Superconductivity Research in 1987: Cocitation Data vs. Peer Review

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1. Superconductivity as a Research Field

The publication of Bednorz and Müller's article in 1986 was a breakthrough in research on high T_c superconductivity[1]. Since then developments in the field have moved increasingly fast – to a degree which is not often to be seen in science. Numerous teams of physicists and chemical scientists all over the world shifted their activities to high T_c superconductivity. From early 1977 on, a fast growing number of articles appeared, and several international workshops and conferences were organized.[2] Because of the wide range of possible applications of this effect there was a rapidly growing interest in superconductivity research, not only from physicists but also from research policy and research administration agencies. Research teams began to publish their latest results in international daily newspapers to be sure that their claim of priority could not be violated. Monthly press conferences on the topic were organized because the normal publication delay of the major physics journals did not allow any "real-time" monitoring of the developments.

This anomalous situation presents a good opportunity for testing the benefits of bibliometric methods for the construction of science indicators. If it is true that important information about a research field can be drawn from the publication and citation patterns in that field, as reflected in the leading journals, then superconductivity should be a very good case because of the very high publication and citation activity in this field. Moreover, it is an interesting case because of the

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high speed of developments in this field. Hitherto it has no been clearly shown to which degree bibliometric methods can reflect such high dynamic fields.
Furthermore, there is another aspect which makes this field an interesting case for bibliometric analyses: on the one hand the research is concentrated on a specific effect (that of superconductivity), on the other hand a variety of different subfields of physics and chemistry is involved. In superconductivity research there are typically close links to theoretical as well as experimental physics, solid state physics, physical chemistry and atomic & molecular physics, material science and spectroscopy and other subfields. The question is whether it is possible to apply bibliometric methods to research fields which are developing beyond the boundaries of classical disciplinary categories.

An additional reason for this study was the interest of German funding agencies, namely the *VDI – Technologiezentrum Physikalische Technologien (VDI – TZ)* at Düsseldorf, which is acting as a project coordinating organization for superconductivity research on behalf of the *German Federal Ministry of Research and Technolgy (BMFT)*. Their interest concentrated on the question of how far bibliometrics could provide background information for evaluation processes – information which would otherwise not be available, or could not be produced with reasonable effort.

2. Aim and Method of the Study

The study is part of a larger research project on "Bibliometric Methods for the Construction of Science Indicators and their Evaluation", funded by the BMFT.[3] Among other methods, cocitation analysis is studied in this project as a tool for developing structural science indicators.[4] The application of cocitation analysis for evaluation processes is comparatively new and still in an experimental stage, but this method is already used in the area of research policy as a source of background information.[5]

The main question in our case – study of research on high T_c superconductivity was: Can a cocitation – based bibliometric profile provide useful structural information on this field with an appropriate degree of immediacy, and can the results be validated by peer review?

Due to methodological reasons, the study was limited to the first year after the publication of Bednorz and Müller's article – i.e. only publications were taken into account which had been published until December 1987. The main reason for this was the quantitative explosion of superconductivity literature in the following years, which would make a study of the whole field much more difficult. Until 1986 there was a worldwide output of publications on superconductivity of about 900 articels per year in the main physics journals. In 1987, 2000 articles were

published, and in the following years there was an even larger increase.[6] Physics Briefs, a major literature database of physics as a discipline with about 125.000 publications per year, covers the following numbers of superconductivity documents:[7]

Year	Documents
1985	1393
1986	1196
1987	4167
1988	6706
1989	5946

Two main sources of information were used in the study: 1. data from the cocitation analysis of the 1987 Science Ciation Index (SCI) and 2. questionnaires and interviews with leading German experts in the field.[8] The study consisted of the following steps:

a) generation of a bibliometric profile on the basis of cocitation analysis, b) questionnaire to leading German experts in the field,
c) personal interviews with these experts.

When filling in the questionnaire and at the beginning of the interviews the experts had no knowledge of the bibliometric results. So their answers at this stage were taken separately, to enable the validation of the bibliometric profile. In the second part of the interviews the experts were confronted with bibliometric results and asked to comment on them in the light of their previous statements.
In order to get results from peer review and bibliometric methods with a maximum degree of comparability, the main question of the study was broken down to a small number of single operational questions. Four basic questions were designed, which could be answered by both "sources" with reasonable effort and which would enable a direct comparison of the answers:

1. Which were the ten most important publications in this area until December 1987?
2. Which were the internationally leading journals on this subject until December 1987?
3. Which specialities were formed by the scientific literature on the subject until December 1987?
4. Which were the internationally leading institutions in the field until December 1987?

These questions, while looking rather simple at a first glance (and therefore easily to be generalized to other fields), were in fact not always easy to answer, as will be shown in the following. The next sections will present a description of the methodological procedure for both paths (bibliometrics and peer review).

2.1 Bibliometric Profile

The preparation of the bibliometric profile was made easier by the fact that in this case the field can be easily delimited through the application of a single keyword: out of the total set of cocitation analyses of the 1987 SCI, all clusters were selected which contained the string "SUPERCONDUCT*" in their title – in any spelling variant. The 54 clusters selected consisted of altogether 394 documents in their cores. As the method of cocitation analysis claims, these documents should represent the intellectual base of the 1987 research front in the field. By ranking the documents by citation frequency and completing their bibliographic data, including corporate address data of the authors, answers to the four basic questions of the study could be formulated on the basis of these lists of clusters and documents. In this way, cocitation analysis functioned as an "expert".

The basic assumption underlying the next methodological steps was as follows: Bibliometrically, the impact of a publication can primarily be measured through its citation frequency. The formula

"highly cited" = "highly important"

was therefore taken to be true. Undoubtedly, this equation implies numerous theoretical and empirical problems, which have been discussed on several occasions.[9] However, for the purposes of this study, this equation seemed to be justified, the more so since it is actually a validation study.

A documentation of all 54 clusters was compiled, with their titles, core documents, additional statistics and an index of authors, citation frequencies and publication years. For each of the cluster cores not only its size (i.e. the number of documents in it), but also the following measures were computed:

- the "age" of the core (i.e. mean publication year of its documents);
- the "immediacy" of the core in relation to the connected "research front" (i.e. number of core documents with publication year not more than 3 years before the "research front" of 1987);
- the "weight" of the cluster core (i.e. total of citations received 1987 for all documents in the core).

This documentation was designed to serve as the foundation for the validation study and was used as a reference source in the peer review process.

The first analysis of the bibliometric material identified high T_c superconductivity research as a highly active, very rapidly developing research front: among the top age and weight ranks of all 1987 cocitation clusters superconductivity was clearly predominant. Six of the 16 "youngest" cluster cores were superconductivity ones, and the cluster which contained the work of Bednorz and Müller in its core was at rank 5 of the most heavily "weighted" cluster cores.

2.2 Peer Review

Peer review was carried out with five leading German experts in research on high T_c superconductivity. The experts were nominated by the VDI–TZ Physikalische Technologien at Düsseldorf.[10]

As a first step, a questionnaire with the four questions mentioned above was sent to the experts. Afterwards, interviews with each of them were arranged. In one case the written answers to the questions were not available before the day of the interview. So it was collected just before the beginning of the interview. Generally, the written peer review was fixed before the experts got knowledge of the bibliometric results. Within the second part of the interviews the experts were confronted with the bibliometric data, and they were asked to comment on these data. The guideline for the interviews was again provided the set of four basic questions. In one case the expert asked the members of his research group to take part in the interview, therefore the answers were influenced by the group. Since this group is working exactly on superconductivity, this turned out to be no disadvantage in the context of the study.

Taking the viewpoint of the end of 1987 was one of the major problems for the experts. When answering the questions, it was obviously very difficult for them to ignore the knowledge which they had accumulated in the field since 1988. Some of the experts concentrated in their answers on publications which had been published after 1987. It took some effort to pull them to the correct time scale of the study.

Another problem were the different meanings attached to the notion of an "important" publication. On the journal level some consensus could be seen, but on the level of single documents there were considerable doubts as to the meaning of 'importance'. This will be discussed in the following section.

3. Results

The results of the bibliometric profile and the peer review process will be presented synoptically for each of the four questions. To enable direct comparisons between the different sources of information, the five experts and the bibliometric method will be handled equivalently. They are coded by characters (A – F).

3.1 Most Important Publications

Some of the experts argued that the answer to the first question would be influenced by differences between subfields("from chemistry this will look differently as from physics"). It is very difficult to agree on an explicit definition of *importance*, not only within the framework of bibliometrics, but also in the peer review process. This can be demonstrated by the following extract from one of the interviews:

"Categories such as *leading*, *important* – it would be necessary to define them more precisely I think ... If you ask me for a definite answer, I would have to ask back: what do you mean by *important*? Is it those publications, which initiated a mass of follow–up studies, or which did something important from the viewpoint of physics, but are not very well cited at all – which criteria should be applied? This is difficult to answer. And it would have been impossible, if 1988 were enclosed, without additional information on what is meant by 'important'. In 87 it was somewhat easier, because there were not so many, you know. And on the other hand, surely, in a few years a better answer can be given; then you will be able to say: o.k., the work of that group was used by many others – this has been really important. With some of the publications you cannot decide it just now." (translated from German)

Nevertheless we insisted on getting the personal opinion of each expert on this question.

Table 1 gives an overview for the answers to question 1 for each of the six sources.[11] It cannot be easily determined which of the sources is the bibliometric profile resulting from cocitation analysis. It is obvious that the consensus among the peers is not greater than the difference between bibliometric results and the answers of each of the experts.[12]

To test the validity two additional points were studied:

a) Which publications were nominated by at least two experts, but had not been ranked by cocitation analysis among the top ten?
b) Which publications were "nominated" by the cocitation analysis, but not mentioned by any of the experts?

There were two publications which fulfilled criterion a). In both cases it could be shown that cocitation analysis did in fact cover the publication, but the ranking process (by citation frequency) placed them below the top ten (Bednorz & Müller in *Europhysics Letters* at rank 16, Chaudhari et al. at rank 48 of a total of 394 publications).

On the other side there were three documents nominated by the bibliometric method as among the top ten which were not mentioned by any of the peers in their written answers (Yu et al., Stewart et al. and Mattheis). In the interviews we included these as well as a further 25 highly cited documents. The experts confirmed that in fact all of these had to be regarded as important ones, too. There was in no case explicit doubt on this.

Table 2 shows the most highly cited publications with the number of recieved citations in 1987. These citation counts (which were reached within a few months) are extremely high, as can be shown by some comparable data:

- more than 56% of the 1955–1987 source documents of the SCI remain uncited, i.e. are not even cited by the authors themselves later on.[13]
- the 1945–1988 SCI covers some 15 mio. source documents with 175 mio. references. pointing to 33 mio. unique cited documents. These cited items have a very skewed distribution for their citedness. 56% of the items are cited only once over the whole period of time, and less then 0.5% get a citation count of 100 or higher.[14] In our case the publications of Bednorz & Müller and Wu et al. reached with more than 500 citations the top ranking of 5800 out of the 33 mio. documents (which is less than 0.02%) some twelve months after publication.
- among the overall 54095 documents in all cluster cores of the 1987 cocitation analysis there are only 14 publications reaching a higher citation count than that of Bednorz & Müller's work. All these documents are at least two years older and came from biochemical subfields, where the highest citation counts at all can be measured. The publications of Bednorz & Müller and Wu et al. were cited far more frequently than any other physics article of that year, and even far more often than any science article outside the biochemical field.

At this point we can conclude: cocitation analysis can give a precise answer to the question on the most important publications of the field, and the quality of this answer is not lower than the quality of peer review with leading experts.

3.2 Most Important Journals

Table 3 gives an overview for the answers to question 2 for each of the six sources. Again, the bibiometric source is not easily identified.

Differences in the opinion among the peers seem to be not smaller than the differences between the bibliometric results and the experts' answers.[15]

In the interviews, experts validated the bibliometric results: bibliometrically "leading" journals were in fact seen by the peers as the most influential ones. On the other hand all journals mentioned by the peers were on the list generated from cocitation analysis, though in some cases not among the absolutely top ones.

In table 4 the bibliometric journal ranking is shown in the way that the 11 journals which are given covered the largest number of all 394 highly cited publications in the field. The top ranking of American journals in this table was verified by all experts, though most of them expressed that they are not very pleased about this imbalance. Experts argued that a main reason for this fact might be the "faster" research and publication behaviour of their North American colleagues. However, this behaviour was also labelled as 'unscrupulous'. European physicists still try to avoid "risky" publications and tend to be more careful in their publication policy. On the other hand, in fact, more and more Europeans try to publish their results in American journals, which in the end are undoubtedly more influential. The appearance of Bednorz and Müller's article in a European journal was absolutely untypical in this respect.

Table 5 gives a ranking of the same journals, weighted by received citations for the superconductivity articles. European journals rank a bit higher in this table, the *Zeitschrift für Physik B* is now within the top group (because of the Bednorz & Müller article), but the American journals are still dominating the list, namely *Physical Review Letters* and *Physical Review B*. In addition, the multidisciplinary journal Science shows up in the top list when counting is performed in this manner.

Most of the experts told us that American physicists have a strong bias in their references towards publications of their own country. Bibliometrically, this cannot be confirmed. As Frame & Narin have shown, for the construction of self citation rates on a national level it is necessary to consider the absolute numbers of publication output of the countries as "citation targets". In this way in some cases the results may lead to opposite conclusions. Frame & Narin found that the national self citation rate for the United Kingdom, France and Germany is not lower than for the US.[16] However, this may differ from field to field. In physics, 5.2% of all references from American authors accounted for German publications, whereas in clinical medicine the corresponding figure is only 1.9%.[17]

Regarding the validation aspect of the study, at this point the following conclusion can be drawn: bibliometric information on the most important journals of the field could be substantially verified by peer review.

3.3 Specialities in Superconductivity Research

Table 6 shows the answers to question 3. In this case cocitation analysis can easily be determined as one of the information sources (source C). Shown are the titles of the relevant C2−clusters (i.e. super clusters of second order, which themselves can be broken down into several subclusters of level C1). Titles of the C1−clusters were not included simply because of the size (54 clusters), but are available in the above mentioned documentation.

Answers to question 3 turned out to be rather heterogeneous. There are a lot of agreement on the terms, but overall it seems impossible to extract a well structured picture from the experts' views in order to confront it with the bibliometric data. The main reason for this could be the differences in the experts' understanding of the question. Especially the term "speciality" obviously caused great variance. Instead of specialities, broad categories like theoretical and experimental physics were mentioned, as well as all sorts of subfields of physics and chemistry which are in some way connected to superconductivity research.

A closer look at the answer of expert D can give a hint at the explanation of the problem: research on high T_c superconductivity cannot simply be divided into smaller subfields. Instead, it is a subfield itself with close connections to certain parts of the classical disciplines of physics and chemistry.

In this sense the question as such may have been wrong. In so far the bibliometric results could neither be verified nor could they be refuted; validation failed as a process.

Bibliometric data from cocitation analysis can normally provide us with much more complex structured information with an enormous amount of details. However, it is still an unsolved problem how to reduce these informations into a format which is suitable to handle in interviews with a limited time budget as for this study. Therefore it was decided not to produce objects like cognitive "maps", which in principle would have been possible from cocitation data. This has to be done in a seperate study, together with other known methods for mapping science structures. A recent study on mapping superconductivity research with co−heading analysis demonstrated the possibility of generating national profiles by bibliometric means.[18]

3.4 Most Important Research Institutions

Table 7 gives an overview for the answers to question 4 for each of the six sources. From cocitation analysis the top 20 institutions were extracted from the authors' addresses of the 20 most highly cited core documents.

There are some differences between the experts' answers, but with one exception (Los Alamos Lab) all institutions nominated by the peers were identified also by cocitation analysis (source C).

On the other hand there were four institutions identified by the bibliometric method which were not mentioned in the written answers of the experts. Within the interview however, peers verified these four institutions to be important as well.

In the bibliometric result there was only one research group from Germany among the top institutions (at the Center for Nuclear Research, Karlsruhe). Experts did explicitly verify this finding.

The conclusion to be drawn at this point is that the question on the most important institutions in the field can be answered by bibliometric means with the same quality as by peer review.

4. Conclusion

In the case of research on high T_c superconductivity it was relatively easy to compile a bibliometric profile with data from cocitation cluster analysis of the SCI. Given four basic questions, the answers of the bibliometric method were of comparable quality to those of leading German experts in the field. The bibliometric results could be verified by personal interviews with the peers. If there was a high consensus among the experts, the bibliometric data also looked very much alike.

One exception concerned the question on the internal structure of the field. There is some evidence that the question was not well formulated in this case; peer answers were so heterogeneous that a comparison of them with the bibliometric results was not possible in any precise way. Further research is necessary at this point to find methods for compact representations of the outcomes of cocitation analysis which have a complex structure and can provide us with a variety of detailed information as background for evaluation purposes. Only such compact representations would allow us to conduct sensible interviews with experts in the field.

It was demonstrated that it is possible to compile useful information from cocitation analysis at a high rate of immediacy. Therefore the method is able to monitor highly active, rapidly developing research fronts. In the case of research on high T_c superconductivity the relevant clusters of 1987 covered a very high percentage of core documents, which had been published just in the same year. The experts' view of the field as an extremely fast developing one was precisely reflected in the bibliometric results.

If it will be possible to transfer the findings of this study to other applications is still to be determined. One of the main problems in this connection will be the

question of immediate access to the relevant clusters. In the case of superconductivity research this was rather straightforward because of the use of the keyword SUPERCONDUCT*.

The aim of this study was not to reconstruct a complete picture of the field of superconductivity research but, instead, to carry out a validation of a certain bibliometric method with a limited set of basic questions.

5. Notes

1 Bednorz & Müller 1986. Eight months after their publication the 1987 Nobel Prize in Physics was awarded to the authors – the shortest period of time in the history of the Nobel Prizes.

2 The session on superconductivity at the spring conference of the American Physical Society in March 1987 in New York City became a "superconductivity happening". The session continued throughout the night until 3 o'clock in the next morning and participants did afterwards speak about a "Woodstock of Physics" (Robinson 1987).

3 BMFT – Grant No. SWF 0029 4.

4 The rather sophisticated procedure of cocitation analysis (which is in fact a cluster analysis of cocitations) is explained elsewhere: cf. Winterhager et al. 1988.

5 E.g. in the US by the National Science Foundation: cf. National Science Board 1988, 99f. and 291; in Switzerland by the Swiss Science Council: cf. Schweizerischer Wissenschaftsrat 1989, 12f., 108 and 117–131; in Australia by the Australian Department of Industry, Technology and Commerce: cf. Experience with the 1983–84 co–citation bibliometric model of Australian science, 1988.

6 Cf. Garfield, 1988, 10.

7 The numbers where searched in file "PHYS" on STN International at Karlsruhe on May 24, 1990. All documents having value 74 in the database field "Classification Code" where counted (SEARCH 74?/CC).

8 The Set of Science Literature Indicators of CHI Research could not be used in this case: recent years were not covered (data available until 1986 only) and, more strikingly, the inherent categorisation of physics into nine subfields only (based on a fixed set of journals) makes it impossible to monitor the dynamic developments in the field.

9 Cf. Weingart & Winterhager 1984, 132ff.

10 We would like to thank Dr. Leson of VDI–TZ for providing us with the list of experts and for his help in establishing the contacts.

11 Full bibliographic information on the publications is given in the 'Bibliography of the Literature in Table 1' at the end of this article.

12 The bibliometric profile is given as source C.
13 Cf. Garfield, 1989, 7.
14 Cf. Garfield, 1990, 3f.
15 Answers from the bibliometric profile are given as source C.
16 Cf. Frame & Narin 1988, 207.
17 Cf. ibid., 208.
18 Cf. Todorov & Winterhager 1989.

6. Literature

Bednorz, J.G. & Müller, K.A.: Possible high T_c superconductivity in the Ba–La–Cu–O system. *Zeitschrift für Physik B – Condensed Matter, 64,* 1986, 189–193.

Experience with the 1983–84 co–citation bibliometric model of Australian science. Final report of a cooperative project between the Department of Industry, Technology and Commerce and the Centre for Technology & Social Change, University of Wollongong, Wollongong 1988.

Frame, J.D. & Narin, F.: The national self–preoccupation of American scientists: An empirical view. *Research Policy, 17,* 1988, 203–212.

Garfield, E.: The 1987 Nobel prize in physics: citations to K.A. Müller and J.G. Bednorz's seminal work mirror developments in superconductivity. *Current Contents (18): 3–11,* 2 May 1988.

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Robinson, A.L.: Superconductivity happening. *Science, 235(4796),* 1987, 1571.

Todorov, R. & Winterhager, M.: Representing superconductivity research in the Federal Republic of Germany. Unpubl. Ms., Bielefeld 1989.

Weingart, P. & Winterhager, M.: *Die Vermessung der Forschung. Theorie und Praxis der Wissenschaftsindikatoren.* Frankfurt a.M./New York 1984.

Winterhager, M., Weingart, P., Sehringer, R.: Die Cozitationsanalyse als bibliometrisches Verfahren zur Messung der nationalen und institutionellen Forschungsperformanz. In: Daniel, H.–D. & Fisch, R. (eds.): *Evaluation von Forschung. Methoden, Ergebnisse, Stellungnahmen.* Konstanz 1988, 319–358.

Table 1

Bibliometric and experts' answers to questions on high T_c superconductivity research

1. Which were the ten most important publications in this area until December 1987?

Publication	nominated by source						Hits
	A	B	C	D	E	F	
Wu et al.	+	+	+	+	+	+	6
Bednorz & Müller 1986	+	+	+	+	+		5
Anderson		+	+	+		+	4
Cava et al. 1987b	+	+	+				3
Chu et al.	+		+			+	3
Bednorz & Müller 1987		+				+	2
Cava et al. 1987a			+			+	2
Chaudhari et al.		+				+	2
Jorgensen et al.	+		+				2
Beno et al.		+					1
van Dover et al.	+						1
Estere et al.						+	1
François et al.	+						1
Gough et al.						+	1
Iye et al.				+			1
Laibowitz et al.				+			1
Maeno et al.				+			1
Mota et al.				+			1
Mattheis			+				1
Michel et al.		+					1
Siegrist et al.						+	1
Stewart et al.			+				1
Uchida et al.		+					1
Yu et al.			+				1

Note: Nominated publications with publication year >1987 were excluded.

Table 2

ISI Cocitation Analysis SCI 1987:
Most highly cited core documents of high T_c superconductivity clusters

No.	Publication	Publication year	cited in 1987
1	Bednorz & Müller	1986	664
2	Wu et al.	1987	583
3	Chu et al.	1987	338
4	Cava et al.	1987a	337
5	Cava et al.	1987b	310
6	Stewart et al.	1987	192
7	Mattheis	1987	182
8	Anderson	1987	173
9	Jorgensen et al.	1987	132
10	Yu et al.	1987	119

Table 3

Bibliometric and experts' answers to questions on high T_c superconductivity research

2. Which were the internationally leading journals on this subject until December 1987?

Journal	nominated by source						Hits
	A	B	C	D	E	F	
Physical Review Letters	+	+	+	+	+	+	6
Physical Review B	+	+	+	+		+	5
Nature	+	+	+	+		+	5
Applied Physics Letters		+	+	+	+	+	5
Zeitschrift für Physik B	+	+		+	+	+	5
Solid State Communications	+	+	+		+		4
Physica C	+			+	+	+	4
Japanese Journal of Applied Physics	+	+		+			3
Europhysics Letters		+		+		+	3
Journal of Low Temperature Physics			+		+		2
Science	+					+	2
Soviet Physics JETP					+		1
Physica Nisteich Temperatur					+		1
Cryogenics					+		1
Journal of Physics				+			1
Journal of Solid State Chemistry	+						1
Journal of Aplied Physics				+			1
IEEE Transactions on Magnetism			+				1
Journal of the American Chemical Society			+				1
Journal of Phys F Met P			+				1
Journal of Solid State Physics			+				1
Review of Modern Physics			+				1

Table 4

Cocitation Analysis SCI 1987:
Distribution of most highly cited core documents of high T_c superconductivity documents over journals:
(journals having >5 documents)

No.	Journal	# Documents
1	Physical Review B	66
2	Physical Review Letters	60
3	Applied Physics Letters	17
4	Solid State Communications	12
5	IEEE Transactions on Magnetism	9
6	Journal of the American Chemical Society	9
7	Journal of Low Temperature Physics	7
8	Journal of Phys F Met P	7
9	Journal of Solid State Physics	7
10	Nature	6
11	Review of Modern Physics	6

Table 5

ISI Cocitation Analysis SCI 1987:
Most highly cited journals in high T_c superconductivity clusters

No.	Journal	# documents	Cited 1987
1	Physical Review Letters	60	3619
2	Physical Review B	66	1586
3	Zeitschrift für Physik B	3	704
4	Review of Modern Physics	6	316
5	Science	4	286
6	Journal of Solid State Physics	7	209
7	Nature	6	190
8	Applied Physics Letters	17	188
9	Japanese Journal of Applied Physics	5	187
10	Solid State Communications	12	174

Table 6

Bibliometric and experts' answers to questions on high T_c superconductivity research

3. Which specialities are formed by the scientific literature on the subject until December 1987?

Source A:
Theoretische Physik
Experimentelle Physik – Magnetismus
– Elektrizität
Dünnschichttechnik (Anwendungen)
Synthese (bekannte vs. neue Materialien)
Strukturelle Charakterisierung, Kristallographie (bis zu lokalen Untersuchungen mit Elektronenspektroskopie)
analytische Charakterisierung
Thermodynamik (Phasendiagramme)

Source B:
Experimentalphysik
Theoretische Physik
Festkörperphysik
Festkörperchemie
Materialwissenschaft (material science)
Supraleitung
Tieftemperaturphysik

Source C:
High TC superconductivity, conducting polymers, heavy fermion systems, electrochemical polymerization, invivo voltammetry, anderson model;
Ordering alloys, uniaxial ferromagnets, thermodynamic model, magnetic spectra, superconducting properties of RBa2Cu3OX compounds, spin density waves;
Superconducting magnets, multifilamentary wires, flux pinning, NB3SN composite, high field performance, scanning electron microscopy;

Table 6 (continued)

Source C: (cont'd)	Magnetic superlattices, perpendicular recording, surface anisotropy, superconducting multilayers, CO CR films, magnetostatic spin waves; Superconducting films, niobium carbides, (100) surface, vacancy state, sig junctions, substoichiometric tin, phonon emission
Source D:	Einkristallpräparation / Struktur Dünnfilmpräparation Elektronische Transporteigenschaften Niederenergetische Anregungen Substitutionsexperimente Magnetische Ordnung Theorie Supraleitende kritische Parameter Elektronenspektroskopie Magnetische Resonanz Phononische Eigenschaften Optische Eigenschaften
Source E:	Supraleitung: Theorie dieses Phänomens, Atomphysik Phänomenologie: Flußliniengitter, kritische Ströme (Theorie) Materialien: Flußliniengitter, kritische Ströme (Experiment) Materialien: Präparation, Chemie Anwendungen: Drähte, Filme, Spulen, Squids
Source F:	Das "Spezialgebiet" umfaßt alle für die Fragestellung "Hochtemperatur – Supraleitung" relevanten Gebiete, insbesondere die Materialklasse des YBaCuO (123 –) – Supraleiters mit Sprungtemperaturen von ca. 90 K.

Table 7

Bibliometric and experts' answers to questions on high T_c superconductivity research

4. Which were the internationally leading institutions in the field until December 1987?

Institution	nominated by source						Hits
	A	B	C	D	E	F	
AT&T Bell Labs	+	+	+	+	+	+	6
IBM San Jose	+	+	+	+	+	+	6
Kernforschungszentrum Karlsruhe		+	+	+	+	+	5
Argonne National Lab	+	+	+			+	4
University of Houston	+		+	+		+	4
IBM Rüschlikon			+	+	+	+	4
University of Tokyo		+	+	+			3
Los Alamos National Lab	+			+		+	3
University of Caen (F)	+		+				2
Universität Bayreuth		+			+		2
MPI für Festkörperforschung Stuttgart		+			+		2
Siemens Forschungslaboratorien					+	+	2
Universität Darmstadt		+					1
Tohoku Univ. Sendai		+					1
University of Helsinki		+					1
University of Alabama			+				1
Princeton University			+				1
University of California Santa Barbara			+				1
Northwestern University Evanston			+				1
Beijing University				+			1
Stanford					+		1
Annes (Iowa)					+		1
University of Leiden					+		1
Philips					+		1
TU München					+		1
Universität München					+		1
Akademie in Garching					+		1
Kernforschungsanlage Jülich					+		1
Japanese Companies (unspecified)						+	1
Istec						+	1
Universities (unspecified)						+	1

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