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SCIENTOMETRIC PORTRAIT OF NOBEL LAUREATE HAROLD W. KROTO

*B.S. Kademani**, *V.L. Kalyane** and *Vijai Kumar**

Scientometric analysis of 190 publications by Harold W. Kroto, the Nobel laureate in Chemistry (1996) published during 1985 - 2000 in domains: Fullerenes (109), Cluster Science (39), Spectroscopy of Unstable Species and Reaction Intermediates (8), Astrophysics (16), and Non Carbon Nanostructures (18) were analysed for authorship pattern with his 181 collaborators. Highest collaborations were with D. R. M. Walton (142), R. Taylor (90), J. P. Hare (60), K. Hsu (53), M. Terrones (48), A.D. Darwish (36), P.R. Birkette (35) and H. Terrone (35). His productivity coefficient was 0.68 which clearly indicates that his productivity increased after 50 percentile age of his 16 years of research publication career. His highest collaboration coefficient (1.00) was found in 1985,1993,1995,1996,1998 - 2000. Publication concentration was 4.5 and publication density was 3.05. Average Bradford multiplier was 3.5. The core journals publishing his papers were: J. Chem. Soc. Chem. Commun.(23), Chem. Phys. Lett. (20), J. Chem .Soc. Perkin Trans.-2 (15), and Nature (10) out of 59 journal and 13 other channels . Most prolific keywords in titles were: C60/Fullerenes/[60] Fullerene/Buckminsterfullerene, C70/[70] Fullerenes, Formation, and Characterisation.

KEYWORDS/DESCRIPTORS: Scientometric portrait; Scientometrics; Individual scientist; Publication productivity; Research collaboration; Bio-bibliometrics; History of science; Sociology of science; Fullerene science and technology

1 INTRODUCTION

Individual scientists including the Nobel laureates are becoming the focus of scientometric studies rather than gross statistical "macro" data [1]. The Nobel prize is regarded as the most honorific recognition of scientific achievement. The prestige of the Nobel prize is so great that it enhances the standing of nations and institutions as well as the reputation of its "laureates"[2-4] .

The Royal Swedish Academy of Sciences awarded the 1996 Nobel Prize in Chemistry jointly to Harold W. Kroto (University of Sussex, Brighton, England), Robert F. Curl (Rice University, Houston TX, USA) and Richard E. Smalley (Rice University, Houston TX, USA).

During an intense working week in the autumn of 1985, Robert F. Curl, Harold W. Kroto and Richard E. Smalley made the completely unexpected discovery that

* Library and Information Services Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400 085, INDIA.

the element carbon can also exist in the form of very stable spheres. They termed these new C60 molecule's structure as buckminsterfullerene or buckyballs for short which resembled the geodesic domes designed by American architect R. Buckminster Fuller. Fullerenes now constitute the fourth major form of carbon, along with graphite, diamond, and amorphous carbon. The discovery and synthesis of fullerenes [5-14] created a new and extremely active branch of chemistry in the early 1990s. Chemists have now developed thousands of fullerene variations, including sturdy tube like and wire like structures of fullerenes that can be made to carry other atoms, bringing the promise of important applications in industry and biomedicine.

After the discovery of Fullerenes in 1985, there is an information explosion in the field of Fullerene science and technology. Tibor Braun [15] et al., have conducted a quantitative study of fullerene sciences for the period 1985 to 1998, which includes year-wise number of papers, countries working in this field, distribution of articles in different journals, highly productive scientists, international collaboration, and citation impact of the papers. A new journal dedicated to Fullerenes , the "Fullerene Science and Technology: An International and Interdisciplinary Journal" was launched in 1993 to provide a platform for international communications on Fullerene research.

2 OBJECTIVES

Harold W. Kroto was taken as a case study for present scientometric analysis Biographical details [16] and a brief resume (Appendix - 1) are well known.

This study highlights Harold W. Kroto's

- domainwise contributions,
- domainwise authorships,
- prominent collaborators,
- use of channels of communications, and
- documentation of keywords from titles of the papers

3 MATERIALS AND METHODS

Scientific publications seem to provide the best available basis for measuring the research output. One of the first writers to suggest scientific papers as a measure of research productivity was Nobel laureate William Shokley [17] who was interested in measuring the research productivity among individuals within a group by analyzing their publications. A few scientometric studies on Nobel laureates [18-27] and others [28-42] have been published.

The complete bibliography of research publications by Harold W. Kroto (1985 -2000) was obtained from Emma Jones , the personal secretary of H.W. Kroto. Present study is limited to the 190 papers by Harold W. Kroto. The bibliographic fields were analysed by Normal Count Procedure [43] for domains, authorships, journals, and keywords in the titles .

4 RESULTS AND DISCUSSION

4.1 Domainwise contributions

Harold W. Kroto had research communications in the following domains:

A = Fullerenes (Chemistry , Physics, and Materials Science) ;
B = Cluster Science (Carbon and Metal Clusters, Micro Particles, and Nanofibres) ;
C = Spectroscopy of Unstable Species and Intermediates (Infrared, Photoelectron, Microwave, and Mass Spectrometry) ;
D = Astrophysics (Interstellar Molecules and Circumstellar Dust); and
E = Non Carbon Nanostructures.

Domainwise cumulative publication productivity during 1985 - 2000 is depicted in Fig.1. Harold W. Kroto had contributed 109 papers in the domain Fullerenes (1985 - 2000) followed by 39 papers in domain Cluster Science (1985 - 2000), 18 papers in domain Non Carbon Nanostructures (1996 - 2000), 16 papers in domain Astrophysics (1986 - 1997), and eight papers in domain Spectroscopy of Unstable Species (See Fig. 1)

4.2 Collaboratorship

Domainwise authorship pattern and number of publications and authorships in each domain are presented in Table 1. Six - authored Fullerenes papers were 22, followed by five papers in Spectroscopy of Unstable Species and Reaction Intermediates. One paper each in Cluster Science, and Non Carbon Nanostructures. Seven - authored Fullerenes papers were 13, followed by five papers in Cluster Science, and two papers in Non Carbon Nanostructures. Five-authored Fullerene papers were 11, followed by four papers in Cluster Science, and one paper in Astrophysics . Nine - authored Fullerenes papers were 11, followed by two papers

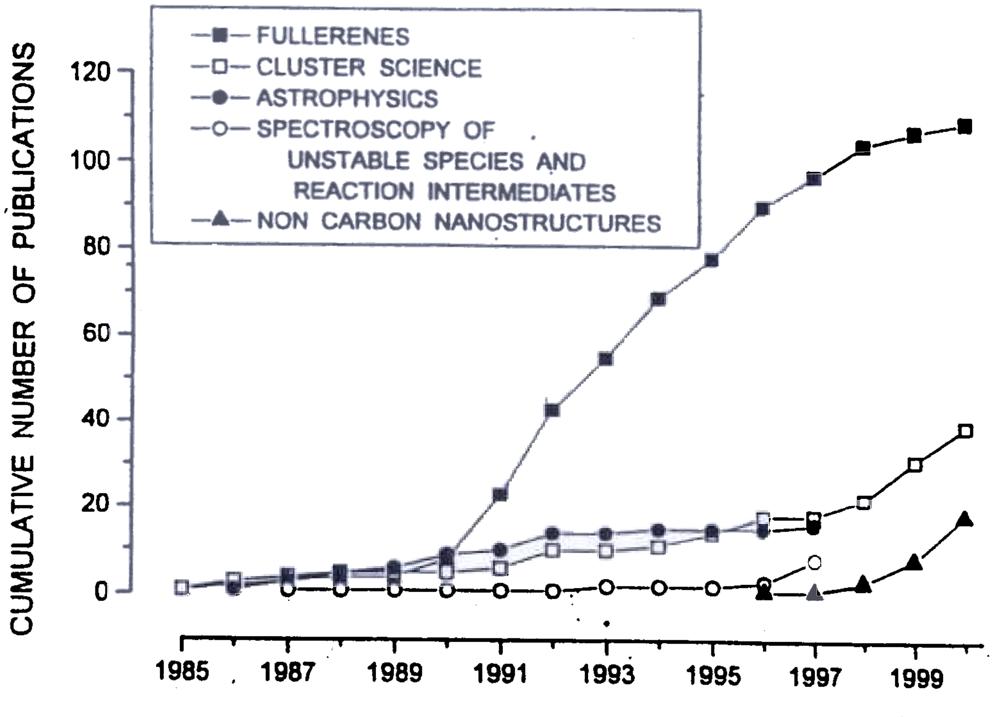

Fig.1. Domainwise publication productivity of Harold W. Kroto

each in Cluster Science, and Non Carbon Nanostructures. There was only one nine-authored paper in Spectroscopy of Unstable Species and Reaction Intermediates. Four- authored 10 papers were in Fullerenes, followed by three papers in Cluster Science, and one paper in Astrophysics.

Table 1: Domainwise productivity of number of papers and authorship pattern of the Nobel laureate H . W. Kroto (1985 -2000)

No. of following authored papers	Domains A	B	C	D	E	Total No. of papers	%	Total No.of authorships	%
1 - authored papers	11	1	-	8	-	20	10.54	20	1..58
2 – authored papers	3	2	1	5	-	11	5.78	22	1.74
3 – authored papers	5	2	-	1	-	08	4.21	24	1.89

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Table 1 Contd....

No. of following authored papers	Domains					Total No. of papers	%	Total No.of authorships	%
	A	B	C	D	E				
4 – authored papers	10	3				14	7.37	56	4.43
5 – authored papers	11	4				16	8.42	80	6.31
6 – authored papers	22					29	15.26	174	13.73
7 – authored papers	13	5			2	20	10.54	140	11.05
8 – authored papers		2			5	14	7.37	12	8.83
9– authored papers	11	2				16	8.42	144	.37
10 – authored papers		5			2	12	6.31	120	
11 – authored papers	5	4			3	12	6.31	132	
12 – authored papers						02	1.05	24	.89
13 – authored papers	5	4				10	5.26	130	10.26
14 – authored papers						02	1.05	28	2.21
15 – authored papers						03	.58	45	3.56
16 – authored papers						01	0.53	16	.26
Total	**109**	**39**	**8**	**16**	**18**	**190**	**100.00**	**1267**	**100.00**
Percentage	57.37	20.52	4.21	8.42	9. 48	100.00			
Collaboration coefficient	0.10	0.02	1	0.5	1	0.10			
Authorships per paper	6.38	7.92	7.12	1.87	9.72	6.67			

(A = Fullerenes; B = Cluster Science; C = Spectroscopy of Unstable and Reaction Intermediates; D = Astrophysics E = Non Carbon Nanostructures)

Ten - authored five papers each were in Fullerenes and Cluster Science, followed by two papers in Non Carbon Nanostructures. Eleven - authored five papers were in Fullerenes, followed by four papers in Cluster Science, and three papers in Non Carbon Nanostructures. Three - authored five papers were in Fullerenes, followed by two papers in Cluster Science, and one paper in Astrophysics. Two - authored five papers were in Astrophysics, followed by three papers in Fullerenes, two papers in Cluster Science, and one paper in Spectroscopy of Unstable Species and Reaction Intermediates. Ten - authored five papers were in Fullerenes, followed by four papers in Cluster Science, and one paper in Spectroscopy of Unstable

Species and Reaction Intermediates. Sixteen - authored one paper was in Cluster Science , fifteen - authored three papers were one each in Fullerenes, Cluster Science, and Non Carbon Nanostructures ; and fourteen - authored two papers one each in Cluster Science and Non Carbon Nanostructures were observed.

H. W. Kroto had 20 single - authored papers in various domains as Fullerenes(11), Astrophysics(8), and Cluster Science (1). Year wise productivity of Harold W. Kroto is shown in Fig.2. He published his first two papers in the year 1985.

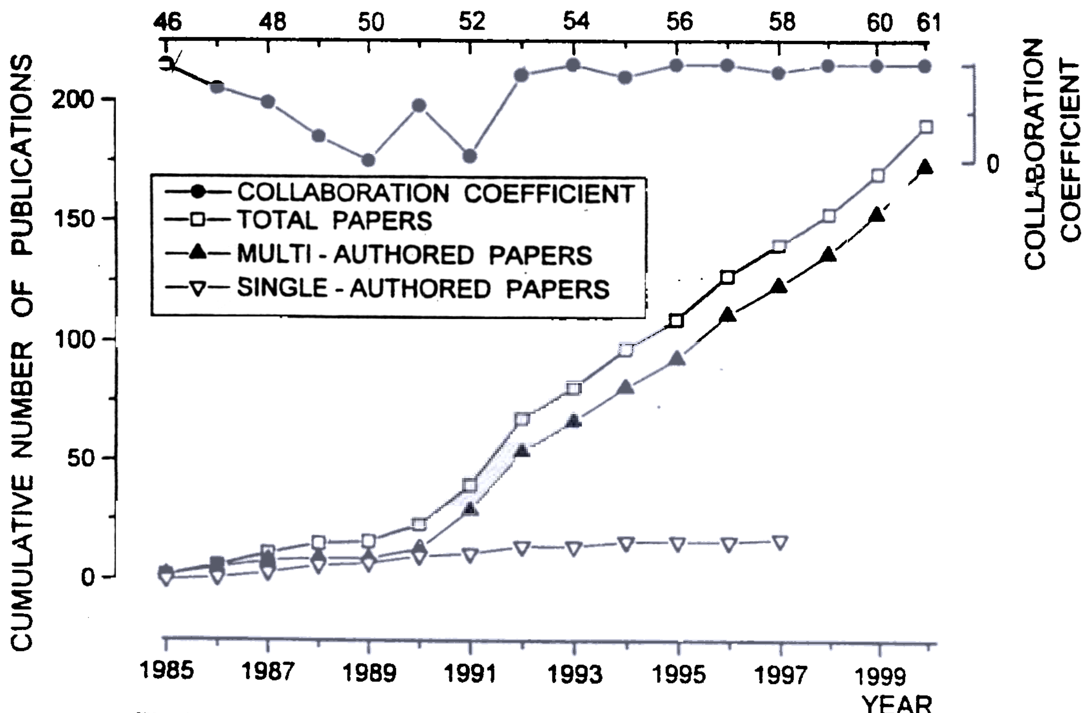

Fig.2. Collaboration pattern of Harold W. Kroto

Twentieth Century has seen a tremendous collaborative research among individual scientists working in groups within and across the geographic boundaries of a country which enhanced the ability of scientists to put in their brain collectively and make significant progress in their respective domains of specialization. Collaboration is inevitable in natural sciences and multidisciplinary areas to make significant advances and breakthroughs.

Whatever the advances made today are the results of endeavours of individual scientists as mentors [44-46] and their concerted efforts to form a group for collaborative research with other scientists.

Today the solitary scientist armed with the tools of a single descipline - seeking to conquer some devastating disease is largely a romantic myth.Whatever we are trying to unlock some fundamental secret of life or turn basic knowledge into a practical application, collaborative relationships usually offer us the best chance of success [44].

To measure the collaborative research pattern, a simple indicator called Collaboration Coefficient [47] (number of collaborative papers divided by total number of papers) is used. Highest collaboration coefficient (1.00) for H.W. Kroto was found in 1985,1993,1995,1996, 1998-2000. His 91.05 percent of papers were collaborative.

The Productive Coefficient [48] is the ratio of the productivity age (corresponding to the 50 percentile productivity) to the total productivity life. Productivity Coefficient for Kroto was 0.68, which is a clear indication that his productivity increased after 50 percentile age. His total productivity age studied here spans 16 years (1985-2000) during which he produced total 190 scientific publications. Fifty percent of his total publications were produced within five years (1996-2000). He had highest number of collaborative papers (25) in 1992 and published highest (28) number of papers in that year.He published twenty papers in 2000, and eighteen papers in 1996, seventeen papers each in 1991 and 1999. Average number of publications per year is 31.66.

Researchers and their authorships in collaboration with Harold W. Kroto in chronological order of their association (starting with first paper publication year) are documented in Table 2 and depicted in Figure 3.

Table 2: Domainwise and chronological profile of the Nobe laureate H. W. Kroto (1985-2000)

Sl. No.	Name	Domains					Period of association	TY	No.of author-ships
		A	B		D	E	FPY – LPY		
	Kroto, H. W.	109	390	8	16	18	1985 – 2000	16	190
	Heath, J. R.	2	3				1985 – 1987	3	7
3	O'Brien, S. C.	2	3				1985 – 1987	3	
	Curl, R. F.	2	3				1985 – 1987	3	
	Smalley, R. E.	2	3				1985 – 1987	3	
6	Zang, Q.						1985 – 1987	3	4

Contd...

Table 2 Contd...

Sl. No.	Name	Domains A	B	C	D	E	Period of association FPY – LPY	TY	No.of author-ships
7	Liu, Y.	1	2				1985 – 1987	3	3
8	Tittle, F. K.						1985 – 1986	2	2
9	McKay, K. G.		2				1988 – 1992	5	2
10	Jura, M.				3		1990 – 1993	4	3
11	Taylor, R.	86		3			1990 – 2000	11	90
12	Hare, J. .P.	27	18	3	3	9	1990 – 2000	11	60
13	Abdul – Sada, A. K.	7					1990 – 2000	11	7
14	Balm, S. P.	2	3		2		1991 – 2000	10	7
15	Walton,D. R. M.	91	25	7		19	1991 – 2000	10	142
16	Allaf, A. W.	2	3				1991 – 1992	2	5
17	Murrel, J . N.						1991 – 1991	1	1
18	Dennis, T. J. S.	21					1991 – 1993	3	21
19	Dworkin, A.	2					1991 – 1991	1	2
20	Szwarc, H.	2					1991 – 1991		2
21	Leach, S.	3					1991 – 1992	2	3
22	Parsons, J. P.	2					1991 – 1994	4	2
23	Avent, A. G.	30		3			1991 – 1999	9	33
24	Rannard, S. P.	1					1991 – 1991		
25	Fabre, C.						1991 – 1991		
26	Schutz, D.						1991 – 1991		
27	Kriza, G.						1991 – 1991		1
28	Ceolin, R.						1991 – 1991		
29	Bernier, P.	1					1991 – 1991		1
30	Jerome, D.						1991 – 1991		
31	Rassat, A.						1991 – 1991		
32	Holloway, J. H.	7					1991 – 1995	5	7
33	Hope, E. G.	7					1991 – 1995	5	
34	Langley, G. J.	19		1			1991 – 1997	7	
35	Gasyna, Z.						1991 – 1991		
36	Schatz, P. N.						1991 – 1991		
37	Fowler, P. W.	3					1991 – 1995	5	3

Contd..

Table 2 Contd..

Sl. No.	Name	Domains					Period of association	TY	No.of author-ships
		A	B		D	E	FPY – LPY		
38	David, W.I. F.	2					1991 – 1991		2.
39	Ibberson, R. M.	1					1991 – 1991	1	1
40	Matthewman, J.						1991 –1991		
41	Prassides, K.	16	3	1	1	2	1991 – 1999	9	23
42	Blau, W. J.						1991 – 1991		
43	Byrne, H. J.						1991 – 1991		
44	Cardin, D. J.	1					1991 – 1991		
45	Thomkinson, J.	4					1991 – 1992	2	4
46	Hendra, P. .						1991 – 1991		
47	Vervloet, M.						1992 – 1992		
48	Despres, A.						1992 – 1992		
49	Breheret, E.						1992 – 1992	1	
50	Meidine, M. F.	15					1992 – 1997	6	15
51	Parsons, J. P.	4					1992 – 1994	3	4
52	Birkette, P. R.	32		3			1992 – 2000	9	35
53	Hitchcock, P. B.	11					1992 – 1997	6	11
54	Endo, M.		3				1992 – 1999	8	4
55	Christides, C.	5					1992 – 1994	3	5
56	Rosseinsky, M. J.	2					1992 – 1992		2
57	Murphy, D. W.	2					1992 – 1992		2
58	Haddon, R. C.	2					1992 – 1992		2
59	Wales,D. J.						1992 – 1992		
60	Manolopoulos,D. E						1992 – 1992		1
61	Crane,J. D.	5					1992 – 1994	3	5
62	Roduner,E.	1					1992 – 1992	1	
63	Hallet,R .A.		2				1992 – 1992	1	2
64	Stace,A. J.		1				1992 – 1993	2	2
65	Gross,I.						1993 – 1993		
66	Hendra,P. J.						1993 – 1993		
67	Bridson,A. K.	2					1993 – 1995	3	2
68	Darwish,A. D.	33		3			1993 – 1999	7	36

Contd..

Table 2 Contd.

Sl. No.	Name	Domains A	B	C	D	E	Period of association FPY – LPY	TY	No.of author-ships
69	Roers,R.	2					1993 – 1994	2	2
70	Firth,S.	2					1993 – 1996	4	8
71	Deigo,H. P.	1					1993 –1993		
72	da Piedade,M. E. M.						1993 –1993		
73	Heimbach,D. K.	1					1994 –1994		
74	Remars,C.	1					1994 –1994		
75	Ohashi,O.	3					1994 –1994		
76	Schneider,N. S.	1					1994 –1994		
77	Locke,I. W.	3					1994 –1997	4	3
78	Sarkar,A.		3				1994 –1996	3	
79	Hsu,K.	5	25	3		19	1994 –2000	7	53
80	Terrones,M.	6	24			17	1994 –1994	7	48
81	Abeysinghe,J. R.						1994 –1996	3	2
	Austen,S. J.						1995 –1995		
	Sandall,J.P. B.						1995 –1995		
84	Pola,J.						1995 –1995		
85	Jackson,R. A.						1995 –1995		
86	Crowley,C. J.	2					1995 –1996	2	2
87	Bratcher,M. S.	1					1995 –1995	1	1
88	Cheng,P. C.	2					1995 –1996	2	2
89	Scott,L. T.	2					1995 –1996	2	2
90	Lappas,A.	1	2				1995 –1996	2	3
91	Maser,W. K.		1				1995 –1995		
92	Pierk,A. J.		1				1995 –1995		
93	Benito,A. M.	3	1				1996 –1997	2	4
94	Dunne,L. J.						1996 –1996		
95	Munn,J.						1996 –1996		
96	Kathirgamanathan,P.		1				1996 –1997		
97	Heinen,U.		1				1996 –1996		
98	Fernandez,J.		1				1996 –1996		
99	Reid,D. G.		3				1996 –1997	2	5
100	Clark,A. D.						1996 – 1996		

Contd..

Table 2 Contd....

Sl. No.	Name	Domains					Period of association FPY – LPY	TY	No.of author-ships
		A	B		D	E			
101	Terrones,H.	4	17			12	1996 – 2000	5	35
102	Manteca – Diego,C.		2				1996 – 1999	4	3
103	Osman,O. I.		1				1996 – 1996		2
104	Cheetham,A. K.		5			2	1996 – 2000	5	8
105	Zhang,J. P.		4				1996 – 2000	5	6
106	Ramos,S.						1996 – 1996		1
107	Castillo,R.						1996 – 1996		
108	O'Donovan,B. F.	2					1997 – 1997		2
109	van Wjnkoop,M.	2					1997 – 1997		2
110	Hahn,I.						1997 – 1997		1
111	O'Loughlin,J.						1997 – 1997		
112	Müller,T .E.						1997 – 1997		
113	Grobert,N..	2	14	4		14	1997 – 2000	4	34
114	Olivares,J.		2				1997 – 2000	4	3
115	Kordatos,K.		1				1997 – 2000	4	2
116	Townsend,P.			2		1	1997 – 1999	4	3
117	Cheetham,A.J.						1997 – 1997		
118	Eggen,B.R.						1997 – 1997	1	1
119	Schilder,A.		2				1997 – 2000	4	3
120	Zhu,Y.Q.	2	14			17	1997 – 2000	4	33
121	Schwoerer,M.						1998 – 1998		
122	Woodhouse,O. B.						1998 – 1998		
123	Kirkland,A. I.						1998 – 1998		
124	Osborne,A. J.	2					1998 – 1998		2
125	Trasobares,S.	2	7				1998 – 2000	3	10
126	Pidduck,A. J.						1998 – 2000	3	
127	Reeves,C. L.		2				1998 – 2000	3	3
128	Vizard,C.						1998 – 1998		
129	Wallis,D. J.		2				1998 – 2000	3	
130	Wright,P. J.						1998 – 1998		
131	Upward,M. D.						1998 – 1998		
132	Moriarty,P.						1998 – 1998		
133	Beton,P. H.						1998 – 1998		
134	Coheur,P. -F.	4					1998 – 2000	3	
135	Cornil,J.	4					1998 – 2000	3	4
136	dos Santos,D. A.	4					1998 – 2000	3	4
137	Lievin,J.	4					1998 – 2000	3	4

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Table 2 Contd..

Sl. No.	Name	Domains					Period of association	TY	No.of author-ships
		A	B	C	D	E	FPY – LPY		
138	Bredas,J. L.	4					1998 – 2000	3	4
139	Janot,J. -M.	2					1998 – 1999	2	2
140	Seta,P.	2					1998 – 1999	2	2
141	Leach,S.	2					1998 – 1999	2	2
142	Colin,R.	4					1998 – 2000	3	4
143	Li,J.	1					1999 – 1999	1	1
144	Picket,C. J.		1				1999 – 1999	1	1
145	Tanaka,K.		1				1999 – 1999	1	1
146	Takeuchi,K.		1				1999 – 1999	1	1
147	Takikawa,H.		1				1999 – 1999	1	1
148	Attfield,J. P.	1					1999 – 1999	1	1
149	Johnston,R. L.	1					1999 – 1999	1	1
150	Redlich,P.		5			1	1999 – 2000	2	6
151	Rühle,M.		6			1	1999 – 2000	2	7
152	Hu,B.	1				5	1999 – 2000	2	6
153	Li,W. Z.		2				1999 – 2000	2	2
154	Escudero,R.		1			1	1999 – 2000	2	2
155	Karali,T.					1	1999 – 2000	2	1
156	Kohler – Redlich,Ph.		3				1999 – 2000	2	3
157	Morales,F.					1	2000 – 2000	1	1
158	Chang,B. H.		2			4	2000 – 2000	1	6
159	Yao,N.		1			1	2000 – 2000	1	2
160	Clark,R.J. H.		2			3	2000 – 2000	1	5
161	Wei,B. Q.					3	2000 – 2000	1	3
162	Han,W. Q.		3			1	2000 – 2000	1	4
163	Seeger,T.		2				2000 – 2000	1	2
164	Ernst,F.		3				2000 – 2000	1	3
165	Scheu,C.		1				2000 – 2000	1	1
166	Chu,S.Y.		1				2000 – 2000	1	1
167	Munoz – Picone,E.		1				2000 – 2000	1	1
168	Boldu,J. L.		1				2000 – 2000	1	1
169	Franchi,P.		1				2000 – 2000	1	1
170	Roberts,P. B.		1				2000 – 2000	1	1
171	McHenry,M. E.		1				2000 – 2000	1	1
172	Boothroyd,C. B.					2	2000 – 2000	1	2
173	Kinlock,I.					2	2000 – 2000	1	2
174	Chen,G. Z.					2	2000 – 2000	1	2

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Table 2 Contd....

Sl. No.	Name	Domains					Period of association	TY	No.of author-ships
		A	B	C	D	E	FPY – LPY		
175	Windle,H.					2	2000 – 2000	1	2
176	Fray,D. J.					2	2000 – 2000	1	2
177	Escudero,R.					1	2000 – 2000	1	1
178	Cooliex	1				1	2000 –2000	1	2
179	Kamalakaran,R.					1	2000 – 2000	1	1
180	Zhou,W. Z.					1	2000 – 2000	1	1
181	Stephen,O.		1				2000 – 2000	1	1
182	Hug,G.		1				2000 – 2000	1	1
	Total	**696**	**309**	**57**	**30**	**175**			**1267**

(A = Fullerenes; B = Cluster Science; C = Spectroscopy of Unstable and Reaction Intermediates; D = Astrophysics; E = Non Carbon Nanostructures; FPY = First Publication Year; LPY = Last Publication Year; TY = Total Years)

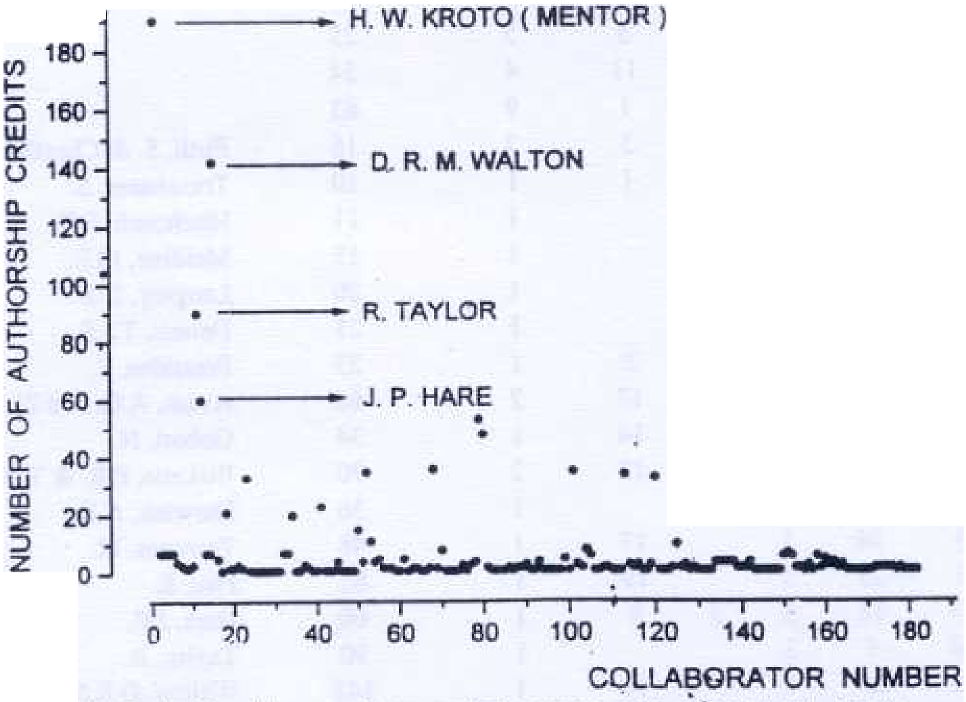

Fig.3. Authorship credits to collaborators with Harold W. Kroto

4.3 Domainwise authorships

Table 3 shows author productivity and distribution of authors in various domains.The research group of Harold W. Kroto had the credits as number of authorships in various domains: Fullerenes (696), Cluster Science (309), Spectroscopy of Unstable and Reaction Intermediates (57), Astrophysics (30), and Non Carbon Nanostructures (175).

Table 3: Publication Productivity of the Nobel laureate H.W. Kroto and his Collaborators (1985-2000)

No. of Papers (p)	Domains					No. of Authors (n)	Total Author-ships (n x p)	Prominent Collaborators
	A	B	C	D	E			
						79	79	
						37	74	
			3	3		15	45	
			1			13	52	
					3	5	25	
			1		11	4	24	
	31		4	6		9	63	
	2				5	2	16	Firth, S. & Cheetham, A.K.
	2						10	Trasobares, S.
								Hitchcock, P.B.
	15						15	Meidine, M.F.
	19						20	Langley, G.J.
	21						21	Dennis, T.J.S.
	16	3		1	2		23	Prassides, K.
	32	14	3		17	2	66	Avent, A.G. and Zhu, Y.Q.
	2	14	4		14		34	Gobert, N.
	36	17	5		12	2	70	Birkette, P.R. & Terrones,H.
	33		3				36	Darwish, A.D.
	6	24			17		48	Terrones, M.
	6	25	3		19		53	Hsu, K.
	27	18	3	3	9		60	Hare, J.P.
	86	1	3				90	Taylor, R.
	91	25	7		19		142	Walton, D.R.M.
	109	39	8	16	18		190	Kroto, H.W.
						182		

(A=Fullerenes; B=Cluster Science; C=Spectroscopy of Unstable Species and Reaction Intermediates; D=Astrophysics; E= Non Carbon Nanostructures)

Prominent collaborators

Most active researchers with Harold W. Kroto were: D. R . M. Walton (142), R. Taylor (90), J. P. Hare (60), K. Hsu (53), M. Terrones (48), A. D. Darwish (36), P. R. Birkett (35), H. Terrones (35), N. Gobert (34), A. G. Avent (33), Y. Q. Zhu (33), K. Prassides (23), T. J. S. Dennis (21), G. J. Langley (20), M. F. Meidine (15), P. B. Hitchcock (11), S . Trasobares (10), S. Firth (8), and A. K. Cheetham (8). Other collaborators having seven papers each were nine. Four scientists had six papers each. Five scientists had collaboration in five papers each.

Thirteen scientists had collaboration in four papers each. Fifteen scientists had collaboration in three papers each. Thirty seven scientists had collaboration in two papers each. Seventy nine scientists could collaborate in only one paper each. Total number of authors in the research group were 182 and total number of authorships were 1267.

Use of channels of communication

Distribution of Harold W. Kroto's 190 publications were spread over 58 journals and 13 conference proceedings, books, etc. Channelwise scattering of publications of Kroto is provided in Table 4 and Figure 4. He has published 23 papers in Journal of Chemical Society, Chemical Communications (1990 - 1998), 20 papers in Chemical Physics Letters (1986 - 2000), 15 papers in Journal of Chemical Society, Perkins Transactions-2 (1993 - 1999), and 10 papers in Nature (1985 - 2000). Inset in Figure 4 indicates the growth of publications by H.W. Kroto in the four core journals. Publication Density was 3.05 and Publication Concentration was 4.5. Average Bradford multiplier was 3.5. Scattering of publications of individual scientists do not follow Bradford Law [49].

Table 4: Dissemination Channels of the Publication of the Nobel laureate H. W. Kroto (1985-2000)

Sl. No.	Channel of Communication	Number of Papers	Cumu-lative	Period of Journal Usage	
				FPY- LPY	TY
	J. Chem. Soc. Chem. Commun.	23	23	1990 – 1998	9
2	Chem. Phys. Lett.	20	43	1986 – 2000	15
3	J. Chem. Soc. Perkin Trans.-2	15	58	1993 – 1999	7
4	Nature	10	68	1985 – 2000	6
5	J. Chem. Soc. Faraday Trans.	6	74	1990 – 1993	3

Contd..

Table 4 Contd...

Sl. No.	Channel of Communication	Number of Papers	Cumulative	Period of Journal Usage FPY – LPY	TY
6	Pure Appl .Chem.	6	80	1990 – 1999	9
7	Appl. Phys. -A.	5	85	1998 – 2000	3
8	Appl. Phys. Lett.	5	90	1999 – 2000	2
9	Fullerene Sci. Technol.	5	95	1993 – 1997	4
10	Carbon	4	99	1992 – 1997	6
11	Chem. Mater.	4	103	1996 – 2000	5
12	J. Mater. .Chem.	4	107	1998 – 2000	3
13	Mol. Mater.	4	111	1994 – 1996	5
14	Adv. Mater.	3	114	1999 – 2000	2
15	J. Am. Chem. Soc	3	117	1985 – 2000	16
16	J. Mol. Struct.	3	120	1993 – 1997	5
17	M. R. S. Bull.	3	123	1994 – 1999	6
18	Synthetic Mets.	3	126	1996 – 1999	4
19	Angew. Chem. Intl. Eng. Ed.	2	128	1992 – 1999	8
20	Astrophys. J.	2	130	1987 – 1990	4
21	C. R. Acad. Sci. Paris T –312Ser. –II	2	132	1991 – 1991	
22	Chem. Commu.	2	134	1998 – 2000	
23	Int. J. Mod. Phys. –B	2	136	1992 – 1992	
24	J. Phys. Chem.	2	138	1992 – 1992	
25	J. Chem. Soc. Dalton Trans.	2	140	1992 – 1997	6
26	Philos. Trans. Roy. Soc. Lond.	2	142	1998 – 1996	3
27	Tetrahedron Lett.	2	144	1995 – 1996	2
28	Univ. Sussex. Ann. Rep.	2	146	1990 – 1992	3
29	Accounts Chem Res.	1	147	1992 – 1992	1
30	Ann. Phys. Fr.		148	1989 – 1989	1
31	Asron. Astrophys.	1	149	1992 – 1992	
32	Chem. Brit.	1	150	1990 – 1990	
33	Chem. Intelligencer		151	1995 – 1995	1
34	Chem. Phys.	1	152	1992 – 1992	
35	Chem. Rev.	1	153	1991 – 1991	
36	Comments Cond. Matt. Phys.		154	1987 – 1987	
37	Comp. Math. Appl.	1	155	1988 – 1988	1
38	Function. Adv. Mat.	1	156	2000 – 2000	
39	Int. J. Mass spect. Ion Proc.		157	1994 – 1994	
40	J. Phys. Chem.		158	1986 – 1986	1
41	J. Phys. Cond. Matt.		159	1996 – 1996	1
42	Mater. Chem.		160	2000 – 2000	1
43	Mon. Not. Roy. Astron. Soc.		161	1990 – 1990	1
44	Nanotechnol.		162	1991 – 1991	1
45	Novel Form. Carbon II MRS		163	1994 – 1994	
46	Phil. Trans. Roy. Soc. Lond. Ser. -A		164	1993 – 1993	1
47	Phys. Rev. Lett.		165	1991 – 1991	

Contd..

Table 4 Contd.

Sl. No.	Channel of Communication	Number of Papers	Cumu-lative	Period of Journal Usage FPY– LPY	TY
48	Phys. Scripta	1	166	1992 – 1992	1
49	Phys. World	1	167	1992 – 1992	1
50	Polycy. Arom. Hydrocarb . Astrophys.	1	168	1987 – 1987	1
51	Proc. Conf. NASA AIMS Res. Centre	1	169	1990 – 1990	1
52	Proc. NATO Workshop	1	170	1996 – 1996	1
53	Proc. Roy. Institution.	1	171	1986 – 1986	1
54	Science	1	172	1988 – 1988	1
55	Space Science Rev.	1	173	1991 – 1991	1
56	Specrochim. Acta	1	174	1991 – 1991	1
57	Surface Sci.	1	175	1998 – 1998	1
58	Tetrahedron	1	176	1996 – 1996	1
59	Topics Curr. Sci.	1	177	1988 – 1988	1
60-72	Others in books, confs. etc.	13	190		

(FPY = First Paper Year , LPY = Last Paper Year , and TY = Total Years)

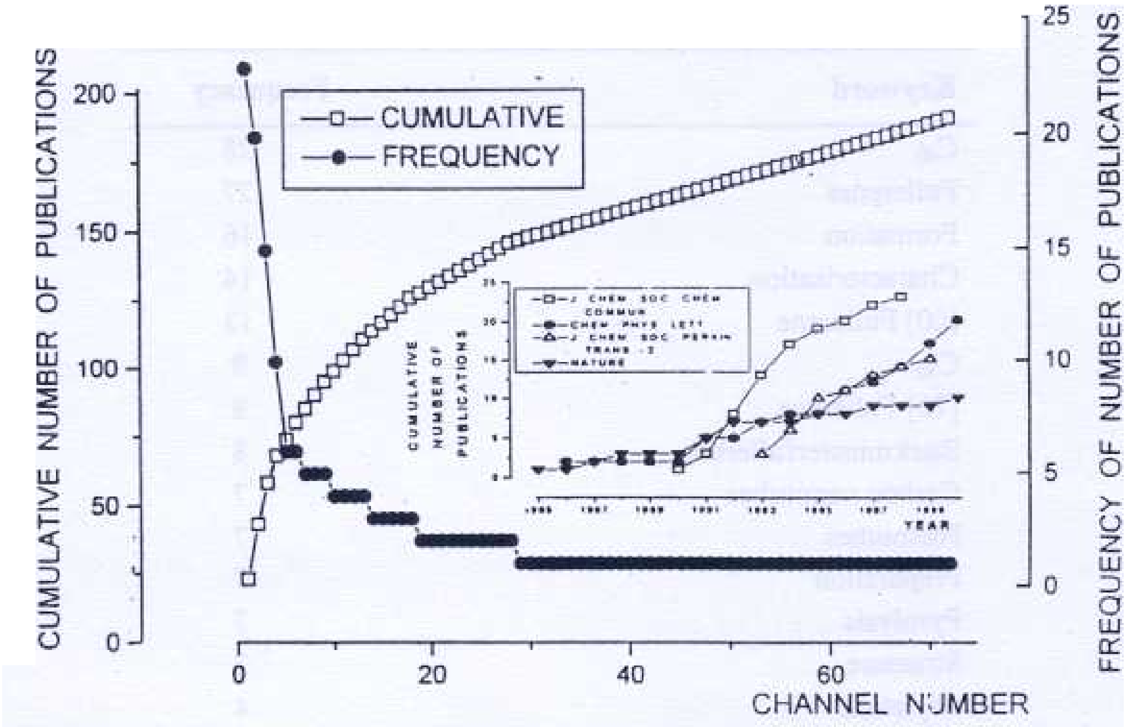

Fig.4. Bradford - Zipf bibliograph for Harold W. Kroto and inset publications growth in four core journals

4.6 Keyword Tomography

Recent study on Database Tomography [50] for Research Impact Assessment is interesting. Titles of the publications convey precisely the thought contents of the papers. The potency of information concentrated on the titles of the papers is more than the rest of the sections of the papers. Therefore if a word occurs more frequently than expected it to occur, then it reflects the emphasis given by the author about the domain of his research. These important words called 'keywords' are one of the best indicators to understand and to grasp instantaneously the thought content of the papers, methodologies used and areas of research addressed to. The keyword frequencies appeared in the titles of the papers is provided in Tables 5 - 7. High frequency keywords were: C60 / Fullerenes / [60] Fullerene / Buckmin sterfullerene, C70 / [70] Fullerene, Characterisation, Carbon nanotubes, Nanotubes, Preparation, Pyrolysis, Structure.

Table 5: Keyword Frequency from the Title of H.W. Kroto (1985-2000)

Keyword	Frequency
C_{60}	28
Fullerenes	27
Formation	16
Characterisation	14
[60] Fullerene	13
C_{70}	9
[70] Fullerene	8
Buckminsterfullerene	8
Carbon nanotubes	7
Nanotubes	7
Preparation	7
Pyrolysis	7
Structure	7
Arylation	4
Isolation	4
Photophysical properties	4
$C_{70}Cl_{10}$	3

Contd..

Table 5 Contd...

Keyword	Frequency
Carbon clusters	3
Electrophilic aromatic substitution	3
Fluorinated C_{60}	3
Fluorination	3
Hydrogenation	3
Material science	3
Nanofibres	3
Nanowires	3
Production	3
Reaction	3
Space	3
Stars	3
Synthesis	3

Table 6: Keywords appeared twice in the titles of the papers of Nobel laureate H.W. Kroto (1985 - 2000)

[84] Fullerene; ^{13}C NMR spectroscopy; Aligned carbon nanotubes; Aligned CN_x nanotubes; Buckminsterfullerene compounds; BxCyNz; $C_{60}Cl_2$; C_{60} derivatives; C_{60} –thin films; $C_{60}Br_6$; $C_{60}Br_8$; Synthesis; $C_{60}Ph_5Cl$; $C_{60}Ph_5H$; $C_{70}Ph_8$; Celestial sphere; Chemical reactions; Chemistry; Discovery; Electrolytic formation; Electrophile; Ferrocene/C_{60}; Fullerides; Giant fullerenes; Hexa – functionalised; Large carbon clusters; Long carbon chain molecules; Nanostructures; Neutron scattering studies; NH_3 atmosphere; Novel nanowires; Nucleophilic substitution; Polyhydrogenation; Quantum – chemical investigations; Reactivity; Single crystal; Soot; Spectroscopic investigations; Spheroidal carbon shells; Sussex; WS_2 nanotubes.

Table 7: Keywords appeared only once in the titles of the papers of Nobel laureate H. W. Kroto (1985 - 2000)

(η-C_{60})Pt(P-P) [P-P =dppe, dppp]; [76] Fullerene; [78] Fullerene; 11 – atom orifice; 11,12 – benzofluoranthene; 11.3 m UIR feature; 21 century materials; 3D silicon oxide; 7,10 – bis(2,2' – dibromovinyl) – fluoranthenen; Absorption spectra; Acetylene; AFGL 2688; Aligned CxNy; Aligned –nanotube bundles; Aligned nanotubes; Alkali – metal; Alternative route; Analogues; Analysis; Anomolous; Anthracene; Argon matrices; Astrophysical problems; Astrophysics studies; Benzene; Benzene solvated C_{60}; Benzo(b)furano[60] fullerenes; Benzo(b)furano[70] fullerenes; Benzo[b]furanyl[60] fullerene; Bicyclopentene addend; Binary phase layered – nanostructures; bis – Lactone derivative; Bonding; Boriding iron nanowires; Boron –-doping effects; Boron containing; buta – 2 – ynoates129; buta –2,3 – dienoates; C/BN layered materials; C_{58} derivative; C_{60} – catalysed oxidation; $C_{60}{}^{2+}$; $C_{60}{}^{3+}$; C_{60} Buckminsterfullerene; $C_{60}(CH_2CH = CH_2)_6$; C_{60}(CHCN); $C_{60}(P_4)_2$; C_{60}.I_2.toluene; $C_{60}{}^{+}$; $C_{60}Br_2$; $C_{60}Br_{24}$; $C_{60}Cl_6$; $C_{60}Cl_{60}$; $C_{60}F_{60}$; $C_{60}Ph_{12}$; $C_{60}Ph_2$; $C_{60}Ph_4$; $C_{60}Ph_5X$(X = H, Cl); C_{70} derivatives; $C_{70}H_{12}$; $C_{70}Ph_{10}$; $C_{70}Ph_9OH$; C_{76}; C_{78}; C_{82}; C_{84}; C_{86} – C_{102}; Cage; Carbocations; Carbon; Carbon – encapsulated WS_2; Carbon chain molecules; Carbon chemistry; Carbon condensation; Carbon nanofibers; Carbon nanostructures; Carbon nanotube walls; Carbon nitride; Carbon re – appraised; Carbon sheathed; Catalysed production; Catalytic agents; Catalytic particles; Catalytic pyrolysis; Catalytic pyrolysis; Catalytic substrates; Chains and grains; Charisma; Chelating phosphine ligands; Chlorination; Chromatographic behaviour; Chromatographic separation; Circumstellar; Circumstellar shells; Cis-Bromine addition; C-MoS_2 nanocomposites; $C_n{}^{+}$ and $C_n{}^{-}$; CN_xnanofibres; CO loss; Cobalt thin films; Comet mass spectrometric data; Condensed phase; Condensed phase electrolysis; Containers for gas filling; Controlled production; Coranulene; Crystal structure; Crystalline fullerene; Crystalline fullerene; Crystallinity; C-WS_2 nanocomposites; Cyclopentadiene; Degradation; Diels – Aldea adduct; Distributions; Dust; Dynamic effects; Dynamics; Efficient route; Electrochemical formation; Electrochemical production; Electron impact conditions; Electron microscope images; Electronic spectra; Electronics; Emmission; Encapsulated compounds; Encapsulated nanowires; Enhanced magnetic coercivities; Enthalpies; Evidence; Experimental observations; Fe nanowires; Ferrocene/melamine mixtures; Filled nanotubes; Fluorinated cage; Fluorine gas; Footballene C_{60}; Fragmentation; Fullerene – 78 isomers; Fullerene – C_{60}; Fullerene cage clusters; Fullerene compounds; Fullerene physics; Fullerene soots; Fullerene studi es; Fullerenes C_n(n = 24, 28 , 32, 50,60 and 70); Fullerols; Functionalised fullerenes; Galaxy; Generation; Graphite;Graphite horizon; Graphite onions; Graphite structures; Ground state of C_{84}; Growth process; Halogenation; Helices; Hemi – toroidal networks; Heterojunctions; Hexa – adduct; Hexaallyl[60]fullerene; Hexagonal rings; Holey fullerenes; Hollow crystalline; Hydrides; Hydroboration; Hydrogen sulphide; Hypothetical twisted structure; Icospiral; Icospiral shells; Inelastic neutron scattering spectrum; Infrared; Intercalation compound; Internal –hydrogens; Internal–hydrogens; Interstellar; Interstellar dust; Interstellar grain formation; Interstellar medium;

Contd.

Table 7 Contd..

Ion beams; IR spectra; KCl crystallization; Laboratory; Lanthanum complexes; Large – scale synthesis; Large arrays; Laser patterned; Laser vapourisation; Laser-etched; Light; Linear carbon molecules; Low – melting metal; Low temperature; Lubricants; Magic numbers; Magnetic; Magnetic circular dichroism; Mass spectrometric/NMR study; Mc@C_{70}; Metal particle; Metallic behaviour; Methanofullerenes; Methylene adducts; Microscopy study; Mixed phase; Mixtures; Molecular shielding; Molybdemum carbide; Molybdenum disulfide; Molybdenum disulphide nanotubes; Monitoring; Morphology; Morphology effects; Morphology of soot; Multiply – phenylated; Nanocapules; Nanocomposites; Nanoflowers; Nanomaterials; Nanoreactors; Nanoscale BN structures; Nanoscale encapsulation; Nanostructured materials; Nanotechnology; Napthalene; Negative carbon cluster; New advances; New evidence; New horizons; New materials; New science; Ni – filled; Nomenclature; Nonlinear optical response; Novel base – catalysed formation; Novel nano materials; Novel nanotubes; Novel route; Optical emission; Oxygenated derivatives; Oxygenated species; Parent ions; Pentamethylcyclopentadiene adducts; Phase transition; Phenylated isoquinolino[3,4:1,2] [60] fullerene; Phenylation; Phoshorus; Phosphine – catalysed cycloaddittion; Physico – chemical studies; Physics; Planar; Platinum(0)-[60] fullerene complexes; Polyyenes; Post – fullerene organic chemistry; Potential – energy function; Precursors; Pyroletic production; Pyrolytic carbon nanotubes; Pyrolytic grown; Pyrolytically grown; Quasi – icosahedral; Radiolaria; Raman spectra; Recent developments; Regiochemical clustering; Regoselective attack; Revolution; Self – assembly; Separation; Sharp nanotubes; Si nanostructures; SiC – SiO_x; Silicon – based nanostructures; Silicon oxide nanoflowers; Silicon oxide nanowires; Silicon surfaces; Simple route; Simulated transmission; Single hydroxy group; Single –walled nanotubes; Small fullerenes; Smaller carbon species; S_n-P_b-nanowires; Solid carbon; Solid phase production; Solid state; Solvated intercalate; Soot – like microparticles; Soot extract; Special nature; Spectroscopy; Spheres; Spheroidal carbon molecules; Spiral shell carbon particals; Spontaneous oxidation; Stabilisation; Stability; Stable [60] fullerene; Stable BC_2N nanostructures; Stable derivatives; Stellar space; Storage and release; Structural; Structural characterization; Structural features; Structure determination; Sulphur; Supersonic expansion; Surface decorated fullerene; Symmetrical; Symmetry; Synthetic routes; Tapered nanotubes; Theoretical; Thermodynamic characterization; Thermodynamic evidence; Thermolysis; THF; Third form of carbon; Titanium–doped; Toroids; Transition metal; Transitions; Tree – like structures; Trimethylamine; Tungsten–niobium – sulfur composite; Tungsten oxide; Tungsten oxide fibres; Uniformed diameter; Unsymmetrical; UV/VIS spectra; Vibrational Raman spectra; $W_xMo_yC_zS_2$ nanotubes; X – ray structure; Zn/DCl; Zn/HCl.

5 CONCLUSION

Harold W. Kroto's publicafion productivity under study for 16 years (1985 - 2000) during which he has published 190 papers indicated that the productivity increased after his 50 percentile age i.e. from 1993 onwards. The percentage of collaborative work of the scientist was found to be very high as he had as many as 181 collaborators whom he guided as mentor. He had 91 collaborators till 1995. The scientist worked in highly specialised fields. His papers have been scattered in 59 scientific journals. He received many awards and honours including the Nobel prize. After he received the Nobel prize in 1996, ninety more scientists joined his research team. This trend shows that honours and awards a scientist receives attract more number of collaborators which results in increase in publication productivity. This kind of quantitative studies with graphic presentations facilitate one to study and grasp with clear perceptions about the work of a scientist. It will be an interesting study if one attempts analysis of citations to his publications.

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Appendix 1

HAROLD W. KROTO

Professor Sir Harold W. Kroto FRS, Royal Society Research Professor
The School of Chemistry, Physics and Environmental Science, The University of Sussex, Brighton, BNl 9QJ, UK
Tel 01 273 678329; Fax 01 273 677196; E-mail: kroto@sussex.ac.uk

Born

7th Oct 1939 Wisbech, Cambridgeshire, England.

Education

1947-58 Bolton School, Bolton, Lancashire.

1958-61 BSc, Sheffield, 1st class honours degree (Chemistry)

1961-64 PhD, Sheffield, Electronic Spectroscopy of Unstable Molecules

Supervisor

R N Dixon

1964-65 PDF, NRC (Ottawa) with D A Ram say

1965-66 PDF, NRC (Ottawa) with C C Costain

1966-67 Memb. Tech. Staff, Bell Laboratories, Murray Hill, NJ (with Y H Pao, and D P Santry)

University Career

(University of Sussex 1967-)

1967-68 (Tutorial Fellow); 1968-78 (Lecturer); 1978-85 (Reader)

1985-91 (Professor); 1991- (Royal Society Research Professor)

Awards

1981-82 Tilden Lecturer (Royal Society of Chemistry)

1990 Elected Fellow of the Royal Society

1991- Royal Society Research Professorship

1992 International Prize for New Materials, (American Physical Society/IBM, with R F Curl and R E Smalley), ltalgas Prize for Innovation in Chemistry, Universite Libre de Bruxelles (DHC), University of Stockholm (PhDHC), Longstaff Medal 1993 (Royal Society of Chemistry), Academia Europaea (Member)

1993 University of Limburg(DHC)

1994 Hewlett Packard Europhysics Prize (with D R Huffman, W Kratschmer and R E Smalley), Moet Hennessy Louis Vuitton Science pour 1:41t Prize

1995 University of Sheffield (Hon Degree), University of Kingston (Hon Degree)

1996 Knighthood, Nobel Prize for Chemistry (with R F Curl and R E Smalley)

1997 University of Sussex (Hon Degree), University of Helsinki (DHC), Nottingham (Hon Degree), Yokohama City (Hon Degree), Hertfordshire (Hon Degree), Sheffield Hallam (Hon Degree)

1998 Aberdeen (Hon Degree), Leicester (Hon Degree)

1999 Aveiro (DHC)

Societies

1990 Fellow of the Royal Society

1993 Academia Europaea

1997 Hon. Foreign Member Korean Academy of Science and Technology (KAST)

1998 Hon. Fellow of the Royal Microscopical Society

Editorial Boards

Chemical Society Reviews 1986- (Chairman 1990-), Zeitschrift fur Physik D (Atoms Molecules and Clusters) 1992-;

Carbon (1992-), J. Chem. Soc. Chem. Comm. (1993-97), Fullerenes, Nanotubes, and Carbon Nanostructures formerly called Fullerene Sci. Technol. (1996 -)

Research Details

University of Sheffield

1961-64 PhD in free radical spectroscopy by flash photolysis

National Research Council

1964-65 free radical spectroscopy by flash photolysis

1965-66 Microwave Spectroscopy

Bell Telephone Laboratories

1966-67 Raman Spectroscopy of Liquids, Quantum Chemistry University of Sussex

1967-72 free radical spectroscopy/flash photolysis

1967-73 Liquid phase interactions/Raman Spectroscopy

1970- Unstable species/Microwave Spectroscopy

1972-90 Unstable species/Photoelectron Spectroscopy

1976- Interstellar Molecules/Radioastronomy

1983-90 Unstable species/fourier Transform IR Spectroscopy

1985- Cluster Studies/Carbon, Metals

1990- Fullerene Chemistry, Carbon nanostructures