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There's More than One Way to Search the Chemical Literature

Eugene Garfield
Institute for Scientific Information
Philadelphia, Pennsylvania 19106

See Introduction on p.524, Essays, Vol:2

Information-gathering habits of both scientists and technologists have remained relatively static while their needs for information have been rapidly changing. That situation portends a significant problem. At one time, the information that most chemists needed most of the time was concerned with specific compounds—their structure, synthesis, physical and functional characteristics. Today, the demand for information, particularly among chemical technologists, has grown much more diversified, with knowledge of concepts relationships and methods being at least as important as the traditional "facts".

In the face of this change, chemists are being rather steadfast in their allegiance to a few basic, familiar information access tools—primarily *Chemical Abstracts, Current Abstracts of Chemistry/Index Chemicus, Beilstein*, and the like. While all these indexes are excellent for searching out specific compounds, information needed about processes, techniques, concepts, and methods often lies beyond their convenient reach, and, in many instances, even beyond the traditional chemical literature they cover. This situation means that chemists who refuse to look beyond their traditional information-retrieval tools are not using the literature as effectively as they could and should. Fortunately the problem is an easy one to rectify. There are concept-oriented indexes available that can help. One of them, first introduced in 1964, is the *Science Citation Index*® (*SCI*®). A study conducted by an ACS committee, headed by Bruce Hannay of Bell Laboratories, showed that chemists using *SCI* credited it with saving them an average of two hours a week.[1] However, the study also showed that of the chemists surveyed, only 20% had ever heard of citation indexing and searching. This article is devoted to the other 80%.

The Hannay finding about the amount of time citation index use can save is almost too impressive. It is believable only within the framework of what a citation index is and how it works. Within almost all papers, notes, reviews, corrections, and correspondence published in journals there are references to documents that support, provide precedent for, illustrate, or elaborate on what the author has to say. *By definition, these references link together papers that have particular points in common.*

A citation index is built around these linkages. It lists publications *that have been cited* and identifies the "new" paper in which the citation appears. Anyone who's doing a literature search can find from one to dozens of papers on the subject just by knowing one paper that has been cited. Thus if Jones, writing on your subject, cites Smith's paper, one looks that paper up in the citation index. There one will find not only Jones's paper but all others that cited Smith and are probably therefore related somehow to Smith's work, and perhaps yours too.

This way of organizing the literature is quite a bit different from the traditional subject indexes, and in the differences lie a number of advantages. The basic difference is the substitution of the author's names and papers for subject terms assigned (sometimes apparently arbitrarily) by an indexer. This difference neatly avoids a number of problems inherent in subject indexes. For one, it eliminates the intellectual judgments an indexer must make, a process that takes its toll in the depth of indexing (the number of terms assigned to describe an entry) and in the timeliness of the index. The average article covered by *Science Citation Index* contains 15 reference citations, but articles from chemistry journals average 20. That's a good many relationships for the searcher to pursue.

Another advantage of using reference citation for indexing a descriptive precision. Word usage varies from person to person. It is patently impossible for an indexer, no matter how competent, to reconcile these personal differences well enough to choose a series of subject terms that will unfailingly communicate the complicated information in a scientific document to anyone who may be searching for it. What's more, the indexer must deal with the dynamics of language; new terms are introduced, old ones disappear, and new meanings are attached to old words. And within this framework, the indexer's choice of terms is limited to a controlled vocabulary that does little justice to the richness and variety of language that the users of the index can bring to the subject.

In contrast, a reference cited by the author is a precise, unambiguous representation of a subject he thought pertinent that requires no interpretation, is immune to changes in terminology, will retain its precision over time, and can even be moved from one language to another without losing its ability to communicate. For someone who knows the Novack-Windsor paper on spectra of hydrocarbon singlet molecules by ruby laser excitation, the citation "Novack J.R., Windsor, N.W., *J. Chem. Phys.*, Vol. 47, page 3075, 1967" will always be an unambiguous indexing term for the subject. Knowing who's citing that paper is knowing who else is working in that field or is somehow connected with it—often in surprising ways.

Citation indexes aren't just a better way of categorizing the individual components of the literature; they go beyond that function to show explicitly the intellectual relationships that exist among new and old components. Since each citation is a published record of a discrete event in the process of scientific development, an index of these events shows the relationships among individual events at different points in time. That means that the structure of a citation index makes it a particularly effective tool for finding out what has happened to something—whether it has been confirmed, extended, improved, tried, corrected, or applied, and where and how it was applied. To anyone concerned with scaling up a process or building properties into a product, answers to these kinds of questions are fundamental.

The perspective that citation indexing brings to the literature also is singularly free of disciplinary divisions and time constraints that often complicate literature searches. Thus any item cited in a journal covered by *SCI* will show up the year *it was cited* regardless of when it was initially published. Thus the paper on determining enzyme disassociation constants that Lineweaver wrote in '34 is still being cited. The citation, "Lineweaver, H., *J. Am. Chem. Soc.*, 56:658, 1934," is still an effective search term for anyone who wants to find out how Lineweaver's data, techniques, and concepts are being used. Any annual edition of *SCI* that someone picks up at random might contain references to this paper or any other of interest going back to the Middle Ages and beyond—all still in perfect working order as search terms.

Citation perspective is just as much at home handling categorizations of disciplines and specialties as it is in handling the passage of time. It identifies explicit relationships among events in different disciplines or specialties just as readily as ones within a single discipline or specialty. Thus there is listed in the '74 *SCI* under P.V. Danckwerts' 1951 paper on liquid-film coefficients in gas absorption, citing articles from general engineering, chemical engineering, environmental sciences, mechanical engineering, pharmacology, metallurgy, and biochemistry journals.

So citation indexing puts literature into a perspective that allows the searcher to follow the path of a development through time, no matter what disciplinary direction it may take—which is a nice feature for the types of multidisciplinary searches that usually require several indexes. The corollary, to that, of course, is that a citation index will bring to the searcher's attention, whenever and wherever it exists, that he or she not only didn't know existed, but also that whose relevance was never suspected.

SCI applies the citation indexing concept to a part of the literature that is sizable, diversified in terms of disciplinary scope, and significant in terms of research utility. Its coverage can be measured in three ways—two quantitative and one qualitative.

The quantitative measures are the number and variety of jounals and articles indexed and the number, variety, and time frame of the reference citations by which they are indexed. *SCI* covers items cited in every article, editorial, letter, meeting report, and note published in some 2600 journals from every scientific discipline. Approximately 1000 of them deal exclusively with, or periodically publish material relevant to, chemical science and technology.

As for the second measure—the reference citations used as indexing terms—*SCI* picks up all that are cited in every item it covers, regardless of where or when the cited article first appeared. This means that our reference citations—and the user's choice of search

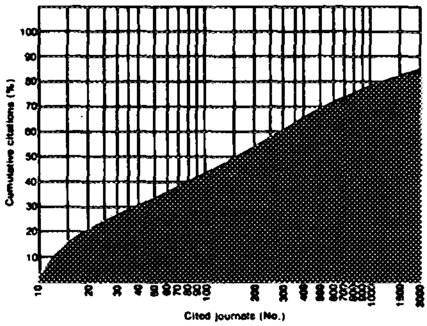

Figure 1. Distribution of references among cited journals

points—is not limited by either journal, publisher, or publication type. Everything an author references is listed, regardless of where it was published or whether it took the form of a journal article, book, thesis, letter, report, or patent. Nor, as was mentioned earlier, are the reference citations limited by time: If references are made to work by da Vinci or Copernicus, they are included. So, the 1974 *SCI*, for example, provides the user with a choice of 2.9 million unique reference citations with which to initiate or conduct a search.

The qualitative measure of *SCI*'s coverage has to do with the importance of the journals it indexes. I think that the most objective criterion for measuring a periodical's importance is the number of times it is cited. *SCI* is the primary source for such statistics and studies we've conducted show that the overlapping coverage of journals is so great that the core literature for all scientific disciplines involves no more than 1000 journals, and may involve as few as 500.[2] Though there are probably on the order of 5000 to 10,000 serial publications whose intent, frequency, and longevity qualify them as serious scientific journals, our studies show that a minority of them produce almost all of the original material that scientists consider important enough to cite. The latest study shows that only 2000 journals accounted

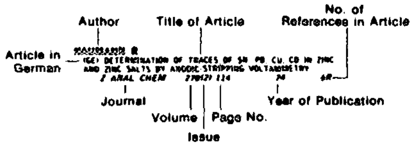

Figure 2. Excerpt from Source Index of *SCI*

for 84% of all references listed in the 1969 edition of *SCI*. In fact, half the cited material came from only 150 periodicals (Figure 1).

SCI is produced on a calendar year basis in the form of quarterly editions that are available eight weeks after the end of the quarter: The last quarterly edition, which cumulates all four quarters, is available within five months of the year's end. This means that all papers cited in 1975 issues of CHEMTECH, or any other periodical, will be available in just two more months.

In physical terms, the most recent *SCI* annual fills eight volumes and consists of five sections. The central section is the Source Index (Figure 2). It contains a full bibliographic description of all items published that year that we examined for citations. Organized by author, the Source Index's primary function is to provide full bibliographic detail for the abbreviated descriptions of items in the other four sections.

The other four sections provide the main search facilities of the index. Two of them—the Citation Index and Patent Index—are for searches, where the search point is some document that is known to deal with the subject of interest. The Citation Index (Figure 3) connects items published during the year with material they have cited. It is organized alphabetically by cited author.

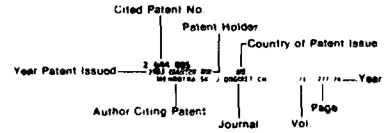

Figure 4. Excerpt from Patent Index of *SCI*

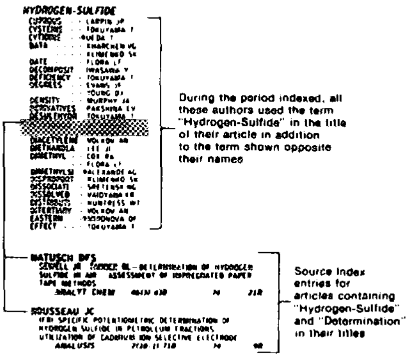

Figure 5. The *SCI* Permuterm Subject Index (PSI) is a variation of the conventional title-word index. It lists under each key title words of articles used as sources for all the other titles' terms with which it has been used. And next to each term in the list is the name of the author of the article whose title contains that particular term in combination with the main term. The author's name and the pair of title terms permits the searcher to find a complete bibliographic description of the article in the Source Index. PSI gives people the option of bypassing the Citation Index when they lack a reference to enter it, or it can identify an article whose bibliography is likely to provide them with several starting points for a citation search. PSI also serves the secondary purpose of easing people into citation searches by letting them start out with the more traditional search technique

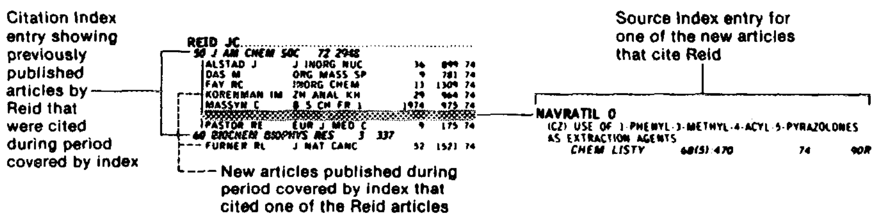

Figure 3. Excerpt from Citation Index of *SCI*

Authors from listed organization who published during period indexed

AMER CYANAMID CO,CHEM RES DIV.
STAMFORD,CT 06904, USA

ARZOUMAN GG	J ORG CHEM	N	39	4443	73
BRINER JS	J ELEC SPEC		4	243	74
COLTHUP NB	SPECT ACT A	A	30	425	74
FINE LW	SOAP COSMET		50	42	74
RAUCH FC	J PHYS CHEM		78	2109	74
STRAZDIN E	TAPPI		57	76	74

Figure 6. Excerpt from Corporate Index of *SCI*

Under each cited author are listed items that cited his article. (Cited anonymous documents are listed in a separate section.) Information given for each source item is enough to lead the searcher to the complete bibliographic description in the Source Index.

The Patent Index (Figure 4) is another citation index whose search points consist entirely of patents. Organized by cited patent number, rather than authors, it provides the same abbreviated description of source items as the Citation Index. Figures 5 and 6 illustrate other indexing approaches provided by *SCI*.

The sum of these parts is a system that is singularly adept at leading you through the literature labyrinth to the particular information that will provide state-of-the-art background, fill in specific detail, or, if one is around, uncover a fresh insight. The most compelling feature of the system is that it requires fewer look-ups than subject searches, produces quick results, and uncovers relevant material from unexpected quarters.

Figures 7 through 10 show diagrams of some typical citation searches.

Once a paper has been identified and judged, by the user, to be relevant, it can be used as a reference citation to continue along the search trail defined by citation linkages (Figures 11 and 12).

A typical multidisciplinary search is depicted in Figure 7. A manufacturer of chemical additives used in the cryogenic storage of biological material is interested in finding out whether his products are being used in unexpected ways, and how well they are working out in agricultural and livestock applications. A traditional literature search to answer these questions would normally involve

MERYMAN HT - CRYOPROTECTIVE AGENTS
CRYBIOLOGY 8:173, 1971

DEAL PH - EFFECT OF FREEZING AND THAWING ON A MODERATELY HALOPHILIC BACTERIUM AS A FUNCTION OF NA+, K+, AND MG2+ CONCENTRATION
CRYBIOLOGY 11(1):13 74 13R

KUTOBA S
GRAHAM EF CRABO BG LILLEHEI RC DIETZMAN RH - *INFLUENCE OF DMSO DISTRIBUTION UPON RENAL-FUNCTION* FOLLOWING FREEZING AND THAWING
J SURG RES 16(6):582 74 27R

LEMESHKO VV
BILOUS AM - (UK) APPLICATION OF GLYCERIN FOR PREVENTING AFFECTION OF RAT-LIVER MITOCHONDRIA UNDER DEEP FREEZING
UKR BIOKHIM 46(2):185 74 11R

MAZUR P
LEIBO SP MILLER RH - PERMEABILITY OF BOVINE RED-CELL TO GLYCEROL IN HYPEROSMOTIC SOLUTIONS AT VARIOUS TERMPERATURES
J MEMBR BIO 15(2):107 74 38R

'RIBOR DB
MULTIFACTOR THEORY FOR ACTION OF CRYOPROTECTIVE AGENTS
CRYOBIOLOGY 10(6):514 74 M NO R

REBELO AE
GRAHAM EF CRABO BG LILLEHEI RC DIETZMAN RH - SURGICAL PREPARATION, PERFUSION TECHNIQUES, AND CRYOPROTECTANTS USED IN SUCCESSFUL FREEZING OF KIDNEY
SURGERY 75(3):319 74 28R

SEXTON TJ
COMPARISON OF VARIOUS CRYOPROTECTIVE AGENTS ON WASHED CHICKEN SPERMATOZOA & METABOLISM AND RELEASE OF GLUTAMIC-OXALACETIC TRANSAMINASE
POULTRY SCI 53(1):284 74 20R

SMITH R
METHOD FOR STORING TOXOPLASMA-GONDII (RH STRAIN) IN LIQUID-NITROGEN
APPL MICROB 26(6):1011 73 N 6R

TAYLOR R
ADAMS GDJ BOARDMAN CF WALLIS RG - CRYOPROTECTION PERMEANT VS NONPERMEANT ADDITIVES
CRYOBIOLOGY 11(5):430 74 24R

WEATHERB. L
SPENCER HH KNORPP CT LINDENAU.SH CIKAS PW THOMPSON WW - COAGULATION STUDIES AFTER TRANSFUSION OF HYDROXYETHYL STARCH PROTECTED FROZEN BLOOD IN PRIMATES
TRANSFUSION 14(2):109 74 28R

WOOLGAR AE
HEMOLYSIS OF HUMAN RED BLOOD-CELLS BY FREEZING AND THAWING IN SOLUTIONS CONTAINING POLYVINYLPYRROLIDONE - RELATIONSHIP WITH POSTHYPERTONIC HEMOLYSIS AND SOLUTE MOVEMENTS
CRYOBIOLOGY 11(1):52 74 23R

Figure 7. A typical citation search on a multidisciplinary subject

at least two, and probably five separate indexes. The majority of relevant material might be identified by *Biological Abstracts, Chemical Abstracts,* and *Index Medicus*. In addition, at least two specialty indexes would be required to search the agricultural and livestock literature.

In this case, however, the researcher involved chose the alternative of conducting a citation search on a paper he knew by H.T. Meryman (# 1 in diagram). The Citation Index entry for that reference identified the 11 citing papers

DE VERDIER CH
LOW BINDING OF 2, 3 DIPHOSPHOGLYCERATE TO HAEMOGLOBIN F. A CONTRIBUTION TO THE KNOWLEDGE OF THE BINDING SITE AND EXPLANATION FOR THE HIGH OXYGEN AFFINITY OF FOETAL BLOOD
SCAND J CLIN LAB INV   23:149   69

BELLINGH.AJ
GRIMES AJ - RED-CELL 2,3-DIPHOSPHOGLYCERATE
BR J HAEM   25(5):555   73   N   37R

BRUIN SHD
JANSSEN LHM - INTERACTION OF 2,3-DIPHOSPHOGLYCERATE WITH HUMAN HEMOGLOBIN - EFFECTS ON ALKALINE AND ACID BOHR EFFECT
J BIOL CHEM   248(8):2774   73   27R

BUNN HF
KITCHEN H - HEMOGLOBIN FUNCTION IN HORSE - ROLE OF 2, 3-DIPHOSPHOGLYCERATE IN MODIFYING OXYGEN AFFINITY OF MATERNAL AND FETAL BLOOD
BLOOD   42(3):471   73   37R

COHENSOL.M
THILLET J   GAILLARD.J   ROSA J - FUNCTIONAL PROPERTIES OF HEMOGLOBIN SAINT ETIENNE - VARIANT CARRYING HEME ONLY ON ALPHA-CHAINS
REV EUR ETU   17(10):988   72   N   29R

JANSSEN LHM
DEBRUIN SH - ALLOSTERIC MODELS FOR INTERACTION OF 2,3-DIPHOSPHOGLYCERIC ACID WITH HEMOGLOBIN
INT J PEPT   5(1):27   73   18R

KILMARTI.JV
ROSSIBER.L - INTERACTION OF HEMOGLOBIN WITH HYDROGEN IONS, CARBON-DIOXIDE, AND ORGANIC PHOSPHATES
PHYSIOL REV   53(4):836   73   194R

ORZALESI MM
HAY WW - RELATIVE EFFECT OF 2,3-DIPHOSPHOGLYCERATE ON OXYGEN AFFINITY OF FETAL AND ADULT HEMOGLOBIN IN WHOLE-BLOOD
EXPERIENTIA   28(12):1480   72   14R

STERN L
USE AND MISUSE OF OXYGEN IN NEWBORN INFANT
PED CLIN NA   20(2):447   73   80R

VERSMOLD H
SEIFERT G   RIEGEL KP - BLOOD OXYGEN AFFINITY IN INFANCY INTERACTION OF FETAL AND ADULT HEMOGLOBIN OXYGEN CAPACITY AND RED-CELL HYDROGEN-ION AND 2,3-DIPHOSPHOGLYCERATE CONCENTRATION
RESP PHYSL   18(1):14   73   37R

Figure 8. A typical citation search to find review articles

RAE PMM
CHROMOSOMAL DISTRIBUTION OF RAPIDLY REANNEALING DNA IN DROSOPHILA-MELANOGASTER
P NAS US   67(2):1018   70   25R

AYLES GB
SANDERS TG   KIEFER BI   SUZUKI DT - TEMPERATURE-SENSITIVE MUTATIONS IN DROSOPHILA-MELANOGASTER 11 MALE STERILE MUTANTS OF Y-CHROMOSOME
DEVELOP BIO   32(2):239   73   76R

BALSAMO J
LARA FJS   HIERRO JM - FURTHER STUDIES ON CHARACTERIZATION OF REPETITIVE RHYNCHOSCIARA DNA
CELL DIFFER   2(2):131   73   30R

BERENDES HD
SYNTHETIC ACTIVITY OF POLYTENE CHROMOSOMES
INT REV CYT   35:61   73   R   375R

BONNER J
WU JR - PROPOSAL FOR STRUCTURE OF DROSOPHILA GENOME
P NAS US   70(2):535   73   18R

BULTMANN H
LAIRD CD - MITOCHONDRIAL DNA FROM DROSOPHILA-MELANOGASTER
BIOC BIOP A   299(2):196   73   38R

HENNIG W
MOLECULAR HYBRIDIZATION OF DNA AND RNA IN-SITU
INT REV CYT   36:1   73   R   130R

LAGOWSKI JM
YU MFW   FORREST HS   LAIRD CD - DISPERSITY OF REPEAT DNA SEQUENCES IN ONCOPELTUR-FASCIATUS, AN ORGANISM WITH DIFFUSE CENTROMERES
CHROMOSOMA   43(4):349   73   47R

LAMBERT B
EGYHAZI E   DANEHOLT B   RINGBORG U - QUANTITATIVE MICRO-ASSAY FOR RNA/DNA HYBRIDS IN STUDY OF NUCLEOLAR RNA FROM CHIRONOMUS-TENTANS SALIVARY-GLAND CELLS
EXP CELL RE   76(2):369   73   29R

PERREAUL.WJ
KAUFMANN BP   GAY H - REPEATED DNA SEQUENCES IN HETEROCHROMATIC Y-CHROMOSOME OF ADULT DROSOPHILA-MELANOGASTER
P NAS US   70(3):773   73   21R

POLAN ML
FRIEDMAN S   GALL JG   GEHRING W - ISOLATION AND CHARACTERIZATION OF MITOCHONDRIAL-DNA FROM DROSOPHILA-MELANOGASTER
J CELL BIOL   56(2):580   73   38R

SMYTH DR
STERN H - REPEATED DNA SYNTHESIZED DURING PACHYTENE IN LILIUM-HENRYL
NATURE-BIOL   245(142):94   73   24R

SPEAR BB
GALL JG - INDEPENDENT CONTROL OF RIBOSOMAL GENE REPLICATION IN POLYTENE CHROMOSOMES OF DROSOPHILA-MELANOGASTER - (RNA-DNA HYBRIDIZATION-EUCHROMATIN-HETEROCHROMATIN)
P NAS US   70(5):1359   73   28R

ULLMAN JS
LIMADEFA.A   JAWORSKA H   BRYNGELS.T - AMPLIFICATION OF RIBOSOMAL DNA IN ACHETA.5.HYBRIDIZATION OF RNA COMPLEMENTARY TO RIBOSOMAL DNA WITH PACHYTENE CHROMOSOMES
HEREDITAS   74(1):13   73   33R

WEINBLUM D
GUNGERIC.U   GEISERT M   ZAHN RK - OCCURRENCE OF REPETITIVE SEQUENCES IN DNA OF SOME MARINE INVERTEBRATES
BIOC BIOP A   299(2):231   73   29R

WOLSTENH.DR
REPLICATING DNA MOLECULES FROM EGGS OF DROSOPHILA-MELANOGASTER
CHROMOSOMA   43(1):1   73   40R

Figure 9. A typical citation search to find the answer to a specific question

listed in Figure 7. Note how broad a range of journals he's covered: *Cryobiology, Journal of Surgical Research, Ukrainskii Biokhimicheskii Zhurnal, Journal of Membrane Biology, Surgery, Poultry Science, Applied Microbiology,* and *Transfusion.* But more interesting is the range of specialties from which the papers come: two on bacterial storage, two on renal function and preservation of kidneys, one on mitochondria, three on preservation and storage of red blood cells, two on performance data of cryoprotected agents, and one on preservation of sperm. It would have been quite challenging to find the same range of papers in conventional indexes. Selection of appropriate subject headings would have called not only for anticipation of what one would find; but also for a thorough understanding of the linguistic structure of each of the indexes. A fair estimate of the time needed to conduct such a search in conventional indexes is 3 h. The citation search took 20 min.

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DILLING WL
  METAL HYDRIDE REDUCTIONS OF ENDOTRICYCLO-5.2.02,6-DECA-4,
  8-DIEN-3-ONE (ENDODICYCLOPENTADIENONE)
    J ORG CHEM            35:2971        70

SAUERS RR
  HENDERSO.TR - PHOTOCHEMISTRY OF POLYCYCLIC 5-ACYLNORBORNENES
    J ORG CHEM            39(13):1850    74        33R

WILDER P
  PORTIS AR   WRIGHT GW   SHEPHERD JN - OXYMERCURATION-
  DEMERCURATION AND HYDROBORATION-OXIDATION OF ENDO-
  DICYCLOPENTADIENE (ENDO-TRICYCLO 5.2.1.02,6 DECA-3,8-
  DIENE)
    J ORG CHEM            39(12):1636    74        52R

CHAU ASY
  DEMAYO A   APSIMON JW   BUCCINI JA   FRUCHIER A -
  CHROMOUS CHLORIDE REDUCTION 8. REACTION OF SOME
  DERIVATIVES AND DEGRADATION PRODUCTS OF HEPTACHLOR
  WITH CHROMOUS CHLORIDE-ETHYLENEDIAMINE COMPLEX AND
  NUCLEAR MAGNETIC-RESONANCE AND MASS-SPECTRA OF PRODUCTS
    J AOAC                57(1):205      74        34R

DURAND J
  TRONGANH N   HUET J - (FR) REGIOSELECTIVITY IN REDUCTION
  BY HYDRIDES - CYCLOPENTENONE AND CYCLOHEXENONE
    TETRAHEDR L           1974(20):2397  74        22R
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Figure 10. A typical citation search to find out work has been done on a reaction what follow-up

A quick background information search is depicted in Figure 8. The objective is to identify review-like papers that can provide a fast overview of, in this case, hemoglobin binding. The criterion for such papers is that each have more than 30 references. The starting point for the search is a paper by C.H. De Verdier (# 1 in diagram) from the researcher's reprint file. The entry for this paper in the 1973 *SCI* Citation Index, identifies nine papers that cited it. Five of them—#2, 4, 7, 9, and 10—are each shown (see squares in Figure 8) to have more than 30 references. And their titles indicate they are all relevant to the subject of the search.

A search to find out whether a particular theory has been confirmed is depicted in Figure 9. The search is conducted in the 1973 Citation Index starting with Rae's paper on the theory of repetitive DNA sequences (#1 in diagram) as the starting point. Fifteen papers are identified as having cited Rae; five of them (#3, 8, 10, 12, and 15) have titles that indicate they are describing repetitive DNA sequences in one type of organism or another. (The others should also be examined to determine their relevancy.)

A search to determine what, if anything, has been published about a particular reaction is outlined in Figure 10. The starting point in the search is the paper in which the reaction was first dedescribed (#1 in diagram). Time required for the search was approximately 10 min.

A search example to see what follow-up work has been published on a compound is a bit more extensive and complex (Figure 11). The search covers 9 annual volumes starting in the 1965 *SCI* and uses the citation for the 1962 announcement of the compound of interest—trimethoprim—(#1 in diagram). Paper #1 identifies papers #2, 3, 4, 7, 8, 9, 12, 13, 14, and 16 in the 1965-74 editions of *SCI*. When the search is continued on paper #2 in the 1966-74 editions of *SCI*, papers #7, 9 and 13 are identified for a second time, but *three new papers are discovered*—5, 10, and 15. Searches on papers #3 and 4 from 1969 through 1974 produced nothing of interest. A search on paper #5 during 1974 again identifies papers #8, 9, 12, 13, 14, 15, and 16, but uncovers paper #6 for the first time. Searching under #6 and 7 leads to nothing to see who's cited them between '70 and '74 but paper #8 leads to #11, a new one, and identifies #9 and 10 again. Papers #9 through 14 produced no new additions to the bibliography when they were used for search points, so this search trail ends. However, new ones could be started using likely references selected from reading any of the papers obtained.

This search yielded a bibliography of 15 papers, whose titles indicate that they trace trimethoprim through the entire classic pharmaceutical cycle of defining its mode of action, in vitro testing, clinical testing, and definition of toxicity and side effects.

Figure 12 is a shorter, but equally involved search on absorption spectra transients initiated in hydrocarbons by nanosecond laser flashes. What makes

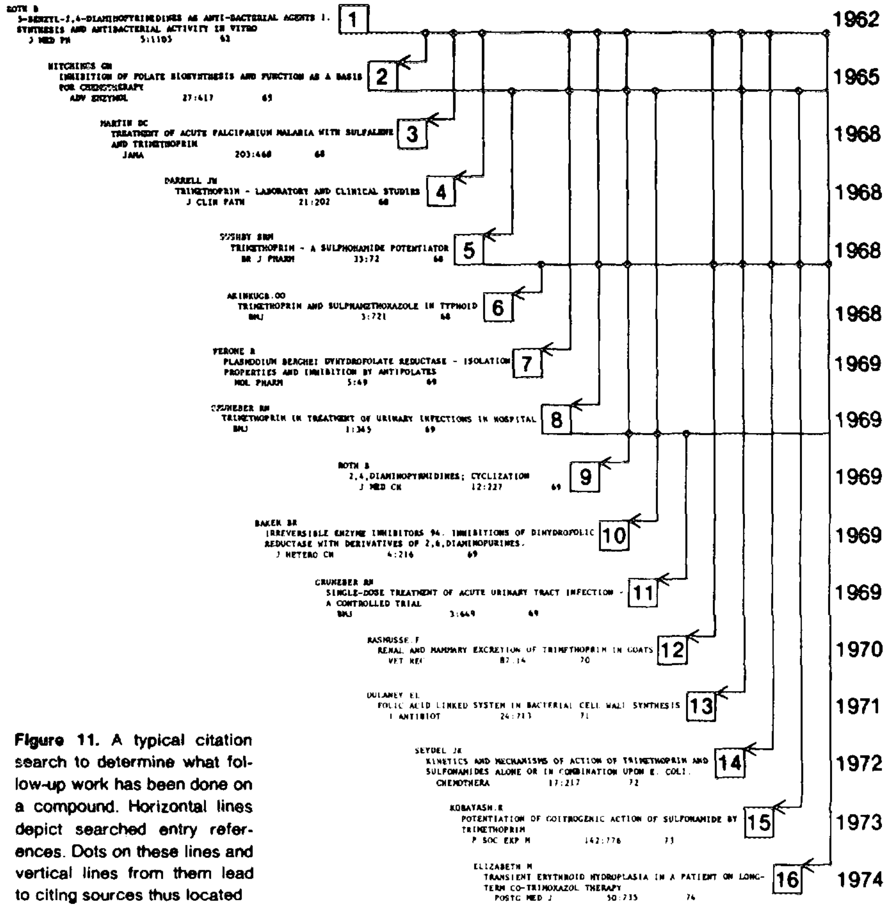

Figure 11. A typical citation search to determine what follow-up work has been done on a compound. Horizontal lines depict searched entry references. Dots on these lines and vertical lines from them lead to citing sources thus located

this search involved is that it consists of two separate cycles. The first starts with searching the 1969 *SCI* on paper #1, which the researcher knows deals with the subject. This search identifies papers #2, 3, 4, and 5, and the search could have ended there. In reading those papers, however, the researcher noticed that they all had in common a reference to paper #6. It thus seemed worthwhile to take the search through another cycle using #6 as the entry citation. This led to identification of #7 and a reference in it identified #8, which had been published in 1968, and introduces the researcher to work done in the picosecond region. The sample search was terminated at this point. It could have been continued through as many cycles as the researcher thought would be fruitful by using references picked up in the identified papers to start new search trials.

While citation searches of this type are the functional capability that has made *SCI* one of the major tools for gaining access to the literature; it can be used also for more traditional searches of subject, organization, and author.

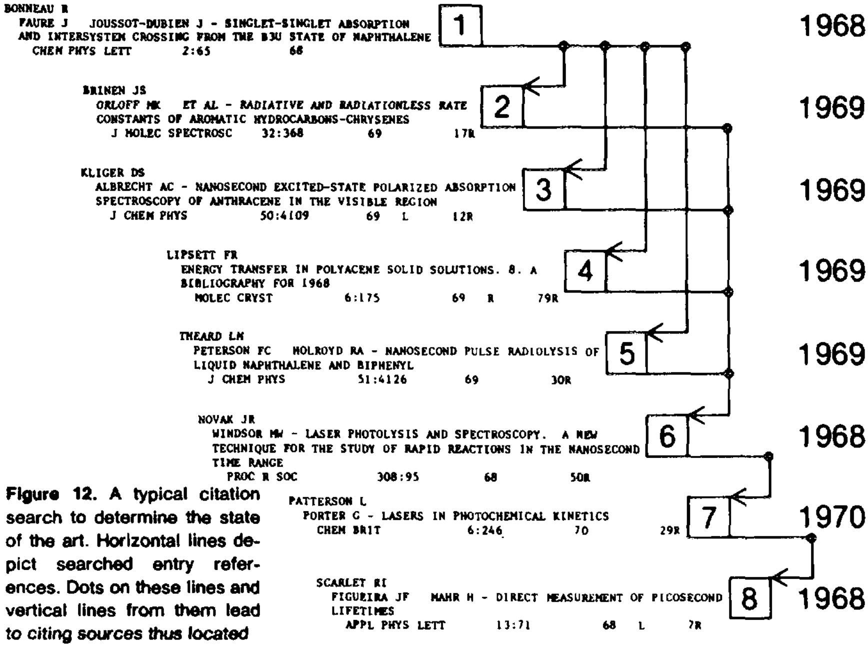

Figure 12. A typical citation search to determine the state of the art. Horizontal lines depict searched entry references. Dots on these lines and vertical lines from them lead *to citing sources thus located*

For all its utility as a search tool, on both a current and retrospective basis, the most important role of citation indexing may be its ability to shed some light on the constantly changing structure of science and technology and the nature of the highly complex process of their development. It does this in a number of ways.

We define two measures of activity by author, paper, and periodical: citation rates (how often cited); and citation links. These measures are useful in managing science—not so much in the detailed sense of defining objectives and timetables, but in the general sense of allocating resources and measuring progress.

A number of studies[3-6] showed that citation rates provide a rough, but objective and useful, relative measure of scientific quality. Thus, some government agencies are using citation analysis to improve their ability to define patterns of activity. A study we conducted for NSF on the characteristics of frequently cited papers in chemistry is typical.

Some of the main findings of the study were:

- Seventy percent of the heavily cited (10 times or more) items were published during the preceding 10 years.
- The most heavily cited items, particularly by applied chemists, are books published early in the 10-year time frame.
- Theoretical papers dominate the list of most-cited items. Experimental methodology is next most frequently cited.
- The central specialty of chemical science seems to be molecular orbital theory.

These findings persuaded NSF to take a closer look at cross-disciplinary papers in chemistry and to include engineering sciences.

Citation rates of individual papers, or groups of papers that define given fields, are also being used to identify areas showing sudden spurts of activity. Price developed an average-citation-rate curve[7] that can be used as a baseline for spotting groups of papers whose use rate is higher, increasing faster, or is more sustained. A study of the literature on pulsars[8] suggests that these characteristics typify an emerging field.

The study of citation links among papers is providing still different views of science. They have been used, for example, to reconstruct the sequence of events that led to the definition of DNA.[9] And they are being used to map the functional structure of science in a way that identifies its specialties and shows both their relative rates of activity and the degree of interaction among them.[10,11] Citation measures are sensitive enough to show subtle changes in productivity and relationships within scientific structure.

And citation analysis is being used to show how well individual periodicals are doing, on a relative basis, at the job of publishing material useful in R&D[12] (where "useful" is defined as frequently cited).

Thus the perspective that citation indexing and analysis brings to the literature is singularly versatile. Citation linkages can be used to search the past literature, monitor the current literature, reconstruct historical work, define development pace and interaction of given specialties within and among disciplines, and measure the utility of individual journals as media for communicating useful research and development material in given areas of study. Any one, or combination, of those capabilities is available to the chemical technologist willing to move beyond his traditional information-retrieval tools.

1. ACS report rates information system efficiency. *Chem. Eng. News* 47:45-6, 1969.
2. **Garfield E.** The mystery of the transposed journal lists; wherein Bradford's law of scattering is generalized according to Garfield's law of concentration. *Current Contents*® No. 31, 4 August 1971, p. 5.
3. **Sher I H & Garfield E.** New tools for improving and evaluating the effectiveness of research. In: *Research program effectiveness; proceedings of the conference sponsored by the Office of Naval Research, Washington, D.C., July 27-29, 1965.* ed. by M.C. Yovits et al. (New York: Gordon & Breach, 1966), pp. 135-46.
4. **Clark K E.** The APA study of psychologists. *Amer. Psychologist* 9:117-20, 1954.
5. **Orr R H & Kassab J L.** Peer group judgements on scientific merit; editorial refereeing. Thirtieth Congress of the International Federation of Documentation, Washington, D.C., October 15, 1965.
6. **Wade N.** Citation analysis; new tool for science administrators. *Science* 188:429-32, 1975.
7. **Price D J D.** Networks of scientific papers. *Science* 149:510-15, 1965.
8. **Meadows A J.** The citation characteristics of astronomical research literature. *J. Documentation* 23:28-33, 1967.
9. **Garfield E, Sher I & Torpie R J.** *The use of citation data in writing the history of science.* Final Report, Air Force Office of Scientific Research, Contract AF 49 (638)-1256. (Philadelphia: Institute for Scientific Information®, 1964).
10. **Small H & Griffith B C.** The structure of scientific literatures. I. Identifying and graphing specialties. *Science Studies* 4:17-40, 1974.
11. **Griffith B C, Small H, Stonehill J A & Dey S.** The structure of scientific literatures. II. Toward a macro- and microstructure for science. *Science Studies* 4:339-65, 1974.
12. **Garfield E.** Citation analysis as a tool in journal evaluation. *Science* 178:471-79, 1972.