SCIENTOMETRIC PORTRAIT OF NOBEL LAUREATE DR. C. V. RAMAN

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ABSTRACT

C. V. Raman, the well known physicist is widely recognised as a very successful scientist. His publications were analysed by year, domain, collaboration pattern, channels of communications used, key-words etc. The results indicate that the temporal variation of his productivity and of the types of papers published by him is of such a nature that he is eminently qualified to be taken as a 'role model' for the younger generation to emulate. He has to his credit 94 papers in 'Scattering of Light', 55 papers in 'Acoustics', 66 papers in 'Optics', 76 papers in 'Optics of Minerals and Diamonds', 89 papers in 'Physics of Crystals', and 85 papers in 'Floral Colours and Visual perception'

The highest collaboration coefficient was 1.0 during 1936-40. The first most productive decade was 1921-30 at the age 33-42 and the second most productive decade was 1956-65 at the age 68-77. The mean synchronous selfcitations rate for his publications was 15.05. Publication density was 22.95 and publication concentration was 10.00. 'Bibliograph of individual scientist does not follow Bradford's law'

1. INTRODUCTION

Chandrashekhar Venkata Raman was born on November 7, 1888 in the small village of Tiruvanaikaval near Trichinopoly in Tamil Nadu. He passed his matriculation at the age of 11 and passed F.A. at the age of 13. He passed his B A. In First Class at the age of 15 from Presidency College, Madras where he ranked first among the students and was awarded the gold medal for Physics. He passed his M.A. examination with highest distinctions when he was 18.

KEYWORDS/DESCRIPTORS :

C. V. Raman, Scattering of light, Acoustics, Optics, Optics of Minerals and Diamonds, Physics of crystals, Floral colours and visual perception, Bibliometrics, Scientometrics, collaboration, publication density, Publication Concentration, History of Science, Sociology of Science, Individual Scientist, Scientometric Portrait.

He became Assistant Accountant General in Calcutta in 1907 and served in tho Finance Department till 1917. He continued his research during his spare time at Indian Association for Cultivation of Science (IACS) which was founded by Mahendralal Sircar in 1876 on the model of Royal Institution of London. The independent research and the publications that resulted from it, lead to his being invited in 1917, to fill the newly established Palit Professorship of physics at the University of Calcutta. He held the Chair during 1917-1933 and actively pursued research on 'Acoustics' and 'Optics'.

Raman became Director, Indian Institute of Science, Bangalore in 1933 and served for a decade. He founded Raman Research Institute in 1943 and remained its Director till his death in 1970.

Raman established a Scientific Culture in India. He founded Indian Academy of Sciences in 1934. The main purpose of the Academy was to have a Scientific Journal in which he and his students could publish Scientific papers without depending on foreign journals. He also founded the 'Indian Journal of Physics'. Thus he was active scientific institution builder.

Raman dedicated throughout his life to tha advancement of Science in India. His work has been well documented [1—20]

Many honours and awards were bestowed on Raman in recognition to his contribution in the field of Physics. Important ones being :

1924 : Elected Fellow of the Royal Society, London
1928 : Matteueci Medal—Societa Installana Della Scienza
1928 : President, Indian Science Congress
1929 : Knighted by the British Government in India
1930 : Hughes Medal—Royal Society, London
1930 : Nobel Prize—Stockholm, Sweden
1934 : President, Indian Academy of Sciences
1935 : Rajasabhabhusana—Decoration by the Maharaja of Mysore

1941 : Franklin Medal, USA
1947 : Corresponding member, Soviet Academy of Sciences
1948 : National professor
1949 : Foreign Associate, Paris Academy of Sciences
1954 : Bharat Ratna—Decoration by the President of india
1957 : International Lenin Prize, USSR

He was also Honorary Fellow of Several National and International scientific Academics. Many Indian Universities also bestowed on him Honorary Doctorates.

Many of our Schools, Colleges and Universities have not made a serious attempt to include 'Role Models' or ideal personalities in science curriculum to enthuse and inspire the younger generation, so as to aspire for the career of a scientist. This article is just such an attempt in the direction to inculcate scientific temper and encourage research even under limited facilities. Indeed C V. Raman is the outstanding example of outstanding work carried out under very very limited facilities. More than costly equipment and infrastructure ideas and dedication to hard work even during leisure time is essential.

2. OBJECTIVES :

Objectives of present work are to highlight quantitative aspects of the research communications :

—authorship pattern,
—domainwise contribution,
—author productivity,
—use of Channels of Communication, and
—documentation of keywords from titles.

3. METHODOLOGY :

Scientometrics is a branch of the science of science (Consciousness of Science). Scientometricians deal with, (1) explaining output in terms of organizational structure and resource inputs; (2) developing benchmarks to evaluate the quality of information sources; (3) packaging of information for

Science policy decision making; (4) defining appropriate data aggregation procedures and methods for diachronic analysis; (5) empirically describing the constantly changing relationships between science, technology and the market; and (9. forecasting productivity of scientists, so that dynamics of scientific research and technological development can be understood.

Scientific publication, seems to provide the best available basis for measuring research output. One of the first writers to suggest scientific publication as a measure of research productivity was Nobel Laureate William Shockley, who was interested in measuring research productivity among individuals within a group by analysing their publications.

The informing activities of a core research group can be evaluated quantitatively (how many publications) and qualitatively (where they are published). The informing activities of C. V. Raman's Research Group [21] were considered for the present study. The entries in the bibliography were arranged in a classified order under the following domains :

A. Scattering of Light
B. Acoustics
C. Optics
D. Optics of Minerals and Diamonds
E Physics of Crystals
F Floral Colours and Visual Perception

Normal count procedure [22] was followed. Full credit was given to each author regardless of whether he happens to be the first or the last author. It is widely recognised that scientists all over the world look at their own papers exclusively in that way. Similarly titles of the articles were analysed and one score was alloted for each keyword, subject, journal etc.

The degree of collaboration [23] in a descipline was defined as the ratio of the number of collaborative research papers to the total number of research papers published in the descipline during a certain period of time.

Vinkler [24] defined publication density as the ratio of the total number of papers published to the total number of journals in which the papers were published, and publication concentration as the ratio in percentage of the journals containing half of the papers published to the total number of journals in which those papers were published during the period under study.

Frequency of keywords from the titles of the articles were recorded. Data obtained from above study were presented in tables and figures.

4. RESULTS AND DISCUSSIONS

During 1906-70, C. V. Raman has published 465 papers out of which single authorship papers were 324 (69.68%), two authorship papers were 138 (29.68%), and three authorship papers were three (0. 64%).

Frequencies of single authorship and multiauthorship papers, cumulative number of papers, and collaboration coefficient are depicted in Figure 1. Latent phase of his research productivity in terms of number of papers published was up to 1906-17. His first paper was published when he was of 18 years old in the Philosophical Magazine (London) in 1906 while he was studying at the college. Rayleigh's 'Theory of Sound' and Helmoltz's 'Sensations of Tones' influenced Raman profoundly. As soon as he got Palit Professorship in 1917 his continuous publications started showing visibility so linear phase was observed. While working at IACS he discovered in 1928 the "Raman Effect" for which he was awarded the 'Nobel Prize' in 1930.

Raman spectra provide information on molecular vibrations and/or rotations complementary to that obtained from infrared spectra. Lasers are utilized as the source of radiation in the far infrared visible region. This technique can be used to study metal bonding, ring compounds, steroids, and a long chain molecules, among others [25].

He became Director of Indian Institute of Science in 1933. He attracted many young talents in the country and became "infective agent" for research ideas, enthusiasm, experimentation, hard work, encouragement and patriotism which resulted in epidemic phase of physics communications [26]. His highest collaboration coefficient (1.0) was found while working at I. I. Sc. during 1936-40 as he had published all (31) multiauthorship papers. Second peak of high collaboration coefficient (0.74) where he had 29 multiauthorship papers which was observed during 1951-55.

Generally positive relationship exists between collaboration and quality [27]. Gains from collaboration may be apparent by more productive quantitative output of Scientific Knowledge, more efficient use of scientific technology and more subjective involvement of individuals in the research output process.

First peak of single authorship papers was during 1921—25 having 39 papers. Second peak of single authorship papers (37) was observed during 1056—60. He has published highest number of single authorship papers (95) during 1961-65 while working as Director of Raman Research Institute.

First peak of multiauthorship papers (30) was observed during 1926-30. Second peak of multiauthorship papers (31) was observed during 1936-40 which was middle period of his research career life.

When we consider total number of papers published, the decade 1921-30 was most productive (at his age 33-42) having 115 papers during the period. Second most productive decade was during 1956-65 (at his age 68-77) during which he had published 133 papers.

This agrees with various scholars who have noted a growing trend towards multiple authorship of scientific papers [28-31]. Later studies [32] found, instead of one peak the productivity of researchers was shown to have two modes. One before the age of 40 and second around the age of 50. Researchers, it was suggested, may reach one type of plateau for Innovative work. and then, at a later age a second plateau for integrative work. Veteran R & D professionals will consist of those who devote most of their time to administration and those who are still active in technical work. The two mature types are basically similar in academic background and in their readiness to develop products, but they differ in their commitments to the scientific community and in the desire for greater extrinsic rewards [33].

The general finding [34-37] was that scientists publish most frequently in their fourth decade of life and there after publication rate drops. Zuckerman [38] compared age distribution of American Nobel Laureates in science with the age distribution of American Scientists in general. The majority of the Nobel laureates were relatively young when they had made their prize winning discovery, but the majority of American scientists also were relatively young. Since the age distribution for laureates matched that for scientists in general, he concluded that when allowance is made for the number of scientists at different ages, younger scientists are not more likely to be creative. However, due to their greater numerical representation, younger scientists are responsible for substantially more important contributions than older scientists.

Lohman [39] found the majority of discoveries in science have come from individuals under the age of 40. The peak age for achievement differed between desciplines, ranging from 26-30 for chemistry to 36-40 for genetics, geology, physiology, and psychology. Scientists remain productive in the sense of publishing frequently, beyond 40, but what they then generate was less likely to have impact. His general conclusion was that genius does not function equally well throughout the years of adulthood. Superior creativity rises rapidly to a maximum which occurs usually in the thirties and then falls of slowly. Einstein was reported [40] to have said of scientists that "a person who has not made his great contribution to science by the age of thirty will never do so".

The "success breeds success" phenomenon has its limits, [41] a saturation takes place and instead of accelerating of a production rate, prolific authors are satisfied with their position and produce less than could be expected from Lotka's law. Whereas Allison and Stewart [42] stated that among highly skewed distribution of productivity among scientists could be partly explained by a process of accumulative advantage. The publication productivity was found to be increasingly unequal as the career age increased.

Studies of stratification in science have increasingly accepted the idea that science is a highly stratified and elitist system with skewed distributions. Attempts to explain in the higher productivity of higher status scientist by pointing to their greater ease of publication as far as acceptance of their work by journals and publishers is concerned were not supported by the data in some recent studies if status in general does not confer greater ease of publication in the paper [43] position within a research organization do: confer greater ease of author or coauthorship and this was the major explanation variable accounting for productivity difference within research laboratories as far as quantity of articles was concerned. Upward moves in laboratory's formal or informal position heirarchy were associated with a change of a scientist's research involvement from goal executing to goal setting functions as well as with an increasing access to scientific manpower and project money. Goal setting tasks provided for a significant reduction of time expenditures in research necessary to assure that the scientist was identified with the research results; consequently, they allowed for an involvement in more research tasks than originally. Equivalently, resources in secientific manpower and project money act as a multiplying element as far as quantity of output was concerned

Domainwise contributions indicate that he has published 94 papers in the domain "scattering of light" in the domain

"Acoustics" he had 55 publications out of which 25 papers belong to 'Vibrations and wave motion'. 14 papers were pertaining to 'Musical Instruments:-The Violin and pianoforte'. His papers on 'Musical Instruments of India' were six. He had nine papers in 'ultrasonics'. He had to his credit a monograph on 'Musical Instruments and their Tones' published in 1927 in Handbuch der physik.

In the domain "Optics" he had published 66 papers.

In the domain of "Optics of Minerals and Diamonds he had published 76 papers out of which 39 papers belong to 'The colour and optics of Minerals'. 16 papers on 'The Diamond', and 21 papers were Miscellaneous'.

In the domain of "physics of crystals" he had 89 papers to his credit out of which 14 papers belong to 'Diffuse X-ray Reflections', 12 papers belong to Dynamics and Crystal Lattice'. He had published four papers on 'Elasticity of Crystals', and 59 papers pertaining to Vibrational and Thermal Energy of Crystals.

In the domain of "Floral Colours and Visual perception" he had to his credit 85 contributions out of which 18 belong to 'Light, Colour and Vision', and 66 papers belong to 'Floral colours and Vision'. He had published a monograph on 'physiology of Vision, also.

The domainwise publication productivity is shown in Figure 2. The domainwise collaborators and their contributions in co-authorships with C. V. Raman are provided in Table 1 in Chronological order of association. Out of 38 collaborators of C. V. Raman highly productive K S Krishnan was collaborator in 21 papers published during 1926-29 which was the most creative period of C V. Raman at the age of 38-41. It was this period of work which raised C. V. Raman at the summit level of international recognition. Other active collabarators were N. S. Nagendra nath (14 papers) and A. Jayaraman (13 papers).

The researchers association with C. V. Raman is visualised in Figure 3 in relation to number of authorships. Indeed C. V. Raman was highly influential as 'Mentor' [44].

three papers each. Six authors had collaborated in

Like many natural phenomenon, the growth of scientific knowledge appears to be cluster like. This seems to be true in physical sense. On a special scale scientific discussion mainly cluster around important Universities, governmental and research Institutions. On temporal scale, scientific discoveries often occur in a relatively short period of time since an impotant break-through makes new advancement possible.

Author productivity and distribution or authors by domains is given in Table 2. Total authorships of the group were 609. Authors having only one paper to their credit in collaboration with C. V. Raman were 13. Seven authors had collaborations in two papers each. Four authors had collaborated in four papers each. One author had collaborated in five papers with C. V. Raman Three authors had collaborations in six papers each. Other prominent collaborators are indicated in the Table 2.

In the present case study, C. V. Raman had used 20 journals as channels of his communications (Table 3). The publication density was 22 95 and publication concentration was 10·00. Top rainking journals publishing papers of C. V. Raman were 'prdceedings of the Indian Academy of Sciences—A, (202) during 1934-66. 'Nature' had published 90 papers. 'Current Science' which is considered to be 'Nature of India' had published 65 papers. His 291 papers were published in Indian Journals. Thus he started research and publication culture, indipendent scientific tradition' in India at a time when Indian researchers were interested to publish papers in foreign journals only [45]. Ofcourse Britishers Influence in India in using Indian talent to solve their research problems had created the research minded dedicated professionals and C. V Raman was leading among them [46-49]. He thus created due status to Indian journals at the international science publication activities. He had contributed 151 papers to journals published from UK indicating the high productivity through British journals He had published 15 papers in journals published from US. He had published one paper each in journals from France and Germany. The bibliograph; on contributions of C. V. Raman is provided in Figure 4.

Journalwise productivity is given in Table 4. Articles in journals are the most used vehicles in contemporary science and reflect a high degree of integration and evalution done by scientific community.

When we apply Bradford distribution (Table 5) indicate that very high concentration of his publication in Zone-I, having 202 papers in only one journal. When we split remaining papers in Zone II having 135 papers in two journals, and Zone III having 102 papers in 17 journals, which are not on par with Zone I and we are left with nil papers for Zone IV.

Since the present study deals with the microtheme about the profile of single researcher, the curves have not followed the Bradford's law of scattering of articles in channels of communication indicating at the tail end "Groos Droop" [50]. Our present study also aupports the views of Bonitz [51] who found that in the transition from a macroscopic into a microscopic field scientific commnnication invalidates the Bradford' law in case of single scientist. The effect seems to confirm a fundamental qualitative difference of both fields of scientific communication. Bradford's law applied for macrotheme like research output of an institute [52] Output based studies seem appropriate for studies of the Sociology of knowledge because they begin with corpous of written knowledge

Path analysis was done to know factors that foster productivity among national scientists in a large research laboratory [53]. In general educational level of the scientists has an important, positive impact on productivity. Years of service has a varying and more modest positive effect. Rank of the scientist has an intermediate positive impact on productivity. Psychological factors have a negligible effect. Finally, the influence scientist has on research endeavours has a modest positive impact on productivity

Domainwise synchronous self citations rate for the publications of C. V. Raman are provided in Table 6. Tne highest synchronous self citations rates were for the domains 'Floral Colours and Visual Perception' (26.92) and ' Physics of Crystals' (26.35) Mean Synchronous rate for all his publications was 15.05. This has sociological implications indicating that C. V. Raman was a highly productive and Key figure in his research speciality [54].

The bibliographic characteristics such as number of pages, visuals, tables and references per article in the publications of C. V Raman are provided in Table 7.

Keywords from the titles of the articles were counted and their frequencies, more than two, included in Table 8. Highest frequency of 64 was for the keyword Physiology of vision. Other keywords having high frequency were Diamonds (35), specific heats (30), crystals (26), scattering of light (23), Liquids (21), Diffraction of light (17), Florals colours (15), Optical behaviour (14), Spectroscopic behaviour(14), Infrared absorption(13), Alkali halides (12), High frequency sound waves (10), Perception of colour (10), and Vibration spectrum (10). The results indicate that he had wide ranging interests in microtheme and superspecializations in physics.

Keywords from the titles of the articles used only once are presented in Table 9. These keywords indicate his wide spectrum of interests materials, methods, instruments used, and the subjects addressed to in the course of his 65 years of research papers publishing life span

Max Perutz, one of Britain's most distinguished scientists in his book "Is Science Necessary : Essays on Science and Scientists" states : "In Science, as in other fields of endeavour, one finds saints and charlatans, warriors and monks, geniuses and cranks, tyrants and slaves, benefactors and misers, but there is one quality that the best of them have in Common, one that they share with great writers, musicians, artists : creativity". On the other hand there must be caution so as not to uphold orthodox scientists who are as adamant as religious fundamentalists on resisting new ideas destructive to some of their own pet theories and systems of thought. However, it takes belief in ones own ability and ideas, and courage to be a potential rising star and it takes a special kind of person like C V Raman to push out the frontiers of knowledge beyond the current state of the art.

A researcher is good if he or she surpasses the expectations of what he or she might achieve. But this is only possible if the focus is on work and the problem involves, and not on competition or success. The effectiveness of research or of running an institution depends primarily on the researcher himself, on models, and, within the institute itself, on the respect he shows his staff members, which in turn enables him to demand that they work to capacity [55] Scientists of all disciplines should learn from the humanities.

The duty of scientists and technologists is not only to conduct their own work at the highest possible level of quality but also to make the societies in which they live more aware of the power and climate of science. Since by definition, scientists and technologists are the first to know of scientific advances they can be described as the cartographers of the future. They must work to ensure that the public, and especially the public's leaders, understand the maps that they draw The options which are possible and sustainable, so that wise democratic decision can be taken [56]

Raman created new specialities which have wide ranging applications in many fields and research is being done in these specialities to explore the applications and uses of the principles enunciated by him. Specialities just cannot be created, It requires hard work, dedication and continuous intellectual intercourse among the people who seize concepts

A very few scientometric studies have been carried out on individual scientisists in India [57-65]. It is felt that more studies should focus attention on the functioning of research groups and their accountability in the economic crisis that the country is facing. Already there is decline in support for science and technology. India was investing 1.1 percent of the GNP which was reduced in 1991 to less than 0. 9 percent. As budgets for research are being restrained, a better allocation of the existing resources is necessary. A rational dirstribution of budgets according to the established priorities is of course needed in order to promote the desired areas of research. Nevertheless, while designing national priorities, the perception of the human scientific potential that a country has is as important as the funds for reseatch

Nagpaul and Gupta [66] have concluded after study of 1460 research units in six countries that professional competence is a necessary but not a sufficient condition for effective leadership; managerial competence is also required for effective leadership, but professional competence is much more important than managerial competence. This implies, inter-alia, that the quality of leadership can not be improved merely through management development programmes. It would also be essential and desirable to improve the level of expertise of the leaders through a package of incentives like sabbatical leave to enable them to work at centres of excellence within or outside the country and by inviting leading scientists from such centres to work in the research institutions.

Librarians have been invisible members of the science community for too long. Through the studies in the interdisciplinary domain of scientometrics they can show their visibility. Science librarians should begin to understand that their economic value is not to publishers so much as it is to the community of interests that we call research and development, national defense, industry, higher education, and national economy.

The librarianship profession should share the concern of educators, public servants, and scientists regarding the science literacy crisis [67]. To date, there has been relatively little written in the literature of librarianship about science literacy. The librarianship profession has to play its potentially significant role in the promotion of science literacy.

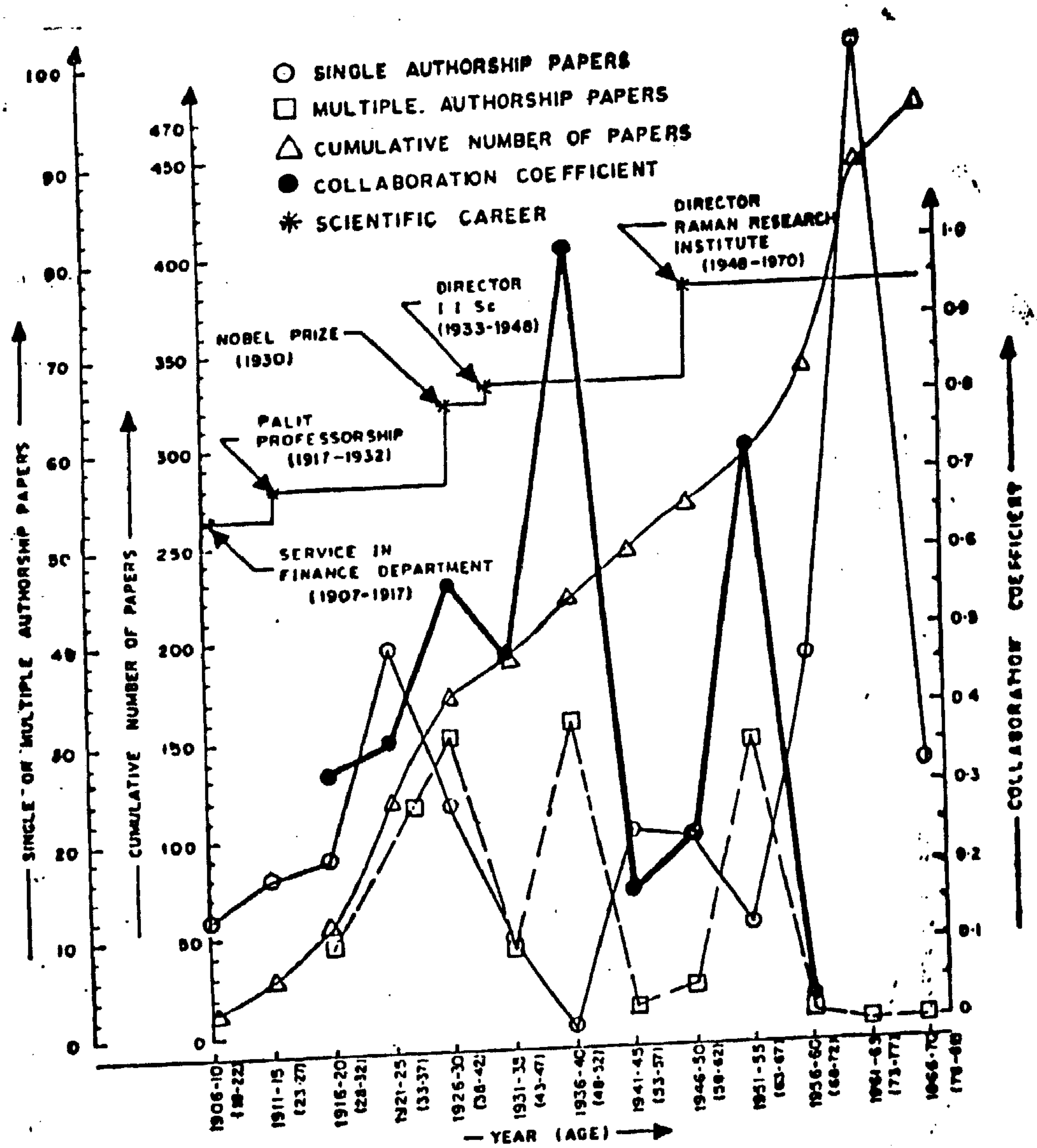

FIG. 1 : PUBLICATION PRODUCTIVITY OF C. V. RAMAN

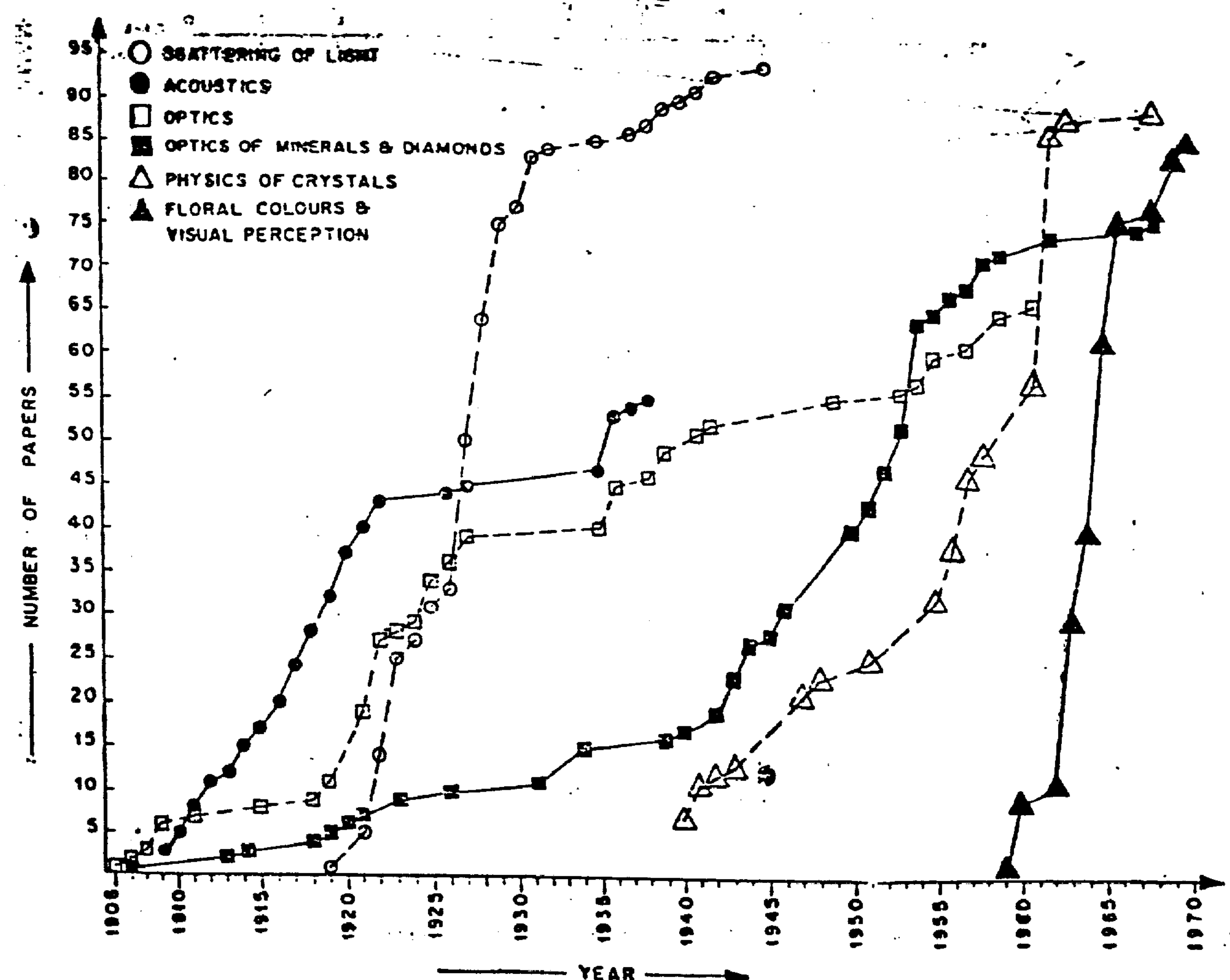

FIG. 2: DOMAINWISE PUBLICATION PRODUCTIVITY OF C. V. RAMAN

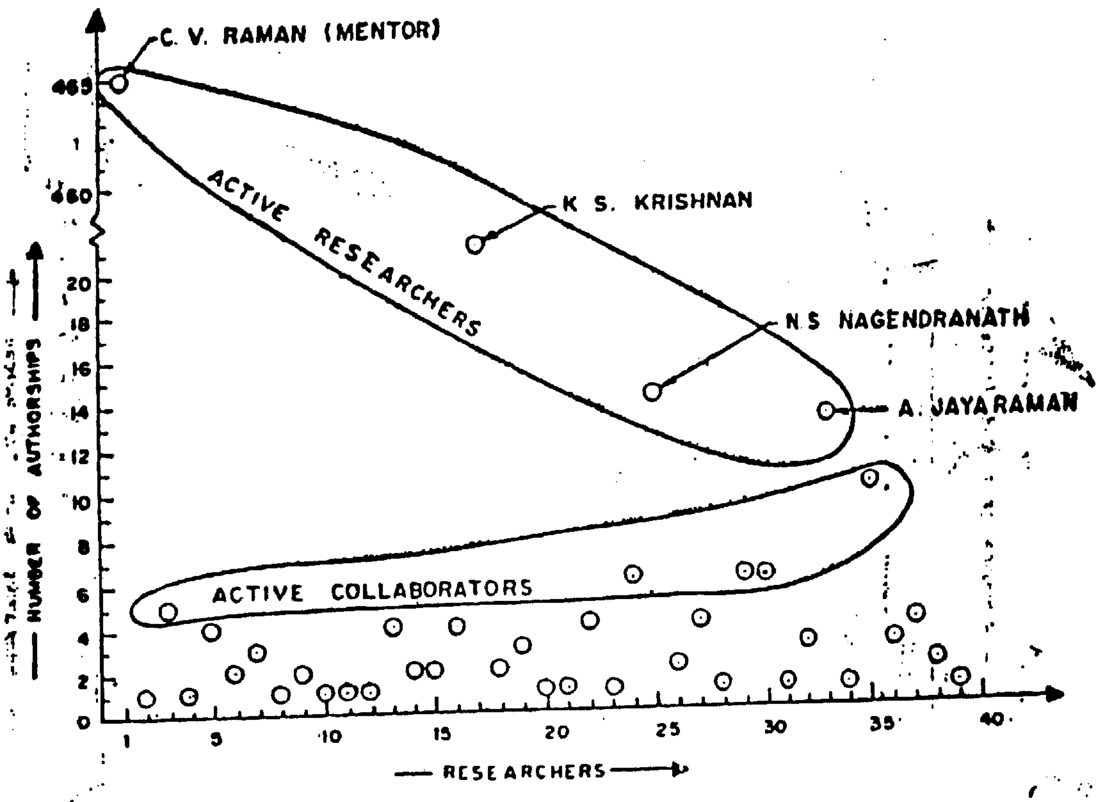

FIG 3 RESEARCHERS ASSOCIATION IN CHRONOLOGICAL ORDER OF OCCURRENCE

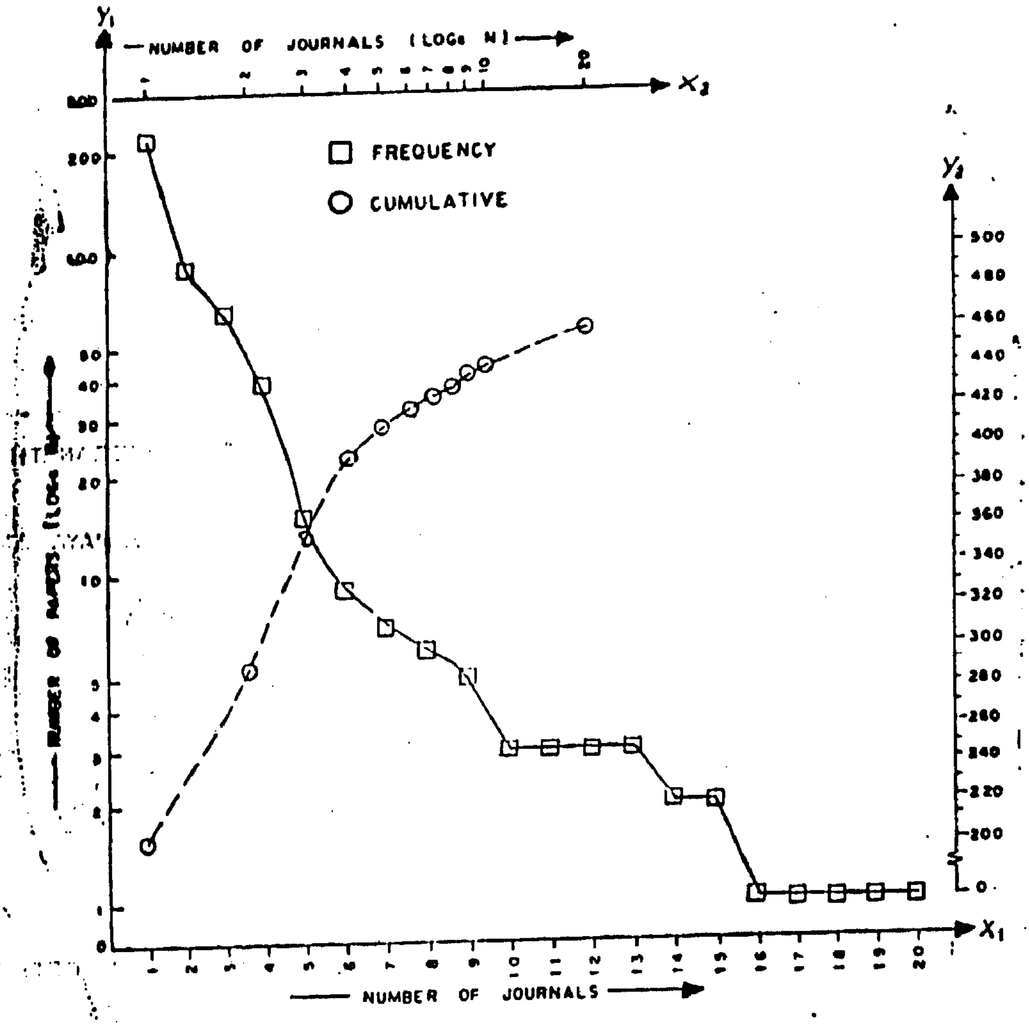

FIG. 4. BIBLIOGRAPH ON PAPERS OF C. V. RAMAN

5. CONCLUSION

Publications productivity analysis of the successful scientist C. V. Raman, carried out here has thrown light on his pivotal contributions to science and technology. He can be considered as a 'role model' for younger researchers to follow. Knowledge is valuable for its own sake and research has cultural values. Desire of being creative is built in our genes. Who knows this effort may switch on genes for creativity in some of those who happen to read this article. Narrating success stories always has an encouraging effect. It is also important to recognise that excellence in science is not just a matter of a few individual successes, what is required is a wide base of high quality, which would enable peaks to come up more frequently and on a more definite basis. New ways to motivate scientists seem as important to contest outcome as new sources of funds. Science policy makers interested to know about functioning of active research teams as centres of excellence and factors responsible for optimizing, maximising and enhancing outputs may find further interest in scientometrics. As per Indian Scientific Policy Resolution 1958, which our scientists regard as their charter, "to ensure that the creative talent of men and women is encouraged and finds full scope in scientific activity" all must work together with holistic approach.

There is no dearth of ideal role model scientists in India, what we lack is the systematic and continuous studies on such scientists. Hence. the comment "Most of the developing countries lack role models to motivate other scientists" [68] does not hold good at least for India.

It is further suggested that citation analysis of C. V. Raman's publications should be undertaken to assess the impact of his research.

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Table—2

Author Productivity and distribution of authors by domains

No of papers	Domainwise authorships A	B	C	D	E	F	No of authors	Total No. of authorships	Prominent collaborators
1	5	1	5	2	—	—	13	13	
2	1	4	7	2	—	—	7	14	
3	5	—	6	1	—	—	4	12	
4	14	1	7	—	2	—	6	24	
5	—	5	—	—	—	—	1	5	
6	3	3	4	2	6	—	3	18	
10	—	—	—	9	1	—	1	10	Krishnamurti, D.
13	—	—	—	13	—	—	1	13	Jayaraman, A.
14	—	6	6	—	2	—	1	14	Nagendranath, N. S.
21	19	—	2	—	—	—	1	21	Krishnan, K. S.
465	94	55	66	76	89	85	1	465	Raman, C. V.
Total	141	75	103	105	100	85	39	609	
Percentage	23.15	12.32	16.91	17.24	16.42	13.96			
Cumulative percentage	23.15	35.47	52.38	69.62	86.04	100.0			

A=Scattering of Light, B=Acoustics, C=Optics, D=Optics of Minerals & Diamonds, E=Physics of Crystals, and F=Floral Colours and Visual Perception

Table—3

Journalwise Scattering of publications of C. V. Raman

Sl. No	Journal	No. of papers	Percentage	Cumulative percentage	Period of journal usage FPY—LPY	Total	Country of publication
1.	Proc. Indian Acad. Sci. A	202	44.00	44.00	1934—1966	33	India
2.	Nature	90	19.61	63.61	1907—1945	39	UK
3.	Curr. Sci.	65	14.16	77.77	1940—1970	31	India
4.	Philos. Mag.	39	8.49	86.26	1906—1929	24	UK
5.	Proc. R. Soc. (London)	15	3.27	89.53	1919—1939	21	UK
6.	Phys. Rev.	9	1.96	91.49	1911—1920	20	US
7.	Bull. Indian Assoc. Cult. Sci.	7	1.53	93.02	1912—1922	11	India
8.	Indian J. Phys.	6	1.31	94.33	1927—1931	6	India
9.	Proc. Indian Assoc. Cult. Sci.	5	1.09	95.42	1920—1926	7	India
10.	Trans. Opt. Soc. (London)	3	0.65	96.07	1925—1927	3	UK
11.	J. Opt. Soc. Am.	3	0.65	96.72	1926—1939	14	US
12.	Astrophys. J.	3	0.65	97.37	1922—1924	3	US
13.	Proc. Phys. Soc. (London)	3	0.65	98.02	1926—1930	5	UK
14.	J. Indian Math. Club	2	0.44	98.46	1909—1910	2	India
15.	Bull. Calcutta Math. Soc.	2	0.44	98.90	1913—1914	2	India
16	C. R. Acad. Sci. (Paris)	1	0.22	99.12	1927—1927	1	France
17.	J. Dept. Sci. Univ. Calcutta	1	0.22	99.34	1919—1919	1	India
18.	J. Madras Univ.	1	0.22	99.56	1957—1957	1	india
19.	Trans. Faraday Soc.	1	0.22	99.78	1929—1929	1	UK
20.	Z. Phys.	1	0.22	100.00	1925—1925	1	Germany
	Total	459					

FPY=First paper publishing year, LPY=Last paper publishing year

Toble-4

Distribution of articles on Bradford's law of scatter among journals for papers of C. V. Raman

C	CH	CH.C	Σ CH.C
1	5	5	5
2	2	4	9
3	4	12	21
5	1	5	26
6	1	6	32
7	1	7	39
9	1	9	48
15	1	15	63
39	1	39	102
65	1	65	167
90	1	90	257
202	1	202	459

C = Communications or No. of publications

CH = Channels of communications

CH.C = Total communications

Σ CH.C = Cumulative total communications

Table 5

Bradford distribution (Four zones) for publications of C. V. Raman

Zone	No. of papers	No. of journals	Bradford multiplier
Zone I	202	1	—
Zone II	155	2	0.5
Zone III	102	17	8.5
Zone IV	—	—	—

Average Bradford muitiplier (b^{-}) = 4.5

Table-6

References cited by C. V. Raman

Domain	No of Citations	No. of self citations	synchronous self citation rate
A	449	25	5.56
B	317	37	11.67
C	279	55	19.71
D	224	44	19.64
E	239	63	26.35
F	26	7	26.92
Total	1534	231	15.05

A = Scattering of Light, B=Acoustics, C= Optics,
D =Optics of Minerals and Diamonds,
E = Physics of crystals. and
F = Floral colours and Visual perception

Table 7

Bibliographic characteristics of papers of C. V. Raman

Feature/Domains	Range	Mean	S. D	SEm
No. of pages				
A	1-89	6.44	10.69	1.10
B	1-158	10.96	12.70	1.71
C	1-160	8.15	19.43	2.30
D	1-24	7.05	4.11	0.47
E	2-22	8.52	4.58	0.48
F	1-110	6.80	11.77	1.27
No. of Visuals				
A	0-13	1.07	2.30	0.23
B	0.54	5.70	9.76	131
C	0-74	4.24	0.09	1.11
D	0-46	11.00	11.24	1.29
E	0-39	3.76	6.22	0.65
F	0-18	1.88	2.55	0.27

No. of Tables				
A	0-9	0.81	1.76	0.18
B	0-3	0.05	0.40	0.05
C	0-6	0.17	0.94	0.11
D	0-2	0.19	0.51	0.05
E	0-15	1.48	2.65	0.28
F	0-2	0.05	0.26	0.02
No. of References				
A	0-64	4.78	9.29	0.95
B	0-162	5.76	21.59	2.91
C	0-96	4.23	9.79	1.20
D	0-20	2.95	4.56	0.52
F	0-32	2.69	5.26	0.55
F	0-18	0.31	2.03	0.22

Domains : A=Scattering of Light (N=94),
B=Acoustics (N=55), C=Optics (N=66),
D=Optics of Minerals and Diamonds (N=76),
E = Physics of Crystals (N=89), and
F = Floral Colours and Visual Perception (N=85)

Table 8

Keyword frequencies in the titles of papers by C. V. Raman

Keyword	Frequency
Physiology of vision	64
Diamonds	35
Specific heats	30
Crystals	26
Scattering of light	23
Liquids	21
Diffraction of light	17
Floral colours	15
Optical behaviour	14
Spectroscopic behaviour	14
Infrared absorption	10

Keyword	Frequency
Alkali halides	12
High frequency sound waves	10
Perception of colour	10
Vibration spectrum	10
X-ray reflections	9
Crystal structures	8
Molecular scattering of light	8
Infrared behaviour	7
Perception of light	7
Iridescence	6
Quantum theory	6
Rock salt	6
Christiansen experiment	5
Luminescence	5
Musical drums	5
Potassium Chlorate	5
Retina	5
Vibrations	5
Amethyst quartz	4
Amorphous solids	4
Birefrigence	4
Colour	4
Compton effect	4
Conical refraction	4
Diffraction of X-rays	4
Doppler effect	4
Fluorite structure	4
Iridescent shells	4
Magnesium oxide	4
Metallic elements	4
Molecular stucture	4
Thermal agitation	4
Wolf-note	4
Anisotropic molecules	3
Astronomical research-India	3

keyword	Frequency
Bowed strings	3
Colour of the Sea	3
Colour vision defects	3
Corpuscles of light	3
Crystal physics	3
Discontinuous wave motion	3
Dynamical theory	3
Forced oscillations	3
Liquid boundaries	3
Liquid mixtures	3
Liquid state	3
Optical anisotropy	3
Maintenance	3
Percussion figures	3
Periodic field of force	3
Raciant spectrum	3
Spectrum of neutral helium	3
Spin of the photon	3
Surface tension	3
Vision in dim light	3
Visual pigments	3
Whispering galleries	3
Acoustic spectrum	2
Amplitude changes	2
Biaxial crystals	2
Birefringence patterns	2
Bowed stringed instruments	2
Carotenoid pigment	2
Coherence phenomena	2
Colour of vegetation	2
Colours of roses	2
Crystalline carbonates	2
Crystalline solids	2
Diamagnetism	2

Keyword	Frequency
Diffusion haloes	2
Einstein's aberration experiment	2
Elasticity of crystals	2
Electric double-refraction	2
Fluid viscosity	2
Gases and vapours	2
Gypsum-Polycrystalline forms	2
Haidinger's rings	2
Huyghen's principle	2
Integration of colour	2
Iridescent feldspars	2
Isotropic solids	2
Light	2
Lithium fluorides	2
Magnetic double-refraction	2
Maintenance of vibrations	2
Motion of bowed strings	2
Motion of nodes	2
Musical instruments	2
Musical tones	2
Napthalene crystals	2
Neodymium filter	2
New radiation	2
Optical anisotrophy of molecules	2
Organic compounds	2
pearls	2
polarity of molecules	2
polarisation effects	2
Quartz	2
Science—Eastern Europe	2
Secondary radiation	2
Small motion	2
Sodium fluorides	2
Solid state	2
Spectral characters	2

Keyword	Frequency
Spectrum	2
Synthesis of colour	2
Total reflection	2
Trichromatic hypothesis	2
Ultrasonic waves	2
Vibrating strings	2
violin-player	2
viscosity of liquids	2
Visibility of distant objects	2
Vision	2
wave theory of light	2
X-ray diffraction	2

Table 9

Keywords used only once in the titles of papers by C. V. Raman

Absorption photometer
Absorption of radiation
Acoustical experiments
Acoustical knowledge
Activity of the normal modes
Adiabatic piezo-optic coefficient.
Agate-iridescence
Alpha-beta transformation
Ancient decomposed glass
Ancient hindus
Angular momentum of light
Anomolous diamagnetism
Anomolous dispersion
Asters
Atomic vibration
Atomic vibration spectra
Atmosphere
Atmosphere of the earth
Atoms and molecules
Avogadro constant
Band spectra
Benzene
Benzene derivatives
Binary liquid mixture
Birefringent powders
Blue
Blue dephiniums
Body colours
Bougainvillea
Breathed-onplates-colours
Brewster's bands
Calcite-tridescence
Carbon dioxide
Ceylon moonstones
Characteristic frequencies
christiaan Huyghens
Chromatic diffusion halo
Chromatic responses
Colloidal solutions
Colour anisotropy
Colour of flowers
Colour of fluorspar
Colour of gemstones
Colour of ice in glaciers
Colour photography
Colour triangle
Colour vision testing
Colours of interference
Colours of iolite