Growth and Trends of Fullerene Research as Reflected in Its Journal Literature

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Contents

I. Introduction

The growth of a science field depends on its ability to organize its findings, and its placing in the wealth of knowledge depends on its growth. Scientists see science fields as somewhat arbitrary divisions of knowledge but as divisions actively working to differentiate themselves further from neighboring fields. Their institutionalization in the academic world emphasizes distinctions between bodies of knowledge and works to magnify them.

One quantitative measure of a research field is the size and structure of its archival literature. This paper reports the findings of an investigation to identify various quantitative features of the journal literature of fullerene sciences in the period from 1985 to 1998, which includes the number of papers year by year, the contributing countries of the papers, the distribution of the journals, the productive individual authors, their international coauthorship, and the citation impact of the papers. Analyses of these features focus on the rate of growth of the literature and certain aspects of its scatter. The tools used in this study are accentuatedly based on statistical analyses of the occurrence frequency of certain elements of the formal literature, as opposed to an analysis of the literature's content.

The function of scientific papers is to publish new knowledge. This is possible by an analysis of the above-mentioned characteristics although many of the papers in the journal literature mainly test previously suggested hypotheses and conclusions under some new conditions or extend established knowledge to some additional places and related fields and subfields. They are also published to uphold the prestige of science and scientists. It seems that many of them are also published to establish and uphold the prestige of nations. Thus, advancement

Tibor Braun was trained in Chemistry at the Victor Babes University in Cluj (Romania) and then worked as a research scientist at the research reactor of the Institute for Atomic Physics, Bucharest, investigating the use of radioisotopes in analytical chemistry and the effect of nuclear irradiation on heterogeneous catalysts. He moved to Budapest, Hungary, in 1963 and joined the Institute for Inorganic and Analytical Chemistry of the Loránd Eötvös University. He continued his research there in radioanalytical and nuclear chemistry and pioneered the use of various new types of polyurethane foam sorbents in separation chemistry. Tibor Braun, who is currently a Professor of Chemistry at the Loránd Eötvös University and Director of the Information Science and Scientometric Research Unit (ISSRU) of the Hungarian Academy of Sciences, earned his Ph.D. and D.Sc. degrees from the Hungarian Academy of Sciences, Budapest, Hungary, in 1967 and 1980, respectively. He is currently working on radiochemical and mechanochemical approaches to fullerene chemistry and on scientometric evaluations of the basic laws and working mechanism of basic research. Professor Braun has published more than 200 papers and 16 books on the above mentioned topics and has been awarded the international George Hevesy Award, the international Derek John de Solla Price Award, and the Chemistry Award of the Hungarian Academy of Sciences. He is the founder and Editor-in-Chief of three international journals (*Journal of Radioanalytical and Nuclear Chemistry, Fullerene Science and Technology, Scientometrics*). He has been a visiting Professor at the Tohoku University, Sendai, Japan, Tokyo Metropolitan University, Tokyo, Japan, and University of Panama, Panama City, and a visiting expert of the International Atomic Energy Agency at the Junta de Control de Energia Atomica, Lima, Peru, and at the University of the West Indies, Kingston, Jamaica.

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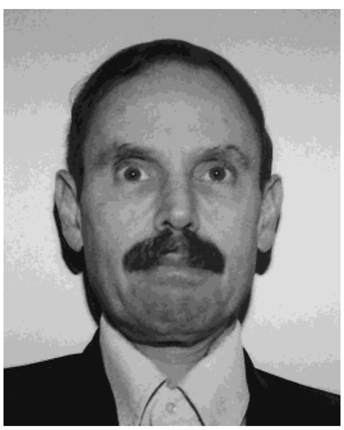
András P. Schubert graduated as a chemical engineer (1970) and received his Ph.D. degree in physical chemistry (1976) at the Budapest Technical University (Hungary). After a decade of teaching physics and physical chemistry and doing research on the kinetics and thermodynamics of transport phenomena and chemical reactions, his interest turned toward studying the scientific enterprise itself and became a member of the Information Science and Scientometrics Research Unit at the Library of the Hungarian Academy of Sciences. In 1993 he was awarded the Derek John de Solla Price Medal "for his outstanding contributions to the quantitative studies of science". He is now the Head of the Bibliometric Service of the Library, the Editor of the international journal *ACH–Models in Chemistry*, and the Associate Editor of the journal *Scientometrics*.



Ronald N. Kostoff received his Ph.D. degree in Aerospace and Mechanical Sciences from Princeton University in 1967. At Bell Labs, he performed technical studies in support of the NASA Office of Manned Space Flight and economic and financial studies in support of AT&T Headquarters. He invented many concepts, including the Orbiting Molecular Shield (aka Wake Shield). This concept pioneered the capability of high vacuum in low orbit, presently exploited by all manned space vehicles. His initial aerobraking research reported in 1970–71 pioneered the Aeroassisted Orbit Transfer subfield of OrbalTransfer Vehicles. His economic and financial studies, which supported AT&T's operations, resulted in potential savings to the Bell System of over one billion dollars. At the U.S. Department of Energy (DOE) from 1975–1983, he managed the Nuclear Applied Technology Development Division, the Fusion Systems Studies Program, and the Advanced Technology Program. He has published numerous technical papers in the fields of pulsed fusion operation, impact fusion options, and fissile fuel production using advanced breeders. At the Office of Naval Research, starting in 1983, he was Director of Technical Assessment for many years. He invented and patented the Database Tomography process, a textual data mining approach that extracts relational information from large databases. After managing the Navy Laboratory Independent Research Program for five years, he established a new effort in textual data mining. His interests continue to revolve around improved methods to assess the impact of science and technology, incorporating maximal use of the massive amounts of data available. He has published many papers on technical, evaluation, and data mining topics and has edited three journal special issues since 1994 (*Evaluation Review* [Feb. 94], *Scientometrics* [July 96], *Journal of Technology Transfer* [Fall 97]).

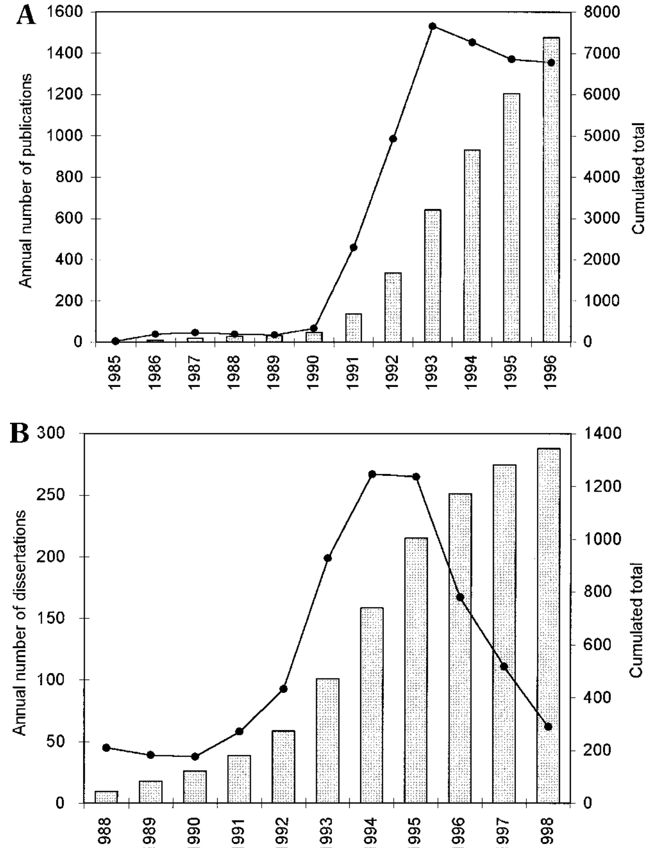


Figure 1. (a) Growth of the journal literature of fullerene science related papers. (b) Growth of the dissertation literature on fullerene science related topics.

is taking place, though possibly somewhat unevenly, over a wide front. Competition is seen, and duplication of effort is unavoidable. But only lack of communication would seem to stand in the way of utilizing the considerable knowledge already accumulated in various parts of the world to the mutual benefit of all concerned.

An understanding of the quantitative patterns of the development of fullerene research could be of use and interest to the scientists working in the field but also to science decision makers and administrators at large by using these data and conclusions to complement their previous qualitative views and feelings and their peer evaluations.

II. Methodology

To identify the growth, structure, and sources of international fullerene research, we employ, as mentioned, journal publication and citation analysis. The rationale behind this approach is that the knowledge base of any field is its published literature and any new information and contribution grows out of past publications.

One presumes also that a frequently cited paper is notable, seminal, and/or innovative. However, many variables in addition to scientific merit determine citation frequency. These include the circulation of the journal and the reputation of the authors.

The database we have used was the computerized bibliography we have published previously[1,2] in book form. The raw material for citation analysis has been

Table 1. Journals Publishing the Greatest Number of Fullerene Science Related Papers During the 1985−1996 Period

rank	journal title	no. of papers	growth ratio	papers/year
1	Chemical Physics Letters	716	0.68	59.7
2	Physical Review B	703	0.99	58.6
3	Journal of Physical Chemistry	418	0.78	31.8
4	Journal of the American Chemical Society	275	0.52	22.9
5	Synthetic Metals	249	1.62	20.2
6	Fullerene Science & Technology	234	2.76	58.2
7	Solid State Communications	231	0.88	19.2
8	Physical Review Letters	226	0.55	18.8
9	Nature	158	0.24	13.1
10	Journal of Chemical Physics	151	0.65	12.6
11	Journal of the Chemical Society, Chemical Communications	145	1.04	12.1
12	Science	144	0.31	12.0
13	Applied Physics Letters	124	1.02	10.3
14	Carbon	113	1.59	9.4
15	Molecular Crystals and Liquid Crystals Science and Technology, Section A	87		
16	Physica C	87		
17	Tetrahedron Letters	77		
18	Journal of Physics and Chemistry of Solids	77		
19	Angewandte Chemie, International Edition in English	74		
20	Japanese Journal of Applied Physics, Part 2	70		
21	Zeitschrift für Physik D	65		
22	Europhysics Letters	65		
23	Chemical & Engineering News	64		
24	Journal of Organic Chemistry	62		
25	International Journal of Mass Spectrometry and Ion Processes	59		
26	Physics Letters A	54		
27	Journal of Physics, Condensed Matter	54		
28	Russian Chemical Bulletin	52		
29	Surface Science	51		
30	THEOCHEM, Journal of Molecular Structure	50		
31	Journal of Applied Physics	49		
32	Journal of the Chemical Society, Faraday Transactions	47		
33	Applied Physics A	47		
34	Journal of the Chemical Society, Perkin Transactions 2	44		
35	Nuclear Instruments & Methods in Physics Research, Section B	43		
36	Journal of the Physical Society of Japan	43		
37	Journal of Physics B	43		
38	Tetrahedron	41		
39	Chemistry Letters	41		
40	Thin Solid Films	41		
41	Physica B	38		
42	Chemical Communications	37		
43	New Scientist	34		
44	JETP Letters	33		
45	Chinese Physics Letters	33		
46	Journal of Materials Research	31		
47	Chemical Physics	29		
48	Chemistry of Materials	28		
49	Zeitschrift für Physik B	27		
50	Journal of Electron Spectroscopy and Related Phenomena	27		

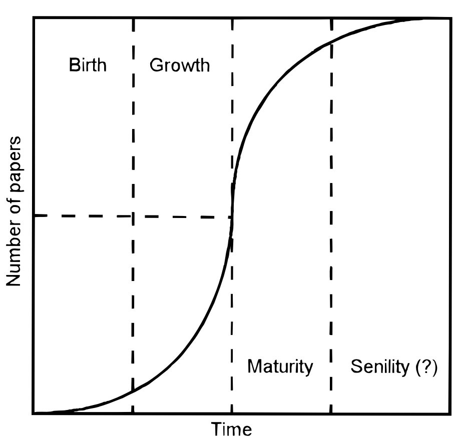


Figure 2. Logistic growth of the literature.

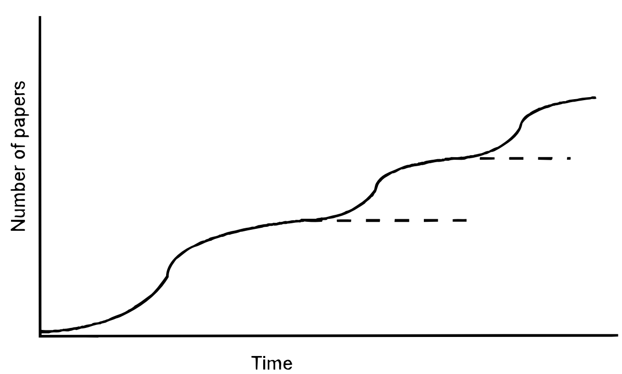


Figure 3. Escalating growth of the literature.

the CD-ROM Edition of the *Science Citation Index* (SCI) database of the Institute for Scientific Information (Philadelphia, PA). The *Dissertation Abstract* (Ann Arbor, MI) has been used for the measurements involving Ph.D. theses dealing with topics related to fullerene sciences.

Table 2. Countries Publishing the Greatest Number of Fullerene Science Related Papers during the 1985−1996 Period

rank	country	number of papers	growth ratio	rank	country	number of papers	growth ratio
1	United States	2687	0.65	26	Czech Republic	36	
2	Japan	1206	1.25	27	Denmark	35	
3	Germany	743	1.26	28	Scotland	34	
4	England	451	0.83	29	Brazil	31	
5	France	409	1.48	30	Mexico	30	
6	Russia	406	2.73	31	Croatia	29	
7	P. R. China	398	3.28	32	Slovenia	27	
8	Switzerland	246	1.76	33	Romania	17	
9	Italy	241	1.93	34	Argentina	16	
10	India	211	0.89	35	Finland	13	
11	Canada	167	0.65	36	Greece	13	
12	Belgium	148	1.20	37	Bulgaria	12	
13	Australia	112	1.28	38	Ireland	12	
14	Austria	102	1.98	39	Slovakia	12	
15	Sweden	95		40	Norway	11	
16	Hungary	92		41	Portugal	11	
17	Taiwan	91		42	Armenia	7	
18	Israel	76		43	New Zealand	6	
19	South Korea	74		44	South Africa	6	
20	Spain	72		45	Lithuania	5	
21	Netherlands	71		46	Latvia	3	
22	Poland	71		47	Yugoslavia	3	
23	Ukraine	44		48	Turkey	3	
24	Hong-Kong	41		49	Wales	3	
25	Uzbekistan	40		50	Estonia	3	

III. Results and Discussion

A. Growth of the Literature

The general appeal of fullerene science research as reflected in journal papers output can be compared to the growth of defended Ph.D. theses on this topic at United States universities in Figure 1. Both curves show similar shape, except for their peak year (1993 for journal papers, 1995 for dissertations). This retardation can be explained by the somewhat slower procedure of defending Ph.D. theses as compared to publishing a paper.

It seems that the field has entered the period of logistic growth approaching maturation (Figure 2). As Derek Price has argued,[3] logistic growth can react to ceiling or "maturation" conditions in various ways. New exponentials can develop as old ones disappear, thus creating an escalating effect (Figure 3). Such escalations can arise out of new directions in research, new discoveries, and new opportunities. But such natural renewed growth cannot occur if the basic field is not nurtured at a level sufficient to support new trends. At this moment it is quite difficult to define exactly the stage fullerene research is in and/or forecast the shape of its growth in future years.

B. Scatter of the Journal Literature

The 7381 bibliographic items were scattered among a total of 437 journal titles; among them 247 were used in the first (1985−1993) and 375 in the second (1994−1996) period; 185 journals were used in both periods. Fifty journals publishing the greatest number of fullerene-related papers during the 1983−1996 period are given in Table 1. For the first 14 (those publishing at least 100 papers) the growth ratio, i.e., the ratio of the journal's percentage share in 1994−1996 versus 1985−1993, and the number of papers/year are also given. Papers from these 14 journals represented more than one-half of the total journal publication output in fullerene science.

The trend of the productivity of the 14 leading journals is presented in Figure 4.

As visible in Table 1, only four journals show a positive growth ratio for the 1994−1996 period as compared to 1985−1993. The highest growth ratio is shown, as expected, by *Fullerene Science and Technology*, the only journal totally devoted to fullerene sciences.

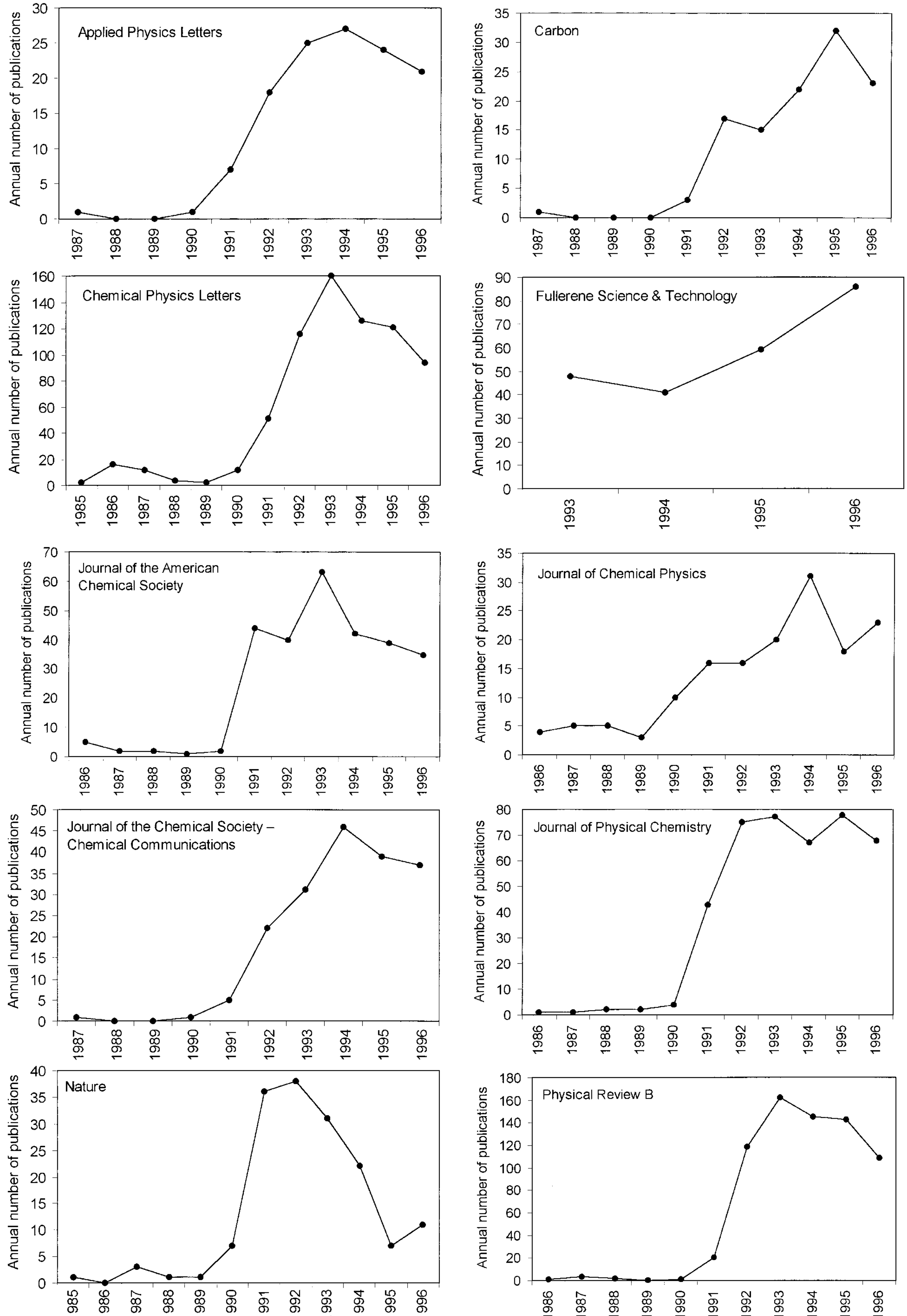
C. Country of Publication

Authors of a total of 62 countries contributed to fullerene science in the world. Fifty countries publishing the greatest number of fullerene-related papers during the 1985−1996 period are given in Table 2. For the first 14 (those publishing at least 100 papers) their growth ratio, i.e., the ratio of the country's percentage share in the total publication output in 1994−1996 to the percentage share in 1985−1993, is also given. Authors from these 14 countries contributed to 86% of the total journal publication output in fullerene research. As visible, the United States is the leading power in fullerene science, followed by Japan and the European triad of Germany, England, and France. Russia's and China's productivity is also remarkable.

In Figure 5 the number of papers from the countries of the world is given in the form of a proportional map, i.e., a map where the relative position of the countries is attempted to reflect their "natural" (geographical) order, whereas their area represents the number of fullerene papers by authors of the given country.

D. International Coauthorship Patterns

Just 1284 bibliographic items (17% of the total) were the results of international coauthorship. A


Applied Physics Letters
Carbon
Chemical Physics Letters
Fullerene Science & Technology
Journal of the American Chemical Society
Journal of Chemical Physics
Journal of the Chemical Society – Chemical Communications
Journal of Physical Chemistry
Nature
Physical Review B
Annual number of publications

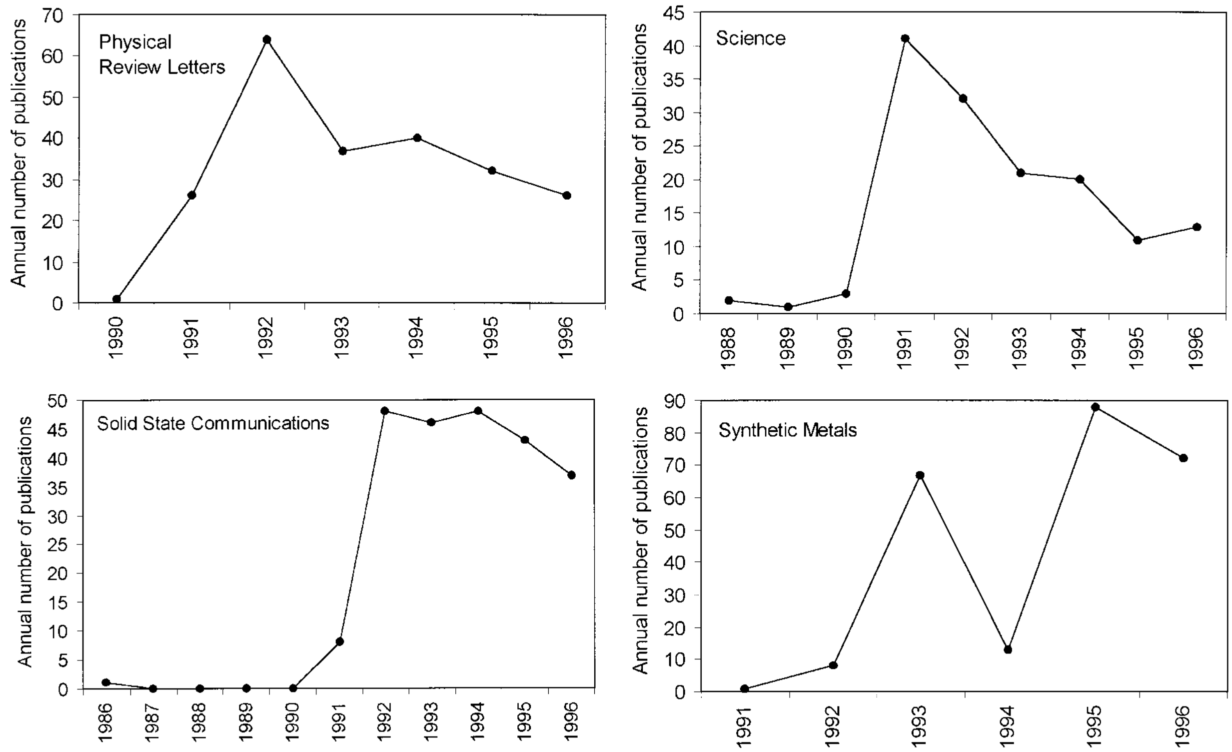


Figure 4. Trend of the productivity of leading journals publishing fullerene science related papers.

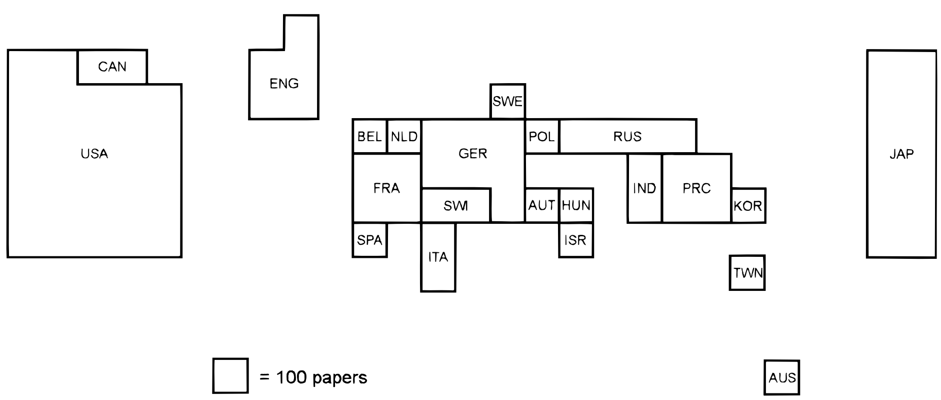


Figure 5. Proportional map of countries based on the number of publications in the bibliographies.

definite increase in the cooperative activity (from 13% in the 1985−1993 period to 20% in the 1994−1996 period) could be observed. There were only 4 of the 62 countries (Egypt, Estonia, Thailand, and Turkey) with a total of 10 publications which were not involved at least once in such cooperative activity. Figure 6 graphically presents the main coauthorship links between the contributing countries.

Figure 6 shows that the world of fullerene research as a collaborative international venture rotates around a strong cluster having the centers in the United States, England, Germany, Switzerland, France, and Italy.

E. Author Productivity

Research in a scientific field is a joint effort, done by "a group of individuals, dividing their labor but continuously and jealously checking each other's contributions".[4]

There have been many individual scientists contributing to the field of fullerene science. Table 3

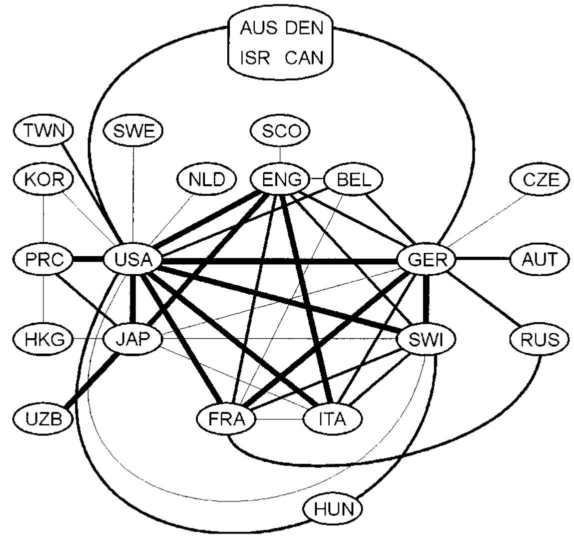


Figure 6. Coauthorship map. Links representing at least 10 joint papers are shown on the map. Weak links (thin lines) represent 10−14; medium strength links (medium thick lines) 15−24; strong links (thick lines) more than 25 coauthored papers.

Table 3. Most Productive 108 Authors in Fullerene Science

rank	name	no. of papers	rank	name	no. of papers
1	Achiba, Y.	129	55	Prato, M.	32
2	Kikuchi, K.	110	56	Scuseria, G. E.	32
3	Kroto, H. W.	106	57	Campbell, E. E. B.	31
4	Saito, Y.	102	58	Hertel, I. V.	31
5	Shinohara, H.	85	59	Nagase, S.	31
6	Wudl, F.	84	60	Sariciftci, N. S.	31
7	Taylor, R.	83	61	Tokumoto, M.	31
8	Fischer, J. E.	82	62	Zahab, A.	31
9	Haddon, R. C.	80	63	Fleming, R. M.	30
10	Suzuki, S.	79	64	Roth, S.	30
11	Fowler, P. W.	71	65	Zettl, A.	30
12	Smalley, R. E.	69	66	Balasubramanian, K.	29
13	Walton, D. R. M.	67	67	Lambin, P.	29
14	Diederich, F.	64	68	Märk, T. D.	29
15	Zakhidov, A. A.	60	69	Orlandi, G.	29
16	Tanigaki, K.	59	70	Cohen, M. L.	28
17	Dresselhaus, M. S.	58	71	Dennis, T. J.	28
18	Ebbesen, T. W.	55	72	Harigaya, K.	28
19	Bernier, P.	54	73	Heeger, A. J.	28
20	Ikemoto, I.	54	74	Holczer, K.	28
21	Whetten, R. L.	50	75	Huffman, D. R.	28
22	Rassat, A.	49	76	Murphy, D. W.	28
23	Weaver, J. H.	49	77	Nagashima, H.	28
24	Prassides, K.	47	78	Osawa, E.	28
25	Dresselhaus, G.	46	79	Pekker, S.	28
26	Kuzmany, H.	46	80	Saito, S.	28
27	Krätschmer, W.	44	81	Böhme, D. K.	27
28	Rao, C. N. R.	44	82	Moses, D.	27
29	Eklund, P. C.	43	83	Nishina, Y.	27
30	Yoshino, K.	43	84	Petrie, S.	27
31	Ruoff, R. S.	41	85	Sakurai, T.	27
32	Fabre, C.	40	86	Sokolov, V. I.	27
33	Hebard, A. F.	40	87	Suzuki, T.	27
34	Kobayashi, K.	40	88	Szwarc, H.	27
35	Maruyama, Y.	40	89	Wilson, M. A.	27
36	Tanaka, K.	39	90	Yakushi, K.	27
37	Slanina, Z.	38	91	Zhou, X. H.	27
38	Chibante, L. P. F.	37	92	Darwish, A. D.	26
39	Smith, A. B., III	37	93	Hare, J. P.	26
40	Meijer, G.	36	94	Hashizume, T.	26
41	Schlögl, R.	36	95	Hirosawa, I.	26
42	Werner, H.	36	96	Lobach, A. S.	26
43	Bethune, D. S.	35	97	Mehring, M.	26
44	Hirsch, A.	35	98	Seshadri, R.	26
45	Kappes, M. M.	35	99	Ajayan, P. M.	25
46	Rosseinsky, M. J.	35	100	Compton, R. N.	25
47	Zerbetto, F.	35	101	Fink, J.	25
48	Takahashi, T.	34	102	Kortan, A. R.	25
49	Wang, Y.	34	103	Maggini, M.	25
50	Yamabe, T.	34	104	McCauley, J. P.	25
51	Forro, L.	33	105	Rachdi, F.	25
52	Baum, R.	32	106	Scheier, P.	25
53	Gu, Z. N.	32	107	Strongin, R. M.	25
54	Lucas, A. A.	32	108	Yamamoto, K.	25

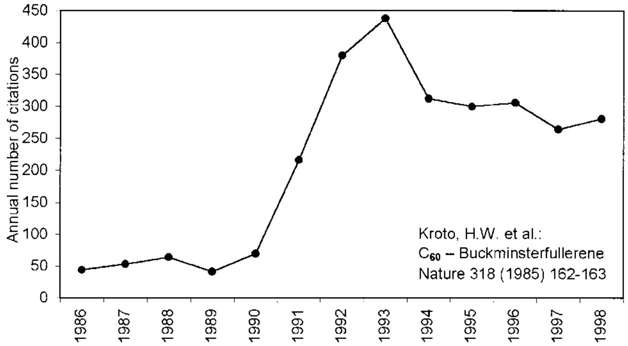
shows the list of the most productive 108 authors. The high productivity of Japanese authors is really remarkable.

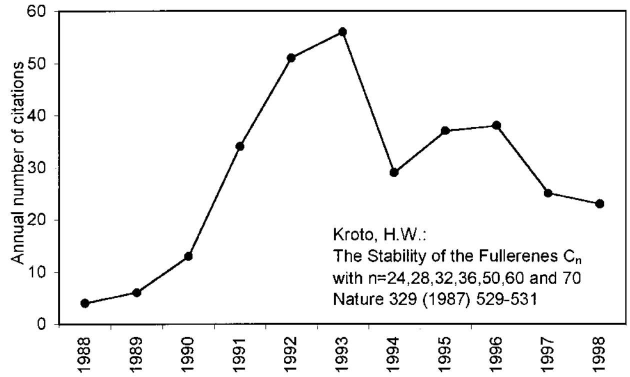
F. Citation Analysis of Fullerene Papers

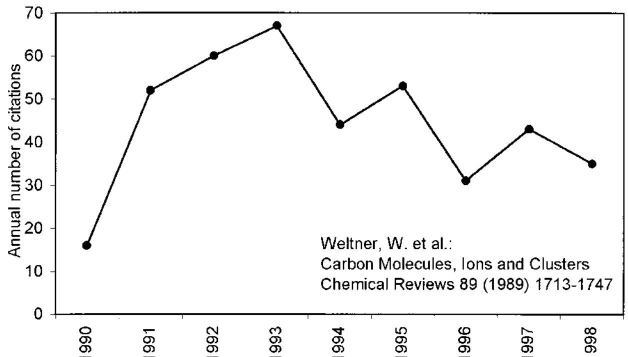
Table 4 presents the 50 fullerene papers published during the 1985−1993 period which were most cited in 1994−1996. We have chosen this differentiation of publication and citation periods by considering that citations to papers need a few years to be being able to accumulate a citation population which can be analyzed. Each paper on this list represents a milestone on the road leading to new vistas in fullerene research.

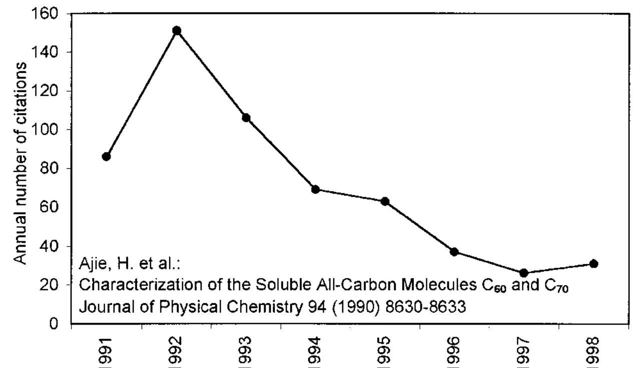
The collection of the time series of the citation histories of those top cited papers is shown in Figure 7.

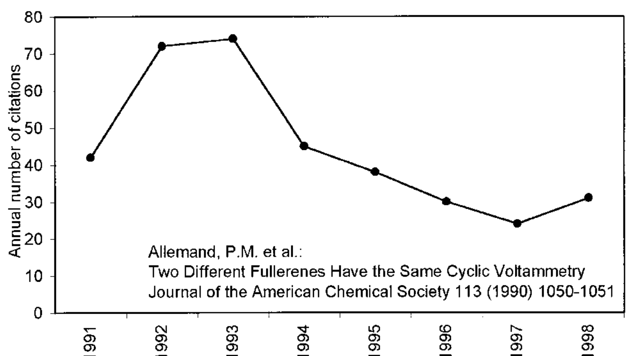
The top cited 50 papers could be categorized somewhat arbitrarily by their research topics into nine fullerene research subfields as follows: fullerene superconductors; crystal structure; electron structure and bonding; fullerene compounds; photophysical properties; electrochemistry; synthesis of fullerenes; covalent chemistry of fullerenes; nanotubes. The grouping of the most cited papers according to these categories did generate the trend of the citation histories of the above mentioned subfields presented in Figure 8.

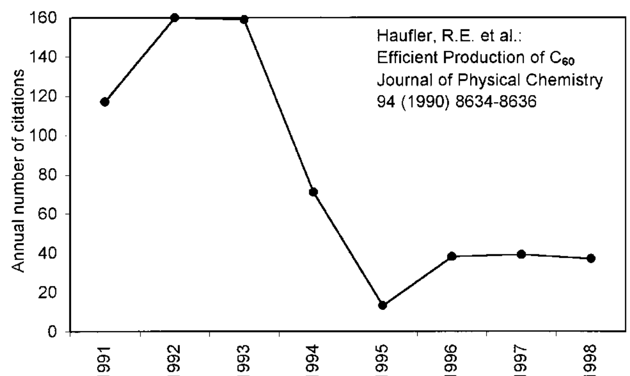

Annual number of citations
Kroto, H.W. et al.:
C_{60} – Buckminsterfullerene
Nature 318 (1985) 162-163

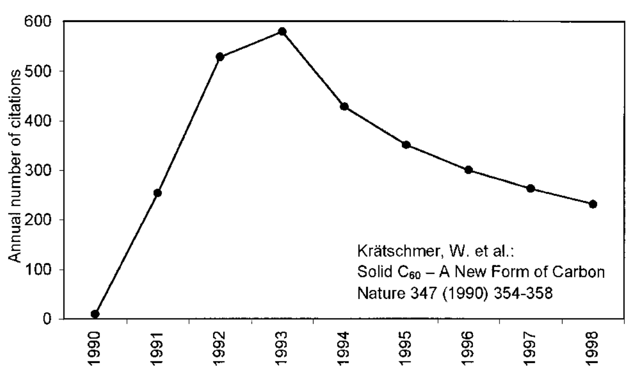

Annual number of citations
Kroto, H.W.:
The Stability of the Fullerenes C_n
with n=24,28,32,36,50,60 and 70
Nature 329 (1987) 529-531

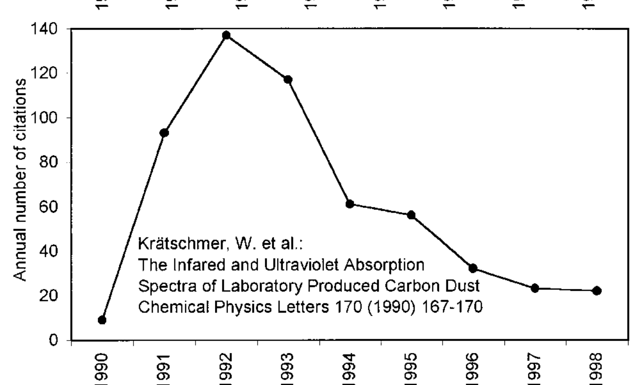

Annual number of citations
Weltner, W. et al.:
Carbon Molecules, Ions and Clusters
Chemical Reviews 89 (1989) 1713-1747

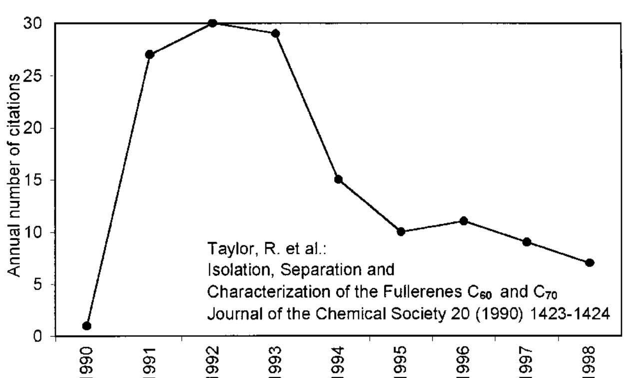

Annual number of citations
Ajie, H. et al.:
Characterization of the Soluble All-Carbon Molecules C_{60} and C_{70}
Journal of Physical Chemistry 94 (1990) 8630-8633

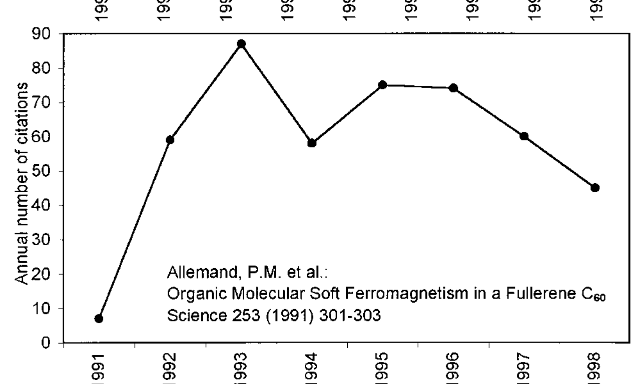

Annual number of citations
Allemand, P.M. et al.:
Two Different Fullerenes Have the Same Cyclic Voltammetry
Journal of the American Chemical Society 113 (1990) 1050-1051

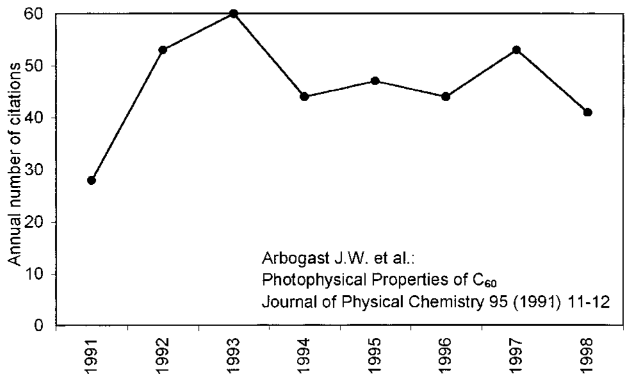

Annual number of citations
Haufler, R.E. et al.:
Efficient Production of C_{60}
Journal of Physical Chemistry
94 (1990) 8634-8636

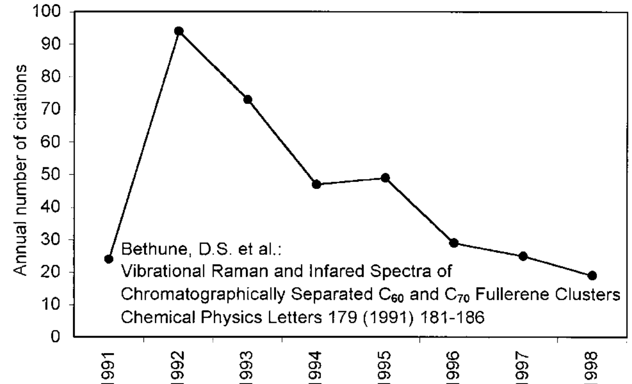

Annual number of citations
Krätschmer, W. et al.:
Solid C_{60} – A New Form of Carbon
Nature 347 (1990) 354-358

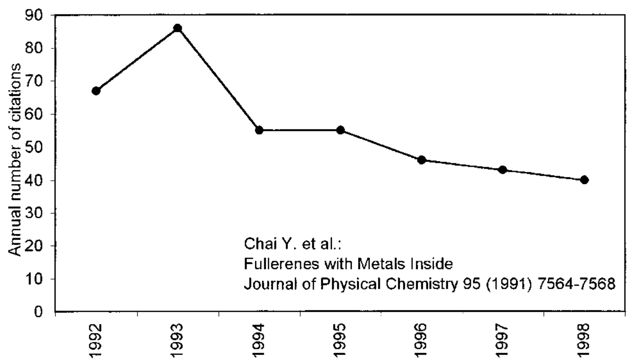

Annual number of citations
Krätschmer, W. et al.:
The Infared and Ultraviolet Absorption
Spectra of Laboratory Produced Carbon Dust
Chemical Physics Letters 170 (1990) 167-170

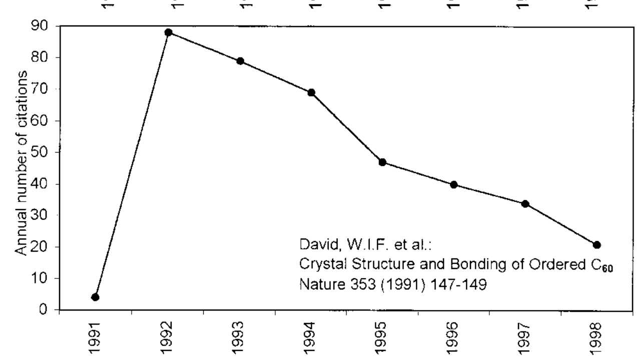

Annual number of citations
Taylor, R. et al.:
Isolation, Separation and
Characterization of the Fullerenes C_{60} and C_{70}
Journal of the Chemical Society 20 (1990) 1423-1424

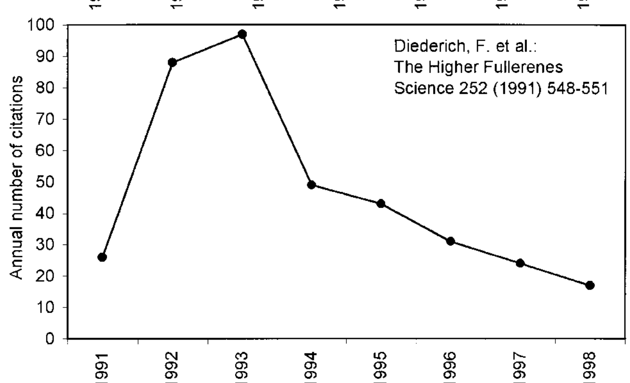

Annual number of citations
Allemand, P.M. et al.:
Organic Molecular Soft Ferromagnetism in a Fullerene C_{60}
Science 253 (1991) 301-303

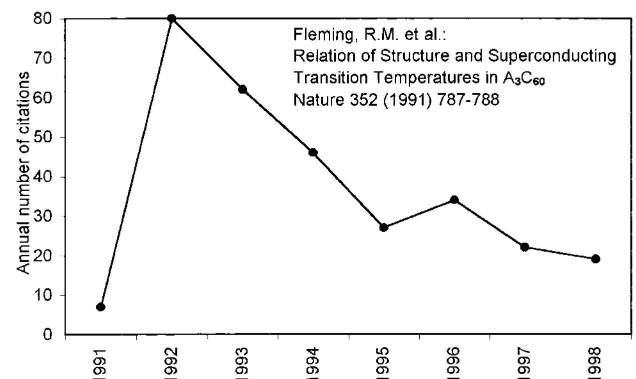

Annual number of citations
Arbogast J.W. et al.:
Photophysical Properties of C60
Journal of Physical Chemistry 95 (1991) 11-12
1991 1992 1993 1994 1995 1996 1997 1998

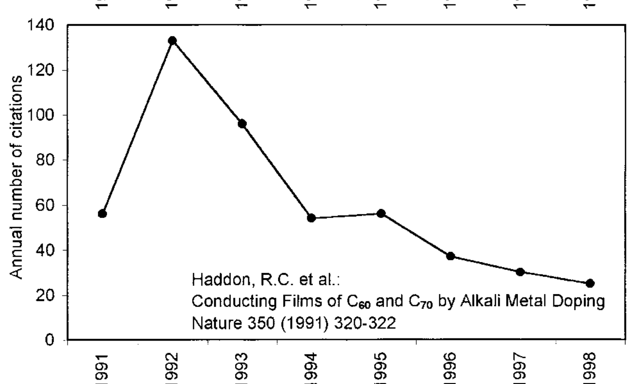

Annual number of citations
Bethune, D.S. et al.:
Vibrational Raman and Infared Spectra of
Chromatographically Separated C60 and C70 Fullerene Clusters
Chemical Physics Letters 179 (1991) 181-186
1991 1992 1993 1994 1995 1996 1997 1998

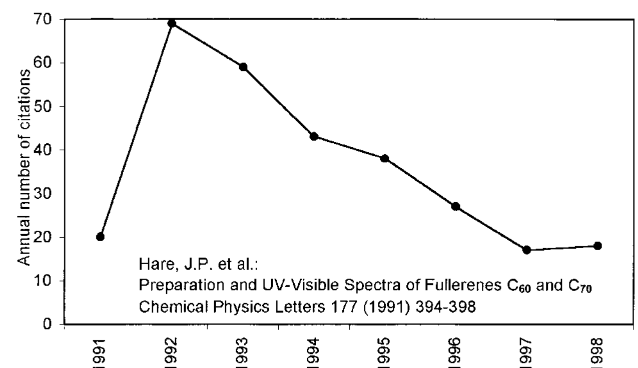

Annual number of citations
Chai Y. et al.:
Fullerenes with Metals Inside
Journal of Physical Chemistry 95 (1991) 7564-7568
1992 1993 1994 1995 1996 1997 1998

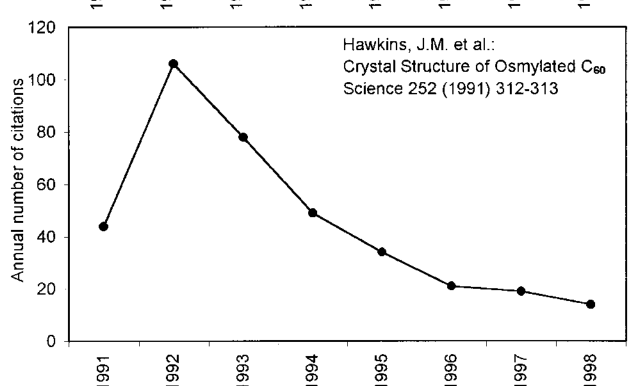

Annual number of citations
David, W.I.F. et al.:
Crystal Structure and Bonding of Ordered C60
Nature 353 (1991) 147-149
1991 1992 1993 1994 1995 1996 1997 1998

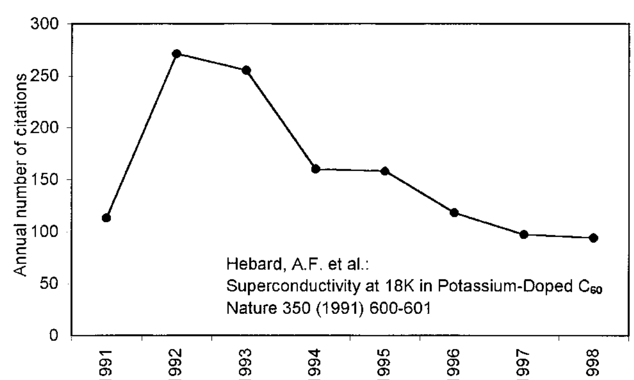

Annual number of citations
Diederich, F. et al.:
The Higher Fullerenes
Science 252 (1991) 548-551
1991 1992 1993 1994 1995 1996 1997 1998

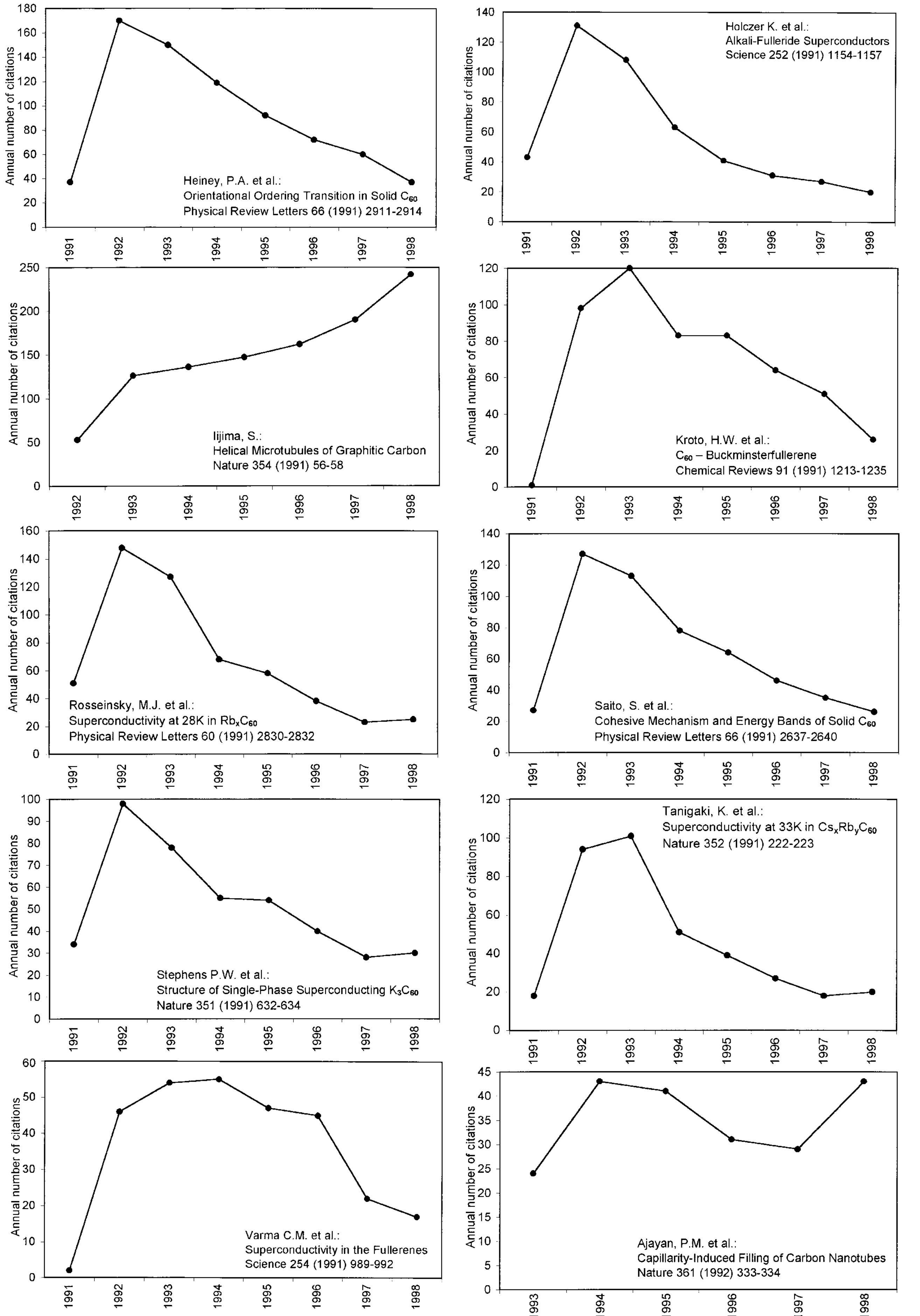

Annual number of citations
Fleming, R.M. et al.:
Relation of Structure and Superconducting
Transition Temperatures in A3C60
Nature 352 (1991) 787-788
1991 1992 1993 1994 1995 1996 1997 1998

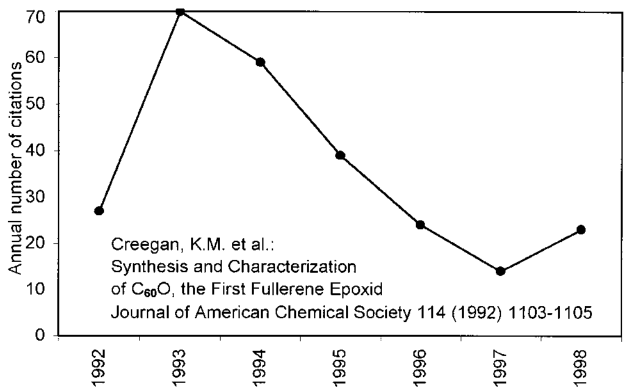

Annual number of citations
Haddon, R.C. et al.:
Conducting Films of C60 and C70 by Alkali Metal Doping
Nature 350 (1991) 320-322
1991 1992 1993 1994 1995 1996 1997 1998

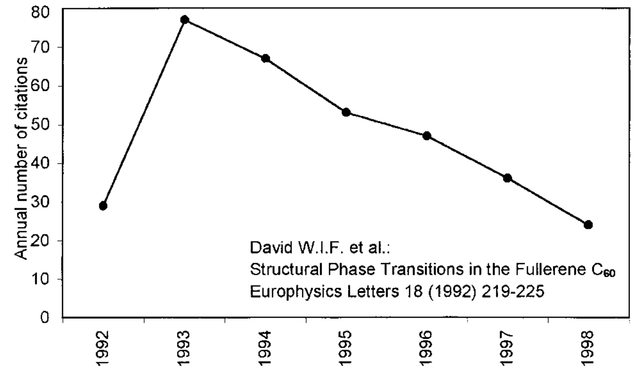

Annual number of citations
Hare, J.P. et al.:
Preparation and UV-Visible Spectra of Fullerenes C60 and C70
Chemical Physics Letters 177 (1991) 394-398
1991 1992 1993 1994 1995 1996 1997 1998

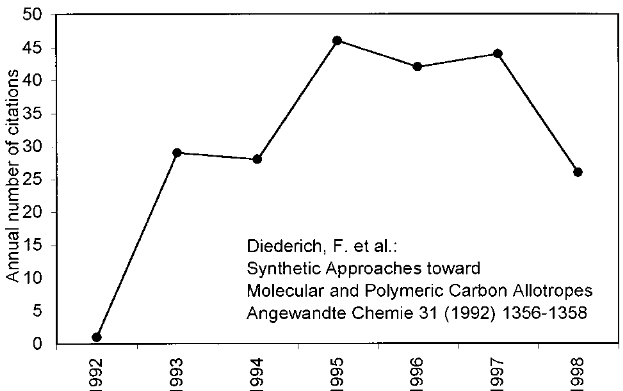

Annual number of citations
Hawkins, J.M. et al.:
Crystal Structure of Osmylated C60
Science 252 (1991) 312-313
1991 1992 1993 1994 1995 1996 1997 1998

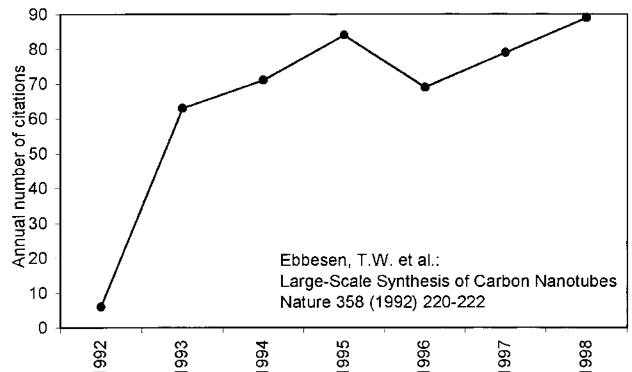

Annual number of citations
Hebard, A.F. et al.:
Superconductivity at 18K in Potassium-Doped C60
Nature 350 (1991) 600-601
1991 1992 1993 1994 1995 1996 1997 1998

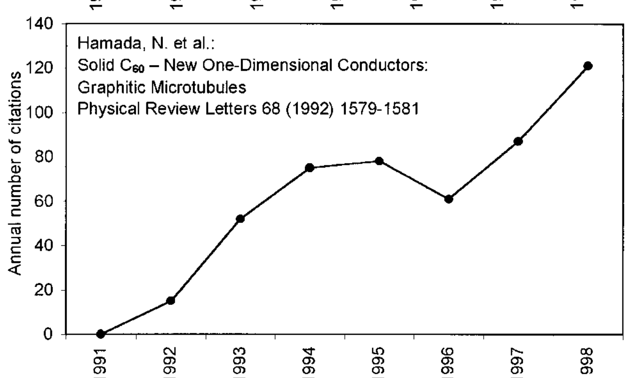

Annual number of citations
Heiney, P.A. et al.:
Orientational Ordering Transition in Solid C_{60}
Physical Review Letters 66 (1991) 2911-2914
Holczer K. et al.:
Alkali-Fulleride Superconductors
Science 252 (1991) 1154-1157
Iijima, S.:
Helical Microtubules of Graphitic Carbon
Nature 354 (1991) 56-58
Kroto, H.W. et al.:
C_{60} – Buckminsterfullerene
Chemical Reviews 91 (1991) 1213-1235
Rosseinsky, M.J. et al.:
Superconductivity at 28K in Rb_xC_{60}
Physical Review Letters 60 (1991) 2830-2832
Saito, S. et al.:
Cohesive Mechanism and Energy Bands of Solid C_{60}
Physical Review Letters 66 (1991) 2637-2640
Stephens P.W. et al.:
Structure of Single-Phase Superconducting K_3C_{60}
Nature 351 (1991) 632-634
Tanigaki, K. et al.:
Superconductivity at 33K in $Cs_xRb_yC_{60}$
Nature 352 (1991) 222-223
Varma C.M. et al.:
Superconductivity in the Fullerenes
Science 254 (1991) 989-992
Ajayan, P.M. et al.:
Capillarity-Induced Filling of Carbon Nanotubes
Nature 361 (1992) 333-334
1991 1992 1993 1994 1995 1996 1997 1998

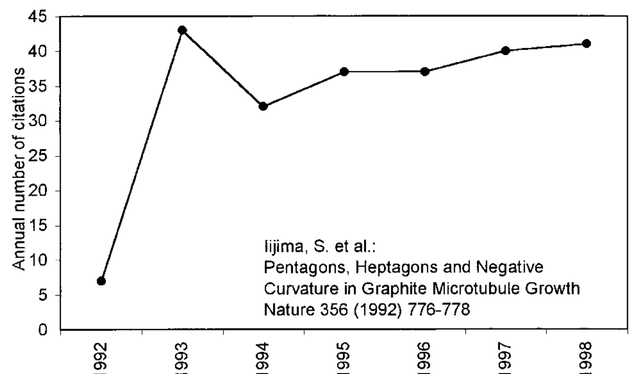

Annual number of citations
Creegan, K.M. et al.:
Synthesis and Characterization
of $C_{60}O$, the First Fullerene Epoxid
Journal of American Chemical Society 114 (1992) 1103-1105
1992 1993 1994 1995 1996 1997 1998

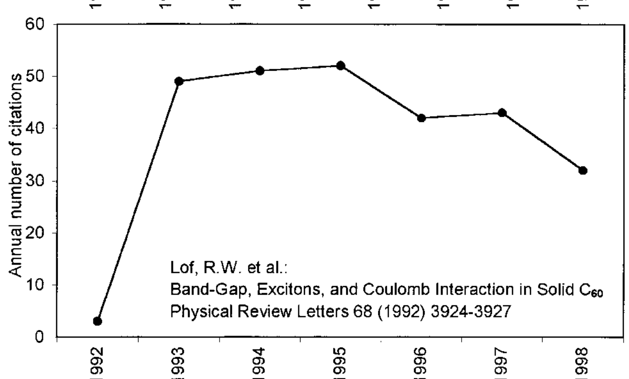

Annual number of citations
David W.I.F. et al.:
Structural Phase Transitions in the Fullerene C_{60}
Europhysics Letters 18 (1992) 219-225
1992 1993 1994 1995 1996 1997 1998

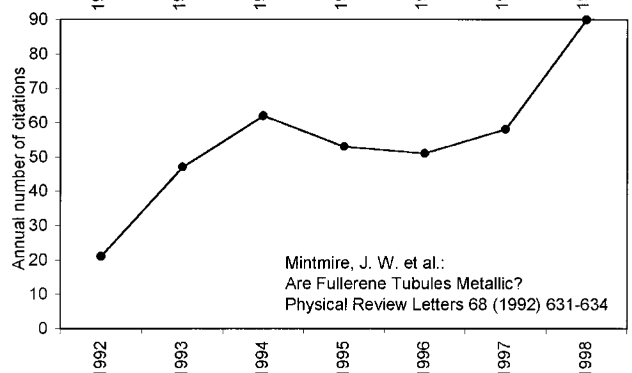

Annual number of citations
Diederich, F. et al.:
Synthetic Approaches toward
Molecular and Polymeric Carbon Allotropes
Angewandte Chemie 31 (1992) 1356-1358
1992 1993 1994 1995 1996 1997 1998

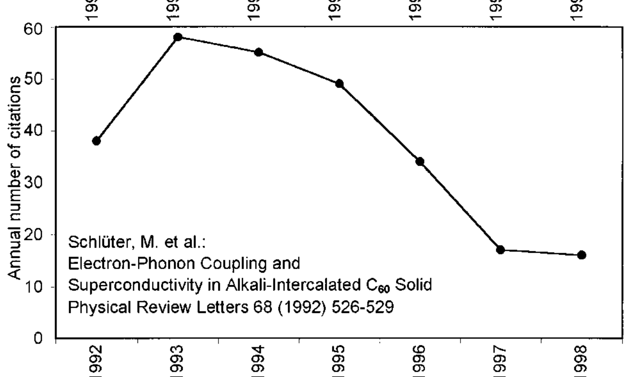

Annual number of citations
Ebbesen, T.W. et al.:
Large-Scale Synthesis of Carbon Nanotubes
Nature 358 (1992) 220-222
1992 1993 1994 1995 1996 1997 1998

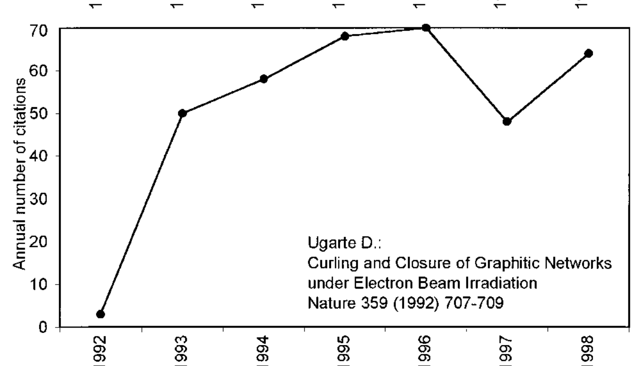

Annual number of citations
Hamada, N. et al.:
Solid C_{60} – New One-Dimensional Conductors:
Graphitic Microtubules
Physical Review Letters 68 (1992) 1579-1581
1991 1992 1993 1994 1995 1996 1997 1998


Annual number of citations
Iijima, S. et al.:
Pentagons, Heptagons and Negative
Curvature in Graphite Microtubule Growth
Nature 356 (1992) 776-778
1992 1993 1994 1995 1996 1997 1998


Annual number of citations
Lof, R.W. et al.:
Band-Gap, Excitons, and Coulomb Interaction in Solid C_{60}
Physical Review Letters 68 (1992) 3924-3927
1992 1993 1994 1995 1996 1997 1998


Annual number of citations
Mintmire, J. W. et al.:
Are Fullerene Tubules Metallic?
Physical Review Letters 68 (1992) 631-634
1992 1993 1994 1995 1996 1997 1998


Annual number of citations
Schlüter, M. et al.:
Electron-Phonon Coupling and
Superconductivity in Alkali-Intercalated C_{60} Solid
Physical Review Letters 68 (1992) 526-529
1992 1993 1994 1995 1996 1997 1998


Annual number of citations
Ugarte D.:
Curling and Closure of Graphitic Networks
under Electron Beam Irradiation
Nature 359 (1992) 707-709
1992 1993 1994 1995 1996 1997 1998

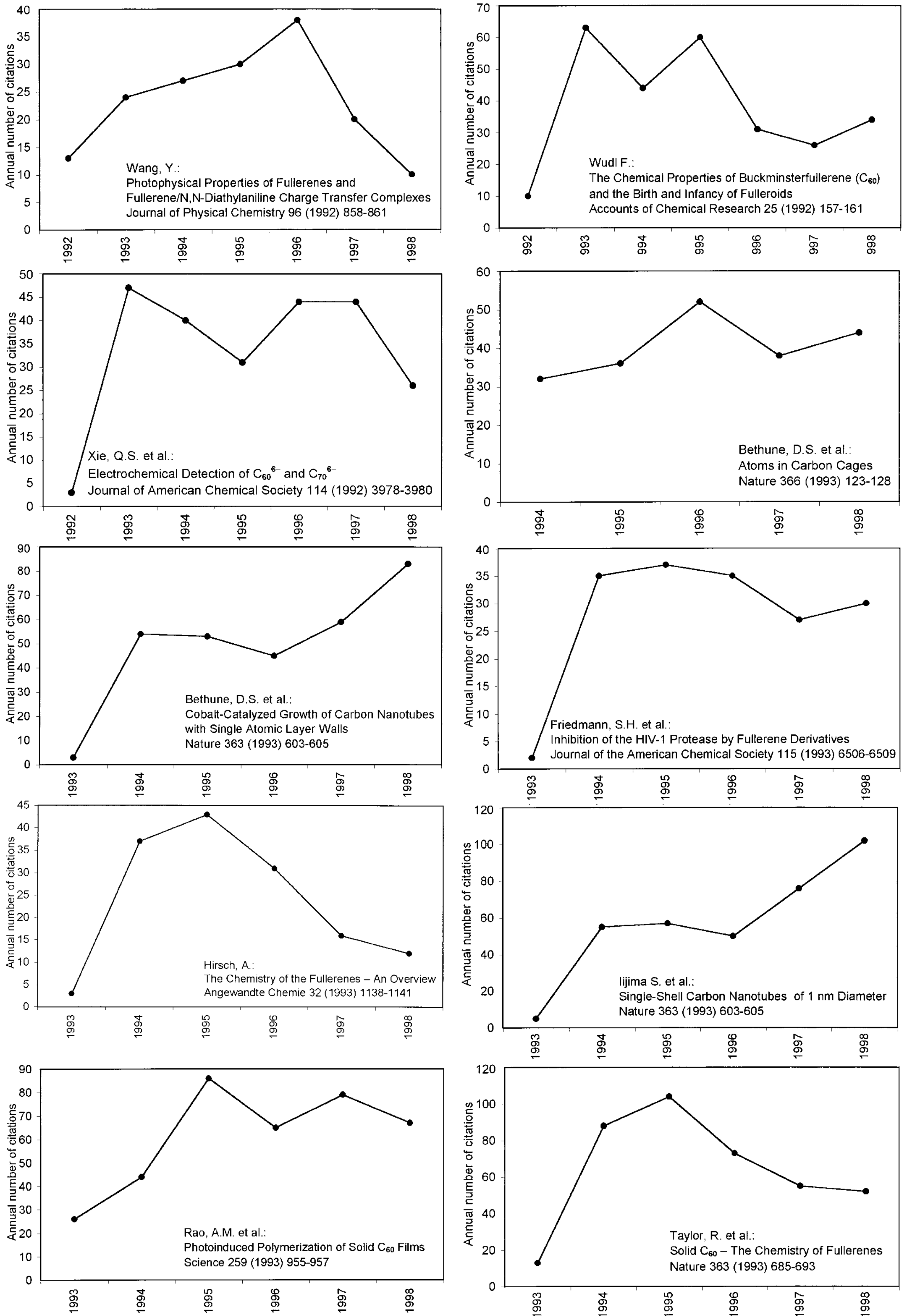


Figure 7. Citation history of the most cited fullerene papers.

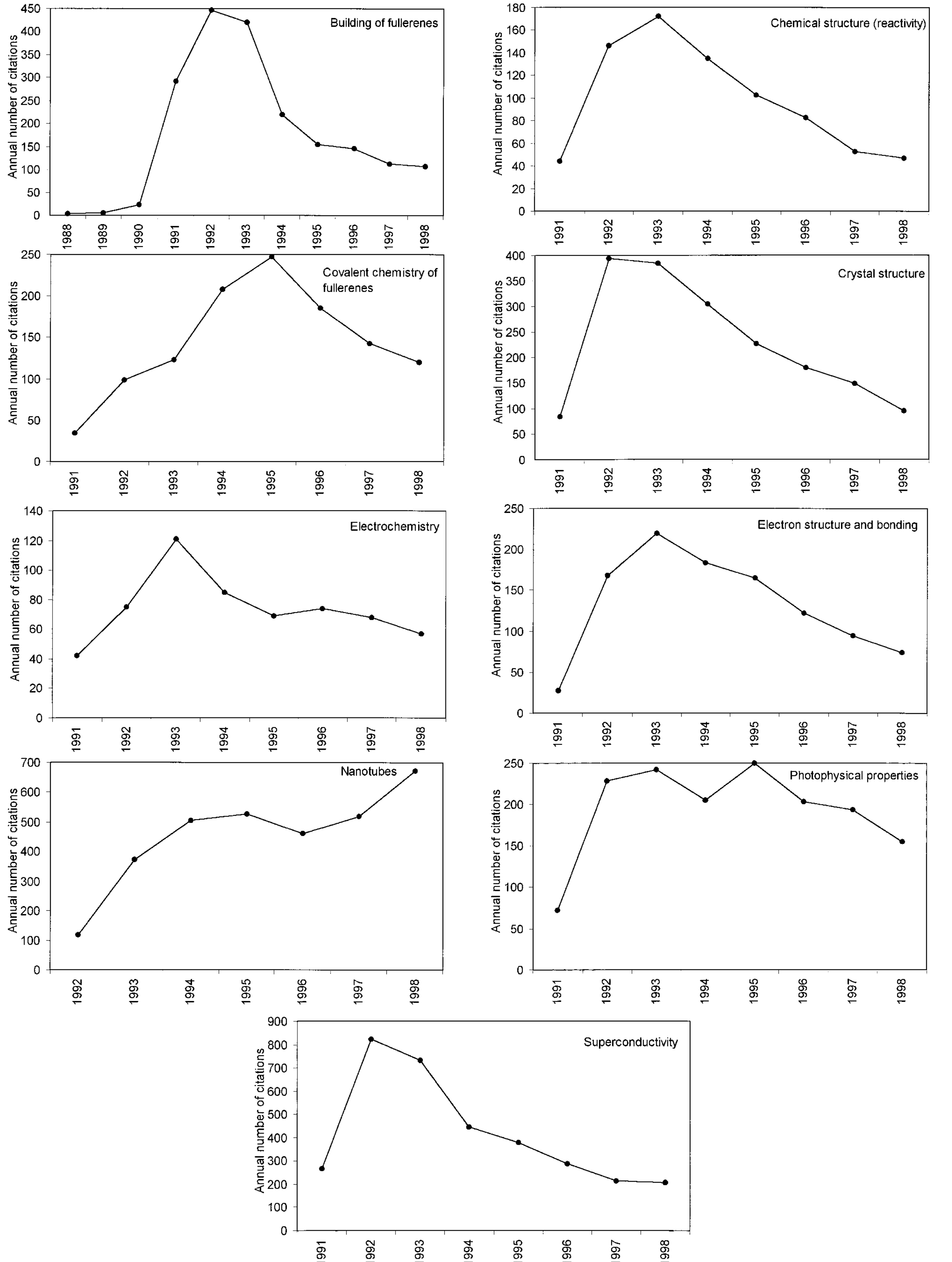


Figure 8. Citation history of subfield clusters formed from most cited fullerene papers.

Although the authors of this evaluation do vividly remember Niels Bohr's "bon mot" stating that "it is very difficult to foresee, especially the future", one cannot neglect by looking at Figure 8 that the only subfield which shows an increasing trend in aggregated citations is that of nanotubes research. This,

Table 4. Fullerene Papers Most Cited in 1985−1998

rank	paper	total citations
1	Krätschmer, W.; Lamb, L. D.; Fostiropoulos, K.; Huffman, D. R. Solid C_{60}−A New Form of Carbon. *Nature* **1990**, *347*, 354−358.	2945
2	Kroto, H. W.; Heath, J. R.; O'Brien, S. C.; Curl, R. F.; Smalley, R. E. C_{60}−Buckminsterfullerene. *Nature* **1985**, *318*, 162−163.	2768
3	Hebard, A. F.; Rosseinsky, M. J.; Haddon, R. C.; Murphy, D. W.; Gkarum, S. H.; Palstra, T. T. M.; Ramirez, A. P.; Kortan, A. R. Superconductivity at 18K in Potassium-Doped C_{60}. *Nature* **1991**, *350*, 600−601.	1266
4	Iijima, S. Helical Microtubules of Graphitic Carbon. *Nature* **1991**, *354*, 56−58.	1056
5	Heiney, P. A.; Fisher, J. E.; McGhie, A. R.; Romanow, W. J.; Denenstein, A. M.; McCauley, J. P.; Smith, A. B., III; Cox, D. E. Orientational Ordering Transition in Solid C_{60}. *Phys. Rev. Lett.* **1991**, *66*, 2911−2914.	737
6	Haufler, R. E.; Conceicao, J.; Chibante, L. P. F.; Chai, Y.; Byrne, N. E.; Flanagan, S.; Haley, M. M.; O'Brien, S. C.; Pan, C.; Xiao, Z.; Billups, W. E .; Ciufolini, M. A.; Hauge, R. H.; Margrave, J. L.; Wilson, L. J.; Curl, R. F.; Smalley, R. E. Efficient Production of C_{60}. *J. Phys. Chem.* **1990**, *94*, 8634−8636.	634
7	Ajie, H.; Alvarez, M. M.; Anz, S. J.; Beck, R. D.; Diederich, F.; Fostiropoulos, K.; Huffman, D. R.; Krätschmer, W.; Rubin, Y.; Schriver, K. E.; Sensharma, D.; Whetten, R. L. Characterization of the Soluble All-Carbon Molecules C_{60} and C_{70}. *J. Phys. Chem.* **1990**, *94*, 8630−8633.	569
8	Krätschmer, W.; Fostiropoulos, K.; Huffman, D. R. The Infared and Ultraviolet Absorption Spectra of Laboratory Produced Carbon Dust. *Chem. Phys. Lett.* **1990**, *170*, 167−170.	550
9	Rosseinsky, M. J.; Ramirez, A. P.; Glarum, S. H.; Murphy, D. W.; Haddon, R. C.; Hebard, A. F.; Palstra, T. T. M.; Kortan, A. R.; Zahurak, S. M.; Makhija, A. V. Superconductivity at 28K in Rb_xC_{60}. *Phys. Rev. Lett.* **1991**, *60*, 2830−2832.	538
10	Kroto, H. W.; Allaf, A. W.; Balm, S. P. C_{60}−Buckminsterfullerene. *Chem. Rev.* **1991**, *91*, 1213−1235.	526
11	Saito, S.; Oshiyama, A. Cohesive Mechanism and Energy Bands of Solid C_{60}. *Phys. Rev. Lett.* **1991**, *66*, 2637−2640.	516
12	Hamada, N.; Sawada, S.; Oshiyama, A. Solid C_{60}−New One-Dimensional Conductors: Graphitic Microtubules. *Phys. Rev. Lett.* **1992**, *68*, 1579−1581.	489
13	Haddon, R. C.; Hebard, A. F.; Rosseinsky, M. J.; Murphy, D. W.; Duclos, S. J.; Lyons, K. B.; Miller, B.; Rosamilia, J. M.; Fleming, R. M.; Kortan, A. R.; Glarum, S. H.; Makhija, A. V.; Muller, A. J.; Eick, R. H.; Zahurak, S. M.; Tycko, R.; Dabbagh, G.; Thiel, F. A. Conducting Films of C_{60} and C_{70} by Alkali Metal Doping. *Nature* **1991**, *350*, 320−322.	487
14	Allemand, P. M.; Khiemani, K. C.; Koch, A.; Wudl, F.; Holczer, K.; Donovan, S.; Grüner, G.; Thomson, J. D. Organic Molecular Soft Ferromagnetism in a Fullerene C_{60}. *Science* **1991**, *253*, 301−303.	465
15	Holczer K.; Klein, O.; Huang, S. M.; Kaner, R. B.; Fu, K. J.; Whetten, R. L.; Diederich, F. Alkali-Fulleride Superconductors. *Science* **1991**, *252*, 1154−1157.	464
16	Ebbesen, T. W.; Ajayan, P. M. Large-Scale Synthesis of Carbon Nanotubes. *Nature* **1992**, *358*, 220−222.	461
17	Stephens, P. W.; Mihály, L.; Lee, P. L.; Whetten, R. L.; Huang, S. M.; Kaner, R.; Deiderich, F.; Holczer, K. Structure of Single-Phase Superconducting K_3C_{60}. *Nature* **1991**, *351*, 632−634.	417
18	Weltner, W.; van Zee, R. J. Carbon Molecules, Ions and Clusters. *Chem. Rev.* **1989**, *89*, 1713−1747.	401
19	Chai, Y.; Guo, T.; Jin, C. M.; Haufler, R. E.; Chibante, L. P. F.; Fure, J.; Wang, L. H.; Alford, J. M.; Smalley, R. E. Fullerenes with Metals Inside. *J. Phys. Chem.* **1991**, *95*, 7564−7568.	392
20	Taylor, R.; Walton, D. R. M. Solid C_{60}−The Chemistry of Fullerenes. *Nature* **1993**, *363*, 685−693.	385
21	Mintmire, J. W.; Dunlap, B. I.; White, C. T. Are Fullerene Tubules Metallic? *Phys. Rev. Lett.* **1992**, *68*, 631−634.	382
22	David, W. I. F.; Ibberson, R. M.; Matthewman, J. C.; Prassides, K.; Dennis, T. J. S.; Hare, J. P.; Kroto, H. W.; Taylor, R.; Walton, D. R. M. Crystal Structure and Bonding of Ordered C_{60}. *Nature* **1991**, *353*, 147−149.	382
23	Diederich, F.; Ettl, R.; Rubin, Y.; Whetten, R. L.; Beck, R.; Alvarez, M.; Anz, S.; Sensharma, D.; Wudl, F.; Khemani, K. C.; Koch, A. The Higher Fullerenes. *Science* **1991**, *252*, 548−551.	375
24	Arbogast, J. W.; Darmanyan, A. P.; Foote, C. S.; Rubin, Y.; Diederich, F. N.; Alvarez, M. M.; Anz, S. J.; Whetten, R. L. Photophysical Properties of C_{60}. *J. Phys. Chem.* **1991**, *95*, 11−12.	370
25	Tanigaki, K.; Ebbessen, T. W.; Saito, S.; Mizuki, J.; Tsai, J. S.; KuboKuroshima, S. Superconductivity at 33K in $Cs_xRb_yC_{60}$. *Nature* **1991**, *352*, 222−223.	368
26	Rao, A. M.; Zhou, P.; Wang, K. A.; Hager, G. T.; Holden, J. M.;Wang, Y.; Lee, W. T.; Bi, X. X.; Eklund, P. C.; Cornett, D. S.; Duncan, M. A.; Amster, I. J. Photoinduced Polymerization of Solid C_{60} Films. *Science* **1993**, *259*, 955−957.	367
27	Hawkins, J. M.; Meyer, A.; Lewis, T. A.; Loren, S.; Hollander, F. J. Crystal Structure of Osmylated C_{60}. *Science* **1991**, *252*, 312−313.	365
28	Ugarte, D. Curling and Closure of Graphitic Networks Under Electron Beam Irradiation. *Nature* **1992**, *359*, 707−709.	361
29	Bethune, D. S.; Meijer, G.; Tang, W. C.; Rosen, H. J.; Golden, W. G.; Seki, H.; Brown, C. A.; de Vries, M. S. Vibrational Raman and Infared Spectra of Chromatographically Separated C_{60} and C_{70} Fullerene Clusters. *Chem. Phys. Lett.* **1991**, *179*, 181−186.	360
30	Allemand, P. M.; Koch, A.; Wudl, F.; Rubin, Y.; Diederich, F.; Alvarez, M. M.; Anz, S. J.; Whetten, R. L. Two Different Fullerenes Have the Same Cyclic Voltammetry. *J. Am. Chem. Soc.* **1991**, *113*, 1050−1051.	356
31	Iijima, S.; Ichihashi, T. Single-Shell Carbon Nanotubes of 1 nm Diameter. *Nature* **1993**, *363*, 603−605.	345
32	David, W. I. F.; Ibberson, R. M.; Dennis, T. J. S.; Hare, J. P.; Prassides, K. Structural Phase Transitions in the Fullerene C_{60}. *Europhys. Lett.* **1992**, *18*, 219−225.	333
33	Kroto, H. W. The Stability of the Fullerenes C_n with n = 24, 28, 32, 36, 50, 60 and 70. *Nature* **1987**, *329*, 529−531.	316
34	Bethune, D. S.; Kiang, C. H.; de Vries, M. S.; Gorman, G.; Savoy, R.; Vazquez, J.; eyers, R. Cobalt-Catalyzed Growth of Carbon Nanotubes with Single Atomic Layer Walls. *Nature* **1993**, *363*, 603−605.	297
35	Fleming, R. M.; Ramirez, A. P.; Rosseinsky, M. J.; Murphy, D. W.; Haddon, R. C.; Zahurak, S. M.; Makhija, A. V. Relation if Structure and Superconducting Transition Temperatures in A_3C_{60}. *Nature* **1991**, *352*, 787−788.	297

Table 4 (Continued)

rank	paper	total citations
36	Hare, J. P.; Kroto, H. W.; Taylor, R. Preparation and UV Visible Spectra of Fullerenes C_{60} and C_{70}. *Chem. Phys. Lett.* **1991**, *177*, 394−398.	291
37	Varma, C. M.; Zaanen, J.; Raghavachari, K. Superconductivity in the Fullerenes. Science **1991**, *254*, 989−992.	288
38	Lof, R. W.; van Vennendaal, M. A.; Koopmans, B.; Jonkman, H. T.; Sawatzky, G. A. Band-Gap, Excitons, and Coulomb Interaction in Solid C_{60}. *Phys. Rev. Lett.* **1992**, *68*, 3924−3927.	272
39	Wudl, F. The Chemical Properties of Buckminsterfullerene (C_{60}) and the Birth and Infancy of Fulleroids. *Acc. Chem. Res.* **1992**, *25*, 157−161.	268
40	Schlüter, M.; Lannoo, M.; Needels, M.; Baraff, G.A.; Tamánek, D. Electron-Phonon Coupling and Superconductivity in Alkali-Intercalated C_{60} Solid. *Phys. Rev. Lett.* **1992**, *68*, 526−529.	267
41	Creegan, K. M.; Robbins, J. L.; Robbins, W. K.; Millar, J. M.; Sherwood, R. D.; Tindall, P. J.; Cox, D. M.; Smith, A. B., III; McCauley, J. P.; Jones, D. R.; allagher, R. T. Synthesis and Characterization of $C_{60}O$, the First Fullerene Epoxid. *J. Am. Chem. Soc.* **1992**, *114*, 1103−1105.	256
42	Iijima, S.; Ichihashi, T.; Ando, Y. Pentagons, Heptagons and Negative Curvature in Graphite Microtubule Growth. *Nature* **1992**, *14*, 776−778.	237
43	Xie, Q. S.; Pérez-Cordero, E.; Echegoyen, L. Electrochemical Detection of $C_{60}{}^{6-}$ and $C_{70}{}^{6-}$. *J. Am. Chem. Soc.* **1992**, *31*, 3978−3980.	235
44	Diederich, F.; Rubin, Y. Synthetic Approaches toward Molecular and Polymeric Carbon Allotropes. *Angew. Chem.* 31 (1992) 1356−1358.	216
45	Ajayan, P. M.; Iijima, S. Capillarity-Induced Filling of Carbon Nanotubes. *Nature* **1992**, *361*, 333−334.	211
46	Bethune, D. S.; Johnson, R. D.; Salme, J. R.; de Vries, M. S.; Yannoni, C. S. Atoms in Carbon Cages. *Nature* **1993**, *366*, 123−128.	202
47	Friedmann, S. H.; Decamp, D. L.; Sijbesma, R. P.; Srdanov, G.; Wudl, F.; Kenyon, G. L. Inhibition of the HIV-1 Protease by Fullerene Derivatives. *J. Am. Chem. Soc.* **1993**, *115*, 6506−6509.	166
48	Wang, Y. Photophysical Properties of Fullerenes and Fullerene/N,N-Diathylaniline Charge Transfer Complexes. *J. Phys. Chem.* **1992**, *96*, 858−861.	162
49	Hirsch, A. The Chemistry of the Fullerenes−An Overview. *Angew. Chem.* **1993**, *32*, 1138−1141.	142
50	Taylor, R.; Hare, J. P.; Abdul-Sada, A. K.; Kroto, H. W. Isolation, Separation and Characterization of the Fullerenes C_{60} and C_{70}. *J. Chem. Soc.* **1990**, *20*, 1423−1424.	139

of course without considering that any of the other subfields also represented in Figure 8, could not begin to show an escalating trend sometime soon.

IV. Conclusions

As mentioned in the Introduction, this paper was aimed at the quantitative investigation of some structural characteristics of the journal literature of fullerene science without implicating an analysis of the literature's content. This can point toward growth, stagnation, or decline.

To be clear, we think that one can speculate on how far the results outlined in this paper could contribute to shed more light on recent statements, e.g., of the type "Fullerenes are an example of promises unfulfilled. Given a totally new material, researchers envisage many possible uses (molecular ball bearings, for lubricants) where the fullerenes might be the best option. But from superconductors to lubricants, fullerenes have *not yet* improved on existing materials".[5]

We consider that the trends revealed in the literature of fullerene science could be viewed as a guarantee that by being actually immersed into the questions of rising the basics of fullerene science, research in this field will be able to prove that the words "not yet" are the key terms of that whole statement. We duly hope that they could change into "already" at any moment in the future. Escalation, as also mentioned is not unusual in promising science fields.

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VI. References

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