From The Science of Science to Scientometrics : Visualizing the History of Science with *HistCite* Software

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Abstract
While ISSI was founded in 1993, scientometrics and bibliometrics are now at least half a century old. Indeed, the field can be traced to early quantitative studies in the early 20th Century. In the thirties, it evolved to the "science of science." The publication of J. D. Bernal's *Social Function of Science* in 1939 was a key transition point but the field lay dormant until after World War II, when DJD Price's books *Science Since Babylon* and *Little Science, Big Science* were published in1961 and 1963. His role as the "father of scientometrics" is clearly evident by using the *HistCite* software to visualize his impact as well as the subsequent impact of the journal *Scientometrics* on the growth of the field. *Scientometrics* owes its name to V. V. Nalimov, the author of *Naukometriya,* and to Tibor Braun who adapted the neologism for the journal. The primordial paper on citation indexing by Garfield which appeared in *Science* 1955 became a bridge between Bernal and Price. The timeline for the evolution of scientometrics is demonstrated by a *HistCite* tabulation of the ranked citation index of the 100,000 references cited in the 3,000 papers citing Price.

Keywords: history of scientometrics; etymology of scientometrics; Derek J.D. Price; V. V. Nalimov; J. D. Bernal; Science of Science; *HistCite*; algorithmic; historiography; bibliometrics.

Introduction

When Henk Moed asked me to present a keynote address to this Eleventh International Conference of the International Society for Scientometrics and Informatics (ISSI) I had mixed feelings. I had previously planned to participate by simply describing my current work on algorithmic historiography. The paper I originally submitted was an up-to-date description of the *HistCite* system *(http://www.histcite.com/)*. Briefly stated, *HistCite*™ is a software system which generates chronological maps of bibliographic collections resulting from subject, author, institutional or source journal searches of the *ISI Web of* Science.® *WoS e*xport files are created in which all cited references for each source document are captured. The software generates chronological historiographs highlighting the most-cited works in the retrieved collection. Other listings include rankings by author, journal, institution, or vocabulary.

But Henk thought that this might be a good chance to provide the current ISSI membership with some personal reflections on the origins of scientometrics, especially as it is now two decades since the first ISSI conference held in Belgium in 1987 and 14 years since ISSI was founded in Berlin. It is noteworthy that the term "scientometrics" itself was not included in the title of the 1987 meeting which was the "First International Conference on Bibliometrics and Theoretical Aspects of Information Retrieval." Twenty years earlier, Alan Pritchard had coined the term bibliometrics in his 1969 paper on statistical bibliography. (Pritchard, 1969).

Most of us have been exposed to the macro history of scientometrics. We recognize names like Derek de Solla Price and V.V. Nalimov and perhaps earlier pioneers in measurement such as Alfred Lotka and George K. Zipf. If you search the *Web of Science* for the past century, these names will pop up very quickly. But when you search year-by-year you obtain a very different micro-perspective. Today, I would like to recall for you aspects of the micro and macro impact of Derek Price's work, since he is usually considered "the father of Scientometrics." However, this simplistic metaphor for his role in the history of scientometrics, does not adequately reflect the influences of earlier statistically and quantitatively oriented scholars.

In the foreword to the second edition of "Little Science, Big Science," (Merton and Garfield, 1986) Robert K. Merton and I identified Derek as the father of scientometrics because he was perceived, in the western world, to have made the greatest impact on the use of quantitative indicators in formulating science policy. The first edition of the 1963 book was aptly identified as a *Citation Classic* (Price, 1983) but at the time the book was written, Derek had not even encountered the term scientometrics, which was coined by the Russian mathematician-philosopher-polymath, V. V. Nalimov. "Scientometrics" is the English translation of the title word of Nalimov's classic monograph *Naukometriya,*[i] (Nalimov and Mul'chenko, 1973) which was relatively unknown to western scholars even after it was translated into English. Without access to the internet and limited distribution, it was rarely cited. However, the term became better known once the journal *Scientometrics* appeared in 1978. Stephen Bensman in a tribute to Tibor Braun recently reminded us how the journal became a bridge between the East and West. (Bensman & Kraft, in press) To simply mention that Nalimov coined the term scientometrics would be an injustice to his impact as a polymathic author. As with Derek Price I am proud go have been Vassili Nalimov's friend for three decades and to have published four of his books in English. And recently the full texts of those books have been digitized and posted to my website: http://garfield.library.upenn.edu/nalimov.html . For a more detailed account of Nalimov's role in the history of scientometrics, see Chapter IV of *The Citation Culture* by Paul Wouters. The full text is posted at http://garfield.library.upenn.edu/wouters/wouters.pdf .

Let me remind you of some historical facts. Price's "*Science Since Babylon*" (Price 1986) was published six years after my 1955 paper in *Science* (Garfield, 1955). The first edition of *Little Science, Big Science* appeared two years later in 1963. The opening page is called a "prologue to a science of science." If Derek was aware of my paper, he did not cite it then. Even in his classic 1965 *Networks* paper in *Science* (Price, 1965) he referred to the 1963 *Genetics Citation Project* and my 1964 *Science* paper by which time we had made personal contact (Garfield, 1964). But even earlier, in 1962, I had written to J.D. Bernal and Robert K. Merton about the experimental *Science Citation Index* which resulted from that project. I met Bernal briefly at the International Conference on Scientific Information in Washington in 1958. It was not until 1983, in his Citation Classic commentary (Price, 1983) cited above, that Derek notes that he was "stimulated much by Robert Merton's writings in the sociology of science, by Eugene Garfield's new book on citation indexing, and by rereading Desmond Bernal's books which had prepared my mind for the initial sensitivity that led me to this field in the first place." Of course, Derek could not have read my book at that time because it did not come out until 1979. Perhaps he should have use the term "work" instead.

In the preface to Volume 3 of my *Essays of an Information Scientist*,[ii] (Price DJD, 1980) Derek himself related how we first encountered each other when he was a member of the National Science Foundation's Science Information Council. He reports how I tried to get the NSF to support printing and distribution of the *Science Citation Index*:

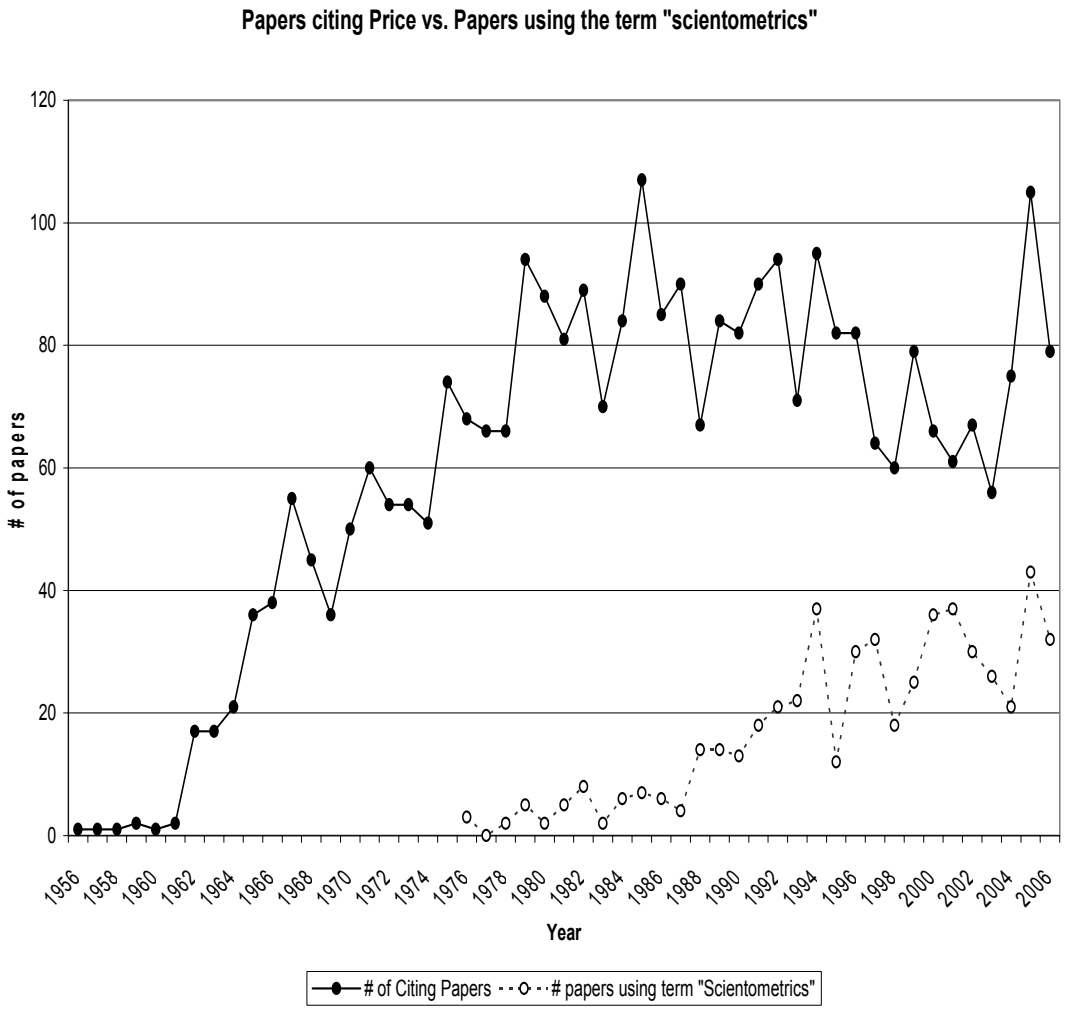
> From that day to the present….I have found megavitamins for my intellectual diet on the cutting room floor of ISI's computer room. Bit by bit we have begun to understand how citations work and in the course of this, there has emerged a new sort of statistical sociology of science that has thrown light on many aspects of the authorship, refereeing, and publication of scientific research papers. The Society of Social Studies in Science now has an annual meeting devoted to this new method of understanding science that has grown, almost as an accidental by-product, from the indexing technology developed by the Institute for Scientific Information. Our initial intuitive perceptions have turned out to be correct.(Price, 1980).

The early 4S group ultimately became the Society for the Social Studies in Science (4S) which together with Thomson ISI sponsors the annual Bernal Award. However, the Society's interest in scientometrics has waned considerably in recent years, perhaps in part because of the growth of ISSI which understandably is not as preoccupied with the history and sociology of science per se as is 4S.

The first co-citational link between Garfield and Price was made in the early sixties by the mathematical statistician, John W. Tukey (Tukey 1962). Between 1955 and 1964 he was the only author who co-cited me and Derek. Keep in mind that Tukey was not a scientometrician. Like myself at the time, he was primarily interested in helping scientists to keep in touch with the literature. He and Joshua Lederberg played a key role, especially through the Weinberg Committee report, in promoting the idea of citation indexes as a new and promising method for information retrieval. No one was then actively talking about citation indexing as a scientometric or science policy tool per se. Alan Pritchard's paper on "Statistical Bibliography," mentioned earlier, did not appear until 1969 but was not cited for science policy purposes.

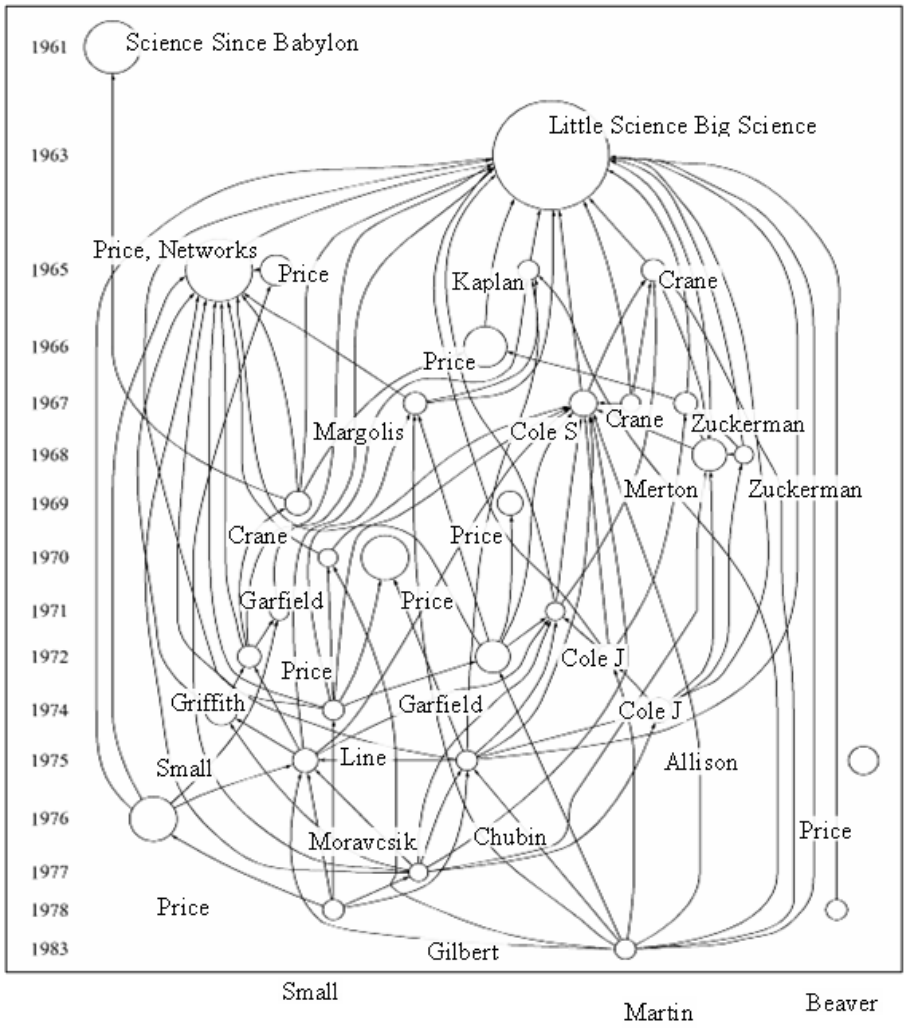
Another early science policy scholar was the Yugoslav Stevan Dedijer. (Dedijer,1962) Like Tukey he was aware of the work by Derek Price but in those early years there were only vague references to the use of bibliometric data for science policy purposes. Rather, the term "science of science" was used by Price, (Price 1975), Maurice Goldsmith), and others to reflect the pioneering work of J.D. Bernal and its offshoots. However, the term "science of science" did not gain favor even though the Society for the Social Study of Science (4S) was formed in 1975.

SLIDE 1: PAPERS CITING PRICE VERSUS PAPERS USING THE TERM "SCIENTOMETRICS," FROM 1956-2006.



Using citations to the work of Price as one indicator of the growth of this field here is the year-by-year graph of citations to Derek's work based on using the histogram feature of *HistCite* or *Web of Science (WoS).*

SLIDE 2: HISTORIOGRAPH OF 33 MOST-CITED WORKS IN THE COLLECTION OF PAPERS CITING PRICE FROM 1956-2006.



In contrast to the visible growth in citations to Price's work, an analysis of papers published in *WOS* containing the term scientometric(s) does not reveal the growth of the topic because the general term is displaced by more specific terminology as the field evolved.

To continue this brief discussion of the work of Derek Price, the following historiograph displays the linkages between the 35 most-cited works of the *HistCite* collection. Each of these papers was cited at least 107 times.

SLIDES 3 AND 4: TIME LINE FOR HISTORY OF SCIENTOMETRICS

The chronological listing of the 200 most-cited works, based on over 102,000 cited references in the collection of 3083 citing papers provides a fairly accurate historical timeline of the field (See slides 3 and 4)..

TIME LINE FOR THE HISTORY OF SCIENTOMETRICS

	Author, year, reference	Cites
1	COLE FJ, 1917, SCI PROGR, V11, P578	36
2	LOTKA AJ, 1926, J WASHINGTON ACADEMY, V16, P317	213
3	GROSS PLK, 1927, SCIENCE, V66, P385	39
4	BRADFORD SC, 1934, ENGINEERING-LONDON, V137, P85	69
5	BERNAL JD, 1939, SOCIAL FUNCTION SCI	42
6	BUSH V, 1945, ATLANTIC MONTHLY, V176, P101	65
7	BRADFORD SC, 1948, DOCUMENTATION	84
8	VICKERY BC, 1948, J DOC, V4, P198	24
9	ZIPF GK, 1949, HUMAN BEHAVIOR PRINCIPLE	86
10	FUSSLER HH, 1949, LIBRARY Q, V19, P19	40
11	BARBER B, 1952, SCIENCE SOCIAL ORDER	36
12	LEHMAN HC, 1953, AGE ACHIEVEMENT,	33
13	SIMON HA, 1955, BIOMETRIKA, V42, P425	76
14	GARFIELD E, 1955, SCIENCE, V122, P108	57
15	PRICE DJD, 1956, DISCOVERY, V17, P240	28
16	MERTON RK, 1957, AM SOCIOL REV, V22, P635	76
17	MERTON RK, 1957, SOCIAL THEORY SOCIAL	48
18	SHOCKLEY W, 1957, P IRE, V45, P279	39
19	POPPER K, 1959, LOGIC SCI DISCOVERY	39
20	BURTON RE, 1960, AM DOC, V11, P18	69
21	WESTBROOK JH, 1960, SCIENCE, V132, P1229	27
22	KENDALL MG, 1960, OPERATIONAL RESEARCH, V11, P31	25
23	PRICE DJD, 1961, SCI SINCE BABYLON, P1	337
24	MERTON RK, 1961, P AM PHILOS SOC, V105, P470	35
25	BARBER B, 1961, SCIENCE, V134, P596	30
26	KUHN TS, 1962, STRUCTURE SCI REVOLUTION	199
27	MACHLUP F, 1962, PRODUCTION DISTRIBUT	41
28	ROGERS EM, 1962, DIFFUSION INNOVATION,	27
29	PRICE DJD, 1963, LITTLE SCIENCE BIG SCIENCE, P1	1454
30	KESSLER MM, 1963, AM DOC, V14, P10	61
31	GARFIELD E, 1963, AM DOC, V14, P289	28
32	GARFIELD E, 1963, AM DOC, V14, P195	27
33	GARFIELD E, 1964, USE CITATION DATA WR,	51
34	GARFIELD E, 1964, SCIENCE, V144, P649	37
35	CLARKE BL, 1964, SCIENCE, V143, P822	31
36	PRICE DJD, 1964, SCIENCE, V144, P655	30
37	PRICE DJD, 1965, SCIENCE, V149, P510	499
38	HAGSTROM WO, 1965, SCIENTIFIC COMMUNITY	214
39	PRICE DJD, 1965, TECHNOL CULT, V6, P553	122
40	CRANE D, 1965, AM SOCIOL REV, V30, P699	63
41	KAPLAN N, 1965, AM DOC, V16, P179	50
42	PRICE DJD, 1965, NATURE, V206, P233	33

TIME LINE FOR THE HISTORY OF SCIENTOMETRICS
continued

	Author, year, reference	Cites
43	PRICE DJD, 1966, AM PSYCHOL, V21, P1011	213
44	BAYER AE, 1966, SOCIOL EDUC, V39, P381	53
45	CARTTER AM, 1966, ASSESSMENT QUALITY G,	42
46	STORER NW, 1966, SOCIAL SYSTEM SCI,	39
47	SCHMOOKLER J, 1966, INVENTION EC GROWTH,	33
48	BENDAVID J, 1966, AM SOCIOL REV, V31, P451	29
49	STORER NW, 1966, SOCIAL SYSTEM SCIENC,	26
50	MAY KO, 1966, SCIENCE, V154, P1672	24
51	COLE S, 1967, AM SOCIOL REV, V32, P377	91
52	MARGOLIS J, 1967, SCIENCE, V155, P1213	62
53	ZUCKERMAN H, 1967, AM SOCIOL REV, V32, P391	61
54	CRANE D, 1967, AM SOCIOL, V2, P195	44
55	LEIMKUHLER FF, 1967, J DOC, V23, P197	40
56	PRICE DJD, 1967, SCI TECHNOL, V70, P84	33
57	MERTON RK, 1968, SCIENCE, V159, P56	128
58	ZIMAN J, 1968, PUBLIC KNOWLEDGE SOC	68
59	ZUCKERMAN H, 1968, AM J SOCIOL, V74, P276	47
60	BROOKES BC, 1968, J DOC, V24, P247	40
61	MULLINS NC, 1968, AM SOCIOL REV, V33, P786	38
62	MERTON RK, 1968, SOCIAL THEORY SOCIAL	37
63	COLE S, 1968, AM SOCIOL REV, V33, P397	32
64	WATSON JD, 1968, DOUBLE HELIX,	24
65	CRANE D, 1969, AM SOCIOL REV, V34, P335	73
66	PRICE DJD, 1969, P ISRAEL ACAD SCI HU, V4, P98	69
67	PRITCHARD A, 1969, J DOC, V25, P348	47
68	FAIRTHORNE RA, 1969, J DOC, V25, P319	46
69	BROOKES BC, 1969, NATURE, V224, P953	40
70	MACRAE D, 1969, AM SOCIOL REV, V34, P631	34
71	PRICE DJD, 1969, FACTORS TRANSFER TEC, V1, P91	30

Starting with F. J. Cole in 1917, AJ Lotka in 1926, Gross & Gross in 1927, Samuel Bradford in 1934, and then Bernal in 1939. Vannevar Bush's classic, "As we may think" appeared in 1945 at the end of World War II (Bush, 1945). A decade later, we find the work of Herb Simon in 1955, and in the same year, the paper by yours truly. Then in 1956 Derek's paper on "the exponential growth in science," appears in 1956 (Price,1956). His first paper on quantitative studies appeared in 1951 but had very little impact! (Price, 1951)

I won't continue to recite all the names that are recalled in this exercise but I believe this list of works cited 30 or more times in the Price *HistCite* collection demonstrates the simple notion that bibliographic history is recapitulated rather well by the collective bibliographic memory of the scholars who have contributed to the literature, both at the macro and micro level of analysis.

SLIDE 5: HISTCITE OF PAPERS CITING PRICE'S WORK IN SCIENTOMETRICS

Here is the first page of the HistCite collection of 3063 papers that cited Price's work in *Scientometrics*.

Publications Related to the Field of scientometrics by DJD Price and the Papers Citing Them

Historiographs Glossary HistCite Guide About

Grand Totals: LCS 12276, GCS 33574

List of All Records

Collection span: 1956 - 2006

Records: 3063, Authors: 2928, Journals: 869, Cited References: 102333, Words: 4624 Yearly output | Document Type | Language | Institution | Institution with Subdivision | Country

Page **1** of 31: [1 2 3 4 5 6 7 8 9 10] 11 21 31

#	LCR	NCR	Date / Author / Journal	LCS	GCS
			1956		
1	0	1	1 PRICE DJD **THE EXPONENTIAL CURVE OF SCIENCE** DISCOVERY. 1956; 17 (1): 240-243	28	28
			1957		
2	1	1832	2 [Anon] **82ND CRITICAL BIBLIOGRAPHY OF THE HISTORY OF SCIENCE AND ITS CULTURAL INFLUENCES (TO 1 JANUARY 1957)** ISIS. 1957; 48 (152): 189-268	0	0
			1958		
3	1	5	3 JOHNSON EA **THE CRISIS IN SCIENCE AND TECHNOLOGY AND ITS EFFECT ON MILITARY DEVELOPMENT** OPERATIONS RESEARCH. 1958; 6 (1): 11-34	1	3
			1959		
4	1	9	4 PETTERSSON M **MAIN STAGES OF SOCIAL EVOLUTION IN MAN** NATURE. 1959; 184 (4684): 481-482	0	3
5	1	72	5 VLEDUTS GE, NALIMOV VV, STIAZHKIN NI **SCIENTIFIC AND TECHNICAL INFORMATION, PROBLEM OF CYBERNETICS** USPEKHI FIZICHESKIKH NAUK. 1959; 69 (1): 13-56	5	8

SLIDE 6: BERNAL HISTCITE: Publications by Bernal and the papers citing him.
(http://garfield.library.upenn.edu/histcomp/bernal-jd_citing-03/index-tl.html)
I plan to present a more detailed analysis of Bernal's work at the forthcoming celebration of his 100th birthday in Ireland in September. Here is a preliminary look at the *HistCite* record for the 8648 papers that cited his work.

Publications by John Desmond Bernal and the Papers citing Bernal.

Historiographs

Glossary HistCite Guide About

Grand Totals: LCS 32913, GCS 300877

Collection span: 1924 - 2007

List of All Records

Records: 8648, Authors: 12001, Journals: 1740, Cited References: 295645, Words: 11676

Yearly output | Document Type | Language | Institution | Institution with Subdivision | Country

Page **1** of 87: [1 2 3 4 5 6 7 8 9 10] 11 21 31 41 51 61 71 81

#	LCR	NCR	Date / Author / Journal	LCS	GCS
			1924		
1	0	10	1 Bernal JD **The structure of graphite** PROCEEDINGS OF THE ROYAL SOCIETY OF LONDON SERIES A-CONTAINING PAPERS OF A MATHEMATICAL AND PHYSICAL CHARACTER. 1924 DEC; 106 (740): 749-773	163	163
			1926		
2	1	4	2 Bernal JD **On the interpretation of X-rays, single crystal, rotation photographs** PROCEEDINGS OF THE ROYAL SOCIETY OF LONDON SERIES A-CONTAINING PAPERS OF A MATHEMATICAL AND PHYSICAL CHARACTER. 1926 NOV; 113 (763): 117-160	99	99
3	1	48	3 Gibbs RE **The polymorphism of silicon dioxide and the structure of tridymite** PROCEEDINGS OF THE ROYAL SOCIETY OF LONDON SERIES A-CONTAINING PAPERS OF A MATHEMATICAL AND PHYSICAL CHARACTER. 1926 DEC; 113 (764): 351-368	1	10
			1927		
4	1	13	4 Hendricks SB **The crystal structure of potassium di-hydrogen-phosphate** AMERICAN JOURNAL OF SCIENCE. 1927; 14 (82): 269-287	0	19
5	1	7	5 Jaeger FM, van Melle FA **Investigations into the constitution of artificial ultramarines II On ultramarine-blue with high silica-content and on silver silversodium-selenium-and silberselenium-ultramarines** PROCEEDINGS OF THE KONINKLIJKE AKADEMIE VAN WETENSCHAPPEN TE AMSTERDAM. 1927; 30 (1/5): 479-498	0	7
6	1	4	6 Morse JK **Atomic lattices and atomic dimensions** PNAS 1927; 13: 227-232	1	5
			1928		
7	2	12	7 Morse JK **The molecular structures of methane** PNAS. 1928; 14: 166-171	0	2

SLIDE 7: BERNAL'S SOCIAL FUNCTION OF SCIENCE HISTCITES

However, a more detailed look at the impact of his book *Social Function of Science* is reflected in the more than 300 citing papers shown in the HistCite collection.

The *Social Function of Science* by JD Bernal (1939, 1967) and the citing papers

List of All Records

Historiographs Glossary HistCite Guide About

Grand Totals: LCS 450, GCS 3199
Collection span: 1939 - 2007

18 June 2007

Records: 367, Authors: 352, Journals: 213, Cited References: 16377, Words: 1053
Yearly output | Document Type | Language | Institution | Institution with Subdivision | Country
Page **1** of 4: [1 2 3 4]

1	1	4	1 [Anon] **Journals or micro-films?** LANCET. 1939; 1: 765-766	0	0
2	0	0	2 BERNAL JD **The Social Function of Science** SOCIAL FUNCTION SCI. 1939;	321	321
3	1	3	3 [Anon] **Science and society.** BRITISH MEDICAL JOURNAL. 1939 JUL-DEC; 2: 286-287	0	0
			1944		
4	1	13	4 Williams JR **The social implications of scientific research** CANADIAN MEDICAL ASSOCIATION JOURNAL. 1944; 51: 99-106	0	0
5	1	18	5 Dudley S **Naval experience in relation to a National Health Service** LANCET. 1944; 2: 134-137	0	0
6	1	10	6 Teich N **Influence of Newton's work on scientific thought** NATURE. 1944 JAN-JUN; 153: 42-45	0	0
			1946		
7	1	15	7 BARD P, ADOLPH EF, DOW P, BOYD TE, COMROE JH **PHYSIOLOGY IN NORTH-AMERICA, 1945 - SURVEY BY A COMMITTEE OF THE AMERICAN-PHYSIOLOGICAL-SOCIETY** FEDERATION PROCEEDINGS. 1946; 5 (3): 407-436	0	0
8	1	3	8 [Anon] **RATIONALIZATION OF THE LITERATURE OF SCIENTIFIC RESEARCH** NATURE. 1946; 157 (3997): 745-748	0	0
			1947		
9	1	2	9 DINGLE H **THE MISSING FACTOR IN SCIENCE** NATURE. 1947; 160 (4056): 108-110	0	1

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