	43	Mockhm-index (Mhm)	18.87
44	Share of articles coauthored with another unit (%CoA)	85	44	w-index	16.67
45	National Collaboration (NCol)	79	45	b-index	23.24
46	International Collaboration (ICol)	21	46	Generalizedh-index	88.95
47	Scientific Leadership (SL)	19.85	47	Single paperh-index	64.8
48	Average Authors per Paper	1.74	48	hint-index	78.88
49	Productivity per Paper	0.19	49	h_{rat}-index	99.88
50	RoG, CAGR, RGR and DT	0.21, (-	50	πv-index	

		)0.789, 0.23, 3.72			

6.3.6.8 To assess the scientific collaboration of Tomas Robert Lindahl.

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Jean-Pierre Sauvage has collaborated with 239 different authors in the conduct and publication of his research work. The author has published only 35 single-authored documents.

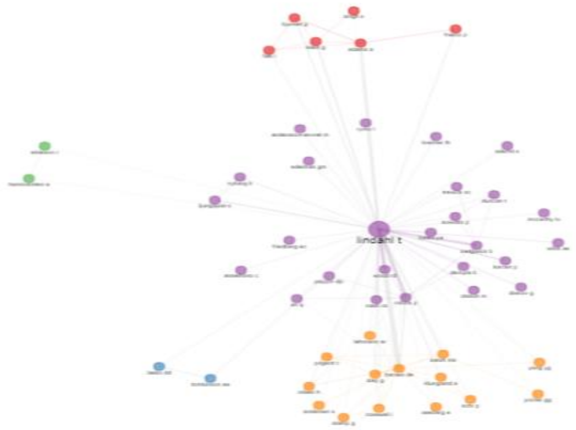


Fig 83: Collaboration Network

6.3.6.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Tomas Robert Lindahl, the collaboration index has been calculated at 2.03.

6.3.6.8.2 National and International Collaboration: Tomas Robert Lindahl has published his papers in collaboration with 404 co-authors of mostly hailing from the United Kingdom, the United States of America, Sweden, and France besides a host of other countries. The collaboration map of Jean-Pierre Sauvage is produced in figure 84.

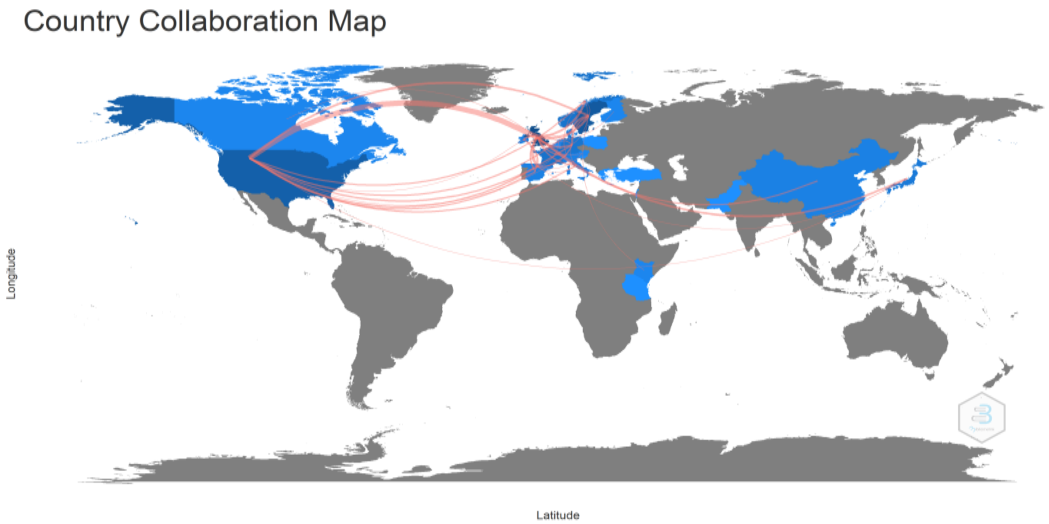


Fig. 84: National and International Collaboration

6.3.6.8.3 Co-authorship index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Tomas Robert Lindahl has been calculated at 4.17.

6.3.6.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources has resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Tomas Robert Lindahl had close communication with 95 authors while publishing his documents.

6.3.6.9 To find out the research network of Tomas Robert Lindahl.

6.3.6.9.1 Co-authorship: Tomas Robert Lindahl had collaborated with 404 co-authors.

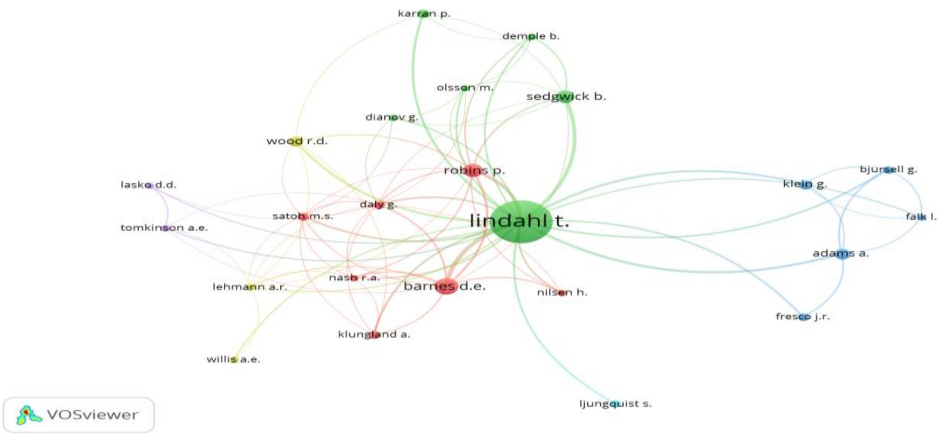


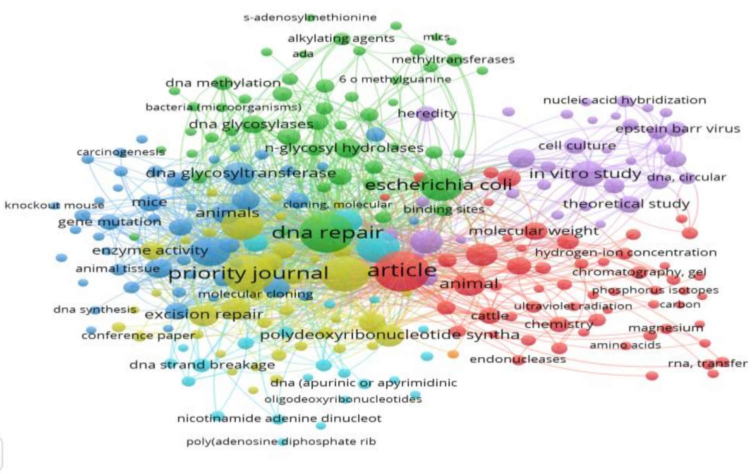
Fig. 85: Co-authorship pattern of Tomas Robert Lindahl

On analysis of the co-authorship pattern, it is observed that the author's collaboration with D E Barnes, P Robins, A Adams, and B Sedgwick were the highest. A graphical representation of the co-authorship pattern is shown in figure 85 below.

6.3.6.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top four keywords on the decreasing order of their link strengths.

Table 62: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	127	2088
dna repair	120	2003
priority journal	108	1882
human	96	1520



Fig, 86: Co-occurrence of Keywords

6.3.6.9.3 Citation analysis: Of the 239 papers published by Tomas Robert Lindahl, either as a single author or in collaboration, 227 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *'Instability and decay of the primary structure of DNA',* published in the journal *Nature* in 1993 has been cited 3962 times followed by the article *'N6-Methyladinosine in uclear RNA is a major substrate of the obesity associated FTO'* published in *Nature of Chemical Biology* in 2011 which received 1383 citations.

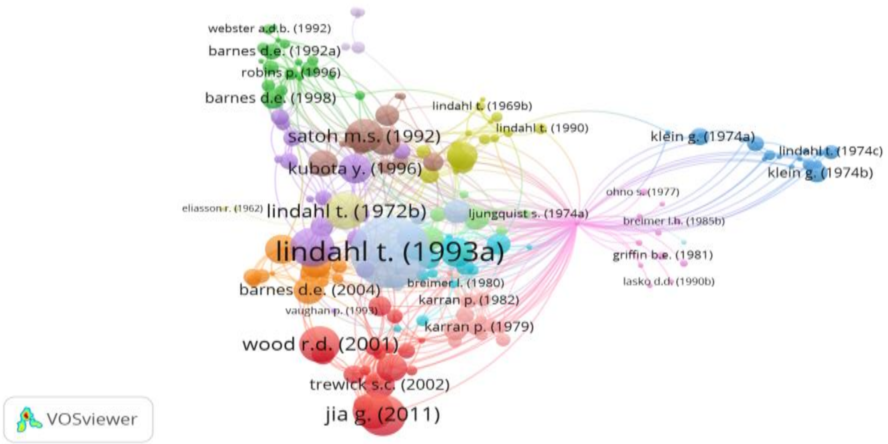


Fig. 87: Citation Analysis

6.3.6.9.4 Bibliographic coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Tomas Robert Lindahl is presented in figure 88.

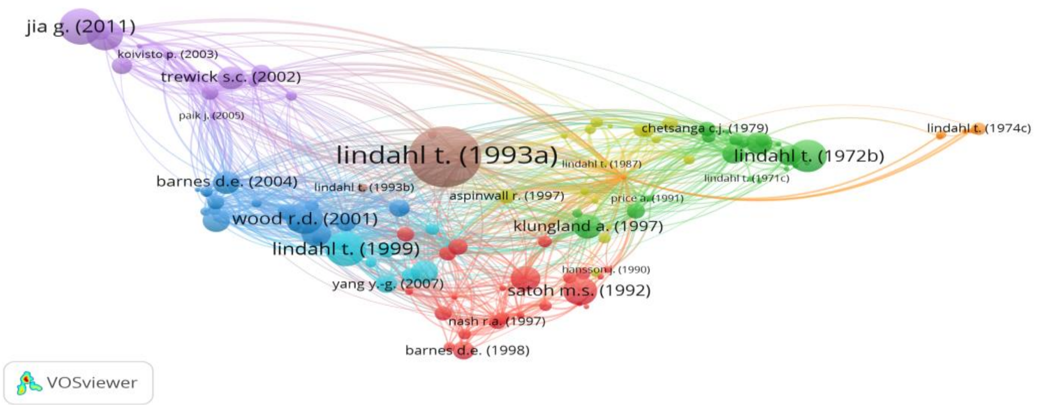


Fig. 88: Bibliographic Coupling

6.3.6.9.5 Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of Tomas Robert Lindahl is produced in Fig. 89. Analysis of the figure shows that the articles published by Tomas Robert Lindahl has been co-cited by 5 clusters, having 29, 17, 13, 10, and 2 authors each. There are a total of 2227 links, with a total link strength of 75404.

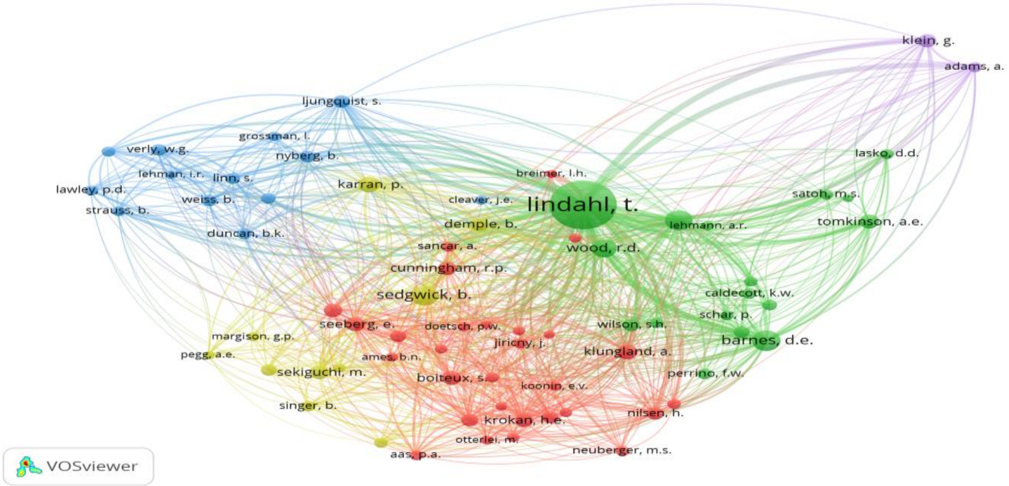


Fig. 89: Co-citation Analysis Pattern

6.3.6.10 To Analyze Cluster Mapping (Tomas Robert Lindahl)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 90 shows the coupling map of Tomas Robert Lindahl.

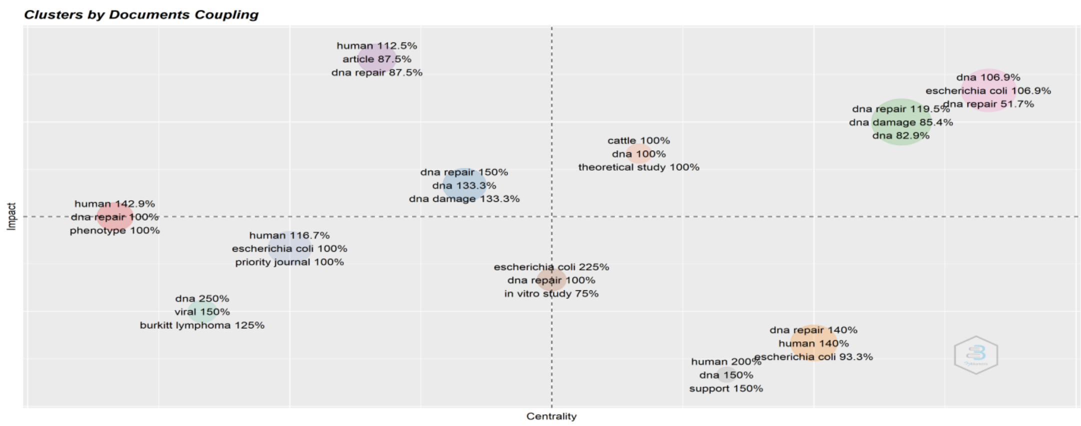


Fig 90: Document Coupling

6.3.6.11 Other Information (Tomas Robert Lindahl)

Table 63: Main Information

Description	**Results**
Timespan	1962:2017
Sources	
Journals, Books, Etc	74
Documents	239
Total	313
Average Years from Publication	32
Average Citations Per Documents	154.6
Average Citations Per Year Per Doc	5.985
References	5004
Document Types	
Article	198
Conference Paper	9
Editorial	4
Erratum	1
Letter	3
Review	23
Short Survey	1
Total	239
Document Contents	
Keywords Plus (Id)	1472
Author's Keywords (De)	113
Authors	
Authors	416
Author Appearances	997
Authors Of Single-Authored Documents	1
Authors Of Multi-Authored Documents	415
Authors Collaboration	
Single-Authored Documents	35
Documents Per Author	0.575
Authors Per Document	1.74

Co-Authors Per Documents	4.17
Collaboration Index	2.03
H-Index	99
Total Citation	38267 Citations by 23603 Documents

The publication productivity of Tomas Robert Lindahl is consistent throughout the entire productive life and he has made outstanding contributions in the field of cancer research and DNA repair in the entire productive years of his life which commenced from 1962. Tomas Robert Lindahl has been consistently active in research despite many administrative responsibilities. He has preferred to work in collaboration and has a high degree of collaboration at institutional, national, and international levels. The high rate of citations received by his papers proves the usefulness and impact that his works have in the field of supramolecular chemistry. Tomas Robert Lindahl's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

2016

The Chemistry Nobel Prize for 2016 was jointly awarded to three researchers for *the design and synthesis of molecular machines.* The award was shared by Jean-Pierre Sauvage, Sir J Fraser Stoddart, and Bernard L. Feringa.

6.3.7 BERNARD LUCAS FERINGA

Bernard Lucar Feringa (dob: 18.05.1951) is a Dutch synthetic organic chemist who specialized in molecular nanotechnology and homogeneous catalysis. He is also the Jacobus van't Hoff Distinguidshed Professor of Melecular Sciences at the Stratingh Institute for Chemistry at the University of Groningen at the Netherlands. He is also an Academy Professor of the Royal Netherlands Academy of Arts and Sciences.

6.3.7.1 To assess the number of scientific communications contributed by Bernard Lucas Feringa.

The works of Bernard L. Feringa has been in the form of articles, books, editorials, conference papers, editorials, erratums, letters, reviews, and short surveys. Table 64 shows the number of such scientific communications conytributed by the scientist.

Table 64: Scientific Communication

Document Types	
Article	753
Book	1
Book Chapter	12
Conference Papers	25
Editorial	3
Erratum	4
Letter	11
Note	4
Review	32
Short Survey	10

6.3.7.2 To analyze the domain-wise scientific communication of Bernard Lucas Feringa.

Among the different domains in which he has published his works include catalysis, material chemistry, molecular nanotechnology, molecular science, and organic chemistry. Table 65 shows the total number of documents published by Bernard L. Feringa in all documents. An analysis of the table shows that most of his studies are in the field of molecular nanotechnology followed by organic chemistry. Among the documents, the maximum numbers of papers are in the form of articles, followed by reviews. Some of his research works have also been published in the form of letters, erratum and short survey, and book and editorial.

Table 65: Number of Scientific Communication

Documents	Domain					Total Papers	%
	A	B	C	D	E		
Article	152	145	252	40	164	753	**88.07**
Book	0	0	1	0	0	1	**0.12**
Book Chapter	4	0	6	0	2	12	**1.40**
Conference Paper	10	3	4	1	7	25	**2.92**
Editorial	0	2	1	0	0	3	**0.36**
Erratum	1	0	1	0	2	4	**0.47**
Letter	1	0	3	6	1	11	**1.29**

Note	2	1	1	0	0	4	**0.47**
Review	2	9	14	0	7	32	**3.74**
Short Survey	1	2	3	3	1	10	**1.16**
Total	**173**	**162**	**286**	**50**	**184**	**855**	
%	**20.23**	**18.95**	**33.45**	**5.85**	**21.52**		

A: Catalysis B: Material Chemistry C: Molecular Nanotechnology D: Molecular Science E. Organic Chemistry

A graphical representation of the above data can be observed in Figure 91 below.

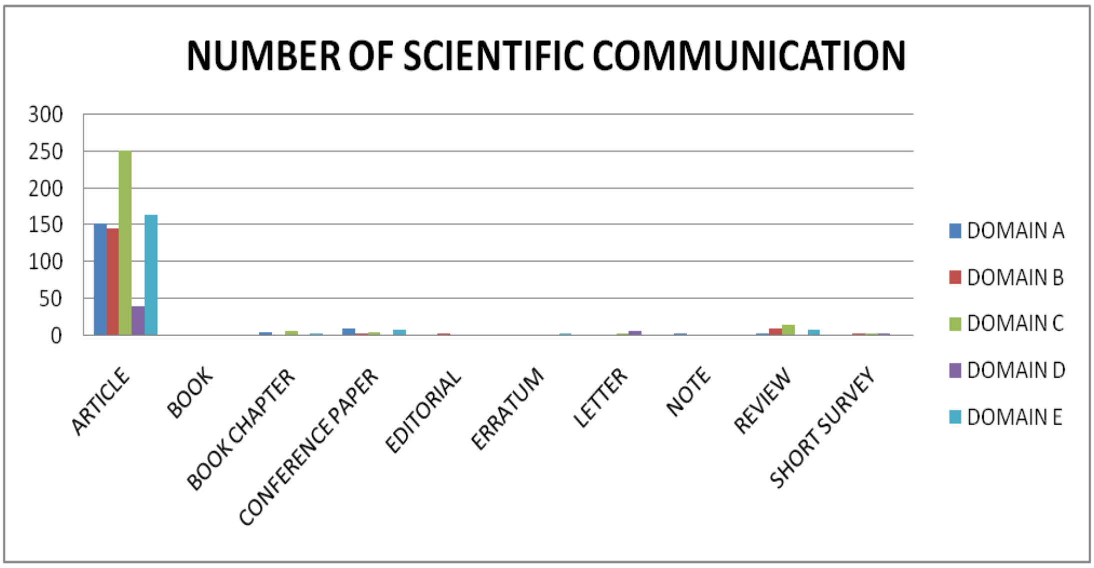


Fig 91: Number of Scientific Communication

6.3.7.3 To analyze the domain-wise authorship pattern of Bernard Lucas Feringa.

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Feringa are multi-authored having more than 3 authors. He has very few single authored publications aith the percentage of such publications standing at 2.46%. The author has contributed with 16 co-authors for publication of his scientific communications. Table 66 is a tabular form of the authorship pattern and Figure 92 presents a graphical view of the data.

Table 66 shows the domain-wise authorship pattern of Bernard L Feringa. Feringa has authored 21 single-authored documents which represent 2.46% of his total publications. However, most of his publications have 5 to 10 authors. Bernard L Feringa has co-authored with a maximum of 16 authors for a single publication. A graphical view of the above information is provided in figure 92.

Table 66: Domain-wise Authorship as per Collaboration

Domain	Authors					
	1 - Author	2 - Author	3 - Author	4 - Author	5 – 10 Author	11 – 16 Author
A	3	24	28	39	75	4
B	2	13	20	34	87	6
C	6	28	47	51	149	5
D	2	4	7	8	28	1
E	8	17	30	40	82	7
Total	**21**	**86**	**132**	**172**	**421**	**23**
%						

A: Catalysis B: Material Chemistry C: Molecular Nanotechnology D: Molecular Science E. Organic Chemistry

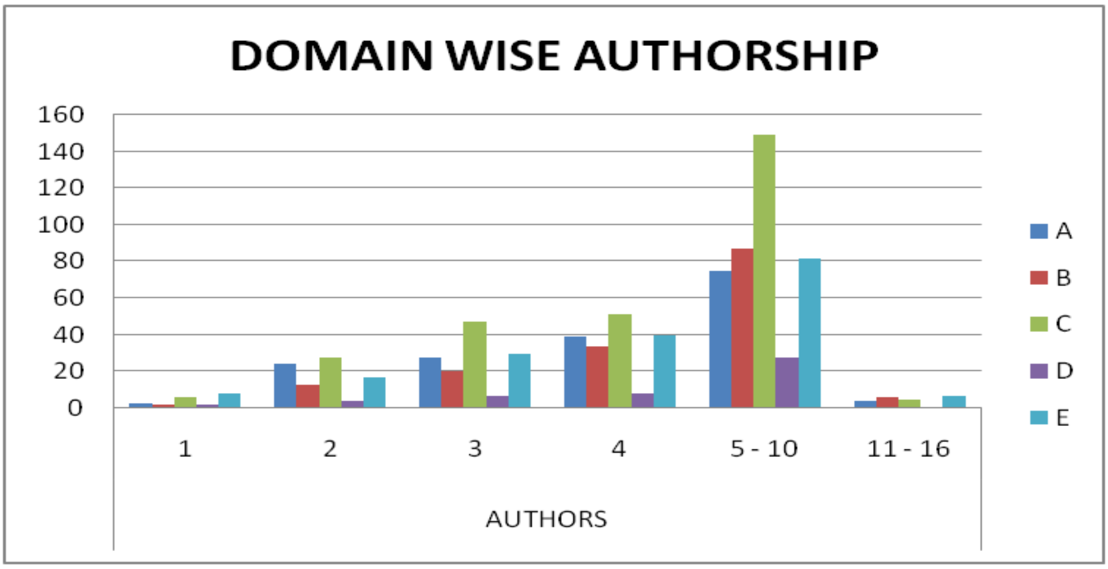


Fig 92: Domain-wise Authorship

6.3.7.4 To analyze the year-wise scientific communication of Bernard Lucas Feringa.

Bernard Lucas Feringa's publication life began in 1976, or when he had attained a biological age of 25 years. A look into his year-wise productivity reveals that the author has published the maximum number of works from 2001 till 2010 when he had published 344 papers in all domains at 40.23%. During the first 10 years of his productive life, Feringa has published 8 papers (0.94%) which is the lowest number of works published by the author. A tabular form of this information is provided in Table 67, while a graphical representation is given in Figure 93.

Table 67: Domain and Year-wise Authorship

Period	Domain					Total Papers	%
	A	B	C	D	E		
1971-1980	0	0	4	0	4	**8**	**0.94**
1981-1990	10	0	15	0	17	**42**	**4.91**
1991-2000	31	1	71	42	25	**170**	**19.88**
2001-2010	101	99	75	8	61	**344**	**40.23**
2011-2020	31	62	121	0	77	**291**	**34.04**

A: Catalysis B: Material Chemistry C: Molecular Nanotechnology D: Molecular Science E. Organic Chemistry

Table 68: Year-wise Productivity

Year	Domain					Total Papers	%
	A	B	C	D	E		
1971	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0
1973	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0
1979	0	0	4	0	0	4	0
1980	0	0	0	0	4	4	0.47
1981	2	0	0	0	0	2	0.23
1982	1	0	0	0	0	1	0.12
1983	2	0	0	0	0	2	0.23
1984	1	0	0	0	0	1	0.12
1985	3	0	0	0	0	3	0.35
1986	3	0	1	0	0	4	0.47
1987	0	0	3	0	0	3	0.35
1988	0	0	7	0	0	7	0.82
1989	0	0	6	0	0	6	0.70
1990	0	0	0	0	9	9	1.05

1991	10	0	0	0	0	10	1.17
1992	15	0	0	0	0	15	1.75
1993	6	1	3	0	0	10	1.17
1994	0	0	20	0	0	20	2.34
1995	0	0	15	0	0	15	1.75
1996	0	0	16	0	0	16	1.87
1997	0	0	17	7	0	24	2.81
1998	0	0	0	15	0	15	1.75
1999	0	0	0	20	2	22	2.57
2000	0	0	0	0	21	21	2.46
2001	22	0	0	0	0	22	2.57
2002	19	0	0	0	0	19	2.22
2003	27	0	0	0	0	27	3.16
2004	26	0	0	0	0	26	3.04
2005	7	34	0	0	0	41	4.79
2006	0	37	0	0	0	37	4.33
2007	0	28	5	0	0	33	3.86
2008	0	0	52	0	0	52	6.08
2009	0	0	26	8	3	37	4.33
2010	0	0	0	0	44	44	5.15
2011	12	17	10	0	0	39	4.56
2012	0	15	12	0	0	27	3.16
2013	5	0	25	0	12	42	4.91
2014	0	15	10	0	15	40	4.68
2015	4	0	15	0	7	26	3.04
2016	0	5	10	0	18	33	3.86
2017	5	0	21	0	10	36	4.21
2018	0	10	5	0	10	25	2.92
2019	5	0	11	0	4	20	2.34
2020	0	0	2	0	0	2	0.23

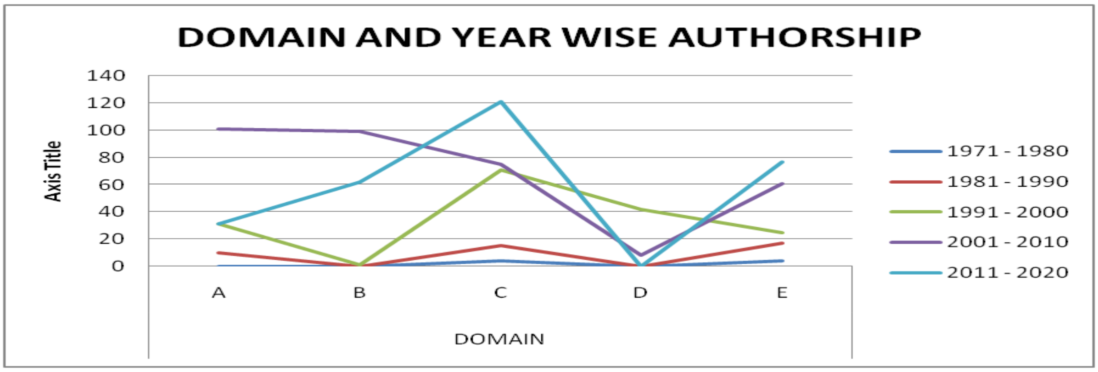


Fig 93: Domain wise and Year wise Authorship

6.3.7.6 Author's production over time (Bernard Lucar Feringa)

The year-wise authorship pattern of Bernard Lucas Feringa is shown in Figure 94.

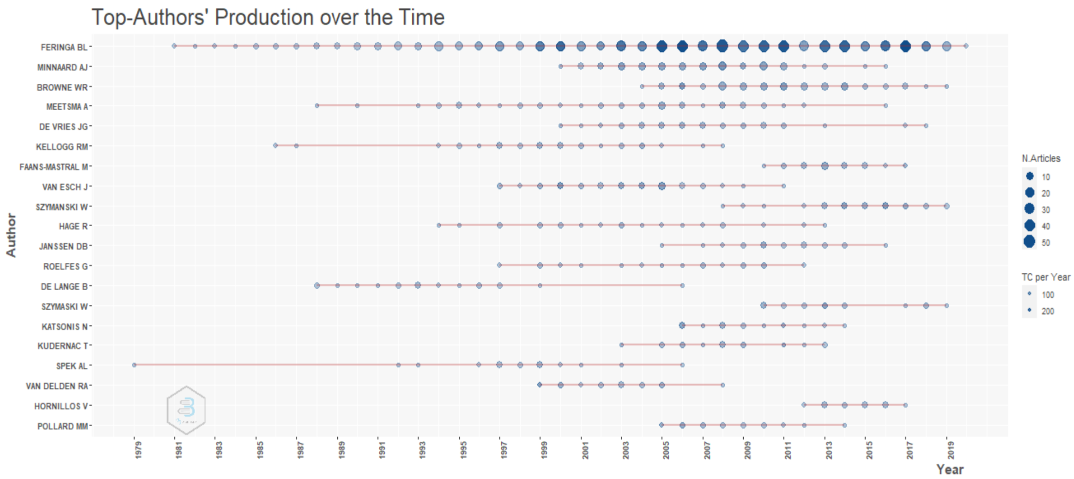


Fig 94: Authors' Production Over Time

6.3.7.7 To find out the channels of communication used by Bernard Lucas Feringa.

Bernard Lucas Feringa has published his works in various journals. Figure 95 is a graphical representation of the data, which indicates that the maximum number of papers (92) have appeared in the journal *'Journal of The American Chemical Society.*

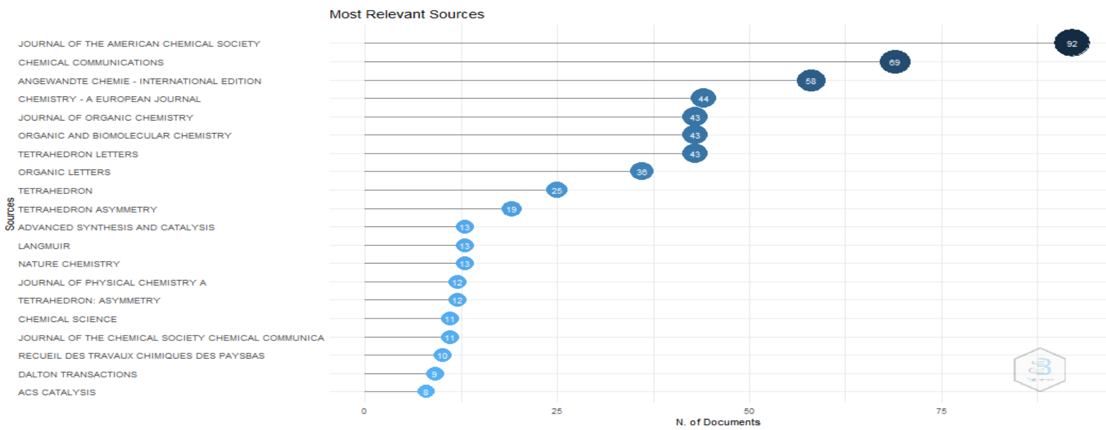


Fig 95: Most Relevant Sources

Table 69: Most Relevant Sources

Sources	Articles
Journal Of the American Chemical Society	105
Chemical Communications	78
Angewandte Chemie - International Edition	69
Chemistry - A European Journal	49
Journal Of Organic Chemistry	44
Organic And Biomolecular Chemistry	44
Tetrahedron Letters	43
Organic Letters	36
Tetrahedron	25
Tetrahedron Asymmetry	19
Chemical Science	17
Advanced Synthesis and Catalysis	14
Langmuir	14
Nature Chemistry	14
Journal Of Physical Chemistry A	13
Tetrahedron: Asymmetry	12
Journal Of the Chemical Society Chemical Communications	11
Recueil Des Travaux Chimiques Des Paysbas	10
Advanced Materials	9
Chemical Society Reviews	9
Dalton Transactions	9
Nature Communications	9
Acs Catalysis	8
European Journal of Organic Chemistry	8
Inorganic Chemistry	8
Journal Of Physical Chemistry C	8
Science	8
Proceedings Of the National Academy of Sciences of The United States of America	7
Chirality	6
Accounts Of Chemical Research	5

Acs Nano	5
Chemical Reviews	5
Chemphyschem	5
Chemsuschem	5
Inorganica Chimica Acta	5
Nature	5
Science Advances	5
Synthesis	5
Synthetic Communications	5
Angewandte Chemie International Edition in English	4
Chembiochem	4
Chimia	4
Molecular Switches Second Edition	4
Nature Nanotechnology	4
Chem	3
Chimica Oggi	3
Journal Of Materials Chemistry	3
Journal Of the Chemical Society - Dalton Transactions	3
Organometallics	3
Physical Chemistry Chemical Physics	3
Pure And Applied Chemistry	3
Synlett	3
Advanced Functional Materials	2
American Chemical Society Polymer Preprints Division of Polymer Chemistry	2
Angewandte Chemie (International Edition in English)	2
Biochemistry	2
Chemical Physics Letters	2
Chemisch Magazine	2
Coordination Chemistry Reviews	2
Epj Web Of Conferences	2
Faraday Discussions	2
From Non-Covalent Assemblies to Molecular Machines	2

Israel Journal of Chemistry	2
Journal Of Controlled Release: Official Journal of The Controlled Release Society	2
Journal Of Medicinal Chemistry	2
Journal Of Physical Chemistry B	2
Journal Of the Chemical Society - Perkin Transactions 1	2
Matter	2
Molecular Crystals and Liquid Crystals	2
Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals	2
Nano Letters	2
Nanotechnology	2
Nature Catalysis	2
Nature Protocols	2
Nuclear Medicine and Biology	2
Optics Infobase Conference Papers	2
Organic Chemistry Frontiers	2
Pharmaceuticals	2
Photochemical And Photobiological Sciences	2
Physical Review B	2
Small	2
Solid State Phenomena	2
Synthesis (Germany)	2
Topics In Organometallic Chemistry	2
2nd Conference on Foundations of Nanoscience: Self-Assembled Architectures and Devices Fnano 2005	1
Acs Chemical Biology	1
Acs Omega	1
Acta Crystallographica Section C: Crystal Structure Communications	1
Advanced Optical Materials	1
Advanced Science	1
Advanced Therapeutics	1
Aip Conference Proceedings	1

Analytical Methods	1
Annual Review of Physical Chemistry	1
Applied And Environmental Microbiology	1
Applied Microbiology and Biotechnology	1
Applied Physics A: Materials Science and Processing	1
Applied Radiation and Isotopes	1
Beilstein Journal of Organic Chemistry	1
Bioconjugate Chemistry	1
Bioorganic And Medicinal Chemistry	1
Bioorganic Chemistry	1
Bulletin Des Socits Chimiques Belges	1
Chemcatchem	1
Chemistry - An Asian Journal	1
Chemistry A European Journal	1
Chemistry And Biology	1
Chempluschem	1
Chemtracts	1
Chirality At the Nanoscale: Nanoparticles Surfaces Materials and More	1
Comprehensive Chiroptical Spectroscopy	1
Comprehensive Chiroptical Spectroscopy: Applications in Stereochemical Analysis of Synthetic Compounds Natural Products and Biomolecules	1
Comptes Rendus Chimie	1
Current Organic Chemistry	1
Enantiomer	1
Enzyme Catalysis in Organic Synthesis Third Edition	1
European Journal of Inorganic Chemistry	1
European Journal of Medicinal Chemistry	1
Graphene Science Handbook: Fabrication Methods	1
Green Chemistry	1
Helvetica Chimica Acta	1
Heterocycles	1
International Journal of Nanotechnology	1

Journal Of Applied Physics	1
Journal Of Chemical Education	1
Journal Of Chromatography A	1
Journal Of Combinatorial Chemistry	1
Journal Of Controlled Release	1
Journal Of Labelled Compounds and Radiopharmaceuticals	1
Journal Of Lipid Research	1
Journal Of Materials Chemistry B	1
Journal Of Materials Chemistry C	1
Journal Of Molecular Catalysis A: Chemical	1
Journal Of Physical Chemistry Letters	1
Journal Of the Chemical Society. Perkin Transactions 2	1
Journal Of Visualized Experiments	1
Lab On a Chip	1
Materials Chemistry Frontiers	1
Materials Research Society Symposium Proceedings	1
Modern Oxidation Methods	1
Molecular Biosystems	1
Molecular Crystals and Liquid Crystals Science and Technology Section A: Molecular Crystals and Liquid Crystals	1
Molecular Gels: Materials with Self-Assembled Fibrillar Networks	1
Nanoscale	1
Nanoscale Advances	1
Nanoscience And Technology: A Collection of Reviews from Nature Journals	1
Nature Materials	1
Nature Reviews Chemistry	1
New Journal of Chemistry	1
Nippon Kagaku Kaishi / Chemical Society of Japan - Chemistry and Industrial Chemistry Journal	1
Particle And Particle Systems Characterization	1
Physica Status Solidi (C) Current Topics in Solid State Physics	1
Physical Review B - Condensed Matter and Materials Physics	1

Physical Review Letters	1
Proceedings Of Spie - The International Society for Optical Engineering	1
Progress In Surface Science	1
Recueil Des Travaux Chimiques Des Pays-Bas	1
Recueil Des Travaux Chimiques des Pays-Bas-Journal of The Royal Netherlands	1
Rsc Advances	1
Soft Matter	1
Studies In Surface Science and Catalysis	1
The Handbook of Homogeneous Hydrogenation	1
Thin Solid Films	1
Topics In Catalysis	1
Topics In Current Chemistry	1
Trends In Biotechnology	1
Trends In Molecular Medicine	1

6.3.7.7 Author's performance based on available metrics indicators (Bernard Lucar Feringa)

Table 70: Performance of Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	45.98	01	i10-index (i10)	726
02	Total Citation	61099	02	h5-index (h5)	39
03	Audience Factor	203	03	g-Index	202
04	CiteScore (Maximum)	56.9	04	a-Index	273.54
05	ResearchGate Citations	25346	05	h(2)-index	11
06	Microsoft Academic Search Citations	45797	06	hg-index (hg)	155.69
07	Google Scholar Citations	32620	07	r-index	181.18
08	Eigenfactor	100.2	08	ar-index (ar)	505
09	Crown Indicator	6.302	09	k-index	0.04
10	Mean Citation Score	72.89	10	q2-index	24
11	Mean Normalized Citation Score	68.21	11	f-index	1.28

	(MNCS)				
12	Mean Citation Rate Subfield (MCRS)	72.89	12	m-index	4.80
13	Scientific Talent Pool (STP)	48.22	13	m quotient (m-q)	4.80
14	Microsoft Academic Search Papers (MASP)	840	14	Contemporary-index (Ch)	206.3
15	Google Scholar Papers (GSP)	781	15	Trendh h-index (Th)	0.07
16	Impact per Paper (IPP)	92.57	16	Dynamic h-Type index (Dh-T)	0.03
17	Citation per paper (CPP)	72.98	17	n-index	4.80
18	Citations per Paper self-citation not included (CPPex)	69.26	18	mean h-index	61
19	The average number of citations per publication (ANCP)	56.29	19	Normalized h-index	18.29
20	Total and the Average Number of Citations (TNCS)	61099 and 56.29	20	Specific-impact s-index (Sis)	22.08
21	Relative Activity Index (RAI)	23.89	21	Seniority independent Hirsch type index (Sih-T)	7
22	Relative Specialization index (RSI)	55.29	22	Hw-index	181.18
23	Relative Citation Rate (RCR)	68.22	23	Hm-index	34
24	Relative Database Citation Potential (RDCP)	44.58	24	Tapered h-index	0.07
25	Journal Acceptance Rate (JAR)	77.53	25	i20-index	607
26	% Self Citations (%SC)	11.28	26	v-index over h	3.45
27	Percentage of papers not cited (%Pnc)	2.68	27	e-index	135.74
28	PR Percentile Ranks (PR)	48	28	Multidimensional h-index	47.95
29	LogZ-score (LogZ)	15.225	29	Research	40.75

				Collaboration Index	
30	Innovative Knowledge (IK)	19.68	30	Communities Collaboration Index	15.98
31	Technological Impact (TI)	62.23	31	ch-index	68.96
32	Scientific Talent Pool (STP)	48.22	32	speed s-iCitationndex	27.65
33	Normalized position of publication journal (NPJ)	19	33	π-index	158.39
34	WorldCat Hold (WCH)	79	34	h5-median (h5-m)	19.87
35	Papers in Top 1 (PT1)	203	35	2^{nd} generation citations h index	89
36	Papers in Top 10 (PT10)	354	36	Role basedh-maj-index (Rbhm)	32.48
37	Papers in Top 50 (PT50)	359	37	h2 lower (h2-l)	7
38	High Cited Papers (HCP)	32	38	h2-center (h2-c)	19
39	Papers in First Quartile (Q1)	212	39	h2-upper (h2-u)	22
40	Publications in Thomson Reuters indices (PwoS)	61	40	h3-index	16
41	Number of highly cited publications (NHCP)	16	41	p-index	25.35
42	Publications in top-ranked journals (PTRJ)	241	42	$\bar{h}$-index (Hbar)	120
43	Papers in Collaboration (Pcol)	834	43	Mockhm-index (Mhm)	55.89
44	Share of articles coauthored with another unit (%CoA)	97.54	44	w-index	13.97
45	National Collaboration (Ncol)	52.30	45	b-index	55.49
46	International Collaboration (Icol)	47.70	46	Generalizedh-index	99.98
47	Scientific Leadership (SL)	21.39	47	Single paperh-index	59

48	Average Authors per Paper	1.06	48	hint-index	98
49	Productivity per Paper	18.95	49	h_{rat}-index	121
50	RoG, CAGR, RGR and DT	0.98, (-)0.25, 0.37, 1.68	50	πv-index	17.95

6.3.7.8 To analyze the scientific collaboration of Bernard Lucar Feringa

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Bernard Lucas Feringa has collaborated with 987 different authors in the conduct and publication of his research work. The author has published only 21 single-authored documents.

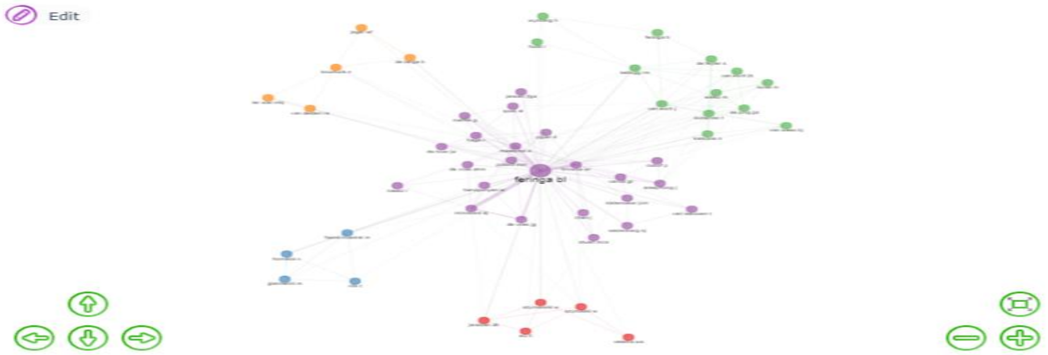


Fig 96: Collaboration Network

6.3.7.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Bernard Lucas Feringa, the collaboration index has been calculated at 1.09.

6.3.7.8.2 National and International Collaboration: Bernard Lucas Feringa has published his papers in collaboration with 987 co-authors of mostly hailing from Belgium, China, Germany, France, Italy, and the United States of America. Of the

855 papers published in collaboration, 834 have been published along with national collaboration, while the others have been published with collaborative efforts from international researchers. The collaboration map of Jacques Dubochet is produced in figure 97.

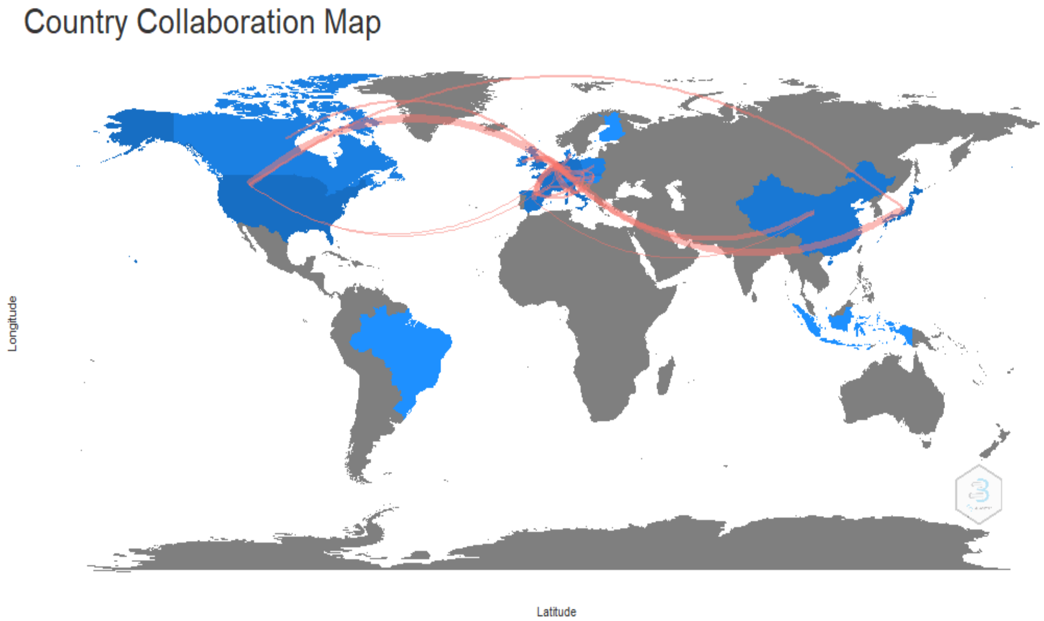


Fig. 97: National and International Collaboration

6.3.7.8.3. Co-authorship Index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Bernard Lucas Feringa has been calculated at 4.95.

6.3.7.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources have resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Bernard Lucas Feringa had close communication with 987 co-authors while publishing his documents.

6.3.7.9 To find out the research network of Bernard Lucas Feringa.

6.3.7.9.1 Co-authorship: Bernard Lucas Feringa had collaborated with 987 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with W R Browne, A J MInnard, A Meetsma and J G De varies were the highest. A graphical representation of the co-authorship pattern is shown in figure 98 below.

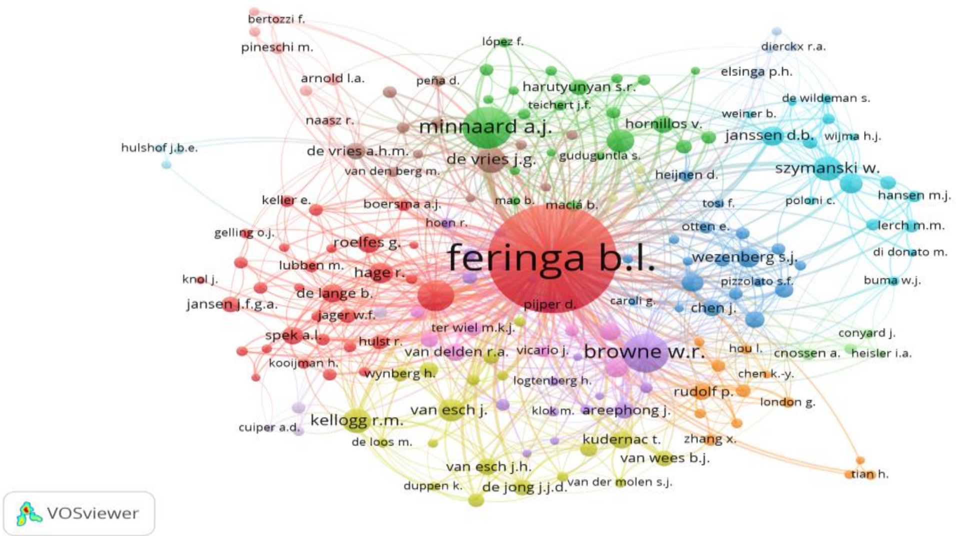


Fig. 98: Co-authorship Pattern of Bernard Lucas Feringa

6.3.7.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top four keywords on the decreasing order of their link strengths.

Table 71: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	432	5534
catalysis	216	2755
Chemical structure	157	2341
chemistry	152	2314

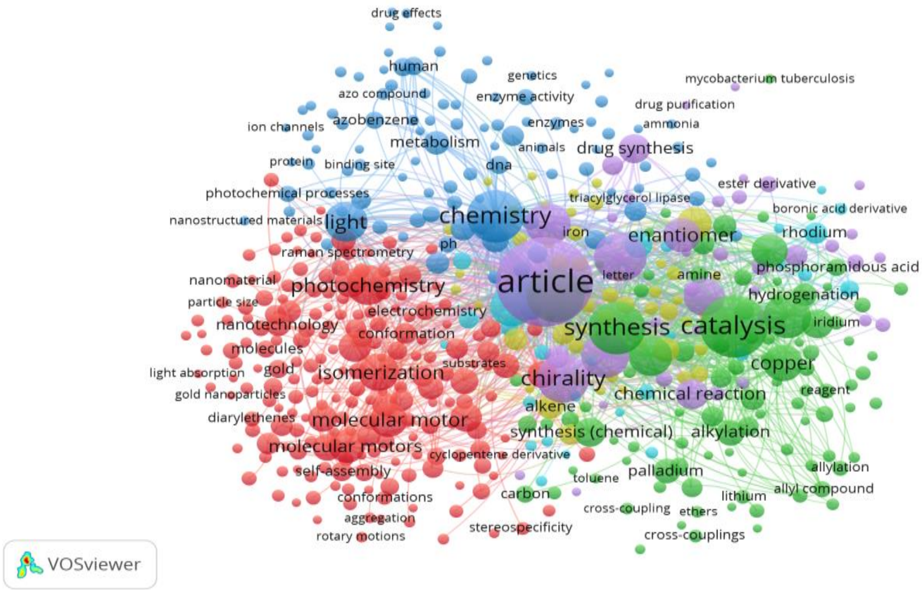


Fig. 99: Keyword Co-occurrences Authorship Pattern

6.3.7.9.3 Citation analysis: Of the 855 papers published by Bernard L. Feringa, either as a single author or in collaboration, 834 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *Light-driven Monodirectional Molecular Rotor*, published in the journal *Nature* during 1999 has been cited 1282 times followed by the article *Making Molecular Machines Work* published in *Nature Nanotechnology* in 2006 which received 1077 citations. Another article, *New Functional Materials based on self-assembling Orgagels: From Serendipity towards Design* published in the journal *Angewandte Chemie-International Edition* during 2000 has been cited 1027 times. A graphical representation of the above information is presented in Figure 100.

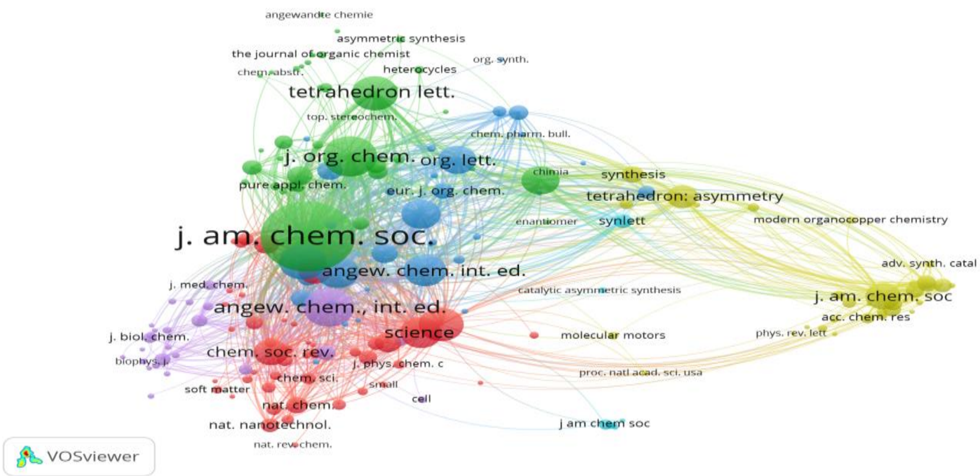


Fig. 100: Citation Analysis

6.3.7.9.4 Bibliographic Coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Bernard Lucas Feringa is presented in figure 101.

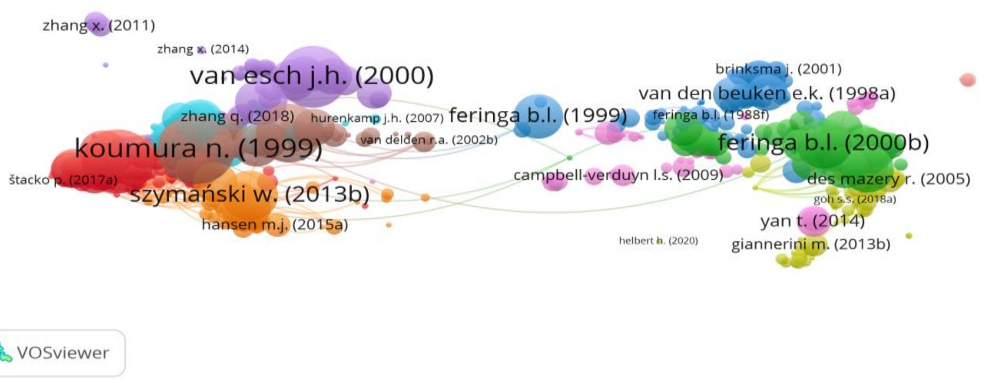


Fig. 101: Bibliographic Coupling

6.3.7.9.5. Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of Bernard Lucas Feringa is produced in Fig. 102. Analysis of the figure shows that the articles published by Bernard Lucas Feringa has been co-cited by 6 clusters, having 45, 40, 34, 32, 25, and 3 items each. There are a total of 9941 links, with a total link strength of 987731.

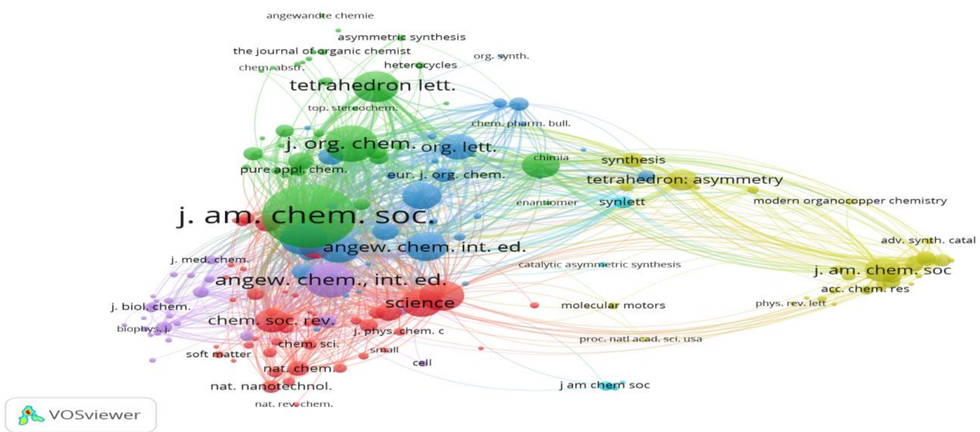


Fig. 102: Co-citation Analysis

6.3.7.10 To analyze cluster mapping (Bernard Lucar Feringa)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 103 shows the coupling map of Bernard Lucas Feringa.

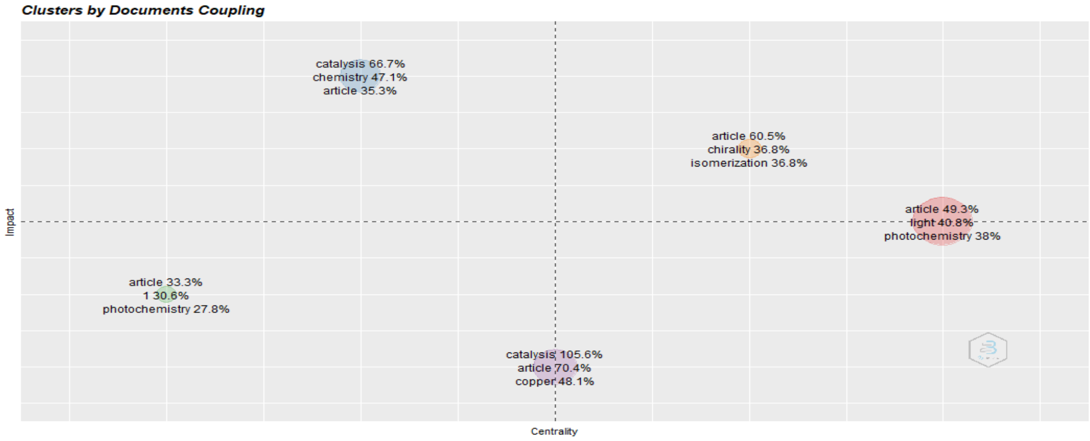


Fig 103: Document Coupling

6.3.7.11 Other Information (Bernard Lucar Feringa)

Table 72: Main Information

Description	**Results**
Timespan	1976:2020
Sources	
Journals, Books, Etc	149
Documents	855
Total	1004
Average Years from Publication	15.1
Average Citations Per Documents	67.11
Average Citations Per Year Per Doc	4.699
References	32825
Document Types	
Article	753
Book	1
Book Chapter	12
Conference Paper	25
Editorial	3

Erratum	4
Letter	11
Note	4
Review	32
Short Survey	10
Total	855
Document Contents	
Keywords Plus (Id)	4338
Author's Keywords (De)	666
Authors	
Authors	908
Author Appearances	4230
Authors Of Single-Authored Documents	2
Authors Of Multi-Authored Documents	906
Authors Collaboration	
Single-Authored Documents	21
Documents Per Author	0.942
Authors Per Document	1.06
Co-Authors Per Documents	4.95
Collaboration Index	1.09
H-Index	120
Total Citation	61099 Citations by 32481 Documents

The publication productivity of Bernard Lucas Feringa is consistent throughout the entire productive life and he has made outstanding contributions in the field of design and synthesis of molecular machines. His publication life commenced in 1976 after he had attained a biological age of 25 years. Bernard Lucas Feringa has been active in research despite many responsibilities. He has worked in collaboration and has a high degree of collaboration at institutional, national, and international levels. Bernard Lucas Feringa has an h-index of 120 and is regarded as one of the most successful scientists in the field of chemistry. Bernard Lucas Feringa’s research efforts have largely been concentrated on molecular nanotechnology and catalysis which proves his strength in this field. Bernard Lucas Feringa’s research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.8 SIR JAMES FRASER STODDART

Sir James Fraser Stoddart, a British-American chemist and a Nobel Laureate was born on 24th May 1942. Stoddart is a Board of Trustees Professor of Chemistry and head of the Stoddart Mechanostereochemistry in the Department of Chemistry at Northwestern University in the United States. Stoddart specializes in the fields of supramolecular chemistry and nanotechnology, who is credited in developing highly efficient synthesis of mechanically-interlocked molecular architectures such as molecular Borromean ring, catenanes, and rotaxanes using molecular recognition and molecular self-assembling processes. Stoddart had shown that these topologies can be used as molecular switches and applied the same in the fabrication of nanoelectroninic devices and nanoelectromechanical systems. Stoddart has been awarded with several awards including the King Faisal International Prize in Science in 2007. In 2016, he was conferred the prestigious Nobel Prize for Chemistry for the design and synthesis of molecular machines which he had shared with Bernard Louis Feranga and Jean-Pierre Sauvage.

6.3.8.1 To assess the number of scientific communications contributed by Sir James Fraser Stoddart.

Sir James Fraser Stoddart has used several media to publish his scientific works. While most of his scientific communication have been through articles that he has published himself or in collaboration with other co-authors, he has also authored books, presented conferencve papers, editorials, reviews, surveys, etc. Table 73 shows the number of scientific communications of the Nobel Laureate.

Table 73: Scientific Communication

Document Types	
Article	978
Book	3
Book Chapter	12
Conference Paper	35
Editorial	6
Erratum	5

Letter	4
Note	4
Review	34
Short Survey	6

6.3.8.2 To analyze the domain wise scientific communication of Sir James Fraser Stoddart.

The works of Sir James Fraser Stoddart can be broadly classified into five categories or domains. These include Applied Chemistry, Nanotechnology, Organic Chemistry, Stereochemistry and Supramolecular Chemistry. Translating the information in numerical and percentage terms, Sir Stoddart has published a total of 1087 papers of which 303 papers are on supramolecular chemistry (27.87%), 263 papers on applied chemistry (24.20%), 238 papers on nanotechnology (21.90%), 223 papers on organic chemistry (20.52%) and 60 on stereochemistry (5.52%). Sir James Fraser Stoddart has published his works using several modes. While most of his works, (978, 89.97%) are in the form of articles, he has also published his works in the form of Book Chapters, Conference Papers, Editorials, Errata, Letters, Notes, Reviews, and Short Surveys in varying proportions. Table 74 is a tabular form of the above information and figure 104 is a graphical form of the same.

Table 74: Number of Scientific Communication

Document	**Domain**					**Total Papers**	%
	A	B	C	D	E		
Article	235	217	193	53	280	**978**	**89.97**
Book	0	1	0	0	2	**3**	**0.28**
Book Chapter	3	3	2	1	3	**12**	**1.10**
Conference Paper	10	5	9	4	7	**35**	**3.22**
Editorial	2	2	1	0	1	**6**	**0.55**
Erratum	4	0	1	0	0	**5**	**0.46**
Letter	2	0	0	0	2	**4**	**0.37**
Note	0	0	1	0	3	**4**	**0.37**
Review	6	9	13	1	5	**34**	**3.13**
Short Survey	1	1	3	1	0	**6**	**0.55**
%	**24.40**	**21.90**	**20.52**	**5.52**	**27.87**		**100**

A: Applied Chemistry B: Nanotechnology C: Organic Chemistry D: Stereo ChemistryE: Supramolecular Chemistry

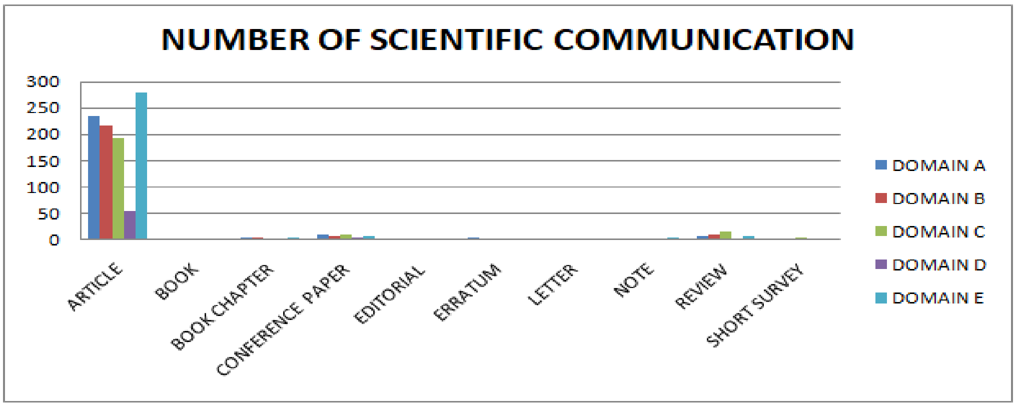


Fig. 104: Number of Scientific Communication

6.3.8.3 To analyze the domain-wise authorship pattern of Sir James Fraser Stoddart.

Sir James Fraser Stoddart had to work in collaboration with other authors due to his numerous responsibilities which is evident from the analysis of his works. While the author has 30 single-authored documents representing 2.76% of his total publications, 588 publications have been published with collaboration with 5 to 10 authors (54.09%). Four documents have been authored by 21 to 30 authors.

Table 75: Domain-wise Authorship as per Collaboration

Domain	Authors						
	1 Author	2 Author	3 Author	4 Author	5 - 10 Author	11-20 Author	21-30 Author
A	8	28	23	33	140	31	0
B	8	18	28	23	123	36	2
C	6	28	22	23	116	27	1
D	0	4	9	10	33	4	0
E	8	22	37	24	176	35	1
Total Papers	**30**	**100**	**119**	**113**	**588**	**133**	**4**
%	**2.76**	**9.20**	**10.95**	**10.40**	**54.09**	**12.24**	**0.37**

A: Applied Chemistry B: Nanotechnology C: Organic Chemistry D: Stereo Chemistry E: Supramolecular Chemistry

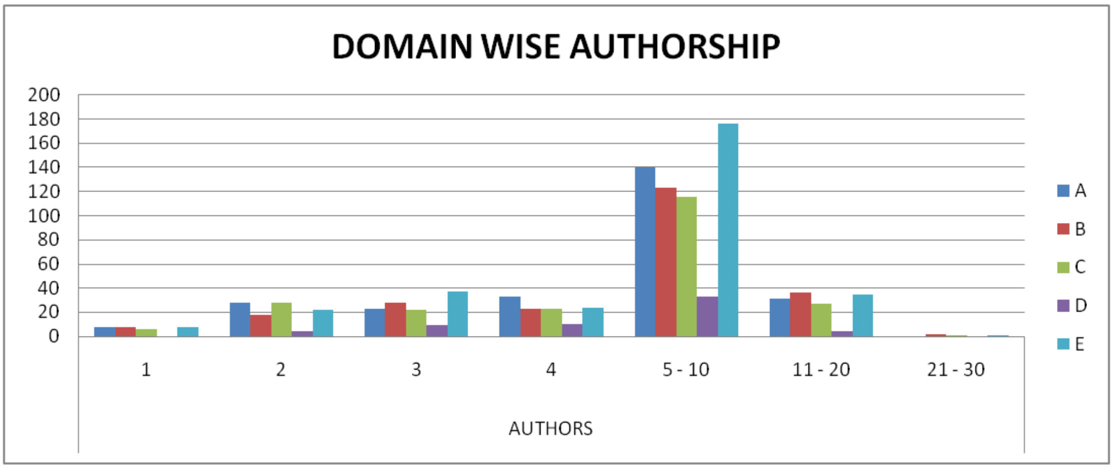


Fig. 105: Domain-wise Authorship Pattern

6.3.8.4 To analyze the year-wise scientific communication of Sir James Fraser Stoddart.

Sir James Fraser Stoddart's publication life began in 1964, 22 years after his birth. A look into his year-wise productivity reveals that the author has published the maximum number of works from 2001 till 2010 when he had published 334 papers in all domains at 30.73%. During the first 10 years of his productive life, Sir James Fraser Stoddart published 13 papers (1.20%) which is the lowest number of works published by the author. A tabular form of this information is provided in table 76, while a graphical representation is given in figure 106.

Table 76: Domain and Year-wise Authorship

Year	Domain					Total Papers	%
	A	B	C	D	E		
1964-1970	9	0	4	0	0	**13**	**1.20**
1971-1980	23	9	12	0	10	**54**	**4.97**
1981-1990	33	23	26	0	26	**108**	**9.94**
1991-2000	57	68	23	0	123	**291**	**26.77**
2001-2010	67	67	67	60	73	**334**	**30.73**
2011-2020	74	71	71	0	71	**287**	**26.40**
Total	**263**	**238**	**203**	**60**	**303**	**1087**	

A: Applied Chemistry B: Nanotechnology C: Organic Chemistry D: Stereo ChemistryE: Supramolecular Chemistry

Table 77: Year-wise Productivity

Year	Domain					Total Papers	%
	A	B	C	D	E		
1961	0	0	0	0	0	0	0
1962	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0
1964	1	0	0	0	0	1	0.09
1965	1	0	0	0	0	1	0.09
1966	4	0	1	0	0	5	0.46
1967	1	0	0	0	0	1	0.09
1968	0	0	0	0	0	0	0
1969	2	0	3	0	0	4	0.37
1970	0	0	0	0	0	0	0
1971	1	0	0	0	0	1	0.09
1972	0	0	0	0	0	0	0
1973	1	1	0	0	0	2	0.18
1974	5	3	2	0	0	10	0.92
1975	3	2	1	0	1	7	0.64
1976	2	1	3	0	0	6	0.55
1977	4	1	2	0	1	8	0.74
1978	3	1	2	0	1	7	0.64
1979	3	0	2	0	2	7	0.64
1980	1	0	0	0	0	1	0.09
1981	3	2	3	0	0	8	0.74
1982	4	5	2	0	0	11	1.01
1983	2	1	1	0	0	4	0.37
1984	2	3	2	0	2	9	0.83
1985	5	4	2	0	1	12	1.10
1986	1	1	1	0	0	3	0.28
1987	6	4	3	0	3	16	1.47
1988	5	1	5	0	2	13	1.19
1989	5	1	7	0	2	15	1.38
1990	0	1	0	0	0	1	0.09

1991	10	9	0	0	0	19	1.75
1992	4	5	3	0	2	14	1.29
1993	6	6	4	0	4	20	1.84
1994	8	5	2	0	3	18	1.66
1995	7	10	0	0	0	17	1.56
1996	16	13	5	0	5	39	3.59
1997	2	5	3	0	24	34	3.13
1998	2	5	3	0	34	44	4.05
1999	2	5	3	0	14	24	2.21
2000	0	5	0	0	28	33	3.04
2001	9	9	1	0	0	19	1.75
2002	15	11	0	0	0	26	2.39
2003	6	10	5	0	0	21	1.93
2004	5	11	10	8	0	34	3.13
2005	6	15	10	5	0	36	3.31
2006	7	2	15	10	0	34	3.13
2007	3	0	15	16	0	34	3.13
2008	5	5	11	5	0	26	2.39
2009	10	5	0	9	10	44	4.05
2010	2	0	0	15	17	34	3.13
2011	30	0	0	0	0	30	2.76
2012	44	0	0	0	0	44	4.05
2013	0	36	0	0	0	36	3.31
2014	0	32	0	0	0	32	2.94
2015	0	3	27	0	0	30	2.76
2016	0	0	17	0	0	17	1.56
2017	0	0	20	0	0	20	1.84
2018	0	0	7	0	5	12	1.10
2019	0	0	0	0	24	24	2.21
2020	0	0	0	0	11	11	1.01

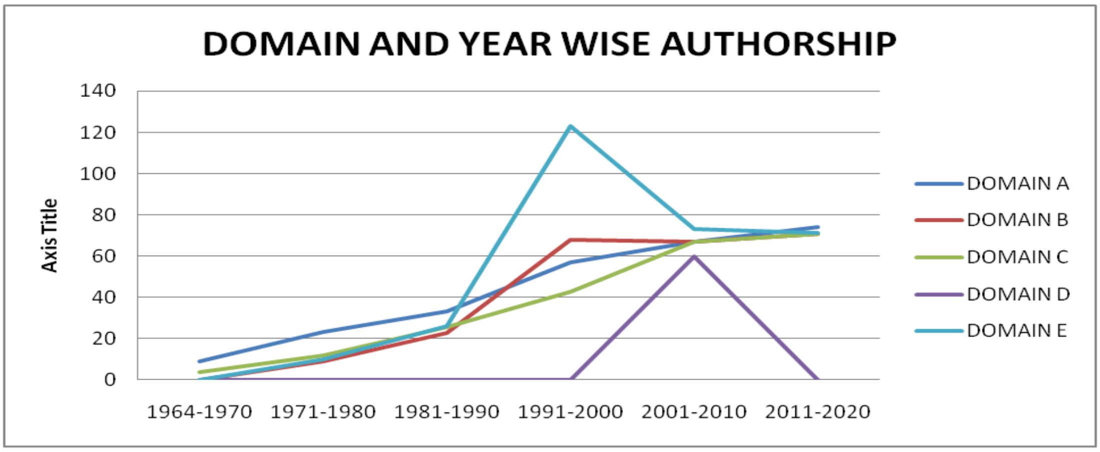


Fig. 106: Domain and Year-wise Authorship

6.3.8.5 Author's Production over time (Sir James Fraser Stoddart)

The productivity of Sir James Fraser Stoddart as a factor of time has been shown in Fig.107. The figure bears testimony to the fact that the productivity has increased till 2010.

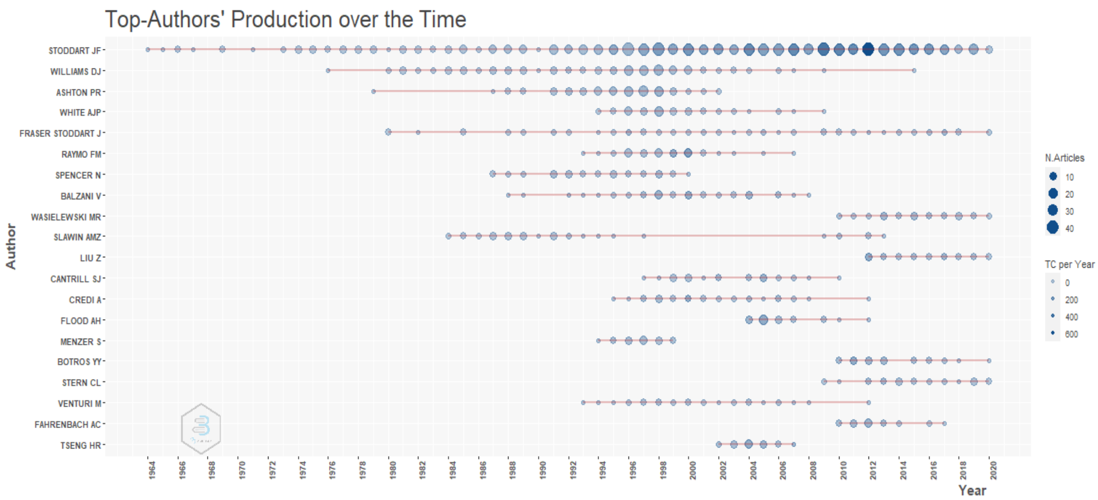


Fig. 107: Author's Production over Time

6.3.8.6 To find out the channels of communication used by Sir James Fraser Stoddart.

Sir James Fraser Stoddart published his scientific works using a variety of methods, be it articles, erratums, editorials, notes, book chapters, etc. The articles published by Sir James Fraser Stoddart have been published in a number of journals. In the order of the decreasing number of articles, the top twenty journals publishing his articles have been shown in Fig 108. The figure shows that 176 articles have been published in the journal *Journal of The American Society*, followed by 76 articles in the journal *Chemistry: A European Journal*.

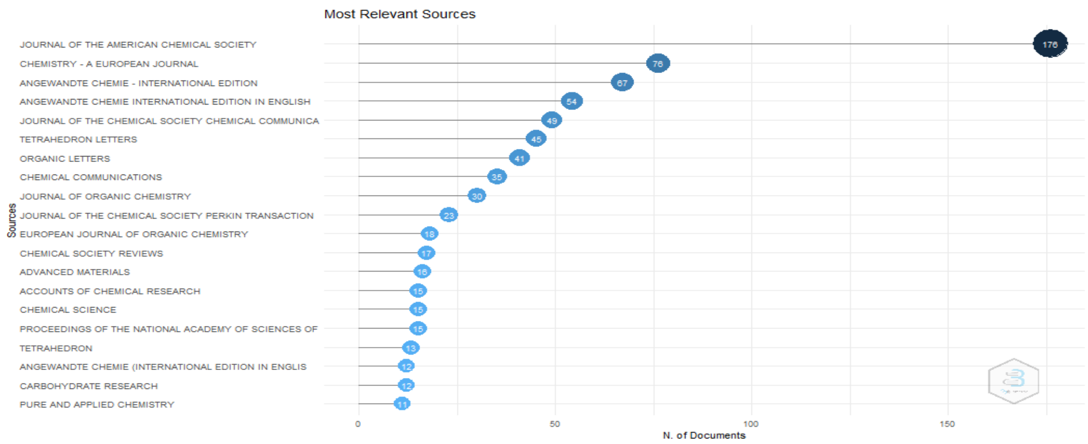


Fig. 108: Channels of Communication

Table 78: Most Relevant Sources

Sources	Articles
Journal Of the American Chemical Society	197
Chemistry – A European Journal	76
Angewandte Chemie – International Edition	70
Angewandte Chemie International Edition in English	54
Journal Of the Chemical Society Chemical Communications	49
Tetrahedron Letters	45
Organic Letters	41
Chemical Communications	36
Journal Of Organic Chemistry	30
Journal Of the Chemical Society Perkin Transactions 1	23
Advanced Materials	18
European Journal of Organic Chemistry	18
Proceedings Of the National Academy of Sciences of The United States of America	18
Accounts Of Chemical Research	17
Chemical Society Reviews	17
Chemical Science	16
Carbohydrate Research	13
Tetrahedron	13
Angewandte Chemie (International Edition in English)	12
Pure And Applied Chemistry	11

Science	11
New Journal of Chemistry	10
Synlett	10
Chem	8
Journal Of Materials Chemistry	8
Nature	8
Nature Chemistry	8
Acs Nano	7
American Chemical Society Polymer Preprints Division of Polymer Chemistry	7
Langmuir	7
Organic And Biomolecular Chemistry	7
Synthesis	7
Journal Of Physical Chemistry B	6
Journal Of the Chemical Society Perkin Transactions 2	6
Nano Letters	6
Nanoscale	6
Nature Communications	6
Supramolecular Chemistry	6
Chemical Reviews	5
Chemistry – An Asian Journal	5
Chemistry Of Materials	5
Chemphyschem	5
Collection Of Czechoslovak Chemical Communications	5
Israel Journal of Chemistry	5
Macromolecules	5
Small	5
7th Annual Conference on Foundations of Nanoscience: Self-Assembled Architectures and Devices Fnano 2010	4
Inorganic Chemistry	4
Journal Of the Chemical Society – Series Chemical Communications	4
Journal Of the Chemical Society Dalton Transactions	4
Nature Nanotechnology	4

Acs Applied Materials and Interfaces	3
Acs Central Science	3
Advanced Functional Materials	3
Angewandte Chemie – International Edition in English	3
Journal Of Inclusion Phenomena and Molecular Recognition in Chemistry	3
Journal Of Physical Chemistry A	3
Journal Of the Chemical Society B: Physical Organic	3
Macromolecular Symposia	3
Polyhedron	3
Proceedings Of the Ieee International Conference on Micro Electromechanical Systems (Mems)	3
Stimulating Concepts in Chemistry	3
Topics In Current Chemistry	3
Annual Reports on The Progress of Chemistry – Section B	2
Applied Physics Letters	2
Australian Journal of Chemistry	2
Bioconjugate Chemistry	2
Canadian Journal of Chemistry	2
Chemtracts	2
Crown Ethers And Analogs: Updates from The Chemistry of The Functional Groups	2
Current Opinion in Colloid and Interface Science	2
Journal Of Physical Organic Chemistry	2
Journal Of the Chemical Society. Perkin Transactions 2	2
Materials Chemistry Frontiers	2
Mendeleev Communications	2
Nanotechnology	2
Nature Reviews Chemistry	2
Proceedings Of the Ieee Conference on Nanotechnology	2
Recueil Des Travaux Chimiques Des Paysbas	2
Science Advances	2
Trends In Chemistry	2

2004 Nsti Nanotechnology Conference and Trade Show – Nsti Nanotech 2004	1
2009 Conference on Lasers and Electro-Optics And 2009 Conference on Quantum Electronics and Laser Science Conference Cleo/Qels 2009	1
Acs National Meeting Book of Abstracts	1
Acs Symposium Series	1
Advances In Polymer Science	1
Anal. Proc.	1
Analyst	1
Analytica Chimica Acta	1
Analytical Chemistry	1
Analytical Proceedings	1
Annual Reports on The Progress of Chemistry	1
Applied Physics A: Materials Science and Processing	1
Asian Journal of Organic Chemistry	1
Biochemical Society Transactions	1
Bulletin Des Socits Chimiques Belges	1
Bulletin Of the Chemical Society of Japan	1
Carbohydrate Polymers	1
Chembiochem	1
Chemical Communications (London)	1
Chemical Physics	1
Chemical Physics Letters	1
Chemical Record	1
Chemische Berichte	1
Chemistry A European Journal	1
Chemistry And Biology	1
Chemistry In Britain	1
Chemistry Of Ethers Crown Ethers Hydroxyl Group and Their Sulphur Analogue	1
Chempluschem	1
Chimia	1
Chimica Oggi	1

Chinese Journal of Organic Chemistry	1
Ciba Foundation Symposium	1
Coordination Chemistry Reviews	1
Croatica Chemica Acta	1
Crystal Growth and Design	1
Faraday Discussions	1
From Non-Covalent Assemblies to Molecular Machines	1
Functional Organic Materials: Syntheses Strategies and Applications	1
Ieee Circuits and Devices Magazine	1
Ieee Transactions on Automation Science and Engineering	1
Ieee Transactions on Nanotechnology	1
International Journal of Pharmaceutics	1
Journal De Physique. Iv: Jp	1
Journal Of Chemical Education	1
Journal Of Chemical Information and Modeling	1
Journal Of Electroanalytical Chemistry	1
Journal Of Inclusion Phenomena	1
Journal Of Macromolecular Science Part A: Pure and Applied Chemistry	1
Journal Of Nanoscience and Nanotechnology	1
Journal Of Physical Chemistry Letters	1
Journal Of Polymer Science	1
Journal Of Polymer Science Part A: Polymer Chemistry	1
Journal Of the American Ceramic Society	1
Journal Of the Chemical Society – Dalton Transactions	1
Journal Of the Chemical Society C: Organic	1
Journal Of the Chemical Society C: Organic Chemistry	1
Journal Of the Mexican Chemical Society	1
Liebigs Annales	1
Materials Research Society Symposium – Proceedings	1
Materials Research Society Symposium Proceedings	1
Matter	1
Microporous And Mesoporous Materials	1
Molecular Catenanes Rotaxanes and Knots: A Journey Through the	1

World of Molecular Topology	
Molecular Pharmaceutics	1
Monographs In Supramolecular Chemistry	1
Mrs Bulletin	1
Nano Research	1
Nature Energy	1
Nature Protocols	1
Nature Reviews Materials	1
Nature Reviews Physics	1
New Comprehensive Biochemistry	1
Optics Infobase Conference Papers	1
Organic Synthesis Highlights Iii	1
Organic Synthesis Set	1
Philosophical Transactions of The Royal Society A: Mathematical Physical and Engineering Sciences	1
Physical Chemistry Chemical Physics	1
Physical Review B – Condensed Matter and Materials Physics	1
Polymer Preprints Japan	1
Polymers For Advanced Technologies	1
Proceedings Of Spie – The International Society for Optical Engineering	1
Proceedings Of the Royal Society A: Mathematical Physical and Engineering Sciences	1
Progress In Polymer Science (Oxford)	1
Qsar And Combinatorial Science	1
Redox Systems Under Nano-Space Control	1
Reviews In Molecular Biotechnology	1
Rsc Advances	1
Science And Technology of Advanced Materials	1
Science Of Crystal Structures: Highlights in Crystallography	1
Seminars In Organic Synthesis	1
Structural Chemistry	1
Supramolecular Science	1
Synthetic Metals	1

Talanta	1
The Analyst	1
The Nature of The Mechanical Bond: From Molecules to Machines	1
Thin Solid Films	1
Topics In Stereochemistry	1
Transducers 2009 – 15th International Conference on Solid-State Sensors Actuators and Microsystems	1

6.3.8.7 Author's performance based on available metrics indicators (Sir James Fraser Stoddart)

Table 79: Performance of Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	98.56	01	i10-index (i10)	898
02	Total Citation	100452	02	h5-index (h5)	43
03	Audience Factor	135.8	03	g-Index	203
04	CiteScore (Maximum)	21.7	04	a-Index	244.30
05	ResearchGate Citations	50024	05	h(2)-index	11
06	Microsoft Academic Search Citations	475	06	hg-index (hg)	167.98
07	Google Scholar Citations	102	07	r-index	184.28
08	Eigenfactor	23.09	08	ar-index (ar)	465.18
09	Crown Indicator		09	k-index	0.03
10	Mean Citation Score	69.12	10	q2-index	25.83
11	Mean Normalized Citation Score (MNCS)	50.24	11	f-index	0.87
12	Mean Citation Rate Subfield (MCRS)	25.14	12	m-index	6.32
13	Scientific Talent Pool (STP)	42.34	13	m quotient (m-q)	6.32
14	Microsoft Academic Search Papers (MASP)	43	14	Contemporary-index (Ch)	398.34
15	Google Scholar Papers (GSP)	3	15	Trendh h-index (Th)	0.08

16	Impact per Paper (IPP)	6528	16	Dynamic h-Type index (Dh-T)	0.04
17	Citation per paper (CPP)	2.26	17	n-index	5.56
18	Citations per Paper self-citation not included (CPPex)	65.26	18	mean h-index	78.5
19	The average number of citations per publication (ANCP)	85.36	19	Normalized h-index	78.26
20	Total and the Average Number of Citations (TNCS)	100452, 2.26	20	Specific-impact s-index (Sis)	19.67
21	Relative Activity Index (RAI)	34.57	21	Seniority independent Hirsch type index (Sih-T)	11
22	Relative Specialization index (RSI)	69.57	22	Hw-index	184.28
23	Relative Citation Rate (RCR)	78.27	23	Hm-index	24
24	Relative Database Citation Potential (RDCP)	23.35	24	Tapered h-index	0.08
25	Journal Acceptance Rate (JAR)	95.20	25	i20-index	768
26	% Self Citations (%SC)	1.89	26	v-index over h	3.45
27	Percentage of papers not cited (%Pnc)	3.59	27	e-index	120.98
28	PR Percentile Ranks (PR)	54	28	Multidimensional h-index	48.29
29	LogZ-score (LogZ)	13.241	29	Research Collaboration Index	42.25
30	Innovative Knowledge (IK)	16.45	30	Communities Collaboration Index	18.39
31	Technological Impact (TI)	59.26	31	ch-index	62.98
32	Scientific Talent Pool (STP)	42.34	32	speed s-iCitationndex	32.88

33	Normalized position of publication journal (NPJ)	48	33	π-index	133.19
34	WorldCat Hold (WCH)	419	34	h5-median (h5-m)	23.69
35	Papers in Top 1 (PT1)	18	35	2^{nd} generation citations h index	120
36	Papers in Top 10 (PT10)	25	36	Role basedh-maj-index (Rbhm)	33.14
37	Papers in Top 50 (PT50)	60	37	h2 lower (h2-l)	10
38	High Cited Papers (HCP)	19	38	h2-center (h2-c)	28
39	Papers in First Quartile (Q1)	354	39	h2-upper (h2-u)	33
40	Publications in Thomson Reuters indices (PwoS)	2	40	h3-index	22
41	Number of highly cited publications (NHCP)	12	41	p-index	18.98
42	Publications in top-ranked journals (PTRJ)	24	42	$\bar{h}$-index (Hbar)	139
43	Papers in Collaboration (Pcol)	1057	43	Mockhm-index (Mhm)	67.25
44	Share of articles coauthored with another unit (%CoA)	97.24	44	w-index	11.29
45	National Collaboration (Ncol)	78	45	b-index	29.06
46	International Collaboration (Icol)	22	46	Generalizedh-index	102.67
47	Scientific Leadership (SL)	16.35	47	Single paperh-index	68
48	Average Authors per Paper	1.21	48	hint-index	115
49	Productivity per Paper	0.24	49	h_{rat}-index	140
50	RoG, CAGR, RGR and DT	0.98, (-)0.13, 0.53, 0.95	50	πv-index	21.09

6.3.8.8 To analyze the scientific collaboration of Sir James Fraser Stoddart

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Sir James Fraser Stoddart has collaborated with 290 different authors in the conduct and publication of his research work. The author has published 30 single-authored documents.

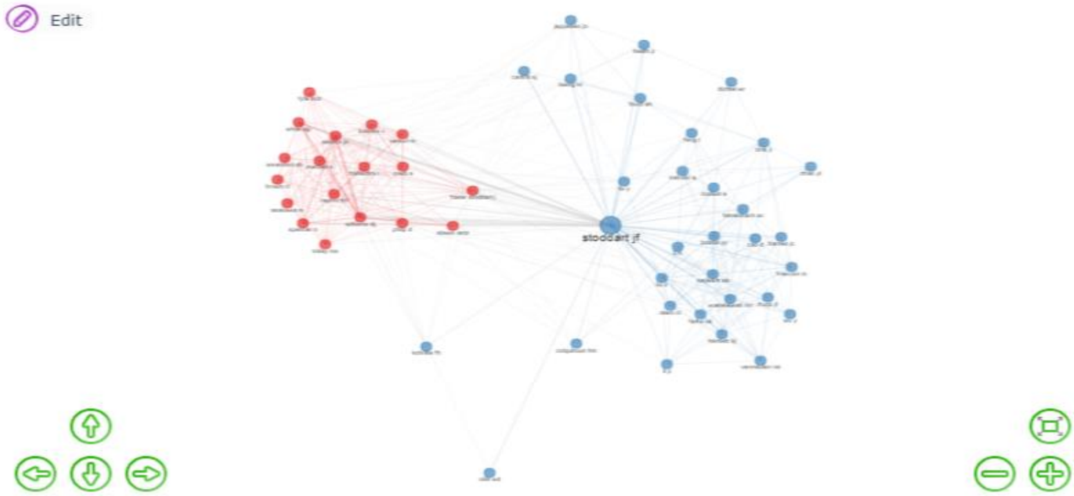


Fig 109: Collaboration Network

6.3.8.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Sir James Fraser Stoddart, the collaboration index has been calculated at 1.24.

6.3.8.8.2 National and International Collaboration: Sir James Fraser Stoddart has published his papers in collaboration with more than 1000 co-authors hailing from the United States, the United Kingdom, China, Australia, Italy, etc. The collaboration map of Sir James Fraser Stoddart is produced in figure 110.

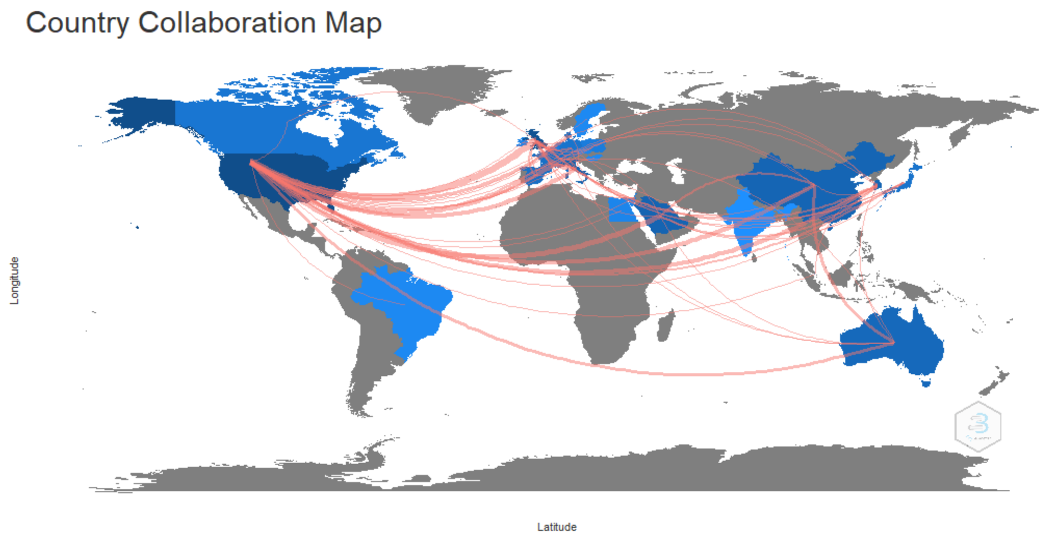


Fig. 110: National and International Collaboration

6.3.8.8.3 Co-authorship Index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Sir James Fraser Stoddart has been calculated at 6.37.

6.3.8.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources have resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Sir James Fraser Stoddart had close communication with 335 co-authors while publishing his documents.

6.3.8.9 To find out the research network of Sir James Fraser Stoddart.

6.3.8.9.1 Co-authorship: Sir James Fraser Stoddart had collaborated with more than 1000 co-authors.

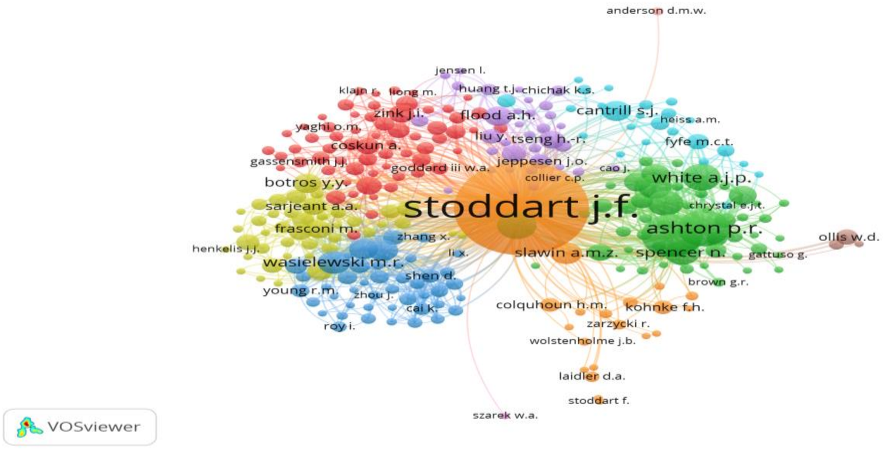


Fig. 111: Co-authorship Pattern of Sir James Fraser Stoddart.

On analysis of the co-authorship pattern, it is observed that the author's collaboration with D J Williams, P R Ashton, M R Wasielewski, and A J P White were the highest. A graphical representation of the co-authorship pattern is shown in figure 111.

6.3.8.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top five keywords on the decreasing order of their link strengths.

Table 80: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	419	6632
chemical structure	153	2829
synthesis	170	2757
Protein nuclear magnetic resonance	128	2424

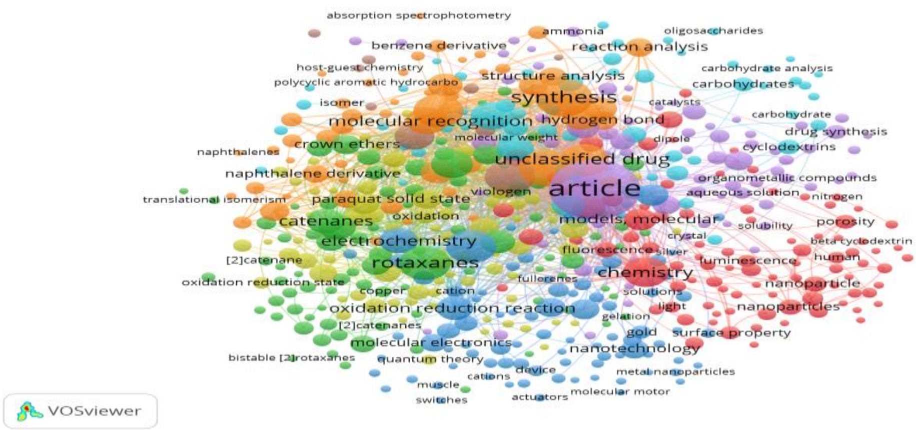


Fig. 112: Keyword Co-occurrences Authorship Pattern

6.3.8.9.3 Citation analysis: Of the 1087 papers published by Sir James Fraser Stoddart, either as a single author or in collaboration, 1048 have been cited by other researchers in their papers. A graphical representation of the above information is presented in Figure 113.

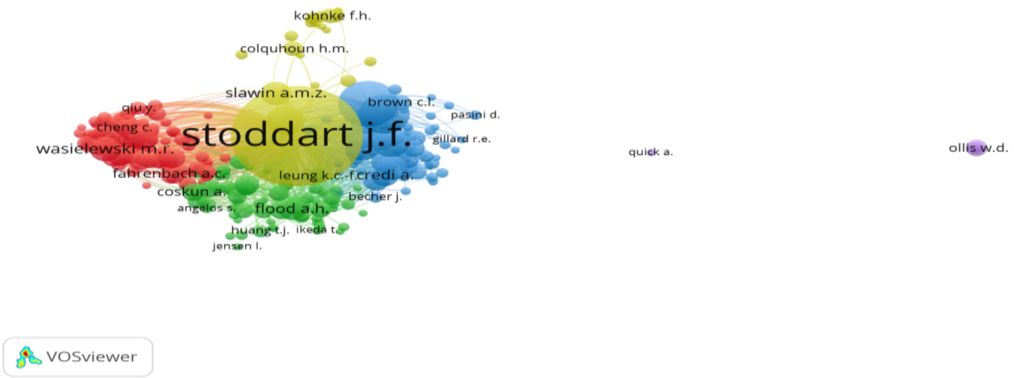


Fig. 113: Citation Analysis

6.3.8.9.4 Bibliographic Coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Sir James Fraser Stoddart is presented in figure 114.

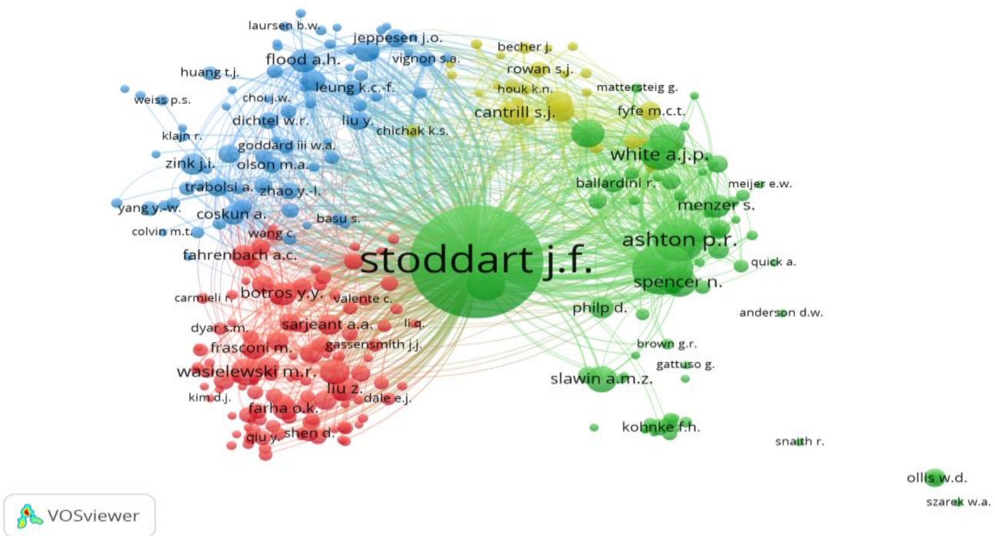


Fig. 114: Bibliographic Coupling

6.3.8.9.5. Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of Sir James Fraser Stoddart is produced in Fig. 115. Analysis of the figure shows that the articles published by Sir James Fraser Stoddart has been co-cited by 4 clusters, having 525, 282, 190, and 3 authors each. There are a total of 498742 links, with a total link strength of 119054534.

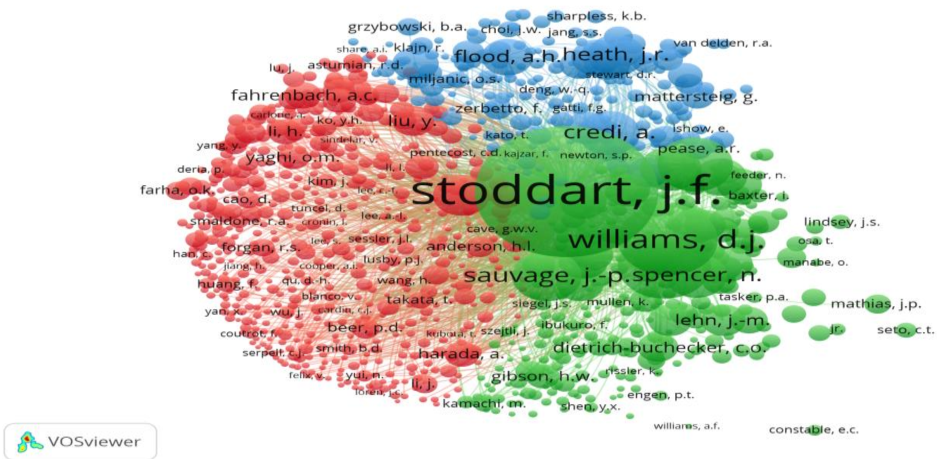


Fig. 115: Co-citation Analysis

6.3.8.10 To analyze cluster mapping (Sir James Fraser Stoddart)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 116 shows the coupling map of Sir James Fraser Stoddart.

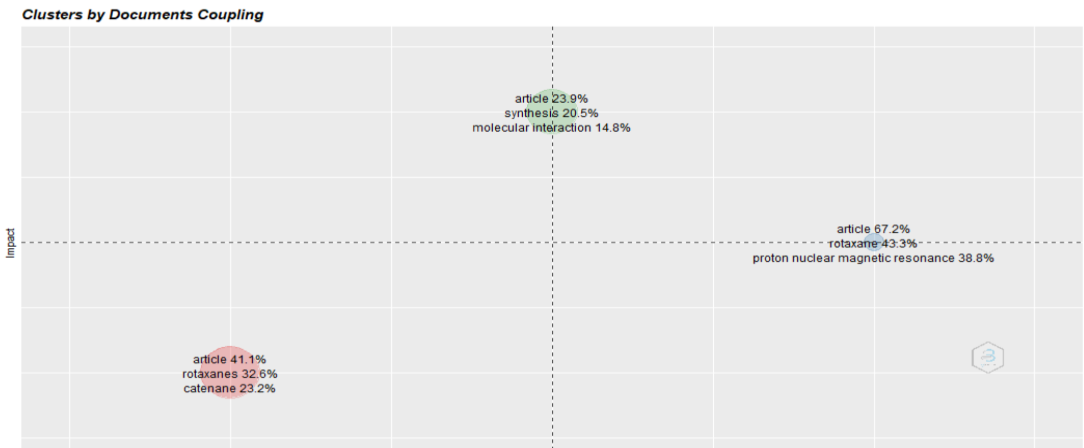


Fig 116: Document Coupling

6.3.8.11 Other information (Sir James Fraser Stoddart)

Table 81: Main Information

Description	Results
Timespan	1964:2020
Sources	
Journals, Books, Etc	174
Documents	1087
Total	1261
Average Years from Publication	19.3
Average Citations Per Documents	88.06
Average Citations Per Year Per Doc	5.741
References	44284
Document Types	
Article	978
Book	3
Book Chapter	12
Conference Paper	35
Editorial	6
Erratum	5
Letter	4
Note	4
Review	34
Short Survey	6
Total	1087
Document Contents	
Keywords Plus (Id)	4093
Author's Keywords (De)	691
Authors	
Authors	1312
Author Appearances	6927
Authors Of Single-Authored Documents	3
Authors Of Multi-Authored Documents	1309
Authors Collaboration	

Single-Authored Documents	30
Documents Per Author	0.829
Authors Per Document	1.21
Co-Authors Per Documents	6.37
Collaboration Index	1.24
H-Index	139
Total Citation	100452 Citations By 44298 Documents

The publication productivity of Sir James Fraser Stoddart is consistent throughout the entire productive life and he has made outstanding contributions in the field of nanotechnology and supramolecular chemistry. His publication life commenced in 1964 after he had attained a biological age of 22 years. Sir James Fraser Stoddart has been active in research despite many administrative responsibilities. Sir James Fraser Stoddart's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.9 JEAN-PIERRE SAUVAGE

Jean-Pierre Sauvage (dob: 21st October 1944) is a French co-ordination chemist who is serving at Strasbourg University. He graduated from the National School of Chemistry of Strasbourg in 1967. Jean-Pierre Sauvage specializes in supramolecular chemistry with Sir J. Fraser Stoddart and Bernard L. Feringa.

6.3.9.1 To assess the number of scientific communications contributed by Jean-Pierre Sauvage.

Table 82: Scientific Communication

Document Types	
Articles	454
Book	3
Book Chapters	8
Conference Papers	7
Editorial	5
Erratum	1
Letter	3

Note	1
Review	13
Short Survey	10

6.3.9.2 To analyze the domain-wise scientific communication of Jean-Pierre Sauvage.

A look into the nature of scientific communication reveals that 36.59% of his works are in the domain of supramolecular chemistry followed by 24.27% in structural chemistry and 21.72% in coordination chemistry. The author has 17.42% of his scientific communications in the field of applied chemistry. Table 83 is the tabular form of the number of scientific communications of Jean-Pierre Sauvage. Regarding the nature of the document, Table 83 shows that most of the papers were in the form of articles (88.85%), followed by short surveys (1.96%). With 0.20% of the total documents, note contributes the lowest to the list of total publications.

Table 83: Number of Scientific Communication

Document	**Domain**				**Total Papers**	**%**
	A	**B**	**C**	**D**		
Article	84	104	107	159	454	**88.85**
Book Chapters	1	0	0	2	3	**0.59**
Conference Papers	2	0	1	5	8	**1.57**
Editorial	0	2	4	1	7	**1.37**
Erratum	1	0	2	2	5	**0.98**
Letter	0	0	0	1	1	**0.20**
Note	0	1	2	0	3	**0.59**
Review	0	0	0	1	1	**0.20**
Short Survey	0	3	1	6	10	**1.96**
%	**17.42**	**21.72**	**24.27**	**26.59**	**511**	

A: Applied Chemistry B: Coordination Chemistry C: Structural Chemistry D: Supra Molecular Chemistry

A graphical form of Table 83 is shown in Figure 117.

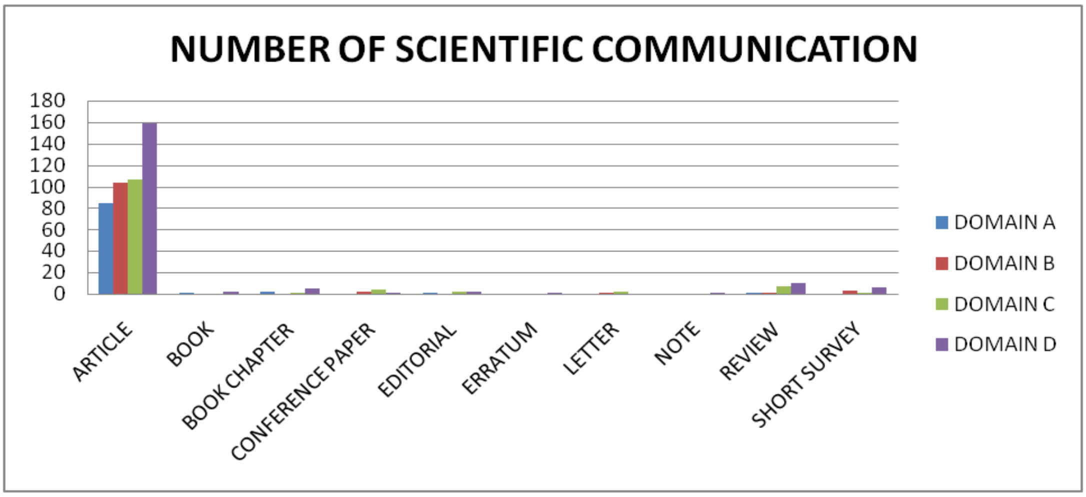


Fig 117: Number of Scientific Communication

6.3.9.3 To analyze the domain-wise authorship pattern of Jean-Pierre Sauvage.

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Jean-Pierre Sauvage are multi-authored. The highest numbers of documents are found to have 5 to 10 authors. This is followed by 3-authored documents. 18 documents representing 3.52% of the total works are single-authored. Table 84 is a tabular form of the authorship pattern and figure 118 presents a graphical view of the data.

Table 84: Domain-wise Authorship as per Collaboration

Domain	**Authors**						
	1 Author	2 Authors	3 Authors	4 Authors	5 – 10 Authors	11 - 20 Authors	21 - 30 Authors
A	1	4	28	19	34	3	0
B	5	13	29	24	39	1	0
C	1	7	34	26	53	3	0
D	11	18	42	36	75	4	1
Total	**18**	**42**	**133**	**105**	**201**	**11**	**1**
%	**3.52**	**8.22**	**26.03**	**20.55**	**39.33**	**2.15**	**0.20**

A: Applied Chemistry B: Coordination Chemistry C: Structural Chemistry D: Supra Molecular Chemistry

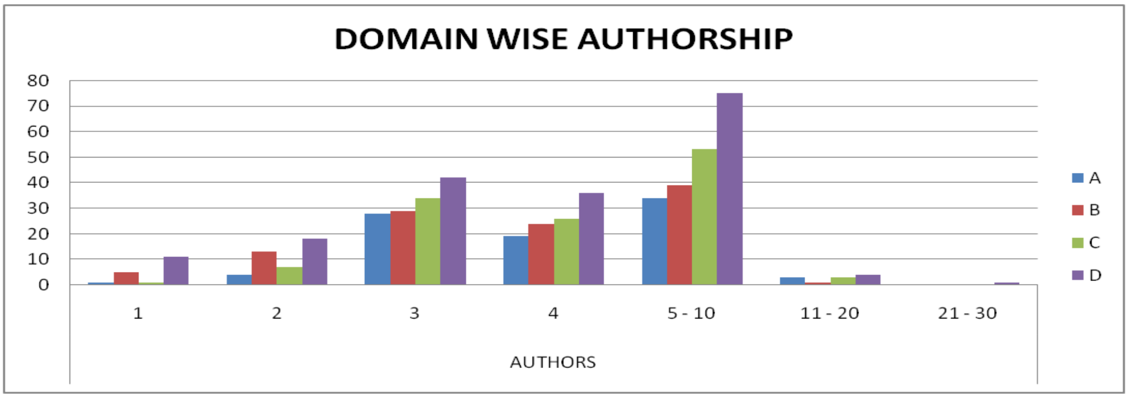


Fig 118: Domain-wise Authorship

6.3.9.4 To analyze the year-wise scientific communication of Jean-Pierre Sauvage.

Table C.4 and Figure C.3 show the domain and year-wise authorship pattern of Jean-Pierre Sauvage. Jean-Pierre Sauvage has published 511 documents on various subjects commencing from the years 1969. An analysis of the data present in table 77 shows that the number of publications has increased with increase in time baring the decade commencing 2010.

Table 85: Domain and Year-wise Authorship

Period	Domain				Total Papers	%
	A	B	C	D		
1961 - 1970	0	0	0	4	**4**	**0.78**
1971 - 1980	26	0	0	5	**31**	**6.07**
1981 - 1990	4	62	0	12	**78**	**15.26**
1991 - 2000	36	11	69	67	**183**	**35.81**
2001 - 2010	8	37	45	72	**162**	**31.70**
2011 - 2019	15	1	10	27	**53**	**10.37**
Total	**89**	**111**	**124**	**187**	**511**	**100**

A: Applied Chemistry B: Coordination Chemistry C: Structural Chemistry D: Supra Molecular Chemistry

Table 86: Year Wise Productivity

Year	Domain				Total Papers	%
	A	B	C	D		
1961	0	0	0	0	0	0
1962	0	0	0	0	0	0

1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	2	2	0.39
1970	0	0	0	2	2	0.39
1971	1	0	0	0	1	0.19
1972	1	0	0	0	1	0.19
1973	3	0	0	1	4	0.78
1974	1	0	0	0	1	0.19
1975	4	0	0	1	5	0.97
1976	10	0	0	5	15	2.91
1977	3	0	0	0	3	0.58
1978	1	0	0	0	1	0.19
1979	1	0	0	0	1	0.19
1980	1	0	0	1	2	0.39
1981	0	0	0	0	0	0
1982	4	1	0	0	5	0.97
1983	0	5	0	1	6	1.16
1984	0	2	0	1	3	0.58
1985	0	6	0	2	8	1.55
1986	0	6	0	4	10	1.94
1987	0	5	0	4	9	1.75
1988	0	7	0	1	8	1.55
1989	0	10	0	2	12	2.33
1990	0	10	0	8	18	3.50
1991	8	2	6	2	18	3.50
1992	2	2	2	4	10	1.94
1993	3	2	8	3	16	3.11
1994	5	2	10	4	21	4.08
1995	1	2	3	0	6	1.16

1996	5	1	10	9	25	4.85
1997	2	0	10	9	21	4.08
1998	3	0	12	5	17	3.30
1999	7	0	8	10	25	4.85
2000	0	0	0	19	19	3.69
2001	8	4	1	0	13	2.52
2002	2	4	5	0	11	2.14
2003	0	0	10	13	23	4.47
2004	0	0	10	7	17	3.30
2005	0	0	8	7	15	2.91
2006	0	0	1	15	16	3.11
2007	0	0	1	24	25	4.85
2008	0	0	1	10	11	2.14
2009	0	0	0	17	17	3.30
2010	0	0	0	12	12	2.33
2011	15	1	3	0	19	3.69
2012	0	0	6	6	12	2.33
2013	0	3	0	2	5	0.97
2014	0	0	0	9	9	1.75
2015	0	0	1	0	1	0.19
2016	0	0	0	2	2	0.39
2017	0	0	0	2	2	0.39
2018	0	0	0	2	2	0.39
2019	0	0	0	1	1	0.19
2020	0	0	0	0	0	0

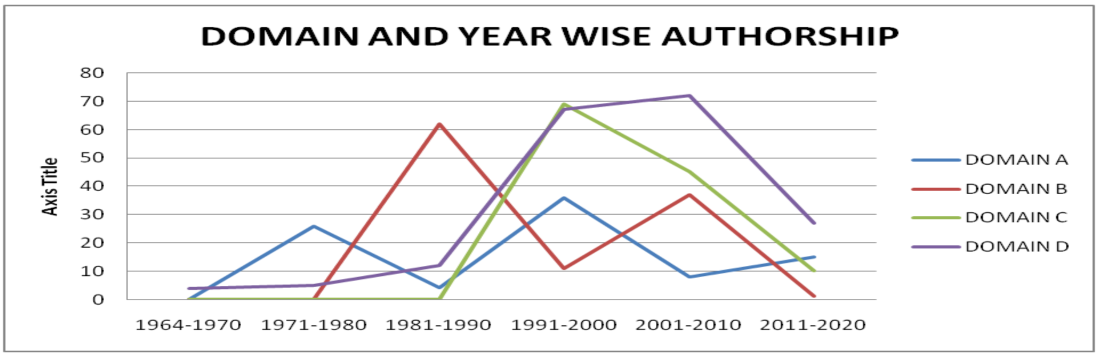


Fig 119: Domain wise and Year wise Authorship

6.3.9.5 Author's production over time (Jean-Pierre Sauvage)

The result of the analysis of the author's production over time can also be seen in Figure 120 which shows that the numbers of publications in various domains have increased over time.

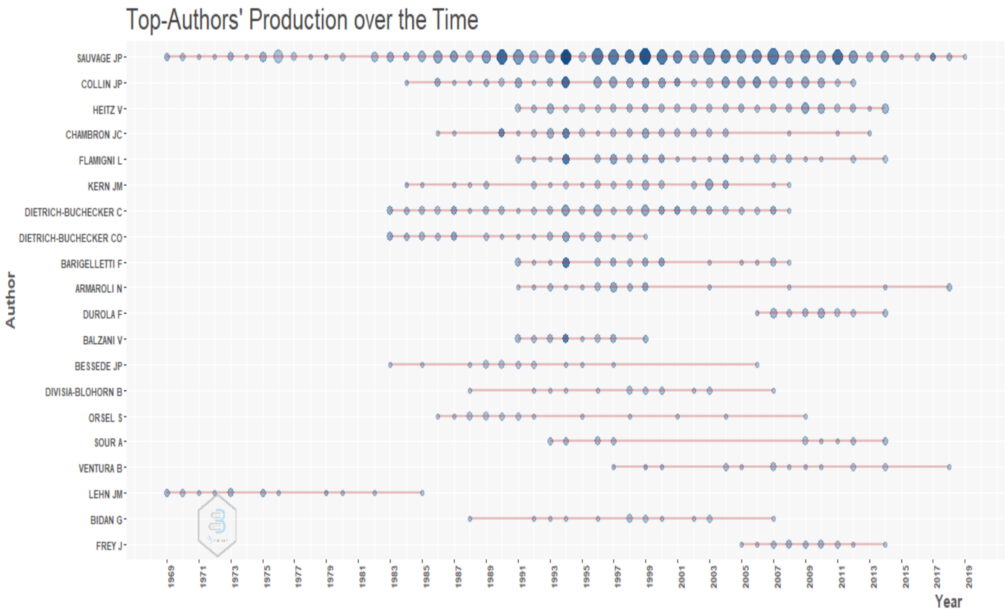


Fig 120: Authors' Production Over Time

6.3.9.6 To find out the channels of communication used by Jean-Pierre Sauvage.

An analysis of Figure 121 shows that Jean-Pierre Sauvage published his works in various journals. The highest number of publications has appeared in the journal *'Journal of the American Chemical Society* followed by *'Inorganic Chemistry.*

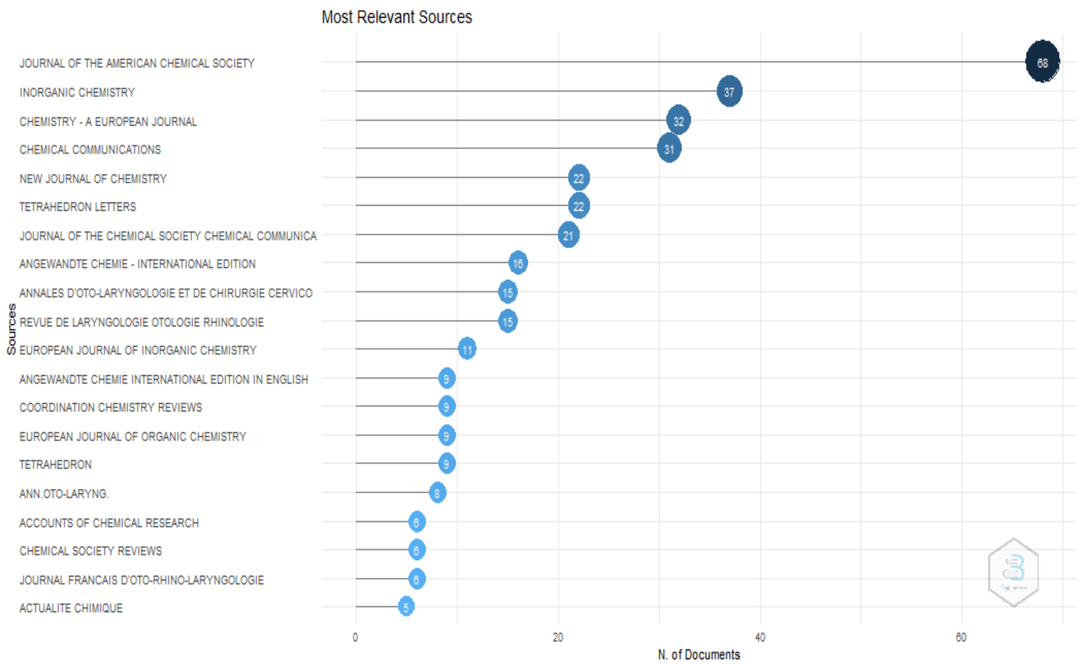


Fig 121: Most Relevant Sources

Table 87: Most Relevant Sources

Sources	**Articles**
Journal Of the American Chemical Society	68
Inorganic Chemistry	37
Chemistry - A European Journal	32
Chemical Communications	31
New Journal of Chemistry	22
Tetrahedron Letters	22
Journal Of the Chemical Society Chemical Communications	21
Angewandte Chemie - International Edition	16
Annales D'oto-Laryngologie Et De Chirurgie Cervico-Faciale	15
Revue De Laryngologie Otologie Rhinologie	15
European Journal of Inorganic Chemistry	11
Angewandte Chemie International Edition in English	9
Coordination Chemistry Reviews	9
European Journal of Organic Chemistry	9
Tetrahedron	9
Ann.Oto-Laryng.	8
Chemical Society Reviews	6
Journal Francais D'oto-Rhino-Laryngologie	6
Accounts Of Chemical Research	5
Actualite Chimique	5
Dalton Transactions	5
Helvetica Chimica Acta	5
Journal Of Electroanalytical Chemistry	5
Journal Of the Chemical Society Dalton Transactions	5
Pure And Applied Chemistry	5
Revue Du Praticien	5
Inorganica Chimica Acta	4
Journal Of Physical Chemistry B	4
Journal Of the Chemical Society. Dalton Transactions	4
Organic Letters	4
Topics In Current Chemistry	4

Angewandte Chemie (International Edition in English)	3
Chemical Reviews	3
Comptes Rendus De L'academie Des Sciences - Series Iic: Chemistry	3
From Non-Covalent Assemblies to Molecular Machines	3
Journal Of Porphyrins and Phthalocyanines	3
Molecular Catenanes Rotaxanes and Knots: A Journey Through the World of Molecular Topology	3
Advanced Materials	2
Annales De Chirurgie Plastique Et Esthetique	2
Australian Journal of Chemistry	2
Bulletin De La Societe Chimique De France	2
Chemical Physics Letters	2
Chemistry Letters	2
Comptes Rendus Chimie	2
Comptes Rendus De Therapeutique Et De Pharmacologie Clinique	2
Concours Medical	2
Gazette Medicale De France	2
Graefe's Archive for Clinical and Experimental Ophthalmology	2
Journal Francais D'ophtalmologie	2
Journal Of Physical Chemistry A	2
Journal Of the Chemical Society - Series Chemical Communications	2
Journal Of the Chemical Society D: Chemical Communications	2
Structure And Bonding	2
Synlett	2
Synthetic Metals	2
Transition Metals in Supramolecular Chemistry	2
Annales D'oto-Laryngologie Et De Chirurgie Cervico Faciale: Bulletin De La Socit D'oto-Laryngologie Des Hpitaux De Paris	1
Annales De L'anesthesiologie Francaise	1
Annales De Pathologie	1
Autoimmunity	1
British Journal of Oral and Maxillofacial Surgery	1
Bulletin Of the Polish Academy of Sciences: Chemistry	1

Canadian Journal of Chemistry	1
Chemie In Unserer Zeit	1
Chemphyschem	1
Chemtracts	1
Chirality	1
Comprehensive Coordination Chemistry Ii	1
Current Medical Research and Opinion	1
Electrochemistry Of Functional Supramolecular Systems	1
Electron Transfer in Chemistry	1
Emc - Oto-Rhino-Laryngologie	1
Gazette Medicale	1
Inorganic Chemistry Communications	1
International Journal of Nanoscience	1
Israel Journal of Chemistry	1
Journal De Chimie Physique Et De Physico-Chimie Biologique	1
Journal Of Electroanalytical Chemistry and Interfacial Electrochemistry	1
Journal Of Inclusion Phenomena and Macrocyclic Chemistry	1
Journal Of Organic Chemistry	1
Journal Of Organometallic Chemistry	1
Journal Of Photochemistry and Photobiology B: Biology	1
Journal Of Physical Chemistry	1
Journal Of Physical Organic Chemistry	1
Journal Of Physics B: Atomic Molecular and Optical Physics	1
Journal Of Polymer Science Part A: Polymer Chemistry	1
Journal Of the Chemical Society - Faraday Transactions	1
Journal Of the Chemical Society Faraday Transactions	1
Journal Of the Chemical Society. Perkin Transactions 1	1
Mendeleev Communications	1
Minimally Invasive Neurosurgery	1
Molecular Crystals and Liquid Crystals	1
Molecular Switches Second Edition	1
Neurochirurgie	1
Nouvelle Presse Medicale	1

Orbit	1
Organic Azides: Syntheses and Applications	1
Photochemistry And Photobiology	1
Physical Chemistry Chemical Physics	1
Recueil Des Travaux Chimiques Des Paysbas	1
Revue De Medecine De Limoges	1
Rhinology	1
Rhinology. Supplement	1
Science	1
Science China Chemistry	1
Supramolecular Chemistry	1
Supramolecular Polymer Chemistry	1
Value In Health	1

6.3.9.7 Author's performance based on available metrics indicators (Jean-Pierre Sauvage)

Table 88: Performance of the Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	24.68	01	i10-index (i10)	393
02	Total Citation	38267	02	h5-index (h5)	.49
03	Audience Factor	45	03	g-Index	176
04	CiteScore (Maximum)	96.9	04	a-Index	249.49
05	ResearchGate Citations	20248	05	h(2)-index	19
06	Microsoft Academic Search Citations	44353	06	hg-index (hg)	132
07	Google Scholar Citations	15248	07	r-index	157.16
08	Eigenfactor	16.8	08	ar-index (ar)	392.06
09	Crown Indicator	7.025	09	k-index	0.06
10	Mean Citation Score	79.72	10	q^2-index	21.11
11	Mean Normalized Citation Score (MNCS)	48.98	11	f-index	1.52
12	Mean Citation Rate Subfield	35.24	12	m-index	4.50

	(MCRS)				
13	Scientific Talent Pool (STP)	20.15	13	m quotient (m-q)	4.50
14	Microsoft Academic Search Papers (MASP)	529	14	Contemporary-index (Ch)	3.04
15	Google Scholar Papers (GSP)	624	15	Trendh h-index (Th)	0.01
16	Impact per Paper (IPP)	79.88	16	Dynamic h-Type index (Dh-T)	0.01
17	Citation per paper (CPP)	2.06	17	n-index	3.96
18	Citations per Paper self-citation not included (CPPex)	65.10	18	mean h-index	50.50
19	The average number of citations per publication (ANCP)	125.0	19	Normalized h-index	9.87
20	Total and the Average Number of Citations (TNCS)	38267, 125.0	20	Specific-impact s-index (Sis)	23.35
21	Relative Activity Index (RAI)	56.98	21	Seniority independent Hirsch type index (Sih-T)	1
22	Relative Specialization index (RSI)	75.25	22	Hw-index	157.16
23	Relative Citation Rate (RCR)	92.66	23	Hm-index	29
24	Relative Database Citation Potential (RDCP)	68.56	24	Tapered h-index	0.11
25	Journal Acceptance Rate (JAR)	15.26	25	i20-index	336
26	% Self Citations (%SC)	1.56	26	v-index over h	3.45
27	Percentage of papers not cited (%Pnc)	6.59	27	e-index	122.06
28	PR Percentile Ranks (PR)	82	28	Multidimensional h-index	48.29
29	LogZ-score (LogZ)	11.264	29	Research Collaboration Index	42.55

30	Innovative Knowledge (IK)	17.25	30	Communities Collaboration Index	18.39
31	Technological Impact (TI)	54.24	31	ch-index	62.98
32	Scientific Talent Pool (STP)	20.15	32	speed s-iCitationndex	32.88
33	Normalized position of publication journal (NPJ)	32	33	π-index	124.97
34	WorldCat Hold (WCH)	357.4	34	h5-median (h5-m)	14.87
35	Papers in Top 1 (PT1)	155	35	2nd generation citations h index	88
36	Papers in Top 10 (PT10)	230	36	Role basedh-maj-index (Rbhm)	26.08
37	Papers in Top 50 (PT50)	348	37	h2 lower (h2-l)	12
38	High Cited Papers (HCP)	5	38	h2-center (h2-c)	35
39	Papers in First Quartile (Q1)	175	39	h2-upper (h2-u)	45
40	Publications in Thomson Reuters indices (PWoS)	10	40	h3-index	19
41	Number of highly cited publications (NHCP)	23	41	p-index	22.33
42	Publications in top-ranked journals (PTRJ)	172	42	$\bar{h}$-index (Hbar)	99
43	Papers in Collaboration (PCol)	493	43	Mockhm-index (Mhm)	42.28
44	Share of articles coauthored with another unit (%CoA)	97.62	44	w-index	7.98
45	National Collaboration (NCol)	69	45	b-index	35.29
46	International Collaboration (ICol)	31	46	Generalizedh-index	82.05
47	Scientific Leadership (SL)	18.25	47	Single paperh-index	54.8
48	Average Authors per Paper	1.09	48	hint-index	82
49	Productivity per Paper	0.19	49	h_{rat}-index	99.9

50	RoG, CAGR, RGR and DT	0.21, (-)0.789, 0.23, 3.72	50	πv-index	11.98

6.3.9.8 To assess the scientific collaboration of Jean-Pierre Sauvage.

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Jean-Pierre Sauvage has collaborated with 541 different authors in the conduct and publication of his research work. The author has published only 18 single-authored documents.

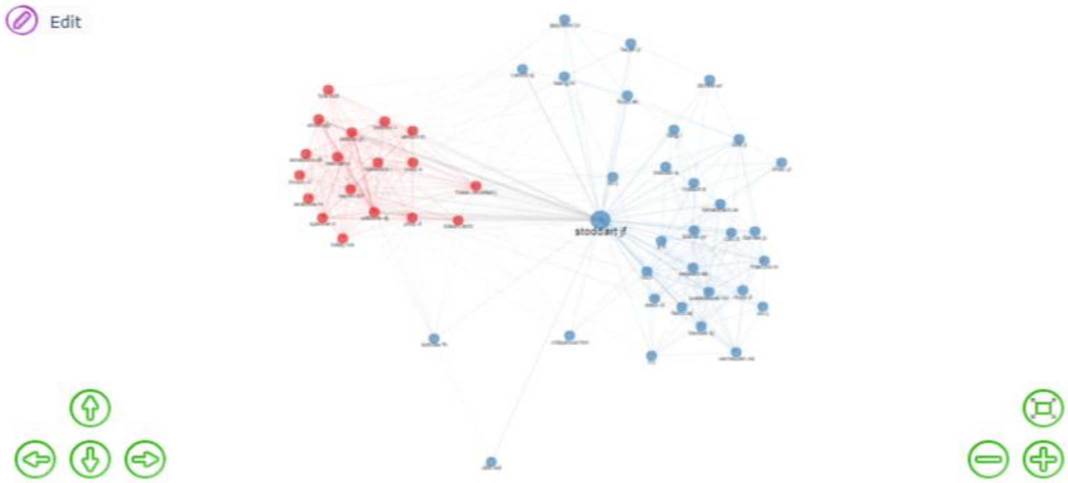


Fig 122: Collaboration Network

6.3.9.8.1 Collaboration Index: The collaboration index is calculated using the following formula:

$$C.I. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Jean-Pierre Sauvage, the collaboration index has been calculated at 1.13.

6.3.9.8.2 National and International Collaboration: Jean-Pierre Sauvage has published his papers in collaboration with 541 co-authors of mostly hailing from the

France, Italy, Switzerland and the United States of America. The collaboration map of Jean-Pierre Sauvage is produced in figure 123.

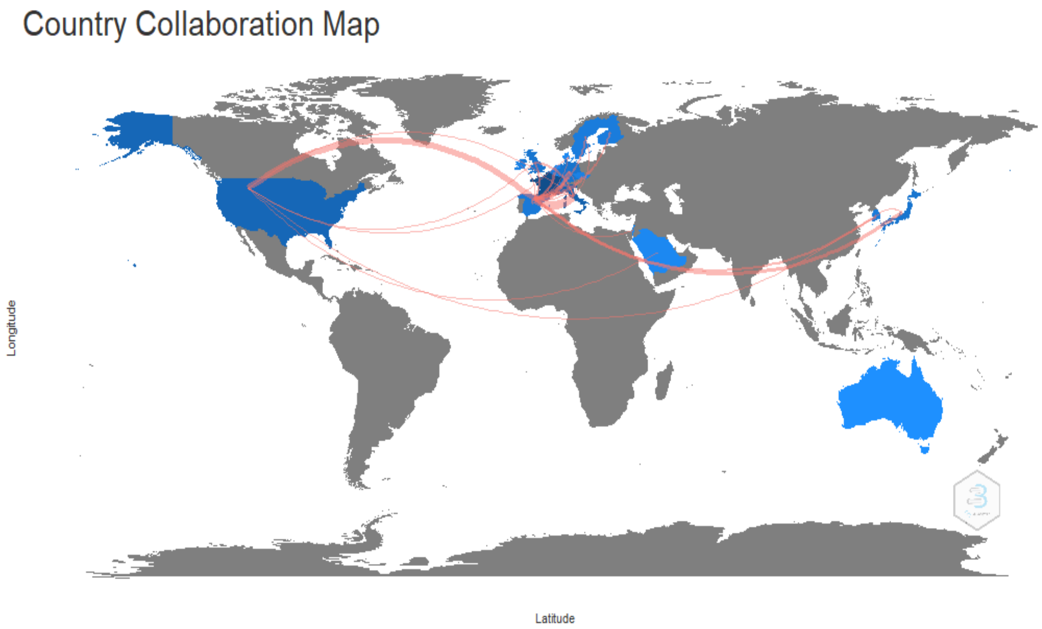


Fig. 123: National and International Collaboration

6.3.9.8.3 Co-authorship index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index $\leq$ co-authorship index. The co-authorship index of Jean-Pierre Sauvage has been calculated at 4.55.

6.3.9.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources have resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Jean-Pierre Sauvage had close communication with 102 authors while publishing his documents.

6.3.9.9 To find out the research network of Jean-Pierre Sauvage.

6.3.9.9.1 Co-authorship: Richard Henderson had collaborated with 541 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with J P Collin, V Heitz, L Flamigni, and F Barigelletti were the highest. A graphical representation of the co-authorship pattern is shown in figure 124 below.

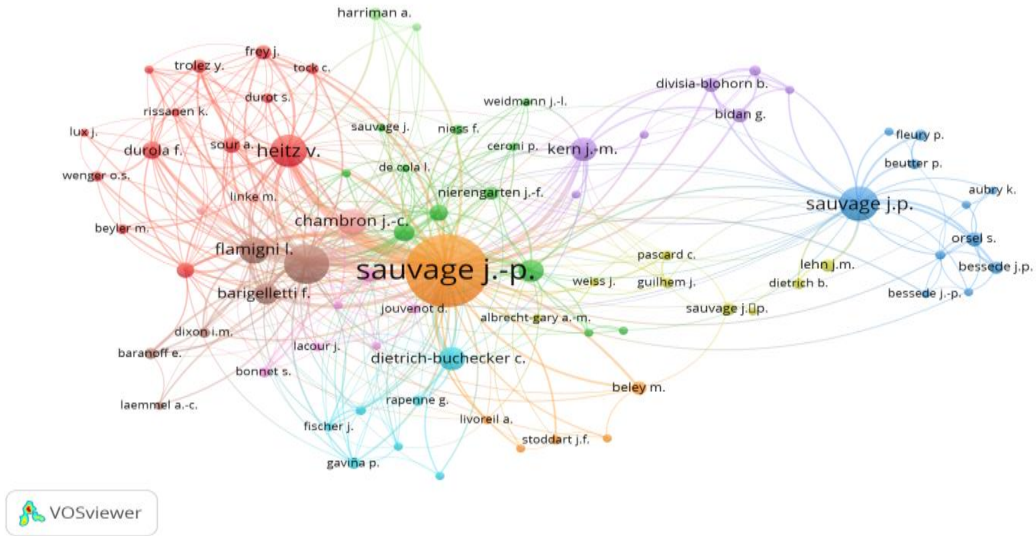
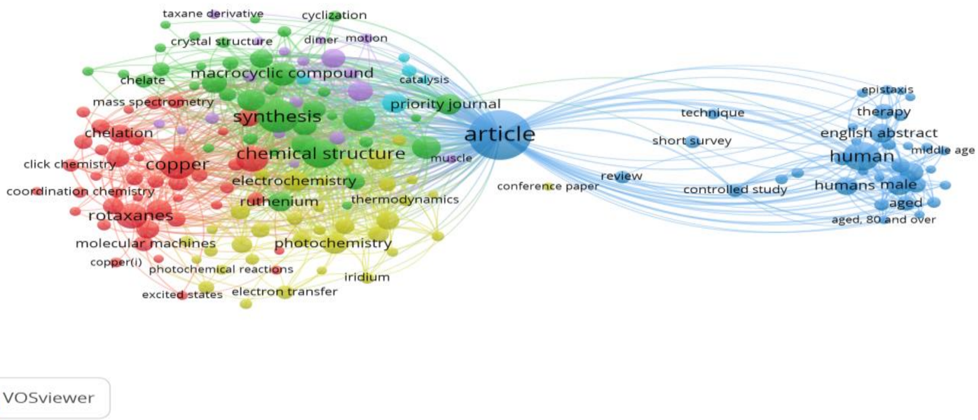


Fig. 124: Co-authorship pattern of Jean-Pierre Sauvage

6.3.9.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top four keywords on the decreasing order of their link strengths.

Table 89: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	184	1762
synthesis	84	1027
chemical structure	65	785
complex formation	49	646



Fig, 125: Co-occurrence of Keywords

6.3.9.9.3 Citation analysis: Of the 511 papers published by Jean-Pierre Sauvage, either as a single author or in collaboration, 481 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *'Ruthenium(II) and Osmium(II) Bis(terpuridine) Complexes in Covalently-linked Multicomponent Systems: Electrochemical Behavior, Absorption Spectra, and Photochemical and Photophysical Properties',* published in the journal *Chemical Reviews* in 1994 has been cited 1443 times followed by the article *'Molecular Light Switch for DNA: $Ru(bpy)_2(dppz)^{2+}$'* published in *Journal of the American Chemical Society* in 1990 which received 1251 citations.

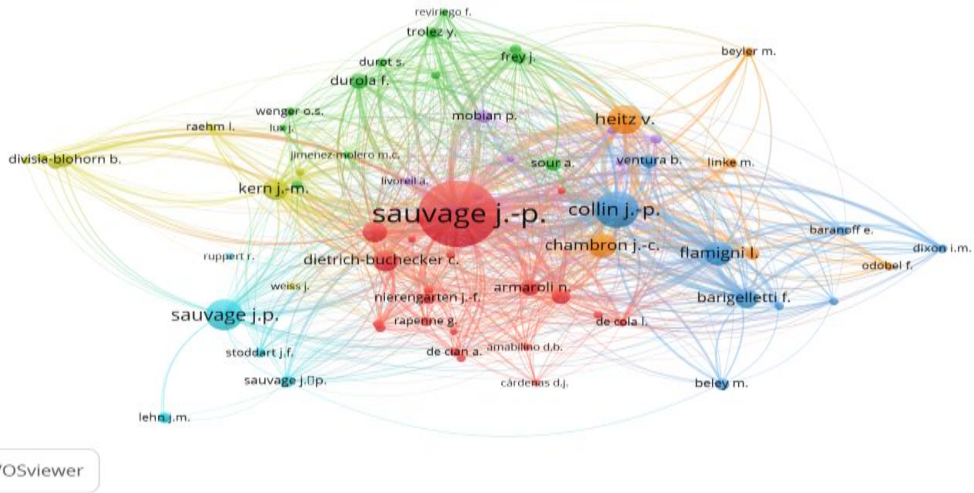


Fig. 126: Citation Analysis

6.3.9.9.4 Bibliographic coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Jean-Pierre Sauvage is presented in figure 127.

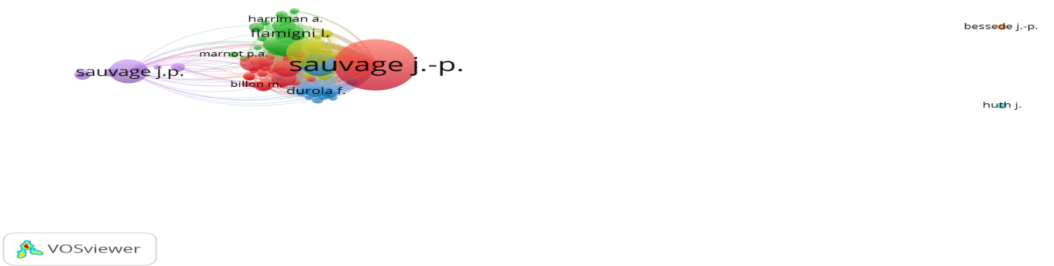


Fig. 127: Bibliographic Coupling

6.3.9.9.5 Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form.

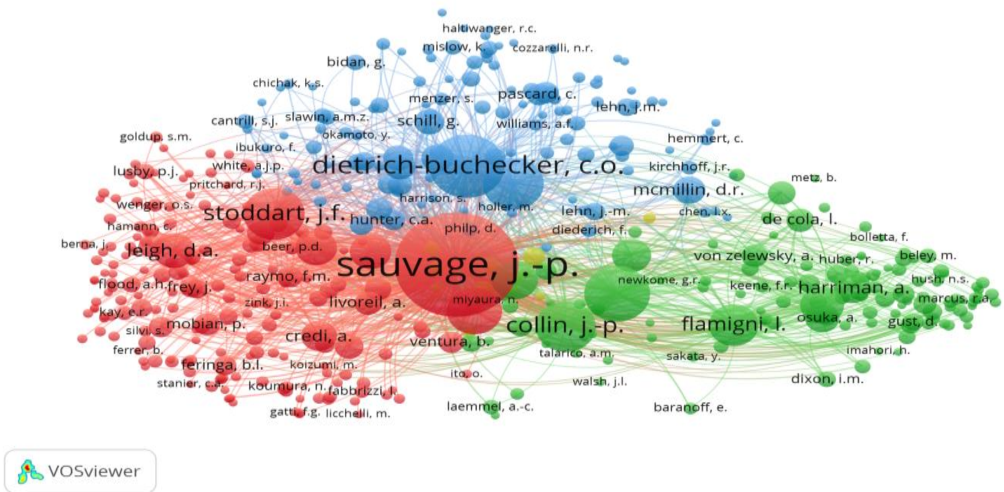


Fig. 128: Co-citation Analysis Pattern

These clusters have some common theme. The co-citation network of Jean-Pierre Sauvage is produced in figure 128. Analysis of the figure shows that the articles published by Jean-Pierre Sauvage has been co-cited by 4 clusters, having 181, 125, 122, and 13 items each. There are a total of 71319 links, with total link strength of 2281946.

6.3.9.10 To Analyze Cluster Mapping (Jean-Pierre Sauvage)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 129 shows the coupling map of Jean-Pierre Sauvage.

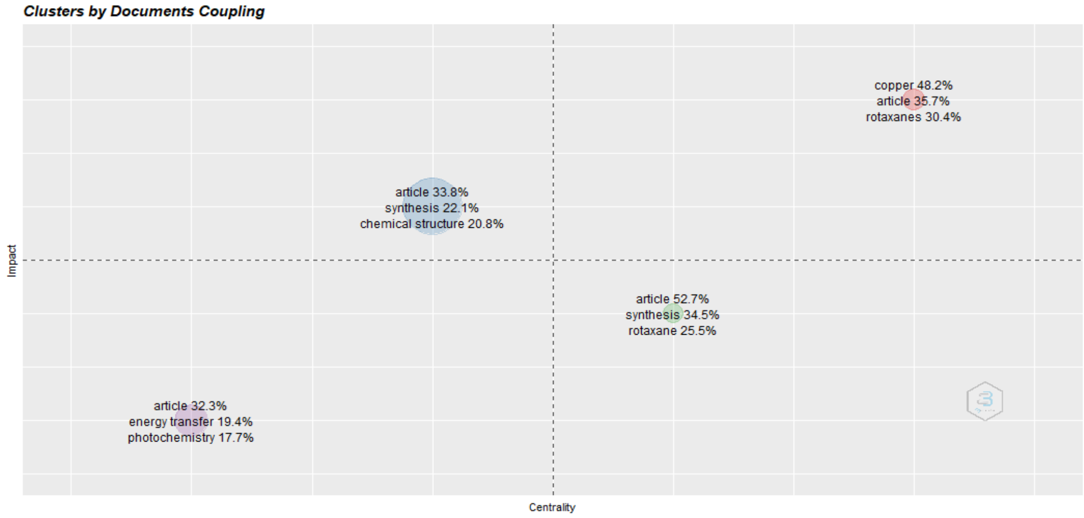


Fig 129: Document Coupling

6.3.9.11 Other Information (Jean-Pierre Sauvage)

Table 90: Main Information

Description	**Results**
Timespan	1969:2019
Sources	
Journals, Books, Etc	108
Documents	511
Total	619
Average Years from Publication	23.3
Average Citations Per Documents	72.78
Average Citations Per Year Per Doc	3.174
References	12888
Document Types	
Article	454
Book	3
Book Chapter	8
Conference Paper	7

Editorial	5
Erratum	1
Letter	3
Note	1
Review	19
Short Survey	10
Total	511
Document Contents	
Keywords Plus (Id)	1828
Author's Keywords (De)	384
Authors	
Authors	562
Author Appearances	2343
Authors Of Single-Authored Documents	1
Authors Of Multi-Authored Documents	561
Authors Collaboration	
Single-Authored Documents	18
Documents Per Author	0.916
Authors Per Document	1.09
Co-Authors Per Documents	4.55
Collaboration Index	1.13
H-Index	99
Total Citation	38267 Citations By 18563 Documents

The publication productivity of Jean-Pierre Sauvage is consistent throughout the entire productive life and he has made outstanding contributions in the field of supramolecular chemistry, structural chemistry, coordination chemistry, and applied chemistry in the entire productive years of his life which commenced from 1969. Jean-Pierre Sauvage has been consistently active in research despite many administrative responsibilities. He has preferred to work in collaboration and has a high degree of collaboration at institutional, national, and international levels. The high rate of citations received by his papers proves the usefulness and impact that his works have in the field of supramolecular chemistry. Jean-Pierre Sauvage's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

2017

The Chemistry Nobel Prize for 2017 was jointly awarded to three researchers for their contribution to *developing cyro-electron microscopy for the high-resolution structure determination of biomolecules in solutions*. The award was shared by Jacques Dubochet, Joachim Frank, and Richard Henderson.

6.3.10 JACQUES DUBOCHET

Jacques Dubochet (dob: 08.06.1942) is a retired Swiss biophysicist and a former researcher at the European Molecular Biology Laboratory in Heidelberg, Germany. He also served as an honorary professor of biophysics at the University of Lausanne in Switzerland. Besides being awarded the Nobel Prize, Dubochet has also received the Royal Photographic Society Progress Medal in 2018 together with Professor Joachim Frank and Dr. Richard Hendersen for an important advance in the scientific or technological development of photography or imaging in the wildest sense.

6.3.10.1 To assess the number of scientific communications contributed by Jacques Dubochet.

The works of Jacques Dubochet has been in the form of articles, books, editorials, conference papers, editorials, erratum, letters, reviews, and short surveys. Table 91 shows the number of such scientific communications contributed by the scientist.

Table 91: Scientific Communication

Document Types	
Article	117
Book	1
Conference Papers	8
Editorial	1
Erratum	2
Letter	4
Review	8
Short Survey	2

6.3.10.2 To analyze the domain-wise scientific communication of Jacques Dubochet.

Among the different domains in which he has published his works include bioengineering, biophysics, cryo-microscopy, and molecular-biology, Table 92 shows the total number of documents published by Jacques Dubochet in all documents. An analysis of the table shows that most of his studies are in the field of cryo-microscopy, and molecular-biology, followed by biophysics and bioengineering. Among the documents, the maximum number of papers are in the form of articles (81.82%), followed by conference papers and reviews (5.59%). Some of his research works have also been published in the form of letters (2.80%), erratum and short survey (1.40%), and book and editorial (0.70%).

Table 92: Number of Scientific Communication

Documents	**Domain**				**Total Papers**	**%**
	A	B	C	D		
Article	20	32	35	30	117	**81.82**
Book	0	0	0	1	1	**0.70**
Conference Paper	4	0	0	4	8	**5.59**
Editorial	1	0	0	0	1	**0.70**
Erratum	1	0	1	0	2	**1.40**
Letter	0	1	2	1	4	**2.80**
Review	1	0	3	4	8	**5.59**
Short Survey	1	0	0	1	2	**1.40**
Total	**28**	**33**	**41**	**41**	**143**	
%	**19.58**	**23.08**	**28.67**	**28.67**		

A: Bioengineering B: Biophysics C: Cryo Microscopy D: Molecular Biology

A graphical representation of the above data can be observed in Figure 130 below.

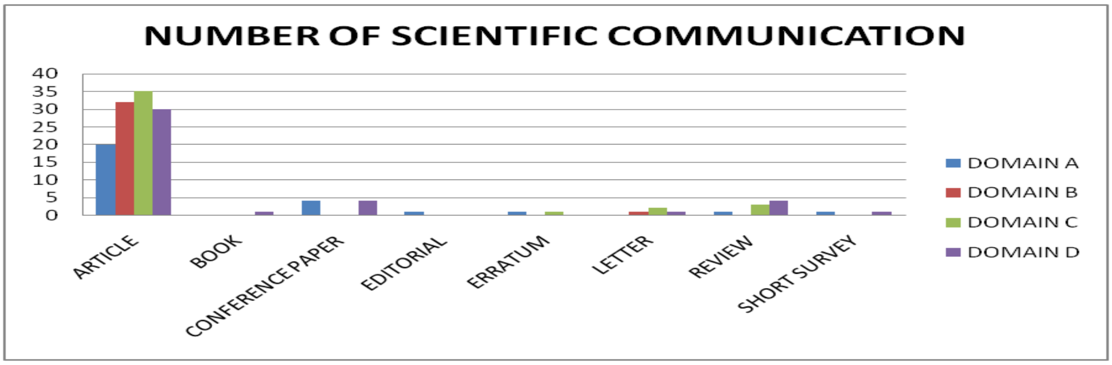


Fig 130: Number of Scientific Communication

6.3.10.3 To analyze the domain-wise authorship pattern of Jacques Dubochet.

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Dubochet are multi-authored having 5 to 10 authors. 10.49% of the total works are single-authored, 8.39% are two-authored, while the contribution of three and four-authored works stand at 18.18% and 16.78% respectively. The percentage of documents co-authored by 11 to 15 authors stand at 2.80%. Table 84 is a tabular form of the authorship pattern and Figure 131 presents a graphical view of the data.

Table 93 shows the domain-wise authorship pattern of Jacques Dubochet. Dubochet has authored 15 single-authored documents which represent 10.49% of his total publications. However, most of his publications have 5 to 10 authors. Jacques Dubochet has co-authored with a maximum of 15 authors. A graphical view of the above information is provided in Figure 131.

Table 93: Domain-wise Authorship as per Collaboration

Domain	**Authors**					
	1 - Author	2 - Author	3 - Author	4 - Author	5 – 10 Author	11 – 15 Author
A	3	3	6	3	12	1
B	3	5	5	7	13	0
C	4	2	8	9	18	0
D	5	2	7	5	19	3
Total	**15**	**12**	**26**	**24**	**62**	**4**
%	**10.49**	**8.39**	**18.18**	**16.78**	**43.36**	**2.80**

A: Bioengineering B: Biophysics C: Cryo Microscopy D: Molecular Biology

Fig 131: Domain-wise Authorship

6.3.10.4 To analyze the year-wise scientific communication of Jacques Dubochet.

Jacques Dubochet's publication life began in 1971, 29 years after his birth. A look into his year-wise productivity reveals that the author has published the maximum number of works from 2001 till 2010 when he had published 48 papers in all domains at 33.57%. During the first 10 years of his productive life, Dubochet has published 17 papers (11.89%). The lowest numbers of works were published from 2011 till 2018. A tabular form of this information is provided in table 94, while a graphical representation is given in figure 132.

Table 94: Domain and Year-wise Authorship

Period	DOMAIN				TOTAL PAPERS	%
	A	B	C	D		
1971-1980	4	4	5	4	**17**	**11.89**
1981-1990	3	23	4	4	**34**	**23.78**
1991-2000	5	2	14	17	**38**	**26.57**
2001-2010	16	2	15	15	**48**	**33.57**
2011-2018	0	2	3	1	**6**	**4.20**
Total	**28**	**33**	**41**	**41**	**143**	

A: Bioengineering B: Biophysics C: Cryo Microscopy D: Molecular Biology

Table 95: Year Wise Productivity

Year	Domain				Total Papers	%
	A	B	C	D		
1971	1	0	0	0	1	0.70
1972	1	0	0	0	1	0.70
1973	2	2	0	0	4	2.80
1974	0	1	0	0	1	0.70
1975	0	1	0	0	1	0.70
1976	0	0	2	0	2	1.40
1977	0	0	0	0	0	0
1978	0	0	1	1	2	1.40
1979	0	0	1	1	2	1.40
1980	0	0	1	2	3	2.10
1981	1	2	1	0	4	2.80

1982	1	2	1	0	4	2.80
1983	1	4	1	0	6	4.20
1984	0	4	1	0	5	3.50
1985	0	1	0	0	1	0.70
1986	0	5	0	0	6	4.20
1987	0	1	0	0	1	0.70
1988	0	2	0	0	3	2.10
1989	0	1	0	1	2	1.40
1990	0	1	0	1	2	1.40
1991	1	0	2	1	4	2.80
1992	1	0	1	0	2	1.40
1993	0	1	1	0	2	1.40
1994	0	1	1	2	4	2.80
1995	0	0	2	5	7	4.90
1996	1	0	4	1	6	4.20
1997	0	0	1	1	2	1.40
1998	1	0	1	4	6	4.20
1999	1	0	0	2	3	2.10
2000	0	0	1	1	2	1.40
2001	5	2	0	0	7	4.90
2002	2	0	1	1	4	2.80
2003	1	0	3	2	6	4.20
2004	1	0	1	1	3	2.10
2005	2	0	2	3	7	4.90
2006	2	0	3	3	8	5.60
2007	1	0	1	1	3	2.10
2008	1	0	2	2	5	3.50
2009	1	0	1	2	4	2.80
2010	0	0	1	0	1	0.70
2011	0	1	0	0	1	0.70
2012	0	1	0	0	1	0.70
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0

2015	0	0	0	0	0	0
2016	0	0	1	0	1	0.70
2017	0	0	1	0	1	0.70
2018	0	0	1	1	2	1.40
2019	0	0	0	0	0	0
2020	0	0	0	0	0	0

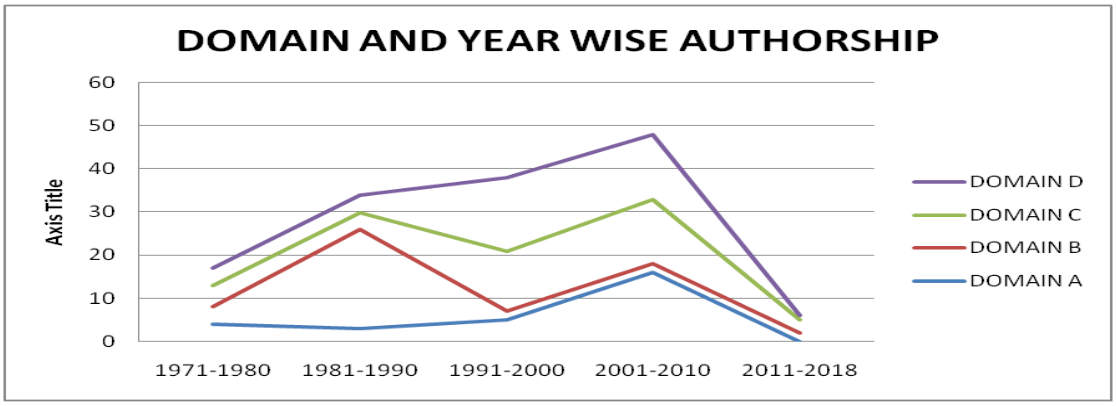


Fig 132: Domain wise and Year wise Authorship.

6.3.10.5 Author's production over time (Jacques Dubochet)

The year-wise authorship pattern of Jacques Dubochet is shown in Figure 133.

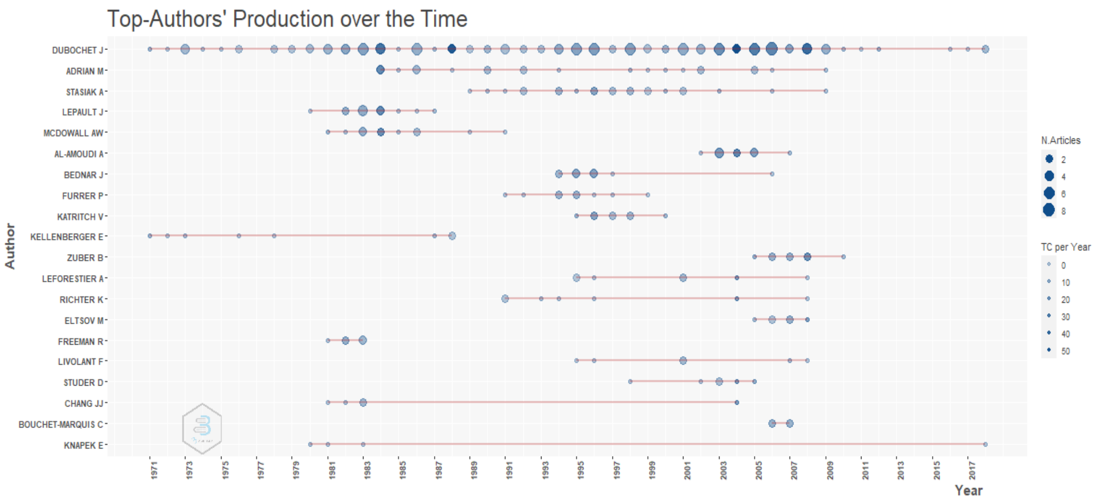


Fig 133: Authors' Production Over Time

6.3.10.6 To find out the channels of communication used by Jacques Dubochet.

Jacques Dubochet has published his works in various journals. Figure 134 is a graphical representation of the data, which indicates that the maximum number of papers (23) have appeared in the journal *'Journal of Microscopy'*.

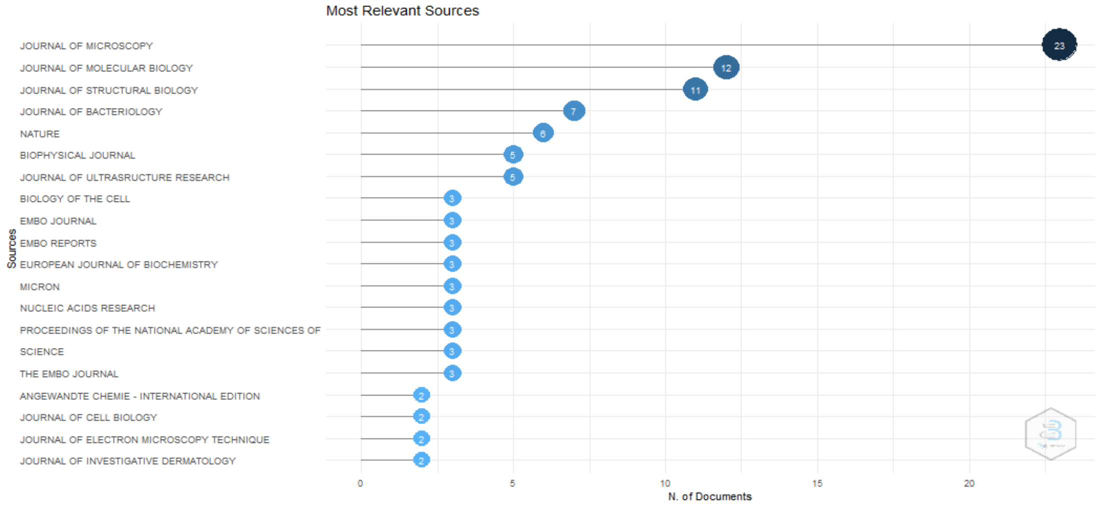


Fig 134: Most Relevant Sources

Table 96: Most Relevant Sources

Sources	Articles
Journal Of Microscopy	23
Journal Of Molecular Biology	12
Journal Of Structural Biology	11
Journal Of Bacteriology	7
Nature	6
Biophysical Journal	5
Journal Of Ultrasructure Research	5
Biology Of the Cell	3
Embo Journal	3
Embo Reports	3
European Journal of Biochemistry	3
Micron	3
Nucleic Acids Research	3
Proceedings Of the National Academy of Sciences of The United States of America	3
Science	3
The Embo Journal	3
Angewandte Chemie - International Edition	2
Journal Of Cell Biology	2
Journal Of Electron Microscopy Technique	2

Journal Of Investigative Dermatology	2
Journal Of Ultrastructure Research and Molecular Structure Research	2
Journal Of Virology	2
Methods In Cell Biology	2
Methods In Enzymology	2
Nature Structural Biology	2
Trends In Cell Biology	2
Ultramicroscopy	2
Adv In Opt and Electron Microsc	1
Annual Review of Biophysics and Bioengineering	1
Bioessays	1
Chemistry World	1
Chimia	1
Comptes Rendus Chimie	1
Comptes Rendus De L'academie Des Sciences - Serie Iii	1
Histochemistry And Cell Biology	1
Journal Of Controlled Release	1
Journal Of Physical Chemistry	1
Journal Of Supramolecular and Cellular Biochemistry	1
Journal Of Ultrastructure Research	1
Langmuir	1
Letters In Mathematical Physics	1
Macromolecules	1
Materials Science and Engineering C	1
Microscopica Acta	1
Microscopy And Microanalysis	1
New Journal of Physics	1
Photosynthesis Research	1
Physical And Numerical Models in Knot Theory: Including Applications to The Life Sciences	1
Physical Review E - Statistical Physics Plasmas Fluids and Related Interdisciplinary Topics	1
Plos Biology	1

Quarterly Reviews of Biophysics	1
Revue Medicale Suisse	1
Scanning Microscopy	1
Trends In Biochemical Sciences	1

6.3.10.7 Author's performance based on available metrics indicators (Jacques Dubochet)

Table 97: Performance of Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	34.85	01	i10-index (i10)	121
02	Total Citation	12344	02	h5-index (h5)	3
03	Audience Factor	148	03	g-Index	110
04	CiteScore (Maximum)	11.3	04	a-Index	182.32
05	ResearchGate Citations	35	05	h(2)-index	13
06	Microsoft Academic Search Citations	19389	06	hg-index (hg)	78.49
07	Google Scholar Citations	922	07	r-index	101.04
08	Eigenfactor	15.8	08	ar-index (ar)	13.27
09	Crown Indicator	7.236	09	k-index	7.09
10	Mean Citation Score	88.81	10	q2-index	10.42
11	Mean Normalized Citation Score (MNCS)	0.06	11	f-index	2.26
12	Mean Citation Rate Subfield (MCRS)	10.03	12	m-index	1.94
13	Scientific Talent Pool (STP)	12.01	13	m quotient (m-q)	1.94
14	Microsoft Academic Search Papers (MASP)	140	14	Contemporary-index (Ch)	345.29
15	Google Scholar Papers (GSP)	4	15	Trendh h-index (Th)	0.02
16	Impact per Paper (IPP)	15.98	16	Dynamic h-Type index (Dh-T)	9.19
17	Citation per paper (CPP)	86.32	17	n-index	1.12

18	Citations per Paper self-citation not included (CPPex)	82.78	18	mean h-index	28.5
19	The average number of citations per publication (ANCP)	1.49	19	Normalized h-index	22.36
20	Total and the Average Number of Citations (TNCS)	12344 and 1.49	20	Specific-impact s-index (Sis)	21.39
21	Relative Activity Index (RAI)	9.89	21	Seniority independent Hirsch type index (Sih-T)	1
22	Relative Specialization index (RSI)	48.67	22	Hw-index	101.04
23	Relative Citation Rate (RCR)	55.44	23	Hm-index	29
24	Relative Database Citation Potential (RDCP)	67.79	24	Tapered h-index	0.09
25	Journal Acceptance Rate (JAR)	17.91	25	i20-index	104
26	% Self Citations (%SC)	4.11	26	v-index over h	3.43
27	Percentage of papers not cited (%Pnc)	2.80	27	e-index	84.11
28	PR Percentile Ranks (PR)	39	28	Multidimensional h-index	40.12
29	LogZ-score (LogZ)	15.893	29	Research Collaboration Index	48.99
30	Innovative Knowledge (IK)	21.35	30	Communities Collaboration Index	65.98
31	Technological Impact (TI)	66.27	31	ch-index	72.35
32	Scientific Talent Pool (STP)	12.01	32	speed s-iCitationndex	28.95
33	Normalized position of publication journal (NPJ)	22	33	π-index	54.98

34	WorldCat Hold (WCH)	372	34	h5-median (h5-m)	21.87
35	Papers in Top 1 (PT1)	13	35	2^{nd} generation citations h index	42
36	Papers in Top 10 (PT10)	25	36	Role basedh-maj-index (Rbhm)	33.86
37	Papers in Top 50 (PT50)	36	37	h2 lower (h2-l)	18
38	High Cited Papers (HCP)	23	38	h2-center (h2-c)	4
39	Papers in First Quartile (Q1)	19	39	h2-upper (h2-u)	9
40	Publications in Thomson Reuters indices (PwoS)	0	40	h3-index	11
41	Number of highly cited publications (NHCP)	2	41	p-index	16.88
42	Publications in top-ranked journals (PTRJ)	26	42	$\bar{h}$-index (Hbar)	56
43	Papers in Collaboration (Pcol)	128	43	Mockhm-index (Mhm)	48.59
44	Share of articles coauthored with another unit (%CoA)	89.51	44	w-index	18.56
45	National Collaboration (Ncol)	55.32	45	b-index	18.98
46	International Collaboration (Icol)	44.68	46	Generalizedh-index	48.97
47	Scientific Leadership (SL)	22	47	Single paperh-index	38
48	Average Authors per Paper	1.94	48	hint-index	42
49	Productivity per Paper	2.16	49	h_{rat}-index	56.98
50	RoG, CAGR, RGR and DT	0.36, (-)0.98, 0.11, 2.08	50	πv-index	48.76

6.3.10.8 To analyze the scientific collaboration of Jacques Dubochet

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Jacques Dubochet has collaborated with 270 different authors in the conduct and publication of his research work. The author has published only 15 single-authored documents.

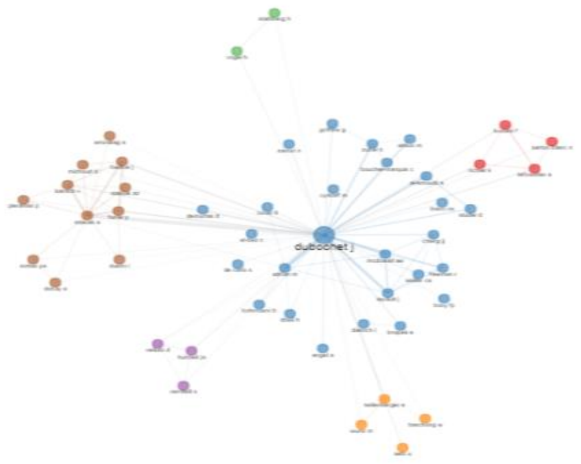


Fig 135: Collaboration Network

6.3.10.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Jacques Dubochet, the collaboration index has been calculated at 2.16.

6.3.10.8.2 National and International Collaboration: Jacques Dubochet has published his papers in collaboration with 270 co-authors of mostly hailing from Switzerland, Germany, France, and the United States of America. Of the 128 papers published in collaboration, 109 have been published along with national collaboration, while the others have been published with collaborative efforts from international researchers. The collaboration map of Jacques Dubochet is produced in figure 136.

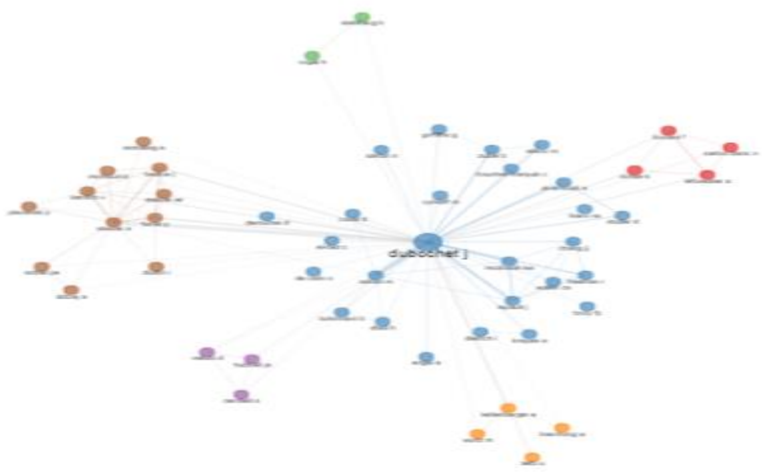


Fig. 136: National and International Collaboration

6.3.10.8.3 Co-authorship Index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Jacques Dubochet has been calculated at 4.54.

6.3.10.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources has resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Jacques Dubochet had close communication with 270 co-authors while publishing his documents.

6.3.10.9 To find out the research network of Jacques Dubochet.

6.3.10.9.1 Co-authorship: Jacques Dubochet had collaborated with 269 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with A Stasiak, M Adrian, and J Lepault were the highest. A graphical representation of the co-authorship pattern is shown in figure 137 below.

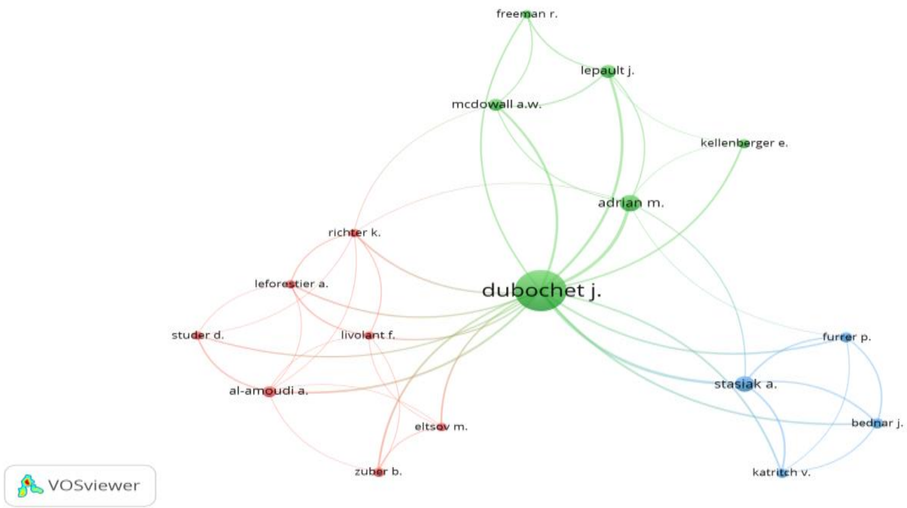


Fig. 137: Co-authorship Pattern of Jacques Dubochet

6.3.10.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top four keywords on the decreasing order of their link strengths.

Table 98: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	77	544
priority journal	64	436
electron microscopy	61	383
cryoelectron microscopy	45	353

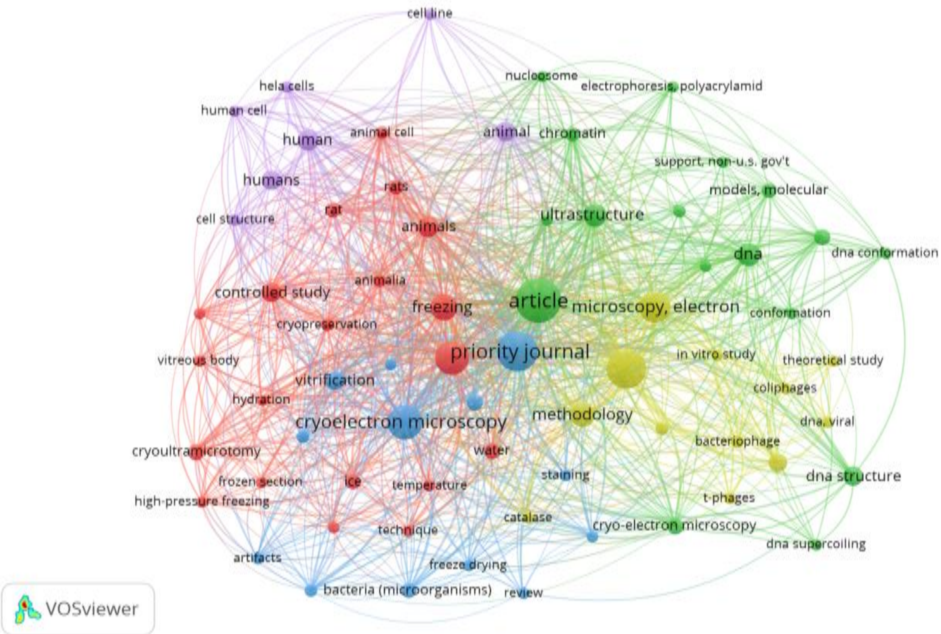


Fig. 138: Keyword Co-occurrences Authorship Pattern

6.3.10.9.3 Citation analysis: Of the 143 papers published by Jacques Dubochet, either as a single author or in collaboration, 139 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *Cryo-electron microscopy of vitrified specimens*, published in the journal *Quarterly Reviews of Biophysics* during 1988 has been cited 1619 times followed by the article *Cryo-electron microscopy of viruess* published in *Nature* in 1984 which received 896 citations. Another article, *Role of LBPA and Alix in Multivascular Liposome Formation and Endosome Organization* published in the journal *Science* during 2004 has been cited 480 times. A graphical representation of the above information is presented in Figure 139.

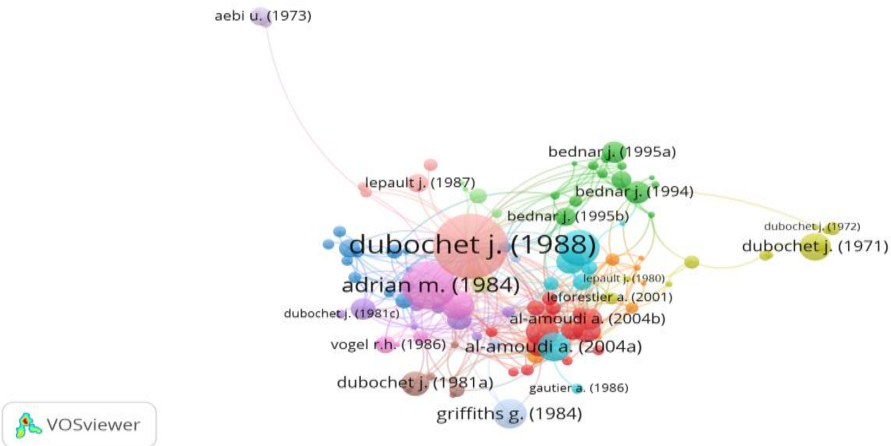


Fig. 139: Citation Analysis

6.3.10.9.4 Bibliographic Coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Jacques Dubochet is presented in figure 140.

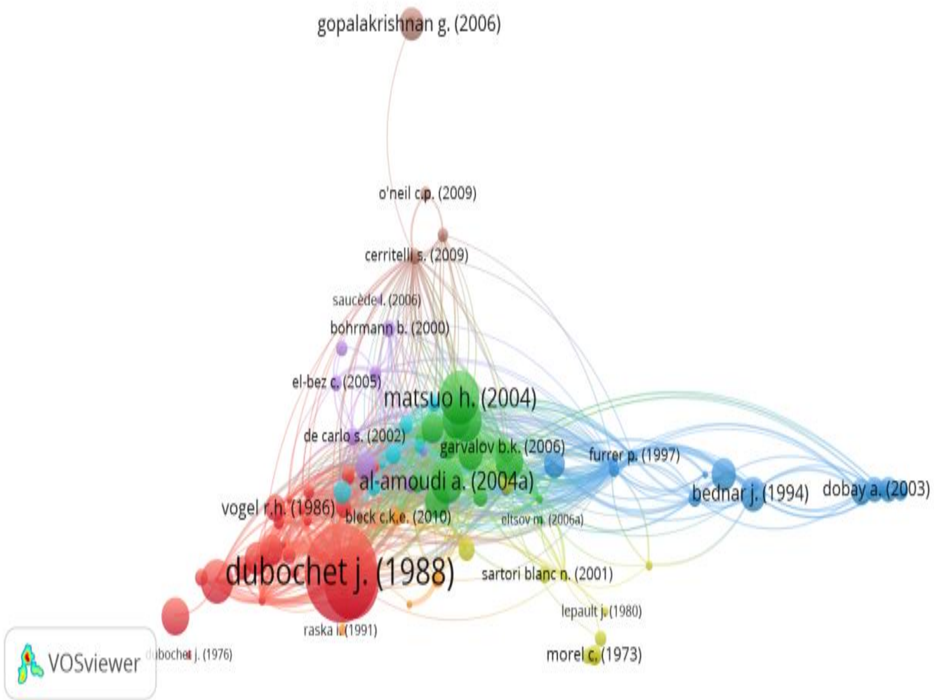


Fig. 140: Bibliographic Coupling

6.3.10.9.5 Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of Jacques Dubochet is produced in Fig. 141. Analysis of the figure shows that the articles published by Jacques Dubochet has been co-cited by 5 clusters, having 11, 11, 7, 4, and 3 items each. There are a total of 524 links, with a total link strength of 36283.

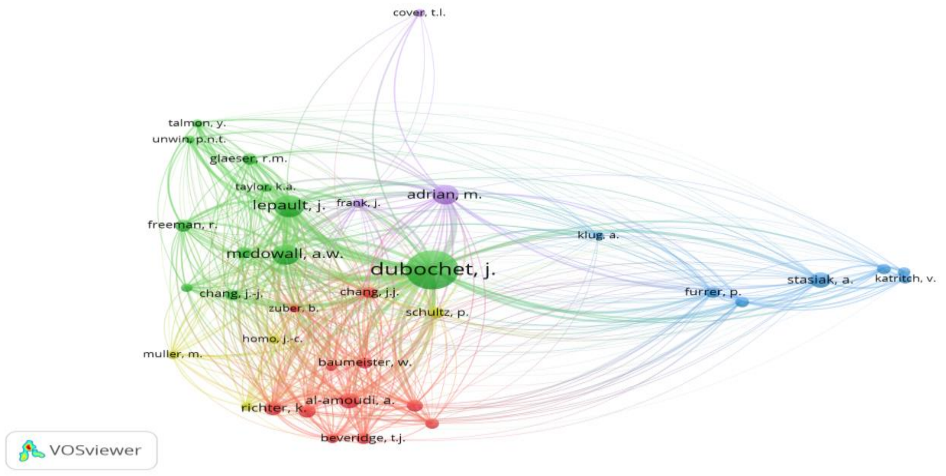


Fig. 141: Co-citation Analysis

6.3.10.10 To analyze cluster mapping (Jacques Dubochet)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 142 shows the coupling map of Jacques Dubochet.

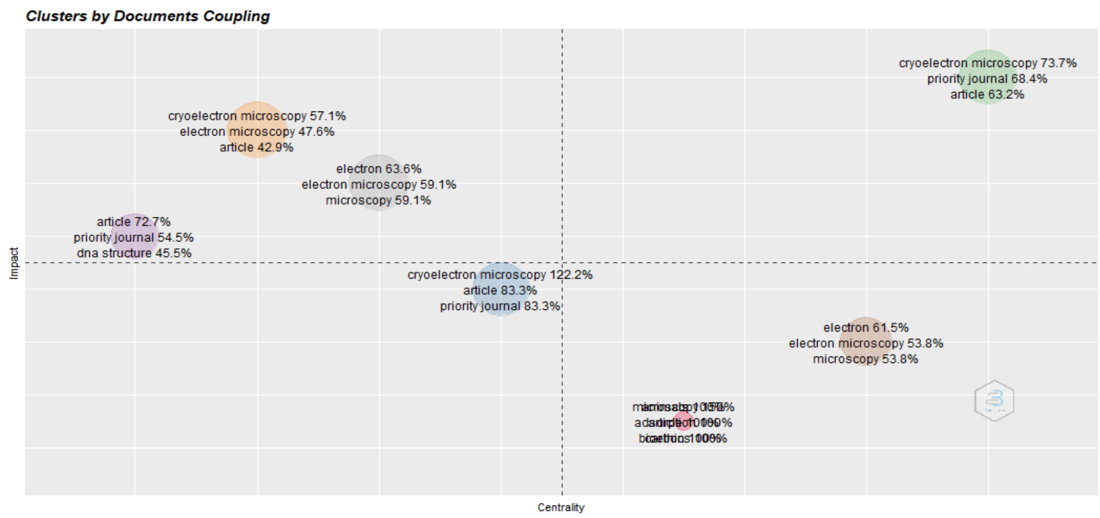


Fig 142: Document Coupling

6.3.10.11 Other information (Jacques Dubochet)

Table 99: Main Information

Description	Results
Timespan	1971:2018
Sources	
Journals, Books, Etc	52

Documents	143
Total	195
Average Years from Publication	26.4
Average Citations Per Documents	83.19
Average Citations Per Year Per Doc	3.306
References	3162
Document Types	
Article	117
Book	1
Conference Paper	8
Editorial	1
Erratum	2
Letter	4
Review	8
Short Survey	2
Total	143
Document Contents	
Keywords Plus (Id)	971
Author's Keywords (De)	250
Authors	
Authors	278
Author Appearances	649
Authors Of Single-Authored Documents	1
Authors Of Multi-Authored Documents	277
Authors Collaboration	
Single-Authored Documents	15
Documents Per Author	0.514
Authors Per Document	1.94
Co-Authors Per Documents	4.54
Collaboration Index	2.16
H-Index	56
Total Citation	12,344 Citations By 8,820 Documents

The publication productivity of Jacques Dubochet is consistent throughout the entire productive life and he has made outstanding contributions in the field of cryo microscopy. His publication life commenced in 1971 after he had attained a biological age of 29 years. Jacques Dubochet has been active in research despite many responsibilities. He has worked in collaboration and has a high degree of collaboration at institutional, national, and international levels. Jacques Dubochet has an h-index of 56 and is regarded as one of the most successful scientists in the field of chemistry. Jacques Dubochet's research efforts have largely been concentrated on molecular biology and genomics which proves his strength in this field. Jacques Dubochet's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.11 JOACHIM FRANK

Joachim Franc, a German American biophysicist at Columbia University and a Nobel Laureate was born on 12th September 1940. Franc is credited with being the founder of single-particle cryo-electron microscopy. Franc has also contributed to the structure and function of the ribosome from bacteria and eukaryotes.

6.3.11.1 To assess the number of scientific communications contributed by Joachim Frank.

Joachim Frank has used several media to publish his scientific works. While most of his scientific communication have been through articles that he has published himself or in collaboration with other co-authors, he has also authored books, presented conference papers, editorials, reviews, surveys, etc. Table 100 shows the number of scientific communications of the Nobel Laureate.

Table 100: Scientific Communication

Document Types	
Article	298
Book	4
Book Chapter	8
Conference Paper	32
Editorial	7
Erratum	5

Letter	3
Note	1
Review	27
Short Survey	3

6.3.11.2 To analyze the domain wise scientific communication of Joachim Frank.

The works of Joachim Frank can be broadly classified into four categories or domains: Biochemistry, Biosciences, Biophysics, and Chemical Engineering. Translating the information in numerical and percentage terms, Frank has published a total of 388 papers of which 100 papers are on biophysics (25.77%), 97 papers on Chemical Engineering (25%), 96 papers on bioscience (24.74%) and 95 on Biochemistry (24.48%). Joachim Frank has published his works using several modes. While most of his works, (298, 76.80%) are in the form of articles, he has also published his works in the form of Book Chapters, Conference Papers, Editorials, Errata, Letters, Notes, Reviews, and Short Surveys in varying proportions. Table 101 is a tabular form of the above information and Figure 143 is a graphical form of the same.

Table 101: Number of Scientific Communication

Document	**Domain**				**Total Papers**	%
	A	B	C	D		
Article	72	74	78	74	**298**	**76.80**
Book	1	2	1	0	**4**	**1.03**
Book Chapter	3	2	0	3	**8**	**2.06**
Conference Paper	8	7	8	9	**32**	**8.25**
Editorial	2	3	0	2	**7**	**1.80**
Erratum	0	0	4	1	**5**	**1.29**
Letter	0	1	2	0	**3**	**0.77**
Note	1	0	0	0	**1**	**0.26**
Review	7	7	7	6	**27**	**6.96**
Short Survey	1	0	0	2	**3**	**0.77**
%	**24.48**	**24.74**	**25.77**	**25**		**100**

A: Biochemistry B: Biosciences C: Biophysics D: Chemical Engineering

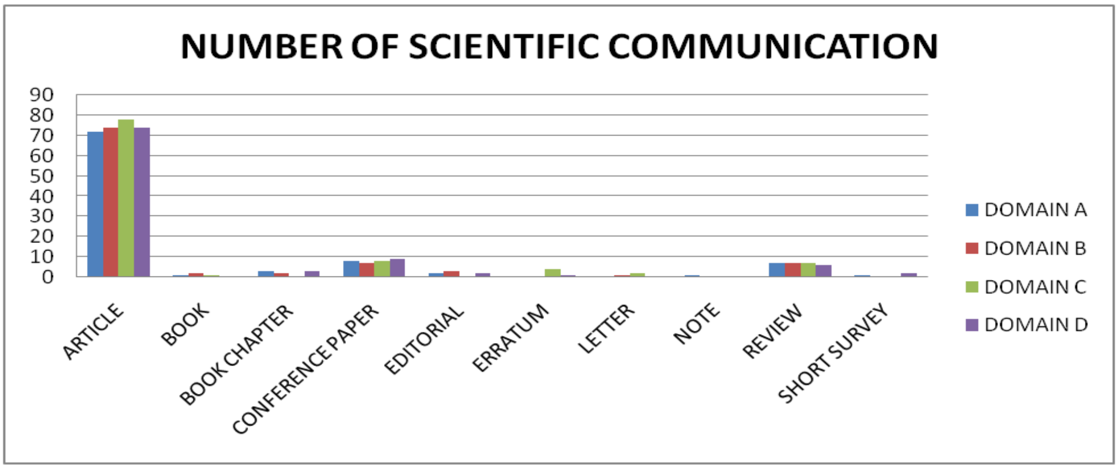


Fig. 143: Number of Scientific Communication

6.3.11.3 To analyze the domain-wise authorship pattern of Joachim Frank.

Joachim Frank had to work in collaboration with other authors due to his numerous responsibilities which is evident from the analysis of his works. While the author has 58 single-authored documents representing 14.95% of his total publications, 254 publications have been published with collaboration with 3 to 10 authors (65.46%). One document was authored by 44 authors.

Table 102: Domain-wise Authorship as per Collaboration

Domain	Authors						
	1- AUTHOR	2- AUTHOR	3- 10 AUTHOR	11-20 AUTHOR	21-30 AUTHOR	31-40 AUTHOR	41-50 AUTHOR
A	23	12	58	2	0	0	0
B	8	15	69	3	1	0	0
C	17	13	63	4	1	1	1
D	10	13	64	8	1	1	0
Total Papers	**58**	**53**	**254**	**17**	**3**	**2**	**1**
%	**14.95**	**13.66**	**65.46**	**4.38**	**0.77**	**0.52**	**0.26**

A: Biochemistry B: Biosciences C: Biophysics D: Chemical Engineering

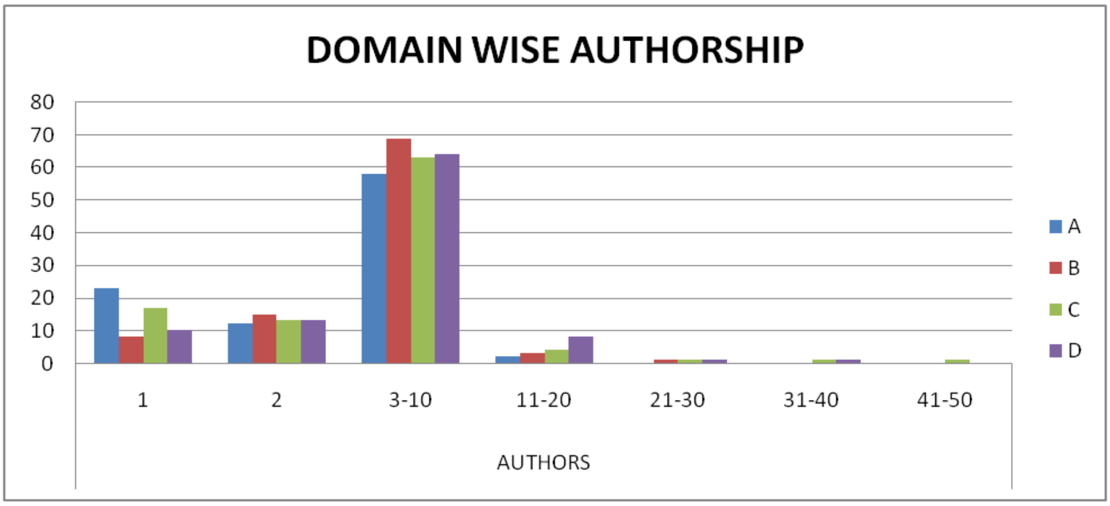


Fig. 144: Domain-wise Authorship Pattern

6.3.11.4 To analyze the year-wise scientific communication of Joachim Frank.

Joachim Frank's publication life began in 1969, 29 years after his birth. A look into his year-wise productivity reveals that the author has published the maximum number of works from 2001 till 2010 when he had published 125 papers in all domains at 32.22%. During the first 10 years of his productive life, Frank published 24 papers (6.19%) which is the lowest number of works published by the author. A tabular form of this information is provided in Table 103, while a graphical representation is given in figure 145.

Table 103: Domain and Year-wise Authorship

Period	DOMAIN				TOTAL PAPERS	%
	A	B	C	D		
1969-1980	12	0	12	0	**24**	**6.19**
1981-1990	10	24	15	26	**75**	**19.33**
1991-2000	19	19	19	19	**76**	**19.59**
2001-2010	30	36	30	29	**125**	**32.22**
2011-2020	24	17	24	23	**88**	**22.68**
Total	**95**	**96**	**100**	**97**	**391**	

A: Biochemistry B: Biosciences C: Biophysics D: Chemical Engineering

Table 104: Year-wise Productivity

Year	Domain				Total Papers	%
	A	B	C	D		
1961	0	0	0	0	0	0

1962	0	0	0	0	0	0
1963	0	0	0	0	0	0
1964	0	0	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	1	0	0	0	1	0.26
1970	0	0	0	0	0	0
1971	0	0	0	0	0	0
1972	1	0	1	0	2	0.52
1973	1	0	1	0	2	0.52
1974	1	0	0	0	1	0.26
1975	3	0	3	0	6	1.55
1976	1	0	2	0	3	0.77
1977	1	0	0	0	1	0.26
1978	1	0	2	0	3	0.77
1979	1	0	1	0	2	0.52
1980	1	0	2	0	3	0.77
1981	2	2	1	1	6	1.55
1982	2	5	1	2	10	2.58
1983	2	1	0	0	3	0.77
1984	2	4	2	2	10	2.58
1985	1	2	3	3	9	2.32
1986	1	2	3	3	9	2.32
1987	0	3	1	1	5	1.29
1988	0	3	2	6	11	2.83
1989	0	0	2	5	7	1.80
1990	0	0	0	5	5	1.29
1991	2	1	0	0	3	0.77
1992	2	4	3	0	9	2.32
1993	2	1	2	0	5	1.29
1994	2	3	1	1	7	1.80

1995	2	5	2	1	10	2.58
1996	2	1	2	2	7	1.80
1997	2	2	1	1	6	1.55
1998	2	1	2	3	8	2.06
1999	2	1	2	4	9	2.32
2000	1	0	4	5	10	2.58
2001	6	3	2	1	12	3.09
2002	6	3	2	1	12	3.09
2003	6	5	2	1	14	3.61
2004	6	2	2	0	10	2.58
2005	6	2	2	0	10	2.58
2006	0	10	5	2	23	5.93
2007	0	8	5	3	16	4.12
2008	0	1	5	4	10	2.58
2009	0	1	4	4	9	2.32
2010	0	1	1	6	8	2.06
2011	8	2	4	0	12	3.09
2012	2	1	2	0	5	1.29
2013	2	2	3	0	7	1.80
2014	5	3	2	0	10	2.58
2015	2	1	5	1	9	2.32
2016	2	1	5	1	9	2.32
2017	3	4	1	3	11	2.83
2018	1	1	1	10	13	3.35
2019	0	1	1	3	5	1.29
2020	0	1	0	6	7	1.80

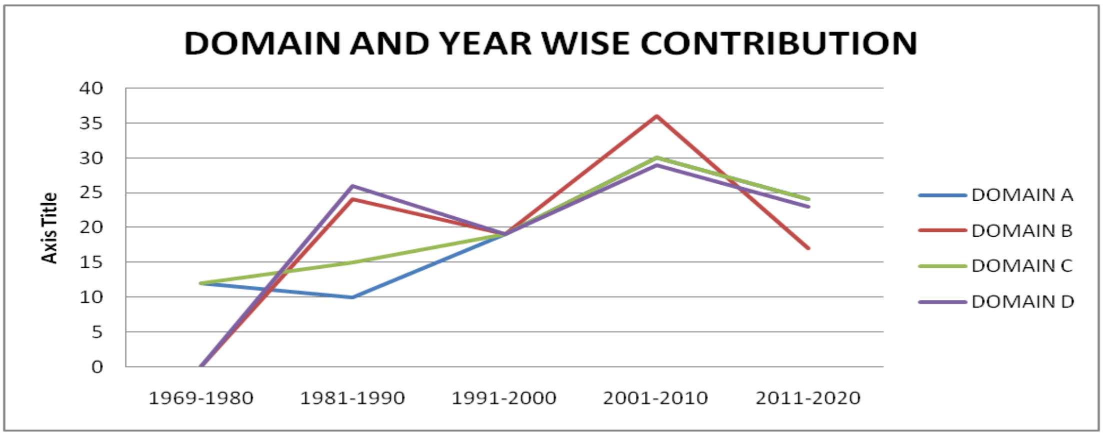


Fig. 145: Domain and Year-wise Authorship

6.3.11.5 Author's Production over time (Joachim Franc)

The productivity of Joachem Frank as a factor of time has been shown in Fig.146. The figure bears testimony to the fact that the productivity has increased till 2010.

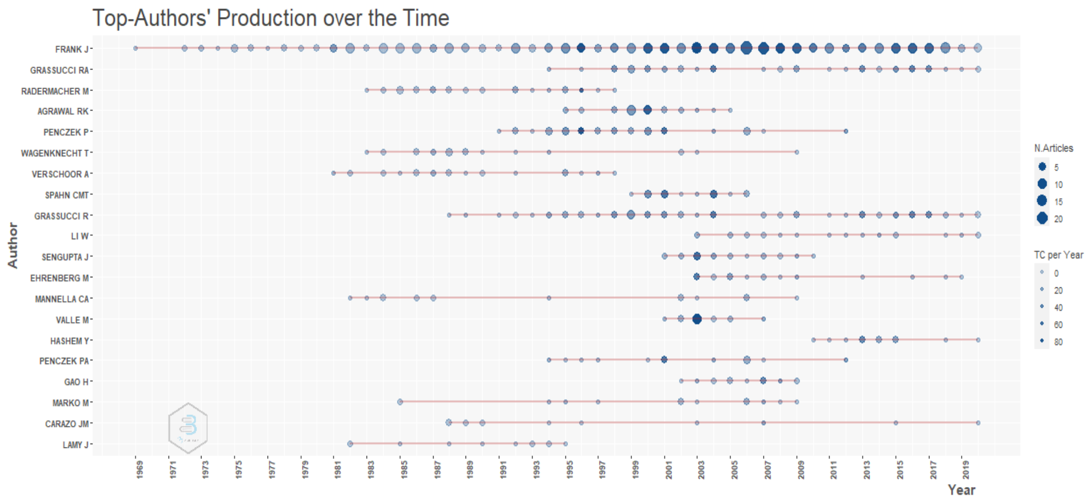


Fig. 146: Author's Production over Time

6.3.11.6 To find out the channels of communication used by Joachim Frank.

Joachim Frank published his scientific works using a variety of methods, be it articles, erratums, editorials, notes, book chapters, etc. The articles published by Joachim Frank have been published in a number of journals. In the order of the decreasing number of articles, the top twenty journals publishing his articles have been shown in fig. 147. The figure shows that 42 articles have been published in the journal *Journal of Structural Biology*, followed by 27 articles in the journal *Journal of Molecular Biology*.

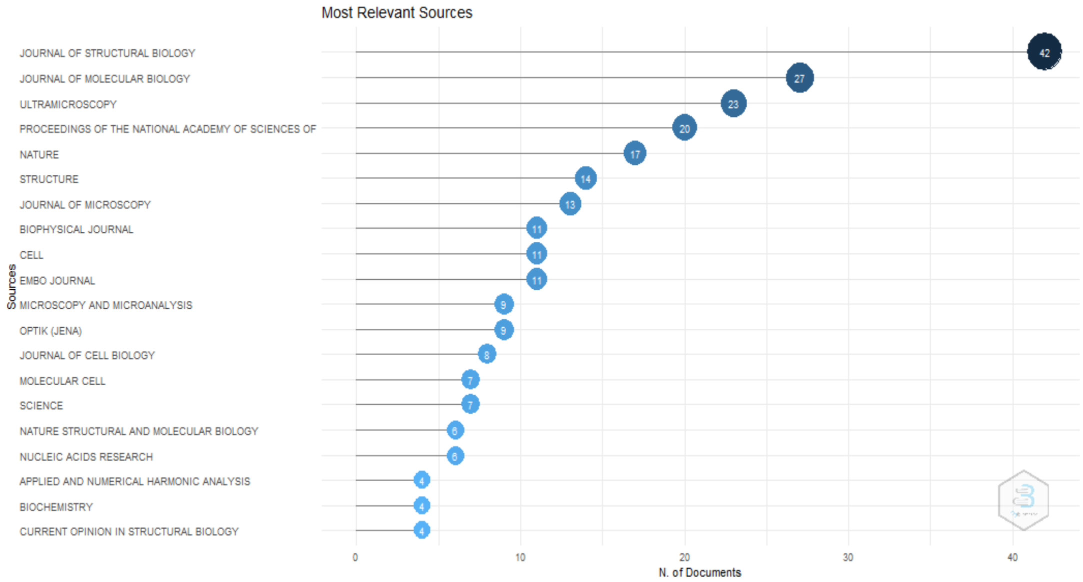


Fig. 147: Channels of Communication

Table 105: Most Relevant Sources

Sources	Articles
Journal Of Structural Biology	42
Journal Of Molecular Biology	27
Ultramicroscopy	23
Proceedings Of the National Academy of Sciences of The United States of America	20
Nature	17
Structure	14
Journal Of Microscopy	13
Biophysical Journal	12
Cell	11
Embo Journal	11
Microscopy And Microanalysis	9
Optik (Jena)	9
Journal Of Cell Biology	8
Molecular Cell	7
Science	7
Nature Structural and Molecular Biology	6
Nucleic Acids Research	6
Biochemistry	5

Applied And Numerical Harmonic Analysis	4
Current Opinion in Structural Biology	4
Electron Tomography: Methods for Three-Dimensional Visualization of Structures in The Cell	4
Molecular Machines in Biology: Workshop of The Cell	4
Nature Protocols	4
Annals Of The New York Academy of Sciences	3
Methods In Enzymology	3
Nature Communications	3
Nature Structural Biology	3
Proteins: Structure Function and Bioinformatics	3
Proteomics	3
Quarterly Reviews of Biophysics	3
Rna	3
Science Advances	3
Annual Review of Biophysics and Biomolecular Structure	2
Biopolymers	2
Cold Spring Harbor Symposia on Quantitative Biology	2
Febs Letters	2
Iscience	2
Journal Of Biological Chemistry	2
Journal Of Chemical Information and Modeling	2
Journal Of Electron Microscopy Technique	2
Journal Of Physical Chemistry B	2
Journal Of the Optical Society of America A: Optics and Image Science and Vision	2
Journal Of Ultrastructure Research and Molecular Structure Research	2
Methods	2
Methods In Cell Biology	2
Microscopy (Oxford England)	2
Nature Methods	2
Proceedings - Annual Meeting Microscopy Society of America	2
Protein Science	2

Subcellular Biochemistry	2
The Embo Journal	2
Trends In Biochemical Sciences	2
2010 7th Ieee International Symposium on Biomedical Imaging: From Nano to Macro Isbi 2010 - Proceedings	1
Aiche Annual Meeting Conference Proceedings	1
American Scientist	1
Angewandte Chemie - International Edition	1
Annual Review of Biochemistry	1
Annual Review of Biophysics	1
Applied Optics	1
Biochemistry (Moscow)	1
Biochemistry And Cell Biology = Biochimie Et Biologie Cellulaire	1
Bioessays	1
Biology Of the Cell	1
Biotechniques	1
Chemistry And Biology	1
Chemistry World	1
Chromosoma	1
Cold Spring Harbor Perspectives in Biology	1
Colloid & Polymer Science	1
Current Opinion in Neurobiology	1
Die Naturwissenschaften	1
Electron Microscopy Reviews	1
Elife	1
Embo Reports	1
Encyclopedia Of Microbiology	1
European Journal of Biochemistry	1
European Journal of Cell Biology	1
F1000research	1
Faseb Journal	1
Genome Biology	1
Human Genomics	1

International Journal of Biochemistry and Cell Biology	1
Israel Journal of Chemistry	1
Iucrj	1
Journal Of Biomolecular Structure and Dynamics	1
Journal Of Cell Science	1
Journal Of Inorganic Biochemistry	1
Journal Of Molecular Evolution	1
Journal Of Neuroscience	1
Journal Of Physics D: Applied Physics	1
Journal Of Physics E: Scientific Instruments	1
Journal Of Supramolecular and Cellular Biochemistry	1
Journal Of Ultrasructure Research	1
Methods In Molecular Biology	1
Microscopy Research and Technique	1
Molecular Microbiology	1
Nature Chemical Biology	1
Nature Chemistry	1
Neuroimage	1
Neuron	1
Optics Infobase Conference Papers	1
Optik (Stuttgart)	1
Philosophical Transactions of The Royal Society B: Biological Sciences	1
Proceedings - Electron Microscopy Society of America	1
Proceedings - International Symposium on Biomedical Imaging	1
Proceedings Of Spie - The International Society for Optical Engineering	1
Proceedings Of the American Association for Cancer Research	1
Rna Biology	1
Scanning	1
Scanning Microscopy. Supplement	1
Single-Particle Cryo-Electron Microscopy: The Path Toward Atomic Resolution/ Selected Papers of Joachim Frank with Commentaries	1
Structural Insights into Gene Expression and Protein Synthesis	1
Three-Dimensional Electron Microscopy of Macromolecular Assemblies:	1

Visualization of Biological Molecules In Their Native State	
Tissue And Cell	1

6.3.11.7 Author's performance based on available metrics indicators (Joachim Franc)

Table 106: Performance of Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	18.9	01	i10-index (i10)	290
02	Total Citation	29448	02	h5-index (h5)	21
03	Audience Factor	135.8	03	g-Index	146
04	CiteScore (Maximum)	5.9	04	a-Index	196.53
05	ResearchGate Citations	23	05	h(2)-index	17
06	Microsoft Academic Search Citations	47522	06	hg-index (hg)	115.26
07	Google Scholar Citations	10245	07	r-index	133.73
08	Eigenfactor	22.43	08	ar-index (ar)	17.56
09	Crown Indicator	5.998	09	k-index	0.05
10	Mean Citation Score	70.89	10	q2-index	12.62
11	Mean Normalized Citation Score (MNCS)	49.82	11	f-index	1.16
12	Mean Citation Rate Subfield (MCRS)	3.65	12	m-index	1.75
13	Scientific Talent Pool (STP)	1.69	13	m quotient (m-q)	1.75
14	Microsoft Academic Search Papers (MASP)	249	14	Contemporary-index (Ch)	265.28
15	Google Scholar Papers (GSP)	50	15	Trendh h-index (Th)	0.08
16	Impact per Paper (IPP)	45.98	16	Dynamic h-Type index (Dh-T)	72.94
17	Citation per paper (CPP)	2.00	17	n-index	1.94
18	Citations per Paper self-citation not included (CPPex)	1.85	18	mean h-index	48.0

19	The average number of citations per publication (ANCP)	65.96	19	Normalized h-index	88.21
20	Total and the Average Number of Citations (TNCS)	29448, 2.00	20	Specific-impact s-index (Sis)	18.79
21	Relative Activity Index (RAI)	59.67	21	Seniority independent Hirsch type index (Sih-T)	6
22	Relative Specialization index (RSI)	67.99	22	Hw-index	133.73
23	Relative Citation Rate (RCR)	43.27	23	Hm-index	0.10
24	Relative Database Citation Potential (RDCP)	43.68	24	Tapered h-index	0.10
25	Journal Acceptance Rate (JAR)	45.29	25	i20-index	243
26	% Self Citations (%SC)	8.59	26	v-index over h	3.48
27	Percentage of papers not cited (%Pnc)	6.70	27	e-index	97.99
28	PR Percentile Ranks (PR)	65	28	Multidimensional h-index	38.29
29	LogZ-score (LogZ)	22.114	29	Research Collaboration Index	57.65
30	Innovative Knowledge (IK)	29.88	30	Communities Collaboration Index	77.26
31	Technological Impact (TI)	69.19	31	ch-index	25.59
32	Scientific Talent Pool (STP)	56.67	32	speed s-iCitationndex	19.87
33	Normalized position of publication journal (NPJ)	28	33	π-index	69.76
34	WorldCat Hold (WCH)	234.21	34	h5-median (h5-m)	18.76
35	Papers in Top 1 (PT1)	10	35	2nd generation	79

				citations h index	
36	Papers in Top 10 (PT10)	14	36	Role basedh-maj-index (Rbhm)	45.01
37	Papers in Top 50 (PT50)	35	37	h2 lower (h2-l)	22
38	High Cited Papers (HCP)	24	38	h2-center (h2-c)	58
39	Papers in First Quartile (Q1)	26	39	h2-upper (h2-u)	72
40	Publications in Thomson Reuters indices (PWoS)	0	40	h3-index	56
41	Number of highly cited publications (NHCP)	48	41	p-index	58.9
42	Publications in top-ranked journals (PTRJ)	26	42	$\bar{h}$-index (Hbar)	91
43	Papers in Collaboration (PCol)	330	43	Mockhm-index (Mhm)	78.98
44	Share of articles coauthored with another unit (%CoA)	87.11	44	w-index	17.06
45	National Collaboration (NCol)	58	45	b-index	25.78
46	International Collaboration (ICol)	42	46	Generalizedh-index	85.36
47	Scientific Leadership (SL)	17.08	47	Single paperh-index	69
48	Average Authors per Paper	1.63	48	hint-index	78
49	Productivity per Paper	1.59	49	h_{rat}-index	91.99
50	RoG, CAGR, RGR and DT	0.21, (-)0.98, 0.12, 1.87	50	πv-index	68.45

6.3.11.8 To analyze the scientific collaboration of Joachim Franc

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Joachim Frank has collaborated with 624 different authors in the conduct and publication of his research work. The author has published 58 single-authored documents.

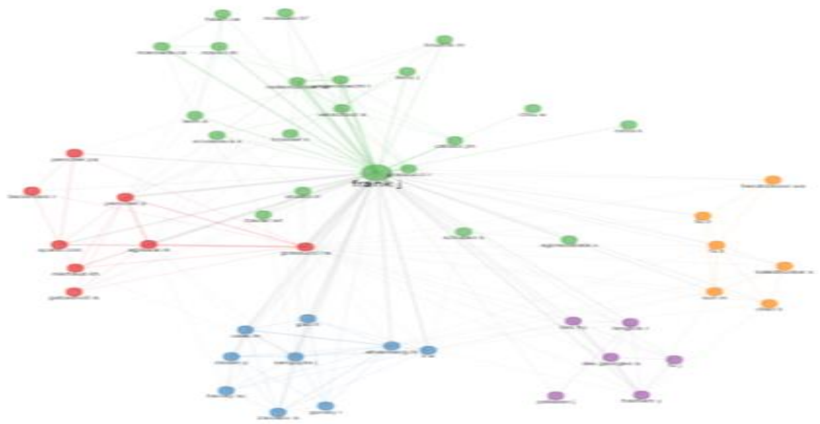


Fig 148: Collaboration Network

6.3.11.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{Total Authors \in multi - authored articles}{Total multi - authored articles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Joachim Frank, the collaboration index has been calculated at 1.91.

6.3.11.8.2 National and International Collaboration: Sir Gregory P. White has published his papers in collaboration with 624 co-authors hailing from the United States, Germany, Spain, France, Sweden and the United Kingdom. The collaboration map of Jaochim Frank is produced in figure 149.

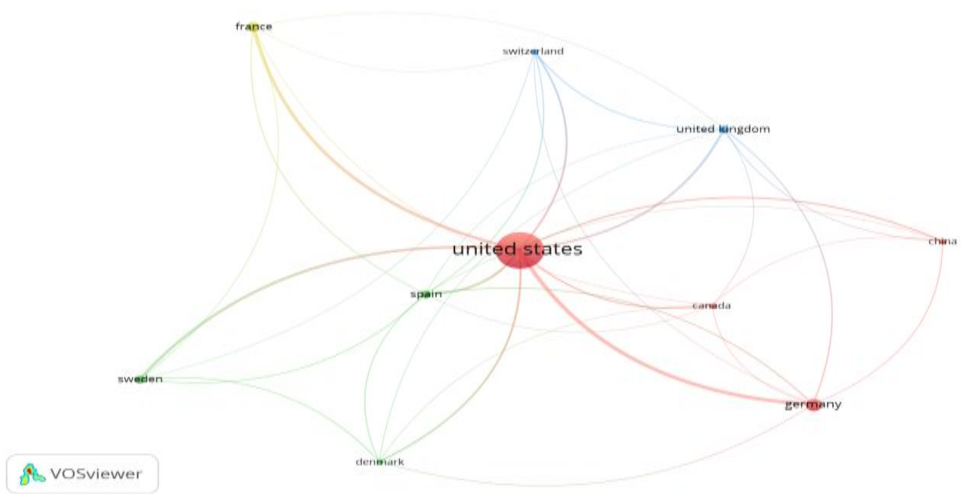


Fig. 149: National and International Collaboration

6.3.11.8.3 Co-authorship Index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Joachim Frank has been calculated at 5.010.

6.3.11.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources has resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Joachim Frank had close communication with 10 co-authors while publishing his documents.

6.3.11.9 To find out the research network of Joachim Frank.

6.3.11.9.1 Co-authorship: Joachim Frank had collaborated with 624 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with R A Grassucci, P Penczek, R K Agarwal, and M Radermacher were the highest. A graphical representation of the co-authorship pattern is shown in figure 150.

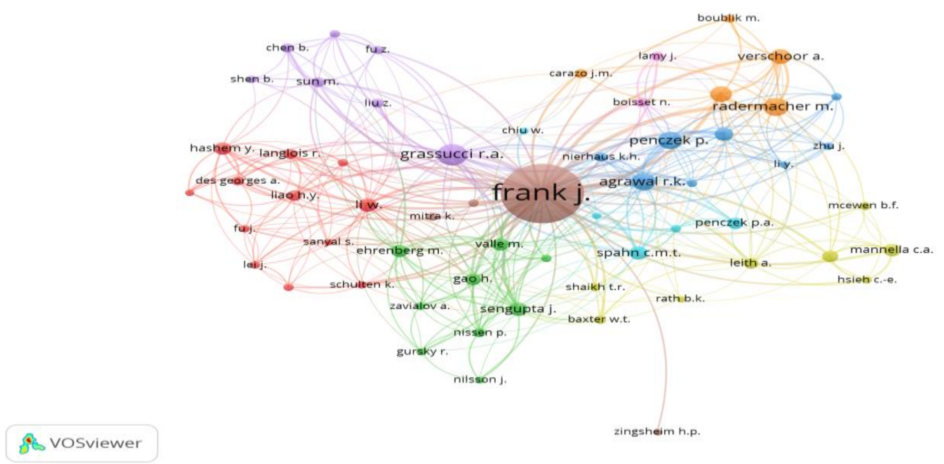


Fig. 150: Co-authorship Pattern of Joachim Frank

6.3.11.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top five keywords on the decreasing order of their link strengths.

Table 107: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	216	3395
priority journal	202	3247
cryoelectron microscopy	165	2964
ribosome	154	2644

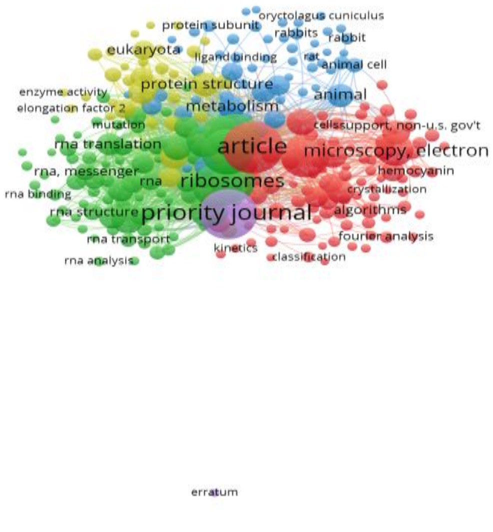


Fig. 151: Keyword Co-occurrences Authorship Pattern

6.3.11.9.3 Citation analysis: Of the 388 papers published by Joachim Frank, either as a single author or in collaboration, 362 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *SPIDER and WEB: Processing and visualization of images in 3Delectron microscopy and related fields*, published in the journal *Journal of Structural Biology* during 1996 has been cited 1756 times followed by the article *A ratchet-like inter-subunit reorganization of the ribosome during translocation* published in *Nature* in 2000 which received 634 citations. Another journal *Flexible Fitting of Atomic Structures into Electron Microscopy Maps Using Molecular Dynamics* published in the journal *Structure* during 2008 has been cited 569 times. A graphical representation of the above information is presented in Figure 152.

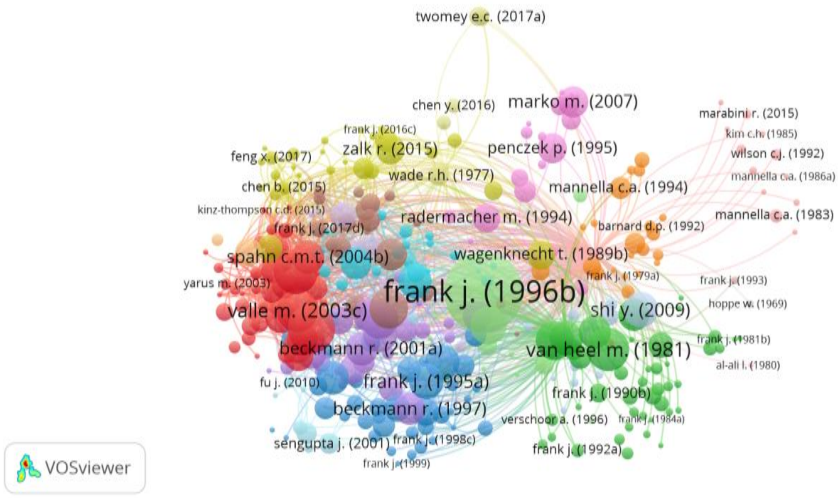


Fig. 152: Citation Analysis

6.3.11.9.4 Bibliographic Coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Joachim Frank is presented in figure 153.

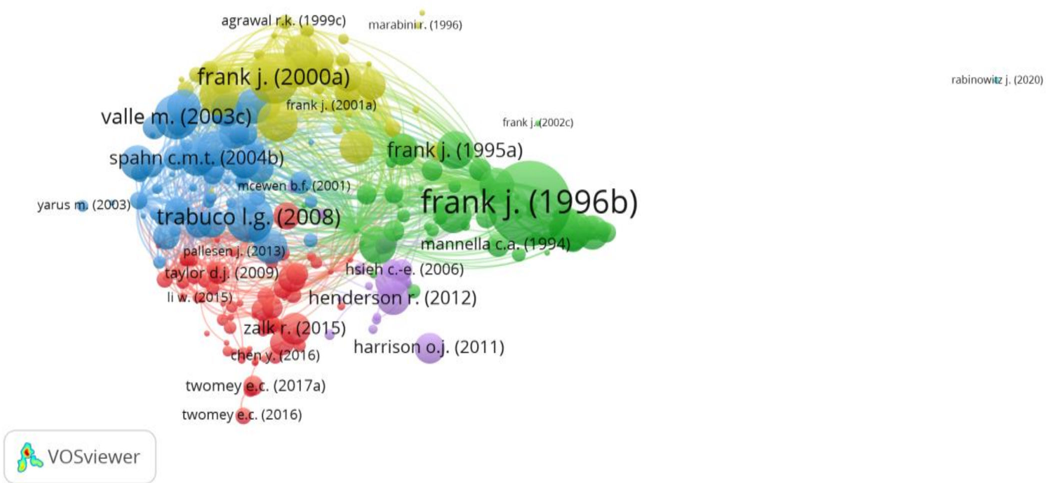


Fig. 153: Bibliographic Coupling

6.3.11.9.5 Co-citation Analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have

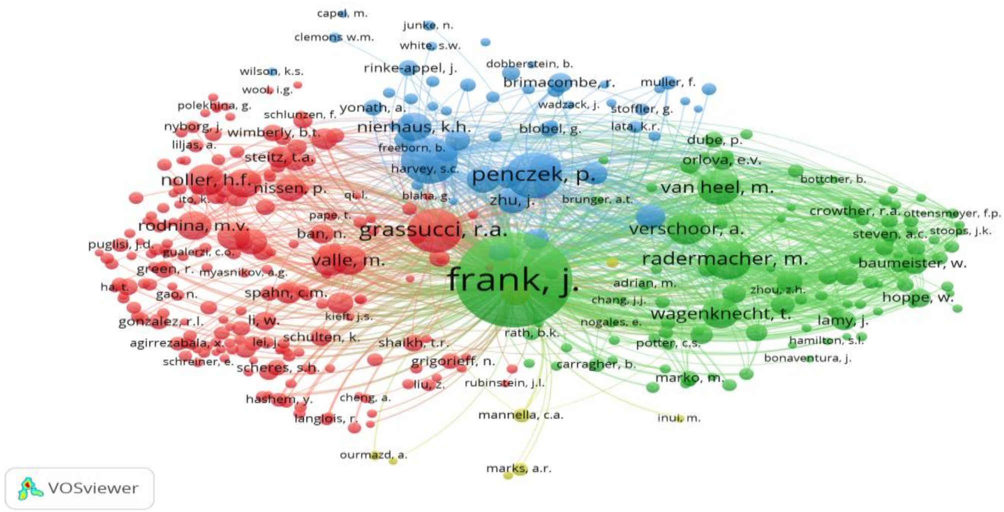


Fig. 154: Co-citation Analysis

some common theme. The co-citation network of Joachim Frank is produced in Fig. 154. Analysis of the figure shows that the articles published by Frank have been co-cited by 5 clusters, having 203, 107, 55, 8, and 1 author each. There are a total of 60093 links, with total link strength of 3639783.

6.3.11.10 To Analyze Cluster Mapping (Joachim Franc)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 155 shows the coupling map of Joachim Frank.

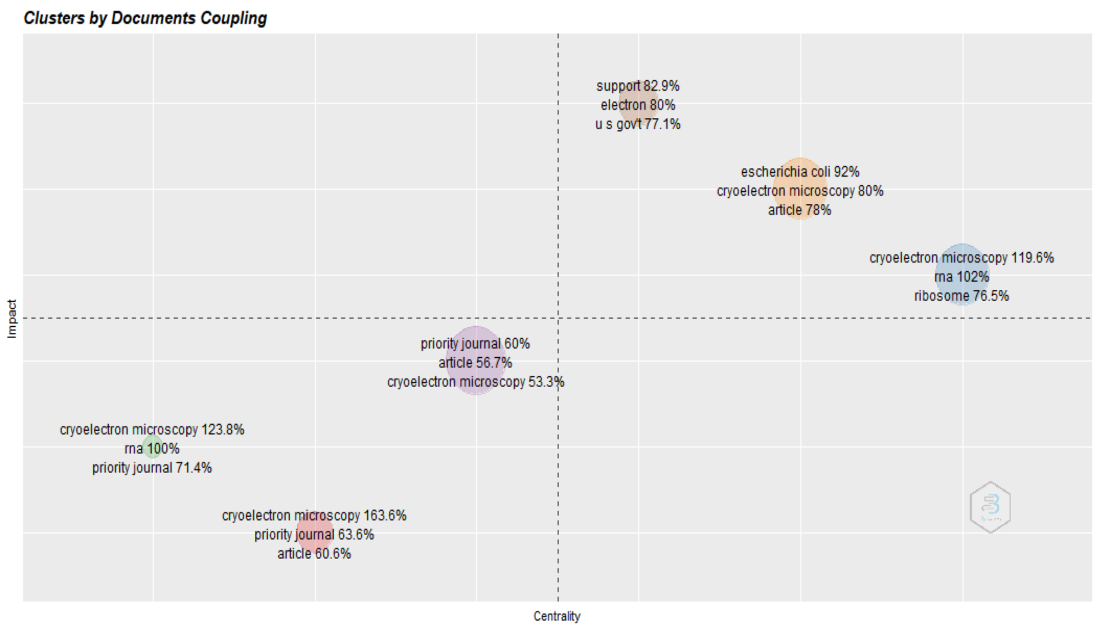


Fig 155: Document Coupling

6.3.11.11 Other Information (Joachim Franc)

Table 107: Main Information

Description	Results
Timespan	1969:2020
Sources	
Journals, Books, Etc	111
Documents	388
Total	499
Average Years From Publication	20.9
Average Citations Per Documents	73.18
Average Citations Per Year Per Doc	4.098
References	11982
Document Types	
Article	298
Book	4
Book Chapter	8
Conference Paper	32
Editorial	7
Erratum	5
Letter	3
Note	1
Review	27
Short Survey	2
Total	388
Document Contents	
Keywords Plus (Id)	1649
Author's Keywords (De)	385
Authors	
Authors	633
Author Appearances	1943
Authors Of Single-Authored Documents	2
Authors Of Multi-Authored Documents	631
Authors Collaboration	

Single-Authored Documents	58
Documents Per Author	0.613
Authors Per Document	1.63
Co-Authors Per Documents	5.01
Collaboration Index	1.91
H-Index	91
Total Citation	29,448 Citations By 14,717 Documents

The publication productivity of Joachim Frank is consistent throughout the entire productive life and he has made outstanding contributions in the field of phage display. His publication life commenced in 1969 after he had attained a biological age of 29 years. Joachim Frank has been active in research despite many administrative responsibilities. Joachim Frank's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.12 RICHARD HENDERSON

Richard Henderson (dob: 19th July 1945) is a molecular biologist and biophysicist born in Scotland. He is regarded as the pioneer in the field of electron microscopy of biological molecules. Besides the Nobel Prize which he shared with two other biophysicists; Henderson has been conferred various awards. Henderson has worked at the Medical Research Council Laboratory of Molecular Biology in Cambridge as its director. He was also a visiting professor at the Miller Institute of the University of California, Berkeley. Currently, Henderson is a mentor for the Academy of Medical Sciences Mentoring Scheme.

6.3.12.1 To assess the number of scientific communications contributed by Richard Henderson

Table 108: Scientific Communication

Document Types	
Article	117
Book Chapters	2
Conference Papers	8
Editorial	1

Erratum	1
Letter	1
Note	3
Review	14
Short Survey	1

6.3.12.2 To analyze the domain-wise scientific communication of Richard Henderson.

A look into the nature of scientific communication reveals that 30.41% of his works are in the domain of cryomicroscopy followed by 29.05% in molecular biology and 20.77% in biophysics. The author has 20.27% of his scientific communications in the field of bioscience. Table 109 is the tabular form of the number of scientific communications of Richard Henderson. Regarding the nature of the document, Table 109 shows that most of the papers were in the form of articles (79.05%), followed by reviews (9.44%). With 0.68% of the total documents, editorials, erratum, letters and short surveys contribute the lowest to the list of total publications.

Table 109: Number of Scientific Communication

Document	**Domain**				**Total Papers**	**%**
	A	**B**	**C**	**D**		
Article	25	25	34	33	117	**79.05**
Book Chapters	0	0	1	1	2	**1.35**
Conference Papers	1	2	4	1	8	**5.41**
Editorial	0	0	1	0	1	**0.68**
Erratum	0	1	0	0	1	**0.68**
Letter	0	0	0	1	1	**0.68**
Note	0	0	1	2	3	**2.03**
Review	4	2	4	4	14	**9.44**
Short Survey	0	0	0	1	1	**0.68**
%	**20.77**	**20.27**	**30.41**	**29.05**		

A: Biophysics B: Bioscience C: Cryomicroscopy D: Molecular Biology

A graphical form of Table 109 is shown in Figure 156.

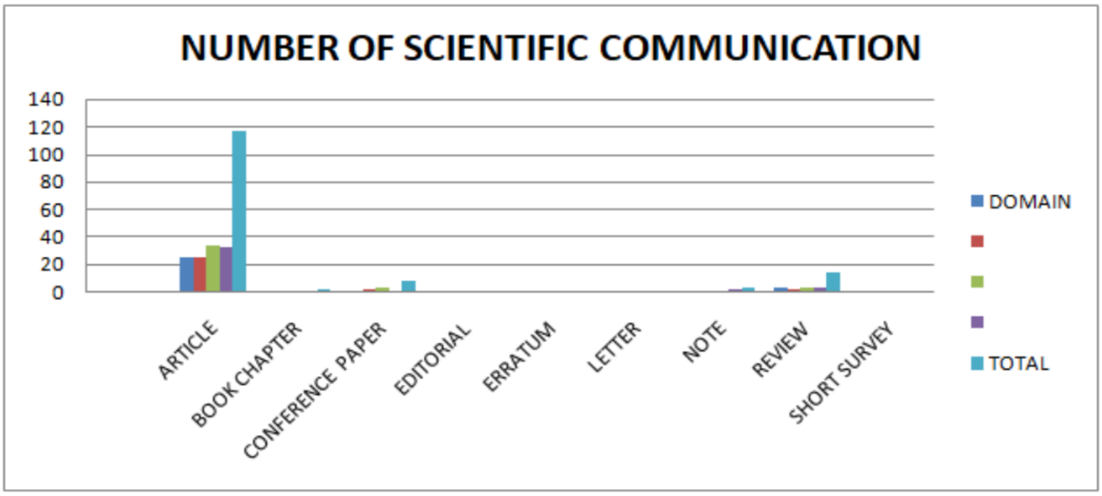


Fig. 156: Number of Scientific Communication

6.3.12.3 To analyze the domain-wise authorship pattern of Richard Henderson.

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Richard Henderson are multi-authored having 3 authors. This is followed by 2-authored documents. 23 documents representing 15.54% of the total works are single-authored. Table 110 is a tabular form of the authorship pattern and Figure 157 presents a graphical view of the data.

Table 110: Domain-wise Authorship as per Collaboration

Domain	**Authors**						
	1 Author	2 Authors	3 Authors	4 Authors	5 Authors	6 And 7 Authors	8 And 9 Authors
A	5	7	3	7	2	4	2
B	1	10	13	3	1	0	2
C	7	13	17	5	2	1	1
D	10	11	9	4	1	4	4
Total	**23**	**41**	**42**	**19**	**6**	**9**	**8**
%	**15.54**	**27.70**	**28.38**	**12.84**	**4.05**	**6.08**	**5.41**

A: Biophysics B: Bioscience C: Cryomicroscopy D: Molecular Biology

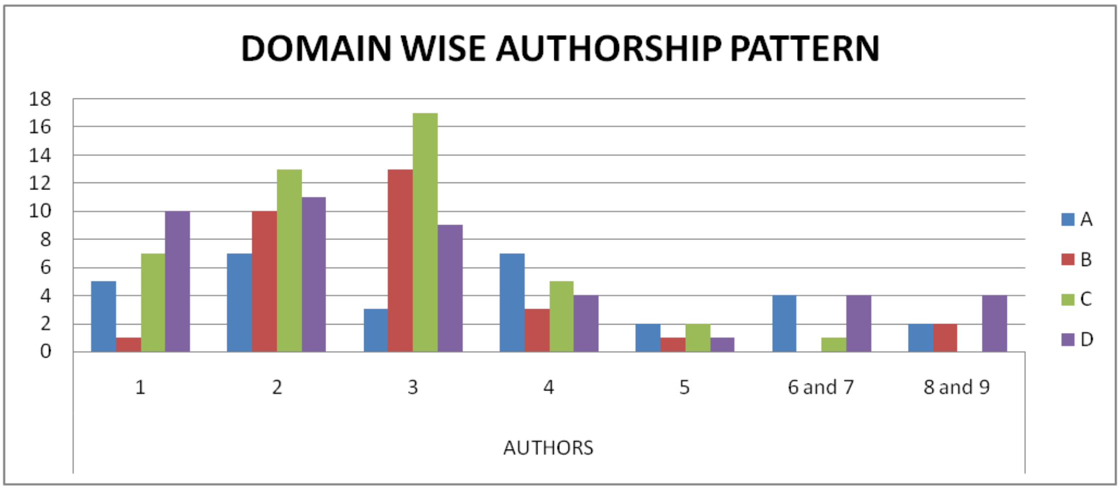


Fig 157: Domain-wise Authorship

6.3.12.4 To analyze the year-wise scientific communication of Richard Henderson.

Table 111 and figure 158 show the domain and year-wise authorship pattern of Richard Handerson. Richard Handerson has published 148 documents on various subjects commencing from the years 1967. An analysis of the data present in table 112 shows that the number of publications has increased with increase in time baring the decade commencing 2001.

Table 111: Domain and Year-wise Authorship

Period	Domain				Total Papers	%
	A	B	C	D		
1967 - 1970	1	0	2	2	**5**	**3.38**
1971 - 1980	0	9	7	10	**26**	**17.57**
1981 - 1990	17	11	0	1	**29**	**19.60**
1991 - 2000	3	0	17	13	**33**	**22.30**
2001 - 2010	5	6	7	7	**25**	**16.90**
2011 - 2019	5	3	12	10	**30**	**20.25**
Total	**31**	**29**	**45**	**43**	**148**	**100**

A: Biophysics B: Bioscience C: Cryomicroscopy D: Molecular Biology

Table 112: Year-wise Productivity

Year	Domain				Total Papers	%
	A	B	C	D		
1967	1	0	0	0	1	0.68
1968	0	0	1	0	1	0.68

1969	0	0	0	0	0	0
1970	0	0	1	1	2	1.35
1971	0	1	0	0	1	0.68
1972	0	2	2	1	5	3.38
1973	0	1	1	0	2	1.35
1974	0	1	1	0	2	1.35
1975	0	2	1	0	3	2.03
1976	0	0	0	0	0	0
1977	0	1	1	1	3	2.03
1978	0	1	1	1	3	2.03
1979	0	0	0	2	2	1.35
1980	0	0	0	5	5	3.38
1981	0	0	0	0	0	0
1982	5	3	0	0	8	5.40
1983	1	0	0	0	1	0.68
1984	2	1	0	1	4	2.70
1985	1	2	0	0	3	2.03
1986	1	1	0	0	2	1.35
1987	1	0	0	0	1	0.68
1988	1	0	0	0	2	1.35
1989	1	0	0	0	1	0.68
1990	4	3	0	0	7	4.73
1991	1	0	1	1	3	2.03
1992	1	0	1	0	2	1.35
1993	1	0	3	2	6	4.05
1994	0	0	1	0	1	0.68
1995	0	0	4	2	6	4.05
1996	0	0	2	1	3	2.03
1997	0	0	2	1	3	2.03
1998	0	0	1	0	1	0.68
1999	0	0	1	3	4	2.70
2000	0	0	1	3	4	2.70
2001	1	0	0	0	1	0.68

2002	1	2	2	2	6	4.05
2003	1	1	1	0	3	2.03
2004	1	0	0	0	1	0.68
2005	1	1	1	0	3	2.03
2006	0	1	1	1	3	2.03
2007	0	1	1	1	3	2.03
2008	0	0	1	0	1	0.68
2009	0	0	0	3	3	2.03
2010	0	0	0	1	1	0.68
2011	1	0	1	1	3	2.03
2012	1	0	1	1	3	2.03
2013	1	0	3	1	5	3.38
2014	0	1	1	0	2	1.35
2015	0	1	3	3	6	4.05
2016	0	1	1	0	2	1.35
2017	0	0	1	1	2	1.35
2018	1	0	1	3	5	3.38
2019	1	0	0	2	2	1.35
2020	0	0	0	0	0	0

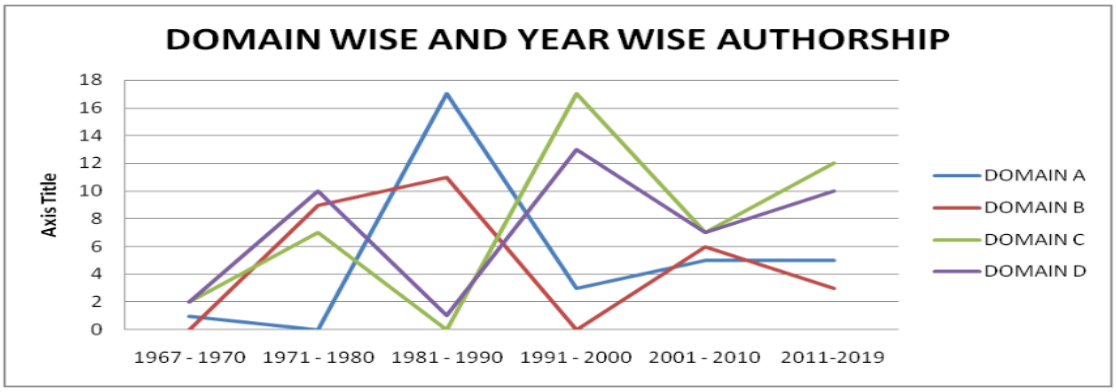


Fig 158: Domain wise and Year wise Authorship

6.3.12.5 Author's production over time (Richard Henderson)

The result of the analysis of the author's production over time can also be seen in Figure 159 which shows that the numbers of publications in various domains have increased over time.

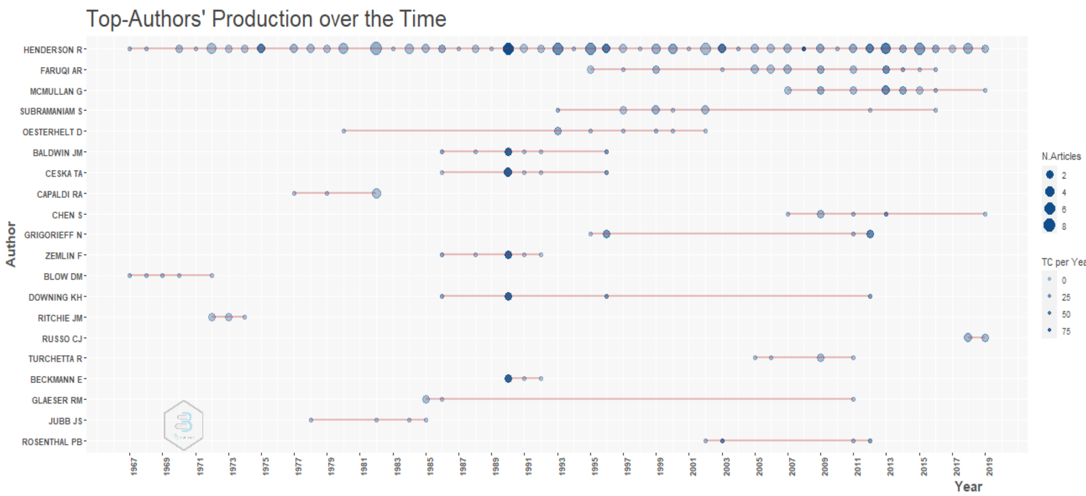


Fig 159: Authors' Production Over Time

6.3.12.6 To find out the channels of communication used by Richard Henderson.

An analysis of Figure 160 shows that Richard Henderson published his works in various journals. The highest number of publications has appeared in the journal *'Journal of Molecular Biology'* followed by *Ultramicroscopy'*.

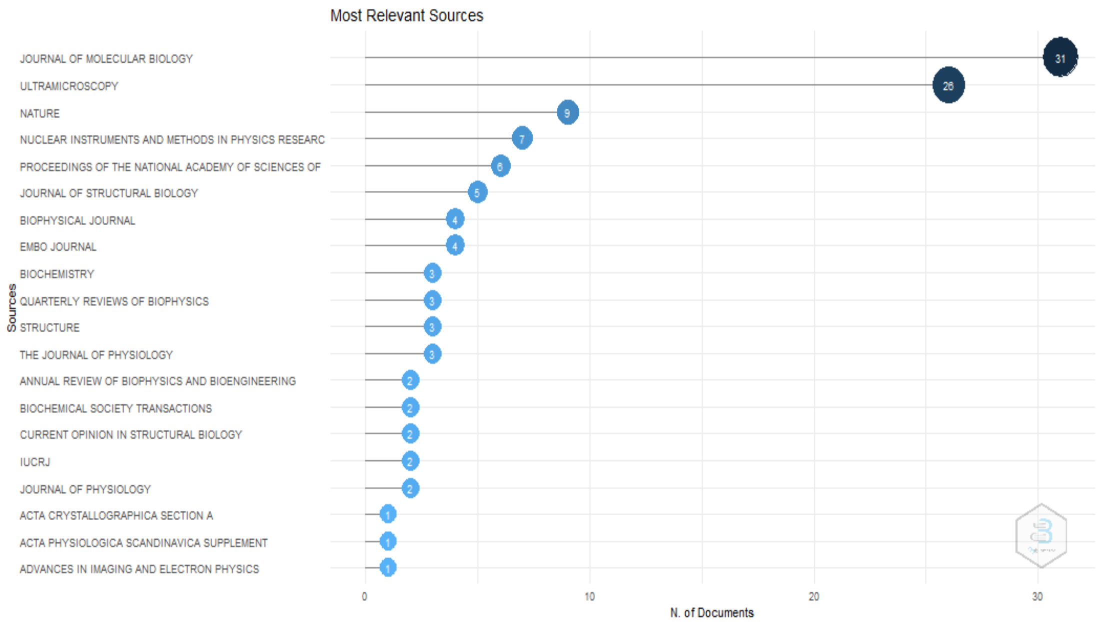


Fig 160: Most Relevant Sources

Table 113: Most Relevant Sources

Sources	Articles
Journal Of Molecular Biology	31
Ultramicroscopy	27
Nature	9

Nuclear Instruments and Methods in Physics Research Section A: Accelerators Spectrometers Detectors And Associated Equipment	7
Proceedings Of the National Academy of Sciences of The United States of America	6
Journal Of Structural Biology	5
Biophysical Journal	4
Embo Journal	4
Biochemistry	3
Quarterly Reviews of Biophysics	3
Structure	3
The Journal of Physiology	3
Annual Review of Biophysics and Bioengineering	2
Biochemical Society Transactions	2
Current Opinion in Structural Biology	2
Iucrj	2
Journal Of Physiology	2
Acta Crystallographica Section A	1
Acta Physiologica Scandinavica Supplement	1
Advances In Imaging and Electron Physics	1
Angewandte Chemie - International Edition	1
Annals Of The New York Academy of Sciences	1
Archives Of Biochemistry and Biophysics	1
Biochemical Journal	1
Biochimica Et Biophysica Acta – Bioenergetics	1
Biochimica Et Biophysica Acta – Biomembranes	1
Biophysics Of Structure and Mechanism	1
Chemica Scripta	1
Chemistry World	1
Cold Spring Harbor Symposia on Quantitative Biology	1
European Neuropsychopharmacology	1
Faseb Journal	1
Journal Of Electron Microscopy	1
Journal Of Instrumentation	1

Journal Of Vacuum Science and Technology B: Nanotechnology and Microelectronics	1
Methods In Enzymology	1
Molecular Immunology	1
Nature Structural and Molecular Biology	1
Nature Structural Biology	1
Novartis Foundation Symposium	1
Nuclear Inst. And Methods in Physics Research A	1
Philosophical Transactions of The Royal Society A: Mathematical Physical and Engineering Sciences	1
Philosophical Transactions of The Royal Society of London. Series B Biological Sciences	1
Philosophical Transactions of The Royal Society of London. Series B: Biological Sciences	1
Proceedings Of Science	1
Proceedings Of the Royal Society B: Biological Sciences	1
Progress In Biophysics and Molecular Biology	1
Science (New York N.Y.)	1
Scientific American	1
Society Of General Physiologists Series	1
Structural Insights into Gene Expression and Protein Synthesis	1
Structure (London England: 1993)	1
The Biochemical Journal	1

6.3.12.7 Author's performance based on available metrics indicators (Richard Henderson)

Table 114: Performance of the Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	14.28	01	i10-index (i10)	101
02	Total Citation	3347	02	h5-index (h5)	2
03	Audience Factor	78	03	g-Index	47
04	CiteScore (Maximum)	4.5	04	a-Index	57.81

05	ResearchGate Citations	489	05	h(2)-index	8
06	Microsoft Academic Search Citations	32163	06	hg-index (hg)	38.17
07	Google Scholar Citations	54	07	r-index	42.33
08	Eigenfactor	5.4	08	ar-index (ar)	29.87
09	Crown Indicator	0.258	09	k-index	0.69
10	Mean Citation Score	22.92	10	q^2-index	6.61
11	Mean Normalized Citation Score (MNCS)	9.88	11	f-index	0.86
12	Mean Citation Rate Subfield (MCRS)	8.88	12	m-index	1.41
13	Scientific Talent Pool (STP)	5.23	13	m quotient (m-q)	1.41
14	Microsoft Academic Search Papers (MASP)	185	14	Contemporary-index (Ch)	196.84
15	Google Scholar Papers (GSP)	2	15	Trendh h-index (Th)	0.03
16	Impact per Paper (IPP)	22.31	16	Dynamic h-Type index (Dh-T)	0
17	Citation per paper (CPP)	22.31	17	n-index	0.98
18	Citations per Paper self-citation not included (CPPex)	19.20	18	mean h-index	16
19	The average number of citations per publication (ANCP)	25.30	19	Normalized h-index	9.87
20	Total and the Average Number of Citations (TNCS)	3347, 25.30	20	Specific-impact s-index (Sis)	22.36
21	Relative Activity Index (RAI)	22.12	21	Seniority independent Hirsch type index (Sih-T)	0
22	Relative Specialization index (RSI)	19.89	22	Hw-index	42.33
23	Relative Citation Rate (RCR)	38.55	23	Hm-index	19
24	Relative Database Citation Potential (RDCP)	76.87	24	Tapered h-index	0.12

25	Journal Acceptance Rate (JAR)	22.34	25	i20-index	59
26	% Self Citations (%SC)	18.11	26	v-index over h	3.41
27	Percentage of papers not cited (%Pnc)	2.67	27	e-index	28.33
28	PR Percentile Ranks (PR)	49.99	28	Multidimensional h-index	39.88
29	LogZ-score (LogZ)	28.158	29	Research Collaboration Index	60.33
30	Innovative Knowledge (IK)	30.69	30	Communities Collaboration Index	18.99
31	Technological Impact (TI)	72.34	31	ch-index	19.99
32	Scientific Talent Pool (STP)	62.25	32	speed s-iCitationndex	22.35
33	Normalized position of publication journal (NPJ)	36	33	π-index	10.53
34	WorldCat Hold (WCH)	311.10	34	h5-median (h5-m)	16.87
35	Papers in Top 1 (PT1)	5	35	2nd generation citations h index	9.75
36	Papers in Top 10 (PT10)	12	36	Role basedh-maj-index (Rbhm)	15.08
37	Papers in Top 50 (PT50)	24	37	h2 lower (h2-l)	13
38	High Cited Papers (HCP)	3	38	h2-center (h2-c)	30
39	Papers in First Quartile (Q1)	8	39	h2-upper (h2-u)	41
40	Publications in Thomson Reuters indices (PWoS)	0	40	h3-index	21
41	Number of highly cited publications (NHCP)	3	41	p-index	21.05
42	Publications in top-ranked journals (PTRJ)	1	42	$\bar{h}$-index (Hbar)	10.53
43	Papers in Collaboration (PCol)	125	43	Mockhm-index	7.85

				(Mhm)	
44	Share of articles coauthored with another unit (%CoA)	84.46	44	w-index	21.48
45	National Collaboration (NCol)	25	45	b-index	16.25
46	International Collaboration (ICol)	100	46	Generalizedh-index	7.38
47	Scientific Leadership (SL)	18.99	47	Single paperh-index	5
48	Average Authors per Paper	6.10	48	hint-index	6
49	Productivity per Paper	0.19	49	h_{rat}-index	31.98
50	RoG, CAGR, RGR and DT	0.25, (-)0.99, 0.18, 2.82	50	πv-index	19.79

6.3.12.8 To assess the scientific collaboration of Richard Henderson.

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Richard Henderson has collaborated with 150 different authors in the conduct and publication of his research work. The author has published only 23 single-authored documents.

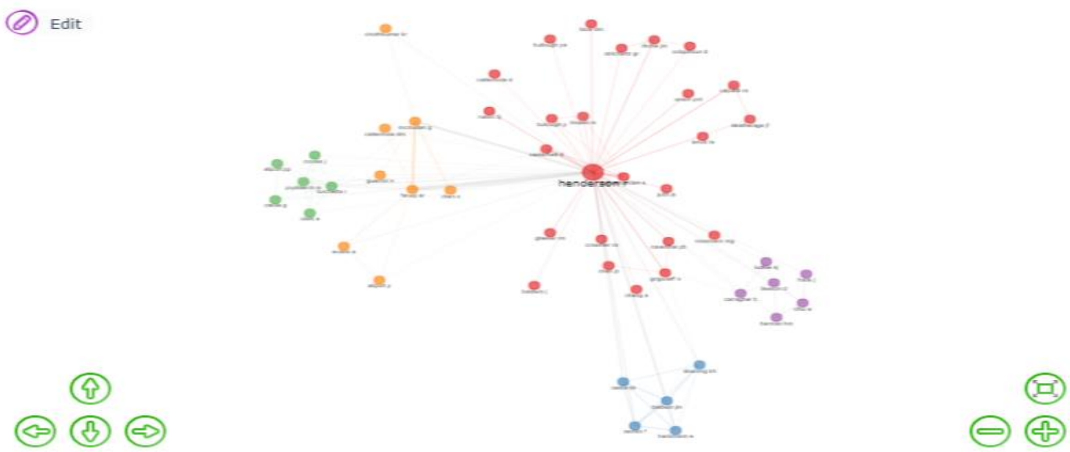


Fig 161: Collaboration Network

6.3.12.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Richard Henderson, the collaboration index has been calculated at 2.20.

6.3.12.8.2 National and International Collaboration: Richard Henderson has published his papers in collaboration with 150 co-authors of mostly hailing from the United Kingdom, Iraq, and Portugal. The collaboration map of Richard Henderson is produced in figure 162.

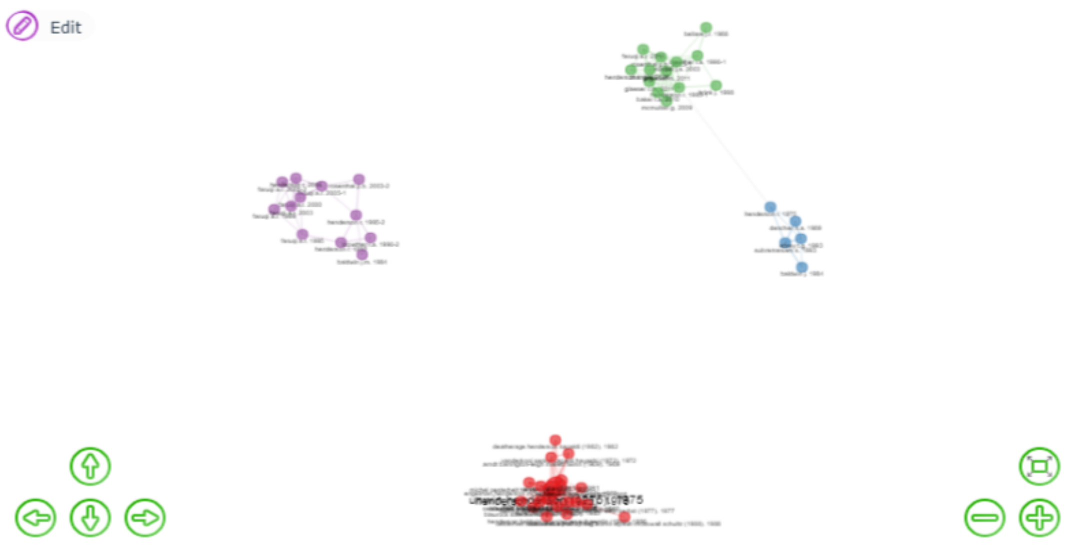


Fig. 162: National and International Collaboration

6.3.12.8.3 Co-authorship index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Richard Henderson has been calculated at 4.24.

6.3.12.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject.

The different definitions emanating from different sources has resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Richard Henderson had close communication with 74 authors while publishing his documents.

6.3.12.9 To find out the research network of Richard Henderson.

6.3.12.9.1 Co-authorship: Richard Henderson had collaborated with 150 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with D L Hughes, K E Oglieve, W Clegg, and R W Harrington were the highest. A graphical representation of the co-authorship pattern is shown in figure 163 below.

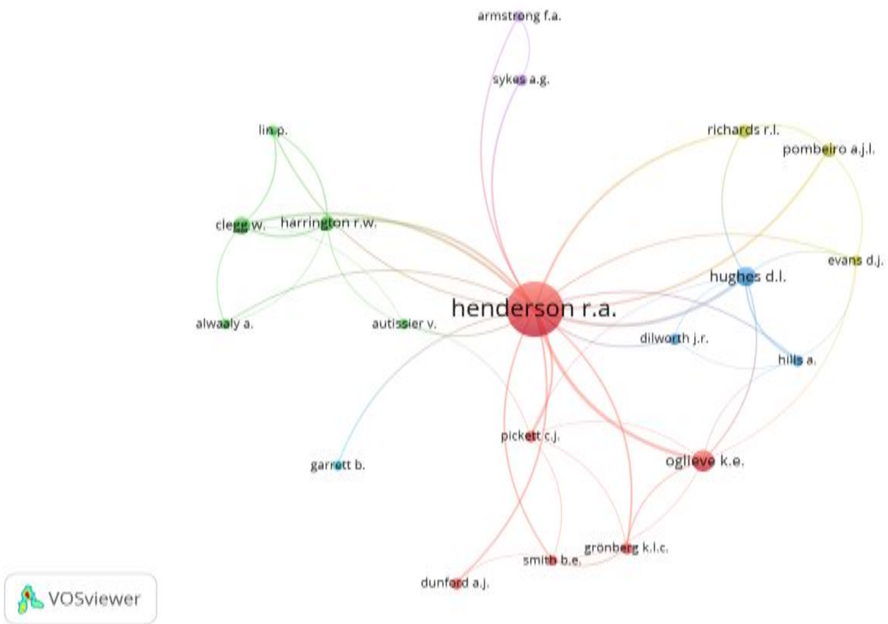


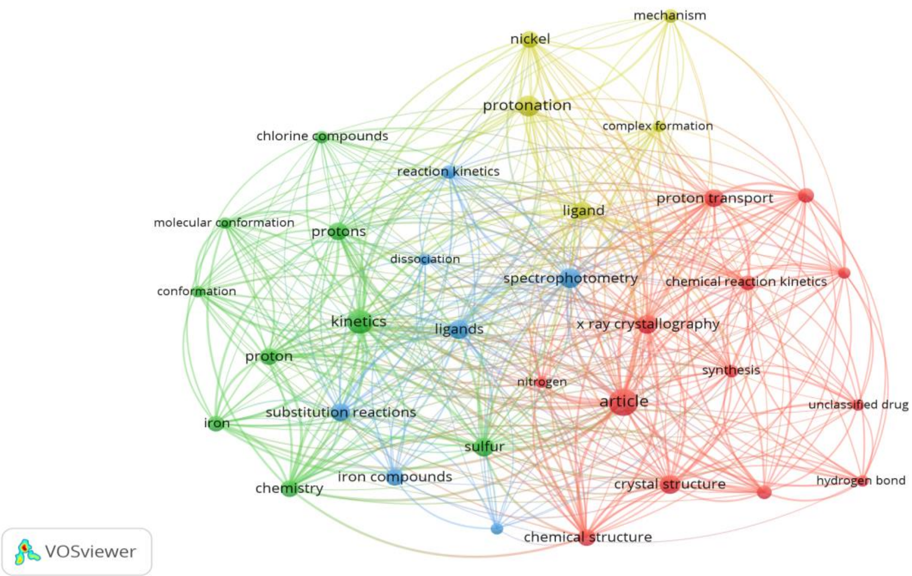
Fig. 163: Co-authorship pattern of Richard Henderson

6.3.12.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which has been tabulated below. Many keywords co-occur in the documents. We have considered the top four keywords on the decreasing order of their link strengths.

Table 115: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	26	183
kinetics	20	139

ligand	12	120
sulphur	13	119



Fig, 164: Co-occurrence of Keywords

6.3.12.9.3 Citation analysis: Of the 148 papers published by Richard Henderson, either as a single author or in collaboration, 146 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *'The chemistry of nitrogen fixation for the reactions of nitrogenase',* published in the journal *Advances in Inorganic Chemistry* during 1983 has been cited 293 times followed by the article *'New 1-and 2-dimensional Polymeric Structures of Cyanopyridine Complexes of Ag^1 and Cu^1'* published in *Inorganic Chemistry* in 2004 which received 87 citations.

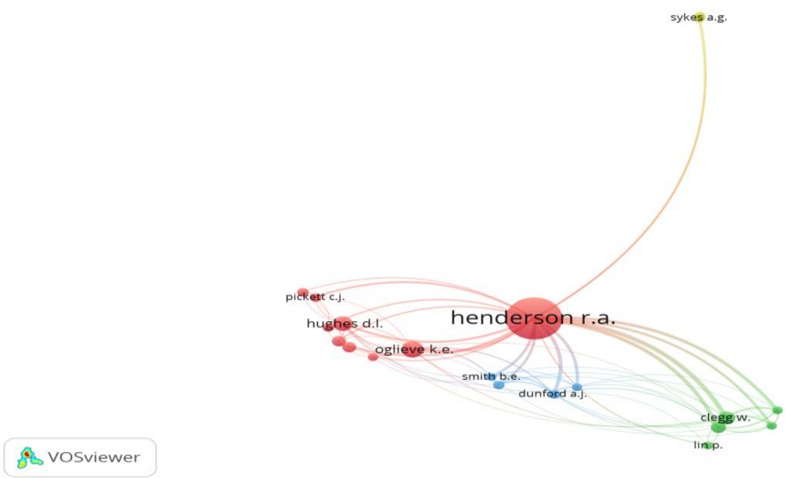


Fig. 165: Citation Analysis

6.3.12.9.4 Bibliographic coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Richard Henderson is presented in figure 166.

Fig. 166: Bibliographic Coupling

6.3.12.9.5 Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same

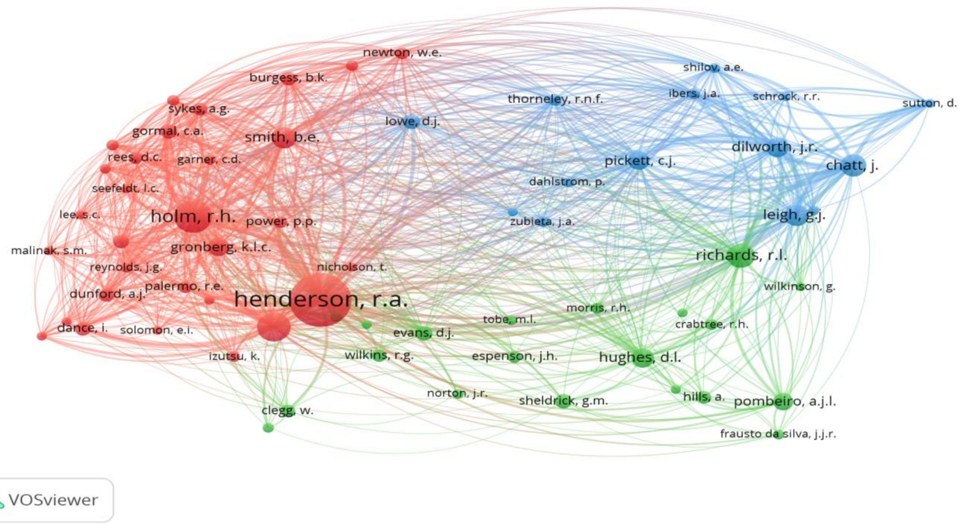


Fig. 167: Co-citation Analysis Pattern

documents are cited by several authors; clusters begin to form. These clusters have some common theme. The co-citation network of Richard Henderson is produced in Fig. 167. Analysis of the figure shows that the articles published by Arnold has been co-cited by 3 clusters, having 30, 20, and 14 items each. There are a total of 1778 links, with a total link strength of 124124.

6.3.12.10 To analyze cluster mapping (Richard Henderson)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 168 shows the coupling map of Richard Henderson.

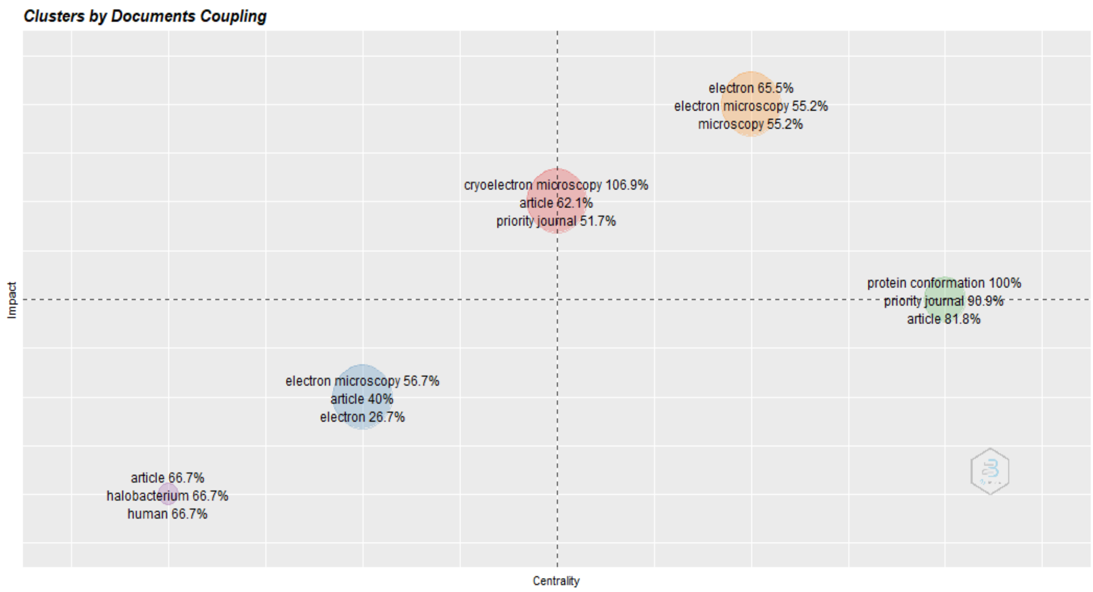


Fig 168: Document Coupling

6.3.12.11 Other information (Richard Henderson)

Table 116: Main Information

Description	**Results**
Timespan	1967:2019
Sources	
Journals, Books, Etc	51
Documents	148
Total	199
Average Years from Publication	26.2
Average Citations Per Documents	136.9

Average Citations Per Year Per Doc	5.79
References	3479
Document Types	
Article	117
Book Chapter	2
Conference Paper	8
Editorial	1
Erratum	1
Letter	1
Note	3
Review	14
Short Survey	1
Total	148
Document Contents	
Keywords Plus (Id)	1044
Author's Keywords (De)	153
Authors	
Authors	282
Author Appearances	627
Authors Of Single-Authored Documents	1
Authors Of Multi-Authored Documents	281
Authors Collaboration	
Single-Authored Documents	20
Documents Per Author	0.525
Authors Per Document	1.91
Co-Authors Per Documents	4.24
Collaboration Index	2.20
H-Index	31
Total Citation	3347 Citations By 2183 Documents

The publication productivity of Richard Henderson is consistent throughout the entire productive life and he has made outstanding contributions in the field of cryomicroscopy, biophysics, and biochemistry in the entire productive years of his life which commenced from 19. Richard Henderson has been consistently active in research despite many administrative responsibilities. He has preferred to work in collaboration and has a high degree of collaboration at institutional, national, and international levels. The high rate of citations received by his papers proves the usefulness and impact that his works have in the field of cryomicroscopy. Richard Henderson's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

2018

The Chemistry Nobel Prize for 2018 was divided into two halves. While one half was awarded to Frances Hamilton Arnold for her work on *'the directed evolution of enzymes'*, the other half was divided equally among George Pearson Smith and Sir Gregory Paul Winter for *'the phage display of peptides and antibodies'*.

6.3.13 GEORGE PEARSON SMITH

George Pearson Smith (dob: 10.03.1941) is an American Biologist who is best known for his exemplary works on phage display, a process where a specific sequence of proteins is inserted artificially into the coat protein gene of a bacteriophage, which causes the protein to express itself on the outer layers of the bacteriophage. This process was made public in 1985 when Smith displayed peptides on filamentous phage fusing specific peptides into gene III of filamentous phage. Presently, George P. Smith is a Curators' Distinguished Professor Emeritus of Biological Sciences at the University of Missouri in Columbia, Missouri in the United States. In 2018, Smith shared the Nobel Prize with another British biologist, Sir Gregory Paul Winter.

6.3.13.1 To assess the number of scientific communications contributed by George Pearson Smith.

The works of George Pearson Smith has been in the form of articles, book chapters, editorials, reviews, and short surveys. Table 117 shows the number of such scientific communications contributed by the scientist.

Table 117: Scientific Communication

Document Types	
Article	45
Book Chapter	1

Editorial	2
Review	6
Short Survey	1

6.3.13.2 To analyze the domain-wise scientific communication of George Pearson Smith

Among the different domains in which he has published his works include genomics, protein engineering, biotechnology, biochemistry, and microbiology, table 118 shows the total number of documents published by George Smith in all documents. An analysis of the table shows that most of his studies are in the field of genomics, followed by biotechnology. He has also researched topics relating to protein engineering, microbiology, and biochemistry al a smaller scale which is evident from the fewer papers that have been published in these subjects. Among the documents, the maximum number of papers are in the form of articles (81.8%), followed by reviews (10.9%). Some of his research works have also been published in the form of editorials (3.6%), and book chapters, and short surveys (1.8%).

Table 118: Number of Scientific Communication

Documents	**Domain**					**Total Papers**	**%**
	A	B	C	D	E		
Article	16	8	12	3	6	45	**81.8**
Book Chapter	0	0	1	0	0	1	**1.8**
Editorial	0	2	0	1	0	2	**3.6**
Review	1	0	2	0	2	6	**10.9**
Short Survey	0	0	0	0	1	1	**1.8**
Total	**17**	**10**	**15**	**4**	**9**	**55**	
%	**30.91**	**18.18**	**27.27**	**7.27**	**16.36**		

A: Genomics B: Protein Engineering C: Biotechnology

D: Biochemistry E: Microbiology

A graphical representation of the above data can be observed in Figure 169 below.

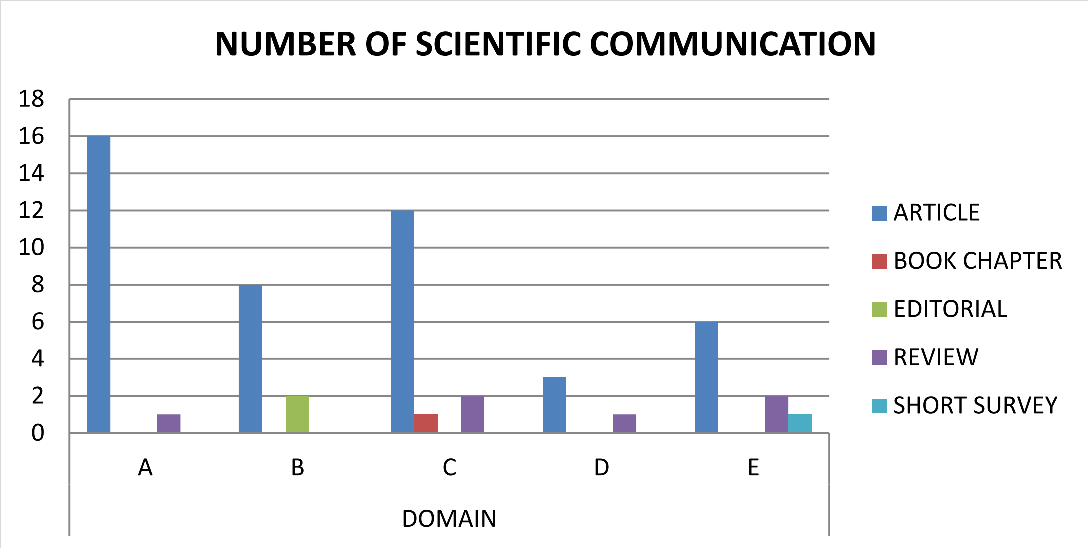


Fig 169: Number of Scientific Communication

6.3.13.3 To analyze the domain-wise authorship pattern of George Pearson Smith

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Whittingham are multi-authored having 5 or more authors. 12.80% of the total works are single-authored and two-authored, while the contribution of three and four-authored works stand at 7.14% and 8.33% respectively. Table 119 is a tabular form of the authorship pattern and Figure 170 presents a graphical view of the data.

Table 119 shows the domain-wise authorship pattern of George Pearson Smith. Smith has authored 17 single-authored documents which represent 30.91% of his total publications. However, most of his publications are two-authored, at 18 (32.73%) with Smith being the principal author. George P. Smith has co-authored with a maximum of 6 authors. Three and four-authored documents comprise 16.34% of his total publications each while five and six-authored documents contribute 1.82% to the total publications each. A graphical view of the above information is provided in Figure 170.

Table 119: Domain-wise Authorship as per Collaboration

Domain	Authors					
	1 - Author	2 - Author	3 - Author	4 - Author	5 – Author	6 – Author
A	6	7	3	1	0	0
B	7	2	1	0	0	0

C	2	6	3	4	0	0
D	1	1	0	0	1	1
E	1	2	2	4	0	0
Total	**17**	**18**	**9**	**9**	**1**	**1**
%	**30.91**	**32.73**	**16.34**	**16.34**	**1.82**	**1.82**

A: Genomics B: Protein Engineering C: Biotechnolog D: Biochemistry E: Microbiology

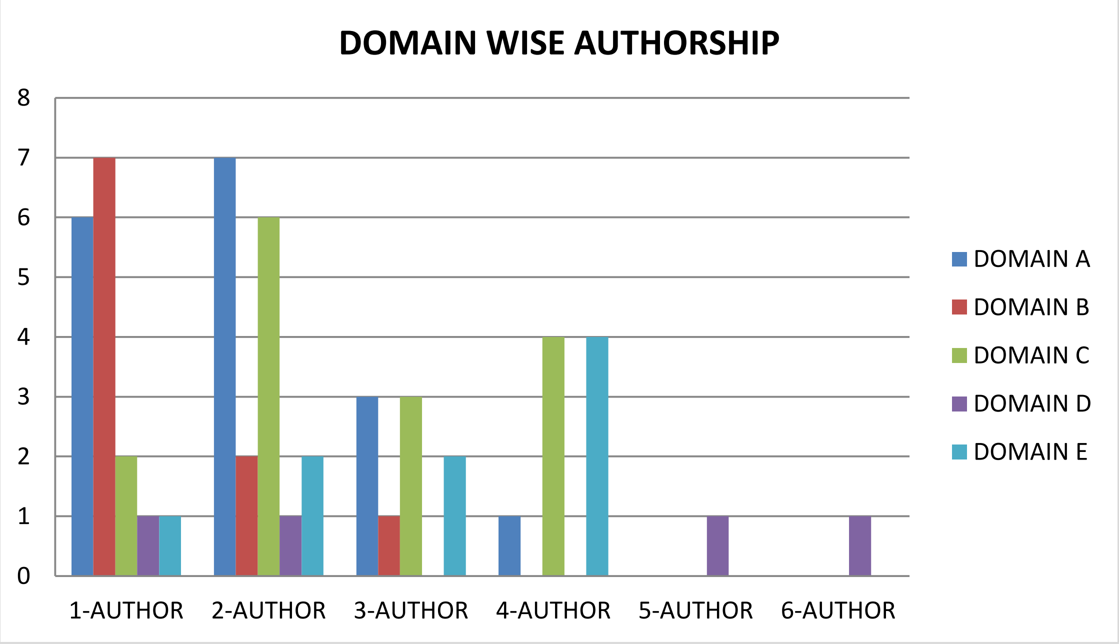


Fig 170: Domain-wise Authorship

6.3.13.4 To analyze the year-wise scientific communication of George Pearsom Smith

George Pearson Smith's publication life began in 1971, 30 years after his birth. A look into his year-wise productivity reveals that the author has published the maximum number of works from 1991 till 2000 when he had published 16 papers in all domains at 29.09%. During the first 10 years of his productive life, Smith has published 12 papers (21.82%). The lowest number of works were published from 2011 till 2019. During the years 1981 – 1990 and 2011 – 2010, 10 publications were made available which contributed 18.18% each to the total publications of the author. A tabular form of this information is provided in Table 120 and 121, while a graphical representation is given in figure 171.

Table 120: Domain and Year-wise Authorship

Period	Domain					Total Papers	%
	A	B	C	D	E		
1971-1980	10	2	0	0	0	**12**	**21.82**
1981-1990	7	2	0	1	0	**10**	**18.18**
1991-2000	0	4	8	0	4	**16**	**29.09**
2001-2010	0	0	4	3	3	**10**	**18.18**
2011-2019	0	2	3	0	2	**7**	**12.73**

A: Genomics B: Protein Engineering C: Biotechnolog D: Biochemistry E: Microbiology

Table 121: Year Wise Productivity

Year	Domain					Total Papers	%
	A	B	C	D	E		
1971	0	0	0	0	0	0	0
1972	1	0	0	0	0	1	1.82
1973	2	0	0	0	0	2	3.64
1974	3	0	0	0	0	3	5.45
1975	0	0	0	0	0	0	0
1976	1	0	0	0	0	1	1.82
1977	2	0	0	0	0	2	3.64
1978	1	1	0	0	0	2	3.64
1979	0	0	0	0	0	0	0
1980	0	1	0	0	0	1	1.82
1981	1	0	0	0	0	1	1.82
1982	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0
1984	1	0	0	0	0	1	1.82
1985	1	0	0	0	0	1	1.82
1986	0	0	0	0	0	0	0
1987	1	0	0	0	0	1	1.82
1988	2	2	0	0	0	4	7.27
1989	1	0	0	0	0	1	1.82
1990	1	0	0	0	0	1	1.82

1991	0	1	0	0	0	1	1.82
1992	0	0	0	0	0	0	0
1993	0	3	2	0	0	5	9.09
1994	0	0	3	0	0	3	5.45
1995	0	0	0	0	0	0	0
1996	0	0	3	0	0	3	5.45
1997	0	0	0	1	0	1	1.82
1998	0	0	0	1	0	1	1.82
1999	0	0	0	1	0	1	1.82
2000	0	0	0	1	0	1	1.82
2001	0	0	1	0	0	1	1.82
2002	0	0	2	0	0	2	3.64
2003	0	0	0	0	0	0	0
2004	0	0	1	0	0	1	1.82
2005	0	0	0	1	0	1	1.82
2006	0	0	0	1	0	1	1.82
2007	0	0	0	0	0	0	0
2008	0	0	0	0	0	0	0
2009	0	0	0	1	0	1	1.82
2010	0	0	0	0	3	3	5.45
2011	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0
2014	0	1	1	0	0	2	3.64
2015	0	1	1	0	0	2	3.64
2016	0	0	0	0	0	0	0
2017	0	0	1	0	1	2	3.64
2018	0	0	0	0	0	0	0
2019	0	0	0	0	1	1	1.82
2020	0	0	0	0	0	0	0

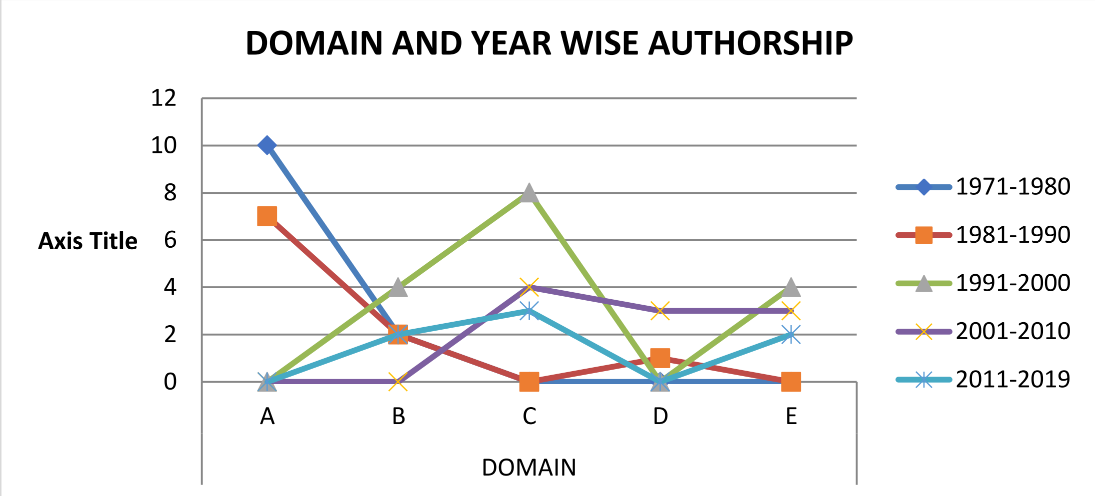


Fig 171: Domain wise and Year wise Authorship.

6.3.13.5 Author's production over time (George Pearson Smith)

The year-wise authorship pattern also shows the fluctuating levels in his productivity till it decreased from 2011 till 2019. This aspect can also be seen in Figure 172.

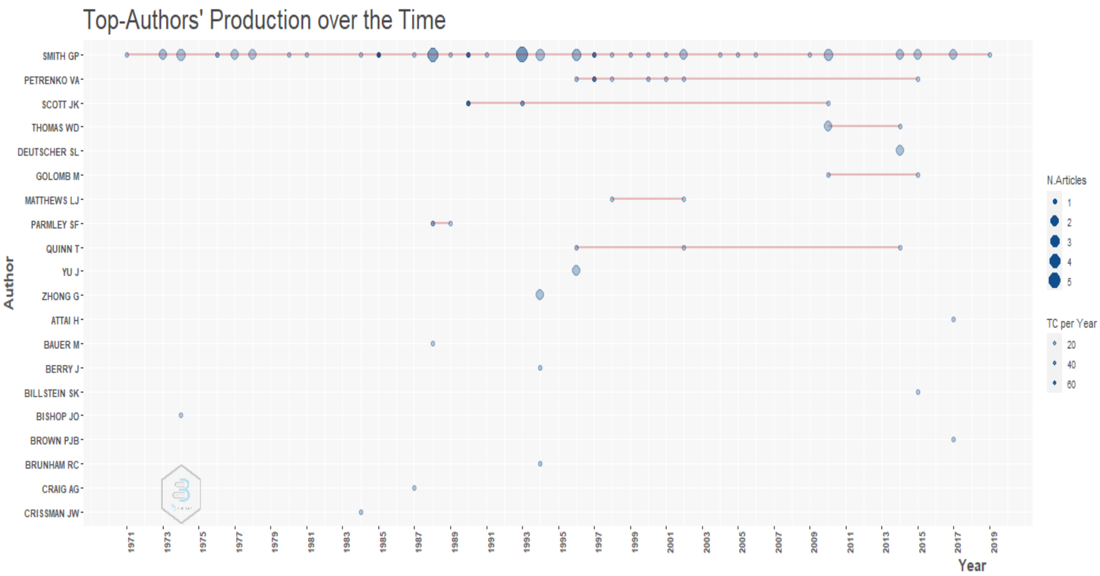


Fig 172: Authors' Production Over Time

6.3.13.6 To find out the channels of communication used by George Pearson Smith

George P. Smith has published his works in various journals. Figure 173 is a graphical representation of the data, which indicates that the maximum number of papers (6) have appeared in the journal *'Biotechniques'*.

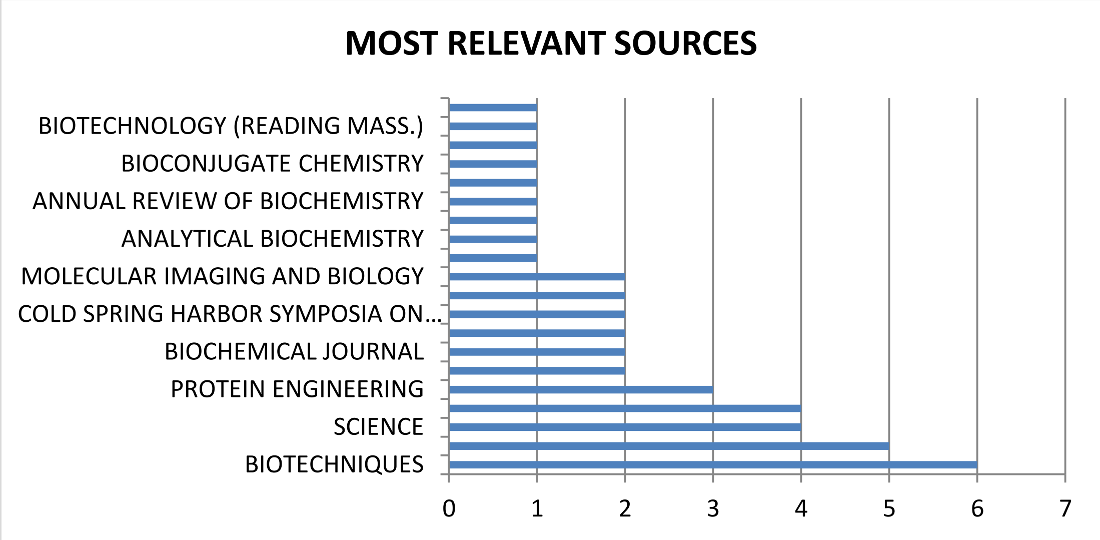


Fig 173: Most Relevant Sources

Table 122: Most Relevant Sources

Sources	Articles
Biotechniques	6
Gene	5
Science	4
Virology	4
Protein Engineering	3
American Biology Teacher	2
Biochemical Journal	2
Cell	2
Cold Spring Harbor Symposia on Quantitative Biology	2
Methods In Enzymology	2
Molecular Imaging and Biology	2
Advances In Experimental Medicine and Biology	1
Analytical Biochemistry	1
Angewandte Chemie - International Edition	1
Annual Review of Biochemistry	1
Applied And Environmental Microbiology	1
Bioconjugate Chemistry	1
Bioinformatics	1
Biotechnology (Reading Mass.)	1

Chemical Reviews	1
Clinical And Diagnostic Laboratory Immunology	1
Current Opinion in Biotechnology	1
Journal Of Biological Chemistry	1
Journal Of Immunological Methods	1
Journal Of Immunology	1
Molecular Diversity	1
Nature	1
Organic Process Research and Development	1
Phage Display in Biotechnology and Drug Discovery Second Edition	1
Proceedings Of the National Academy of Sciences of The United States of America	1
Symposia On Quantitative Biology	1
Trends In Biochemical Sciences	1
Vaccine	1

6.3.13.7 Author's performance based on available metrics indicators (George Pearson Smith)

Table 123: Performance of Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	28	01	i10-index (i10)	42
02	Total Citation	10281	02	h5-index (h5)	4
03	Audience Factor	1598	03	g-Index	55
04	CiteScore (Maximum)	46.8	04	a-Index	29
05	ResearchGate Citations	135	05	h(2)-index	37.39
06	Microsoft Academic Search Citations	981	06	hg-index (hg)	39.94
07	Google Scholar Citations	2554	07	r-index	29
08	Eigenfactor	12.8	08	ar-index (ar)	5.99
09	Crown Indicator	0.001	09	k-index	124.53
10	Mean Citation Score	1.40	10	q2-index	5.29
11	Mean Normalized Citation Score	36.58	11	f-index	0.97

	(MNCS)				
12	Mean Citation Rate Subfield (MCRS)	29.78	12	m-index	0.97
13	Scientific Talent Pool (STP)	9.89	13	m quotient (m-q)	0.97
14	Microsoft Academic Search Papers (MASP)	15	14	Contemporary-index (Ch)	34.38
15	Google Scholar Papers (GSP)	24	15	Trendh h-index (Th)	1.27
16	Impact per Paper (IPP)	103.98	16	Dynamic h-Type index (Dh-T)	0
17	Citation per paper (CPP)	186.64	17	n-index	0.63
18	Citations per Paper self-citation not included (CPPex)	184.29	18	mean h-index	15
19	The average number of citations per publication (ANCP)	1.40	19	Normalized h-index	0.53
20	Total and the Average Number of Citations (TNCS)	10281 & 1.40	20	Specific-impact s-index (Sis)	39.87
21	Relative Activity Index (RAI)	36.58	21	Seniority independent Hirsch type index (Sih-T)	5
22	Relative Specialization index (RSI)	73.26	22	Hw-index	99.72
23	Relative Citation Rate (RCR)	16.89	23	Hm-index	22
24	Relative Database Citation Potential (RDCP)	72.35	24	Tapered h-index	4.95
25	Journal Acceptance Rate (JAR)	25.38	25	i20-index	37
26	% Self Citations (%SC)	1.26	26	v-index over h	0.05
27	Percentage of papers not cited (%Pnc)	0.02	27	e-index	28.51
28	PR Percentile Ranks (PR)	71.08	28	Multidimensional h-index	49.88
29	LogZ-score (LogZ)	9.998	29	Research	31.55

				Collaboration Index	
30	Innovative Knowledge (IK)	19.89	30	Communities Collaboration Index	32.39
31	Technological Impact (TI)	51.21	31	ch-index	29.87
32	Scientific Talent Pool (STP)	25.36	32	speed s-iCitationndex	18.97
33	Normalized position of publication journal (NPJ)	24	33	π-index	83.34
34	WorldCat Hold (WCH)	45	34	h5-median (h5-m)	19.57
35	Papers in Top 1 (PT1)	3	35	2nd generation citations h index	14
36	Papers in Top 10 (PT10)	3	36	Role basedh-maj-index (Rbhm)	17.98
37	Papers in Top 50 (PT50)	3	37	h2 lower (h2-l)	16
38	High Cited Papers (HCP)	3	38	h2-center (h2-c)	38
39	Papers in First Quartile (Q1)	20	39	h2-upper (h2-u)	71
40	Publications in Thomson Reuters indices (PwoS)	0	40	h3-index	26
41	Number of highly cited publications (NHCP)	3	41	p-index	19.99
42	Publications in top-ranked journals (PTRJ)	39	42	$\bar{h}$-index (Hbar)	29
43	Papers in Collaboration (Pcol)	39	43	Mockhm-index (Mhm)	18.23
44	Share of articles coauthored with another unit (%CoA)	69.64	44	w-index	25.59
45	National Collaboration (Ncol)	32.48	45	b-index	24.97
46	International Collaboration (Icol)	67.52	46	Generalizedh-index	19.25
47	Scientific Leadership (SL)	17.36	47	Single paperh-index	7
48	Average Authors per Paper	2.83	48	hint-index	12
49	Productivity per Paper	0.53	49	h_{rat}-index	29.97
50	RoG, CAGR, RGR and DT	0.26, (-	50	πv-index	18.26

		)0.98, 0.12, 1.39			

6.3.13.8 To analyze the scientific collaboration of George Pearson Smith

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. George Pearson Smith has collaborated with 69 different authors in the conduct and publication of his research work. The author has published only 17 single-authored documents.

Fig 174: Collaboration Network

6.3.13.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of George Pearson Smith, the collaboration index has been calculated at 2.87.

6.3.13.8.2 National and International Collaboration: George Pearson Smith has published his papers in collaboration with 69 co-authors of mostly hailing from the United States of America, Canada, and the United Kingdom. Of the 38 papers published in collaboration, 34 have been published along with researchers hailing from the United States, while 2 papers each have been published with collaborative efforts from researchers from Canada and the United States of America. The collaboration map of G P Smith is produced in figure 175.

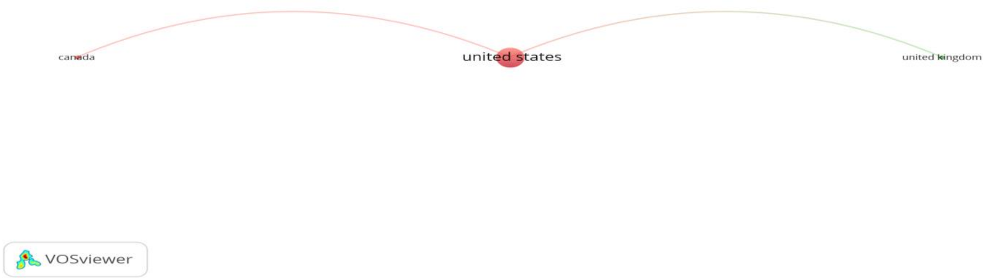


Fig. 175: National and International Collaboration

6.3.13.8.3. Co-authorship Index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of George P Smith has been calculated at 2.39.

6.3.13.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources has resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that George P Smith had close communication with 69 co-authors while publishing his documents.

6.3.13.9 To find out the research network of George Pearson Smith.

6.3.13.9.1 Co-authorship: George P. Smith had collaborated with 68 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with A A Petrenko, J K Scott and W D Thomas were the highest. A graphical representation of the co-authorship pattern is shown in figure 176 below.

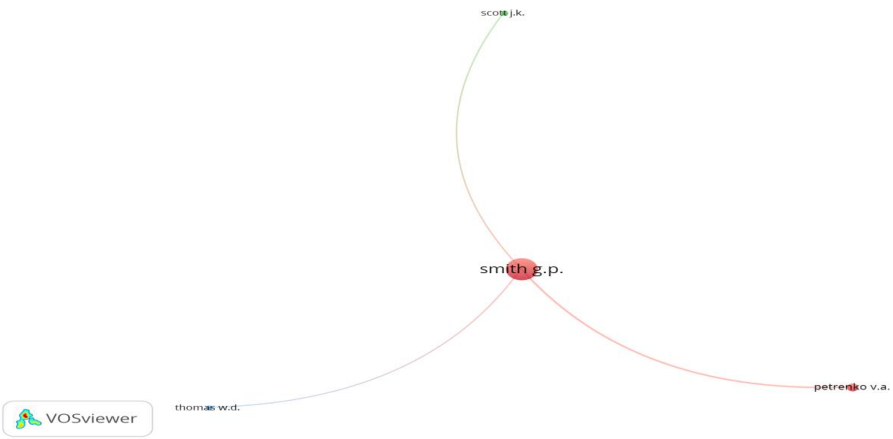


Fig. 176: Co-authorship Pattern of George Pearson Smith

6.3.13.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top five keywords on the decreasing order of their link strengths.

Table 124: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
bacteriophage	27	264
article	29	258
non human	24	231
priority journal	19	196

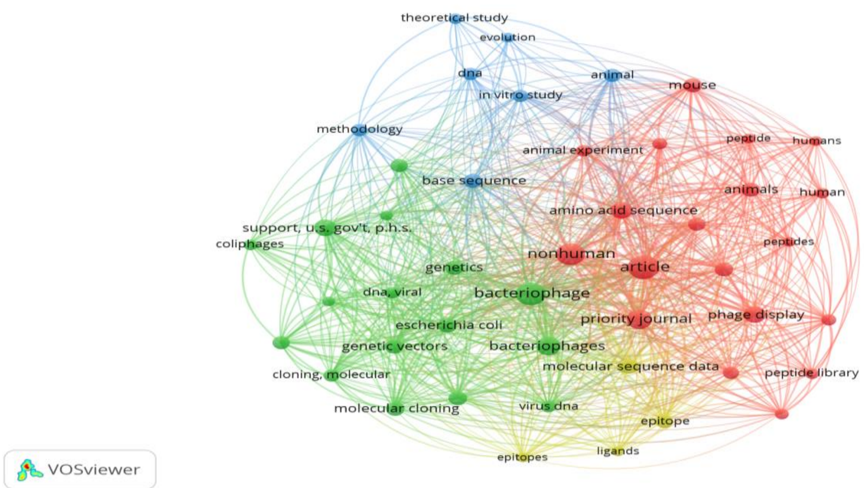


Fig. 177: Keyword Co-occurrences Authorship Pattern

6.3.13.9.3 Citation analysis: Of the 56 papers published by George Pearson Smith, either as a single author or in collaboration, 55 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *Philamentous fusion phage: Novel expression vectors that display cloned antigens on the virion surface*, published in the journal *Science* during 1985 has been cited 2801 times followed by the article *Searching for Peptide Ligands with an epitome library* published in *Science* in 1990 which received 1834 citations. Another article, *Phage display* poublished in the journal *Chemical Reviews* during 1997 has been cited 1268 times. A graphical representation of the above information is presented in Figure 178.

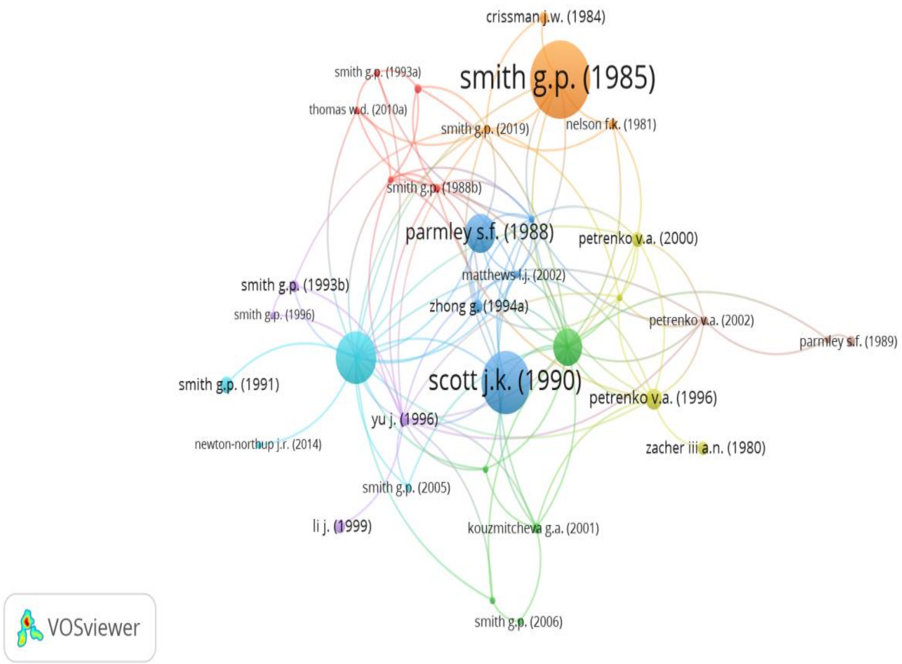


Fig. 178: Citation Analysis

6.3.13.9.4 Bibliographic Coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of George Pearson Smith is presented in figure 179.

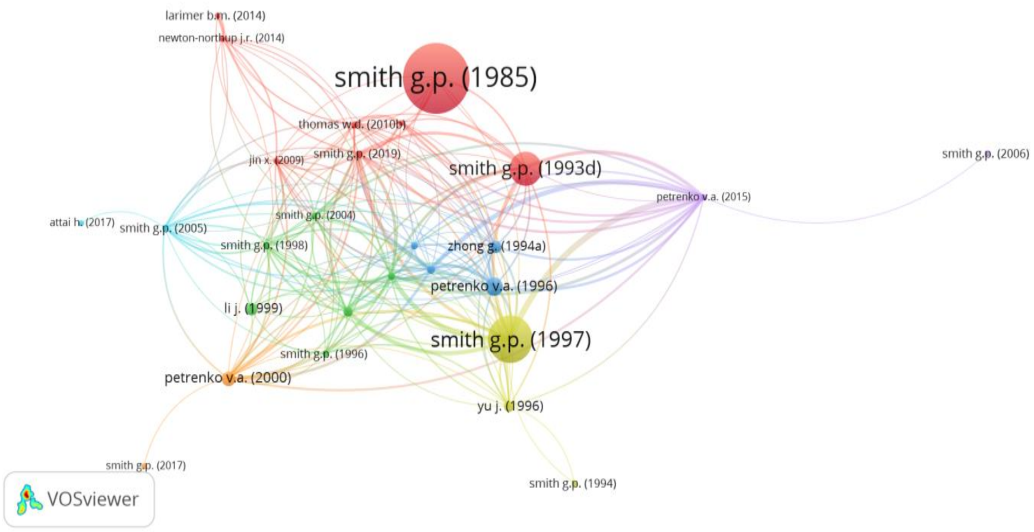


Fig. 179: Bibliographic Coupling

6.3.13.9.5 Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of George Pearson Smith is produced in Fig. 180. Analysis of the figure shows that the articles published by Yoshino has been co-cited by 2 clusters, having 5 items each. There are a total of 40 links, with a total link strength of 5225.

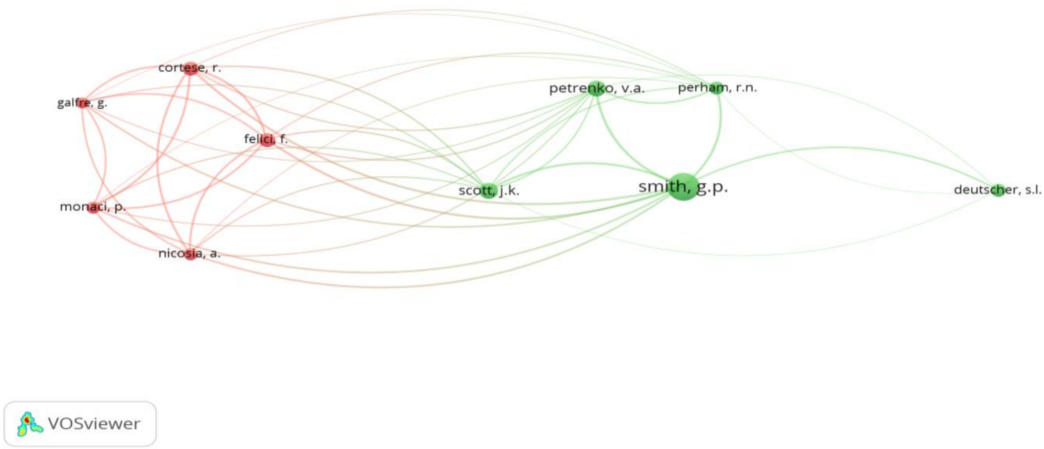


Fig. 180: Co-citation Analysis

6.3.13.10 To analyze cluster mapping (George Pearson Smith)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 181 shows the coupling map of George Pearson Smith.

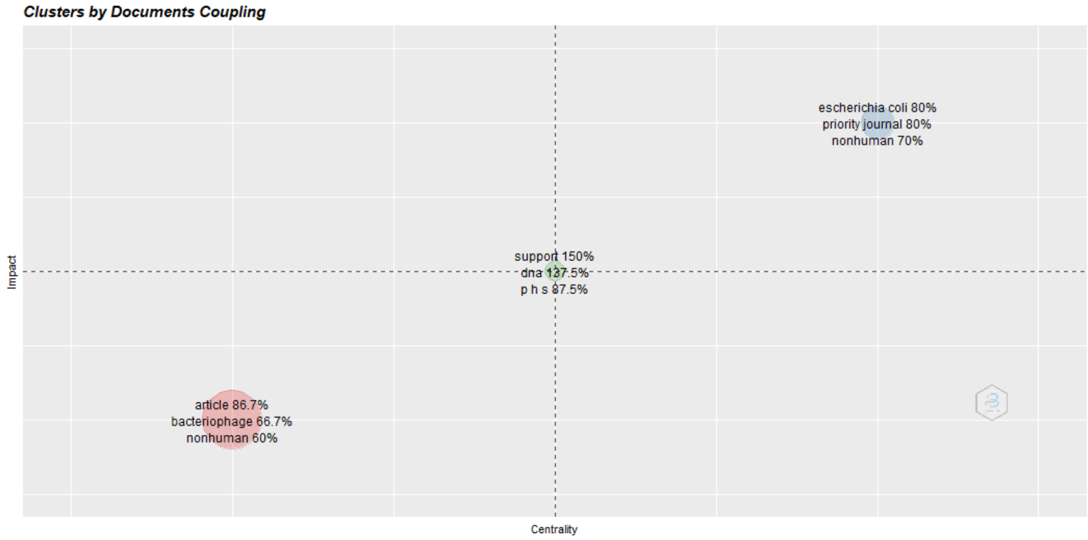


Fig 181: Document Coupling

6.3.13.11 Other Information (George Pearson Smith)

Table 125: Main Information

Description	**Results**
Timespan	1971:2019
Sources	
Journals, Books, Etc	32
Documents	55
Total	87
Average Years from Publication	27.1
Average Citations Per Documents	181
Average Citations Per Year Per Doc	5.774
References	1351
Document Types	
Article	45
Book Chapter	1
Editorial	2
Review	6
Short Survey	1
Total	55

Document Contents	
Keywords Plus (Id)	610
Author's Keywords (De)	80
Authors	
Authors	56
Author Appearances	127
Authors Of Single-Authored Documents	1
Authors Of Multi-Authored Documents	55
Authors Collaboration	
Single-Authored Documents	17
Documents Per Author	0.982
Authors Per Document	1.02
Co-Authors Per Documents	2.31
Collaboration Index	1.45
H-Index	29
Total Citation	10,243 Citations By 7,337 Documents

The publication productivity of George Pearson Smith is consistent throughout the entire productive life and he has made outstanding contributions in the field of phage display. His publication life commenced in 1971 after he had attained a biological age of 30 years. George Pearson Smith has been active in research despite many administrative responsibilities. He has worked in collaboration and has a high degree of collaboration at institutional, national, and international levels. George Pearson Smith has an h-index of 29 and is regarded as one of the most successful scientists in the field of chemistry. George Pearson Smith's research efforts have largely been concentrated on molecular biology and genomics which proves his strength in this field. George Pearson Smith's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.14 GREGORY PAUL WINTER

Sir Gregory Paul Winter, a well-known British molecular biologist was born on 14 April 1951. He is known for pioneering works on the therapeutic use of monoclonal antibodies. Sir Gregory Paul Winter concentrated most of his research at the Medical Research Council Laboratory of Molecular Biology and the Medical Research Council Centre for Protein Engineering in Cambridge, England. Sir Gregory P. Winter invented techniques to humanize phage display and antibodies for medical use. For these developments, Winter received the Nobel Prize in Chemistry in 2018 with Sir George Pearson Smith and Frances Hamilton Arnold.

Sir Gregory Paul Winter has been bestowed with several fellowships and has been given several duties. He is a Fellow of Trinity College, Cambridge, and was also appointed as the Master of Trinity College, Cambridge. He also served as the Deputy Director of the Laboratory of Molecular Biology, Medical Research Council, and went to become the acting Director of the institute. He has also served as the Head of the Division of Protein and Nucleic Acids Chemistry and the Deputy Director of the Medical Research Council Centre for Protein Engineering.

6.3.14.1 To assess the number of scientific communications contributed by Sir Gregory Paul Winter

Sir Gregory P. Winter has used several media to publish his scientific works. While most of his scientific communication have been through articles that he has published himself or in collaboration with other co-authors, he has also authored books, presented conference papers, editorials, reviews, surveys, etc. Table 126 shows the number of scientific communications of the Nobel Laureate.

Table 126: Scientific Communication

Document Types	
Article	172
Book Chapter	1
Conference Paper	6
Editorial	5
Erratum	3
Letter	2
Note	4
Review	9
Short Survey	1

6.3.14.2 To analyze the domain wise scientific communication of Sir Gregory Paul Winter

The works of Sir Gregory Winter can be broadly classified into four categories or domains: Antibody Engineering, Biochemistry, Molecular Biology, and Protein Engineering. In tune with his professional requirements, most of Sir White's works are in the fields of Protein Engineering and Molecular Biology. While Sir Gregory Winter has also researched on the domain of Antibody Technology and Biochemistry, these are less in numbers. Translating the information in numerical and percentage terms, Sir Gregory Winter has published a total of 203 papers of which 77 papers are on Protein Engineering (37.93%), 68 papers on Molecular Biology (33.50%), 31 papers on Antibody Technology (15.27%) and 27 on Biochemistry (13.30%). Sir Gregory Paul Winter has published his works using several modes. While most of his works, (172, 84.73%) are in the form of articles, he has also published his works in the form of Book Chapters, Conference Papers, Editorials, Errata, Letters, Notes, Reviews, and Short Surveys in varying proportions. Table 127 is a tabular form of the above information and figure 182 is a graphical form of the same.

Table 127: Number of Scientific Communication

Document	**Domain**				**Total Papers**	%
	A	B	C	D		
Article	27	23	55	67	**172**	**84.73**
Book Chapter	0	0	0	1	**1**	**0.49**
Conference Paper	1	1	3	1	**6**	**2.96**
Editorial	0	0	2	3	**5**	**5.46**
Erratum	1	1	0	1	**3**	**1.48**
Letter	1	0	1	0	**2**	**0.99**
Note	1	0	2	1	**4**	**1.97**
Review	0	2	4	3	**9**	**4.43**
Short Survey	0	0	1	0	**1**	**0.49**
%	**15.27**	**13.30**	**33.50**	**37.93**		**100**

A: Antibody Technology B: Biochemistry C: Molecular Biology D: Protein Engineering

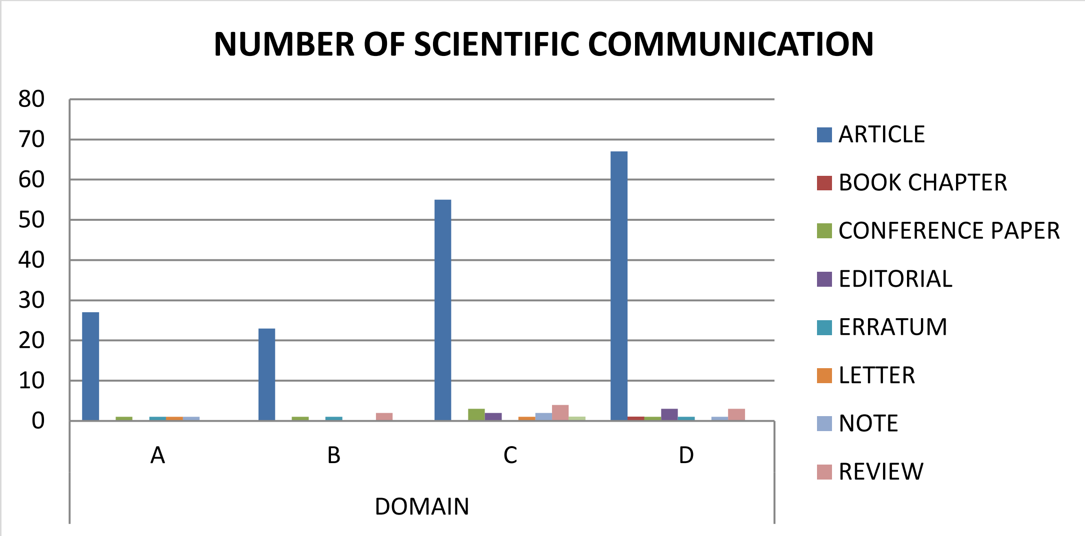


Fig. 182: Number of Scientific Communication

6.3.14.3 To analyze the domain-wise authorship pattern of Sir Gregory Paul Winter

Sir Gregory Paul Winter had to work in collaboration with other authors due to his numerous responsibilities which is evident from the analysis of his works. While the author had only 10 single-authored documents representing 4.93% of his total publications, 76 publications at 37.44% were authored by 5 to 10 authors. However, Sir Gregory Paul Winter was the main author of these documents. One document was authored by 47 authors.

Table 128: Domain-wise Authorship as per Collaboration

Domain	**Authors**						
	1-Author	2-Author	3-Author	4-Author	5-10 Author	11-20 Author	41-50 Author
A	2	0	2	3	20	4	0
B	0	4	3	5	13	2	0
C	6	19	13	13	15	1	1
D	2	14	16	12	28	5	0
Total Papers	**10**	**37**	**34**	**33**	**76**	**12**	**1**
%	**4.93**	**18.23**	**16.75**	**16.26**	**37.44**	**5.91**	**0.49**

A: Antibody Technology B: Biochemistry C: Molecular Biology D: Protein Engineering

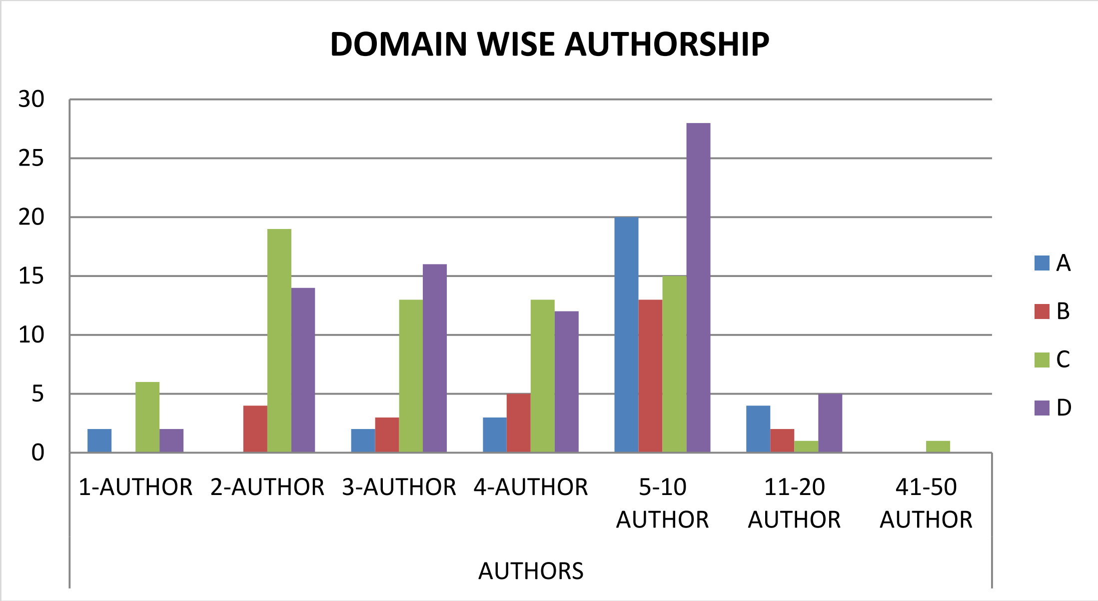


Fig. 183: Domain-wise Authorship Pattern

6.3.14.4 To analyze the year-wise scientific communication of Sir Gregory Paul Winter.

Sir Gregory Paul Winter's publication life began in 1977, 26 years after his birth. A look into his year-wise productivity reveals that the author has published the maximum number of works from 1991 till 2000 when he had published 100 papers in all domains at 49.26%. During the first 10 years of his productive life, Sir Winter published 49 papers (≈25%). The lowest number of works was published from 1971 till 1980. During the years 2001 – 2010 and 2011 – 2019, 31 and 23 publications resoectively were made available which contributed 15.27% and 11.33% each to the total publications of the author. A tabular form of this information is provided in Table 129 and 130, while a graphical representation is given in figure 184.

Table 129: Domain and Year-wise Authorship

Period	Domain				Total Papers	%
	A	B	C	D		
1971-1980	0	0	0	4	**4**	**1.97**
1981-1990	5	6	19	15	**45**	**22.17**
1991-2000	7	8	27	58	**100**	**49.26**
2001-2010	10	9	12	0	**31**	**15.27**
2011-2019	9	4	10	0	**23**	**11.33**

A: Antibody Technology B: Biochemistry C: Molecular Biology D: Protein Engineering

Table 130: Year-wise Productivity

Year	Domain				Total Papers	%
	A	B	C	D		
1971	0	0	0	0	0	0
1972	0	0	0	0	0	0
1973	0	0	0	0	0	0
1974	0	0	0	0	0	0
1975	0	0	0	0	0	0
1976	0	0	0	0	0	0
1977	0	0	0	2	2	0.98
1978	0	0	0	1	1	0.49
1979	0	0	0	0	0	0
1980	0	0	0	1	1	0.49
1981	1	1	2	2	6	2.95
1982	1	1	2	2	6	2.95
1983	1	1	1	1	4	1.97
1984	1	1	2	1	5	2.46
1985	1	1	2	5	9	4.43
1986	0	1	1	3	5	2.46
1987	0	0	1	0	1	0.49
1988	0	0	2	5	7	3.45
1989	0	0	4	4	8	3.94
1990	0	0	2	3	5	2.46
1991	1	1	2	4	8	3.94
1992	1	1	2	13	17	8.37
1993	1	1	0	13	15	7.39
1994	1	1	0	11	13	6.40
1995	1	1	2	1	5	2.46
1996	1	1	2	8	12	5.91
1997	1	1	0	10	12	5.91
1998	0	1	0	8	9	4.43
1999	0	0	0	9	9	4.43
2000	0	0	0	3	3	1.48

2001	1	1	2	0	4	1.97
2002	1	1	1	0	3	1.48
2003	1	0	0	0	1	0.49
2004	1	2	4	0	7	3.45
2005	1	1	1	0	3	1.48
2006	1	1	4	0	6	2.95
2007	1	1	0	0	2	0.98
2008	1	1	0	0	2	0.98
2009	2	1	0	0	3	1.48
2010	0	0	0	0	0	0
2011	1	0	0	0	1	0.49
2012	1	1	0	0	2	0.98
2013	0	0	0	0	0	0
2014	0	0	0	0	0	0
2015	1	1	0	0	2	0.98
2016	0	0	0	0	0	0
2017	0	0	0	0	0	0
2018	0	0	0	0	0	0
2019	1	1	0	0	2	0.98
2020	1	0	0	0	1	0.49

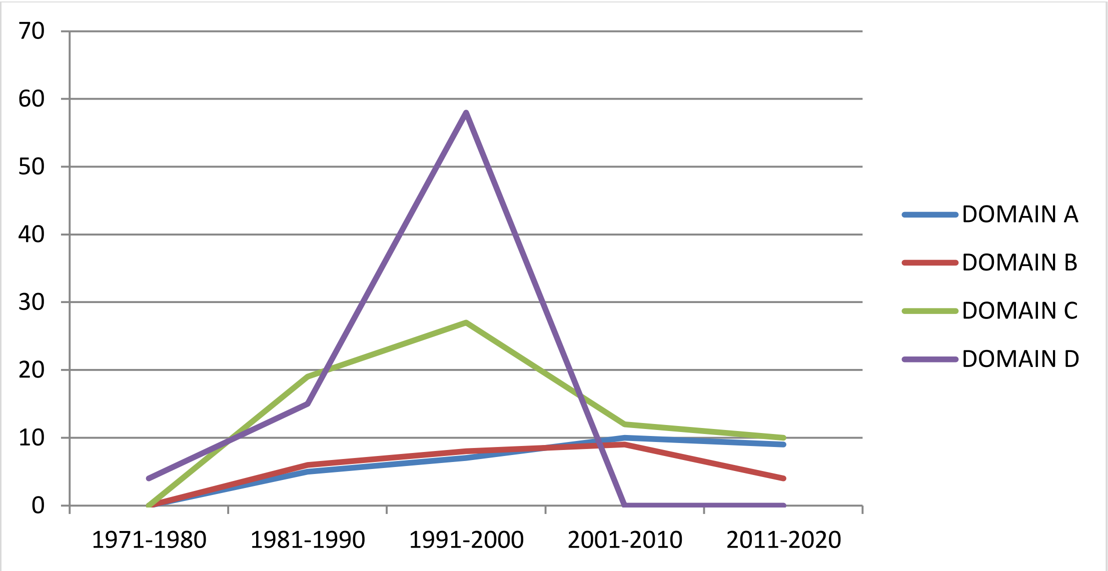


Fig.184: Domain and Year-wise Authorship

6.3.14.5 Author's Production over time (Sir Gregory Paul Winter)

The productivity of Sir Gregory P. Winter as a factor of time has been shown in Fig.185. The figure bears testimony to the fact that the maximum productivity is witnessed during the period post 1991. The productivity, however, decline in the later years. Sir Winter was also bestowed several duties which may have contributed to this decline.

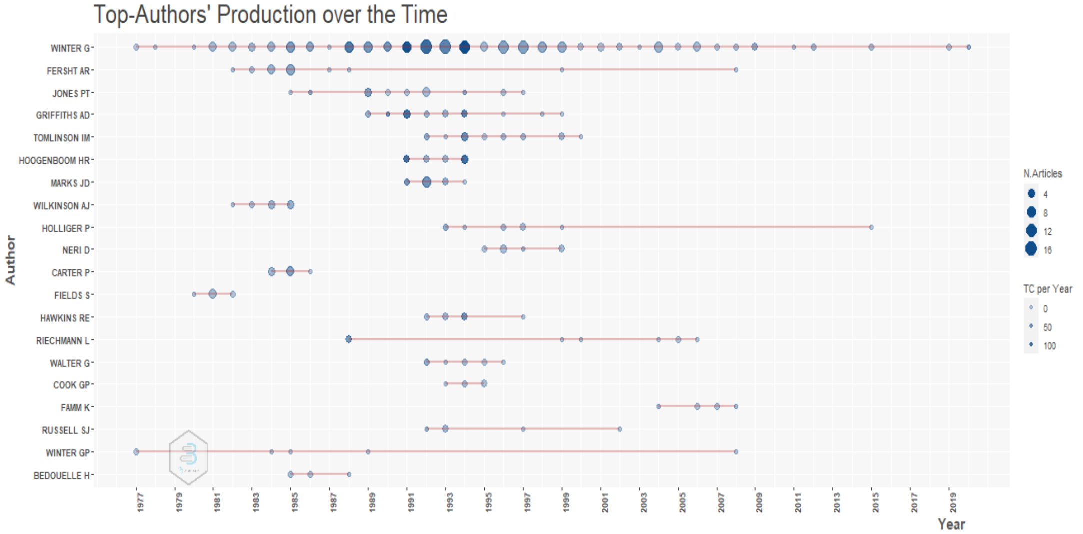


Fig. 185: Author's Production over Time

6.3.14.6 To find out the channels of communication used by Sir Gregory Paul Winter.

Sir Gregory P. Winter published his scientific works using a variety of methods, be it articles, erratums, editorials, notes, book chapters, etc. The articles published by Sir

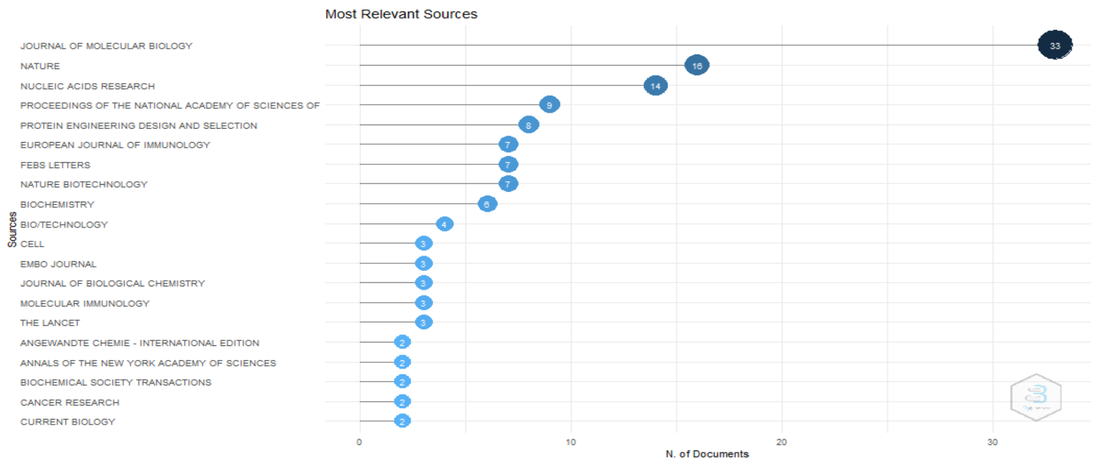


Fig. 186: Channels of Communication

Winter has been published in a number of journals. In the order of the decreasing number of articles, the top twenty journals publishing his articles have been shown in Fig 186. The figure shows that 33 articles have been published in the journal *Journal* *of Molecular Biology*, followed by 16 and 14 articles in the journals *Nature* and *Nucleic Acids Research*.

Table 131: Most Relevant Sources

Sources	Articles
Journal Of Molecular Biology	33
Nature	16
Nucleic Acids Research	14
Proceedings Of the National Academy of Sciences of The United States of America	9
Protein Engineering Design and Selection	8
European Journal of Immunology	7
Febs Letters	7
Nature Biotechnology	7
Biochemistry	6
Bio/Technology	4
Cell	3
Embo Journal	3
Journal Of Biological Chemistry	3
Molecular Immunology	3
The Lancet	3
Angewandte Chemie - International Edition	2
Annals Of The New York Academy of Sciences	2
Biochemical Society Transactions	2
Cancer Research	2
Current Biology	2
European Journal of Biochemistry	2
Fresenius' Journal of Analytical Chemistry	2
Human Molecular Genetics	2
Journal Of Immunology	2
Oncogene	2
Protein Engineering	2
Virology	2
Acs Chemical Biology	1

Acta Crystallographica Section D: Biological Crystallography	1
Aids Research and Human Retroviruses	1
American Journal of Pathology	1
Analytical Biochemistry	1
Angewandte Chemie International Edition in English	1
Annual Review of Immunology	1
Australian Doctor	1
Behring Institut Mitteilungen	1
Behring Institute Mitteilungen	1
Biochimie	1
Biotechniques	1
Biotechnology (Reading Mass.)	1
Blood	1
Cancer Immunology Immunotherapy	1
Chemmedchem	1
Ciba Foundation Symposium	1
Cold Spring Harbor Symposia on Quantitative Biology	1
Current Opinion in Biotechnology	1
Current Opinion in Chemical Biology	1
Current Opinion in Immunology	1
Enzymes In Organic Synthesis	1
Febs Journal	1
Folding And Design	1
Gene	1
Gene Therapy	1
Human Antibodies and Hybridomas	1
Human Gene Therapy	1
Hybridoma And Hybridomics	1
Immunological Reviews	1
Immunology Today	1
Immunotechnology	1
International Journal of Cancer	1
Journal Of Clinical Investigation	1

Journal Of Experimental Medicine	1
Journal Of Immunological Methods	1
Journal Of Immunotherapy	1
Journal Of Molecular Catalysis B: Enzymatic	1
Journal Of Molecular Recognition	1
Methods In Enzymology	1
Nature Chemical Biology	1
Nature Genetics	1
Philosophical Transactions of The Royal Society of London. Series B Biological Sciences	1
Recombinant Antibodies for Immunotherapy	1
Research In Microbiology	1
Revue Francaise De Transfusion Et D'hemobiologie	1
Science	1
Scientist	1
Structure	1
The Embo Journal	1
Trends In Biochemical Sciences	1
Trends In Biotechnology	1
Trends In Pharmacological Sciences	1

6.3.14.7 Author's performance based on available metrics indicators (Sir Gregory Paul Winter)

Table 132: Performance of Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	23.4	01	i10-index (i10)	172
02	Total Citation	31887	02	h5-index (h5)	4
03	Audience Factor	245.8	03	g-Index	178
04	CiteScore (Maximum)	56.9	04	a-Index	327.5
05	ResearchGate Citations	231	05	h(2)-index	20
06	Microsoft Academic Search Citations	18379	06	hg-index (hg)	123.73

07	Google Scholar Citations	16894	07	r-index	167.82
08	Eigenfactor	25.69	08	ar-index (ar)	25.30
09	Crown Indicator	92.894	09	k-index	8.22
10	Mean Citation Score	167.79	10	q2-index	5.29
11	Mean Normalized Citation Score (MNCS)	18.85	11	f-index	0.97
12	Mean Citation Rate Subfield (MCRS)	3.87	12	m-index	3.31
13	Scientific Talent Pool (STP)	1.67	13	m quotient (m-q)	3.31
14	Microsoft Academic Search Papers (MASP)	99	14	Contemporary-index (Ch)	44.01
15	Google Scholar Papers (GSP)	145	15	Trendh h-index (Th)	5.95
16	Impact per Paper (IPP)	25.69	16	Dynamic h-Type index (Dh-T)	15.26
17	Citation per paper (CPP)	1.83	17	n-index	1.26
18	Citations per Paper self-citation not included (CPPex)	1.77	18	mean h-index	44.5
19	The average number of citations per publication (ANCP)	26.79	19	Normalized h-index	19.86
20	Total and the Average Number of Citations (TNCS)	31887, 1.83	20	Specific-impact s-index (Sis)	40.59
21	Relative Activity Index (RAI)	44.34	21	Seniority independent Hirsch type index (Sih-T)	1
22	Relative Specialization index (RSI)	18.79	22	Hw-index	167.82
23	Relative Citation Rate (RCR)	10.08	23	Hm-index	32
24	Relative Database Citation Potential (RDCP)	80.20	24	Tapered h-index	10.13
25	Journal Acceptance Rate (JAR)	15.99	25	i20-index	156
26	% Self Citations (%SC)	3.19	26	v-index over h	3.44

27	Percentage of papers not cited (%Pnc)	6.40	27	e-index	144.11
28	PR Percentile Ranks (PR)	55.05	28	Multidimensional h-index	57.11
29	LogZ-score (LogZ)	17.354	29	Research Collaboration Index	37.68
30	Innovative Knowledge (IK)	62.96	30	Communities Collaboration Index	28.99
31	Technological Impact (TI)	76.38	31	ch-index	77.25
32	Scientific Talent Pool (STP)	55.65	32	speed s-iCitationndex	33.98
33	Normalized position of publication journal (NPJ)	46	33	π-index	318.45
34	WorldCat Hold (WCH)	259	34	h5-median (h5-m)	20.02
35	Papers in Top 1 (PT1)	2	35	2nd generation citations h index	72
36	Papers in Top 10 (PT10)	4	36	Role basedh-maj-index (Rbhm)	22.09
37	Papers in Top 50 (PT50)	16	37	h2 lower (h2-l)	9
38	High Cited Papers (HCP)	5	38	h2-center (h2-c)	22
39	Papers in First Quartile (Q1)	25	39	h2-upper (h2-u)	55
40	Publications in Thomson Reuters indices (PWoS)	2	40	h3-index	18
41	Number of highly cited publications (NHCP)	54	41	p-index	22.37
42	Publications in top-ranked journals (PTRJ)	33	42	$\bar{h}$-index (Hbar)	86
43	Papers in Collaboration (PCol)	193	43	Mockhm-index (Mhm)	78.02
44	Share of articles coauthored with	95.07	44	w-index	32.29

	another unit (%CoA)				
45	National Collaboration (NCol)	33	45	b-index	33.48
46	International Collaboration (ICol)	75	46	Generalizedh-index	82.35
47	Scientific Leadership (SL)	16.55	47	Single paperh-index	19
48	Average Authors per Paper	0.20	48	hint-index	57
49	Productivity per Paper	0.69	49	h_{rat}-index	86.99
50	RoG, CAGR, RGR and DT	0.46, (-)0.99, 0.14, 2.71	50	πv-index	65.49

6.3.14.8 To analyze the scientific collaboration of Sir Gregory Paul Winter

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. George Pearson Smith has collaborated with 420 different authors in the conduct and publication of his research work. The author has published only 10 single-authored documents.

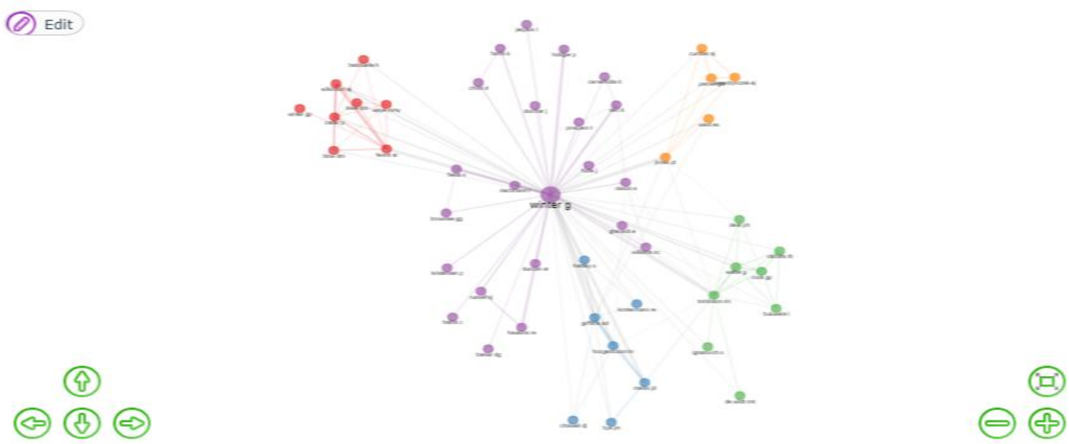


Fig 187: Collaboration Network

6.3.14.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Gregory P. Winter, the collaboration index has been calculated at 0.20.

6.3.14.8.2 National and International Collaboration: Sir Gregory P. White has published his papers in collaboration with 420 co-authors of mostly hailing from the United States of America, and the United Kingdom. 184 papers have been published either as a single authored publication or with researchers from the United Kingdom. 20 papers have been published in collaboration with researchers hailing from the United States, while 11 papers each have been published with collaborative efforts from researchers from Italy and Switzerland. The collaboration map of Sir Gregory P. Winter is produced in figure 188.

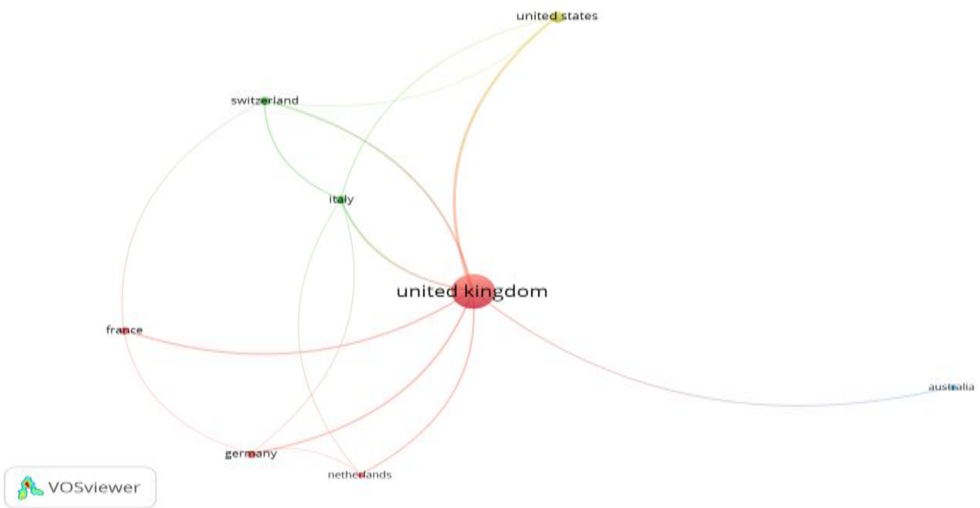


Fig. 188: National and International Collaboration

6.3.14.8.3 Co-authorship Index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index $\leq$ co-authorship index. The co-authorship index of Sir Gregory P. Winter has been calculated at 5.00.

6.3.14.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources has resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Sir Gregory P. Winter had close communication with 12 co-authors while publishing his documents.

6.3.14.9 To find out the research network of Sir Gregory Paul Winter.

6.3.14.9.1 Co-authorship: Sir Gregory P. Winter had collaborated with 420 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with A R Fersht, A D Griffiths, I M Tomlinson, and A J Wilkinson were the highest. A graphical representation of the co-authorship pattern is shown in figure 189 below.

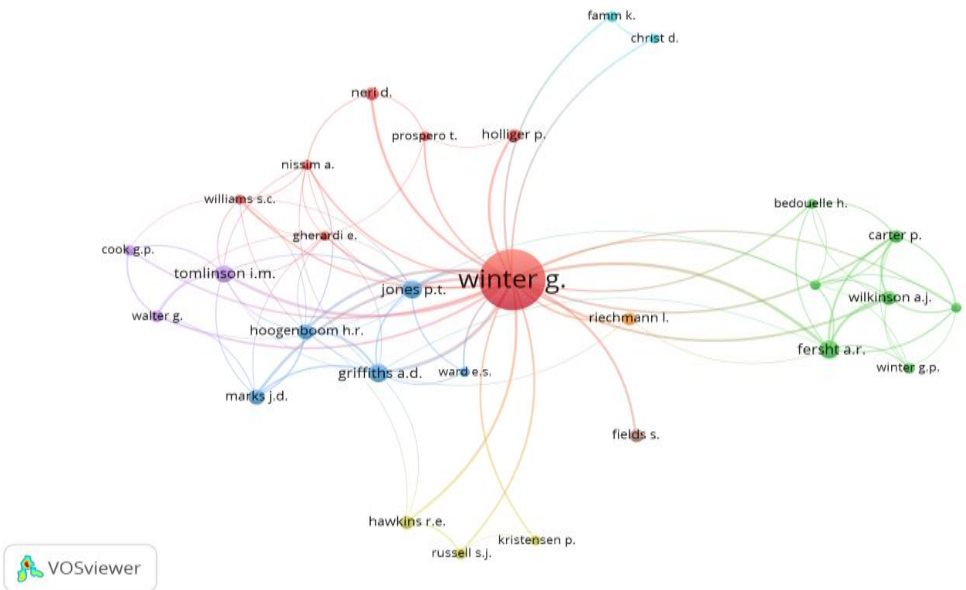


Fig. 189: Co-authorship Pattern of George Pearson Smith

6.3.14.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top five keywords on the decreasing order of their link strengths.

Table 133: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
article	134	1938
priority journal	132	1895
non human	84	1319
human	73	1112

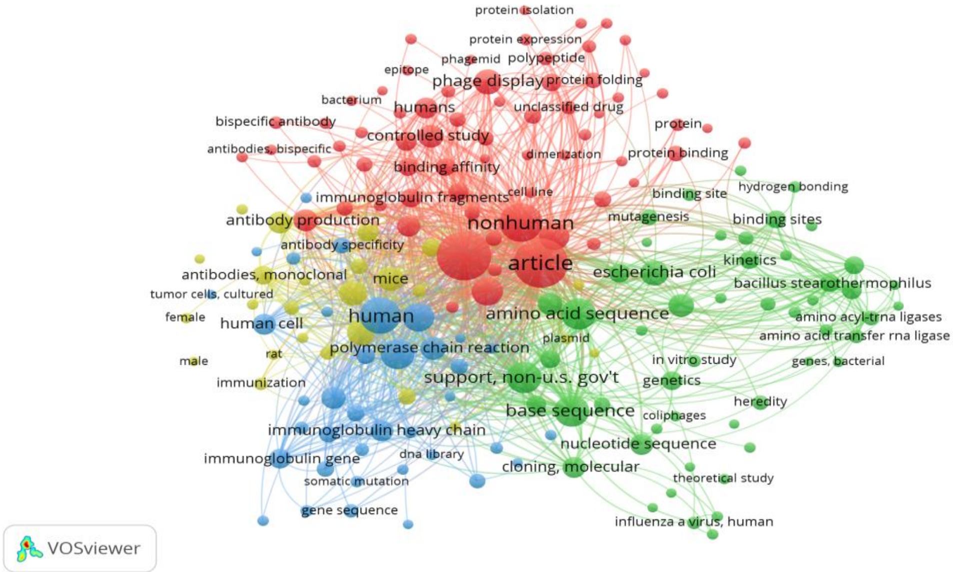


Fig. 190: Keyword Co-occurrences Authorship Pattern

6.3.14.9.3 Citation analysis: Of the 203 papers published by George Pearson Smith, either as a single author or in collaboration, 190 have been cited by other researchers

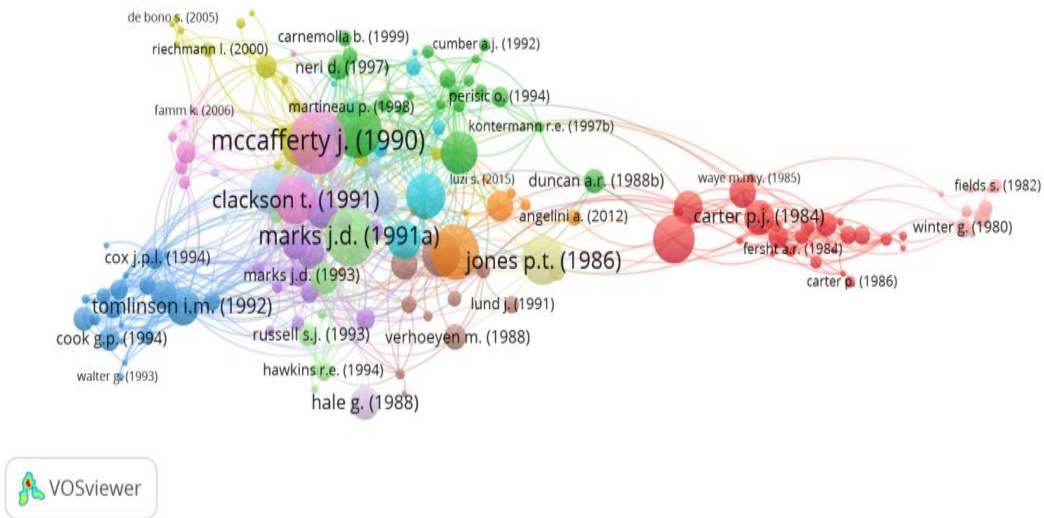


Fig. 191: Citation Analysis

in their papers. An analysis of the citation network reveals that the article *Phage antibodies: filamentous phage displaying antibody variable domains*, published in the journal *Nature* during 1990 has been cited 1786 times followed by the article *By-passing Innumization. Human antibodies from V-gene libraries displayed on phage* published in *Journal of Molecular Biology* in 1991 which received 1387 citations. Another article, *Making antibodies by phage display technology* published in the journal *Annual Review of Immunology* during 1994 has been cited 1307 times. A graphical representation of the above information is presented in Figure 191.

6.3.14.9.4 Bibliographic Coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of George Pearson Smith is presented in figure 192.

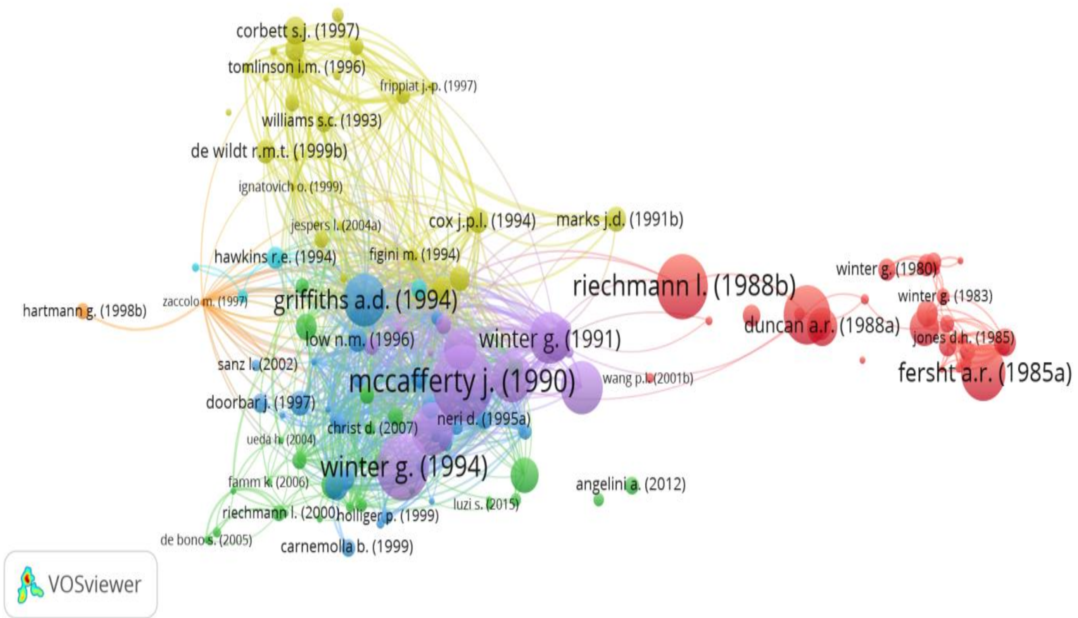


Fig. 192: Bibliographic Coupling

6.3.14.9.5 Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of Sir Gregory P, Winter is produced in Fig. 193. Analysis of the figure shows that the articles published by Yoshino have been co-cited by 4 clusters, having 41, 23, 13, and 7 items each. There are a total of 2286 links, with a total link strength of 114369.

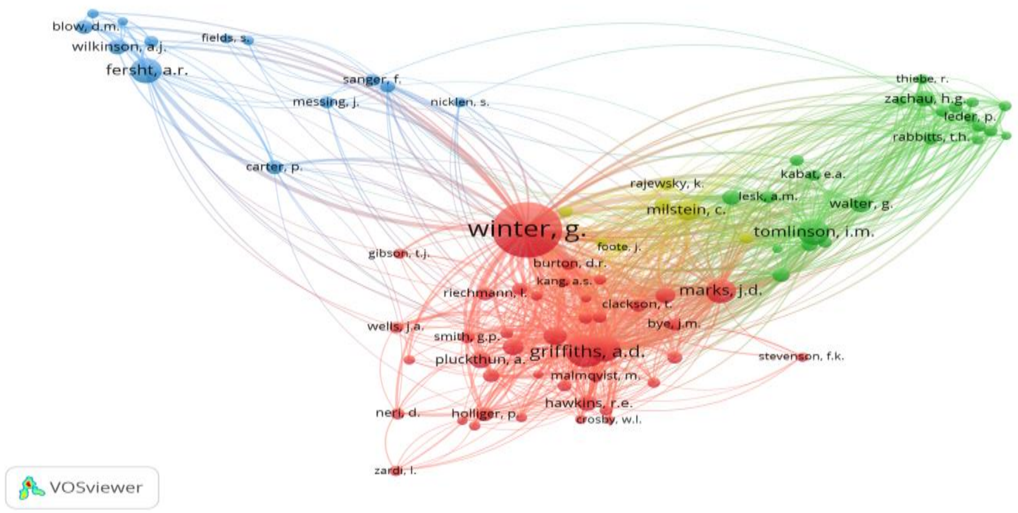


Fig. 193: Co-citation Analysis

6.3.14.10 To analyze cluster mapping (Sir Gregory Paul Winter)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 194 shows the coupling map of Sir Gregory Paul Winter.

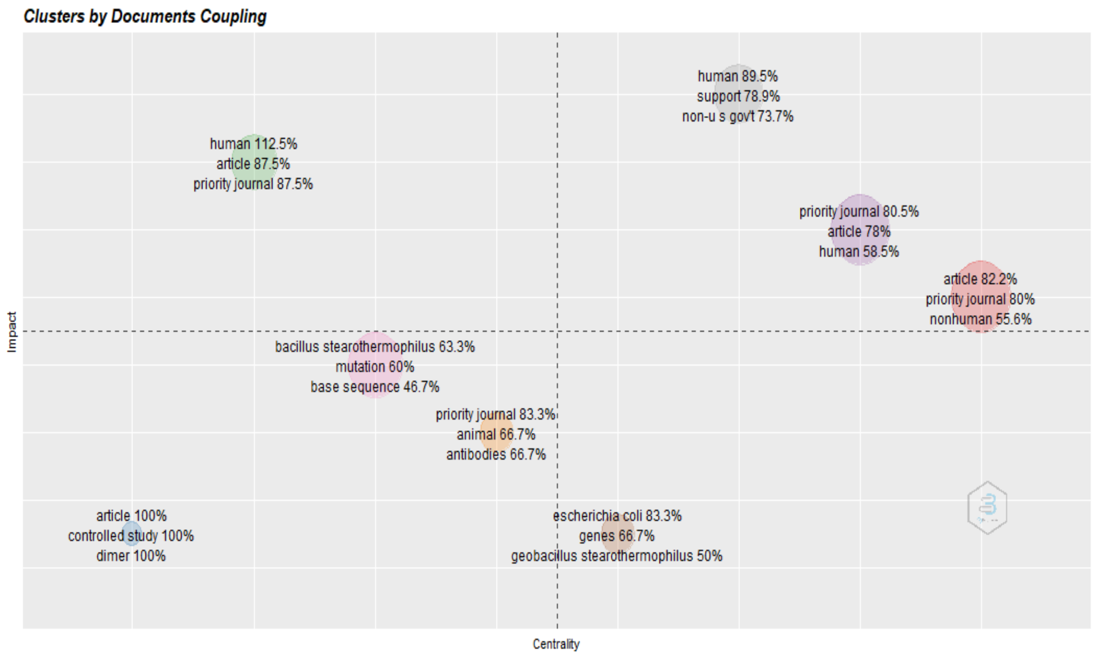


Fig 194: Document Coupling

6.3.14.11 Other Information (Sir Gregory Paul Winter)

Table 134: Main Information

Description	**Results**
Timespan	1977:2019
Sources	
Journals, Books, Etc	80
Documents	203
Total	283
Average Years from Publication	26.7
Average Citations Per Documents	153.8
Average Citations Per Year Per Doc	5.455
References	5471
Document Types	
Article	172
Book Chapter	1
Conference Paper	6
Editorial	5
Erratum	3
Letter	2
Note	4
Review	9
Short Survey	1
Total	203
Document Contents	
Keywords Plus (Id)	121
Author's Keywords (De)	236
Authors	
Authors	440
Author Appearances	1015
Authors Of Single-Authored Documents	2
Authors Of Multi-Authored Documents	438
Authors Collaboration	
Single-Authored Documents	10

Documents Per Author	0.461
Authors Per Document	2.17
Co-Authors Per Documents	5
Collaboration Index	2.27
H-Index	86
Total Citation	31,887 Citations By 17,454 Documents

The publication productivity of Sir Gregory Paul Winter is consistent throughout the entire productive life and he has made outstanding contributions in the field of phage display. His publication life commenced in 1977 after he had attained a biological age of 26 years. Sir Gregory Paul Winter has been active in research despite many administrative responsibilities. He has worked in collaboration and has a high degree of collaboration at institutional, national, and international levels. Sir Gregory Paul Winter has an h-index of 86 and is regarded as one of the most successful scientists in the field of chemistry. Sir Gregory Paul Winter's research efforts have largely been concentrated on molecular biology and genomics which proves his strength in this field. Sir Gregory Paul Winter's research productivity portrays him as an eminently qualified researcher and a role model for the younger generation. His contributions to the field of science need to be emulated. He is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

6.3.15 FRANCES HAMILTON ARNOLD

Frances Hamilton Arnold (DOB: 25th July 1956) is an American chemical engineer who is the Linus Pauling Professor of Chemical Engineering, Bioengineering, Biochemistry at Caltech. She won the Nobel Prize in 2018 for her pioneering work on the use of directed evolution to engineer enzymes. She has also been given various responsibilities like serving as an external co-chair of President's Joe Biden's Council of Advisors on Science and Technology.

6.3.15.1 To assess the number of scientific communications contributed by Frances Hamilton Arnold

Table 135: Scientific Communication

Document Types	
Article	270
Book	1

Book Chapters	7
Conference Papers	15
Editorial	4
Erratum	6
Letter	1
Note	3
Review	38
Short Survey	4

6.3.15.2 To analyze the domain-wise scientific communication of Frances Hamilton Arnold

A look into the nature of scientific communication reveals that 36.68% of her works are in the domain of chemical engineering followed by 25.50% in bioengineering and 19.77% in biochemistry. The domains include 18.05% in bioinformatics. Table 136 is the tabular form of the number of scientific communications of Frances H. Arnold. Regarding the nature of the document, Table 136 shows that most of the papers were in the form of articles (77.36%), followed by reviews (10.89%). With 0.29% of the total documents, books, and letters contribute the lowest to the list of total publications.

Table 136: Number of Scientific Communication

Document	Domain				Total Papers	%
	A	B	C	D		
Article	55	68	55	92	270	**77.36**
Book	0	0	0	1	1	**0.29**
Book Chapters	3	1	0	3	7	**2.01**
Conference Papers	4	4	1	6	15	**4.30**
Editorial	1	1	1	1	4	**1.15**
Erratum	1	2	1	2	6	**1.72**
Letter	0	0	0	1	1	**0.29**
Note	0	1	0	2	3	**0.86**
Review	4	10	5	19	38	**10.89**
Short Survey	1	2	0	1	4	**1.15**
%	**19.77**	**25.50**	**18.05**	**36.68**	**349**	**100**

A: Biochemistry B: Bioengineering C: Bioinformatics D: Chemical Engineering

A graphical form of Table 136 is shown in figure 195.

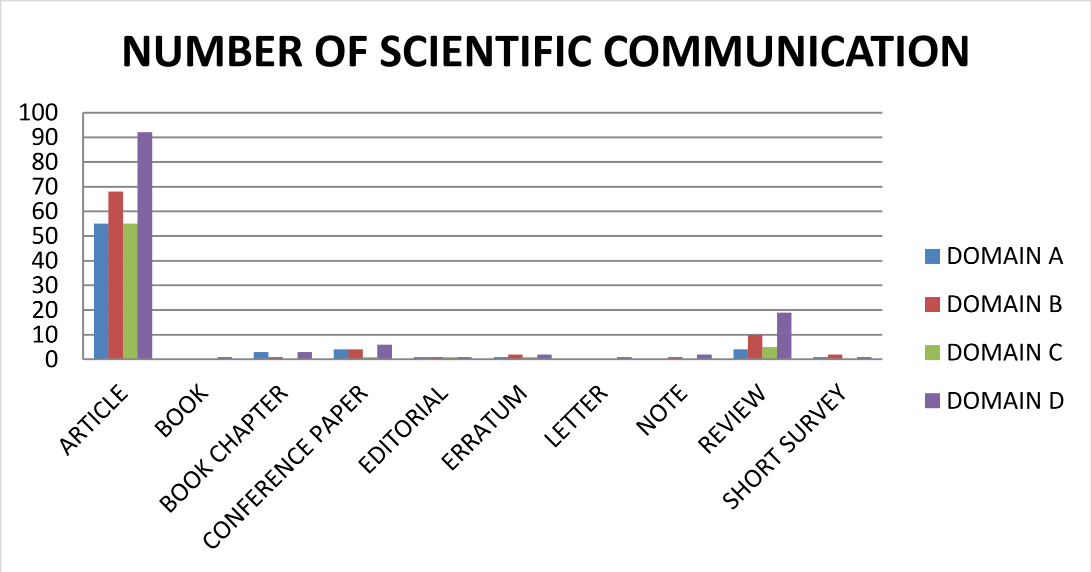


Fig 195: Number of Scientific Communication

6.3.15.3 To analyze the domain-wise authorship pattern of Frances Hamilton Arnold

The domain-wise authorship pattern is indicative of the fact that most of the papers published by Yoshino are multi-authored having 5 to 10 authors. This is followed by 21.78% of the documents which have 3 authors. 72 documents representing 20.63% of the total works are two-authored, 53 documents (15.19%) are four-authored. With 22 documents (6.30%), 5 documents (1.43%), and 1 document (0.29%), the contribution of one, 11 to 15 authored documents, and 16 to 20 authored documents respectively contribute little to the overall tally of the total documents. Table 137 is a tabular form of the authorship pattern and figure 196 presents a graphical view of the data.

Table 137: Domain-wise Authorship as per Collaboration

Domain	Authors						
	1 Author	2 Authors	3 Authors	4 Authors	5 To 10 Authors	11 To 15 Authors	16 To 20 Authors
A	5	18	9	9	29	2	0
B	10	16	24	14	23	2	0
C	2	11	9	10	28	0	0

D	5	27	34	20	40	1	1
Total	**22**	**72**	**76**	**53**	**120**	**5**	**1**
%	**6.30**	**20.63**	**21.78**	**15.19**	**34.38**	**1.43**	**0.29**

A: Biochemistry B: Bioengineering C: Bioinformatics D: Chemical Engineering

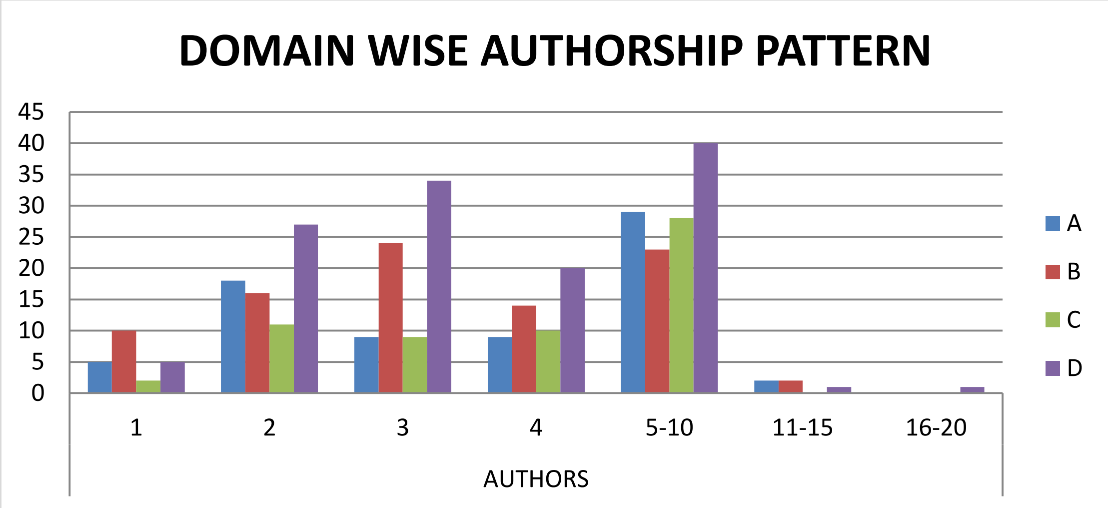


Fig 196: Domain-wise Authorship

6.3.15.4 To analyze the year-wise scientific communication of Frances Hamilton Arnold

Table 138 and figure 197 show the domain and year-wise authorship pattern of Frances H. Arnold. Frances Arnold has published 349 documents on various subjects commencing from the years 1980 and continues till date. An analysis of the data present in table 139 shows that the number of publications has increased with increase in time.

Table 138: Domain and Year-wise Authorship

Period	**Domain**				**Total Papers**	**%**
	A	**B**	**C**	**D**		
1980	0	0	0	2	**2**	**0.57**
1981-1990	4	2	0	12	**18**	**5.16**
1991-2000	17	33	20	24	**94**	**26.93**
2001-2010	27	28	28	35	**118**	**33.81**
2011-2019	24	26	12	55	**117**	**33.52**
Total	**72**	**89**	**60**	**128**	**349**	**100**

A: Biochemistry B: Bioengineering C: Bioinformatics D: Chemical Engineering

Table 139: Year-wise Productivity

Year	Domain				Total Papers	%
	A	B	C	D		
1980	0	0	0	2	2	0.57
1981	0	0	0	0	0	0
1982	1	0	0	0	1	0.29
1983	0	0	0	0	0	0
1984	1	1	0	0	2	0.57
1985	1	1	0	2	4	1.15
1986	1	0	0	1	2	0.57
1987	0	0	0	1	1	0.29
1988	0	0	0	2	2	0.57
1989	0	0	0	1	1	0.29
1990	0	0	0	4	4	1.15
1991	5	4	2	0	11	3.15
1992	4	1	0	0	5	1.43
1993	3	2	2	0	7	2.00
1994	1	2	2	0	5	1.43
1995	2	2	2	2	8	2.29
1996	2	5	2	2	11	3.15
1997	0	5	5	3	13	3.72
1998	0	4	4	0	8	2.29
1999	0	5	1	8	14	4.01
2000	0	4	0	8	12	3.43
2001	6	4	2	2	14	4.01
2002	5	4	1	1	11	3.15
2003	4	5	1	3	13	3.72
2004	4	5	1	1	11	3.15
2005	2	2	5	5	14	4.01
2006	0	2	5	7	14	4.01
2007	2	2	5	3	12	3.43
2008	1	2	0	2	5	1.43
2009	1	2	5	6	14	4.01

2010	2	0	3	1	6	1.72
2011	3	5	2	4	14	4.01
2012	2	4	2	1	9	2.58
2013	3	6	2	3	14	4.01
2014	3	6	2	8	19	5.44
2015	2	1	2	7	12	3.43
2016	5	1	2	3	11	3.15
2017	3	1	0	9	13	3.72
2018	1	1	0	13	15	4.30
2019	1	1	0	3	5	1.43
2020	1	0	0	2	3	0.86

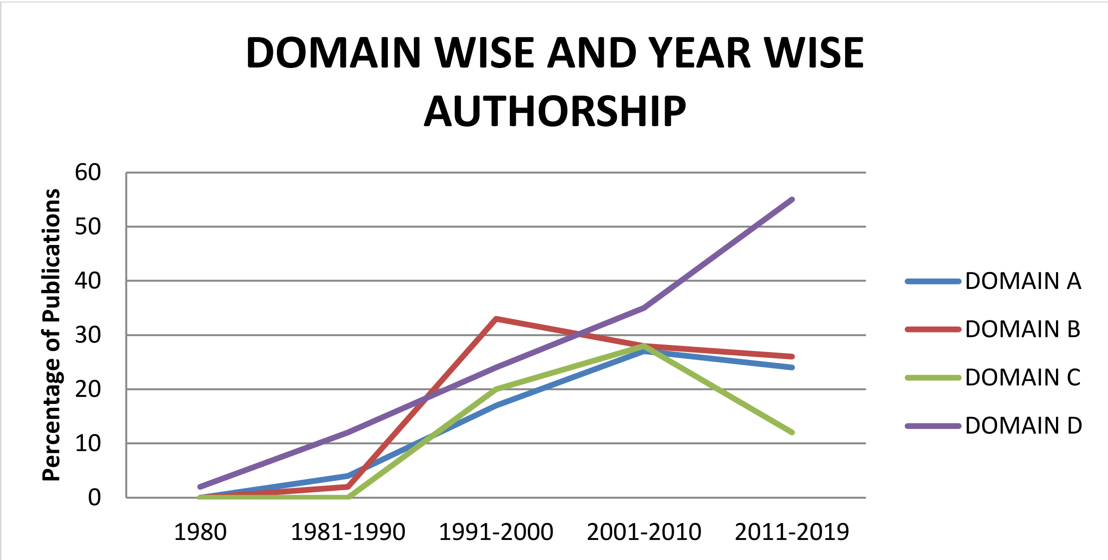


Fig 197: Domain wise and Year wise Authorship

6.3.15.5 Author's production over time (Frances Hamilton Arnold)

The result of the analysis of the author's production over time can also be seen in Figure 198 which shows that the numbers of publications in various domains have increased over time.

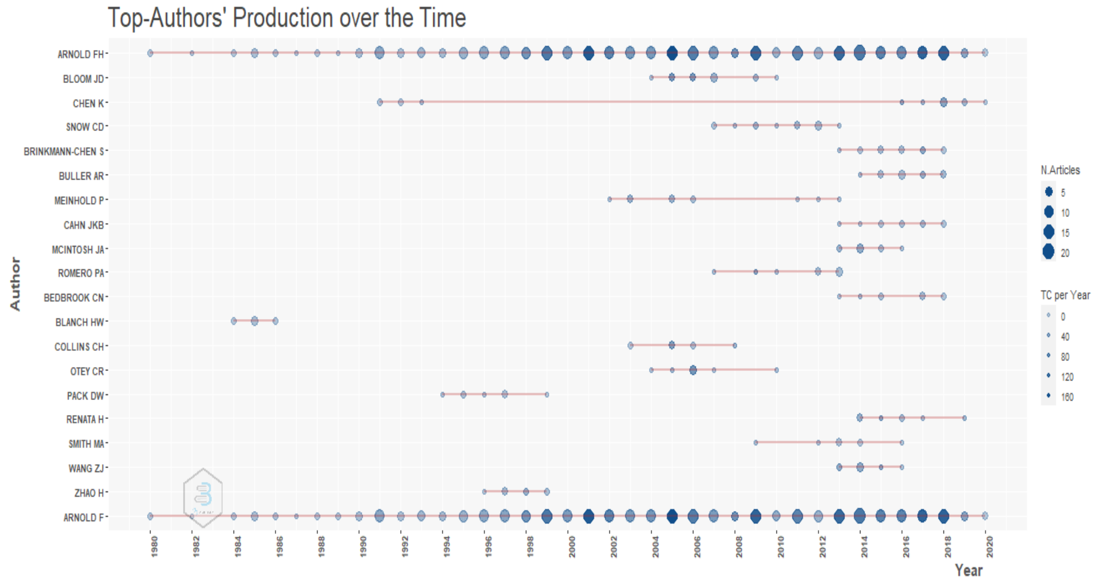


Fig 198: Authors' Production Over Time

6.3.15.6 To find out the channels of communication used by Frances Hamilton Arnold

An analysis of Figure 199 shows that Frances H. Arnold published his works in various journals. The highest number of publications has appeared in the journal *'Proceedings of the National Academy of Sciences in the United States of America'* followed by *Journal of the American Chemical Society'.*

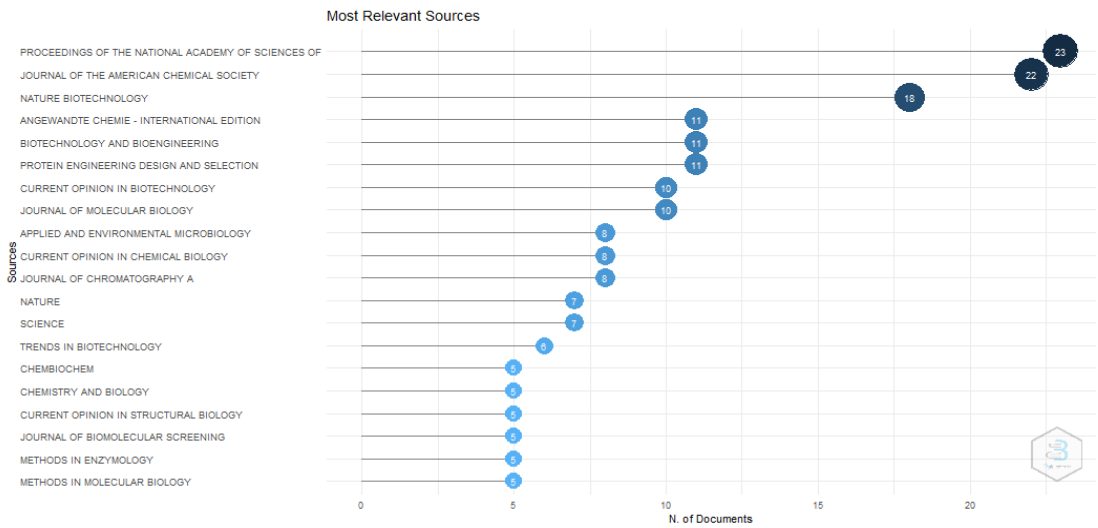


Fig 199: Most Relevant Sources

Table 140: Most Relevant Sources

Sources	Articles
Journal Of the American Chemical Society	29
Proceedings Of the National Academy of Sciences Of The United States	25

Of America	
Nature Biotechnology	18
Angewandte Chemie - International Edition	15
Biotechnology And Bioengineering	12
Current Opinion in Biotechnology	11
Protein Engineering Design and Selection	11
Journal Of Molecular Biology	10
Current Opinion in Chemical Biology	9
Science	9
Applied And Environmental Microbiology	8
Journal Of Chromatography A	8
Acs Catalysis	7
Chembiochem	7
Nature	7
Current Opinion in Structural Biology	6
Trends In Biotechnology	6
Chemistry And Biology	5
Journal Of Biomolecular Screening	5
Methods In Enzymology	5
Methods In Molecular Biology	5
Acs Central Science	4
Acs Synthetic Biology	4
Advanced Synthesis and Catalysis	4
Metabolic Engineering	4
Nature Chemistry	4
Protein Engineering	4
Protein Science	4
Annals Of The New York Academy of Sciences	3
Biochemistry	3
Nucleic Acids Research	3
Accounts Of Chemical Research	2
Acs National Meeting Book of Abstracts	2
Acs Symposium Series	2

Advances In Protein Chemistry	2
Bio/Technology	2
Bioinformatics	2
Biotechnology Progress	2
Chemical Society Reviews	2
Chemistry - A European Journal	2
Current Protocols in Protein Science	2
Faseb Journal	2
Journal Of Bacteriology	2
Journal Of Biological Chemistry	2
Journal Of Organic Chemistry	2
Langmuir	2
Methods	2
Molecular Systems Biology	2
Nature Chemical Biology	2
Nature Communications	2
Nature Methods	2
Plos Computational Biology	2
Plos One	2
The Chemical Engineering Journal	2
Advances In Biochemical Engineering/Biotechnology	1
Aiche Annual Meeting Conference Proceedings	1
Aiche Journal	1
American Chemical Society Polymer Preprints Division of Polymer Chemistry	1
Analytical Chemistry	1
Angewandte Chemie International Edition in English	1
Annual Meeting - American Institute of Chemical Engineers	1
Annual Review of Biophysics and Biomolecular Structure	1
Biochemical And Biophysical Research Communications	1
Biochemical Journal	1
Biochimica Et Biophysica Acta - Molecular and Cell Biology of Lipids	1
Biochimica Et Biophysica Acta - Protein Structure and Molecular	1

Enzymology	
Biochimica Et Biophysica Acta - Proteins and Proteomics	1
Biochimica Et Biophysica Acta (Bba)/Protein Structure and Molecular	1
Biofutur	1
Biology Direct	1
Biophysical Journal	1
Bioprocess Engineering	1
Biotechnology And Applied Biochemistry	1
Biotechnology For Biofuels	1
Biotechnology Letters	1
Biotechnology Techniques	1
Bmc Biology	1
Catalysis Science and Technology	1
Cell Chemical Biology	1
Cell Systems	1
Chembiochem: A European Journal of Chemical Biology	1
Chemcatchem	1
Chemical Communications	1
Chemical Engineering Science	1
Chemical Science	1
Chemistry And Physics of Lipids	1
Chemistry Of Materials	1
Chimia	1
Cold Spring Harbor Symposia on Quantitative Biology	1
Comprehensive Organic Synthesis: Second Edition	1
Coordination Chemistry Reviews	1
Current Opinion in Green and Sustainable Chemistry	1
Current Protocols in Protein Science / Editorial Board John E. Coligan ... [Et Al.]	1
Directed Enzyme Evolution: Advances and Applications	1
Enzyme Catalysis in Organic Synthesis: Second Edition	1
Febs Journal	1
Gateway Energy Conference	1

Genetic Engineering	1
In The Light of Evolution	1
Industrial Bioprocessing	1
Inorganic Chemistry	1
Israel Journal of Chemistry	1
Journal Of Biotechnology	1
Journal Of Cellular Biochemistry	1
Journal Of Hepatology	1
Journal Of Inorganic Biochemistry	1
Journal Of Membrane Science	1
Journal Of Molecular Evolution	1
Journal Of Physical Chemistry	1
Journal Of Solar Energy Engineering Transactions of The Asme	1
Journal Of Visualized Experiments	1
Macromolecules	1
Methods In Molecular Biology (Clifton N.J.)	1
Microbe	1
Microbiology And Molecular Biology Reviews	1
Molecular Biology and Evolution	1
Molecular Microbiology	1
Natural Computing	1
Nature Catalysis	1
Nature Reviews Molecular Cell Biology	1
Nature Structural Biology	1
New Journal of Chemistry	1
Physical Review Letters	1
Plos Biology	1
Polymeric Materials Science and Engineering Proceedings of The Acs Division of Polymeric Materials Science and Engineering	1
Proceedings Of the Annual Meeting - American Section of The International Solar Energy Society	1
Promise Of Science The: Essays and Lectures from Modern Scientific Pioneers	1

Protein Engineering Handbook Volume 1 & Volume 2	1
Proteins: Structure Function and Bioinformatics	1
Quarterly Reviews of Biophysics	1
Supramolecular Science	1
Swe Magazine	1
Synlett	1
Tetrahedron	1
Trends In Biochemical Sciences	1
Vaccine	1

6.3.15.7 Author's performance based on available metrics indicators (Frances Hamilton Arnold)

Table 141: Performance of the Author

SN	Bibliometric & Scientometric Indicator	Value	SN	h-index based indicator	Value
01	Author Impact (2020)	20.95	01	i10-index (i10)	292
02	Total Citation	35985	02	h5-index (h5)	38
03	Audience Factor	289	03	g-Index	160
04	CiteScore (Maximum)	12.4	04	a-Index	208.51
05	ResearchGate Citations	2145	05	h(2)-index	17
06	Microsoft Academic Search Citations	59204	06	hg-index (hg)	127.12
07	Google Scholar Citations	546	07	r-index	145.12
08	Eigenfactor	8.2	08	ar-index (ar)	19.39
09	Crown Indicator	14.359	09	k-index	3.31
10	Mean Citation Score	213.77	10	q^2-index	12.63
11	Mean Normalized Citation Score (MNCS)	144.29	11	f-index	1.06
12	Mean Citation Rate Subfield (MCRS)	122.36	12	m-index	1.58
13	Scientific Talent Pool (STP)	22.33	13	m quotient (m-q)	1.58
14	Microsoft Academic Search Papers (MASP)	375	14	Contemporary-index (Ch)	24.07

15	Google Scholar Papers (GSP)	349	15	Trendh h-index (Th)	0.08
16	Impact per Paper (IPP)	21.8	16	Dynamic h-Type index (Dh-T)	131.93
17	Citation per paper (CPP)	88.10	17	n-index	3.85
18	Citations per Paper self-citation not included (CPPex)	84.22	18	mean h-index	52.5
19	The average number of citations per publication (ANCP)	91.79	19	Normalized h-index	12.07
20	Total and the Average Number of Citations (TNCS)	35985, 91.79	20	Specific-impact s-index (Sis)	35.24
21	Relative Activity Index (RAI)	45.23	21	Seniority independent Hirsch type index (Sih-T)	1
22	Relative Specialization index (RSI)	22.89	22	Hw-index	145.12
23	Relative Citation Rate (RCR)	25.99	23	Hm-index	32
24	Relative Database Citation Potential (RDCP)	66.98	24	Tapered h-index	0.07
25	Journal Acceptance Rate (JAR)	14.23	25	i20-index	272
26	% Self Citations (%SC)	4.40	26	v-index over h	3.45
27	Percentage of papers not cited (%Pnc)	4.01	27	e-index	104.21
28	PR Percentile Ranks (PR)	62.35	28	Multidimensional h-index	52.65
29	LogZ-score (LogZ)	14.678	29	Research Collaboration Index	38.99
30	Innovative Knowledge (IK)	28.76	30	Communities Collaboration Index	29.89
31	Technological Impact (TI)	74.89	31	ch-index	36.97

32	Scientific Talent Pool (STP)	72.98	32	speed s-iCitationndex	42.18
33	Normalized position of publication journal (NPJ)	42	33	π-index	104.21
34	WorldCat Hold (WCH)	581	34	h5-median (h5-m)	23.25
35	Papers in Top 1 (PT1)	15	35	2nd generation citations h index	84
36	Papers in Top 10 (PT10)	75	36	Role basedh-maj-index (Rbhm)	25.04
37	Papers in Top 50 (PT50)	349	37	h2 lower (h2-l)	21
38	High Cited Papers (HCP)	9	38	h2-center (h2-c)	49
39	Papers in First Quartile (Q1)	20	39	h2-upper (h2-u)	58
40	Publications in Thomson Reuters indices (PWoS)	15	40	h3-index	35
41	Number of highly cited publications (NHCP)	124	41	p-index	24.38
42	Publications in top-ranked journals (PTRJ)	33	42	$\bar{h}$-index (Hbar)	101
43	Papers in Collaboration (PCol)	327	43	Mockhm-index (Mhm)	99
44	Share of articles coauthored with another unit (%CoA)	93.70	44	w-index	15.89
45	National Collaboration (NCol)	155	45	b-index	13.24
46	International Collaboration (ICol)	172	46	Generalizedh-index	95.45
47	Scientific Leadership (SL)	24.33	47	Single paperh-index	6
48	Average Authors per Paper	3.81	48	hint-index	5
49	Productivity per Paper	0.30	49	h_{rat}-index	101.99
50	RoG, CAGR, RGR and DT	0.17, (-)0.96, 0.15,	50	πv-index	88.97

		1.05			

6.3.15.8 To assess the scientific collaboration of Frances Hamilton Arnold

Collaboration among researchers is an important aspect as it helps to share expertise and resources among various researchers and also increases the visibility of research

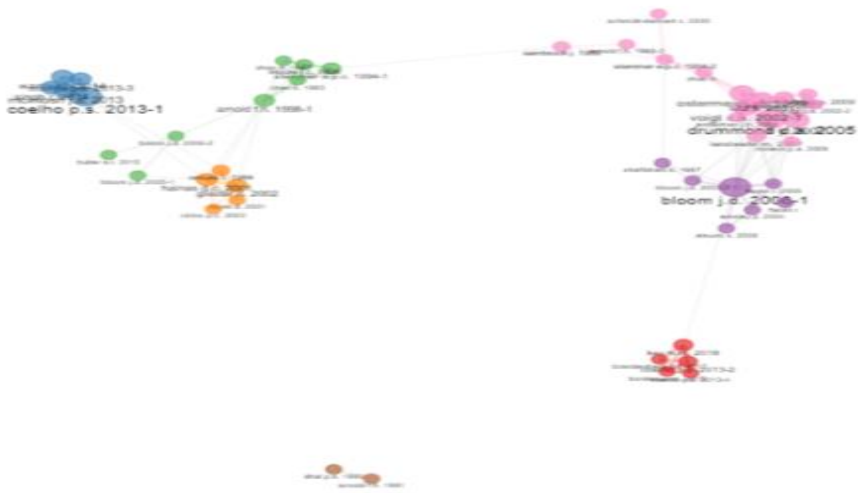


Fig 200: Collaboration Network

works. In the context of this study, we have calculated the degree of collaboration as the ratio of the total number of collaborative publications to the total number of publications. Frances H. Arnold has collaborated with 488 different authors in the conduct and publication of her research work. The author has published only 22 single-authored documents.

6.3.15.8.1 Collaboration Index: The collaboration index is calculated using the formula

$$C.I. = \frac{TotalAuthors \in multi - authoredarticles}{Totalmulti - authoredarticles}$$

In other words, collaboration index is an extension of co-authorship index using the set of multi-authored articles. In the case of Frances H. Arnold, the collaboration index has been calculated at 0.19.

6.3.15.8.2 National and International Collaboration: Frances H. Arnold has published her papers in collaboration with 488 co-authors of mostly hailing from Japan, Germany, and Switzerland. The collaboration map of Frances H. Arnold is produced in figure 201.

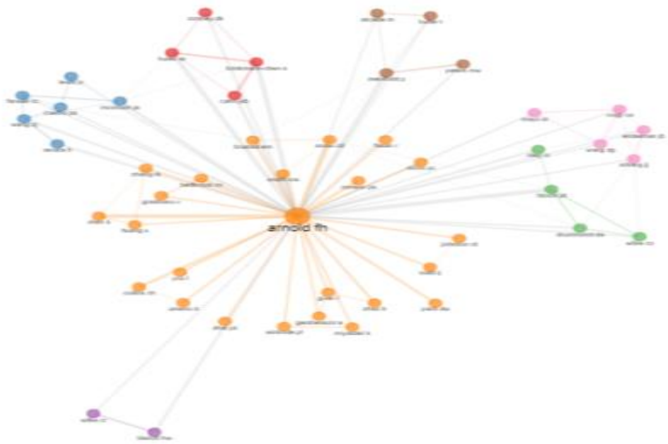


Fig. 201: National and International Collaboration

6.3.15.8.3 Co-authorship index: The co-authorship index is calculated on the basis of the arithmetic mean of the number of co-authors who have authored the documents. This index takes into consideration the appearances of an author. Hence, Author(s) per article index ≤ co-authorship index. The co-authorship index of Frances H. Arnold has been calculated at 5.78.

6.3.15.8.4 Invisible College: The term *invisible college* has been defined by various scholars using different terminologies. As per the traditional definition, the term has been used to mean a group of researchers who were closer, shared common interests, but belonged to different institutions. The modern definition of the term was prescribed by Crane in 1968, where the researcher had defined *invisible college* as an elite group of mutually interacting and productive researchers within a given subject. The different definitions emanating from different sources has resulted in various shortcomings in the way the term is interpreted. To bring in a sense of equality, *invisible college* is defined as a set of informal communication relation between researchers who share common interests. Invisible College can be calculated using data available from co-citation network and document coupling. An analysis of these data shows that Frances H. Arnold had close communication with 354 authors while publishing her documents.

6.3.15.9 To find out the research network of Frances Hamilton Arnold

6.3.15.9.1 Co-authorship: Frances H. Arnold had collaborated with 488 co-authors. On analysis of the co-authorship pattern, it is observed that the author's collaboration with J D Bloom, K Chen, and S Chen-Brinkmann were the highest with the publication of 2755, 1542, and 548 documents. A graphical representation of the co-authorship pattern is shown in figure 202 below.

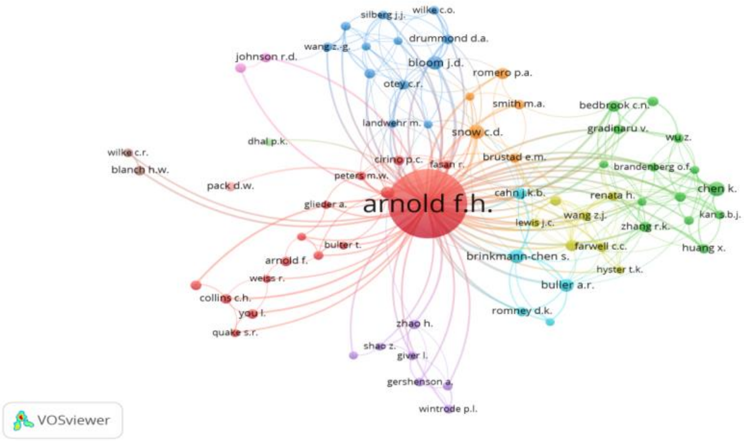
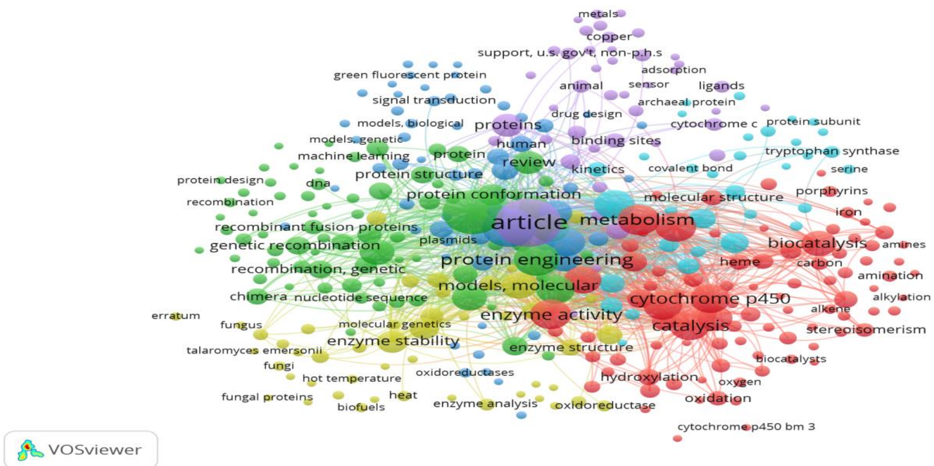


Fig. 202: Co-authorship pattern of Frances Hamilton Arnold

6.3.15.9.2 Keyword occurrences: An analysis of the occurrences of keywords in more than one document reveals the information which have been tabulated below. Many keywords co-occur in the documents. We have considered the top four keywords on the decreasing order of their link strengths.

Table 142: Co-occurrence of Keywords

Key Words	Occurrences	Link Strength
Article	210	3934
priority journal	173	3052
non human	135	2787
protein engineering	96	2014



Fig, 203: Co-occurrence of Keywords

6.3.15.9.3 Citation analysis: Of the 349 papers published by Frances H. Arnold, either as a single author or in collaboration, 335 have been cited by other researchers in their papers. An analysis of the citation network reveals that the article *'Dynamic pattern formation in a vesicle-generating microfluidic device',* published in the journal *Physical Review Letters* during 2001 has been cited 1562 times followed by the article *'A microfabricated fluorescence-activated cell sorter'* published in *Nature Biotechnology* in 1999 which received 817 citations.

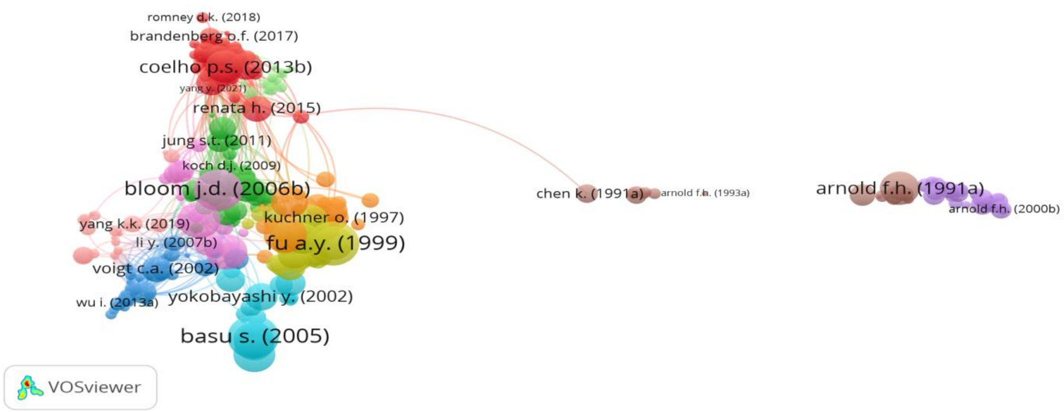


Fig. 204: Citation Analysis

6.3.15.9.4 Bibliographic coupling: Bibliographic coupling is a measure of similarity based upon analysis of the citations and is used to express the similarity between two or more documents. This occurs when two documents refer the same third document in their bibliography. Bibliographic coupling indicates the probability of the existence of two documents that relate to the same document. Two documents are said to be bibliographically coupled if they cite common documents. The bibliographic coupling of Frances H Arnold is presented in figure 205.

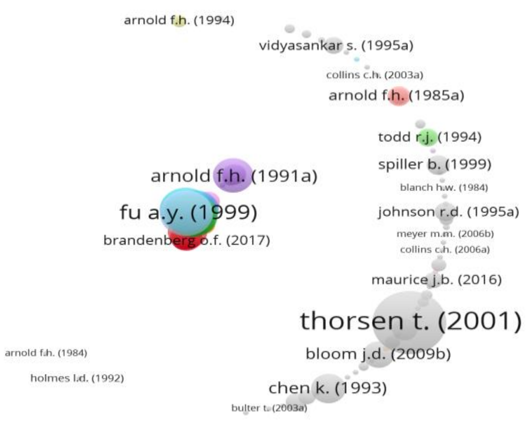


Fig. 205: Bibliographic Coupling

6.3.15.9.5 Co-citation analysis: Co-citation analysis is the process of tracking documents that have been cited together in the source document. When the same documents are cited by several authors, clusters begin to form. These clusters have some common theme. The co-citation network of Frances H Arnold is produced in Fig. 206. Analysis of the figure shows that the articles published by Arnold has been co-cited by 6 clusters, having 76, 54, 40, 12, 11 and 8 items each. There are a total of 11973 links, with a total link strength of 306221.

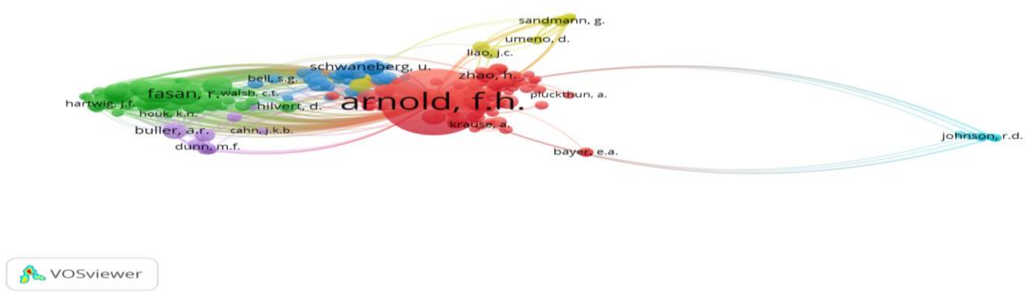


Fig. 206: Co-citation Analysis Pattern

6.3.15.10 To analyze cluster mapping (Frances Hamilton Arnold)

Bibliometric researchers use cluster mapping to bibliometric publications to identify research areas and scientific fields. These methods categorize publications into clusters based on their relations in a citation network. The connections of the nodes in the same cluster are stronger than those in different clusters. Figure 207 shows the coupling map of Frances Hamilton Arnold.

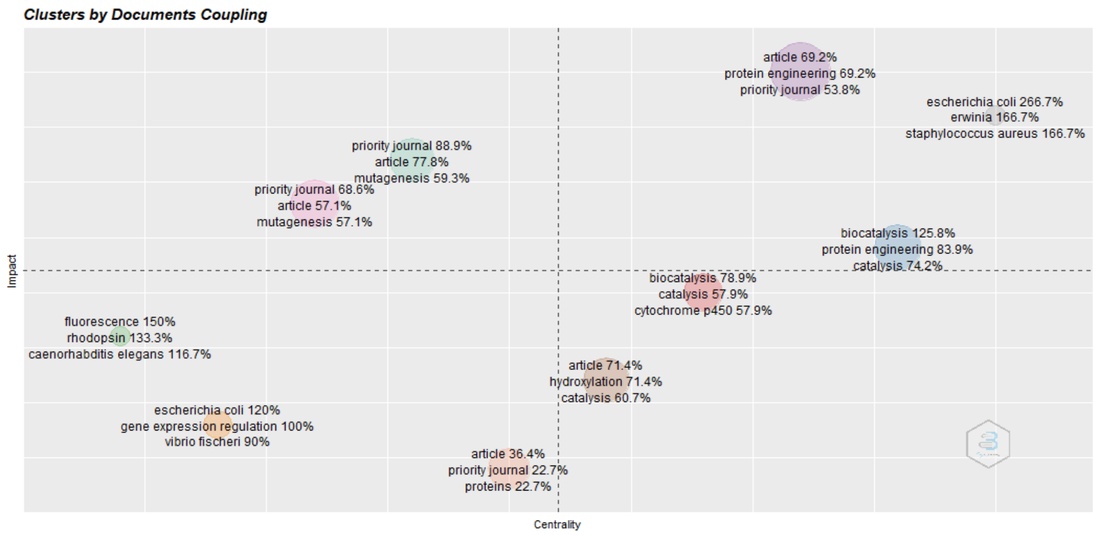


Fig 207: Document Coupling

6.3.15.11 Other Information (Frances Hamilton Arnold)

Table 143: Main Information

Description	**Results**
Timespan	1980:2020
Sources	
Journals, Books, Etc	132
Documents	349
Total	581
Average Years from Publication	16.1
Average Citations Per Documents	94.36
Average Citations Per Year Per Doc	6.363
References	10224
Document Types	
Article	270
Book	1
Book Chapter	7
Conference Paper	15
Editorial	4
Erratum	6
Letter	1
Note	3
Review	38
Short Survey	4
Total	349
Document Contents	
Keywords Plus (Id)	2454
Author's Keywords (De)	399
Authors	
Authors	468
Author Appearances	1416
Authors Of Single-Authored Documents	1
Authors Of Multi-Authored Documents	467
Authors Collaboration	

Single-Authored Documents	22
Documents Per Author	0.746
Authors Per Document	1.34
Co-Authors Per Documents	4.06
Collaboration Index	1.43
H-Index	101
Total Citation	35985 Citations By 20325 Documents

The publication productivity of Frances Hamilton Arnold is consistent throughout the entire productive life, and she has made outstanding contributions in the field of directed evolution to engineer enzymes in the 40 productive years of his life which commenced from 1980. Frances Hamilton Arnold has been consistently active in research despite many administrative responsibilities. She has preferred to work in collaboration and has a high degree of collaboration at institutional, national, and international levels. The high rate of citations received by her papers proves the usefulness and impact that her works have in the field of directed evolution to engineer enzymes. Frances Hamilton Arnold’s research productivity portrays her as an eminently qualified researcher and a role model for the younger generation. Her contributions to the field of science need to be emulated. She is, undoubtedly one of the most outstanding scientists and worthy of receiving the Nobel Prize.

The next and final chapter 7 is concerned with the finding & conclusion made by scholar on the basis of the finding and observation during the study.

CHAPTER - 7
FINDINGS AND CONCLUSION

7.0 Introduction

The Nobel Prize is the highest honour that may be bestowed upon someone working in the fields of chemistry, physics, physiology, international peace, literature, or economics. Any researcher's ultimate goal is to be nominated for the Nobel Prize.

This paper analyzes the researchers who had received the Nobel Prize for Chemistry from 2014 till 2018. The aim of the paper lies in understanding the productivity of the researchers using various scientometrics indicators. While the required information has been sourced from *Scopus*, the data has been analyzed using *Bibliometrix* with *Biblioshiny* package in R.

Nobel Prize in Chemistry is being conferred since the commencement of the award in 1901. Except a few years during the World Wars when the awards were not presented, prizes have been given 111 times to 194 Nobel Laureates. This includes Fredeick Sanger, who was awarded the Nobel Prize during 1958 and 1980. This paper analyses the scientific productivity of all the Nobel Laureates.

While the data has been analyzed using statistical methods as mentioned in previous chapters, visualization of the data has been done using Microsoft Excel and VOS Viewer.

The scope of the paper lies in analyzing the following aspects of individual Nobel Laureate:

(i) Number of scientific works produced and the mode of production;

(ii) Domain wise, Author wise, and Year wise productivity;

(iii) Channels of Communication;

(iv) Bibliometrics and Scintometrics indicator;

(v) Collaboration: National and International; and

(vi) Citation, Bibliometric Coupling, Co-occurrences of keywords, and others.

7.1 Findings

Analyses of the data of all Nobel Laureates in chemistry for 2014 till 2018 have led to the following findings:

7.1.1 General Findings

In terms of the last will left behind by Alfred Nobel, chemistry is one of the disciplines for award of the Nobel Prize. A maximum of three researchers can be nominated for the Nobel Prize in any discipline during any year. The years 2014 till 2018 have witnessed the Nobel Prize in chemistry being awarded to 15 researchers. In 2014, Eric Betzig, Stefan Walter Hell and William Esco Moerner received the Nobel Prize in chemistry for their works on developing super-resolved fluorescence microscopy. Tomas Lindahl, Paul Lawrence Modrich received the Nobel Prize in 2015 for their works on mechanistic studies of DNA repair, while Jean-Pierre Sauvage, Sir James Fraser Stoddart, and Bernard Lucas Feringa was awarded the Nobel Prize in 2016 for their works on designing and synthesizing molecular machines. The Nobel Committee was motivated to award the Nobel Prize in Chemistry for 2017 to Jacques Dubochet, Joachim Frank, and Richard Henderson for their works on developing cryo-electron microscopy that has revolutionized the field of determination of the structure of biomolecules in solution using high resolution images. With Frances Hamilton Arnold being conferred one half of the Nobel Prize in 2018 for her works on the directed evolution of enzymes, the other half was shared by George Pearson Smith and Sir Gregory Paul Winter for their works on phage display of peptides and antibodies.

7.1.2 Analyzing Productivity

The year-wise productivity of the researchers who have been awarded the Nobel Prize in Chemistry has been tabulated in Table 144.

Table 144: Year-wise Productivity of Nobel Laureates

Author	Year						Total
	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2011-2020	
Eric Betzig	0	0	8	28	22	79	137
Stefan Walter Hell	0	0	2	73	194	176	445
William Esco Moerner	0	3	55	109	150	135	452
Tomas Robert Lindahl	17	56	47	68	41	10	239
Paul Lawrence Modrich	12	10	46	61	45	14	188
Aziz Sancar	0	10	81	141	101	81	414
Jean Pierre Sauvage	4	31	78	183	162	53	511

James Fraser Stoddart	13	54	108	291	334	287	1087
Bernard Lucas Feringa	0	8	42	170	344	291	855
Jacques Dubochet	0	17	34	38	48	6	143
Jaochim Frank	9	15	75	76	125	88	388
Richard Henderson	5	26	29	33	25	30	148
Frances Hamilton Arnold	0	2	18	94	118	117	349
George Pearson Smith	0	12	10	16	10	7	55
Gregory Paul Winter	0	4	45	100	31	23	203

A look at Table 144 indicates that while James Fraser Stoddart has published the maximum number of scientific documents, George Pearson Smith has the least number of publications to his credit. All the Nobel Laureates commenced their productive life in the late 1960s and have continued to contribute till 2020.

7.1.3 Type of Documents

The researchers have published their scientific documents in various ways, be it in the form of articles, books, book chapters, conference papers, and the like. Table 145 is a tabulation of the mode used by the Nobel Laureates to publish their works. While most of the works are in the form of articles (83.76%), scientific documents have also been published in the form of books, editorials, conference papers, notes, reviews, etc. This shows that the Nobel Laureates find ease in producing articles to disseminate their knowledge.

Table 145: Type of Documents

Name	Article	Book	Book Chapter	Conference Paper	Data Paper	Editorial	Erratum	Letter	Lectures	Note	Review	Short Survey	Total
Eric Betzig	100	0	0	24	0	0	3	0	0	1	9	0	137
Stefan W. Hell	371	0	0	5	0	3	3	0	0	2	13	5	445
William	27	1	4	13	0	2	5	3	0	5	20	3	452

E. Moerner	0			9									
Tomas Lindahl	198	0	0	9	0	4	1	3	0	0	23	0	238
Paul L. Modrich	170	0	0	3	0	0	1	0	0	0	11	3	188
Aziz Sancar	348	0	4	3	0	2	8	2	0	6	29	12	414
Jean-Pierre Sauvage	454	3	8	7	0	5	1	3	0	1	13	10	505
Sir J. Fraser Stoddart	978	3	12	35	0	6	5	4	0	4	34	6	1087
Bernard L. Feringa	753	1	12	25	0	3	4	11	0	4	32	10	855
Jacques Dubochet	117	1	0	8	0	1	2	4	0	0	8	2	143
Joachim Frank	298	4	8	32	0	7	5	3	0	1	27	3	388
Richard Henderson	117	0	2	8	0	1	1	1	0	3	14	1	148
Frances Arnold	270	1	7	15	0	4	6	1	0	3	38	4	349
George P. Smith	45	0	1	0	0	2	1	0	0	0	6	1	55
Sir Gregory P. Winter	172	0	1	6	0	5	3	2	0	4	9	1	203

7.1.4 Type of Authorship

The scientific publications that have been published by the Nobel Laureates were either single-authored or multiple-authored. The Nobel Laureates are engaged in several other assignments making it difficult for them to devote time to writing and publishing scientific papers. Though they do contribute by way of producing single-authored documents, in majority of the cases, they accept help from the co-authors. Table 146 shows the percentage of single-authored documents published by the Nobel Laureates. Analysis of the table indicates that for all the Nobel Laureates, except George Pearson Smith, the percentages of single authored documents are very less. G P Smith has the highest single-authored document at 30.91%, while Bernard Lucas Feringa has the lowest percentage of single-authored documents at 2.46% followed by James Fraser Stoddart at 2.76%.

Table 146: Nature of publications by the Nobel Laureates

Author	Total Documents	Single Authored	% Of Single Authored Document
Eric Betzig	137	20	14.6
Stefan Walter Hell	445	28	6.3
William Esco Moerner	452	38	8.41
Tomas Robert Lindahl	239	35	14.65
Paul Lawrence Modrich	188	14	7.45
Aziz Sancar	414	20	4.84
Jean Pierre Sauvage	511	18	3.53
James Fraser Stoddart	1087	30	2.76
Bernard Lucas Feringa	855	21	2.46
Jacques Dubochet	143	15	10.49
Jaochim Frank	388	58	14.95
Richard Henderson	148	20	13.52
Frances Hamilton Arnold	349	22	6.31
George Pearson Smith	55	17	30.91
Gregory Paul Winter	203	10	4.93

7.1.5 Collaboration Index

As has been observed in the previous sections, the Nobel Laureates whose scientometric portraits have been drawn in this thesis have published their documents with several co-authors. To put it in a different language, the Nobel Laureates had collaborated with several authors to publish their scientific documents. This may have been necessitated due to administrative exigencies that they might have been subjected to. Table 147 shows the collaboration index of the Nobel Laureates. On analyzing the data, it is observed that while George Pearson Smith had collaborated with 69 co-authors (Collaboration index = 2.87), James Fraser Stoddart had collaborated with 1429 co-authors (Collaboration index = 1.24). Table 147 further shows that Gregory Paul Winter has the lowest collaboration index at 0.20, while the highest collaboration index has been observed in case of Eric Betzig whose collaboration index has been calculated at 3.99. Most of the other Nobel Laureates has collaboration index more than 1, while the collaboration index of a few Nobel Laureates has been calculated at more than 2. This is indicative of the fact that the Nobel Laureates whose works have been analyzed had a high belief in multi-authorship.

Table 147: Collaboration Index of Nobel Laureates

Author	Number Of Co-Authors	Collaboration Index
Eric Betzig	456	3.99
Stefan Walter Hell	848	1.97
William Esco Moerner	923	2.22
Tomas Robert Lindahl	405	2.03
Paul Lawrence Modrich	359	2.26
Aziz Sancar	616	1.52
Jean Pierre Sauvage	534	1.13
James Fraser Stoddart	1429	1.24
Bernard Lucas Feringa	1065	1.09
Jacques Dubochet	270	2.16
Jaochim Frank	631	1.91
Richard Henderson	272	2.20
Frances Hamilton Arnold	482	1.43
George Pearson Smith	69	2.87

Gregory Paul Winter	420	0.20

7.1.6 Domains

The domains in which the researchers who have been conferred the Nobel Prize have published their scientific documents have been tabulated in Table 148. Despite the fact that the researchers have done commendable work to enhance the scope of chemistry as a science, they have also published their scientific works in other domains. This shows the relation that chemistry has with other subjects, which has been discussed in detail in the previous sections.

Table 148: Analysis of domains of Nobel Laureates

Name	Eric Betzig	Stefan W. Hell	William E. Moerner	Tomas Lindahl	Paul L. Modrich	Aziz Sancar	Jean-Pierre Sauvage	Sir J. Fraser Stoddart	Bernard L. Feringa	Jacques Dubochet	Joachim Frank	Richard Henderson	Frances Arnold	George P. Smith	Sir Gregory P. Winter
Applied Physics	29	88	109	0	0	0	0	0	0	0	0	0	0	0	0
Cell Biology	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microscopy	30	111	105	0	0	0	0	0	0	0	0	0	0	0	0
Molecular Biology	30	0	0	0	0	0	0	0	0	41	0	43	0	0	68
Biophysics	0	95	114	0	0	82	0	0	0	0	100	30	0	0	0
Nanobiophotonics	0	151	0	0	0	0	0	0	0	0	0	0	0	0	0
Chemistry	0	0	127	0	0	0	0	0	0	0	0	0	0	0	0
Biochemistry	0	0	0	40	61	96	0	0	0	33	95	0	69	4	27
Dna	0	0	0	0	38	15	0	0	0	0	0	0	0	0	0

Mismatch						4									
Dna Repair	0	0	0	78	46	0	0	0	0	0	0	0	0	0	0
Microbiology	0	0	0	0	43	82	0	0	0	0	0	0	0	9	0
Genetics Of Cancer	0	0	0	79	0	0	0	0	0	0	0	0	0	0	0
Organic Chemistry	0	0	0	39	0	0	0	223	184	0	0	0	0	0	0
Catalysis	0	0	0	0	0	0	0	0	173	0	0	0	0	0	0
Material Chemistry	0	0	0	0	0	0	0	0	162	0	0	0	0	0	0
Molecular Nanotechnology	0	0	0	0	0	0	0	0	286	0	0	0	0	0	0
Molecular Science	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0
Applied Chemistry	0	0	0	0	0	0	88	263	0	0	0	0	0	0	0
Nanotechnology	0	0	0	0	0	0	0	238	0	0	0	0	0	0	0
Stereo Chemistry	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0
Supramolecular Chemistry	0	0	0	0	0	0	0	303	0	0	0	0	0	0	0
Coordination Chemistry	0	0	0	0	0	0	110	0	0	0	0	0	0	0	0
Structural Chemistry	0	0	0	0	0	0	117	0	0	0	0	0	0	0	0
Supra	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0

Molecular Chemistry							7								
Bioengineering	0	0	0	0	0	0	0	0	0	28	0	0	89	0	0
Cryo Microscopy	0	0	0	0	0	0	0	0	0	41	0	45	0	0	0
Biosciences	0	0	0	0	0	0	0	0	0	0	96	30	0	0	0
Chemical Engineering	0	0	0	0	0	0	0	0	0	0	97	0	128	0	0
Genomics	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0
Protein Engineering	0	0	0	0	0	0	0	0	0	0	0	0	0	10	77
Biotechnology	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0
Antibody Technology	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31
Bioinformatics	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0

The maximum number of documents have been published in the field of organic chemistry (446, 7.99%) followed by biochemistry (425, 7.61%), and biophysics (421, 7.54%). The lowest numbers of documents were published in the domain of biotechnology (15, 0.27%), followed by genomics (17, 0.3%) and antibody technology (31, 0.56%).

7.1.7 Analyzing the Scientometric Indices

The data extracted from Scopus has been used to calculate various scientometric indices of the Nobel Laureates. A synopsis of the findings has been mentioned below for referral.

- Author Impact: - Author impact measures the number of publications authored by any researcher and the number of times these publications have been cited by other researchers. All the authors whose works have been analyzed have author impact of more than 10. This is indicative of the fact that most of their works have been cited by other researchers, which also goes to show the popularity of their works. Both James Fraser Stoddart ad Aziz Sancar have author impact of 98.56.
- Total Citation: - Total citation is a count of the number of times the document published by any author is cited by successive researchers. Analysis of the data shows that all the authors under review had a large count of citation. This indicates that they could inspire the future generation of scientists to continue their works. Sir James Fraser Stoddart's works have been cited more than 1 lakh times showing the popularity of the domain of his research. This also shows the reason for the high author impact.
- Audience Factor: - Baring a few researchers, calculation done with data sourced from Scopus shows that most of the authors had an audience factor of more than 100.The figures show that the documents published by the authors have received numerous views and citations from later researchers showing the popularity of their works.
- CiteScore: CiteScore of a journal is calculated on the basis of the citations that the journal has received in one year compared to the number of documents published in the previous three years. It is calculated as per the documents indexed by Scopus. A high citeScore indicates high value of the journal. Other than Richard Henderson, all the authors who have been studied had a very high citeScore, signifying that they had published their documents in the top 100 journals.
- h-Index: - Analysis of the h-Index of the Nobel Laureates in Chemistry whose works have formed a part of this study shows that the Nobel Laureates have a high value of h-Index. With the median h-Index being calculated at 91, almost all the Nobel Laureates have the values of h-Index near the median. This shows that a vast majority of the documents published by the Nobel Laureates have been cited various times by several researchers.

Table 149: Analysis of h-Index of Nobel Laureates

Author	h-Index
Eric Betzig	61
Stefan Walter Hell	102
William Esco Moerner	78
Tomas Robert Lindahl	99
Paul Lawrence Modrich	79
Aziz Sancar	107
Jean Pierre Sauvage	99
James Fraser Stoddart	139
Bernard Lucas Feringa	120
Jacques Dubochet	56
Jaochim Frank	91
Richard Henderson	31
Frances Hamilton Arnold	101
George Pearson Smith	29
Gregory Paul Winter	86

- Self-citation: - Self citation is related to citing one's own document in future documents. Self-citation increases the number of citations and impacts the value of h-Index. Analysis of data from Scopus reveals that William Esco Moerner has a self-citation of more than 99%, while the percentage of self-citation of George Pearson Smith has been calculated at little above 1%. No doubt, Moerner has an h-Index of 78 compared to 29 in case of George Pearson Smith.
- Technological Impact: Analysis of the data shows that the technological impact of all the Nobel Laureates is more than 20 which shows the usefulness of their works in the benefit of mankind.
- Relative Specialization Index: A high value of the relative specialization index is indicative of the level of specialization importance the Nobel Laureates had over other researchers of the era.
- Mean Citation Score: Analysis of the data show that all the Nobel Laureates considered to form a part of this study had a significant value of mean citation score. As explained above, the documents published by these authors have

been read and cited by future researchers. The importance of their work can be gauged from this data.

- Crown Indicator: Crown indicator is a bibliometric indicator that is used to assess the research performance of any scientist. The aim of this indicator lies in normalizing citation counts for differences among the domains of knowledge. The Nobel Laureates whose productivity has been analyzed has a high value of this indicator.
- Papers in Top 1: This indicator shows the number of documents that have been published in the leading scientific journal. The number of documents published in top journals has a direct positive correlation with the status of the author. All the Nobel Laureates who have been studied have had a significant percentage of their works published in the topmost scientific journal, which shows the importance of their work in benefitting humans.
- Highly Cited Publication: Analysis of data shows wide variation in the number of highly cited publications among the Nobel Laureates. While some of the Nobel Laureates have significantly large number of highly cited publications, majority of the Nobel Laureates have a low number of highly cited publications. This is due to the fact that documents published in languages other than in English or published in regional scientific journals fail to attract attention of future researchers.
- Relative Growth Rate: Relative growth rate is a measure of the change in the number of documents published over a specific period of time. This study specifies the time between the commencements of productive life till 2019. The relative growth rate of the Nobel Laureates corresponds to the best rates among the researchers.
- Doubling Time: Doubling time is defined as the time required to double the productivity as per exponential growth. Analysis of the data shows that the doubling time is very low, signifying the level of commitment of the Nobel Laureates for research.

Values of the various scientometrics indicators show that all Nobel Laureates had maintained a consistent productivity during the period of their productive life. All the Nobel Laureates worked in collaboration in various degrees. The mode of publication of the scientific work has been through articles, though other modes like boo, book chapters, conference papers, editorials, erratum, letters, notes, reviews, short surveys have also been used.

Regarding the number of citations, it is observed that the articles published by the Nobel Laureates have been cited by later researchers in their works. The Nobel Laureates have had a huge impact on the future generations and their works have truly enriched the scope and knowledge of chemistry.

Analysis of the Hirsch Index also indicates the high citations received by the scientific production of the authors. Several of the published papers have been published in top scientific journals and have also been cited by future researchers.

7.3 Road ahead for future research

The researchers can choose the journal to conduct the scientometric study by using different criteria based on their statement of the problem. They can use different advanced software beside this Excel, Bibliometrix-R, and VosViewer to carry out advanced level data analysis.

- For domain analysis, there are lots of categorization developed by every journal or scholarly database, its hard to select paper in this category. So there is scope to develop a single standard domain category for researcher.
- There are lots of software for metric analysis, there is scope to develop a single software for this.
- For old researcher/scientists, in respect of present indicator, researcher have scope to analysis of his/her scientific contribution of unsung researcher/scientists.
- There is scope to develop new indicator.
- Metric analysis with the help of Machine Learning and Artificial Analysis, its produce better result, so new researcher has scope to develop new tool for this.
- There are other subject field are not study yet so researcher have scope to study in different subject field and domain.

7.4 Conclusion

The scientometric study is an open area of research that is applicable for mapping and analyzing any subject field by author, publisher, institution & country using numbers of scientometric indicators. The present study was an attempt to measure the scholarly communications of Nobel laureates of chemistry. However, a study is guaranteed to look into the different aspects of study such as comparative analysis of academic professionals of Chemistry, comparative study of chemistry Nobel laureates.

APPENDIX – A

DOCUMENT TYPES

SN	Name	Article	Book	Book Chapter	Conference Paper	Data Paper	Editorial	Erratum	Letter	Lectures	Note	Review	Short Survey	Total
1	Eric Betzig	100	0	0	24	0	0	3	0	0	1	9	0	137
2	Stefan W. Hell	371	0	0	5	0	3	3	0	0	2	13	5	445
3	William E. Moerner	270	1	4	139	0	2	5	3	0	5	20	3	452
4	Tomas Lindahl	198	0	0	9	0	4	1	3	0	0	23	0	238
5	Paul L. Modrich	170	0	0	3	0	0	1	0	0	0	11	3	188
6	Aziz Sancar	348	0	4	3	0	2	8	2	0	6	29	12	414
7	Jean-Pierre Sauvage	454	3	8	7	0	5	1	3	0	1	13	10	505
8	Sir J. Fraser Stoddart	978	3	12	35	0	6	5	4	0	4	34	6	1087
9	Bernard L. Feringa	753	1	12	25	0	3	4	11	0	4	32	10	855
10	Jacques Dubochet	117	1	0	8	0	1	2	4	0	0	8	2	143
11	Joachim Frank	298	4	8	32	0	7	5	3	0	1	27	3	388
12	Richard Henderson	117	0	2	8	0	1	1	1	0	3	14	1	148
13	Frances Arnold	270	1	7	15	0	4	6	1	0	3	38	4	349
14	George P. Smith	45	0	1	0	0	2	1	0	0	0	6	1	55
15	Sir Gregory P. Winter	172	0	1	6	0	5	3	2	0	4	9	1	203

APPENDIX – B

DOMAIN WISE ANALYSIS

Name	Eric Betzig	Stefan W. Hell	William E. Moerner	Tomas Lindahl	Paul L. Modrich	Aziz Sancar	Jean-Pierre Sauvage	Sir J. Fraser Stoddart	Bernard L. Feringa	Jacques Dubochet	Joachim Frank	Richard Henderson	Frances Arnold	George P. Smith	Sir Gregory P. Winter
APPLIED PHYSICS	29	88	109	0	0	0	0	0	0	0	0	0	0	0	0
CELL BIOLOGY	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MICROSCOPY	30	111	105	0	0	0	0	0	0	0	0	0	0	0	0
MOLECULAR BIOLOGY	30	0	0	0	0	0	0	0	0	41	0	43	0	0	68
BIOPHYSICS	0	95	114	0	0	82	0	0	0	0	100	30	0	0	0
NANOBIOPHOTONICS	0	151	0	0	0	0	0	0	0	0	0	0	0	0	0
CHEMISTRY	0	0	127	0	0	0	0	0	0	0	0	0	0	0	0
BIOCHEMISTRY	0	0	0	40	61	96	0	0	0	33	95	0	69	4	27
DNA MISMATCH	0	0	0	0	38	154	0	0	0	0	0	0	0	0	0
DNA REPAIR	0	0	0	78	46	0	0	0	0	0	0	0	0	0	0
MICROBIOLOGY	0	0	0	0	43	82	0	0	0	0	0	0	0	9	0
GENETICS OF CANCER	0	0	0	79	0	0	0	0	0	0	0	0	0	0	0
ORGANIC CHEMISTRY	0	0	0	39	0	0	0	223	184	0	0	0	0	0	0
CATALYSIS	0	0	0	0	0	0	0	0	173	0	0	0	0	0	0
MATERIAL CHEMISTRY	0	0	0	0	0	0	0	0	162	0	0	0	0	0	0
MOLECULAR NANOTECHNOLOGY	0	0	0	0	0	0	0	0	286	0	0	0	0	0	0
MOLECULAR SCIENCE	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0
APPLIED CHEMISTRY	0	0	0	0	0	0	88	263	0	0	0	0	0	0	0
NANOTECHNOLOGY	0	0	0	0	0	0	0	238	0	0	0	0	0	0	0
STEREO CHEMISTRY	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0
SUPRAMOLECULAR CHEMISTRY	0	0	0	0	0	0	0	303	0	0	0	0	0	0	0
COORDINATION	0	0	0	0	0	0	110	0	0	0	0	0	0	0	0

CHEMISTRY															
STRUCTURAL CHEMISTRY	0	0	0	0	0	0	117	0	0	0	0	0	0	0	0
SUPRA MOLECULAR CHEMISTRY	0	0	0	0	0	0	177	0	0	0	0	0	0	0	0
BIOENGINEERING	0	0	0	0	0	0	0	0	0	28	0	0	89	0	0
CRYO MICROSCOPY	0	0	0	0	0	0	0	0	0	41	0	45	0	0	0
BIOSCIENCES	0	0	0	0	0	0	0	0	0	0	96	30	0	0	0
CHEMICAL ENGINEERING	0	0	0	0	0	0	0	0	0	0	97	0	128	0	0
GENOMICS	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0
PROTEIN ENGINEERING	0	0	0	0	0	0	0	0	0	0	0	0	0	10	77
BIOTECHNOLOG Y	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0
ANTIBODY TECHNOLOGY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31
BIOINFORMATICS	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0

APPENDIX – C

AUTHORSHIP PATTERN

Name	1 AUTHOR	2 AUTHORS	3 AUTHORS	4 AUTHORS	5 TO 10 AUTHORS	11 TO 15 AUTHORS	16 TO 20 AUTHORS	21 TO 25 AUTHORS	26 TO 30 AUTHORS	31 TO 40 AUTHORS	41 TO 50 AUTHORS	51 TO 60 AUTHORS	61 TO 70 AUTHORS	71 TO 80 AUTHORS	81 TO 90 AUTHORS	TOTAL
Eric Betzig	20	7	12	11	63	8	12	1	2	1	0	0	0	0	0	137
Stefan W. Hell	28	50	62	68	188	18	25	3	2	1	0	0	0	0	0	445
William E. Moerner	38	64	68	148	120	5	4	2	1	1	0	0	0	0	1	452
Tomas Lindahl	47	75	48	28	10	5	0	5	0	0	0	0	0	0	0	238
Paul L. Modrich	14	34	41	27	58	7	6	1	0	0	0	0	0	0	0	188
Aziz Sancar	20	108	55	115	105	5	3	2	0	0	0	0	0	0	1	414
Jean-Pierre Sauvage	18	42	133	105	201	6	5	0	1	0	0	0	0	0	0	505
Sir J. Fraser Stoddart	30	100	119	113	588	73	60	3	1	0	0	0	0	0	0	1087
Bernard L. Feringa	21	86	132	172	421	20	3	0	0	0	0	0	0	0	0	855
Jacques Dubochet	15	12	26	24	62	4	0	0	0	0	0	0	0	0	0	143
Joachim Frank	58	53	51	103	100	10	7	3	0	2	1	0	0	0	0	388
Richard Henderson	23	41	42	19	23	0	0	0	0	0	0	0	0	0	0	148
Frances Arnold	22	72	76	53	120	5	1	0	0	0	0	0	0	0	0	349
George P. Smith	17	18	9	9	2	0	0	0	0	0	0	0	0	0	0	55
Sir Gregory P. Winter	10	37	34	33	76	4	8	0	0	0	1	0	0	0	0	203

APPENDIX – D

SCIENTIFIC COMMUNICATION

SN	Name	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2010-2020
1	Eric Betzig	0	0	8	28	22	79
2	Stefan W. Hell	0	0	2	73	194	176
3	William E. Moerner	0	3	55	109	150	135
4	Tomas Lindahl	17	56	47	68	41	10
5	Paul L. Modrich	0	22	46	61	45	14
6	Aziz Sancar	0	10	81	141	101	81
7	Jean-Pierre Sauvage	4	31	78	183	162	53
8	Sir J. Fraser Stoddart	13	54	108	291	334	287
9	Bernard L. Feringa	0	8	42	170	344	291
10	Jacques Dubochet	0	17	34	38	48	6
11	Joachim Frank	2	22	75	76	125	88
12	Richard Henderson	5	26	29	33	25	30
13	Frances Arnold	0	0	18	94	118	117
14	George P. Smith	0	12	10	16	10	7
15	Sir Gregory P. Winter	0	4	45	100	31	23

APPENDIX – E

YEAR-WISE SCIENTIFIC COMMUNICATION

Year	Robert Eric Betzig	Stefan Walter Hell	William Esco Moerner	Tomas Lindahl	Paul L. Modrich	Aziz Sancar	Jean-Pierre Sauvage	Sir J. Fraser Stoddart	Bernard L. Feringa	Jacques Dubochet	Joachim Frank	Richard Henderson	Frances Arnold	George P. Smith	Sir Gregory P. Winter
1961	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1962	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
1963	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
1965	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1966	0	0	0	4	0	0	0	5	0	0	0	0	0	0	0
1967	0	0	0	5	0	0	0	1	0	0	0	1	0	0	0
1968	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0
1969	0	0	0	2	0	0	2	4	0	0	1	0	0	0	0
1970	0	0	0	0	1	0	2	0	0	0	0	2	0	0	0
1971	0	0	0	4	1	1	1	1	0	1	0	1	0	0	0
1972	0	0	0	4	1	0	1	0	0	1	2	5	0	1	0
1973	0	0	0	5	3	0	4	2	0	4	2	2	0	2	0
1974	0	0	3	7	1	0	1	10	0	1	1	2	0	3	0
1975	0	0	0	5	2	0	5	7	0	1	6	3	0	0	0
1976	0	0	0	6	2	0	15	6	0	2	3	0	0	1	0
1977	0	0	0	5	2	0	3	8	0	0	1	3	0	2	2
1978	0	0	0	8	1	3	1	7	0	2	3	3	0	2	1
1979	0	0	0	7	3	4	1	7	0	2	2	2	0	0	0
1980	0	0	0	5	4	2	2	1	0	3	3	5	2	1	1
1981	0	0	3	4	7	5	0	8	2	4	6	0	0	1	6
1982	0	0	3	9	4	4	5	11	1	4	10	8	1	0	6
1983	0	0	6	4	7	3	6	4	2	6	3	1	0	0	4
1984	0	0	9	4	2	6	3	9	1	5	10	4	2	1	5
1985	0	0	7	5	3	7	8	12	3	1	9	3	4	1	9
1986	4	0	3	3	2	9	10	3	4	6	9	2	2	0	5
1987	1	0	8	3	5	11	9	16	3	1	5	1	1	1	1
1988	2	0	3	5	5	8	8	13	7	3	11	2	2	4	7
1989	0	0	6	3	7	12	12	15	6	2	7	1	1	1	8
1990	0	0	7	7	2	15	18	1	9	2	5	7	4	1	5
1991	1	0	9	7	1	15	18	19	10	4	3	3	11	1	8
1992	5	0	8	8	1	18	10	14	15	2	9	2	5	0	17
1993	5	0	13	7	9	17	16	20	10	2	5	6	7	5	15
1994	10	10	22	8	3	15	21	18	20	4	7	1	5	3	13
1995	2	15	6	5	8	19	6	17	15	7	10	6	8	0	5

1996	2	8	9	7	8	17	25	39	16	6	7	3	11	3	12
1997	0	6	12	9	10	16	21	34	24	2	6	3	13	1	12
1998	2	13	13	4	10	6	17	44	15	6	8	1	8	1	9
1999	0	5	8	5	7	11	25	24	22	3	9	4	14	1	9
2000	0	11	8	8	4	7	19	33	21	2	10	4	12	1	3
2001	0	14	8	6	5	4	13	19	22	7	12	1	14	1	4
2002	0	13	12	6	2	10	11	26	19	4	12	6	11	2	3
2003	0	11	16	3	4	12	23	21	27	6	14	3	13	0	1
2004	0	6	13	10	5	14	17	34	26	3	10	1	11	1	7
2005	7	10	17	5	5	13	15	36	41	7	10	3	14	1	3
2006	2	22	11	3	8	11	16	34	37	8	23	3	14	1	6
2007	2	28	21	5	3	9	25	34	33	3	16	3	12	0	2
2008	7	27	10	0	4	9	11	26	52	5	10	1	5	0	2
2009	2	29	21	3	4	10	17	44	37	4	9	3	14	1	3
2010	2	31	18	0	5	9	12	34	44	1	8	1	6	3	0
2011	6	30	19	1	4	12	19	30	39	1	12	3	14	0	1
2012	5	19	15	3		8	12	44	27	1	5	3	9	0	2
2013	5	20	15	1	2	8	5	36	42	0	7	5	14	0	0
2014	10	17	20	0	2	7	9	32	40	0	10	2	19	2	0
2015	17	26	22	0	1	8	1	30	26	0	9	6	12	2	2
2016	12	14	6	4	2	8	2	17	33	1	9	2	11	0	0
2017	8	18	8	1	1	13	2	20	36	1	11	2	13	2	0
2018	4	13	7	0	1	5	2	12	25	2	13	5	15	0	0
2019	9	13	10	0	0	8	1	24	20	0	5	2	5	1	2
2020	3	3	9	0	1	4		11	2	0	7	0	3	0	1
Total	**137**	**445**	**452**	**238**	**188**	**414**	**515**	**1087**	**855**	**143**	**388**	**148**	**349**	**55**	**203**

APPENDIX – F

AUTHOR PERFORMANCE BASED ON AVAILABLE BIBLIOMETRIC & SCIENTOMETRIC INDICATOR

Name	Robert Eric Betzig	Stefan Walter Hell	William Esco Moerner.	Tomas Lindahl	Paul L. Modrich	Aziz Sancar	Jean-Pierre Sauvage	Sir J. Fraser Stoddart	Bernard L. Feringa	Jacques Dubochet	Joachim Frank	Richard Henderson	Frances Arnold	George P. Smith	Sir Gregory P. Winter
Author Impact (2020)	25.21	58.23	76.86	32.35	23.79	98.56	24.68	98.56	45.98	34.85	18.9	14.28	20.95	28	23.4
Total Citation	24415	255670	29150	38267	22608	38672	38267	100452	61099	12344	29448	3347	35985	10281	31887
Audience Factor	21.27	34.85	182	36.85	187	214.9	45	135.8	203	148	135.8	78	289	1598	245.8
CiteScore (Maximum)	46.8	95.8	57.8	56.9	50.1	50.1	96.9	21.7	56.9	11.3	5.9	4.5	12.4	46.8	56.9
Research Gate Citations	1905	8323	5	12349	3786	25298	20248	50024	25346	35	23	489	2145	135	231
Microsoft Academic Search Citations	35345	40525	14590	55130	36508	56659	44353	475	45797	19389	47522	32163	59204	981	18379
Google Scholar Citations	13145	52	22350	45160	37859	48972	15248	102	32620	922	10245	54	546	2554	16894
Eigenfactor	7.789	65.9	5.78	12.93	82.6	52.09	16.8	23.09	100.2	15.8	22.43	5.4	8.2	12.8	25.69
Crown Indicator	14.298	2.803	6.28	99.257	88.215	9.218	7.025	3.205	6.302	7.236	5.998	0.258	14.359	0.001	92.894
Mean Citation Score	212.23	62.26	71.19	169.24	122.51	95.50	79.72	69.12	72.89	88.81	70.89	22.92	213.77	1.40	167.79
Mean Normalized Citation Score	180.95	87.25	35.32	125.97	98.99	86.24	48.98	50.24	68.21	0.06	49.82	9.88	144.29	36.58	18.85

(MNCS)															
Mean Citation Rate Subfield (MCRS)	162.28	62.27	25.03	158.29	88.19	72.14	35.24	25.14	52.94	0.03	3.65	8.88	122.36	29.78	3.87
Scientific Talent Pool (STP)	89.82	18.26	19.36	80.28	72.63	58.25	20.15	19.78	48.22	0.01	1.69	5.23	22.33	9.89	1.67
Microsoft Academic Search Papers (MASP)	163	119	219	197	206	452	529	43	840	140	249	185	375	15	99
Google Scholar Papers (GSP)	219	231	326	180	257	355	624	3	781	4	50	2	349	24	145
Impact per Paper (IPP)	76.28	15.34	17.25	69.23	77.78	36.29	79.88	6528	92.57	15.98	45.98	22.31	21.8	103.98	25.69
Citation per paper (CPP)	2.35	1.44	2.32	1.62	119.26	2.02	2.06	2.26	72.98	86.32	2.00	22.31	88.10	186.64	1.83
Citations per Paper self-citation not included (CPPex)	209.23	1.01	66.20	153.18	117.69	86.56	65.10	65.26	69.26	82.78	1.85	19.20	84.22	184.29	1.77
The average number of citations per publication (ANCP)	11.99	98.93	3.74	5.985	1.91	90.28	125.0	85.36	56.29	1.49	65.96	25.30	91.79	1.40	26.79
Total and the Average Number of	24417/ 11.99	255670 and 98.93	29150 and 3.74	38267, 5.985	22608 and 1.91	38672, 90.28	38267, 125.0	100452, 2.26	61099 and 56.29	12344 and 1.49	29448, 2.00	3347, 25.30	35985, 91.79	10281 & 1.40	31887, 1.83

Citations (TNCS)															
Relative Activity Index (RAI)	64.19	36.29	39.85	25.31	7.43	76.35	56.98	34.57	23.89	9.89	59.67	22.12	45.23	36.58	44.34
Relative Specialization index (RSI)	95.23	18.43	16.91	98.99	15.26	90.28	75.25	69.57	55.29	48.67	67.99	19.89	22.89	73.26	18.79
Relative Citation Rate (RCR)	85.80	25.45	35.07	72	1.56	23.24	92.66	78.27	68.22	55.44	43.27	38.55	25.99	16.89	10.08
Relative Database Citation Potential (RDCP)	87.85	19.89	25.01	52.01	23.34	16.89	68.56	23.35	44.58	67.79	43.68	76.87	66.98	72.35	80.20
Journal Acceptance Rate (JAR)	28.789	69.89	38.27	78	22.53	67.20	15.26	95.20	77.53	17.91	45.29	22.34	14.23	25.38	15.99
% Self Citations (%SC)	1.34	52	99.73	4.29	3.94	9.74	1.56	1.89	11.28	4.11	8.59	18.11	4.40	1.26	3.19
Percentage of papers not cited (%Pnc)	16.06	23.4	24.06	5.44	2.66	9.74	6.59	3.59	2.68	2.80	6.70	2.67	4.01	0.02	6.40
PR Percentile Ranks (PR)	53	28	52.36	5.99	72	76	82	54	48	39	65	49.99	62.35	71.08	55.05
LogZ-score (LogZ)	12.556	26.29	13.67	15.993	36.29	10.23	11.264	13.241	15.225	15.893	22.114	28.158	14.678	9.998	17.354
Innovative Knowledge (IK)	56.23	15.36	26.94	78.24	6.24	90.2	17.25	16.45	19.68	21.35	29.88	30.69	28.76	19.89	62.96
Technological Impact (TI)	76.16	23.39	38.93	89.84	26.31	82.31	54.24	59.26	62.23	66.27	69.19	72.34	74.89	51.21	76.38
Scientific Talent Pool	76.31	31.67	19.30	76.25	64.19	25.35	48.98	42.34	45.55	52.25	56.67	62.25	72.98	25.36	55.65

(STP)															
Normalized position of publication journal (NPJ)	61.24	10	27.07	23	56	25	32	48	19	22	28	36	42	24	46
WorldCat Hold (WCH)	82	218	55	2104	41	1335	3574	419	79	372	23421	31110	581	45	259
Papers in Top 1 (PT1)	12	73	3	4	24	25	155	18	203	13	10	5	15	3	2
Papers in Top 10 (PT10)	25	93	7	14	54	52	230	25	354	25	14	12	75	3	4
Papers in Top 50 (PT50)	31	189	17	35	75	158	348	60	359	36	35	24	349	3	16
High Cited Papers (HCP)	12	203	2	3	8	17	5	19	32	23	24	3	9	3	5
Papers in First Quartile (Q1)	21	62	8	35	26	123	175	354	212	19	26	8	20	20	25
Publications in Thomson Reuters indices (PWoS)	15	25	0	1	6	12	10	2	61	0	0	0	15	0	2
Number of highly cited publications (NHCP)	9	183	181	48	4	7	23	12	16	2	48	3	124	3	54
Publications in top-ranked journals (PTRJ)	15	195	204	172	72	118	172	24	241	26	26	1	33	39	33

Papers in Collaboration (PCol)	117	417	414	204	174	394	493	1057	834	128	330	125	327	39	193
Share of articles coauthored with another unit (%CoA)	85.40	72	91.59	85	27.98	4.48	97.62	97.24	97.54	89.51	87.11	84.46	93.70	69.64	95.07
National Collaboration (NCol)	45	252	217	79	65.38	44.28	69	78	52.30	55.32	58	25	155	32.48	33
International Collaboration (ICol)	72	312	235	21	34.62	55.72	31	22	47.70	44.68	42	100	172	67.52	75
Scientific Leadership (SL)	22.32	25.98	11.25	19.85	20.36	23.32	18.25	16.35	21.39	22	17.08	18.99	24.33	17.36	16.55
Average Authors per Paper	11.99	1.85	5.6	1.74	1.06	1.44	1.09	1.21	1.06	1.94	1.63	6.10	3.81	2.83	0.20
Productivity per Paper	19.87	0.19	0.33	0.19	18.95	9.99	0.19		18.95	2.16		0.19	0.30	0.53	
RoG,	-1.18	-0.35	-0.34	-0.21	-0.72	-0.67	0.21	-0.98	-0.98	0.36	0.21,	0.25	0.17	0.26,	0.46
CAGR	0.96	0.68	0.89	0.789	0.35,	0.23	-0.789,	0.13	0.25	-0.98	-0.98	-0.99	-0.9	-0.98	-0.99
RGR	0.15	0.25	0.12	0.23	0.12,	0.48	0.23	0.53	0.37	0.11	0.12	0.18	0.15	0.12	0.14
DT	1.05	1.68	1.36	3.72	1.75	1.25	3.72	0.95	1.68	2.08	1.87	2.82	1.05	1.39	2.71

APPENDIX – G

AUTHORSHIP PATTERN

Author performance based on available h-index based indicator

Name	Robert Eric Betzig	Stefan Walter Hell	William Esco Moerner	Tomas Lindahl	Paul L. Modrich	Aziz Sancar	Jean-Pierre Sauvage	Sir J. Fraser Stoddart	Bernard L. Feringa	Jacques Dubochet	Joachim Frank	Richard Henderson	Frances Arnold	George P. Smith	Sir Gregory P. Winter
i10-index (i10)	98	348	266	200	168	365	393	898	726	121	290	101	292	42	172
h5-index (h5)	27	42	21	4	0	22	.49	43	39	3	21	2	38	4	4
g-Index	115	136	144	195	149	177	176	203	202	110	146	47	160	55	178
a-Index	380.11	318.66	216.03	338.88	236.65	237.12	249.49	244.30	273.54	182.32	196.53	57.81	208.51	29	327.5
h(2)-index	17	104.29	16	20	23	18	19	11	11	13	17	8	17	37.39	20
hg-index (hg)	83.76	197.50	105.98	138.94	108.49	137.62	132	167.98	155.69	78.49	115.26	38.17	127.12	39.94	123.73
r-index	152.27	71.44	129.81	183.16	136.73	159.29	157.16	184.28	181.18	101.04	133.73	42.33	145.12	29	167.82
ar-index (ar)	429.39	18.10	337	609.98	359.52	409.23	392.06	465.18	505	13.27	17.56	29.87	19.39	5.99	25.30
k-index	0.10	39.06	0.06	0.10	0.04	0.08	0.06	0.03	0.04	7.09	0.05	0.69	3.31	124.53	8.22
q2-index	13.31	31.87	17.02	20.21	18.85	21.40	21.11	25.83	24	10.42	12.62	6.61	12.63	5.29	5.29
f-index	5.23	1.55	1.77	2.42	1.64	1.64	1.52	0.87	1.28	2.26	1.16	0.86	1.06	0.97	0.97
m-index	2.90	3.65	3.71	4.13	3.29	4.28	4.50	6.32	4.80	1.94	1.75	1.41	1.58	0.97	3.31
m quotient (m-q)	2.90	3.65	3.71	4.13	3.29	4.28	4.50	6.32	4.80	1.94	1.75	1.41	1.58	0.97	3.31
Contemporary index (Ch)	1134.91	126.21	420.78	0.22	0.69	301.93	3.04	398.34	206.3	345.29	265.28	196.84	24.07	34.38	44.01
Trendh h-index (Th)	0.14	0..38	0.11	0.01	0.01	0.07	0.01	0.08	0.07	0.02	0.08	0.03	0.08	1.27	5.95
Dynamic h-Type index (Dh-T)	401.45	64.96	59	33.30	12.43	28.96	0.01	0.04	0.03	9.19	72.94	0	131.93	0	15.26
n-index	2.10	6.48	3.90	3.30	4.16	3.96	3.96	5.56	4.80	1.12	1.94	0.98	3.85	0.63	1.26
mean h-index	31	65.5	41.50	51.50	40	53.5	50.50	78.5	61	28.5	48.0	16	52.5	15	44.5
Normalize	57	0.16	52.1	78.6	55	91.4	9.87	78.2	18.2	22.3	88.2	9.87	12.0	0.53	19.8

d h-index			7	1		6		6	9	6	1		7		6
Specific-impact s-index (Sis)	47.35	21.08	46.12	17.35	26.78	19.75	23.35	19.67	22.08	21.39	18.79	22.36	35.24	39.87	40.59
Seniority independent Hirsch type index (Sih-T)	42	112	5	2	1	1	1	11	7	1	6	0	1	5	1
Hw-index	152.27	68.36	129.81	186.16	136.73	159.29	157.16	184.28	181.18	101.04	133.73	42.33	145.12	99.72	167.82
Hm-index	20	54.28	26	19	34	19	29	24	34	29	0.10	19	32	22	32
Tapered h-index	0.09	0.45	0.12	0.05	0.06	0.06	0.11	0.08	0.07	0.09	0.10	0.12	0.07	4.95	10.13
i20-index	54	313	221	179	152	335	336	768	607	104	243	59	272	37	156
v-index over h	3.44	0.15	3.44	3.45	3.44	3.45	3.45	3.45	3.45	3.43	3.48	3.41	3.45	0.05	3.44
e-index	139.52	185.09	103.76	154.10	111.60	118	122.06	120.98	135.74	84.11	97.99	28.33	104.21	28.51	144.11
Multidimensional h-index	52	5	49.97	78.26	45	56.32	48.29	65.28	47.95	40.12	38.29	39.88	52.65	49.88	57.11
Research Collaboration Index	97.26	26.31	39.14	85.37	7.95	35.06	42.55	38.69	40.75	48.99	57.65	60.33	38.99	31.55	37.68
Communities Collaboration Index	39.23	65.95	52.03	62.13	99.42	9.95	18.39	22.69	15.98	65.98	77.26	18.99	29.89	32.39	28.99
ch-index	72.86	54.31	16.78	17.98	52	55.55	62.98	47.89	68.96	72.35	25.59	19.99	36.97	29.87	77.25
speed s-I Citation index	75.5	68.97	55.26	5.91	36.87	48.53	32.88	69.78	27.65	28.95	19.87	22.35	42.18	18.97	33.98
π-index	149.16	3.65	70.15	155.95	7.79	114.83	124.97	133.19	158.39	54.98	69.76	10.53	104.21	83.34	318.45
h5-median (h5-m)	22.5	29.8	8	4	0	15.38	14.87	23.69	19.87	21.87	18.76	16.87	23.25	19.57	20.02
2nd generation citations h index	48	98	62	76	67.98	99	88	120	89	42	79	9.75	84	14	72
Role basedh-maj-index (Rbhm)	32	25	25.08	22.22	12.03	75	26.08	33.14	32.48	33.86	45.01	15.08	25.04	17.98	22.09
h2 lower (h2-l)	14	72.35	17	6	12	2	12	10	7	18	22	13	21	16	9

h2-center (h2-c)	60	230.65	79	18	24.03	19	35	28	19	4	58	30	49	38	22
h2-upper (h2-u)	108	416.23	159	34	34	36	45	33	22	9	72	41	58	71	55
h3-index	24	78.25	55.54	17	14	12	19	22	16	11	56	21	35	26	18
p-index	17.62	65.39	59.58	86.2	2.79	11.05	22.33	18.98	25.35	16.88	58.93	21.05	24.38	19.99	22.37
$\bar{h}$-index (Hbar)	61	99	78	88.99	79	107	99	139	120	56	91	10.53	101	29	86
Mockhm-index (Mhm)	55.08	29.89	37.36	18.87	32.28	39.95	42.28	67.25	55.89	48.59	78.98	7.85	99	18.23	78.02
w-index	25.27	95.23	16.96	16.67	1.39	2.85	7.98	11.29	13.97	18.56	17.06	21.48	15.89	25.59	32.29
b-index	27.98	126.98	21.20	23.24	28.28	19.20	35.29	29.06	55.49	18.98	25.78	16.25	13.24	24.97	33.48
Generalized h-index	58	96.35	59.19	88.95	62.13	92	82.05	102.67	99.98	48.97	85.36	7.38	95.45	19.25	82.35
Single paper h-index	26	65	53	64.8	19.68	58	54.8	68	59	39	69	5	6	7	19
hint-index	42	76.85	89.28	78.88	26.35	78	82	115	98	42	78	6	55	12	57
h_{rat}-index	61.98	95	78.99	99.88	79.99	108	99.9	140	121	56.98	91.99	31.98	101.99	29.97	86.99
πv-index	48.39	68.26	12.05	3.56	62.28	0.26	11.98	21.09	17.95	48.76	68.45	19.79	88.97	18.26	65.49

APPENDIX – H

WEB VISIBILITY

Name	Scopus	WOS	GS	MA	Academia	Orchid	RG	Total
Eric Betzig	137	0	0	0	0	0	0	137
Stefan W. Hell	445	0	0	0	0	0	0	445
William E. Moerner	452	0	0	0	0	0	0	452
Tomas Lindahl	238	0	0	0	0	0	0	238
Paul L. Modrich	188	0	0	0	0	0	0	188
Aziz Sancar	414	0	0	0	0	0	0	414
Jean-Pierre Sauvage	505	0	0	0	0	0	0	505
Sir J. Fraser Stoddart	1087	0	0	0	0	0	0	1087
Bernard L. Feringa	855	0	0	0	0	0	0	855
Jacques Dubochet	143	0	0	0	0	0	0	143
Joachim Frank	388	0	0	0	0	0	0	388
Richard Henderson	148	0	0	0	0	0	0	148
Frances Arnold	349	0	0	0	0	0	0	349
George P. Smith	55	0	0	0	0	0	0	55
Sir Gregory P. Winter	203	0	0	0	0	0	0	203
John B. Goodenough	958	0	0	0	0	0	0	958
M. Stanley Whittingham	336	0	0	0	0	0	0	336
Akira Yoshino	69	0	0	0	0	0	0	69

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1. Presented a paper "**Using Scopus Data to Draw the Scientometric Profile of Nobel Laureates in Chemistry Discipline (2014 - 2018)"** "in "**Pratap IPDA**

International Conference". Organized by Pratap college of education, Ludhiana, India collaboration with Kazan Federal University, Kazan, Russia. Held on April 08, 2022.

2. Presented a paper **"Scientometric Assessment of Chemistry Nobel Laureate Frances H. Arnold"** in online "**International Conference on Knowledge Management in Higher Education Institutions**". Organized by Central Library, Manipal University Jaipur, India Jointly with University Library, Uva Wellassa University, Sri Lanka. Held on April 07 -08, 2020. www.ickhi.in
3. Presentied a paper **"Delineating Knowledge Domains in Scientific Domains in Scientific Literature using Machine Learning (ML)"** in online "**10th Annual Global Tech Mining Conference**" with the Beijing Institute of Technology, China and organized by The VP Institute. Held on Nov 11 -13, 2020. http://www.gtmconference.org/

Workshop, Training

1. One-week UGC STRIDE (Component - I) workshop on "**Sequence to database and database to sequence**" held from 06th January 2021 to 12th January 2021 at the Mizoram University, Aizawl, Mizoram.
2. One day workshop on "**Indian Research Information Network System (IRINS): Adoption & Promotion**" January 10, 2020, organized by INFLIBNET With Collaboration with Banaras Hindu University held at Banaras Hindu University, Uttar Pradesh.
3. One-week advanced training program on "**Bibliometric and Research output analysis**", 02^{nd}- 07^{th} September 2019 held at Information and Library Network (INFLIBNET) center.
4. National Workshop on "**Trends in LIS Research: Approaches and Methods**", 11th – 15th March 2019 organized by & held at Department of Library & Information Science, Mizoram University, Mizoram.

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DEPARTMENT	:	Library and Information Science
TITLE OF THESIS	:	A Scientometric Study on Portrait of Nobel Laureates in Chemistry
DATE OF ADMISSION	:	03.08.2018

APPROVAL OF RESEARCH PROPOSAL

1. DRC	:	08.04.2019
2. BOS	:	22.04.2019
2. SCHOOL BOARD	:	07.05.2019
MZU REGISTRATION NO.	:	1800110
REGISTRATION NO. & DATE	:	MZU/Ph.D./1187 of 03.08.2018
EXTENSION (IF ANY)	:	N/A

Head

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ABSTRCT

ON

A SCIENTOMETRIC STUDY ON PORTRAIT OF NOBEL LAUREATES IN CHEMISTRY

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Ph.D. REGISTRATION NO.: MZU/Ph.D./1187 of 03.08.2018

DEPARTMENT OF LIBRARY & INFORMATION SCIENCE

SCHOOL OF ECONOMICS, MANAGEMENT AND INFORMATION SCIENCE

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1. Introduction

Among all individuals who have dedicated their lives to the development of chemistry, literature, medicine, physics, and world peace, The Nobel Prize is the most coveted award that these individuals can receive. It is the distant dream of all researchers to be included in the list of Nobel Prize awardees. Nobel Prize awardees or Nobel Laureates, the term used to generally address them, are regarded as assets to the globe and the countries of their origin witness a steep rise in their prestige. The Nobel Prize has continued to receive much fanfare among all the global citizens, especially among the researchers. The Nobel Prizes chemistry, literature, medicine, physics, and world peace are awarded annually. As expressed by Alfred Nobel, which has been taken from his will, "the awards will be presented to individuals 'who have conferred the greatest benefit to humankind in the last 12 months". Nobel Prizes were first awarded in the year 1901, and the same has been going on till the present. However, these prizes were not conferred during the first and the second world wars. The prestige associated with the Nobel Prize can be gauged from the fact that this award has been compared with the "laurel wreath" that was conferred to various competitors in ancient Greece. The words "laurel wreath" has been modified as Laureate. Today, Nobel Prizes are awarded in six disciplines, with the inclusion of Nobel Prize in Economics which was added in the year 1968 by the central bank of Sweden from the grant that was given to it by the Nobel Foundation to commemorate the 300th anniversary of the bank. Economics was not included for the award in the will of 1895 left behind by Alfred Nobel. Several scholars have expressed their inability to regard prize in Economics as a Nobel Prize.

The process of awarding the Nobel Prize is long and arduous and commences with submitting of nominations by previous winners, professors from universities, and scientists. The process does not allow self-nomination. The process begins in the month of September every year and culminates on the 10th day of December, when the awards are finally presented to the rightful winners. While the awards under all the categories are awarded in Sweden, the Nobel Prize for peace is awarded in Norway. As per the doctrines in the will of Alfred Nobel and the conditions of nominations, the Nobel Prize can only be conferred to researchers and academicians during their lifespan and not after their death. Though the strictures in the will do not specify the number of researchers who are eligible to receive the prize in any category, the norm allows a maximum of three researchers to share the award in any category. The Nobel Prize is not a single award but includes a Diploma, a Medal, and a cash prize.

Nobel Prizes play a twin role. Besides recognizing the contributions made by any researcher for bringing betterment to the society, these prizes also help to motivate upcoming generations to follow further studies in these fields. R. P. Upadhye and others have suggested that all techniques are adopted that aid in projecting the entire lifetime accomplishments of all Nobel Prize winners who have become heroes after dedicating their lives to find the confirmable truth in the constrictive field in which he/she specializes (Upadhye, et al. 2004).

Almost every researcher who has spent his/her entire productive life in pursuing his/her research in such fields that have a positive effect on humanity receives recognition by receiving various awards and prizes during his/her lifetime. Despite being the recipient of several awards and recognition, they yearn for the Nobel Prize. The Nobel Prize exceeds all other prizes considering the magnificence and the status that is inherent to the prize. Several writers have written about the Nobel Prize: its history, its founder, the complicate and lengthy procedure involved in the process of electing the winners, and also their accomplishments. The reputation of the Nobel Prize has reached such heights that one can find 1500 journals with the words "Nobel" and "Nobel Prize" in the title in the database of 'Web of Science' (Karazija & Momkauskaite, 2004). A majority of these publications had been published to commemorate the 100th anniversary of the foundation of this prize. For the benefit of interested students of science who wanted to have a glimpse of the Nobel Prizes, the materials concerning the Nobel Prize that are present in the Nobel archive and belonging to the first half of the 20th century were made public during 2002. This development started a series of investigations on the process of nominations for the Nobel Prize, or "Nobel population". The investigators observed that several aspects went into the decision-making process of selecting the awardees: distribution of nominees according to country, national and international character in the nominations, winners or losers, most nominated scientists, the predominance of the male nominees, etc.

The Nobel Foundation has been given the responsibility of awarding the Nobel Prize. The Foundation is a private organization that was established on 29th June 1900 to fulfil the wishes of Alfred Nobel as mentioned in his will. The principal function of the Foundation lies in managing the finances left behind by Alfred Nobel and guarantying a constant financial resource for the Nobel Prize. The Foundation also guarantees freedom in the work of the recipients. Nobel Foundation has representatives from all the Nobel organizations. The will of Alfred Nobel restricts the Nobel Foundation from having any role in selecting the nominees or in choosing the winners. The high level of secrecy can be understood from the fact that the nominated individuals are even not aware of their nominations. The final selection of the individuals is made by the Prize Awarding Institutions who are independent entities and do not have any affiliation with any government agencies and organizations. These institutions are also not liable to the Nobel Foundation. The independence of the Prize Awarding Institutions is important as it helps to maintain the purposes of the Nobel Prize and also to see that the best individual in the respective fields receive the awards.

Alfred Nobel died on 10th December 1896, leaving behind a will dated 1895. All the Nobel Prizes are being awarded as per his will. The first set of Nobel Prizes, barring the Nobel Prize in Economics, was presented in 1901 and has a close correlation with the history of modern science, arts, and political developments taking place throughout the entire 20th century. The provisions mentioned in the will left behind by Alfred Nobel had managed to attract global attention and led to severe unfavourable judgment and disbelief. The fact that the Nobel Prizes can be awarded to extraordinary people from across the globe did not go down well with the general population, who also criticized Alfred Nobel for internationalizing the awards. The Nobel foundation was established after skirting or overpowering several unending hindrances and difficulties and after several years of discussions which led to hostile conflicts. The covenants of the will were approved by the Norwegian Parliament (Storting) on the 26th day of April 1897. This paved the way for the foundation of the prize-awarding Norwegian Nobel Committee of the Storting and had elected representatives as its members. The other prize-awarding bodies were founded during 1898 as per the will through arbitration. These bodies include the Karolinska Institute, which was formed on 7th June, the Swedish Academy which was formed on 9th June, and the Royal Swedish Academy of Sciences which was formed on the 11th day of June.

2. Scientometrics Explained

The term' Scientometrics dimensions' has been used to refer to the communication process and is considered a science of science that emphasises the quantitative parts of research. The term 'Scientometrics dimensions' is used to represent a system of knowledge that are available in the field of science and technology and attempts to investigate the system of science and technology utilising a variety of approaches in a broad sense. As an integral part of the sociology of science, Scientometrics has numerous applications, one of them being the formulation of scientific policies. The term “Scientometrics” is the English version of the Russian term that is used to define the process of applying quantitative methods to the chronicle of science. The term "Scientometrics" was coined in the magazine "Scientometrics," edited by T. Braun moved to the United States from Hungary in 1977 and quickly rose to fame. The journal is currently published in Amsterdam. The term 'Scientometrics' refers to the quantitative parts of scientific communication, as well as those aspects of society and culture that have grown associated with science over time. Some scholars believe that Scientometrics is a field of sociology that may be used to make scientific policy. This viewpoint is based on the term's broad definition, which envisions a system of knowledge that aims to investigate many scientific and technical systems utilising a range of scientifically supported methodologies.

Several scholars which included J. Tague-Sutcliffe have defined Scientometry as the study of the quantitative facets of science, either to enrich the subject or as a profitable business venture As a result, Scientometrics is a multi-disciplinary study that includes the study of scientific behaviour, the history of science, the development of science and scientific institutions, the behaviour of science and scientists, and the formulation of policies and decisions that promote the growth of science and scientific temperament. Scientometrics is also known as the science of measuring and analysing. Bibliometrics, which is defined as the measurement of (scientific) publications, is used in Scientometrics in practise (Tague-Sutcliffe, 1992).

2.1 Scientometric Portrait

Bio-bibliometric analysis is the art of generating information about individual scientists in order to increase the odds of visibility for a good scientist who would otherwise be hidden from public view. This research has shown to be extremely valuable to anyone interested in the advancement of science and technology. A bio-bibliometric study, also known as biographical bibliometrics, Scientometric portrait, or bio-bibliometrics, is the process of examining individual authors, scientists, or groups of authors/scientists' contributions to the advancement of science and scientific thinking over the course of their lives.

The mathematical and statistical study of a scientist's or researcher's career in order to associate their bibliographical analysis of publications with academic and scientific achievements is known as Scientometric portrait research. The study of the Scientometric portrait has recently gotten a lot of interest because of how useful it is to scientists in terms of highlighting many aspects of their careers, such as productivity based on biological age, collaboration patterns, authorship, and other factors (Sangam et al. 2006). S.K. Sen and S.K. Gan coined the term "bio-bibliometrics" to describe the quantitative and analytical methodologies used for the discovery and development of diverse structural correlations between the elements comprising biographical data and bibliographic data (Sen & Gan, 1990). The term ‘Scientometric portrait’ was used for the first time in 1993 and was meant to include bio-bibliometric studies of scientists (Kalyane & Kalyane, 1993). Several scholars have, however, preferred to use the word ‘Information profile’ to describe such studies (Sinha & Bhatnagar, 1980; Sinha & Ullah, 1994). S.K. Sen used the term 'Micro-bibliometrics' to encompass research on respective scientists when presenting his paper on the theme 'Networking of libraries issues and possibilities' at the IASLIC Conference held at the famous Indian Institute of Technology, Bombay in 1994 (Sen, 1995).

Despite the fact that the word bio-bibliometrics is used to refer to both quantitative and analytical approaches for locating and analysing information, setting up a structural correlation between the elements that constitute biographical data and bibliometric data. Many studies on bio-bibliometrics haven't used the term in the title of their articles, despite the fact that it exists. Bio-bibliometrics is a word that has lately gained popularity as a tool for determining gene naming co-occurrence, words to retrieve and visualize genetic information medical science to create linguistic links between different genes (Stapley & Benoit 2000). It has, therefore, been recommended that both ‘Scientometric portrait’ and ‘informetric portrait’ are befitting phrases that correctly define all studies that are conducted on scientists, as well studies concerning researchers who have enriched our knowledge of other subjects like Arts, Humanities, and Social Sciences.

3. Study of Chemistry as a Subject

Chemistry is the study of atoms, molecules, ions, elements, and compounds, as well as their structure, composition, characteristics, behaviour, and reactions. Chemistry is a branch of science that sits between physics and biology in terms of scope. The word chemistry comes from the Greek word alchemy, which refers to a collection of intuitive but non-scientific disciplines that include chemistry, metallurgy, philosophy, astrology, astronomy, mysticism, and medicine. Organic chemistry, inorganic chemistry, and physical chemistry are some of the sub-disciplines of chemistry. Analytical chemistry, biochemistry, surface chemistry, fuel chemistry, neuro chemistry, nuclear chemistry, and so on are some of the different fields of chemistry (Wikipedia, n.d.)

4. Significance of the Study

Due to its utility in comprehending the growth of literature or trends in related subjects or within a specific geographical area, the usage of Scientometric research has increased in recent years. Several Scientometric studies have been undertaken at both the micro and macro levels to analyse research in certain disciplines. Aside from that, Scientometric research focusing on Nobel Laureates has also been carried out. Although there are fewer field-specific Scientometric studies, none have been undertaken to date that cater to the Scientometric portrait of Nobel Laureates in Chemistry. This research aims to fill the hole that has been created in the literary world. Since the award's establishment in 1901, the current study will provide a Scientometric portrait of all Nobel Laureates in Chemistry. The total number of research articles published in various journals, as well as the total number of citations obtained, are used to determine all Scientometric indices. Other indicators like as the h-index, SJR index, g-index, and citations are now used to determine the quality of research, and these characteristics also help to boost the reputation of Nobel Laureates and the fields in which they operate. This piece of research helps scientists and individual researchers to understand and build an interest in developing equivalent measures for other areas, as well as provide an overview of the field's strengths and flaws. Furthermore, future LIS scholars may be enticed to do similar studies in order to better understand different subject domains. This study's findings are also likely to yield some significant findings. Apart from what has already been stated, the current research will aid in the creation of a Scientometrics portrait of Nobel Laureates in Chemistry by analysing author-by-author research productivity, domain-by-domain contributions, domain-by-domain authorships, prominent collaborators, document type research productivity, total research documents, total citations, co-author network, international collaboration, channels of communication, keywords analysis, and so on.

5. Scope of the Study

The focus of this research is limited to examining the Scientometrics portraits of all Nobel Laureates in Chemistry from 2014 to 2018. The study's goals include:

a) Determining the number of scientific communications contributed by Nobel Laureates;

b) Determining the number of scientific communications contributed by Nobel Laureates;

c) A study of Nobel Laureates' domain-specific scientific communication, authorship patterns, and communication routes;

d) An examination of the authorship credits of Nobel Laureates' collaborators; and

e) Discovering the Nobel Laureates' citation network.

The names of scientists who have won the Nobel Prize in chemistry and who fall within the scope of this study have been compiled for reference.

Table 1: List of Nobel Laureates in chemistry from 2014 to 2018

S. No.	Year	Name	Rationale
01	2014	Eric Betzig	For the development of super-resolved fluorescence microscopy.
02		Stefan W. Hell	
03		William E. Moerner	
04	2015	Tomas Lindahl	For mechanistic studies of DNA repair.
05		Paul L. Modrich	
06		Aziz Sancar	
07	2016	Jean-Pierre Sauvage	For the design and synthesis of molecular machines.
08		Sir J. Fraser Stoddart	

09		Bernard L. Feringa	
10	2017	Jacques Dubochet	For developing cryo-electron microscopy for the high-resolution structure determination of biomolecules in solution.
11		Joachim Frank	
12		Richard Henderson	
13	2018	Frances Arnold	For the directed evolution of enzymes.
14		George P. Smith	For the phage display of peptides and antibodies.
15		Sir Gregory P. Winter	

6. Statement of the Problem

The exponential growth of literature and rapid development of libraries generated several evolutionary studies about the effectiveness and efficiency of information services. These studies led to the identification and application of appropriate quantitative measuring techniques known as Scientometrics. Scientometric assessment of research is a kind of process to identify the growth and development of published research output in a specific subject domain with the help of various Scientometric indicators. Library and Information professionals throughout the world began to use Scientometric studies to throw light on the pattern of growth of literature, collaborative research, the ranking of journals, inter-relationship among different branches of knowledge, productivity and influence of authors, the pattern of the collection built up, their use, etc.

An exhaustive literature survey was made to know whether the study on the Scientometric portrait of scientists in the field of science & technology, and social sciences has been done or not; and found number of studies on the Scientometric portrait of scientists in the field of science & technology as well as social sciences. Researchers have conducted numbers of studies in certain fields of specific subject domains but observed rare studies in the field of Chemistry itself and particularly the Scientometric portrait of Nobel Laureates in Chemistry has not been found from any corner of the world till today. Due to lack of such research in the field of Chemistry and personal interest towards conducting the study on Chemistry, need arises to draw the Scientometric portrait of Nobel Laureates in Chemistry. Therefore, the study is an attempt to fill up the gap created in the field of Chemistry especially with contribution of Nobel Laureates.

7. Objectives of the Study

The objectives of the study area to:

i. Assess the number of scientific communications contributed by Nobel Laurates;

ii. Analyze the domain-wise scientific communication of Nobel Laureates;

iii. Analyze the domain-wise authorship patterns of Nobel Laureates;

iv. Analyze the year-wise authorship patterns of Nobel Laureates;

v. Find out the channels of communication used by Nobel Laureates;

vi. Author performance based on available metrics indicator;

vii. Aanalyze the scientific collaborations; and

viii. Find out the research network of Nobel Laureate.

8. Research Methodology

The project is self-exploratory, and its goal is to use Scientometrics indicators to create a portrait of Nobel Laureates who received the coveted prize in Chemistry between 2014 and 2018. Since its introduction in 2014, the Nobel Prize in Chemistry has been awarded to 15 Nobel Laureates. The study includes all 15 Nobel Laureates. Various factors used to measure research are included in the Scientometrics portraits of Nobel Laureates. The study looks at author-by-author research productivity, domain-by-domain contributions, domain-by-domain authorships, notable collaborators, document-type research productivity, total research documents, total citations, co-author network, international collaboration, communication channels, and keyword analysis, among other things. And further, to maintain the uniformity in references and text citation, the latest version of APA 7th ed. has been used.

9. Review of Literature

The review of literature gives the glimpses of studies of Scientometric and provides certain solid guiding lights for the present study. The review of the study is presented in the following heading such as the Scientometric, chemistry, Nobel prize and profile of Nobel laureates. The study is further arranged in ascending chronological order. Total 282 scholarly document (journal article, conference paper, books, books chapter, thesis, and news article) cited.

10. Chapterization

The present study consists of the following chapters:

Chapter 1: Introduction explains about the basics of chemistry discipline and Scientometric followed by review of literature related area, research gap, significance of the study, scope of the study, research design. In short, the chapter provides a brief introduction about the research conducted.

Chapter 2: Chemistry: History, Scope, Philosophy, and Relationship explain about history of chemistry, division of chemistry, scope of chemistry and relation of chemistry with other science.

Chapter 3: Nobel Prize: History discusses about the history of Nobel Prize, Nobel foundation and its functions, and Nobel statistics.

Chapter 4: Profile of Nobel Laureates in Chemistry (2014-2018) highlights the biographical detail of Nobel laureates who won Nobel Prize during 2014 to 2018.

Chapter 5: The Science behind Scientometry gives a quick view of history of Scientometric and Scientometric theory which included citation analysis, scattering, bibliomerics laws, metrics indicator (Journal, author, and article).

Chapter 6: Data Analysis and Interpretation explains research methodology in beginning mentioning database and software used for the result output. It also explains scientists' performance with the help of bibliometrics and Scientometrics indicator.

Chapter 7: Findings and Conclusion puts forward the research finding followed by conclusion and suggestion for further studies based upon previous chapter.

Bibliography

11. Finding

11.1 Analyzing Productivity

The year-wise productivity of the researchers who have been awarded the Nobel Prize in Chemistry has been tabulated in table 2.

Table 2: Year-wise Productivity of Nobel Laureates

Author	Year						Total
	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2011-2020	
Eric Betzig	0	0	8	28	22	79	137
Stefan Walter Hell	0	0	2	73	194	176	445

William Esco Moerner	0	3	55	109	150	135	452
Tomas Robert Lindahl	17	56	47	68	41	10	239
Paul Lawrence Modrich	12	10	46	61	45	14	188
Aziz Sancar	0	10	81	141	101	81	414
Jean Pierre Sauvage	4	31	78	183	162	53	511
James Fraser Stoddart	13	54	108	291	334	287	1087
Bernard Lucas Feringa	0	8	42	170	344	291	855
Jacques Dubochet	0	17	34	38	48	6	143
Jaochim Frank	9	15	75	76	125	88	388
Richard Henderson	5	26	29	33	25	30	148
Frances Hamilton Arnold	0	2	18	94	118	117	349
George Pearson Smith	0	12	10	16	10	7	55
Gregory Paul Winter	0	4	45	100	31	23	203

A look at table 2 indicates that while James Fraser Stoddart has published the maximum number of scientific documents, George Pearson Smith has the least number of publications to his credit. All the Nobel Laureates commenced their productive life in the late 1960s and have continued to contribute till 2020.

11.2 Type of Documents

The researchers have published their scientific documents in various ways, be it in the form of articles, books, book chapters, conference papers, and the like. Table 3 is a tabulation of the mode used by the Nobel Laureates to publish their works. While most of the works are in the form of articles (83.76%), scientific documents have also been published in the form of books, editorials, conference papers, notes, reviews, etc. This shows that the Nobel Laureates find ease in producing articles to disseminate their knowledge.

Table 3: Type of Documents

Name	Article	Book	Book Chapter	Conference	Data Paper	Editorial	Erratum	Letter	Lectures	Note	Review	Short Survey	Total
Eric	100	0	0	24	0	0	3	0	0	1	9	0	137

Betzig													
Stefan W. Hell	371	0	0	5	0	3	3	0	0	2	13	5	445
William E. Moerner	270	1	4	139	0	2	5	3	0	5	20	3	452
Tomas Lindahl	198	0	0	9	0	4	1	3	0	0	23	0	238
Paul L. Modrich	170	0	0	3	0	0	1	0	0	0	11	3	188
Aziz Sancar	348	0	4	3	0	2	8	2	0	6	29	12	414
Jean-Pierre Sauvage	454	3	8	7	0	5	1	3	0	1	13	10	505
Sir J. Fraser Stoddart	978	3	12	35	0	6	5	4	0	4	34	6	1087
Bernard L. Feringa	753	1	12	25	0	3	4	11	0	4	32	10	855
Jacques Dubochet	117	1	0	8	0	1	2	4	0	0	8	2	143
Joachim Frank	298	4	8	32	0	7	5	3	0	1	27	3	388
Richard Henderson	117	0	2	8	0	1	1	1	0	3	14	1	148
Frances Arnold	270	1	7	15	0	4	6	1	0	3	38	4	349
George P. Smith	45	0	1	0	0	2	1	0	0	0	6	1	55
Sir Gregory P.	172	0	1	6	0	5	3	2	0	4	9	1	203

Winter														

11.3 Type of Authorship

The scientific publications that have been published by the Nobel Laureates were either single-authored or multiple-authored. The Nobel Laureates are engaged in several other assignments making it difficult for them to devote time to writing and publishing scientific papers. Though they do contribute by way of producing single-authored documents, in majority of the cases, they accept help from the co-authors. Table 4 shows the percentage of single-authored documents published by the Nobel Laureates. Analysis of the table indicates that for all the Nobel Laureates, except George Pearson Smith, the percentages of single authored documents are very less. G P Smith has the highest single-authored document at 30.91%, while Bernard Lucas Feringa has the lowest percentage of single-authored documents at 2.46% followed by James Fraser Stoddart at 2.76%.

Table 4: Nature of publications by the Nobel Laureates

Author	Total Documents	Single Authored	% Of Single Authored Document
Eric Betzig	137	20	14.6
Stefan Walter Hell	445	28	6.3
William Esco Moerner	452	38	8.41
Tomas Robert Lindahl	239	35	14.65
Paul Lawrence Modrich	188	14	7.45
Aziz Sancar	414	20	4.84
Jean Pierre Sauvage	511	18	3.53
James Fraser Stoddart	1087	30	2.76
Bernard Lucas Feringa	855	21	2.46
Jacques Dubochet	143	15	10.49
Jaochim Frank	388	58	14.95
Richard Henderson	148	20	13.52
Frances Hamilton Arnold	349	22	6.31

George Pearson Smith	55	17	30.91
Gregory Paul Winter	203	10	4.93

11.4 Collaboration Index

As has been observed in the previous sections, the Nobel Laureates whose Scientometric portraits have been drawn in this thesis have published their documents with several co-authors. To put it in a different language, the Nobel Laureates had collaborated with several authors to publish their scientific documents. This may have been necessitated due to administrative exigencies that they might have been subjected to. Table 147 shows the collaboration index of the Nobel Laureates. On analyzing the data, it is observed that while George Pearson Smith had collaborated with 69 co-authors (Collaboration index = 2.87), James Fraser Stoddart had collaborated with 1429 co-authors (Collaboration index = 1.24). Table 5 further shows that Gregory Paul Winter has the lowest collaboration index at 0.20, while the highest collaboration index has been observed in case of Eric Betzig whose collaboration index has been calculated at 3.99. Most of the other Nobel Laureates has collaboration index more than 1, while the collaboration index of a few Nobel Laureates has been calculated at more than 2. This is indicative of the fact that the Nobel Laureates whose works have been analyzed had a high belief in multi-authorship.

Table 5: Collaboration Index of Nobel Laureates

Author	Number Of Co-Authors	Collaboration Index
Eric Betzig	456	3.99
Stefan Walter Hell	848	1.97
William Esco Moerner	923	2.22
Tomas Robert Lindahl	405	2.03
Paul Lawrence Modrich	359	2.26
Aziz Sancar	616	1.52
Jean Pierre Sauvage	534	1.13
James Fraser Stoddart	1429	1.24
Bernard Lucas Feringa	1065	1.09

Jacques Dubochet	270	2.16
Jaochim Frank	631	1.91
Richard Henderson	272	2.20
Frances Hamilton Arnold	482	1.43
George Pearson Smith	69	2.87
Gregory Paul Winter	420	0.20

11.5 Domains

The domains in which the researchers who have been conferred the Nobel Prize have published their scientific documents have been tabulated in table. Despite the fact that the researchers have done commendable work to enhance the scope of chemistry as a science, they have also published their scientific works in other domains. This shows the relation that chemistry has with other subjects, which has been discussed in detail in the previous sections.

Table 6: Analysis of domains of Nobel Laureates

Name	Eric Betzig	Stefan W. Hell	William E. Moerner	Tomas Lindahl	Paul L. Modrich	Aziz Sancar	Jean-Pierre Sauvage	Sir J. Fraser Stoddart	Bernard L. Feringa	Jacques Dubochet	Joachim Frank	Richard Henderson	Frances Arnold	George P. Smith	Sir Gregory P. Winter
Applied Physics	29	88	109	0	0	0	0	0	0	0	0	0	0	0	0
Cell Biology	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Microscopy	30	111	105	0	0	0	0	0	0	0	0	0	0	0	0
Molecular Biology	30	0	0	0	0	0	0	0	0	41	0	43	0	0	68
Biophysics	0	95	114	0	0	82	0	0	0	0	100	30	0	0	0
Nanobiophotonics	0	151	0	0	0	0	0	0	0	0	0	0	0	0	0
Chemistry	0	0	127	0	0	0	0	0	0	0	0	0	0	0	0
Biochemistry	0	0	0	40	61	96	0	0	0	33	95	0	69	4	27
Dna Mismatch	0	0	0	0	38	154	0	0	0	0	0	0	0	0	0
Dna Repair	0	0	0	78	46	0	0	0	0	0	0	0	0	0	0
Microbiology	0	0	0	0	43	82	0	0	0	0	0	0	0	9	0
Genetics Of Cancer	0	0	0	79	0	0	0	0	0	0	0	0	0	0	0
Organic Chemistry	0	0	0	39	0	0	0	223	184	0	0	0	0	0	0
Catalysis	0	0	0	0	0	0	0	0	173	0	0	0	0	0	0
Material Chemistry	0	0	0	0	0	0	0	0	162	0	0	0	0	0	0

Molecular Nanotechnology	0	0	0	0	0	0	0	0	286	0	0	0	0	0	0
Molecular Science	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0
Applied Chemistry	0	0	0	0	0	0	88	263	0	0	0	0	0	0	0
Nanotechnology	0	0	0	0	0	0	0	238	0	0	0	0	0	0	0
Stereo Chemistry	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0
Supramolecular Chemistry	0	0	0	0	0	0	0	303	0	0	0	0	0	0	0
Coordination Chemistry	0	0	0	0	0	0	110	0	0	0	0	0	0	0	0
Structural Chemistry	0	0	0	0	0	0	117	0	0	0	0	0	0	0	0
Supra Molecular Chemistry	0	0	0	0	0	0	177	0	0	0	0	0	0	0	0
Bioengineering	0	0	0	0	0	0	0	0	0	28	0	0	89	0	0
Cryo Microscopy	0	0	0	0	0	0	0	0	0	41	0	45	0	0	0
Biosciences	0	0	0	0	0	0	0	0	0	0	96	30	0	0	0
Chemical Engineering	0	0	0	0	0	0	0	0	0	0	97	0	128	0	0
Genomics	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0
Protein Engineering	0	0	0	0	0	0	0	0	0	0	0	0	0	10	77
Biotechnology	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0
Antibody Technology	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31
Bioinformatics	0	0	0	0	0	0	0	0	0	0	0	0	63	0	0

The maximum number of documents have been published in the field of organic chemistry (446, 7.99%) followed by biochemistry (425, 7.61%), and biophysics (421, 7.54%). The lowest numbers of documents were published in the domain of biotechnology (15, 0.27%), followed by genomics (17, 0.3%) and antibody technology (31, 0.56%).

11.6 Analyzing the Scientometric Indices

The data extracted from Scopus has been used to calculate various Scientometric indices of the Nobel Laureates. A synopsis of the findings has been mentioned below for referral.

a) Author Impact: - Author impact measures the number of publications authored by any researcher and the number of times these publications have been cited by other researchers. All the authors whose works have been analyzed have author impact of more than 10. This is indicative of the fact that most of their works have been cited by other researchers, which also goes to show the popularity of their works. Both James Fraser Stoddart ad Aziz Sancar has author impact of 98.56.

b) Total Citation: - Total citation is a count of the number of times the document published by any author is cited by successive researchers. Analysis of the data shows that all the authors under review had a large count of citation. This indicates that they could inspire the future generation of scientists to continue their works. Sir James Fraser Stoddart’s works have been cited more than 1 lakh times showing the popularity of the domain of his research. This also shows the reason for the high author impact.

c) Audience Factor: - Baring a few researchers, calculation done with data sourced from Scopus shows that most of the authors had an audience factor of more than 100.The figures show that the documents published by the authors have received numerous views and citations from later researchers showing the popularity of their works.

d) CiteScore: CiteScore of a journal is calculated on the basis of the citations that the journal has received in one year compared to the number of documents published in the previous three years. It is calculated as per the documents indexed by Scopus. A high citeScore indicates high value of the journal. Other than Richard Henderson, all the authors who have been studied had a very high citeScore, signifying that they had published their documents in the top 100 journals.

e) h-Index: - Analysis of the h-Index of the Nobel Laureates in Chemistry whose works have formed a part of this study shows that the Nobel Laureates have a high value of h-Index. With the median h-Index being calculated at 91, almost all the Nobel Laureates have the values of h-Index near the median. This shows that a vast majority of the documents published by the Nobel Laureates have been cited various times by several researchers.

f) Self-citation: - Self citation is related to citing one’s own document in future documents. Self-citation increases the number of citations and impacts the value of h-Index. Analysis of data from Scopus reveals that William Esco Moerner has a self-citation of more than 99%, while the percentage of self-citation of George Pearson Smith has been calculated at little above 1%. No doubt, Moerner has an h-Index of 78 compared to 29 in case of George Pearson Smith.

g) Technological Impact: Analysis of the data shows that the technological impact of all the Nobel Laureates is more than 20 which shows the usefulness of their works in the benefit of mankind.

h) Relative Specialization Index: A high value of the relative specialization index is indicative of the level of specialization importance the Nobel Laureates had over other researchers of the era.

i) Mean Citation Score: Analysis of the data show that all the Nobel Laureates considered to form a part of this study had a significant value of mean citation score. As explained above, the documents published by these authors have been read and cited by future researchers. The importance of their work can be gauged from this data.

j) Crown Indicator: Crown indicator is a bibliometric indicator that is used to assess the research performance of any scientist. The aim of this indicator lies in normalizing citation counts for differences among the domains of knowledge. The Nobel Laureates whose productivity has been analyzed has a high value of this indicator.

k) Papers in Top 1: This indicator shows the number of documents that have been published in the leading scientific journal. The number of documents published in top journals has a direct positive correlation with the status of the author. All the Nobel Laureates who have been studied have had a significant percentage of their works published in the topmost scientific journal, which shows the importance of their work in benefitting humans.

l) Highly Cited Publication: Analysis of data shows wide variation in the number of highly cited publications among the Nobel Laureates. While some of the Nobel Laureates have significantly large number of highly cited publications, majority of the Nobel Laureates have a low number of highly cited publications. This is due to the fact that documents published in languages other than in English or published in regional scientific journals fail to attract attention of future researchers.

m) Relative Growth Rate: Relative growth rate is a measure of the change in the number of documents published over a specific period of time. This study specifies the time between the commencements of productive life till 2019. The relative growth rate of the Nobel Laureates corresponds to the best rates among the researchers.

n) Doubling Time: Doubling time is defined as the time required to double the productivity as per exponential growth. Analysis of the data shows that the doubling time is very low, signifying the level of commitment of the Nobel Laureates for research.

Values of the various Scientometrics indicators show that all Nobel Laureates had maintained a consistent productivity during the period of their productive life. All the Nobel Laureates worked in collaboration in various degrees. The mode of publication of the scientific work has been through articles, though other modes like boo, book chapters, conference papers, editorials, erratum, letters, notes, reviews, short surveys have also been used.

Regarding the number of citations, it is observed that the articles published by the Nobel Laureates have been cited by later researchers in their works. The Nobel Laureates have had a huge impact on the future generations and their works have truly enriched the scope and knowledge of chemistry.

Analysis of the Hirsch Index also indicates the high citations received by the scientific production of the authors. Several of the published papers have been published in top scientific journals and have also been cited by future researchers.

12. Conclusion

The Scientometric study is an open area of research that is applicable for mapping and analyzing any subject field by author, publisher, institution & country using numbers of Scientometric indicators. The present study was an attempt to measure the scholarly communications of Nobel laureates of chemistry. However, a study is guaranteed to look into the different aspects of study such as comparative analysis of academic professionals of Chemistry, comparative study of chemistry Nobel laureates.

13. Road ahead for Future Research

The researchers can choose the journal to conduct the Scientometric study by using different criteria based on their statement of the problem. They can use different advanced software beside this Excel, Bibliometrix-R, and VosViewer to carry out advanced level data analysis.

1. For domain analysis, there are lots of categorization developed by every journal or scholarly database, it’s hard to select paper in this category. So there is scope to develop a single standard domain category for researcher.
2. There are lots of software for metric analysis, there is scope to develop a single software for this.
3. For old researcher/scientists, in respect of present indicator, researcher have scope to analysis of his/her scientific contribution of unsung researcher/scientists.
4. There is scope to develop new indicator.
5. Metric analysis with the help of Machine Learning and Artificial Analysis, its produce better result, so new researcher has scope to develop new tool for this.
6. There are other subject field are not study yet so researcher have scope to study in different subject field and domain.