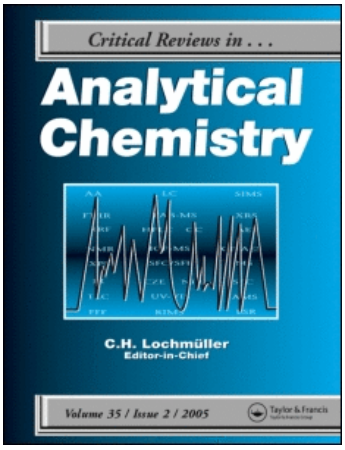

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THE GROWTH OF MODERN ANALYTICAL CHEMISTRY AS REFLECTED IN THE STATISTICAL EVALUATION OF ITS SUBJECT LITERATURE

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I. INTRODUCTION

As written by Derek DeSolla Price in the foreword of his book *Little Science — Big Science,*[1] "My goal is not discussion of the content of science or even a humanistic analysis of its relations. Rather, I want to clarify these more usual approaches by treating separately all the scientific analyses that may be made of science. Why should we not turn the tools of science on science itself? Why not measure and generalize, make hypotheses, and derive conclusions?

"My approach will be to deal statistically, in a not very mathematical fashion, with general problems of the shape and size of science and the ground rules governing growth and behavior of science-in-the-large. That is to say, I shall not discuss any part of the detail of scientific discoveries, their use and interrelations. I shall not even discuss specific scientists. Rather, treating science as a measurable entity, I shall attempt to develop a calculus of scientific manpower, literature, talent, and expenditure on a national and on an international scale."

Price is cited at this length because we think his ideas were the first to express explicitly the endeavor toward the quantification of science, which has led to scientometrics as it is now known and interpreted.

"Quantification of science?" a peculiar notion, the reader will say. Have the natural sciences not been quantified a long time ago? Indeed they have, to varying degrees, and so the subject of scientometrics is not the quantification of the natural sciences themselves but the quantification of the science of those sciences, which is so young that it has not had time to quantify itself. The science of science in fact is a recent hybrid (some readers will like to call it interdisciplinary) field involving the study of science-making from a philosophical, methodological, historical, economic, managerial, administrative, policy-making, and sociological angle. It began to show the first signs of an identity perhaps two decades ago. By no means all of the science of science is devoted to the quantification of science. There has been, nevertheless, a significant movement to try to approach the science-making process with the help of some quantitative tools.

What is it about science that we want to quantify? It is helpful in many respects to look at the process of science-making as an input-output phenomenon (see Figure 1), and accordingly, we can try to quantify the input and the output. The primary input consists of money and manpower. The application of these two items leads to secondary input items which can also be quantified: the number of pencils used by theorists, the number of litres of liquid nitrogen bought, the number of computer hours clocked, the number of laboratory buildings needed, etc. Finally, there is the scientific output which consists of knowledge.[2]

In Figure 1 knowledge is represented under the heading of recorded knowledge, and this is in fact nothing else than the scientific subject literature. The literature — the body of writings on a subject — is the prime means of communication in any subject; it is a representation and record of the knowledge and activities in the subject. So, the importance of the quantitative analysis of the literature of a subject field lies in the fact that it contributes to the understanding of and insight into that field. The notion that scientific subject literatures are phenomena susceptible to systematic investigation in much the same way as are physical or biological phenomena is at least 60 years old. One of the earliest papers of this type was that of Cole and Eales[3] in 1917 in which they described and interpreted a count of the literature of comparative anatomy from the years 1543 through 1860. Cole and Eales were interested in measuring the relative contributions and performance of the participating countries over three centuries. Their study had a clearly defined objective: to determine which groups of animals and which aspects of anatomy engaged the attention of workers, and to trace the influence of contemporary events on the history of anatomical thought. They attempted to detach and

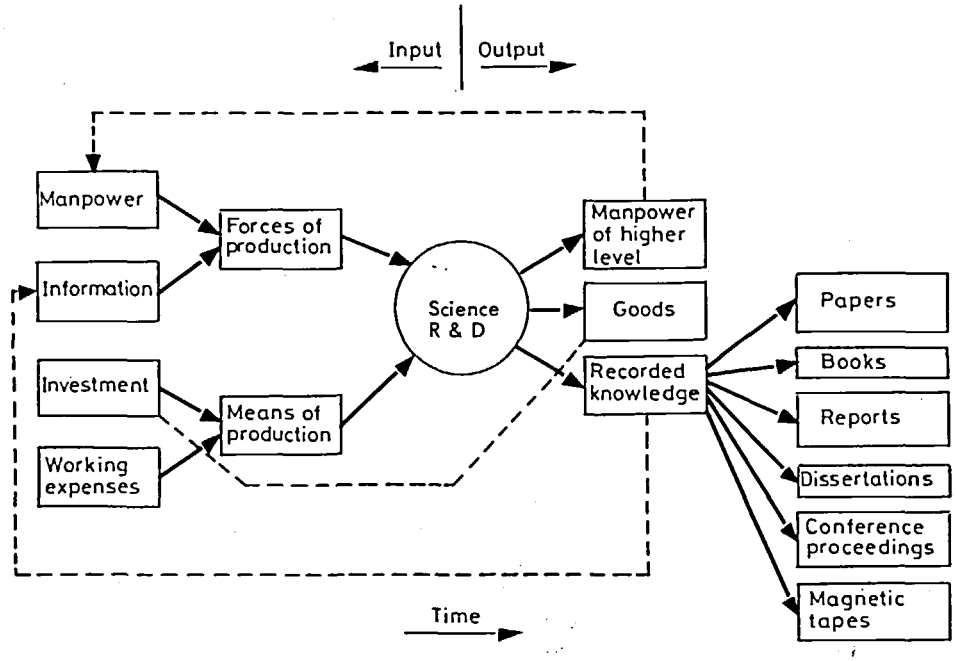

FIGURE 1. Flow chart of the simplified working "mechanism" of scientific research.

plot separately the performance of each European country. They summed these goals by stating that ". . . it seemed possible to reduce to geometrical form the activities of the corporate body of anatomical research, and the relative importance from time to time of each country and division of the subject."

Cole and Eales[3] were acutely aware of some kind of the limitations of their techniques: "A chart represents numerical values only, and may by itself be seriously misleading. The author of 50 small ephemeral papers, judged by figures, is of greater importance than William Harvey, represented by two entries, both of great significance. It is hence necessary that any conclusions drawn from the charts should be checked by an examination of the literature dealt with."

The paper of Cole and Eales was followed by a whole series of studies dealing with similar investigations, and sometimes extended to the study of various scientific fields and/or specialties. The bibliography of Hjerppe[4] on this topic already lists several hundred papers. If this bibliography is scanned, one can see that in the titles of papers the word "bibliometrics" occurs quite frequently. Pritchard,[5] who is generally given credit for coining the term "bibliometrics", defines it as follows: "The definition and purpose of bibliometrics is to shed light on the process of written communication and of the nature and course of a discipline (in so far as this is displayed through written communication) by means of counting and analysing the various facets of written communication."

The term "bibliometrics" is also sometimes used to denote an investigation of a field of science or of scientific activity based on the analysis of scientific publications through the references from and citations to them. As such, a reference is defined as the acknowledgment one scientific article *gives* to another, and a citation is the acknowledgment one article *receives* from another. Thus, for instance, the fifth reference noted in this article is considered to be a reference from this article to the article of Pritchard, as well as a citation to the article of Pritchard from this article.

On the other hand, it was Vasilij Nalimov[6] who first coined the term "scientometrics", and outlined its subject field. His views agree with those of Price in that science is a

process developing in time, and as such it can obviously be subjected to quantitative investigations just as the time-dependent processes of biology, chemistry, or physics. Phenomenologically, as said by Nalimov,[6] science is a process of searching basically new pieces of information. This process has a cumulative and collective character: any scientific result is built, to a certain extent, on a set of previously declared principles. Novel scientific results are born as a development or reevaluation of previous ones. Science is a self-organizing system, the development of which is governed by its information flows. According to Nalimov,[6] scientometrics stands for those quantitative methods which deal with the investigation of science viewed as an information process. This approach is cybernetic in character. As known, complicated systems may be studied by observing the information flows governing the system.

The primary purpose of this review is collecting and presenting in an organized manner the most pertinent scientometric and bibliometric information dealing with the statistical evaluation of the literature of analytical chemistry. Some aspects of the literature of analytical chemistry were investigated statistically soon after World War II. This review does not follow the chronological order of the investigations of such type; our intention was rather to classify and analyze the set of knowledge gathered so far according to various bibliometric or scientometric techniques and laws.

At the end of this introduction, there is an important issue to be clarified. We consider it probable that Crane,[7] the late director of *Chemical Abstracts,* has launched the type of investigations which later has become the source of certain misinterpretations. Crane, quite correctly and logically from the viewpoints of the head of Chemical Abstracts Service and the managing of that abstract journal, endeavored to get an insight into the development of world chemical literature by grouping the papers processed by *Chemical Abstracts* according to various statistical points of view. These statistical studies and some later investigations of Crane[8] inspired the work of Strong,[9] published in 1947 under the title "Trends in Quantitative Analysis. A Survey of Papers for the Year 1946". In his investigations Strong attempted to follow the progress of quantitative analytical chemistry through a statistical analysis of the papers abstracted in *Chemical Abstracts,* and this (i.e., that the trends are followed exclusively from the survey of the literature) was duly stressed in the title of the work.

This paper of Strong inspired most probably the work Fischer et al.[10] published in 1956 entitled "Trends in Analytical Chemistry — 1955". This was followed by a further study by Fischer[11] entitled "Trends in Analytical Chemistry — 1965", and a later study in 1975 by Brooks and Smythe[12] entitled "The Progress of Analytical Chemistry 1910-1970".

As can be seen in the title of these papers dealing with the analysis of analytical subject literature, the words "trends" or "progress" stand without the mention of "of the literature", and this could, and in fact did, make the impression that the progress or the trends of the scientific field are concerned. This is, however, not the case. Therefore, commenting on the paper of Brooks and Smythe,[12] it is emphasized by Braun[13] that ". . . The authors have tried to approach a very much up-to-date problem with methods and means applied only in very few cases to analytical chemistry. To follow the progress of analytical chemistry between 1910 and 1970 they consider the number of publications, its time-dependent growth, and the distribution of publications with respect to various factors (country, language, subfield, elements) in order to evaluate some of the long-term trends of this century. Now, the statistical distribution and growth of scientific publications, citations, and manpower has been dealt with in some basic works[1,6,14,15] and it has been shown in these that the statistical data on the number of scientific publications can be correlated to the data on new scientific achievements, although scientific achievement and scientific information are different concepts. However, one should avoid the misjudgment that the number of publications is the only and fundamental measure (indicator) of the 'size of science' or its 'development', 'trend' or 'progress'. Thus

as a title, 'Progress (or Trends) of the Literature of Analytical Chemistry 1910-1970' would have been more relevant."

II. VOLUME OF THE LITERATURE ON ANALYTICAL CHEMISTRY

For the investigation of the subject literature of analytical chemistry useful hints would be given, obviously, by knowing the complete volume of the literature. In our opinion, however, accurate measurements in this respect are almost impossible. The problems in attempting to assess the total volume of the analytical literature are so great and diverse as to cast doubts on the value of any such estimate. In all the measurements known up to the moment, the volume of the analytical literature was derived largely from study of review journals as *Chemical Abstracts, Referativnyj Zhurnal,* and/or *Analytical Abstracts.*

Baker, the director of Chemical Abstracts Service, has been publishing since 1961 (five annually) data on the size and growth of the world chemical literature,[16-19] reflecting in fact the development of *Chemical Abstracts* itself. These papers can be regarded as a continuation of the already-mentioned investigations of Crane,[7,8] but on a better methodological basis.

The counting of the items representing the total chemical literature processed in *Chemical Abstracts* is not too complicated a task. The share of analytical chemistry in the total literature, and its accurate measurement, is, however, a much more complex problem. For a measurement of this type it is hardly conceivable that someone would be able to count all the abstracts connected with analytical chemistry in all sections of *Chemical Abstracts.* It was found by Fischer[11] that the "Analytical Chemistry" section of the 1965 volumes of *Chemical Abstracts* contained only 48% of the abstracts concerned with analytical chemistry.

In the possession of this fact, Brooks and Smythe[12] mention that the volume of the literature on analytical chemistry can be calculated by multiplying the number of items in the "Analytical Chemistry" section of *Chemical Abstracts* by 2.1. For this, it must be assumed that the 48% share has not changed since 1965. Instead of this method, Brooks and Smythe[12] counted all entries dealing with analytical aspects for 25 common elements for the entire years 1955, 1960, 1965, and 1970 in both *Chemical* and *Analytical Abstracts.* The measurements showed that *Analytical Abstracts* contained only 54% of the total analytical items for these elements in *Chemical Abstracts.* Entries for *Analytical Abstracts* were therefore multiplied by 1.86 to give values which in turn were found to be 2.49 times the total number of entries in the "Analytical Chemistry" section of *Chemical Abstracts.* To obtain an estimate for the total number of analytical papers in any 1 year, therefore, the total number of entries for the "Analytical Chemistry" section of *Chemical Abstracts* was counted and multiplied by 2.5.

According to the above authors, and this is in our opinion more or less correct, the percentage of analytical literature was reasonably constant over the 1910-1970 period, and apart from 1920 it never fell outside the limits of 5.6 to 7.5. Their final, correct conclusion: "Overall it appears that analytical chemistry is at least maintaining itself in relation to chemistry as a whole."[12] It was pointed out by Braun et al.[20] that in all investigations carried out on the basis of abstracting journals, the recorded data cover the literature from a certain period only, i.e., from the beginning of the abstracting service involved. Failure to include earlier literature, i.e., that published before abstracting began, may cause serious errors in assessing total cumulative values. In order to bridge the gap, a correction procedure was applied by Braun et al.[20] which will be discussed in slightly more detail in Section III. Perhaps for the sake of interest it is worth mentioning that the total estimated number of the world chemical papers was, according to the calculations, about 198×10^3 items in 1910, and that of the analytical literature in 1915

about 16×10^3 items. In turn, the 1970 world chemical literature had a volume of about 5224×10^3 and that of analytical chemistry of about 312×10^3; this means a share of 6% of analytical chemistry from the world chemical literature, in agreement with the value suggested by Brooks and Smythe.[12]

III. GROWTH OF THE LITERATURE ON ANALYTICAL CHEMISTRY

In the natural sciences, if a mathematical model is to be constructed for the description of the phenomenon studied, generally the following is done: one or more possible hypotheses are set up first on the basis of preliminary, logically interpreted information arising from previous experiments. These hypotheses are translated into the language of mathematics and compared to the experimental data. The investigation is concluded by selecting the appropriate hypothesis, which is corrected according to the new experimental data. It may happen that in setting up the hypothesis the analogy of known and already-studied natural phenomena is also utilized.

The same procedure may be followed in studying the increase of information flow in analytical chemistry. On the basis of Price[1] it is stated by Nalimov and Mulchenko[6] that in the absence of limiting factors the growth rate of publications regarded as carriers of scientific information, i.e., the increase of literature, is determined by the actual level of science. All sound and new scientific theories should give rise to a certain amount of new scientific work in which these theories are developed, supported, or refuted. Consequently, the growth rate of scientific literature reflected in the number of papers, p(t)[6] can be described by the following differential equation:

$$\frac{dp}{dt} = k \cdot p \qquad (1)$$

This equation shows that the growth rate, dp/dt, is proportional to the actual level of p, i.e., the relative growth rate, $\frac{1}{p}\frac{dp}{dt}$, is constant. The solution of the above differential equation with the initial condition that $p = p_o$ at time $t = O$ is an exponential function

$$p(t) = p_o e^{kt}, \qquad k > O \qquad (2)$$

The exponential curve is well characterized by time during which the value of p is doubled (doubling time).

In general, the growth may be exponential only until the external conditions under which the literature of the given field develops do not change substantially. Changes, such as caused by war, inevitably disturb exponential growth, but the growth rate is later regenerated. The growth process described by the above exponential relationship cannot go forever; limiting factors, e.g., shortage of money or manpower, must and do gradually manifest their effect. In this case the mechanism of growth will be better described by the Pearl-Reed logistic function or the Gompertz differential equations.

The Pearl-Reed logistic function has the form of the differential equation

$$dp/dt = kp(b - p) \qquad O \leq p < b \qquad \text{and } k > O \qquad (3)$$

Here the growth is limited, since b is considered to be the limit of p.

The relative growth rate

$$\frac{1}{p}\frac{dp}{dt} = k\,(b - p) \qquad (4)$$

is already not constant, being a linear function of p. This means that the higher the level of p, the lower the growth rate. By solving the above differential equations with the former initial conditions, one obtains the logistic equation

$$p(t) = \frac{b}{1 + a \exp(-kbt)} \qquad k > 0 \tag{5}$$

where

$$a = \frac{b}{p} - 1 \tag{6}$$

In the initial stage, when $p \ll b$, the logistic curve practically coincides with the exponential one. The $p = b$ and $p = 0$ lines are asymptotes of the logistic curve. The curve has an inflection at $p = b/2$, where the sign of acceleration changes.

The Gompertz function has the following form:

$$p(t) = b\left(\frac{p_0}{b}\right)^{e^{-kt}} \tag{7}$$

which can be obtained by integration of the differential equation

$$\frac{dp}{dt} = k\, p \ln \frac{b}{p} \tag{8}$$

where the symbols used are the same as above. Whereas the logistic function has a symmetric shape, the Gompertz function has the inflexion point shifted towards 0; the S-curve is shortened and more curved at the first bend than the second one.

Another model of growth was suggested by Moravcsik,[74] who considered science a spherical body of knowledge growing at its epidermis, i.e., along the research fronts based on knowledge acquired in the most recent research in an n-dimensional space, where the dimensions can be identified with the various directions in which science can grow independently of the other directions:

$$\frac{dQ}{dt} = C_n S(t) \tag{9}$$

$Q(t)$ being the amount of scientific knowledge, $S(t)$ its surface area at time t, and C a constant.

The solution of this equation is

$$(Q)t = \beta\, t^n \tag{10}$$

where β is a proportionality constant. This equation gives an exact exponential growth if n, i.e., the number of freedom in the system of scientific research goes to infinity.

Let us now see how the above mathematical models agree with the investigations on the growth of analytical subject literature. This question was studied almost simultaneously by Orient[21] and Brooks and Smythe.[12] According to the latter authors, in the analytical literature there is "an exponential increase for 1920-30. The exponential increase is not maintained for 1930-35, probably because of the influence of the Great Depression. An expected decrease for the war years is followed by an exponential increase from 1950 onwards."[12]

Table 1
PERCENTAGE OF ANALYTICAL WORK CARRIED OUT IN VARIOUS COUNTRIES

Country	Year 1965	1970
U.S.S.R.	25.4	28.4
U.S.A.	15.8	17.7
Japan	11.0	7.7
Germany[a]	6.4	6.1
U.K.	4.3	5.9
Czechoslovakia	5.3	5.6
France	3.5	2.6
India	3.5	2.6
Scandinavia	0.7	2.1
Romania	3.5	2.0
Poland	4.1	1.8
Spain	1.8	1.5
The Netherlands	0.8	1.3
Italy	1.7	1.0
China	3.1	—
Rest of the world	9.1	11.1

[a] Both East and West Germany.

From Brooks, R. R. and Smythe, L. E., *Talanta*, 22, 495 (1975). With permission.

In our opinion these statements are incorrect, mostly for methodological reasons, since the authors drew their conclusions on the basis of a growth rate curve obtained by plotting the yearly number of analytical papers against the years. However, exponential growth and the corresponding doubling times may be determined reliably only on the basis of cumulative growth curves.

Orient[21] counted the abstracts in the "Analytical Chemistry" section of *Referativnyj Zhurnal, Khimiya*. The results between 1953 (the first publication year of the journal) and 1972 indicate, too, that the growth was exponential with approximate doubling times of 8 years between 1964 and 1972 and 6 years between 1953 and 1964. Orient also studied the growth rate of the U.S.S.R. analytical chemical literature (in relation to the growth rate of world analytical literature), and the growth rate of literature dealing with organic and inorganic compounds and with the theory of analytical chemistry. Credit can be given to these investigations for proving for the first time that the growth of analytical chemical literature indeed follows an exponential model. The numerical results on doubling times are, however, incorrect. The origin of the errors, also committed by other authors investigating the exponential growth of other subject literatures, is another methodological one, pointed out first by May,[22] and also mentioned briefly at the beginning of this chapter. Namely, in all data on the basis of which Orient calculated the results, the literature before 1953, e.g., before the starting point of investigations, was neglected.

Failure to include earlier literature can cause serious errors in determination of growth rates. Braun et al.[20] have used the data of Brooks and Smythe[12] and Baker[16-19] to compute the corrected dynamic growth rates of the world chemical and analytical literature and that of the chemical and analytical literature output of various countries. The procedure used was to multiply the yearly number of abstracts of analytical papers in *Chemical*

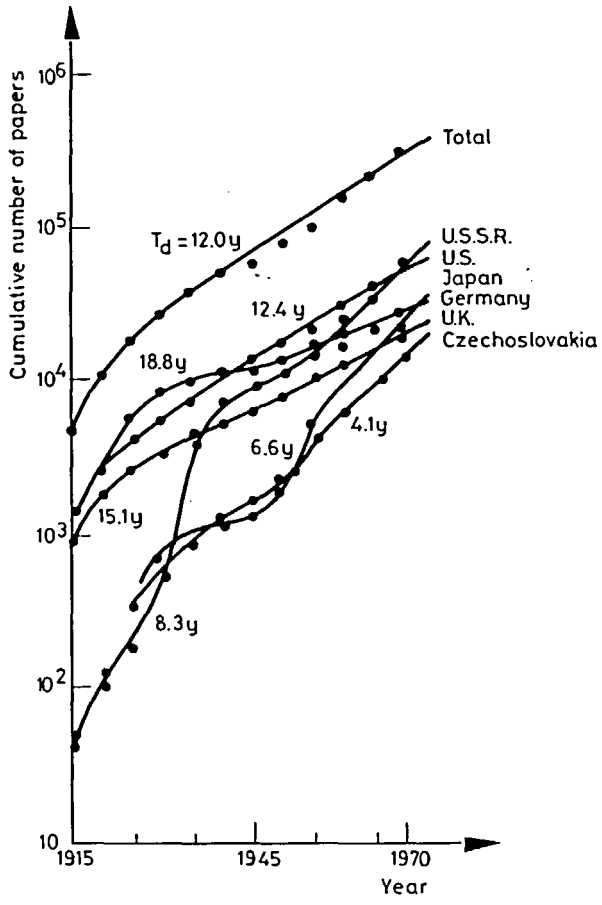

FIGURE 2. Growth of the number of papers on analytical chemistry in some leading countries (uncorrected data). T_d = doubling time, years. (Reprinted with permission from Braun, T., Bujdosó, E., and Lyon, W. S., *Anal. Chem.*, 52(6), 617A (1980). Copyright 1980 American Chemical Society.)

Abstracts by the interpolated share values of the countries given in Table 1. The logarithms of the cumulated number of papers were then plotted vs. time. Figures 2 and 4 show the results. The upper ends of the curves indicate a constant rate exponential growth with the doubling times shown. But these apparent doubling times are incorrect as a result of the same reason mentioned above for Orient's data. Braun et al.[20] have assumed that the growth rate is constant over the whole historical period and have applied to the data a multistep correction procedure. The total estimated correction (number of analytical papers published before 1915) was found to be 11.053. When this value is added to each point of the total analytical data curves, and interpolated national fractions obtained are added to each national point, the semilog data plots shown in Figures 3 and 5 are obtained. Note that the data of Figures 3 and 5 now have a straight line fit over the entire time period, not just at the upper end. Note also — and it is very important and significant — that the apparent doubling time has increased. The same procedure was carried out with the chemical literature. The raw and corrected data are shown in Figures 6 and 8, and 7 and 9, respectively. Tables 2 and 3 show the corrected data for the world total publication and a number of different countries. Note that the doubling times of the world chemical and analytical chemical literature are 14.5 years and

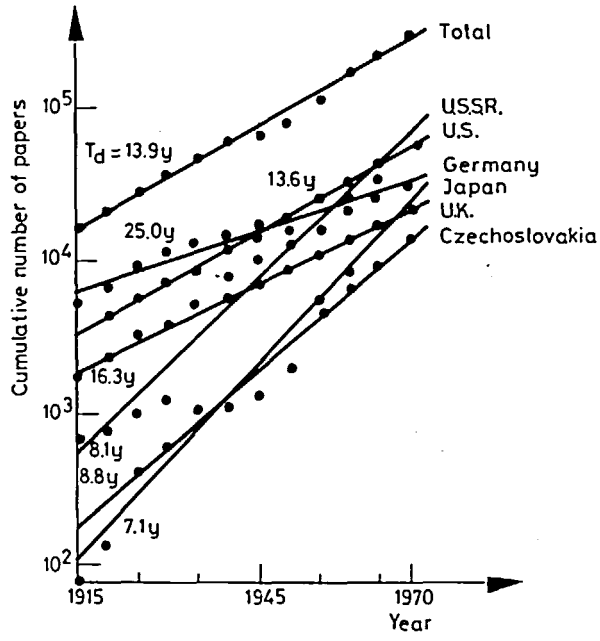

FIGURE 3. Growth of the number of papers on analytical chemistry in some leading countries (corrected data). T_d = doubling time, years. (Reprinted with permission from Braun, T., Bujdoso, E., and Lyon, W. S., *Anal. Chem.*, 52(6), 617A (1980). Copyright 1980 American Chemical Society.)

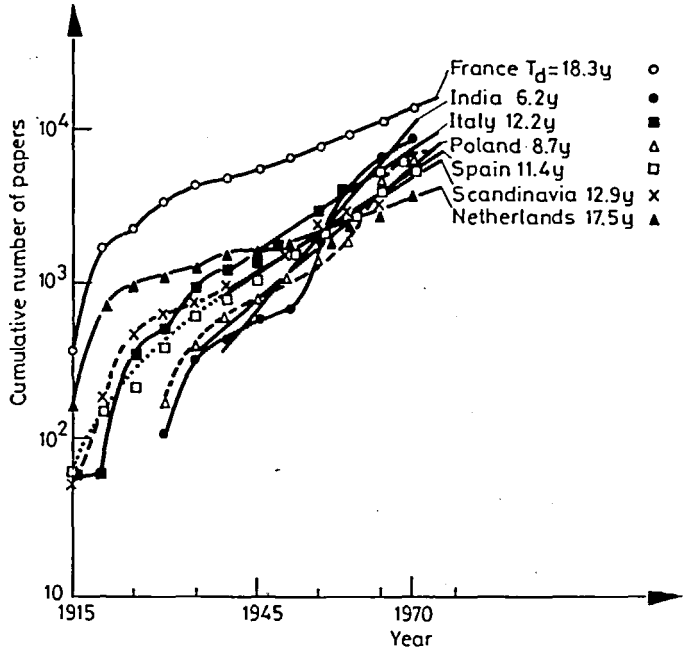

FIGURE 4. Growth of the number of papers on analytical chemistry in some leading countries (uncorrected data). T_d = doubling time, years.

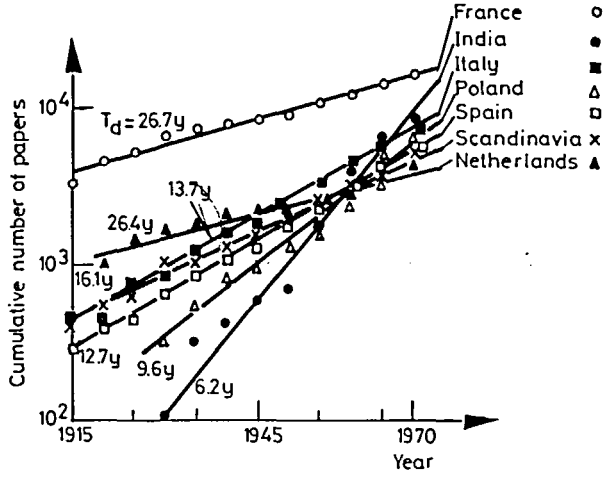

FIGURE 5. Growth of the number of papers on analytical chemistry in some leading countries (corrected data). T_d = doubling time, years.

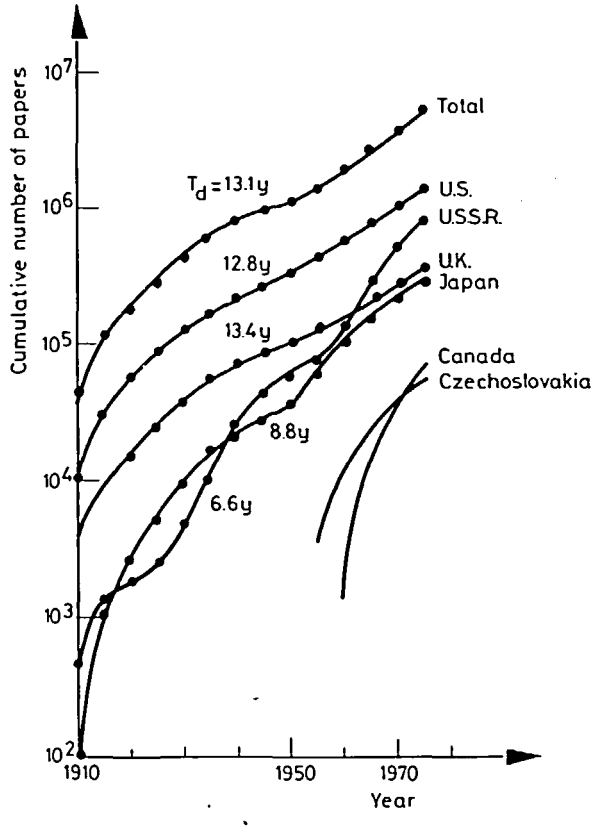

FIGURE 6. Growth of the number of papers on all branches of chemistry in some leading countries (uncorrected data). T_d = doubling time, years. (Reprinted with permission from Braun, T., Bujdosó, E., and Lyon, W. S., *Anal. Chem.*, 52(6), 617A (1980). Copyright 1980 American Chemical Society.)

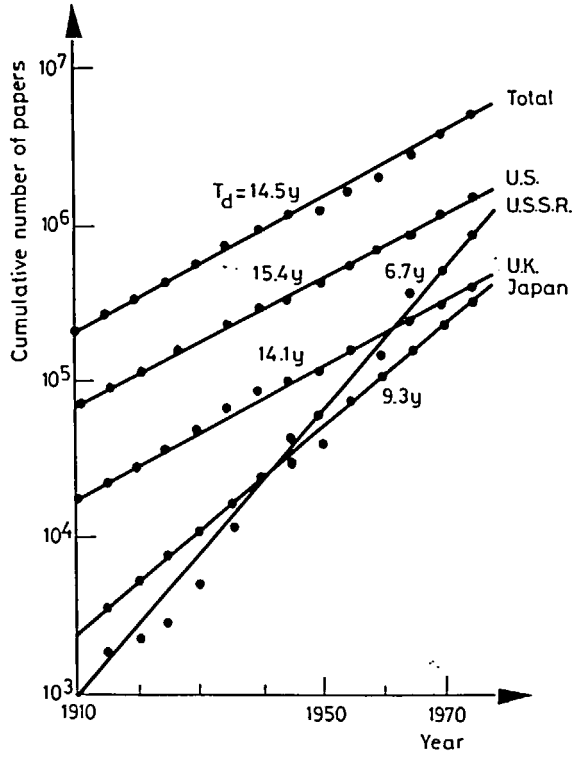

FIGURE 7. Growth of the number of papers on all branches of chemistry in some leading countries (corrected data). T_d = doubling time, years. (Reprinted with permission from Braun, T., Bujdosó, E., and Lyon, W. S., *Anal. Chem.*, 52(6), 617A (1980). Copyright 1980 American Chemical Society.)

13.9 years, respectively, and compare these values with Orient's data of about 7 years in average. If we suppose some relationship or correlation between the growth rate of the analytical literature and that of the analytical knowledge (or progress), we can only speculate about the consequences such a 100% difference can have on our planning, forecasting, and evaluation of any of our educational, research, or development activities. Note also that the U.S.S.R. and U.S. were essentially equal in total analytical publications in 1970, but the U.S. was still far ahead in chemistry publications even in 1975. With a doubling time in chemical publications of 6.7 years vs. 15 for the U.S., the U.S.S.R. can be expected to pass the U.S. in 1986. This has obviously already occurred in analytical chemistry. From the data one can also calculate the relationship between the growth rates of all chemical and analytical chemical literature; this is given in Table 4. It is also enlightening to compare doubling times in analytical chemistry and chemistry with those of other disciplines. Holt and Schrank[23] studied growth rates of journal literature in various disciplines. Table 5 shows their data along with those for analytical chemistry and chemistry.[20]

In the above-discussed cases the growth laws of the total analytical literature of the world or various countries were dealt with. As could be seen, in measuring growth rates with sufficient accuracy, problems are caused by the lack of numerical data on the literature not processed by abstract journals, i.e., literature before 1910. This problem could be solved only by corrections described above, and it necessarily follows from this procedure that even the corrected data can be regarded only as informative. More

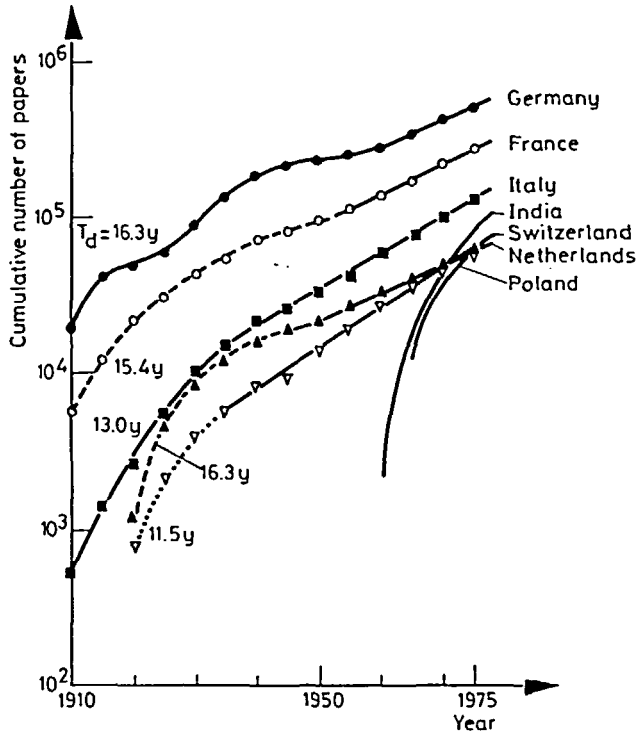

FIGURE 8. Growth of the number of papers on all branches of chemistry in some leading countries (uncorrected data). T_d = doubling time, years.

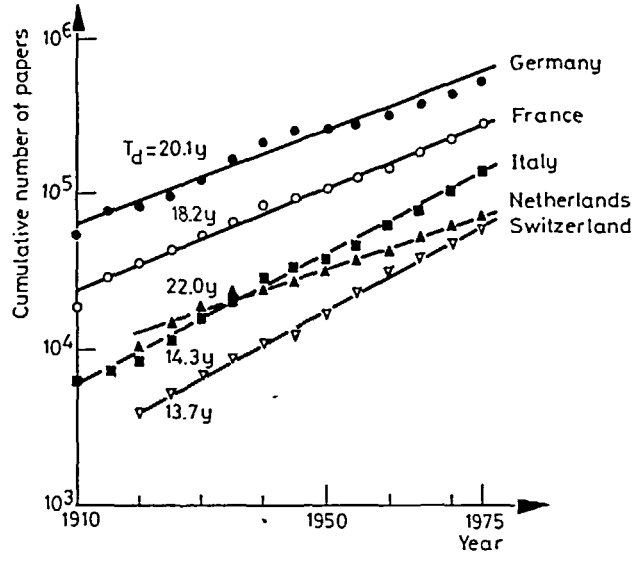

FIGURE 9. Growth of the number of papers on all branches of chemistry in some leading countries (corrected data). T_d = doubling time, years.

Table 2
DATA FOR ANALYTICAL LITERATURE CORRECTED FOR "COUNTING LOSS"

Country	No. of publications in 1915 $\times 10^3$	No. of publications in 1970 $\times 10^3$	Share of the total analytical literature (%)	Growth rate (doubling time), (years)
U.S.S.R.	0.70	58.61	18.8	8.1
U.S.A.	3.18	59.43	19.0	13.6
Japan	0.08	23.17	7.4	7.1
Germany[a]	5.58	31.77	10.2	25.0
U.K.	1.79	31.83	10.2	16.3
Czechoslovakia	0.18	14.59	4.7	8.8
France	3.32	16.71	3.4	26.7
India	—	8.65	2.8	6.2
Scandinavia	0.42	5.46	1.7	16.1
Poland	—	6.67	2.1	9.6
Spain	0.28	5.70	1.8	12.7
The Netherlands	0.67	4.54	1.4	26.4
Italy	0.46	6.53	—	—
World literature	16.03	311.89	—	13.9

[a] Both East and West Germany.

Table 3
DATA FOR CHEMICAL LITERATURE CORRECTED FOR "COUNTING LOSS"

Country	Total no. of publications in 1910 $\times 10^3$	Total no. of publications in 1975 $\times 10^3$	Share of the total chemical literature (%)	Growth rate (doubling time), (years)
U.S.A.	74.64	1520.55	29.1	15.4
U.S.S.R.	0.97	862.98	16.5	6.7
U.K.[a]	16.75	394.46	7.5	14.1
Japan	2.57	339.63	6.5	9.3
Germany[b]	55.08	367.54	7.0	20.1
France	19.32	269.15	5.1	18.2
Italy	6.37	141.25	2.7	14.3
The Netherlands	3.97[c]	75.16	1.4	22.0
Switzerland	3.38[c]	63.97	1.2	13.7
World literature	197.70	5223.96	—	14.5

[a] Data before 1951 calculated: U. K. = 0.65 × British Commonwealth.
[b] Both East and West Germany.
[c] Extrapolated from 1920 data.

Table 4
RELATIONSHIP BETWEEN CHEMICAL AND ANALYTICAL CHEMICAL LITERATURE

Country	Analytical literature % of total chemistry in 1970	Relative growth rate of the development of analytical literature $T_{d\ anal.}/T_{d\ chem.}$
U.S.S.R.	11.2	1.2
U.S.A.	5.1	0.9
Japan	9.8	0.8
Germany[a]	6.7	1.2
U.K.	10.3	1.1
France	7.1	1.5
The Netherlands	7.4	1.2
Italy	5.9	0.9
World literature	8.2	1.0

[a] Both East and West Germany.

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Table 5
LONG-TERM GROWTH RATES OF JOURNAL LITERATURE IN VARIOUS DISCIPLINES

Field	Range of data	Growth rate (% per year)
Biology	1927—1964	4.39
Economics	1886—1959	5.50
Electrical engineering	1903—1962	3.50
Physics	1903—1964	3.73
Psychology	1927—1964	2.90
Chemistry	1910—1970	4.89
Analytical chemistry	1915—1970	5.11

From Holt, Ch. C. and Schrank, W. E., *Am. Doc.*, 19, 18 (1968) and Braun, T., Bujdosó, E., and Lyon, W. S., *Anal. Chem.*, 52, 617A (6), (1980).

reliable data can be expected, however, from the growth studies of the literature of younger subfields of analytical chemistry, for which the publication times of the first papers can be determined accurately, and the increase in the number of publications is easier to follow from *Chemical Abstracts,* other abstract journals, or a carefully prepared bibliography. Some of these results follow.

Orient and Markusova[24] studied the growth of the world literature of electroanalytical chemistry and related it to the growth of the same field in the U.S.S.R. As database, the

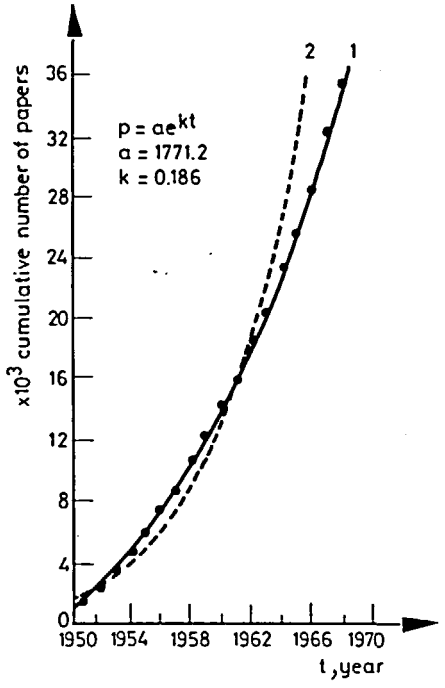

FIGURE 10. Growth of the world literature of electroanalytical chemistry between 1950 and 1968. Curve 1, experimental; curve 2, theoretical. (From Orient, I. M. and Markusova, V. A., *Electrochemical Methods of Analysis*, Sbornik, Izd. Metallurgiya, Moskva, 1972, 95 (in Russian). With permission.)

"Electrochemistry" section of *Chemical Abstracts* was used. The observed functions describing the cumulative growth of electroanalytical literature between 1950 and 1968 can be seen in Figures 10 and 11. The curves follow the exponential growth model already mentioned and appear to indicate that the U.S.S.R. electroanalytical literature grew somewhat faster than that of the world. The authors, using the method of the least squares, approximated the curves by the $p = ae^{kt}$ equation, with $a = 1771$, $k = 0.186$, and $\sigma = 17\%$ for the curve of Figure 10, and $a = 196.4$, $k = 0.249$, and $\sigma = 21\%$ for the curve of Figure 11 (σ is the mean square error). It is characteristic for both curves that between 1950 and 1965 they are well described by the $p = ae^{kt}$ equation. The authors also show that from 1965 the theoretical curve raises more steeply than the observed one. This (i.e., some recession in electrochemical literature) appears to be supported by the results of Orient and Pats,[25] too, on the growth of the literature on polarography between 1950 and 1974, drawn from *Referativnyj Zhurnal Khimiya* as a database (Figure 12). As seen in the figure, the slope of the exponential curve changes in 1965, i.e., the growth decelerates.

The growth of radioanalytical literature was investigated in particular detail by Braun et al.[20,26,60] Some of the results are shown in Figures 13 to 17. In connection with these growth curves perhaps two points are worth noting. The first concerns the extremely fast growth rate of the literature of some subfields of radioanalytical chemistry (activation analysis, use of semicoductor detectors in radioanalytical chemistry). It can be seen, e.g., that the literature of activation analysis doubled every 2.2 years, and this growth rate remained constant for more than 10 doubling periods. This indicates an extremely dynamic progress of the field.

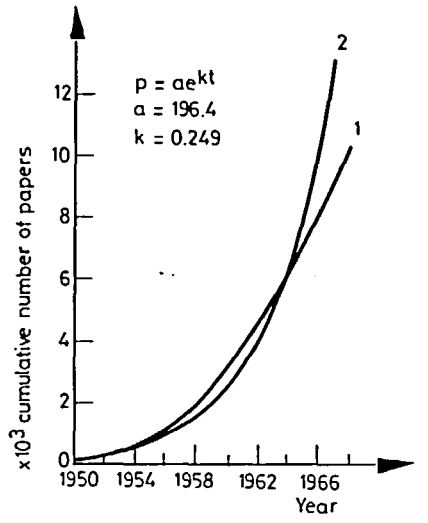

FIGURE 11. Growth of the Soviet literature of electroanalytical chemistry between 1950 and 1968. Curve 1, experimental; curve 2, theoretical. (From Orient, I. M. and Markusova, V. A., *Electromedical Methods of Analysis*, Sbornik, Izd. Metallurgiya, Moskva, 1972, 95 (in Russian). With permission.)

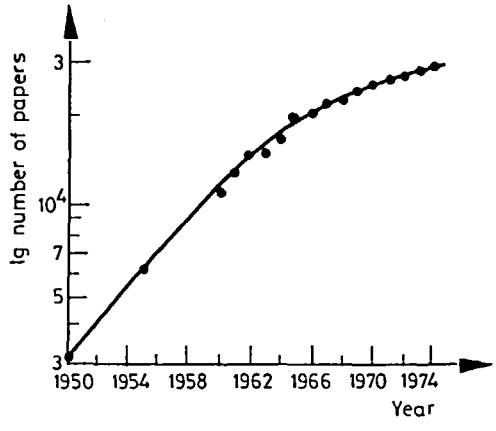

FIGURE 12. Growth of the world literature on polarography between 1950 and 1974. (From Orient, I. M. and Pats, R. G., *Polarography, Problems and Trends*, Strabynya, Ya. P. and Majranovskij, S. A., Eds., Sbornik, Izd. Zinatne, Riga, 1977, 388 (in Russian). With permission.)

The other characteristic growth behavior can be seen in the case of 14-MeV neutron generator activation analysis (Figures 16 and 17), which reflects the logistic model mentioned at the beginning of this chapter.

The growth of literature on analysis with prompt nuclear reactions was investigated by Bujdosó and Tóth.[75] The increase in the number of papers reporting analyses with various types of nuclear reactions are shown in Figure 18. The doubling times of papers

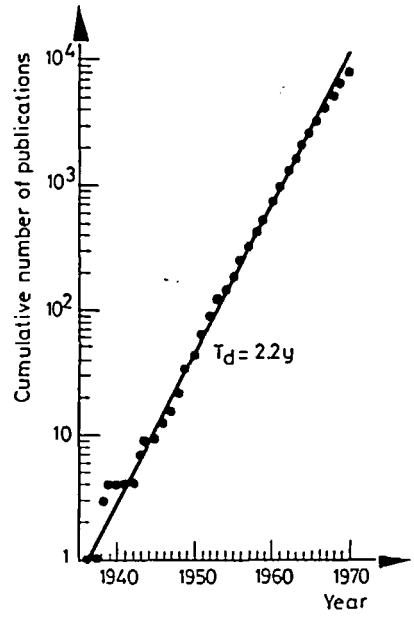

FIGURE 13. Growth of publications on activation analysis. (Reprinted with permission from Braun, T., Lyon, W. S., and Bujdosó, E., *Anal. Chem.*, 49, 682A (1977). Copyright 1977 American Chemical Society.)

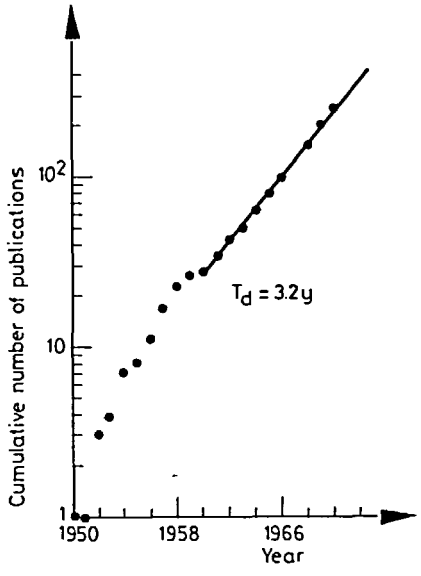

FIGURE 14. Growth of publications of charged particle activation analysis. (Reprinted with permission from Braun, T., Lyon, W. S., and Bujdosó, E., *Anal. Chem.*, 49, 682A (1977). Copyright 1977 American Chemical Society.)

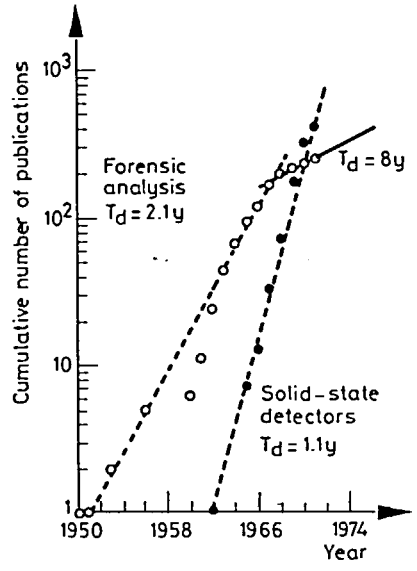

FIGURE 15. Growth of publications on forensic analysis and solid-state detectors. (Reprinted with permission from Braun, T., Lyon, W. S., and Bujdosó, E., *Anal. Chem.*, 49, 682A (1977). Copyright 1977 American Chemical Society.)

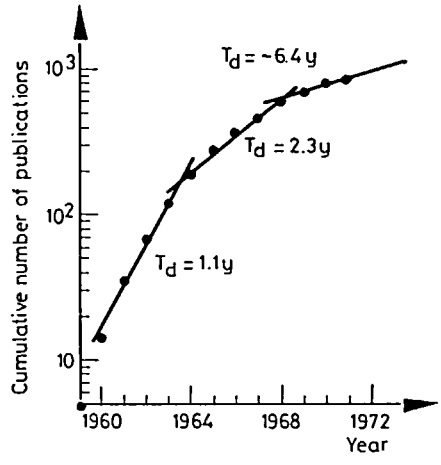

FIGURE 16. Growth of publications on activation analysis by 14-MeV-neutron generators. (Reprinted with permission from Braun, T., Lyon, W. S., and Bujdosó, E., *Anal. Chem.*, 49, 682A (1977). Copyright 1977 American Chemical Society.)

on charged particle—charged particle reactions, Rutherford back-scattering, and chaneling are below 2 years.

In the list of extremely fast growth rates perhaps the literature of atomic absorption must also be mentioned. For this field a doubling time of 2.5 years was found by Orient et al.[42] in the Soviet Union.

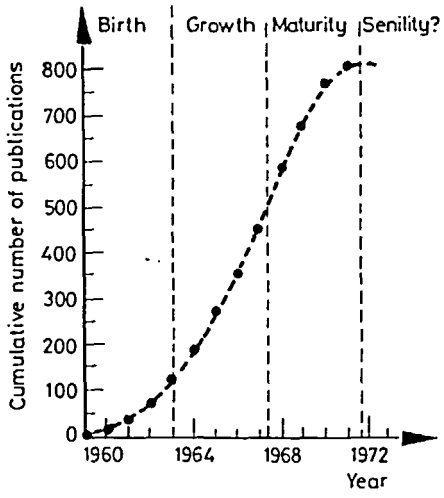

FIGURE 17. Four ages of neutron generators. (Reprinted with permission from Braun, T., Lyon, W. S., and Bujdosó, E., *Anal. Chem.*, 49, 682A (1977). Copyright 1977 American Chemical Society.)

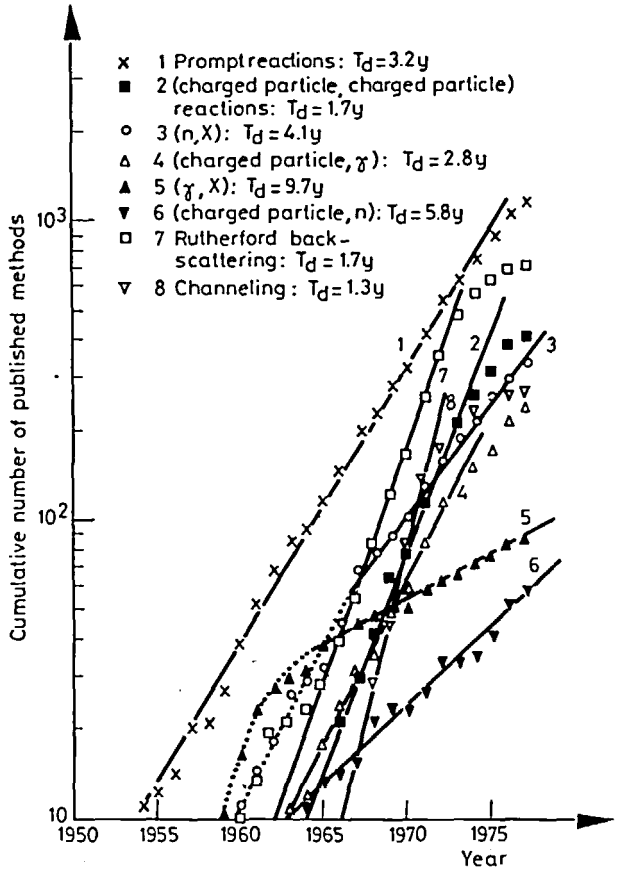

FIGURE 18. The increase in number of prompt nuclear reactions applied for analytical purposes with the doubling times of the occurrence of these methods in various publications.

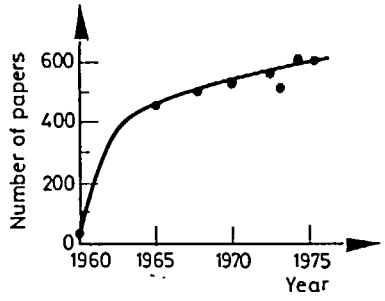

FIGURE 19. Growth of the literature on organic reagents between 1960 and 1975. (From Orient, I. M., *Zh. Anal. Khim.*, 32, 502 (1977) (in Russian). With permission.)

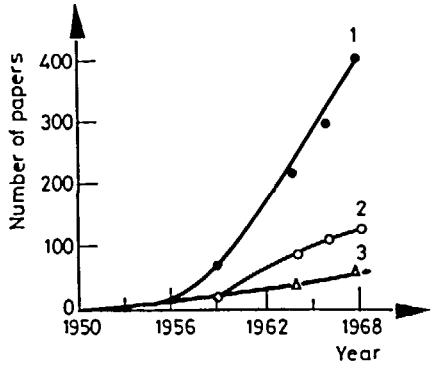

FIGURE 20. Growth of the literature on separation of traces by zone-melting (2) and directed crystallization (3) for purification (curve 1 is the sum of curves 2 and 3).

In showing the growth characteristics of analytical subject literature a third model is worth mentioning in which the growth is linear. The growth of literature on organic reagents was investigated by Orient[27] (see Figure 19) and found to be linear between 1964 and 1975. A linear growth was also observed by Melikhov and Berdonosova[28] for the literature on the separation of mixtures by zone melting as well (Figure 20).

As we have seen, the growth of the total analytical chemical literature follows the exponential or logistic model, and so does the literature of some analytical subfields. At the same time, however, the linear growth model also occurs. Magyar,[87] to reconcile in another field the linear and exponential growth models, postulated that it is the creation of some new subfields on top of the linear growth of the already existing fields that might lead to an overall exponential growth. This may hold on analytical chemistry, too.

As a direct outcome of the results outlined in this section, we considered it worthy to mention the views of Menard,[15] who states that if we can measure different growth rates in scientific literature and suppose it to be related in some way to the growth of science, we are in a position to evaluate how they affect the careers and lives of scientists working in those fields (see also Section VII.A).

He noted that the literature of different science subfields is growing at highly variable rates and for illustration considered three models in which doubling times were at the average of 15 years and the extremes of 5 and 45 years. The professional life of a scientist

may be taken as beginning when he becomes a graduate student and ending 45 years later when he retires at 65. Thus, in a slow subfield in which the literature doubles in 45 years, the number of scientists is constant because new appointments merely balance retirements. Typically, such a subfield might have 200 specialists, if we suppose that manpower grows parallel to the growth of the literature and follows the same mathematical model, and it never varies. Nor can it long continue. Either the doubling time increases, or the scientists double their output each 45 years. In a field doubling in 15 years, retirements amount to only one eighth of new recruitments during a 45-year career and thus are almost negligible. The number of new people in the field increases rapidly. If the initial number is 100, it is 200 in only 15 years, and after 45 years it is 700, allowing for retirement. Such a subfield, starting smaller than a slow one, would rapidly outgrow it.

The growth of a subfield doubling in 5 years or less is truly spectacular. If only 10 men transfer into it at the beginning, there are more than 1000 in 35 years. These growth rates have major effects on the age distribution among the specialists in a subfield, and thus on the queuing position of a new person after a given time. The median age in the slow subfield is halfway from beginning to end, or 42 years. In the average and fast subfields it is the initial age plus one doubling period, or 35 years and 25 years, respectively. This means that in the fast field a student is at the median age when he receives his doctorate after 5 years of graduate study. So rapidly does the field expand that he is in the senior one eight by the time he is 35, whereas in both the average and slow subfields he would have to wait until he is about 60.

We can estimate the living literature existing in a subfield as approximately that produced in the three previous doubling periods by the average population of specialists during the period. In the fast model there are 10 people and thus a total literature of 190 papers. In the average subfield there are 100 people and almost 6000 papers. In the slow model we have to assume that an equilibrium population of 200 has just been established, and in the past the population and literature have expanded at the same rate; the literature consists of 27,000 papers. We may now consider the activities of a student entering into graduate study in one of these subfields. A diligent speed reader, he plunges into the literature of the fast subfield and emerges 38 days later, tired but "au courant". In the average subfield a student would have to read 5 papers a day for 3 years to catch up. What then of the student in the old and slow subfield who is confronted with 27,000 papers? They hang over him for his entire professional life. Not only students but also skilled senior investigators are kept busy compiling ever more massive bibliographies.

We can also consider the growth of the literature during the 5 years a student is engaged in graduate studies. Another 190 papers come out in the fast field, and the student absorbs them gradually. Thus he has seen half of the literature develop around him. In the average subfield another 1200 papers have appeared, or about 1 every second day, which is simply too much to read. The situation is even worse in the slow subfield in which the literature increases by almost 3000 papers. From the very beginning of their careers, therefore, specialists in average and slow subfields are losing ground relative to the growing volume of unread literature. The situation changes with continuing expansion. Within 20 years all the subfields have a backlog of literature too large, and each is increasing by 3000 papers in 5 years. After 10 years more the fast field would acquire 12,000 papers during 5 years of graduate study. Long before, it would have broken into a group of narrower and diverging sub-subfields. It appears that the time for a student or young scientist to get into a fast subfield is somewhere between the third doubling period, when it is identifiable, and the sixth, when it begins to be unwieldy.

Let us consider now the effort necessary to become established in the subfield. At three-papers-per-year productivity, and the age distributions we have calculated, a

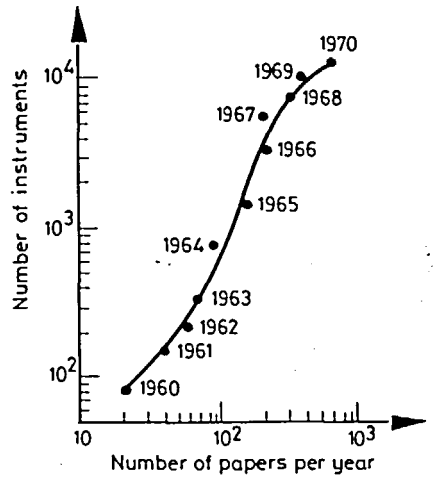

FIGURE 21. Relationship between the total number of atomic-absorption spectrophotometers in existence in any 1 year and the total number of atomic-absorption papers published in the same year. (From Brooks, R. R. and Smythe, L. E., *Talanta*, 22, 495 (1975). With permission.)

newcomer in a fast subfield need only write six papers before arriving at the median age. In an average subfield 36 papers represent the effort of the middle man in the queue, but in the slow subfield it is 57 papers by age 42. Thus the sustained effort to become established as a sound experienced specialist varies enormously. After only 26 papers, a man in a fast subfield is a patriarch in the oldest one eighth of the population. In the average and slow subfields, 110 papers are required. Even with single-minded dedication, the production of scientific papers cannot be sustained for a lifetime by many. At some point the scientist drops out of the race to enter a different one or to become a spectator. Few people write 50 papers. Consequently, most people in average and slow subfields drop below the normal level of scientific productivity before reaching the midpoints of their career. Hardly any of the senior group are still active in research. In contrast, the senior persons in a fast subfield are much younger, and most engage in research even though they are also administrators and committeemen. The administration and evaluation of research in the fast subfield consequently is guided by people engaged in it, which presumably is as effective as the system can be.

At the end of this section it is perhaps also worthy to mention two investigations, which in the case of instrumental analytical subfields, studied the correlation between the number of papers published in the subfield and the number of instruments extant in the subfield. Brooks and Smythe[12] carried out such investigations in atomic absorption analysis; Braun et al.[26] in the subfield of activation analysis. The curves reflecting the correlations are shown in Figures 21 and 22. The reasons governing the mechanism are not clear yet, but the S-shaped curve obtained for atomic absorption is interpreted by Brooks and Smythe[12] so that at first there is a rush for scientists to publish in a new field like atomic absorption. Brooks and Smythe refer to this as the "bandwagon effect". Later in time when the method becomes well established, the ever-increasing number of instruments are used more and more for routine analysis rather than for producing "publishable" research topics.

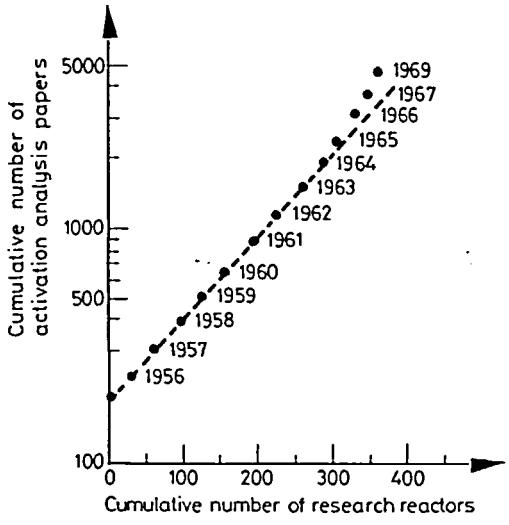

FIGURE 22. Relationship between world activation analysis publication output and the number of research reactors. (From Braun, T. and Bujdosó, E., *J. Radioanal. Chem.*, 50, 9 (1979). With permission.)

IV. OBSOLESCENCE AND REFERENCE HALF-LIVES OF THE LITERATURE ON ANALYTICAL CHEMISTRY

References in journal papers have the common characteristic that their number rapidly decreases in time. If the number of references taken from a certain number of analytical papers (e.g., from all the papers in a yearly volume of a certain analytical journal) older than time t is plotted against time, an exponentially decaying curve is obtained:[29]

$$R(t) = N \exp -\frac{0.693}{T_{1/2}} \qquad (11)$$

with R(t) the number of references older than t years, N the total number of references, and $T_{1/2}$ the half-life of the literature.

This equation is very similar in character to that of radioactive decay. It is valid for papers published in periodicals only, as these are the references which can be cited continuously in time. The analogy to radioactive decay is only partial, since a paper does not disappear or disintegrate after being cited like a nucleus does by decay, and a paper can potentially be cited at any point in time. The half-life of a subject literature indicates the rate with which the frequency of citation (or use of that literature) decreases, i.e., the literature gets less used or becomes obsolete.

The model so far outlined assumes that the decline in frequency of citation (i.e., referencing) can be ascribed to "obsolescence", i.e., lessening of interest (reflected in referencing) in papers (or scientific results) as they grow older. Line[30] pointed out that this is too simple a model. As we have seen in Section III, the volume of the literature is itself growing, apparently exponentially, so the number of papers available for use declines with age. In principle, the whole "obsolescence" of the literature might be ascribable to literature growth. Figure 23 gives a schematic view of a subject literature that is growing exponentially; the area within the curves represents the volume of

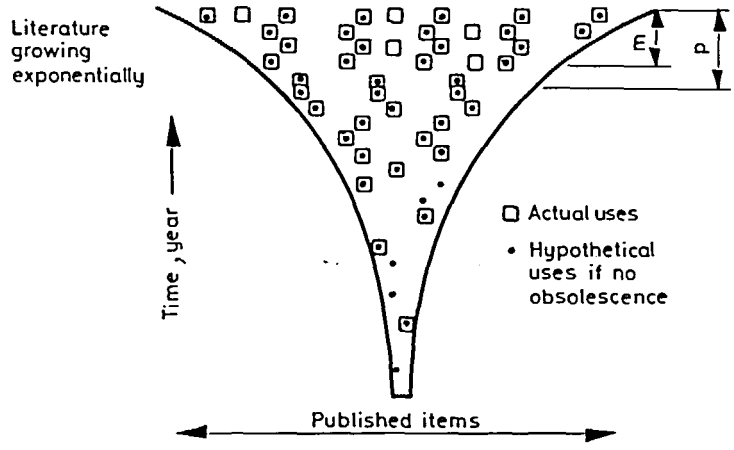

FIGURE 23. Literature growth and use. (From Line, M. B., *J. Docum.*, 26, 46 (1970). With permission.)

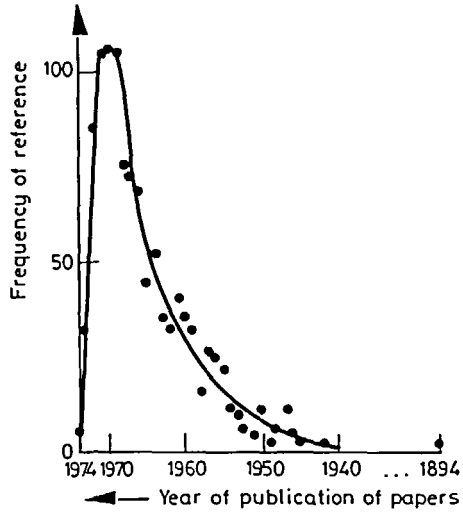

FIGURE 24. The distribution of references of papers published in *Zh. Anal. Khim.*, 1974. (From Orient, I. M., *Zavodsk. Lab.*, 41(9), 1071 (1975). With permission.)

publication, with the number of items published per year doubling in 5 years. The squares represent recorded uses (citations) during the current year. The dots represent hypothetical uses — those that would occur if every published item had an equal chance of being used. The half-life of actual use, within which the squares lie, is m. The median age of the published literature, within which half the dots lie, is p. Now m is less than p if the more recent literature is more likely to be useful, and the older items are less likely to be used. It is the difference between m and p that truly represents "obsolescence".

Orient[21] and Brown[37] were concerned with the obsolescence of the total literature of analytical chemistry. Orient[21] investigated the distribution in time of the references in the papers published in the 1974 volumes of *Zhurnal Analiticheskoi Khimii* (Figure 24).

As seen there is a short rising curve (Orient calls its maximum, modus) followed by a

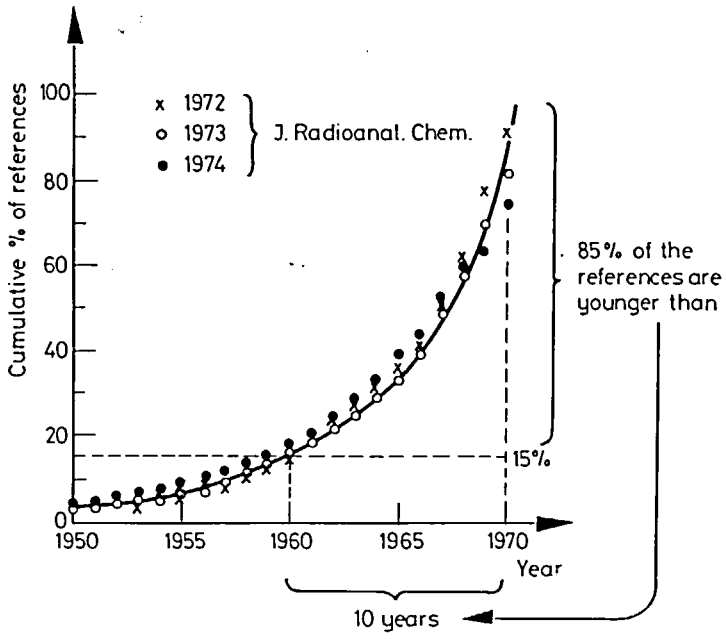

FIGURE 25. Decay of radioanalytical references. (Reprinted with permission from Braun, T., Lyon, W. S., and Bujdosó, E., *Anal. Chem.*, 49, 682A (1977). Copyright 1977 American Chemical Society.)

descending curve concave upwards, flattening as age increases (its half-life is called median). The whole curve can be interpreted as an increase of use as knowledge of papers diffuses, followed by a steady decline in use as papers grow older. The second part of the curve can be plotted semi-logarithmically as one of exponential decay and a half-life can be calculated as mentioned at the beginning of this section.

The decay curves obtained by Orient indicated that in the periodical literature of analytical chemistry the median, i.e., the half-life of the citations to foreign authors, is 7.6 $\pm$ 0.6 years and the modus 3.5 $\pm$ 0.5 years. In the case of U.S.S.R. authors these values are 6.3 $\pm$ 0.6 and 3.2 $\pm$ 0.4 years, respectively.

Brown[37] calculated 9.3 years half-life for the chemical literature from the Poisson distribution of the average citation per article of 11 chemical journals.

Braun et al.[60] were dealing with the decay of radioanalytical literature. Their results can be seen in Figures 25 and 26. We may note on Figure 25 that from 1972 to 1974 in the *Journal of Radioanalytical Chemistry*, 85% of the references were less than 10 years old.

Burton and Kebler[31] suggest the half-lives collected in Table 6. Although their data for individual fields appear to be accurate, the comparison between various fields shows a probable range of figures rather than absolute ones. However, the half-lives in Table 6 can give reasonable indications of the sort of time scale in different subject areas.

V. DISTRIBUTION OF THE LITERATURE ON ANALYTICAL CHEMISTRY

In Section III the publications dealing with the statistical analysis of the growth of analytical subject literature were reviewed. In this section the distribution of literature according to various aspects will be subjected to similar formal statistical analysis with respect to countries, language, subfields, topics, and techniques.

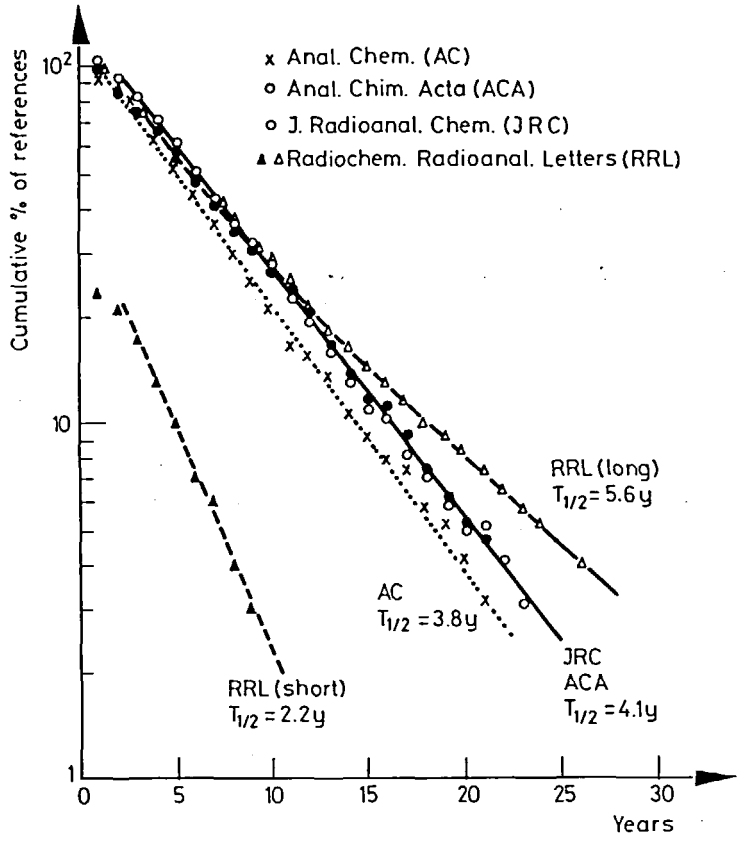

FIGURE 26. Component resolved decay curve of radioanalytical references. (Reprinted with permission from Braun, T., Lyon, W. S., and Bujdosó, E., *Anal. Chem.*, 49, 682A (1977). Copyright 1977 American Chemical Society.)

Table 6
THE HALF-LIVES OF SOME MAJOR SUBJECT DISCIPLINES

Subject	Half-life (years)
Metallurgical engineering	3.9
Physics	4.6
Chemical engineering	4.8
Mechanical engineering	5.2
Physiology	7.2
Chemistry	8.1
Botany	10.0
Mathematics	10.5
Geology	11.8

From Burton, R. E. and Kebler, R. W., *Am. Soc.*, 11, 18 (1960). With permission.

A. With Respect to Countries

The distribution of the world literature of analytical chemistry with respect to countries has been analyzed by Boig and Howerton,[32] Fischer,[10,11] and Brooks and Smythe.[12] Their main results are collected in Tables 7 to 9. The tables show sometimes significant differences between the data of different authors. Nevertheless, from the measurements a general view can be obtained on the publication efforts of analytical chemical research in various countries. It should be stressed that all the data on literature distribution by countries are comparative rather than absolute. Thus, a decline in German analytical chemistry means a decline in the fraction of the world analytical chemical literature that is German and not an absolute decline in the amount of German analytical chemical research or publication. The tables show that at the end of the last century half or more of the analytical chemistry publications were German. Second to Germany were France and the U.K. As one moves through the 20th century, the positions change significantly. Immediately following World War II, the prime country is the U.S. while Germany shows the massive effect of the war. The data also show a steady postwar rise in Soviet publications, and a decline in the U.S. position. The relative German contribution to analytical chemical publication today is a pale shadow of its level 80 years ago. It is also striking that the position of the Soviet Union superseded that of the U.S. The French contribution by 1970 is remarkably low as compared to its position prior to World War I. The above data pertain to the total subject literature of analytical chemistry. It would not be irrelevant to have similar results on the literature of various analytical subfields. Unfortunately, on this, very few results are available.

Futekov et al.[33] investigated the contributions of various countries to the literature on the analysis of selenium and tellurium. It is interesting to observe here that the ranking of countries follows with almost complete fidelity the 1970 ranking concerning the total analytical literature, i.e., the U.S.S.R. is in the first place followed by U.S., Japan, Germany (East and West), England, and India. The ranks of the various countries in the literature of instrumental and noninstrumental methods used for the analysis of selenium and tellurium were also set up by the above authors. They have shown that in the application of X-ray fluorescence, spectrographic, radioanalytical, electroanalytical, and fluorimetric method, the U.S.S.R. is in the first place, and the U.S. occupies this place only in the literature on the application of atomic absorption.

Brooks and Smythe[34] investigated the country distribution of the literature on atomic absorption in 1962 and 1970 (Table 10). As can be seen from the table, the leading role is held by the U.S., and its advantage has been increasing. The progress of England, Czechoslovakia, and Canada can also be considered significant, as well as the decline of Australia, Germany, and particularly South Africa.

B. With Respect to Language

The distribution of the world literature of analytical chemistry with respect to languages has been investigated in many older and recent papers. It was noted by Strong[9] in 1947 that "there is much discussion in educational circles today on the relative importance to scientists of the various languages, especially Russian." His results pertaining to 1946 and calculated on the basis of *Chemical Abstracts* can be seen in Table 11. The contention that knowledge of the Russian language is and will be important to analytical chemists is borne out in the table. Russian papers are next to English in frequency, though one sixth in their number. French is a close third.

In 1952 Boig and Hoverton[32] gave a much deeper analysis of the language of analytical papers. Their results can be found in Table 12. The table shows that German was the most important language until the first world war, at which time it lost the lead to English.

Table 7
PERCENTAGE OF ANALYTICAL WORK CARRIED OUT IN VARIOUS COUNTRIES

Country	1950		1949		1948		1947		1937		1927		1917		1907		1897		1887		1877	
	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%
U.S.A.	1	25.56	1	23.07	1	25.22	1	26.43	3	17.42	2	15.89	1	41.25	3	10.74	4	8.82	5	4.56	6	1.66
U.S.S.R.	2	20.18	2	22.69	4	9.22	2	11.76	1	25.00	7	3.01	—	0.63	10	0.50	7	2.33	8	1.91	—	0.03
England	3	10.18	3	9.62	3	11.48	3	10.92	4	6.23	4	10.82	3	13.44	4	8.08	3	10.25	2	12.06	3	12.96
France	4	6.61	6	7.58	2	13.11	4	10.61	5	6.16	3	11.37	4	8.75	2	17.99	2	18.94	3	10.44	2	17.28
Germany	5	6.43	4	7.71	5	7.50	6	5.31	2	19.05	1	36.84	2	21.88	1	49.01	1	48.00	1	57.80	1	58.14
The Netherlands	6	5.50	5	7.65	6	5.88	8	2.39	—	0.99	5	3.56	5	5.31	6	3.08	9	1.04	—	0.29	—	—
Czechoslovakia	7	3.51	13	1.27	12	1.63	—	0.31	9	1.70	12	0.96	—	—	9	0.50	—	0.39	7	1.91	—	—
Austria	8	2.98	9	2.04	9	3.44	12	0.21	6	5.24	9	2.33	—	0.94	7	1.92	6	4.02	6	3.82	4	5.32
Japan	9	2.92	12	1.47	8	4.34	5	7.60	7	2.83	11	1.64	7	18.75	—	0.08	—	—	—	—	—	—
Spain	10	2.69	7	3.63	7	5.06	7	4.68	—	0.71	17	0.55	—	0.31	—	—	—	—	—	—	—	—
Belgium	11	2.11	—	0.76	16	0.90	15	1.52	—	1.13	8	2.74	—	—	8	1.25	8	1.04	—	0.29	—	0.33
India	12	1.81	11	1.47	11	1.99	16	1.25	—	1.06	—	—	6	1.88	—	—	—	—	—	—	—	—
Italy	13	1.34	8	3.00	13	1.45	9	2.39	8	2.05	6	3.01	—	—	5	5.41	5	4.41	4	4.71	5	1.99
Argentina	14	1.16	10	1.91	10	2.17	14	1.46	—	0.64	13	0.82	—	—	—	—	—	—	—	—	—	—
Denmark	15	1.05	—	0.06	—	0.36	—	0.52	—	0.07	—	—	—	—	—	—	—	—	—	—	—	—
Canada	16	0.99	—	0.44	17	0.72	—	1.14	—	0.28	—	0.27	—	—	—	0.08	—	—	—	—	—	—
Sweden	17	0.70	15	0.88	14	1.27	10	2.19	—	0.64	15	0.68	—	0.63	—	—	—	—	—	0.15	—	0.33
Switzerland	18	0.58	14	1.21	15	1.27	11	2.19	—	1.06	10	1.92	—	0.63	11	0.42	—	0.39	9	1.03	—	0.33

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Table 8
PERCENTAGE OF ANALYTICAL WORK CARRIED OUT IN VARIOUS COUNTRIES

Country	% of total 1965[a]	1955[b]	1946	Country	% of total 1965[a]	1955[b]	1946
U.S.S.R.	21.7	9.1	12.3	Israel	0.4	0.4	—
U.S.A.	20.2	23.8	41.6	Holland	0.3	0.1	—
Germany	10.0	10.2	0.2	Chile	0.2	0.6	0.2
Japan	6.8	12.3	0.2	Greece	0.2	0.1	0.2
Poland	5.1	0.6	—	Scotland	0.2	0.3	—
Great Britain	4.3	7.4	14.6	Portugal	0.2	0.1	—
France	4.2	4.7	8.0	Brazil	0.1	0.2	0.9
Czechoslovakia	3.6	3.7	0.2	Egypt	0.1	0.4	0.1
Italy	3.0	5.2	2.5	Korea	0.1	—	—
Hungary	2.6	1.1	0.1	Norway	0.1	0.4	0.2
India	2.5	3.9	1.7	Peru	0.1	0.2	0.1
China	1.3	0.1	0.1	Puerto Rico	0.1	—	0.1
Austria	1.2	1.7	—	South Africa	0.1	0.3	0.2
Canada	1.2	2.2	1.1	Turkey	0.1	—	—
Spain	1.2	1.7	2.2	Wales	0.1	—	—
Australia	1.1	0.6	1.4	Argentina	0.04	0.9	0.9
Bulgaria	1.1	—	—	Ceylon	0.04	—	—
Romania	1.1	—	0.2	Lebanon	0.04	0.1	—
Switzerland	1.1	1.2	2.4	Lichtenstein	0.04	—	—
Belgium	0.9	1.3	1.0	Mexico	0.04	0.1	0.1
Sweden	0.9	1.7	3.3	United Arab Republic	0.04	—	—
The Netherlands	0.6	1.0	1.8				
Yugoslavia	0.5	0.5	0.2	Venezuela	0.04	—	—
Denmark	0.4	0.6	0.8				
Finland	0.4	0.6	0.3				

[a] Based on 2261 entries.
[b] Eight additional countries were represented in the 1955 survey, each at 0.1% of the total.

However, German led once more by 1927, only to lose first place again to English by 1937. English has been the most important language ever since. Russian, second in 1952, has become the leading foreign language. French has usually been second or third, except in 1937 and 1949, when it was in fourth place. Spanish was fifth in 1952 followed in order by Japanese, Czech, Italian (fourth in 1877), Dutch, and Portuguese.

Numerically not in complete agreement, but in conclusions similar results are reported by Fischer,[10,11] Brooks and Smythe.[12] The results of the latter authors are shown in Table 13. The order of importance of the various major languages in analytical chemistry in 1970 was the following: English, Russian, German, Japanese, Czech, French, and Spanish. This is almost the same as the order pertaining to chemistry literature as a whole, namely English, Russian, German, French, Japanese, Polish, and Italian. In 1975,[19] 95.7% of the world chemical literature was published in these seven languages.

C. With Respect to Subfields, Topics, and Techniques

It is considered that a convenient and objective indication of the future practical

Table 9
PERCENTAGE OF ANALYTICAL WORK CARRIED OUT IN VARIOUS COUNTRIES

Country	Year												
	1910	1915	1920	1925	1930	1935	1940	1945	1950	1955	1960	1965	1970
U.S.S.R.	1.0	—	—	0.8	5.7	29.4	30.8	18.2	17.8	13.0	22.9	25.4	28.4
U.S.A.	28.9	30.4	25.3	13.4	18.8	14.6	25.0	48.3	19.9	18.0	20.7	15.8	17.7
Japan	1.0	1.0	—	3.2	2.6	3.1	2.9	—	5.0	12.3	7.7	11.0	7.7
Germany[a]	31.9	30.4	19.9	39.7	26.3	16.4	10.5	2.5	6.7	12.1	4.8	6.4	6.1
U.K.	17.6	20.2	12.3	11.9	10.5	6.4	7.1	12.4	12.0	8.2	6.0	4.3	5.9
Czechoslovakia	—	—	—	4.8	3.5	2.8	1.7	—	6.0	8.1	3.8	5.3	5.6
France	10.3	4.5	21.0	7.1	14.5	7.6	3.8	2.5	9.2	4.7	3.1	3.5	2.6
India	—	—	—	—	1.3	1.8	0.8	2.1	0.6	4.3	5.0	3.5	2.6
Scandinavia	—	1.1	1.8	3.9	1.8	0.8	2.1	2.6	3.3	2.4	1.0	0.7	2.1
Romania	—	2.3	3.5	4.8	—	0.8	0.4	—	—	0.8	2.0	3.5	2.0
Poland	—	—	—	—	2.2	2.0	—	—	—	1.6	1.5	4.1	1.8
Spain	2.1	1.1	1.8	0.8	2.2	2.1	2.5	1.6	4.2	1.8	1.7	1.8	1.5
The Netherlands	—	3.4	8.8	3.2	1.3	1.5	2.9	0.5	0.8	0.8	0.8	0.8	1.3
Italy	—	1.1	—	4.0	1.8	4.1	2.5	—	2.3	4.2	2.5	1.7	1.0
China	—	—	—	—	—	2.6	—	—	0.8	—	5.6	3.1	—
Rest of the world	7.2	4.4.	5.1	2.4	7.7	4.0	7.0	9.3	11.4	7.7	10.9	9.1	11.1

[a] Both East and West Germany.

From Brooks, R. R. and Smythe, L. E., *Talanta,* 22, 495 (1975). With permission.

Table 10
COUNTRIES IN WHICH ATOMIC ABSORPTION RESEARCH WAS CARRIED OUT

Country	Percentage of atomic absorption papers	
	1962	1970
U.S.A.	35.5	43.8
U.K.	3.4	14.0
U.S.S.R.	7.0	5.6
Czechoslovakia	1.7	5.5
Canada	1.7	5.1
Australia	15.8	4.9
Japan	7.0	4.5
France	1.7	4.3
Germany[a]	10.5	3.0
South Africa	14.0	0.3
Others	1.7	9.0

[a] Both East and West Germany.

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Table 11
LANGUAGE IN WHICH ANALYTICAL PAPERS WERE PUBLISHED IN 1946

Language	No. of papers	% of papers
English	870	66.2
Russian	153	11.6
French	137	10.4
Spanish	57	4.3
Italian	31	2.4
German	23	1.7
Swedish	19	1.4
Dutch (Flemish)	16	1.2
Danish	3	0.2
Japanese	2	0.2
Norwegian	1	0.1
Czech	1	0.1
Yugoslavian	1	0.1
Total	1314	99.9

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importance of the various analytical subfields, topics, and techniques can be obtained by a statistical analysis of the research papers.

In order to prove the validity of this statement, we should know the distribution of analytical literature among the various forms of publication. The investigations of Earle

Table 12
LANGUAGES IN WHICH ANALYTICAL PAPERS WERE PUBLISHED, 1877—1950

	1950		1949		1948		1947		1937		1927		1917		1907		1897		1887		1877	
Language	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**
English	1	43.9	1	39.77	1	44.39	1	43.70	1	28.82	2	29.32	1	55.9	2	19.27	3	19.07	2	16.62	3	14.95
Russian	2	20.18	2	22.69	4	9.22	3	11.34	2	24.36	6	2.33	8	0.06	6	0.5	5	2.33	6	0.74	—	—
French	3	10.70	4	11.15	2	15.82	2	14.67	4	8.92	3	14.11	3	9.06	3	19.23	2	19.97	3	11.47	2	17.61
German	4	10.64	3	11.34	3	12.38	4	0.83	3	24.22	1	41.37	2	23.43	1	51.87	1	53.05	1	64.70	1	64.12
Spanish	5	4.44	5	5.74	5	7.50	6	6.45	6	0.23	7	2.19	6	1.88	—	—	—	—	—	—	—	—
Japanese	6	2.80	7	1.27	6	4.25	5	6.97	5	2.41	9	0.82	7	0.94	—	—	—	—	—	—	—	—
Czech	7	2.75	12	0.57	10	0.81	—	0.21	8	1.20	8	0.96	—	—	—	—	—	—	5	1.62	—	—
Italian	8	1.40	6	3.00	7	1.45	7	2.39	7	2.05	5	3.01	5	1.88	4	5.41	4	4.41	4	4.71	4	—
Dutch	9	1.17	8	0.89	8	1.36	10	0.83	10	0.71	4	3.56	4	5.31	5	3.08	6	1.04	—	—	—	1.99
Portuguese	10	0.64	13	0.57	11	0.63	8	2.08	14	0.42	14	0.03	10	0.31	—	—	—	—	—	—	—	—
Yugoslavian (Croatian)	11	0.29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Swedish	12	0.29	9	0.83	9	1.18	9	1.66	12	0.5	10	0.07	9	0.06	—	—	—	—	—	—	—	—
Danish	13	0.18	—	—	12	0.27	—	0.21	—	0.07	—	—	—	—	—	—	—	—	—	—	—	—
Hungarian	14	0.18	11	0.70	13	0.27	11	0.62	9	1.06	—	—	—	—	—	—	—	—	—	—	—	—
Bulgarian	15	0.12	—	—	—	—	—	—	17	0.21	—	—	—	—	—	—	—	—	—	—	—	—
Polish	16	—	10	0.76	14	0.27	—	—	11	0.50	13	0.03	—	—	—	—	—	—	—	—	—	—

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Table 13
LANGUAGES IN WHICH ANALYTICAL PAPERS WERE PUBLISHED 1910—1970

Language	Year												
	1910	1915	1920	1925	1930	1935	1940	1945	1950	1955	1960	1965	1970
English	50.6	51.7	40.4	26.1	32.8	23.8	34.1	64.9	35.4	32.3	34.2	24.8	30.3
Russian	1.0	—	—	0.8	5.7	29.4	30.8	18.2	17.8	13.0	22.9	25.4	28.4
German	32.9	31.5	21.7	39.7	27.6	16.7	12.6	3.0	9.2	14.0	6.7	9.8	8.1
Japanese	1.0	1.1	—	3.2	2.6	3.1	2.9	—	5.0	12.3	7.7	11.0	7.7
Czech	—	—	—	4.8	3.5	2.8	1.7	—	6.0	8.1	3.8	5.3	5.6
French	12.4	5.6	21.0	7.9	16.7	8.4	4.2	2.5	11.7	5.2	3.5	4.2	3.6
Spanish	2.1	2.2	2.3	1.6	4.0	2.9	5.4	7.8	5.9	3.1	3.7	1.8	2.6
Scandinavian	—	1.1	1.8	3.9	1.8	0.8	2.1	2.6	3.3	2.4	1.0	0.7	2.1
Romanian	—	2.3	3.5	4.8	—	0.8	0.4	—	—	0.8	2.0	3.5	2.0
Polish	—	—	—	—	2.2	2.0	—	—	—	1.6	1.5	4.1	1.8
Hungarian	—	—	—	—	—	0.8	—	—	0.8	0.2	1.9	1.0	1.8
Dutch	—	3.4	8.8	3.2	1.3	1.5	2.9	0.5	0.8	0.8	0.8	0.8	1.3
Italian	—	1.1	0.5	4.0	1.8	4.1	2.5	—	2.3	4.2	2.5	1.7	1.0
Chinese	—	—	—	—	—	2.6	—	—	0.8	—	5.6	3.1	—
Other	—	—	—	—	—	0.3	0.4	0.5	1.0	2.0	2.2	2.8	3.7

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Table 14
DISTRIBUTION OF CITATIONS TO DIFFERENT TYPES OF PUBLICATIONS IN SCIENCE, TECHNOLOGY, AND SOCIAL SCIENCE

Type of publication	Science (%)	Technology (%)	Social sciences (%)
Books	12	14	46
Periodicals	82	70	29
Other (including reports)	6	16	25

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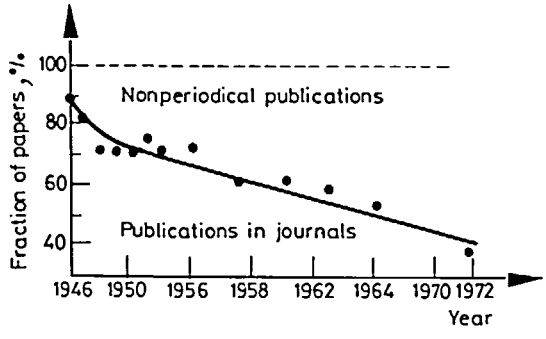

FIGURE 27. Distribution of analytical publications between periodicals and nonperiodicals. (From Orient, I. M., *Zavodsk. Lab.*, 41(9), 1071 (1975). With permission.)

and Vickery[35] indicated, as can be seen in Table 14, that about 80% of the literature in the whole field of science is represented by papers in periodicals, and their relative ratio decreases proportionally towards technology and the so-called soft sciences. In our knowledge, no such investigation was carried out on the whole field of analytical chemistry, but Braun and Bujdosó[36] have shown that about 75% of the literature of radioanalytical chemistry is represented by papers published in periodicals. On the other hand, Orient[21] disclosed some data indicating that the share of nonperiodical publications in analytical literature shows an increasing tendency between 1946 and 1972 (Figure 27). We incline to state that the distribution of the whole analytical literature is reflected better by the figure given by Braun and Bujdosó, because the data of Orient is distorted by an effect of a peculiar situation. Namely, in the U.S.S.R., particularly in the field of analytical chemistry, a sudden recent increase can be witnessed in the forms of publication such as "Obzors" and "Sborniks". According to the data of Orient,[54] 62% of the papers published in the U.S.S.R. in 1972 appeared in such publication forms. It must be taken into account, as noticed by Orient, that in the international literature very few references are made to these papers, since they represent only a channel of information within the country. Incidentally, the paper in which Orient discusses this problem was published also in a "Sbornik".[55]

The specific weights of various subfields within the literature of analytical chemistry have been investigated for 1946, 1955, and 1965 by Fisher[11] using *Chemical Abstracts* as a database (Table 15).

Table 15
DISTRIBUTION OF ANALYTICAL CHEMISTRY LITERATURE ACCORDING TO SUBFIELDS

Method	% of Total		
	1965[a]	1955	1946
Optical Methods	40.5	43.2	36.7
Colorimetry	15.2	20.2	23.0
Spectrophotometry	13.3	15.5	5.7
Visible	7.2	5.9	—[b]
Ultraviolet	3.6	5.8	—[b]
Infrared	2.4	2.8	—[b]
Raman	0.1	0.6	—[b]
Other	—	0.3	—[b]
Emission	6.7	4.2	5.3
Arc and spark	4.3	2.9	—[b]
Flame	2.4	1.3	—[b]
Fluorescence	3.4	1.3	1.6
Light scattering	0.9	2.0	1.1
Refractometry	0.6	—[c]	—[c]
Optical activity	0.4	—[c]	—[c]
Titrimetry	12.6	22.0	25.6
Visual	8.1	17.2	—[b]
Potentiometric	2.7	3.2	—[b]
Amperometric	1.0	0.9	—[b]
Conductometric	0.3	0.3	—[b]
Other titrimetry	0.5	0.4	—[b]
Gas analysis	12.0	2.3	1.4
Gas chromatography	9.5	—[c]	—
Other gas analysis	2.5	2.3	1.4
Electrical methods	10.2	6.2	4.4
Polarography	7.3	4.8	4.0
Coulometry	1.1	—[c]	—[c]
Potentiometry	1.1	—[c]	—[c]
Electrical conductivity	0.5	1.4	0.4
Chronopotentiometry	0.2	—[c]	—
Radioactivity	7.4	2.0	1.1
Gravimetric	3.6	6.5	8.5
X-ray methods	3.4	3.3	0.6
Fluorescence	2.2	0.6	—[b]
Diffraction	0.8	2.3	—[b]
Absorption	0.4	0.3	—[b]
Biological assay	2.7	2.8	3.6
Thermal analysis	1.9	—[c]	—[c]
Mass spectrometry	1.4	—[c]	—[c]
Kinetic methods	1.1	—[c]	—[c]
Electron probe	0.8	—	—
Microscopy	0.6	1.6	0.5
NMR and ESR	0.4	—	—
Data handling	0.4	—[c]	—[c]
All other methods	1.0	9.5	17.8

[a] Based on 2052 entries.
[b] Not available as separate data, but included in appropriate group totals.
[c] Not available as separate data, but probably very small and included in "All other methods" category.

Reprinted with permission from Fischer, R. B., *Anal. Chem.*, 37 (13), 27A (1965).

Table 16
DISTRIBUTION OF PAPERS BETWEEN VARIOUS SUBFIELDS OF ANALYTICAL CHEMISTRY

Subfield	1965 (%)	1970 (%)	1975 (%)
Chromatography	24	30	27
Gas chromatography	8	11	9
Spectroscopy (ESR, NMR, photometry)	36	37	36
Electroanalytical chemistry	10	13	20
Gravimetry, titrimetry, etc.	30	20	17

From Berezkin, V. G. and Chernysheva, T. Yu., *J. Chromatogr.*, 141, 241 (1977). With permission.

Table 17
DISTRIBUTION OF PAPERS BETWEEN VARIOUS SUBFIELDS OF ANALYTICAL CHEMISTRY IN 1970

Subfield	%
Photometry	15.7
Fluorescence and luminescence	4.0
Spectral	8.7
Radioactivation	7.5
Electroanalysis	12.0
Polarography	6.6
Potentiometry	2.4
Coulometry	1.0
Conductometry	0.2
Others	1.8

From Orient, I. M., *Trends in the Logics of Development and Scientometrics in Chemistry*, Kabanov, V. A., Ed., Moscow State University Press, Moscow, 1976, 90 (in Russian). With permission.

The same was investigated by Berezkin and Chernysheva[38] for the years 1965, 1970, and 1975 (Table 16). The difference between the two sets of data arises probably from the fact that the latter authors carried out their measurements on the basis of *Chemical Abstracts, Analytical Abstracts,* and *Journal of Chromatography.*

On the basis of a third data base, the 1970 volumes of *Referativnyj Zhurnal, Khimia,* calculations were done by Orient.[88] Her results are given in Table 17. Berezkin and Chernysheva[38] dealt also with the distribution of literature pertaining to the analysis of organic compounds according to various points of view. Their results are shown in Tables 18 to 21. It is interesting to compare these data with the results of Beyermann[39] calculated on the basis of the 1976 volumes of *Analytical Abstracts* (Tables 22 to 24). Without any detailed evaluation of the data, it can be stated safely that the most striking relative progress is still shown by the literature of chromatography. This is also proved by Petruzzi,[40] who states that " . . . if the health of a scientific specially can be measured by

Table 18
DISTRIBUTION OF PAPERS ON ANALYTICAL CHEMISTRY OF ORGANIC COMPOUNDS ACCORDING TO THE USED METHOD

Subfield	1965 (%)	1970 (%)	1975 (%)
Chromatography	39	48	44
Gas chromatography	14	17	15
Spectroscopy (ESR, NMR, photometry)	29	29	31
Electroanalytical chemistry	17	16	18
Gravimetry, titrimetry	15	8	7

From Berezkin, V. G. and Chernysheva, T. Yu., *J. Chromatogr.*, 141, 241 (1977). With permission.

Table 19
DISTRIBUTION OF PAPERS ON CHROMATOGRAPHIC ANALYSIS OF ORGANIC COMPOUNDS

Subfield	1970 (%)	1975—1976 (first 6 months) (%)
Gas chromatography (GC)	29	26
Paper chromatography (PC)	13	7
Thin-layer chromatography (TLC)	32	28
Column liquid chromatography (CLC)	26	39

From Berezkin, V. G. and Chernysheva, T. Yu., *J. Chromatogr.*, 141, 241 (1977). With permission.

Table 20
DISTRIBUTION OF PAPERS ON CHROMATOGRAPHIC ANALYSIS OF ORGANIC COMPOUNDS

Technique	1970 GC (%)	1975—1976 (first 6 months) GC (%)	TLC (%)	CLC (%)
Detectors	21	19	15	6
Efficiency and filling of columns	17	22	—	23
Equipment and materials	22	24	23	14
Automation	10	9	11	4
Measurement of physics-chemical characteristics	13	16	—	8
Other	17	10	51	15

From Berezkin, V. G. and Chernysheva, T. Yu., *J. Chromatogr.*, 141, 241 (1977). With permission.

Table 21
DISTRIBUTION OF PAPERS ON CHROMATOGRAPHIC ANALYSIS OF ORGANIC COMPOUNDS

Compound	GC (%)		CLC (%)		PC (%)		TLC (%)	
	1970	1975—1976[a]	1970	1975—1976[a]	1970	1975—1976[a]	1970	1975—1976[a]
Hydrocarbons, aromatic compounds polymer synthesis products	19	13	5	2	6	2	10	3
Oxygen-containing compounds (phenols, carbohydrates, organic acids, alcohols, etc.)	28	19	14	13	24	24	28	28
Biologically active and pharmaceutical substances	8	25	4	5	14	13	16	20
Nitrogen-containing substances	9	13	67	64	36	34	22	21
Insecticides and pesticides	12	6	1	2	2	3	6	12
Other	24	24	9	14	19	24	18	16

[a] First 6 months.

From Berezkin, V. G. and Chernysheva, T. Yu., *J. Chromatogr.*, 141, 241 (1977). With permission.

Table 22
DISTRIBUTION OF PAPERS ON ANALYSIS OF ORGANIC COMPOUNDS

Type of matrix	1976 (%)	Publications dealing with traces (%)
Biochemical	20	4
Industrial organic chemicals	13	1
Air, water	8	1
Pharmaceuticals	7	1
Food	6	1
Agricultural	3	1

From Beyermann, K., *Pure Appl. Chem.*, 50, 87 (1978). With permission.

Table 23
DISTRIBUTION OF PAPERS ON SEPARATION IN ORGANIC TRACE ANALYSIS

Method	1976 (%)
Liquid-liquid extraction	33
Gas chromatography	29
Thin-layer chromatography	18
Chromatography	16
HPLC	6
Ion-exchange chromatography	3
Other	4

From Beyermann, K., *Pure Appl. Chem.*, 50, 87 (1978). With permission.

Table 24
DISTRIBUTION OF PAPERS ON DETERMINATION OF TRACES OF ORGANIC COMPOUNDS

Method	1976 (%)	Sensitivity
Gas chromatography	30	pg
UV spectrometry	20	μg
Fluorescence spectrometry	19	μg
Gas chromatography + mass spectrometry	14	μg
Thin-layer scanning methods	9	μg
Radioimmunoassay	5	pg
Electroanalytical	3	μg

From Beyermann, K., *Pure Appl. Chem.*, 50, 87 (1978). With permission.

Table 25
DISTRIBUTION OF PUBLICATIONS IN ANALYTICAL CHEMISTRY IN 1976

Field	Percentage of publications
Organic chemistry	57
Inorganic chemistry	31
Analytical techniques	12

From Beyermann, K., *Pure Appl. Chem.*, 50, 87 (1978). With permission.

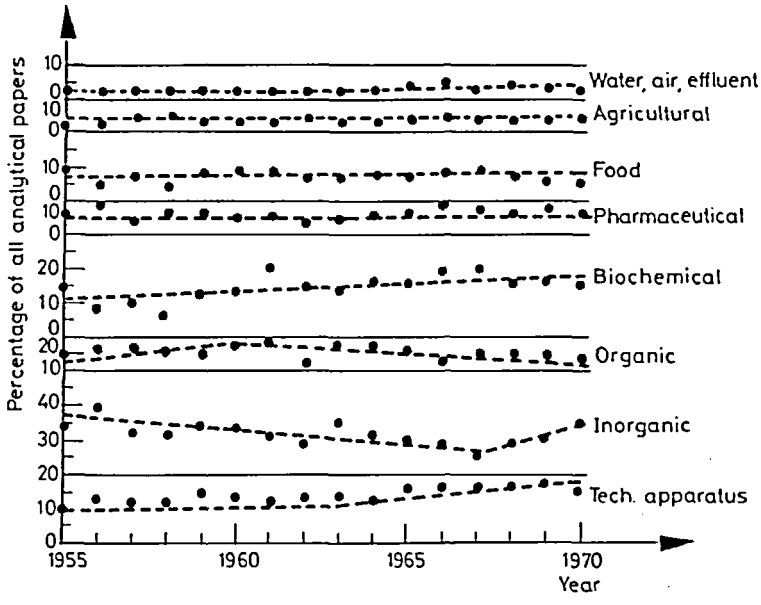

FIGURE 28. Broad trends of the literature of analytical chemistry for eight subfields for the period 1955 to 1970. (From Brooks, R. R. and Smythe, L. E., *Talanta*, 22, 495 (1975). With permission.)

the number of journals and meetings on the subject, then we can be sure that chromatography is robust. The growth of chromatographic separation techniques is also attested by other measures such as current instrument sales and projections based on studies of the growth areas of analytical instrumentation."

Beyermann,[39] on the basis of the 1976 volumes of *Analytical Abstracts,* also investigated the distribution of analytical literature among the analysis of organic and inorganic compounds (Table 25). From the data of the table the author draws the interesting conclusion that although there are about 10^3 times more known organic compounds than inorganic ones, the literature dealing with the analysis of organic compounds is slightly less than double that of inorganic compounds.

With the distribution of analytical literature among the analysis of various matrices Brooks and Smythe[12] were concerned, so was the investigation of the 1955 to 1970 volumes of *Analytical Abstracts.* Their results are shown in Figure 28. As the authors state, " . . . there is an appreciable increase in the relative proportion of the literature of

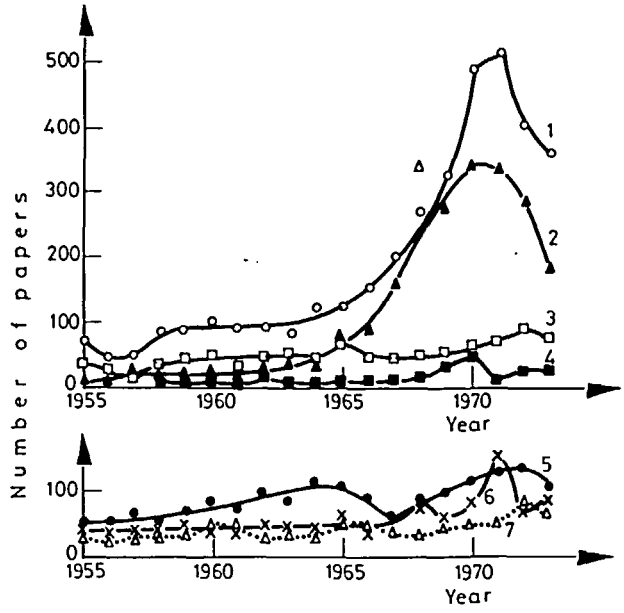

FIGURE 29. Yearly output of electroanalytical papers for the period 1955 to 1976. Curves: 1, potentiometry; 2, voltametry; 3, coulometry; 4, new electroanalytical methods; 5, amperometry; 6, conductometry; 7, electroanalysis. (From Kabanova, O. L. and Kurilina, N. A., *Zh. Anal. Khim.*, 30, 2432 (1975) (in Russian). With permission.)

biochemical analysis and technical apparatus, and a smaller increase in analysis of water, air and effluent. These trends appear to be at the expense of inorganic and organic analysis which both show significant downward trends except for the last three years of inorganic anlaysis. These trends were not unexpected, because of the phenomenal rise of biochemistry during the past 15 years."

Kabanova and Kurilina[41] investigated the distribution of papers on the electroanalytical methods of inorganic compounds in the 1955 to 1973 period on the basis of *Referativnyj Zhurnal, Khimiya.* Part of their results are shown in Figure 29. The number of papers belonging to total electroanalytical chemistry, coulometry, and conductometry increases, monotonously disregarding from the maximum in the number of conductometric papers in 1971. Between 1960 and 1965 papers on amperometry and potentiometry dominated. From 1970 to 71 the number of papers on potentiometry shows a maximum, due to the first avalanche of papers concerning ion selective electrodes. The sharp rise of voltametric papers starts in 1965, and reaches a maximum in the 1968 to 1971 period. In constructing this curve, the authors also took into account papers on mercury electrode inversion voltametry, but disregarded papers concerning dropping mercury electrodes. In 1968 the number of the latter was higher than that of potentiometric papers (about 40%). Figure 30 shows the share of individual methods within the literature of electroanalytical chemistry. As can be seen, maximum share is taken by potentiometry (30% in 1955 and 40% between 1970 and 1973). About the same is the share of amperometry between 1955 and 1965 (20 to 25%), but this decreases to 10% of all papers in the 1967 to 72 period. The contributions of conductometry, coulometry, and electrogravimetry were 10 to 15% between 1955 and 1965, but this has decreased to 3 to 10% in the past years. The number of papers on theoretically new methods was very small in the period studied (1 to 4%). Such methods were, e.g., the analytical techniques based on the measurement of impedance or dielectric permeability.

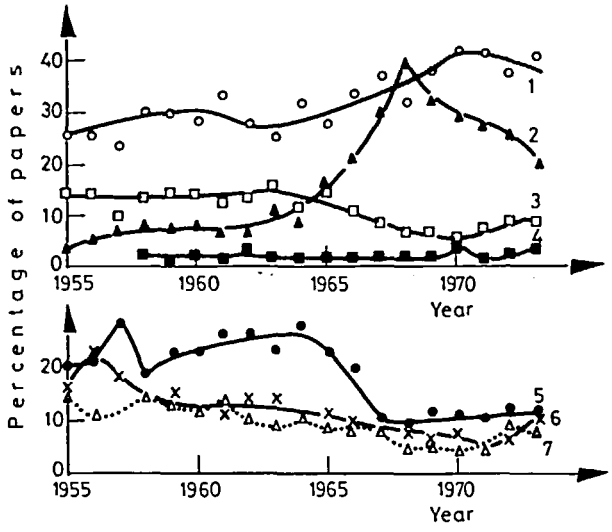

FIGURE 30. Distribution of electroanalytical papers for the period 1955 to 1973. Curves: 1, potentiometry; 2, voltametry; 3, coulometry; 4, new electroanalytical methods; 5, amperometry; 6, conductometry; 7, electroanalysis. (From Kabanova, O. L. and Kurilina, N. A., *Zh. Anal. Khim.*, 30, 2432 (1975) (in Russian). With permission.)

Table 26
PERCENTAGE OF ATOMIC ABSORPTION PAPERS ANALYZING VARIOUS MATRICES

	Year					
Matrix	**1961**	**1963**	**1965**	**1967**	**1969**	**1971**
Agricultural	3.6	1.8	3.3	4.9	4.9	5.4
Biological	17.9	10.9	19.8	17.9	17.9	12.9
Food	—	—	1.1	4.6	2.0	3.2
Geochemical	3.6	3.6	10.9	9.8	10.4	10.2
Industrial	3.6	5.5	9.9	8.4	9.3	9.7
Instrumental	25.1	49.1	39.6	44.2	44.6	47.9
Metallurgical	14.2	20.0	7.7	7.7	9.2	9.8
Reviews	32.0	9.1	7.7	2.5	1.7	0.9

From Brooks, R. R. and Smythe, L. E., *Anal. Chim. Acta*, 74, 35 (1975). With permission.

Two papers were concerned with the scientometric analysis of the literature on atomic absorption methods in the past few years.[34,42] Brooks and Smythe,[34] on the basis of the *Atomic Absorption Newsletter* as database, investigated the distribution of literature according to the matrix analyzed (Table 26), and according to the various atomic absorption techniques (Table 27).

It can be seen that in the period 1961 to 1971, nearly half of the research effort was devoted to instrumental developments. All other categories except "Geochemical" and "Reviews" have maintained a relatively constant proportion during the period 1965 to 1971. The sharp increase in the "Geochemical" category after 1963 is almost certainly due to the worldwide mineral boom, when atomic absorption spectrometry afforded a ready,

Table 27
ATOMIC ABSORPTION PAPERS IN VARIOUS INSTRUMENTAL CATEGORIES EXPRESSED AS A PERCENTAGE OF THE TOTAL INSTRUMENTAL TOPIC

	Year					
Instrumental category	**1961**	**1963**	**1965**	**1967**	**1969**	**1971**
Automation	—	—	3.6	4.0	5.2	3.0
Burners and flames	—	29.1	7.1	15.9	9.7	10.1
Electrodeless discharge tubes	—	—	—	—	7.8	3.0
Flameless atomic absorption (Hg)	—	—	—	4.7	0.6	9.3
Hollow cathodes	—	16.7	17.8	8.7	4.5	3.0
Instruments	50.0	29.2	21.4	15.8	7.1	2.6
Nebulization	—	8.3	3.6	5.5	3.2	1.1
Nonflame excitation (carbon rod, etc.)	—	—	—	2.4	5.2	9.7
Sources (other than above)	—	—	17.8	4.0	1.9	0.7
Techniques and theory	17.0	12.5	10.9	29.5	15.9	7.5
Other techniques	33.0	4.2	17.8	9.5	38.8	50.0

From Brooks, R. R. and Smythe, L. E., *Anal. Chim. Acta*, 74, 35 (1975). With permission.

speedy, accurate, and inexpensive method for analyzing very large numbers of geochemical samples such as soils, stream sediments, rocks, vegetation, and waters. It is noteworthy that the number of reviews has fallen sharply and consistently since the euphoria of the early days. Altogether, a total of nearly 100 reviews has appeared in the period 1960 to 1971, half of which appeared during the first 4 years. From Table 27 it is visible that the proportion of research into hollow-cathode lamps has dropped steadily from 17.8% in 1965 to 3.0% in 1971. This is probably because of diversion of effort to other sources such as electrodeless discharge tubes, and because hollow cathodes have reached a degree of refinement which does not warrant such extensive work upon them. Work on other "Sources" has also dropped from 17.8% in 1965 to 0.7% in 1971, perhaps because most other possible sources have been investigated and found to be less suitable than hollow cathodes or electrodeless discharge tubes. Developments in nebulization seem to have slackened, as the proportion of work in this field has dropped steadily since 1963. Perhaps the most interesting finding to emerge from the survey is the enormous decrease in work on new instruments — from 50.0% in 1961 to 2.6% in 1971. This trend confirms the "coming of age" of atomic absorption spectrometry, when basic instrument design has become more or less standardized and where further work is devoted to refinement rather than innovation. Table 27 also shows the increasing interest in nonflame excitation (carbon rod atomizer, etc.) and in flameless atomic absorption analysis of mercury. The large increase in "Other" techniques is almost entirely due to atomic fluorescence research (11.0% in 1969 and 13.2% in 1971).

It is interesting to compare these data with the results of Orient et al.,[42] who investigated the development and distribution of the literature on atomic absorption analysis on the basis of another database, the 1965 and 1970 to 1975 volumes of *Referativnyj Zhurnal Khimiya* (Table 28).

Orient and co-workers[42] also report how according to their measurements the literature, in the average of the 1966 to 1975 volumes of *Atomic Absorption Newsletter*, is distributed according to analyses applied in various fields. The results are biology and medical sciences, 26.2%; miscellaneous industrial branches, 26.1%; metallurgy, 14.7%; geology and mining industry, 14.4%; agriculture, 9.3%; and protection of the biosphere,

Table 28
DISTRIBUTION OF ATOMIC ABSORPTION ANALYSIS PAPERS ACCORDING TO THE ANALYZED MATRICES

Matrix	% of papers
Mineral raw materials, ores, and concentrates	29.9
Metals and alloys	16.2
Technological liquors, electrolytes	11.1
High purity materials, semiconductors	10.3
Organic compounds	8.6
Reagents	7.7
Inorganic materials	6.8
Waste and natural water	5.1
Soil, plants	4.3

From Orient, I. M., Artemova, O. A., and Davidova, S. L., *Zavodsk. Lab.*, 43, 419 (1977). With permission.

9.3%. According to the various elements determined the papers showed the following distribution: A8, 14.01%; Ag, 10.63%; Zn, 6.76%; Mg, 5.80%; Cu and Pd, 5.31% each; Fe and Pt, 4.83% each; Ni and Pb, 4.35% each; Co, 3.38%; Cd, K, Na, and Rb, 2.90% each; Mn and Ru, 2.42% each; Ca and Ir, 1.93% each; V, 1.45%; Mo, Sn, and Hg, 0.97% each; other elements, 5.80%.

The statistical distribution of the literature on the analysis of mineral raw materials was investigated by Volkova and Kontsova,[43] using sections 19 G and D of the 1968 to 1973 volumes of *Referativnyj Zhurnal Khimiya* as a database. Their results are shown in Table 29. As can be seen from the table, both in U.S.S.R. and abroad, the majority of papers in 1973 was concerned with photometric, spectrometric, electroanalytical, volumetric and complexometric, atomic absorption, activation analysis, chromatographic methods. However, in U.S.S.R. the photometric and spectrometric methods (44%), whereas in the other countries atomic absorption, photometric and chromatographic methods (43.8%), were most widespread. The other methods have contributions of about 5% each, of which the most popular ones are radioanalytical and X-ray spectrometric methods (6% abroad, 3.3% in U.S.S.R.). In the fields of photometric, electroanalytical, and spectrometric methods the Russian and foreign publication activities were at about the same level. Abroad, the greatest number of the photometric papers was published in 1969 and 1972; in the U.S.S.R. in 1970. This is due to the fact that at that time some new organic reagents were thoroughly investigated from analytical aspects. The peak in 1970 to 1971 can be attributed to the consequences of the intense electroanalytical research carried out in the 1960s (amalgam, pulse, and film polarography). Papers dealing with the classical analytical methods (gravimetry, volumetry, and complexometry) applied to the analysis of geological raw materials have approximately the same share in the U.S.S.R. and the rest of the world. The literature dealing with flame photometry is meager and has not changed during the past years (approximately 2%). This method is already well known, thoroughly investigated, and widely applied (mostly in the U.S.S.R.). Atomic absorption methods are the subject of mainly foreign publications: in 1973 three times more papers were published abroad than in U.S.S.R. The number of papers dealing with activation methods suddenly increased between 1970 and 1972.

Meliknov and Berdonosova[28] investigated the distribution of the literature on

Table 29
DISTRIBUTION OF PAPERS ON ANALYSIS OF MINERAL RAW MATERIALS

Method	1968		1969		1970		1971		1972		1973	
	Soviet Union	Rest of the world	Soviet Union	Rest of the world	Soviet Union	Rest of the world	Soviet Union	Rest of the world	Soviet Union	Rest of the world	Soviet Union	Rest of the world
Photometry (absorption)	23.4	19.4	25.9	21.5	27.7	14.5	25.8	17.7	20.7	22.9	23.1	16.1
Spectrometry (emission)	25.0	13.1	24.3	8.6	18.2	12.9	13.3	9.4	21.4	4.7	20.9	7.9
Electroanalytical	14.3	7.5	10.8	8.2	14.3	10.6	14.5	9.3	9.3	8.1	9.6	7.7
Volumetric	3.1	2.8	2.8	2.8	3.9	3.4	2.3	2.6	3.5	5.3	5.0	4.2
Complexometric	5.2	3.7	3.5	5.2	3.3	4.5	2.7	3.7	3.0	4.6	3.2	3.6
Atomic absorption	1.3	7.6	2.5	8.3	2.8	11.2	4.1	9.9	7.3	12.5	5.6	16.5
Neutron activation	12.8	14.5	8.4	11.3	4.9	9.4	5.9	19.6	12.1	8.6	5.4	8.9
Chromatography	2.3	8.5	3.5	7.5	5.0	9.9	4.5	6.2	2.7	7.6	5.2	11.2
Nuclear methods	1.0	0.9	1.2	0.8	1.6	1.3	1.8	2.0	0.3	3.9	1.7	1.7
X-ray spectrometry	1.9	7.4	1.4	5.3	3.7	3.7	2.2	3.6	2.0	2.2	1.6	4.3
Flame photometry	2.2	2.2	2.3	1.8	3.1	1.9	3.5	1.2	1.2	1.3	1.4	0.8
Gravimetry	1.2	2.5	1.9	2.9	1.5	2.2	1.3	2.2	1.8	3.6	0.9	2.2
Radioanalytical	0.4	1.1	1.0	1.6	0.4	1.1	0.3	0.9	0.7	0.4	0.4	0.7
Mass spectrometry	—	—	—	1.9	0.4	1.9	0.3	2.6	0.2	0.6	—	0.5
Other	5.9	9.8	10.5	12.3	9.2	11.6	17.5	9.4	13.8	15.7	16.0	13.7

From Volkova, G. A. and Kontsova, V. V., Zavodsk. Lab., 42, 395 (1976) (in Russian). With permission.

inorganic sorbents according to various points of view. Subert and Blesova[44] subjected the information flows dealing with pharmaceutical analysis to detailed analysis. Futekov et al.[33] analyzed the distribution of the analytical subject literature of selenium and tellurium among the various instrumental methods in the 1970 to 1975 period. Finally, Kara-Murza[45] investigated the mechanism and speed of dissemination of gas and liquid chromatography through the statistical investigation of the information flows dealing with this subject.

D. Miscellaneous

The application of mathematical methods greatly determines the exactness of scientific research work on various fields. In this respect it may be interesting to study the diffusion of mathematical methods into analytical chemical research. Such information can be practically acquired from two sources: by analyzing and carefully interpreting the papers published on the given fields of analytical chemistry or by purely formal scientometric methods. The latter appears to be more advantageous since it is less laborsome and can be better formalized. For the scientometric method two possibilities are offered:

1. The bibliographic references of scientific publications can be analyzed and thus, for instance, from the number of cited mathematical publications, the frequency of their use can be estimated. The authors, however, often cite textbooks, reviews, or bibliographies, and in such cases it cannot be determined what kind of mathematical method is concerned. Moreover, analytical chemical literature may also deal with mathematical methods, and thus the author applying a specific mathematical method may refer to this paper and not to a mathematics textbook.
2. Another possibility arises from the formal investigation of the mathematical terms found in analytical papers. From the analysis of their character, tracing of the change in their use with time can be done. This latter method was applied by Preobrazhenskaya et al.,[46] by investigating the frequency of terms used by mathematical statistics and analytical error estimation. The database comprised the papers published on emission spectrometry during 1958 to 1968 in the periodicals *Zhurnal Analiticheskoj Khimii* (U.S.S.R.), *Zavodskaya Laboratoriya* (U.S.S.R.), and *Analytical Chemistry* (U.S.). The authors have shown that the papers investigated contained a very large number of statistical terms. According to the authors this large number is due to the lack of a universal terminology; analytical chemists apply several terms for expressing the very same concept. The nonuniqueness of terminology is also obvious. In *Zhurnal Analiticheskoj Khimii* 31 variants, in *Zavodskaya Laboratoriya* 26 variants, and in *Analytical Chemistry* 17 variants are used to express the concept of "error". The paper cited also discusses several other results of the statistical evaluation of mathematical terms.

VI. ANALYTICAL CHEMISTRY JOURNALS

A. The Scatter of Analytical Chemistry Literature, Bradford's Law

The concentration or the scatter of the scientific literature is regulated by objective "laws", the most general of which proved to be the Bradford law of literature scatter discovered in 1934 and again stated in 1948.[47] Bradford's original question: "To what extent do different journals contribute papers to a given subject literature?" In general, a relation between a quantity (journals) and yield (papers) was of interest. After ingeniously arranging the data he formulated the law as follows: "... if scientific journals are arranged in order of decreasing productivity of papers on a given subject, they may be divided into a nucleus of periodicals more particularly devoted to the subject and several

groups or zones containing the same number of papers as the nucleus, where the number of periodicals in the nucleus and succeeding zones will be as $1:m:m^2$ (with usually $m = 5$). This indicates that the same number of papers is produced by a number of journals which increases from zone to zone in such a way that the ratio between the number of journals in the second and first zone is the same as between the third and second .... The first group can be called 'core journals'. In other words, articles of interest to a specialist must occur not only in periodicals specializing in his subject, but also, from time to time, in other periodicals, which grow in number as the relation of their field to that of his subject lessens and the number of articles on his subject in each periodical diminishes. It is to be noted that during phases of rapid and vigorous growth of knowledge in a scientific field, articles of interest to that field appear in increasing numbers in periodicals distant from that field."

It has become later apparent that Bradford's law is in fact a particular case of a very common statistical distribution. It was soon recognized that the division into three zones was not unique; the same distribution could be fitted to any number of zones. It has also been realized that Bradford's law is related to another well-known distribution, Zipf's law. Zipf, a linguist, was particularly interested in the frequencies with which different words are used. He demonstrated that if the words appearing in any reasonably long piece of text are counted and ranked in order of frequency of occurrence, this frequency is proportional to the rank order. For example, a word ranked tenth in terms of frequency of usage is employed one tenth as often as the word ranked first. According to Zipf,[48] this sort of rank-frequency relationship is obeyed by a wide range of social phenomena. It is a result, he argues, of a natural tendency to use more frequently those intellectual tools with which one is best acquainted and which are more flexible. The rank-order relationship therefore reflects the operation of some "principle of least effort". The relationship between Bradford's law and Zipf's law can be easily seen if we rephrase the latter slightly. Instead of relating frequency of word usage to rank order, we ask the question: How many words (N) occur exactly x times in a text? The answer follows from Zipf's law: $N = 1/x^2$. But Bradford's law can also be rewritten in a power-law from the number of journals j containing exactly p articles on a specified subject which is given by $j = 1/p^2$.[49]

The graphical formulation of Bradford's law is a plot of the cumulative number of articles vs. the logarithm of the cumulative number of journals in which the articles appear. The plot, as currently understood, has an S-shape with a central straight section following Bradford's log-linear law. The upward curving bottom of the curve represents the small nuclear zone of the most relevant journals. The upper end of the curve represents the peripheral zone where relevant references are widely scattered among a great number of journals (Figure 31).[50] How may the Bradford-Zipf distribution be conceptually modeled? Why, for example, are articles on a subject distributed in this way among journals? Brookes[50] suggests the following model. The first papers on a new topic are distributed at random among a set of, say, N journals. Initially, the probabilities of a paper on the new topic being published in any journal of this set are equal to $1/N$. But as soon as any journal of the set publishes its first paper on the topic, the probability of that journal publishing a second paper on the same topic increases from $1/N$ to $2/N$. As soon as any journal publishes two papers on the topic, its probability of attracting a third paper increases to $3/N$, and so on. Such a model leads to the straight-line portion of the distribution. But limitations of space and editorial decisions impose restrictions on the number of new papers entering the "core" or "nuclear zone", which therefore contains fewer papers than a straight-line relation would predict.

Suppose that we have an analytical chemistry bibliography, a special literature collection, or an abstract journal. If we analyze the items according to the frequency of

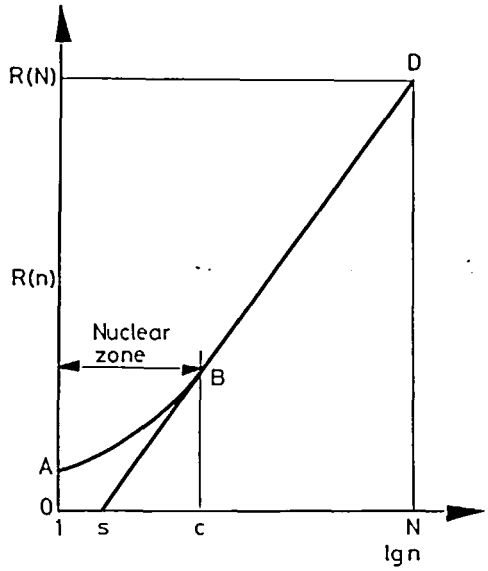

FIGURE 31. The idealized Bradford distribution. Along the horizontal axis are the ranked periodicals 1, 2, . . . , n, . . . in decreasing order of productivity; R(n) is the cumulative totals of papers. The resulting graph begins with a rising curve AB which at some critical points B runs into a straight live BD. (Reprinted with permission from Brookes, B. C., *J. Doc.*, 24, 247 (1968).)

occurrence of each journal title, we can plot the data as in Figure 31. The plot need only be continued far enough beyond point B to establish the slope of the line BD. Brookes[50] has shown that this slope R(n)/log n, is equal to N, an estimate of the expected total number of journals that will contribute at least one paper to the field. N is marked on the log n axis, and the vertical ND drawn to cut the line BD. The horizontal from D then established R(N), the expected total number of papers in the field. This can be compared with the actual number of papers in the bibliography, collection, or abstract journal to give an estimate of its completeness.

An alternative to graphical estimation is to use the expression for the linearity:

$$R(n) = k \log n/s \qquad (c \leqslant n \leqslant N) \tag{12}$$

where R(n) is the number of papers, k is the slope of the curve, n is the journal rank, and s is the intercept. The application of Bradford-type scattering analyses to analytical chemistry was done until now in only a very few cases. To determine scatter in the general analytical chemistry literature, Braun et al.[20] used the 1977 issues of *Analytical Abstracts* as a database. There were 8311 papers distributed in 741 journals. The Bradford distribution (Figure 32) shows 12 core and 88 neighboring analytical journals; Table 30 shows data for the first 50 of these. The Bradford curve for *Analytical Abstracts* drops heavily at the end. A possible reason for this could be that the core and half of the neighboring journals are completely (cover to cover) abstracted, but gathering scattered articles from other peripheral journals are somewhat haphazard.

A similar study has been made by Braun and Bujdosó[26] concerning the scatter of the radioanalytical literature. Their results are shown in Figure 33.

The characterization of periodicals dealing with analytical chemistry or, respectively,

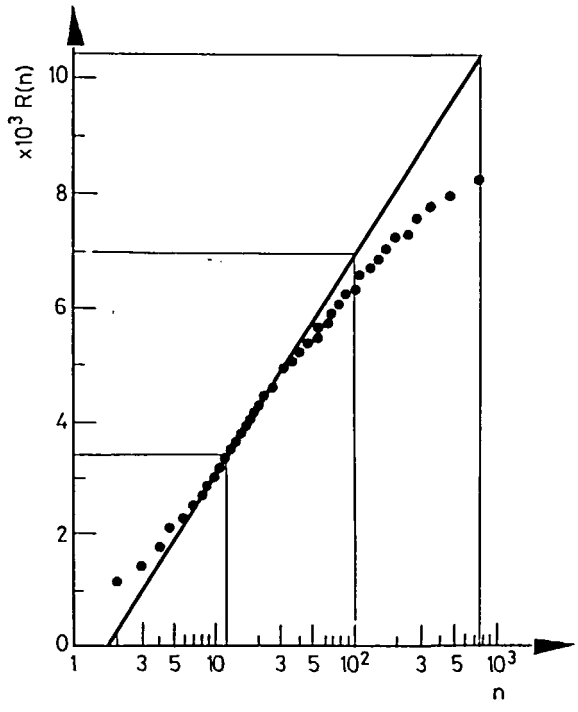

FIGURE 32. Scatter of analytical chemical literature. Bradford's distribution of the abstracts in *Analytical Abstracts*, 1977. R(n): cumulative totals of papers contributed by the journals ranked 1 to n. n = the rank of journals. (Reprinted with permission from Braun, T., Bujdosó, E., and Lyon, W. S., *Anal. Chem.*, 52, 617A (1980). Copyright 1980 American Chemical Society.)

publishing also papers of analytical character, and the ranking of these periodicals had already been the subject of investigation before the Bradford-type studies. Using *Chemical Abstracts* and *Chemisches Zentralblatt* as a database, Boig and Howerton[32] attempted to rank analytical chemical periodicals for the period 1977 to 1950 on the basis of their productivity (Table 31).

Later, Brooks and Smythe,[12] investigating what they call the important analytical periodicals on the basis of the 1970 volumes of *Analytical Abstracts*, state that some 26 journals accounted for 35% of the world total papers in analytical chemistry in 1970. The major journals (each containing more than 1.0% of the world total) arranged alphabetically, are as follows: *Analytica Chimica Acta, Analytical Biochemistry, Japan Analyst, Journal of Electroanalytical Chemistry, Journal of the Association of Official Analytical Chemists, Microchimica Acta, Nukleonika, Talanta, The Analyst, Zavodskaya Laboratoriya, Zeitschrift für Analytische Chemie,* and *Zhurnal Analitcheskoi Khimii.* These 13 journals together accounted for about 30% of the world total.

Braun et al.,[20] on the other side, showed that in 1977 (Figure 34) 50 and 90% of the papers could be found in only 3 and 36% of the journals, respectively.

On the basis of the 1975 volumes of *Referativnyj Zhurnal Khimiya,* Orient et al.[42] investigated the distribution of papers dealing with atomic absorption analysis among the various periodicals. Their results (Table 32) show that 50% of all papers are concentrated in 8 periodicals (2 U.S. 2 international, 2 Russian, 1 German, and 1 Japanese). Twenty percent, of the papers can be found in 13 very widespread analytical

Table 30
THE FIRST 50 LEADING JOURNALS ON ANALYTICAL CHEMISTRY COMPUTED FROM *ANALYTICAL ABSTRACTS* 1977, RANKED BY PRODUCTIVITY

Rank	Journal	No. of papers found
1	*J. Chromatogr.*	710
2	*Anal. Chem.*	511
3	*Anal. Chim. Acta*	338
4	*Zh. Anal. Khim.*	315
5	*Anal. Biochem.*	300
6	*Fresenius Z. Anal. Chem.*	212
7	*J. Assoc. Off. Anal. Chem.*	206
8	*Talanta*	198
9	*Bunseki Kagaku*	171
10	*Zavodsk. Lab.*	170
11	*Chem. Anal. (Warsaw)*	169
12	*Clin. Chem.*[a]	161
13	*J. Radioanal. Chem.*	147
14	*Analyst*	146
15	*J. Pharm. Sci.*	132
16	*Mikrochim. Acta*	116
17	*Clin. Chim. Acta*	109
18	*Anal. Lett.*	92
19	*Chromatographia*	91
20	*Radiochem. Radioanal. Lett.*	85
21	*J. Chromatogr. Sci.*	76
22	*Revista Chim. (Bucharest)*	75
23	*J. Agric. Food. Chem.*	71
24	*Indian J. Chem. Sect. A*	60
25	*Farmatsiya (Moscow)*	52
26	*Rev. Sci. Instr.*	52
27	*Lab. Pract.*	51
28	*J. Clin. Chem. Clin. Biochem.*	51
29	*Pharmazia*	46
30	*Appl. Spectrosc.*	45
31	*Quim. Anal.*	40
32	*Ukr. Khim. Zh.*	37
33	*Environ. Sci. Technol.*	37
34	*J. Electroanal. Chem. Interfacial Electrochem.*	35
35	*Biochem. Med.*	34
36	*Appl. Opt.*	34
37	*J. Am. Oil. Chem. Soc.*	33
38	*Bull. Environ. Contam. Toxicol.*	33
39	*Int. J. Appl. Radiat. Isot.*	32
40	*Z. Lebensm.-Unters.*	31
41	*X-Ray Spectrom.*	31
42	*At. Absorpt. Newslett.*	31
43	*J. Phys. Sci. Instrum.*	30
44	*Nucl. Instrum. Methods*	29
45	*Ann. Quim.*	29
46	*Yukugaku Zasshi*	28
47	*Curr. Sci. (India)*	28
48	*Acta Pol. Pharm.*	28
49	*Z. Chem. (Leipzig)*	27
50	*Chem. Pharm. Bull. (Tokyo)*	27

[a] End of the core journals

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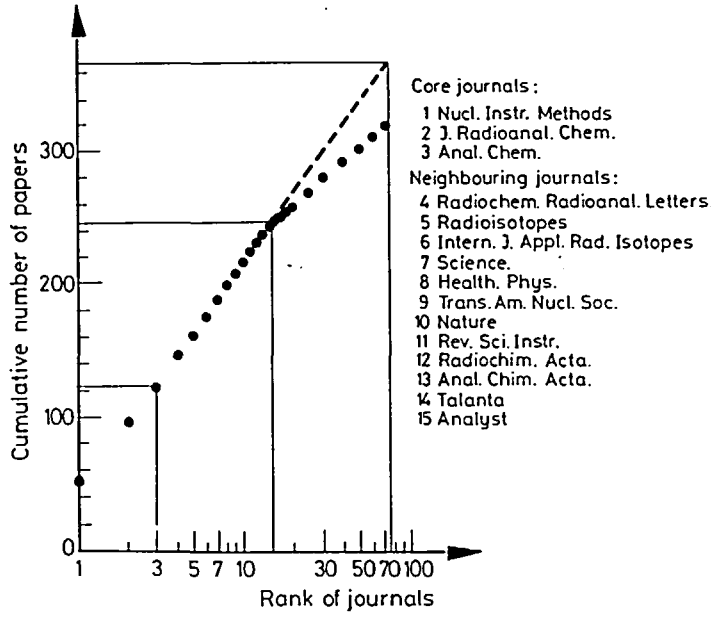

FIGURE 33. Bradford's distribution for the journals and articles cited by Lyon et al.[51-54] in the period 1972 to 1978. (From Braun, T. and Bujdosó, E., *J. Radioanal. Chem.*, 50, 9 (1979). With permission.)

periodicals, and the remaining 30% are dispersed among the journals of various countries, and "Sborniks" and "Trudys" published by various high schools, universities, and other institutions of the U.S.S.R.

As in the case of all very rapidly developing subfields, like atomic absorption analysis, initially the supply of information in the leading periodicals is very high. Later, however, when the method had become routine technique, the emphasis is shifted from the leading analytical periodicals to more specialized ones. It is worth observing that, as already mentioned in general consequences in the previous section, 45% of the Russian papers on atomic absorption analysis were not published in "regular" periodicals.

On the basis of *Atomic Absorption and Flame Emission Abstracts* (AAFESA) and the bibliographies of *Atomic Absorption Newsletter* (AAN), Brooks and Smythe[34] also investigated the distribution of atomic absorption papers among the various journals in the 1950 to 1971 period. According to their results (Table 33), 21 journals published nearly 60% of the world total atomic absorption papers since 1955. *Spectrochimica Acta* and *Analyst* were the first in publishing AA papers to any extent before 1962.

B. Citation Analysis of Analytical Chemistry Journals

Rankings based on the Bradford distribution use productivity as an indicator. It is interesting to see how rankings change when they are based on some journal "quality" indicator. Quality is, of course, quite difficult to define. Braun et al.[20] have used the so-called "impact factor" for ranking suggested by Garfield.[56] The impact factor is a spinoff from citation counts in the *Science Citation Index* database and is a measure of the frequency with which the average cited article in a journal has been cited. Thus the 1978 impact factor is the number of 1978 citations of articles of 1976 and 1977 in the journal divided by the total number of articles the journal published in those same 2 years. Table 34 shows analytical journal rankings based on this indicator. By combination of the data from Tables 30 and 34, it was found[20] that 49% of the analytical citations in 1978 were coming from the 12 core journals of Table 30.

Table 31
PRODUCTIVITY RANKING OF PERIODICALS DEDICATED TO ANALYTICAL CHEMISTRY (1877 TO 1907 INCLUSIVE, *CHEMISCHES ZENTRABLATT)* (1917 TO 1950 INCLUSIVE, *CHEMICAL ABSTRACTS)*

Journal	Country	1950 Position	1949 Position	1948 Position	1947 Position	1937 Position	1927 Position	1917 Position	1907 Position	1897 Position	1887 Position	1877 Position
Anal. Chem. (1947—)[a]	U.S.A.	1	1	1	1	—	—	—	—	—	—	—
Ind. Eng. Chem. (1909—1946)	U.S.A.	—	—	—	—	2	3	1	—	—	—	—
Zavodsk. Lab. (1935—)	U.S.S.R.	2	2	2	2	1	—	—	—	—	—	—
Zh. Anal. Khim. (1946—)	U.S.S.R.	3	3	—	18	—	—	—	—	—	—	—
Anal. Chim. Acta (1947—)	Holland	4	4	3	28	—	—	—	—	—	—	—
Analyst (1876—)	England	5	5	6	4	5	2	12	17	20	14	—
Bull. Soc. Chim. (France) (1858—)	France	6	17	10	6	15	20	—	12	9	11	7
Chem. Listy (1907—); *Listy Chem.* (1875—1891)[b]	Czechoslovakia	7	—	—	—	—	—	—	—	—	19	—
Mikrochem. Ver. Mikrochim. Acta (1914—)[c]	Austria	8	11	8	8	6/7	19	—	—	—	—	—
Z. Anal. Chemie (1862—)	Germany	9	6	4	—	3	1	5	5	8	1	1
Ann. (Real.) Soc. Espan. Fis. Quim. (1902—)[d]	Spain	10	10	5	5	—	—	17	—	—	—	—
Nature (1869—)	England	11	14	—	26	—	—	—	—	—	—	—
Chim. Anal. (1919—); *Ann. Chim. Anal.* (1893—1919)[e]	France	12	7	7	10 -	—	17	7	3	—	—	—
J. Assoc. Off. Agric. Chem. (1918—)	U.S.A.	13	8	—	30	16	16	—	—	—	—	—
Metallurgia	England	14	13	9	15	—	—	—	—	—	—	—
Izvestiya Akad. Nauk (1925—)	U.S.S.R.	15	—	—	—	—	—	—	—	—	—	—
Izvestiya Sektora Platiny (1923—)	U.S.S.R.	16	—	—	—	—	—	—	—	—	—	—
J. Chem. Soc. Jpn (1880—)	Japan	—	—	—	3	12	—	—	—	—	—	—
Comptes Rendus (1835—)	France	—	18	13	9	18	12	14	13	3	15	4
Chemist-Analyst (1912—)	U.S.A.	—	—	—	11	10	10	3	—	—	—	—
Angew. Chem.[f]	Germany	—	—	—	—	8	8	20	8	4	6	—
J. Appl. Chem. (U.S.S.R.) (1928—)	U.S.S.R.	—	—	—	—	4	—	—	—	—	—	—
J. Am. Chem. Soc. (1876—)	U.S.A.	—	—	15	—	9	9	2	2	2	—	—
J. Chem. Educ. (1924—)	U.S.A.	—	—	16	—	17	—	—	—	—	—	—
J. Soc. Chem. Ind. (1882—)	England	—	12	12	—	13	—	6	10	6	8	—
Chem. Zeitung (1877—)	Germany	—	—	—	—	—	5	4	1	1	2	—
Pharm. Zentralhalle (1860—)	Germany	—	—	—	—	—	—	—	11	—	3	8
Chem. News (1859—1932)	England	—	—	—	—	—	—	10	—	12	4	3
Chem. Berichte (1945—); *Berichte* (1867—1945)[g]	Germany	—	—	—	—	—	11	—	15	—	10	2

[a] *Anal. Chem.* (1947) was previously known as *Ind. Eng. Chem.* (1909—1947), Analytical Edition.
[b] *Chem. Listy* (1907—) may be a somewhat belated revision of *Listy Chem.*, published from 1875 to about 1891.
[c] *Mikrochemie* was combined with *Mikrochim. Acta* in 1937.
[d] *Ann. Soc. Espan. Fis. Quim.* was changed about 1941 to *Ann. Real. Soc. Espan. Fis. Quim.*
[e] *Ann. Chim. Anal.* was changed in 1919 to *Chim. Anal.*
[f] *Angew. Chem.*, the present name, was formerly known as *Z. Angew. Chem.* (1888—1932) and Repertorium anal. Chem. (1881—1887).
[g] *Berichte* was changed in 1945 to *Chem. Berichte.*

From Boig, F. S. and Howerton, P. W., *Science*, 115, 555 (1952). With permission.

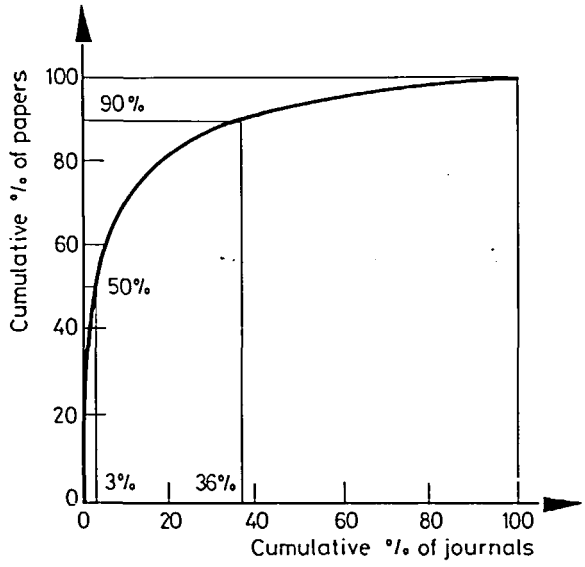

FIGURE 34. Concentration of the analytical chemical literature: 50% of the papers abstracted by *Analytical Abstracts* in 1977 were concentrated in only 3% of the journals. (Reprinted with permission from Braun, T., Bujdosó, E., and Lyon, W. S., *Anal. Chem.*, 52 (6), 617A (1980). Copyright 1980 American Chemical Society.)

Table 32
DISTRIBUTION OF PAPERS ON AAS IN DIFFERENT JOURNALS

Journal	% of all papers
Anal. Chem.	11.60
Anal. Chim. Acta	8.20
Atom. Absorp. Newslett.	7.51
Zh. Anal. Khim.	6.48
Bunseki Kagaku	5.80
Talanta	5.12
Zavodsk. Lab.	4.44
Z. Anal. Chem.	3.75
Analysis	2.39
Zh. Prikl. Spektrosk.	2.05
Appl. Spectrosc.	1.71
Spectrochim. Acta, Part B	1.36
Analyst	1.36
Scan	1.36
Anal. Lett.	1.02
Lab. Pract.	1.02
Mikrochim. Acta	1.02
Bull. Chem. Soc. Jpn	1.02
Flam. Emission Atom. Absorp.	1.02
Erdöl Kohle	1.02
Chem. Anal. (Warsaw)	1.02
Other journals outside U.S.S.R.	18.77
Various other publications in the U.S.S.R.	10.58

From Orient, I. M., Artemova, O. A., and Davidova, S. L., *Zavodsk. Lab.*, 43, 419 (1977). With permission.

Table 33
DISTRIBUTION OF PAPERS ON AAS IN DIFFERENT JOURNALS

Journal	Period							Total	% of all papers
	1955—1959	1960—1961	1962—1963	1964—1965	1966—1967	1968—1969	1970—1971		
Atom. Absorp. Newslett. (U.S.A.)	—	—	16	69	110	92	94	381	15.22
Anal. Chim. Acta (Holland)	—	4	11	10	30	67	72	194	7.75
Anal. Chem. (U.S.A.)	1	5	11	17	31	45	44	154	6.15
Spectrochim. Acta (U.K.)	5	12	5	8	17	37	31	115	4.59
Analyst (U.K.)	4	7	3	2	10	35	33	94	3.75
Appl. Spectrosc. (U.S.)	—	—	2	2	15	25	21	63	2.52
Bunseki Kagaku (Jpn)	—	—	—	3	2	9	37	51	2.04
J. Assoc. Off. Anal. Chem. (U.S.A.)	—	—	—	2	10	16	22	50	2.00
Talanta (U.K.)	—	—	1	6	6	23	13	49	1.96
Zh. Prikl. Spektrosk. (U.S.S.R.)	—	—	—	2	10	18	17	47	1.88
Zh. Anal. Khim. (U.S.S.R.)	—	1	4	8	4	10	18	45	1.80
Z. Anal. Chem. (Germany)	—	1	2	5	6	12	11	37	1.48
Clin. Chem. (U.S.A.)	—	—	—	—	6	11	18	35	1.40
Zavodsk. Lab. (U.S.S.R.)	—	1	4	6	3	7	10	31	1.24
Nature (U.K.)	1	7	3	4	6	2	5	30	1.20
Clin. Chim. Acta (Holland)	—	—	—	—	—	12	6	18	0.72
Anal. Biochem. (U.S.A.)	—	—	1	1	6	4	4	16	0.64
Mikrochim. Acta (Austria)	—	2	2	2	1	—	6	13	0.52
Chim. Anal. (France)	—	—	—	1	—	5	6	12	0.48
Jpn Analyst (Jpn)	—	—	—	3	1	4	2	10	0.40
Chem. Listy (Czechoslovakia)	—	—	—	1	2	1	2	6	0.24
Total	11	40	65	152	276	435	472	1451	57.98

From Brooks, R. R. and Smythe, L. E., Anal. *Chim. Acta,* 74, 35 (1975). With permission.

Table 34
IMPACT FACTOR AND TOTAL NUMBER OF CITATIONS IN 1978 OF 50 LEADING JOURNALS ON ANALYTICAL CHEMISTRY RANKED BY "IMPACT FACTOR"

Rank	Journal	Impact factor	Total number of citations
1	*Clin. Chem.*	3.106	6,948
2	*Anal. Chem.*	3.058	19,507
3	*J. Chromatogr. Sci.*	2.586	2,142
4	*Anal. Biochem.*	2.309	15,131
5	*J. Chromatogr.*	2.302	11,770
6	*Appl. Spectrosc.*	2.161	1,263
7	*Chromatographia*	1.972	1,200
8	*Appl. Opt.*	1.934	6,136
9	*Clin. Chim. Acta*	1.676	8,120
10	*Analyst*	1.666	2,606
11	*J. Electroanal. Chem. Interfacial Electrochem.*	1.525	4,506
12	*J. Agric. Food Chem.*	1.503	4,665
13	*Environ. Sci. Technol.*	1.436	2,123
14	*Anal. Chim. Acta*	1.404	3,856
15	*Anal. Lett.*	1.244	980
16	*Talanta*	1.182	2,304
17	*J. Pharm. Sci.*	1.171	6,724
18	*J. Clin. Chem. Clin. Biochem.*	1.163	298
19	*Nucl. Instrum. Methods*	1.141	6,035
20	*Rev. Sci. Instrum.*	1.131	4,730
21	*X-Ray Spectrom.*	1.118	212
22	*Chem. Pharm. Bull.*	0.979	4,497
23	*Fresenius Z. Anal. Chem.*	0.930	2,077
24	*J. Assoc. Off. Anal. Chem.*	0.916	2,373
25	*Int. J. Appl. Radiat. Isot.*	0.790	1,091
26	*J. Phys. Sci. Instrum.*	0.714	1,375
27	*Mikrochim. Acta*	0.697	808
28	*J. Radioanal. Chem.*	0.685	997
29	*Radiochem. Radioanal. Lett.*	0.639	674
30	*Z. Chem. (Leipzig)*	0.623	1,344
31	*Pharmazie*	0.483	881
32	*Z. Lebensm.-Unters. Forsch.*	0.455	502
33	*Bunseki Kagaku*	0.410	641
34	*Zh. Anal. Khim.*	0.403	1,701
35	*Ann. Quim.*	0.393	552
36	*Indian J. Chem. Sect. A.*	0.322	313
37	*J. Am. Oil Chem. Soc.*	0.278	2,616
38	*Acta Pol. Pharm.*	0.262	313
39	*Curr. Sci. (India)*	0.221	1,167
40	*Ukr. Khim. Zh.*	0.173	840
41	*Yukugaku Zasshi*	0.145	1,251
42	*Zavodsk. Lab.*	0.117	974
43	*Revista Chim. (Bucharest)*	0.082	106

Note: Data unavailable for *Atom. Absorp. Newslett.; Biochem. Med.; Bull. Environ. Contam. Toxicol.; Chem. Anal. (Warsaw); Farmatsiya (Moscow); Lab. Pract. (London); and Quim. Anal.*

C. Influence and Interrelationship of Analytical Chemistry Journals

As seen, scientists engaged in analytical chemistry research disseminate their findings to the international scientific community by publishing in a wide variety of scientific

journals. The range of subjects covered in a particular journal extends from the specific focus of a narrowly defined research specialty, e.g., the *Journal of Electroanalytical Chemistry,* to the broad analytical coverage of *Analytica Chimica Acta* or to the even broader cross disciplinary coverage of the physical, chemical, and life sciences in interdisciplinary journals like *Science* and *Nature.* The process of grouping chemistry or analytical chemistry journals into subject categories requires a decision as to the level of aggregation that will render the classification most useful for subsequent analyses. A useful criterion for designating a separate category is to require that the candidate group of journals serve as the primary publication outlet for the area of study. An example from the analytical chemistry literature will serve to illustrate this point. Journals dealing with chromatography and those dealing with electroanalytical chemistry represent subfields of analytical chemistry; however a high amount of research in these subfields is published not in specialty journals, but rather in general analytical chemistry or even general chemistry journals.

The journal "impact factor" introduced by Garfield[56] is a size-independent measure or indicator of some sort of quality of journals. This measure or indicator — e.g., the total number of citations — has no meaning on an absolute scale. In addition, the impact factor suffers from two significant limitations. First, although the size of a journal as reflected by the number of articles is corrected, the average length of individual papers appearing in the journal is not. Thus, journals publishing longer papers, namely review journals, tend to have higher impact factors. The second limitation is that the citations are unweighted, all citations being counted with equal weight, regardless of the citing journal. It seems more reasonable to give higher weight to a citation from a prestigious journal than to a citation from a peripheral one.

To overcome these limitations three related influence measures were developed, each of which measures one aspect of journal influence, with explicit recognition of the size factor. These measures are

1. The influence weight of the journal
2. The influence per publication for the journal
3. The total influence of the journal

The influence methodology and its statistical underpinning has been worked out by Narin and co-workers,[57-59] and our description of these topics relies heavily on their writings.

Influence weights for journals are derived from an analysis of the referencing interactions among members of the set of journals being considered. The influence weight is a weighted, normalized citation measure, weighted by the influence of the referencing journal and normalized by the size of the journal.

The reference-citation matrix contains the information describing the flow of influence among journals. It has the form

$$C = \begin{vmatrix} C_{11} & C_{12} & \dots & C_{1n} \\ C_{21} & C_{22} & \dots & C_{2n} \\ . & . & \dots & . \\ . & . & \dots & . \\ C_{n1} & C_{n2} & \dots & C_{nn} \end{vmatrix} \qquad (13)$$

Here, the terms reference and citation have been used interchangeably but, to avoid confusion in discussing influence weights, a specific role is assigned to each of these terms. The term reference will be used to designate the issuing unit, while the term citation will designate the receiving unit. A term C_{ij} in the reference-citation matrix

indicates both the number of references unit i gives to unit j and the number of citations unit j receives from unit i. The time frame of a citation matrix must also be clearly understood in order that a measure derived from it may be properly interpreted. Suppose that the citation data are based on references issued in 1978. These may refer to papers published in any year, up to and including 1978. In general, the papers issuing the references will not be the same as those receiving the citations. Any conclusions drawn from such a matrix assume an ongoing, relatively constant nature for each of the units. It is assumed that the journals have not changed in size relative to each other, and that they represent a constant subject area. Journals in rapidly changing fields and new journals must therefore be treated with caution.

Starting with the reference-citation matrix, an algorithm was developed for the calculation of the "influence weight" for each journal. As a database Narin et al.[57-59] used the citation tapes of the Science Citation Index database for 1973. The reference-citation matrix may be thought of as an input-output matrix, with the medium of exchange being the citation. Each journal gives out references and receives citations; it is above average if it has a "positive citation balance", i.e., receives more than it gives out. This reasoning provides a first-order approximation to the weight of each journal, which is, simply

$$w^{(1)} = \frac{\text{Total number of citations to the journal from other journals}}{\text{Total number of references from the journal to other journals}} \qquad (14)$$

This ratio is the starting point for an iterative procedure for the calculation of the influence weights. In the first approximation, all citations to a journal were weighted equally; however, some of these citations come from peripheral journals. In the next order of approximation, a reference from any journal is weighted with the weight it received in the first approximation, yielding a set of second-order weights $w^{(2)}$. This process is continued and rapidly converges to a stable, self-consistent set of influence weights. This set of influence weights provides a size-independent measure for each journal. There is no tendency for a journal to have a higher or a lower weight due to its size, whether measured by the number of publications or by the average length of its publications.

There is the second influence measure, introduced by Narin et al.,[57-59] called "influence per publication". Two journals might have the same influence weights, but one may contain much longer articles, as would be the case for review journals. This journal would be expected to have a larger influence on a per publication basis. From the mathematical formulation of the problem it turns out that the two measures are related by

$$\text{(Influence per publication)} = \text{(influence weight)} \times \text{(reference per publication)} \qquad (15)$$

The influence per publication measure is particularly valuable in weighting counts of publications since it compensates for editorial policies which might affect the number of references in an article, and because a count of publications is the natural starting point for comparative analysis.

This measure should not be confused with the third influence measure, the "total influence" of a journal. Two journals could have the same influence weight and the same influence per publication, and yet have widely different total influence, solely due to the difference in the number of publications. The total influence of a journal is defined as

Table 35
INFLUENCE MEASURES FOR SOME ANALYTICAL JOURNALS

Journal	Influence weight	References / Publication	Influence / Publication	Publications	Total influence
Anal. Lett.	0.40	7.2	2.9	123	353
Analusis	0.12	8.5	1.1	85	90
Analyst	0.82	9.7	7.9	131	1039
Anal. Chem.	0.75	20.9	15.6	603	3401
Anal. Chim. Acta	0.51	8.9	4.5	344	1555
J. Assoc. Off. Anal. Chem.	1.04	5.1	5.3	321	1692
J. Chromatogr. Sci.	0.94	11.9	11.2	118	1317
J. Chromatogr.	0.53	10.7	5.6	631	3553
J. Radioanal. Chem.	0.20	6.4	1.3	143	186
J. Therm. Anal.	0.34	9.7	3.3	45	147
Jpn Analyst (Bunseki Kagaku)	0.02	25.9	0.5	231	119
Microchem. J.	0.31	7.5	2.3	86	201
Mikrochim. Acta	0.43	9.9	4.2	124	525
Talanta	0.49	10.1	4.9	155	763
Z. Anal. Chem.	0.76	6.4	4.9	249	1210
Zh. Anal. Khim.	0.15	8.4	1.3	463	602

$$\text{(Total influence)} = \text{(influence per publication)} \times \text{(number of publications)} \quad (16)$$

It should be emphasized that the influence measures could properly be called "citation influence measures". There are numerous factors which are relevant to a journal that contribute to these de facto measures: true merit, journal circulation, availability, degree of specialization, country of origin, language, etc.

Some influence measures for analytical journals are presented in Table 35. The analytical journals were considered as the basic units for an analysis resulting in an influence map for these journals as seen in Figure 35. The following conventions apply to this map.

1. A solid rectangle is used to represent journals within the field and subfields. The area of a rectangle is proportional to the size of a journal, as measured by the number of articles, notes, and reviews in the corporate index of the *Science Citation Index* in 1973.
2. The vertical scale shows influence per publication for each journal on a logarithmic scale, where weights for a set of units tend to be distributed uniformly, i.e., less crowding for the lower weight units.
3. The horizontal direction is used to separate either different subfields appearing on the map, or journals with different specific foci. Journals in the same column tend to be more similar to each other than to journals in neighboring columns.
4. Arrows are directed from a journal to the other journals, exclusive of itself, to which it refers most frequently. Usually, two arrows are drawn from each journal showing the two other journals that are most frequently referenced; occasionally three are given if the number of references to the second and third are close, or there may be only one if a single arrow best characterizes the referencing priority of

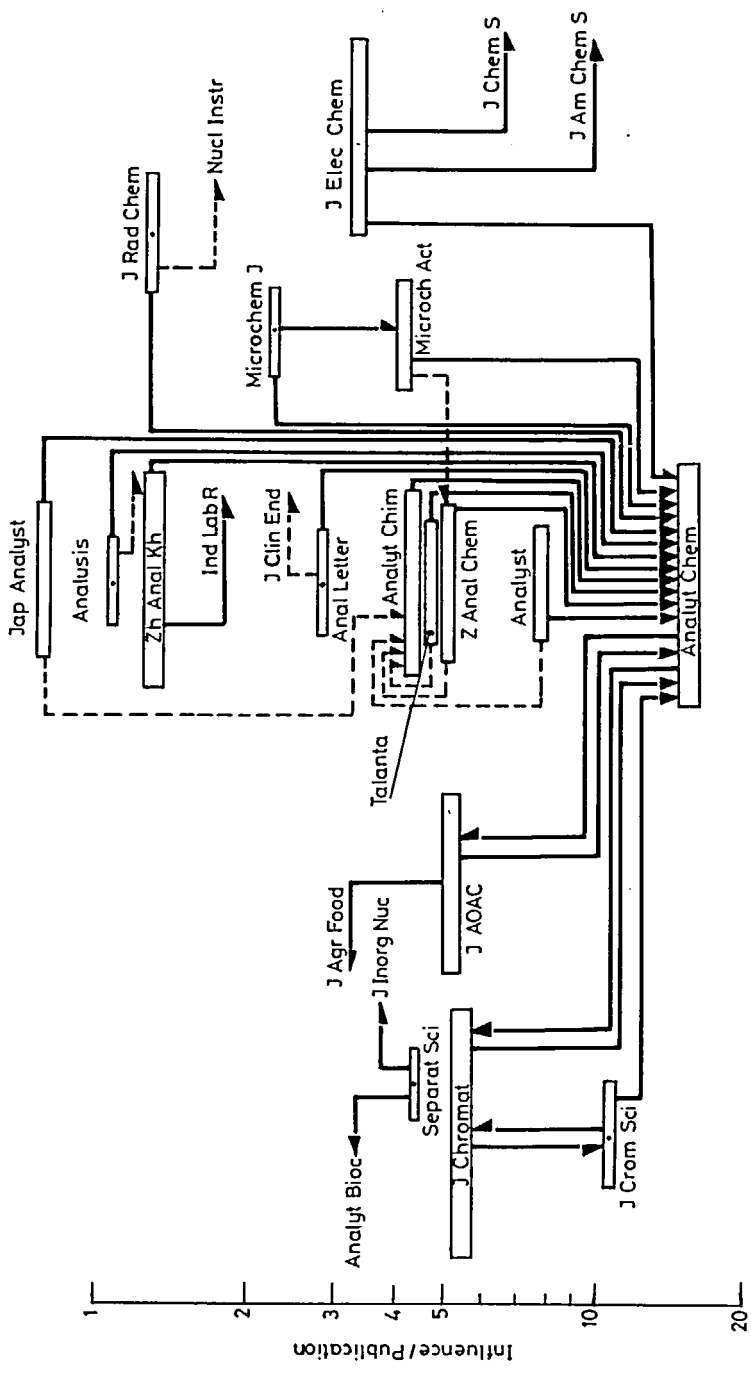

FIGURE 35. Influence map for analytical chemistry journals. See text for information. (Reprinted with permission from Pinski, G., *J. Chem. Inf. Comp. Sci.*, 17, 67 (1977). Copyright 1977 American Chemical Society.)

the journal. An arrow with a full head is used for a first arrow (largest number of references), while a half head is used for a second or third arrow. A dotted arrow is used for a secondary arrow which is considerably weaker than the primary arrow.

5. Arrows directed out of the field to journals which are not of central importance for the field are generally short arrows leading to the unenclosed journal name. For this case there is no significance to the vertical placement of the cited journal.

Classification of the chemistry journals into subfields on the basis of influence measures enabled Pinski[59] to analyze the flow of influence among subfields. In the overall flow of influence through the fields of science, there is a hierarchy which can be represented by the scheme

$$\text{Biology} \longrightarrow \text{Chemistry} \longrightarrow \text{Physics} \longrightarrow \text{Mathematics}$$

The subfields of chemistry may be thought of as spread out in a spectrum from biology to physics. The interface between chemistry and biology has itself developed into a major field, namely biochemistry. Although the *Journal of Biochemistry* for example is published by the American Chemical Society, it is one of the central journals to the literature of biochemistry, and only a small portion of its references is directed at chemistry journals. The interface at the other end of the spectrum presents a different situation. Physical chemistry has remained within chemistry, and as a subfield is not a borderline area between chemistry and physics. Chemical physics does provide an interface linking chemistry and physics. Although the direct physics-chemistry linking is too weak to establish a strong hierarchical relationship, the inclusion of chemical physics provides a strong connection with both chemistry and physics, establishing the strong hierarchical relationship

$$\text{Chemistry} \longrightarrow \text{Chemical Physics} \longrightarrow \text{Physics}$$

This means that chemistry refers to chemical physics more often than it is cited by chemical physics, and chemical physics refers to physics more often than it is cited by physics. Pinski[59] aggregated the influence data for journals from nine subfields of chemistry including analytical chemistry. A 9 × 9 reference-citation matrix was then constructed and the subfield influence measures were derived. These are given in Table 36. The different subfields of chemistry interact to a very different degree with the two "endpoints" of the chemistry spectrum, biochemistry and chemical physics. The ratio

$$\frac{\text{References to chemical physics}}{\text{References to biochemistry}} \qquad (17)$$

calculated for each subfield, is a measure of the physical to biochemical orientation of each field. This suggests a diagrammatic representation of the chemical literature as a generalized hierarchy shown in Figure 36. The vertical coordinate is the influence weight, with values increasing in the downward direction, while the horizontal coordinate is the above ratio. A logarithmic scale is used for both coordinates. Physical orientation of subfields increases towards the right. As a subfield, analytical chemistry is of medium influence and size at about half distance between biochemistry and physical chemistry.

The interdependency, interactivity, and cluster trees for the major broad based, i.e., journals dealing with all aspects of analytical chemistry publishing research papers from theory through analytical operations till data processing,[94] and specialty analytical chemistry journal was investigated by Bujdosó et al.[61] on the basis of the reference-

Table 36
INFLUENCE MEASURES AND PUBLICATION DATA FOR THE SUBFIELDS OF CHEMISTRY

Subfield	Influence weight	References / Publication	Influence / Publication	Publications	Total influence
General chemistry	1.043	15.72	16.40	16,089	263,809
Biochemistry	0.747	20.65	15.42	12,049	185,749
Analytical chemistry	0.737	11.78	8.69	4,243	36,860
Organic chemistry	0.598	14.24	8.52	5,968	50,855
Inorganic chemistry	0.776	14.47	11.23	2,515	28,244
Applied chemistry	0.846	12.22	10.34	2,762	28,571
Polymer chemistry	0.562	11.37	6.39	3,224	20,614
Physical chemistry	1.340	12.37	16.58	7,188	119,206
Chemical physics	3.218	15.71	50.54	3,220	162,732

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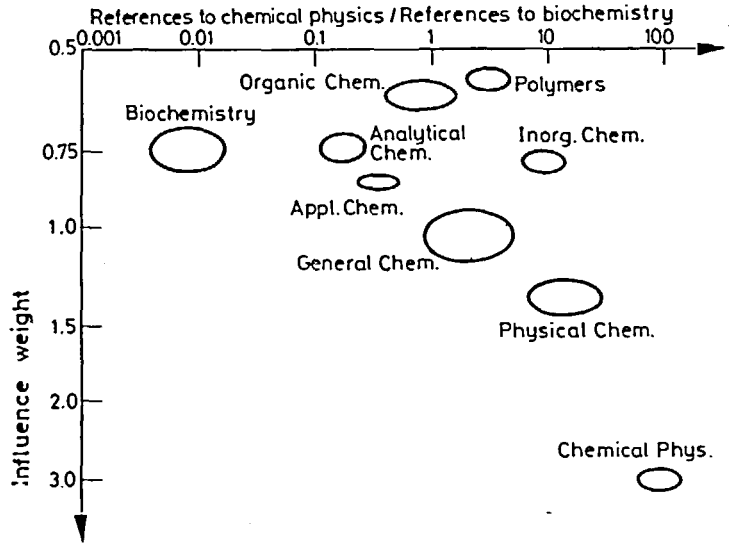

FIGURE 36. Influence structure for the chemical literature. (Reprinted with permission from Pinski, G., *J. Chem. Inf. Comp. Sci.*, 17, 67 (1977). Copyright 1977 American Chemical Society.)

citation matrices. The expectation analysis for the interdependency of journals showed diagonal strength values for *Anal. Chem., Anal. Chim. Acta, Analyst, Anal. Lett.*, and *Talanta* between 1.9 and 4.4, while *Fresen. Z. Anal. Chem., Analusis* between 10.9 and 13.8, and for *Zavodsk. Lab.* an especially high value 43.4. These values indicate how much more a journal cites itself than would be supposed from the group behavior. The analyses also show a tightly linked subcluster of journals, *Zavodsk. Lab.* and *Zh. Anal. Khim.*, being little related to others. There are especially tight links between the following pairs: *Analusis and Anal. Lett.; Anal. Chim. Acta and Analyst; Bunseki Kagaku and Talanta.*

The cluster trees with the amalgamation distances for the group of broad based and

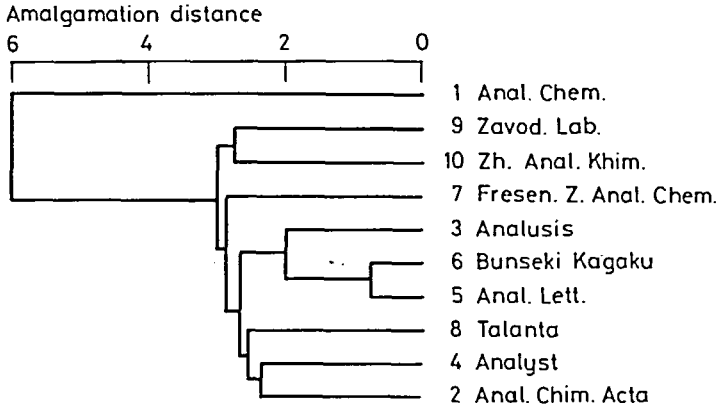

FIGURE 37. Cluster tree of the group of the main broad-based analytical journals.[61]

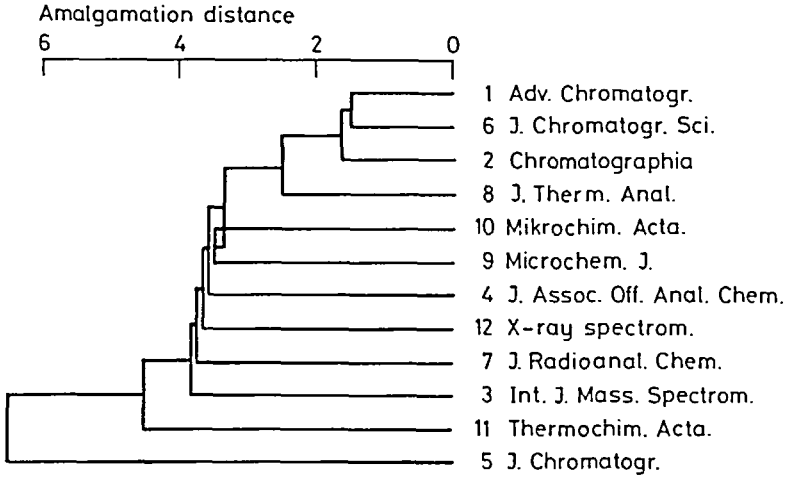

FIGURE 38. Cluster tree of the group of specialty analytical journals.[61]

specialty journals and for their combinations are shown in Figures 37 to 39. Amalgamation distance should be considered as a distance in a 2 m dimensional space in the case of an m × m matrix between two journals or between the center of the "masses" of subgroups represented by their weighted citation values as coordinates.

In the cluster tree the group of broad-based journals (Figure 37), the Russian subcluster 9,10, the *Analusis- Bunseki Kagaku-Anal. Lett.* 3,6,5 subcluster, and the *Talanta- Analyst-Anal. Chim. Acta* 8,4,2 subcluster are clearly visible. In the groups of specialty analytical journals (Figure 38), the subcluster of the chromatographic journals 1,6,2 and the two microchemical journals 9,10 are significant. The cluster tree of all the 22 analytical journals (Figure 39) shows new interconnections and also the separation of some specialty journals 22,13,14,17,21 and the two "big" journals *Anal. Chem.* and *J. Chromatogr.*

D. Inflow-Outflow of Analytical Chemical Information

Analytical chemistry, a subfield of chemistry, is characterized by the prompt response to results and methods of other fields applicable for its purposes urged by its own inner

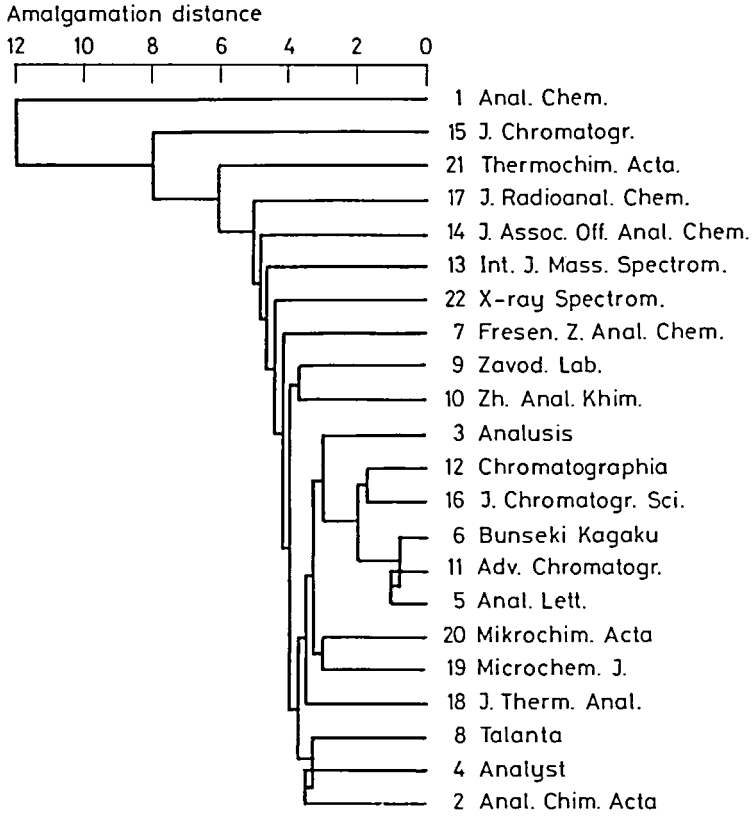

FIGURE 39. Cluster tree of the analytical journals.[61]

activity and the growing needs of science and technology for analytical results. This activity manifests itself in a strong information transfer with subfields and fields of other disciplines. This information transfer was investigated by Bujdosó et al.[61] by citation analysis using the 1978 *Journal Citation Reports.*[56] The extent to which authors in one journal reference the work of scientists in another journal can be taken to be a good measure of cross-journal information flow. A study of the flow of these information quanta through the citation network connecting journals and also the fields they represent can map the interdependency of basic research in analytical chemistry.

As representing the subfield of analytical chemistry, a group of the major broad based (BB) analytical journals was selected according to Petruzzi.[94] References from one of the BB journals were taken as inflow; citations to one of the BB journals as outflow to or from analytical chemistry. In order to be able to measure the flow of information among the fields of science, journals were classified into subfields according to Narin.[57]

The information flow among the group of main broad based and specialty analytical journals as well as journals of all other disciplines are shown in Figure 40. Figure 41 shows the information flow map for chemistry subfields drawn from the BB journal database including the group of specialty analytical chemistry journals. The inflow and outflow data are in percentages of the total analytical information flow in the field of chemistry. The area of circles representing the subfields are proportional to their virtual size, i.e., the number of published items multiplied by the appropriate impact factor of the journals then summed for the whole subfield.

According to Figure 41, the main information sources of analytical chemistry within

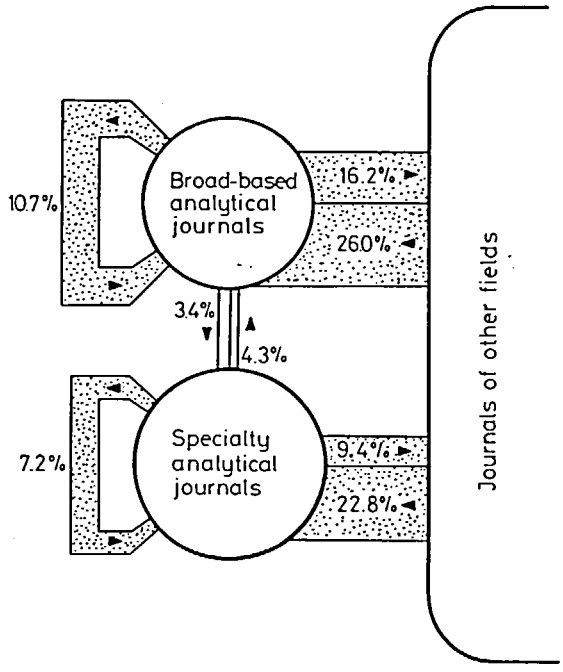

FIGURE 40. The information flow among the group of main broad-based and specialty analytical journals as well as the journals of all other disciplines. Data are in percentages of the whole information traffic.[61]

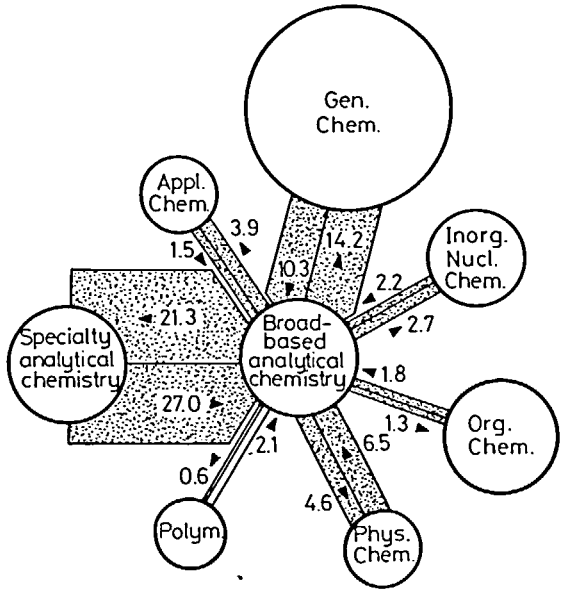

FIGURE 41. The information flow between the group of main broad-based analytical journals and the subfields of chemistry in percentages of the total analytical information flow in the field of chemistry.[61]

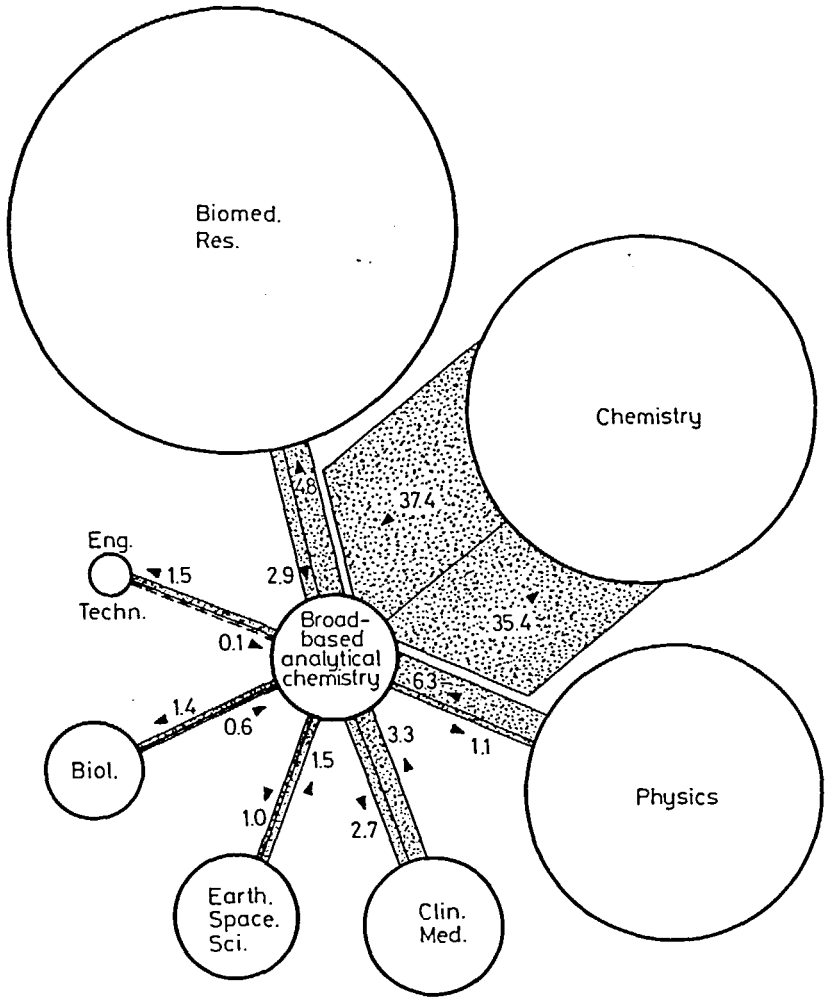

FIGURE 42. The information flow between analytical chemistry and other fields of science in percentages of the total analytical information flow.[61]

overall chemistry are the specialty analytical, general, and physical chemistry journals. The rate of in- and outflow changes in every subfield; for applied, general, inorganic, and nuclear chemistry, analytical chemistry is an emitter of information; i.e., all these fields are drawing information from analytical chemistry.

Figure 42 shows the information flow between analytical chemistry and other disciplines. The main information sources of analytical chemistry are physics, clinical medicine, earth and space sciences, i.e., analytical chemistry absorbs information from all these disciplines.

E. Peer Review in Analytical Chemistry Journals

Price has suggested[62] that the number of published scientific articles that are "good" increases as the square root of the total number of published articles. This implies that if total publication volume continues to increase, the percentage of those that are "good" decreases. The burden on readers to sort "wheat from chaff" would increase. This might increase the need for lower acceptance rates, resulting in an increased quality of the

Table 37
EDITORIAL DECISION CONCERNING MANUSCRIPTS IN THE JOURNAL *ANALYTICAL CHEMISTRY*

Decision	No.	%
Accepted	299	68.5
Rejected	107	24.5
Inactivated	15	3.4
In process	12	2.7
Withdrawn	4	0.9

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Table 38
REVISION REQUIREMENTS FOR MANUSCRIPTS IN *ANALYTICAL CHEMISTRY*

Action requested	No.	%
Minor revision	177	40.5
Major revision	130	29.7
Accepted without change	19	4.3
Rejected or withdrawn	111	25.4

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manuscripts accepted for publication. The present acceptance rate is about 55% for journals receiving at least 300 manuscripts per year and about 70% for "smaller" journals.[62] The acceptance rate is also higher for papers in the "hard" (e.g., physical) sciences than in the "soft" ones. It can be as low as 10% in some social science journals and as high as 90% in mathematics and physics.[66] The systems used by research journals to evaluate and select manuscripts for publication are seen to be of vital importance to science. And, not surprisingly, one finds the behavior of individuals taking part in these systems, especially the behavior of anonymous referees consulted by journal editors, to be of great sensitivity and heated debate. Within this debate, accusations of deliberate referee bias are sometimes presented, usually by aggrieved authors. Such deliberate bias is not, however, thought to occur very often, and it can usually be identified by the editor, with or without a second or third referee's report or author's letter of appeal. Its influence upon the overall pattern of growth of the literature of a discipline can be considered minimal.

In the field of analytical chemistry the peer review process — as far as we know — has been investigated in some detail only for the journal *Analytical Chemistry*. Thus, Petruzzi[64] followed the fate of 437 manuscripts submitted for publication from February 21 through August 20, 1975. The results of this study are shown in Table 37. The "in process" manuscripts represent papers either out for second review or in the hands of the authors for revision. The revision requirements for manuscripts are shown in Table 38.

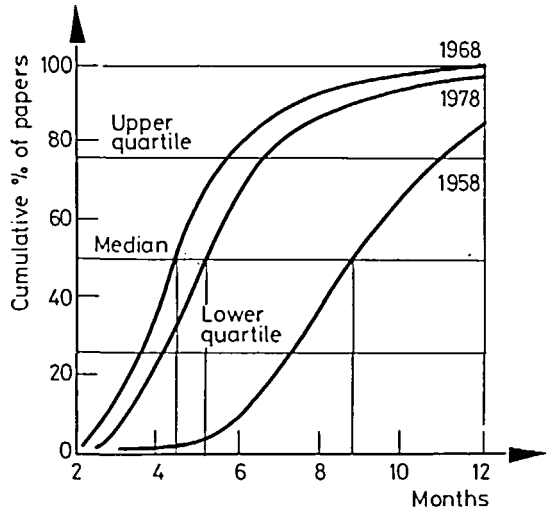

FIGURE 43. Publication times of papers in *Anal. Chem.* (Reprinted with permission from Braun, T., Bujdosó, E., and Lyon, W. S., *Anal. Chem.*, 52(6), 617A (1980). Copyright 1980 American Chemical Society.)

Two or more reviewers reviewed 95% of the manuscripts, 16% were sent to referees (a term reserved for persons consulted when the two reviews did not agree), and 33.3% of the rejected manuscripts have been seen by a referee. Data collected on the reasons for the rejection of manuscripts showed that 52% of the rejections were to be attributed to such terms as insufficient new information, already published, lack of originality, and not relevant. As other reasons, insufficient supporting data (13%) and questions regarding scientific merit and validity of data (12%) are mentioned.[64]

F. Publication Speed (Time) of Papers in Analytical Chemistry Journals

Authors of research papers in analytical chemistry usually complain about how much time it takes to get their manuscripts published and how outdated the research findings are at publication as a consequence of lengthy publication times. As this problem is of crucial importance to the whole communication process in analytical chemistry, Braun et al.[20] investigated one of the steps — that of journal publication time — of the long way leading to the publication of a scientific paper in analytical chemistry. Namely, between the hypothesis and publication of research results in analytical chemistry, time is needed to design and complete the research leading to the paper, to write it, and to edit it.

All these are preceding publication times (journal handling times). A rough estimate indicates that publication time, i.e., the time between submission of a manuscript to a journal and its ultimate publication, is only about 25% of the total. Psychologically, the interval seems much longer, for once the scientist has completed his work, time hangs heavy. Authors in analytical chemistry (but that seems to be true for science in general) are not only eager to see their own results in print but also may be concerned that similar results of someone else might be published before theirs. Authors are generally not recognizing that the major lapses in time are spent in setting up the investigation, doing it, and writing the manuscript. Even if editing and journal processing were instantaneous, the research idea would be in average 3 years old by the time it is read. The problem of journal publication times of analytical papers was not dealt with too frequently. In a recent editorial[65] some such data were published. Figure 43 presents the publication times

of papers in *Analytical Chemistry* in 1958, 1968, and 1978.[20] As seen, there was a sharp increase in publication speed from 1958 to 1968 with some drop in 1978. Nevertheless, this drop is only relative. Table 39 shows that in comparison with the data for some other leading analytical journals, the median publication time of 5.7 months in *Analytical Chemistry* in 1978 is the shortest in the series.

Another approach of the publication time problem could be the following. As shown in Section IV, the results of a research and so the publication itself become obsolete with time. Let us suppose that a countdown begins when the experimental work and its evaluation by intellectual processes are completed, i.e., a manuscript is ready for publication. It is reasonable to allow a maximum of 10% decay during the publication time, i.e., the advising and editing, printing, the author's galley proof reading as well as mailing, etc. of a paper. Taking into account the 4-year half-life of a paper on analytical chemistry,[60] this time can be at maximum 8 months.[20] The leading analytical journals seem to be trying to keep their publication times under this value.

VII. AUTHORS OF ANALYTICAL CHEMISTRY PAPERS

A. Productivity of Analytical Authors, Lotka's Law

Authors are central to the cumulative literature of any subject. No matter what editors and publishers add to or subtract from manuscripts, the published results remain unequivocally the authors' contribution to knowledge. Studies analyzing the characteristics of subject literatures have increasingly focused attention on the quantity and rates at which authors publish in their fields.

Of course, this measure is far from perfect. One paper may report an epoch-making discovery while another describes only some relatively trivial redetermination of certain experimental values or variations in the conditions for a reaction. There is a difficulty also over multiple authorship, which is increasing as a proportion of all work. Because publications are used as a basis to help in deciding appointments and promotions, there may be a tendency to try to spin out a given amount of work into more papers than are really necessary. Whatever it is that is measured by a paper count is perhaps better described as productivity than as quality. But at least it is something measurable by which one can compare the output of different scientists. Though there are flagrant anomalies in individual cases, there does seem on the whole to be reasonably good correlation between productivity in terms of papers and eminence as judged in other ways.

Using paper counts, one can investigate the frequency distribution of scientific productivity. What kind of distribution would one expect? Would one guess that the productivity of most scientists clusters around some average number, with only exceptionally good or exceptionally bad ones producing many more or many fewer? In fact, one finds quite a different kind of distribution which is nothing like the sort of normal distribution that one gets for chance events. Plotted as a graph, Curve 1 resembles in Figure 44, not the familiar bell shape of Curve 2. The great majority of people who publish at all do not publish more than a few papers. Many manage to produce one or two as research students but never any more. Only a selected minority produce more than a few.

In 1926 Lotka[67] proposed an inverse-square law relating authors of scientific papers to the number of papers written by each author. Lotka was interested in determining "if possible, the part which men of different calibre contribute to the progress of science". He counted the number of authors and the number of contributions made by each of them in the decennial index of *Chemical Abstracts,* 1907 to 1916; only the letters A and B were covered. Similar data were also collected from Geschichtstafeln der Physik (J. A. Barth, Leipzig, 1910). Lotka plotted, on a logarithmic scale, the number of authors against the

Table 39
PUBLICATION TIMES OF PAPERS IN FOUR LEADING ANALYTICAL JOURNALS IN MONTHS

	Anal. Chem.			*Anal. Chim. Acta*			*Analyst*			*Talanta*		
Year	Median	Inter-quartile range	Range	Median	Inter-quartile range	Range	Median	Inter-quartile range	Range	Median	Inter-quartile range	Range
1958	8.7	7.2—10.9	1—26	6.8	5.8—7.6	3—11	—	—	—	—	—	—
1968	4.4	4.6—5.4	2—14	5.2	4.7—7.6	1—21	6.2	5.0—7.3	4—40	7.1[a]	5.9—8.6[a]	2—18[a]
1978	5.1	3.9—6.4	3—17	5.7	4.7—7.0	1—17	5.6	4.2—6.8	3—19	8.1	6.1—10.3	2—22

[a] 1969.

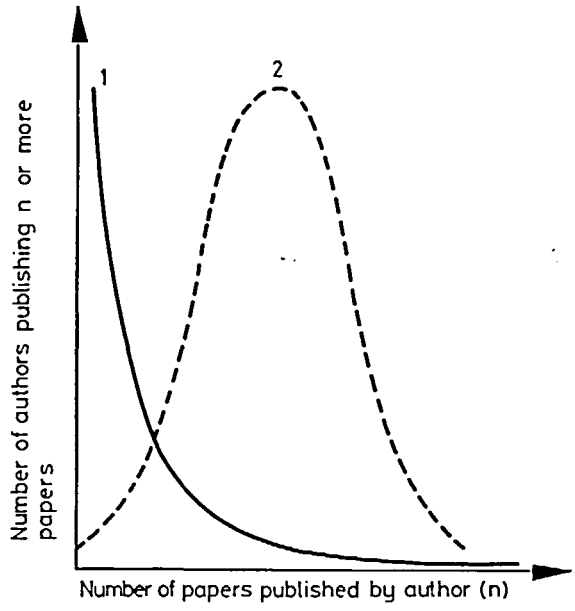

FIGURE 44. Productivity of authors of scientific papers. Curve 1, real distribution; curve 2, hypothetical distribution.

number of contributions made by each author and found that in each case the points were closely scattered about a straight line having a slope of approximately two. On the basis of these data, Lotka deduced the general equation

$$mn^c = k \qquad (18)$$

where m is the fraction of authors making n contributions each and c and k are constants. For the special case of $c = 2$ (inverse-square law of scientific productivity), the value of the constant k was 0.6079. This meant that the proportion of authors who contribute a single item should be 0.6079, or just over 60% of the total number of authors. The observed figures for the proportion of authors making one contribution each were 57.9% for the *Chemical Abstracts* data and 59.2% for the *Auerbach* data. Lotka[67] summarized his findings: "In the cases examined, it is found that the number of persons making 2 contributions is about one fourth of those making one; the number of making 3 contributions is about one ninth, etc; the number making n contributions is about $1/n^2$ of those making one; and the proportion of all contributors, that make a single contribution, is about 60 percent."

In other words, for every 100 authors contributing 1 article each, there would be 25 others contributing 2 articles each ($100/2^2 = 25$), about 11 contributing 3 articles each ($100/3^2 = 11.1$), about 6 contributing 4 articles each ($100/4^2 = 6.25$), and so on.

Lotka's law can also be expressed by the equation

$$a_n = a_1/n^2, \qquad n = 1, 2, 3, \ldots \qquad (19)$$

where a_n is the number of authors contributing n papers each. Price[1] has suggested that one half of all the scientific papers are contributed by the square root of the total number of scientific authors.

In recent years several attempts have been made to verify Lotka's law and to apply it to

the literature of various fields.[68] For example, in some cases an exponent different from 2 was required to provide a good fit with empirical data. The range of exponents extended from 1.5 to 4.0.[65]

Coming now to analytical chemistry there were only a very few attempts to verify Lotka's law. Vlachy[69] found in the author indexes of *Analytical Abstracts* 1954 and 1970 (January-December) and 1971 and 1974 (July-December), exponents ranging from 3.5 to 4.0. Braun et al.[60] found an exponent around 2.0 working with a world activation analysis bibliography for the period 1936 to 1970.[70]

Though Lotka's law of scientific productivity may be applicable with or without modification to the literature of analytical chemistry or to that of its subfields, it seems obvious that more thorough investigations are necessary.

In some studies on Lotka's law, when considering a paper written by a number of authors, each co-author was assumed to have contributed one paper. Coile[71] has pointed out that such an assumption can lead to erroneous conclusions. Clearly, contributing part of a paper as a co-author in a team effort is not the same as writing a paper by oneself. It is extremely difficult, if not impossible, to ascertain the extent of contribution of each co-author. In Lotka's original study, joint contributions were credited to the senior author only.

B. Citation Analysis in Analytical Chemistry

It is emphasized by Nalimov and Mulchenko[6] that if the progress of science is attempted to be interpreted through an information model, particular attention must be paid to the analysis of the specific coding language of scientific references and citations within the flow of scientific information. The references found in a scientific publication can be regarded as the particular, specific language of scientific information. All scientific papers are based on the multitude of already expressed ideas. These ideas may be rather new and unknown for the reader of a paper. Despite this fact, the author of the paper does not deal with the explanation of these ideas at any length; instead he refers to the previous papers in which these ideas were first explained or stated. The system of scientific references and citations is the code that enables the author to write concise papers without repetitions. The theories on which the research is based are conveyed in this language. According to the statement of Kessler,[72] the references reflect the spiritual atmosphere in which the publication was born. Many scientists understand and apply this language to such an extent that they are able to form an idea about a paper without actually reading it. Let us suppose that we look through a mathematical periodical, and bump into a lengthy and hardly digestable paper with a short abstract that is also indigestable. Then, we will turn our attention to the references. If we find familiar names or publications, immediately an idea can be formed about the subject of the paper.

The contents of scientific publications are therefore coded or indexed by the author in the references. In a certain sense this coding reflects the richness in ideas of a publication much better than, e.g., coding with descriptors. Consequently, the system of bibliographic references can be regarded as a special information language. Its statistical analysis has proved to be an efficient means of investigating the development of scientific information flow.[73] By applying this method, the progress and trends of scientific fields, the infiltration of new ideas or methods into frontier areas, can be followed and also the impact of the work of scientists can be evaluated, by starting from their impact on the information flow of scientific literature.

Based mainly on the above considerations, there is a tendency in the scientometric literature[76] to use citations in order to inject a quality factor into the evaluation of scientific publications.[6] The claim is that such a factor can be had by counting not the number of publications but the number of citations a publication or a set of publications receives in the scientific literature. The image underlying this claim is that the impact of a

scientific paper is in its influence on subsequent research papers, and each instance of such influence will manifest itself by the influenced paper referring to the influencing paper.

Although the authors of the present review paper believe in the utility of citation analysis as a research tool, they also have to mention that the above philosophy is not free of deficiencies, and neither is the practical application of it. In fact, citation measures have been blamed on various grounds, including that they simply describe and do not explain, that they are dubious until we understand the psychology and sociology of who cites whom and why, that the "Science Citation Index" is not a true reflection of the citation structure, and that citations are not all of equal value and intent.[77,78]

Nevertheless, citations are used with increasing frequency as both a practical and a conceptual tool.[6,76] It is a question of matching a given purpose with a tool of appropriate reliability, and not expecting exceedingly much out of a given application.

According to Orient and Markusova,[24] all scientific publications can be regarded as the result of two factors. The first factor includes the ideas taken by the author from the papers of others and coded in the references. The second contains the new ideas of the author produced in connection with the notions known before. When the paper of a given author is cited by future papers, just these new ideas are utilized. Therefore, by investigating citations the dissemination of new ideas and methods can be followed; the interrelationship of the development of ideas and the internal structure of scientific research can be revealed. Citation measures the contribution of the cited author to the information flow. However, it must be mentioned that this criterion has substantial limitations. While the great impact of a paper witnesses its efficiency or perhaps its value, the lack of impact does not necessarily mean the worthlessness of the given paper. In investigating the impact of a paper it must be taken into account that this depends also on the "popularity" of the periodical in which the paper was published, the speed of the research front in the given field, the citation habits of the given field or country, etc.

The most used database for citation analysis is the *Science Citation Index* (SCI) compiled by the Institute for Scientific Information (Philadelphia), which is available from 1964 both in printed form and on magnetic tape. Concerning all aspects and details of the database, citation indexing and analysis, we refer to Garfield's[73] recent monograph.

Orient[79] carried out elaborate investigations on the basis of *Science Citation Index* in order to determine in what measure the papers of Russian analysts were cited in the world chemical literature during 1965. As a subject of the investigations, a group of authors was chosen which had published not less than two papers yearly for 3 years in *Zhurnal Analyticheskoi Khimii* and *Zavodskaya Laboratoriya.* Of the 119 authors chosen, 90 were cited 1098 times. The data given in Table 40 were subjected to further analyses. In the 1965 volume of *SCI,* 29 of the above 119 authors were not cited at all. Of the authors cited, 1 appeared more than 100 times, 2 of them more than 70 times, 2 more than 40 times, 4 more than 30 times, 9 more than 20 times, 6 more than 10 times, 18 more than 5 times, and 38 were cited less than 5 times. The distribution of citations referring to the various subfields of analytical chemistry are given in Table 41.

Finally, an attempt was made to determine the "quality level" of Russian analytical chemical research on the basis of five different criteria.[79] The data are given in Table 42.

Since citation is used as a measure of the impact of publications, and since — as we mentioned — citation is the language of science which codes in a given paper the information published previously, it is worth investigating the logical bases of citation in papers published on analytical chemistry. Orient[79] has subjected the experimental analytical papers published in *Zhurnal Analyticheskoj Khimii* and *Zavodskaya Laboratoriya* to conceptual analysis. Before starting the analysis no classification was fixed; this developed during the process in which all citations received their appropriate

Table 40
AVERAGE LEVEL OF CITABILITY OF ANALYTICAL CHEMISTRY PAPERS PUBLISHED BY SOVIET AUTHORS IN 1965

No. of authors	No. of authors cited in *SCI*	Total no. of citations	From the total: Citations in the world analytical literature	From the total: Citations in the Soviet analytical literature
119	90	1098	508	590

Note: Average level of citability 1098:90 = 12.2. Average level of citability in the world literature 508:90 = 5.6. Average level of citability in the Soviet literature 590:90 = 6.6.

From Orient, I. M., *Zavodsk. Lab.*, 33, 1383 (1967). With permission.

Table 41
DISTRIBUTION OF CITATION OF ANALYTICAL PAPERS ACCORDING TO SUBFIELDS

Methods	Total citation	In the foreign literature	In the Soviet literature
Electrochemistry	296	99	197
Polarography	197	57	140
Amperometry	66	26	40
Other	33	16	17
Photometry	265	126	139
Fluorometry	30	11	19
Extraction	47	31	16
Other	188	84	104
New organic reagents	158	99	59
Determination of constants and theoretical work	111	67	44
Titrimetry	75	27	48
Nonaqueous	26	8	18
Other	49	19	30
Gas chromatography	58	34	24
Phase analysis of gases in minerals, ores, alloys, and steel	52	7	45
Kinetic methods	43	21	22
Radiochemical methods	40	28	12
Total	1098	508	509

From Orient, I. M., *Zavodsk. Lab.*, 33, 1383 (1967). With permission.

meaning. The classification developed after the analysis of 1200 references and the corresponding distribution is shown in Table 43. A part of references has "soft" character and reflects the individual citation habits of the author such as references to previous works, their critical judgment, etc. The number of such references is usually very different in various papers and they reflect the traditions of the journal or sometimes the lack of

Table 42
RANKINGS OF SOVIET ANALYTICAL CHEMISTRY RESEARCH IN FIVE CATEGORIES

Methods	Ranking				
	I	II	III	IV	V
Electrochemistry	2	1	1—3	4—5	6
New organic reagents	6—8	3	1—3	2	2
Determination of constants, theoretical papers	10	4	4	1	1
Photometry	1	2	1—3	8—9	8
Gas chromatography	4	6	5	8—9	7
Radiochemical methods	9	8—10	7—8	4—5	4
Extraction	6—8	8—10	6	7	5
Kinetic methods	11	8—10	9	3	3
Titrimetry	3	5	7—8	10	9
Phase analysis of ores, alloys	6—8	7	10	6	10
Liquid chromatography	5	11	11	11	11

Note: Rank based on: I, number of papers; II, number of citations; III, number of citations in the foreign literature; IV, specific citation (citations/papers); V, specific citation in the foreign literature.

From Orient, I. M., *Zavodsk. Lab.*, 33, 1383 (1967). With permission.

Table 43
CATEGORIZATION OF REFERENCES IN ANALYTICAL CHEMISTRY PAPERS (NO. OF REFERENCES: 1200)

Type of reference	% of total number of references
Stated in preceding papers (reviews)	40
Reference to apparatus used, method, preparation of reagent, calculation, synthesis ("methodological")	20
Reference to the use of ideas, methods, theory ("idea")	15
Reference to earlier established facts, effects ("phenomonological")	13
Critical discussions	4
Comparison of results with literature data	3
References to handbook data	2
Historical	1
Not identified	2

From Orient, I. M., *Zavodsk. Lab.*, 41(9), 1071 (1975). With permission.

generalizing, or refer to review papers. The other part of references is "hard", such as handbook data, methods of the evaluation of results, description of syntheses, preparation of reagents, or hints to the procedure followed. "Hard" references, as it appears from Table 43, amount to nearly 38% of all references.

It is obvious that the citations concerning the level of "contribution" are not equal in value, but to assign different "weights" to them in order to take into account citability as a criterion would be complicated and unsound in practice. If results are compared to the citations found in metallurgical papers,[80] it can be seen that in analytical chemistry the weight of methodological references is significantly higher.

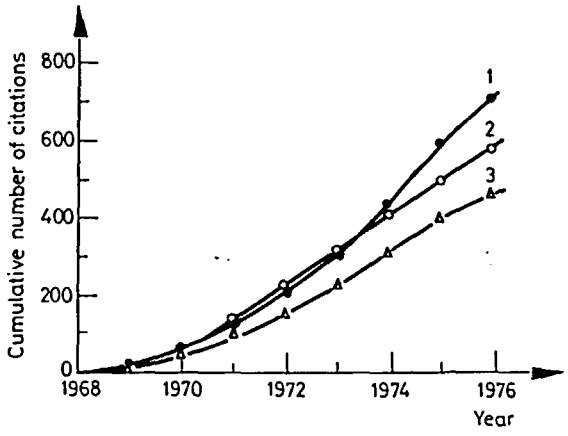

FIGURE 45. Growth of the number of citations to the first three papers on affinity chromatography. Curves: 1, Axén et al.;[82] 2, Cuatrecasas et al.;[84] 3, Porath et al.[83] (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya,* Ser. 1(1), 7 (1979). With permission.)

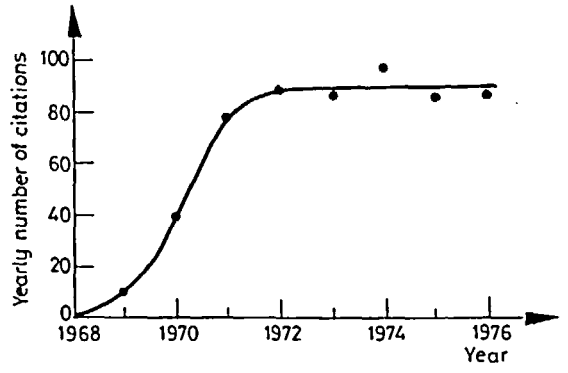

FIGURE 46. Yearly citation rate of the papers by Cuatrecasas et al.[84] (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya,* Ser. 1(1), 7 (1979). With permission.)

Special attention may be devoted to the work of Kara-Murza[81] in which the birth and spread of affinity chromatography is studied by means of citation analysis. Affinity chromatography was established almost simultaneously in Sweden (Axén, Porath, and Ernback[82,83]) and in the U.S. (Cuatrecasas, Wilchek, and Anfinsen[84]). Kara-Murza counted the number of citations to the fundamental papers of the authors and the number of citations to their later papers. The data concerning the publication activity of the authors concerning the method and the extent of scientific relations and links were obtained from the 1968 to 1976 volumes of *SCI.*

In analyzing the "diffusion" of the method it was found that it obeys a logistic model, i.e., in the initial stage of dissemination the dynamics of diffusion speeds up and can be expressed by an exponential curve. The accumulation of citations to the first three publications on affinity chromatography shows this relationship (Figure 45). However, the exponential curves turn quite rapidly into straight lines, i.e., the growth rate of the number of citation becomes nearly constant, which is well seen in the annual citation curve of the paper of Cuatrecasas et al.[84] (Figure 46). This can be attributed to the fact

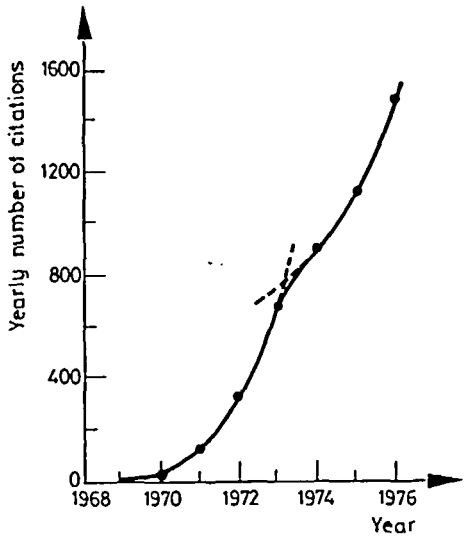

FIGURE 47. Yearly citation rate of papers published by Cuatrecasas after the paper of Reference 84. (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya*, Ser. 1(1), 7 (1979). With permission.)

that the scientists who applied this method referred later to those papers which use affinity chromatography in their specific topic. The original papers are cited only by those who recommend the method for new topics.

The citation dynamics of the first papers on affinity chromatography shows already after the first three to four years how rapidly this method was introduced into the research labs. No doubt that the discoverers became citation recorders. However, the rate of spreading of affinity chromatography can be estimated more thoroughly from the dynamics of the number of citations to all papers of Cuatrecasas published after the appearance of the first (Figure 47).[81]

No doubt, a certain fraction of citations can be found in the papers of those authors who do not utilize affinity chromatography, but have not forgotten the important results discussed by Cuatrecasas in his publications. However, the difference is not great and can be calculated since the main activity of Cuatrecasas after 1968 was the application of affinity chromatography to various fields, which affected his results on his par excellence field of research (enzymology).

Figure 48 shows the dynamics of citation of the papers of Cuatrecasas published until 1968.[81] After 5 years it dropped to half, roughly corresponding to the general laws pertaining to the obsolescence of "normal" scientific literature. The citation maximum of papers leaving the press between 1961 and 1967 appeared in 1970 with 67 citations, i.e., the papers published during 1 year (in the interval investigated) received an average of 10 citations at the time of maximum citation. It is obvious that if this value were subtracted from the number of citations given in Figure 47, this would not affect the parameters of the curve significantly. At any rate, the error is certainly smaller than the number of citations connected exclusively with the application of affinity chromatography, which disappears because in several later publications Cuatrecasas is not the first author, and thus he is not recorded in the *Science Citation Index*.

The citation curve shown in Figure 47 (after subtracting self citations) consists of two exponential sections, which can be observed particularly well in Figure 49 where the curve is plotted in logarithmic form. The number of citations decreases in 1972, but does

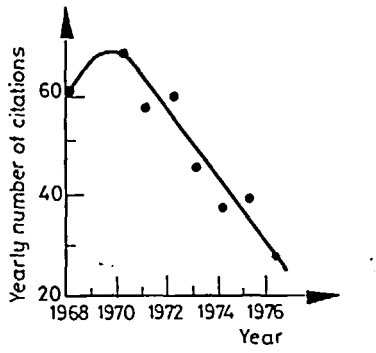

FIGURE 48. Dynamics of citations to papers published by Cuatrecasas[84] until 1968. (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya*, Ser. 1(1), 7 (1979). With permission.)

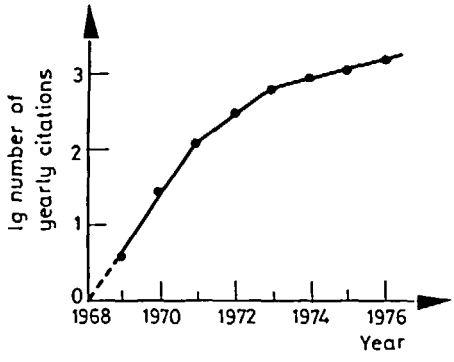

FIGURE 49. Growth of the number of citations to papers by Cuatrecasas published after 1968. (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya*, Ser. 1(1), 7 (1979). With permission.)

not stop. Consequently, the growth rate of publications dealing with the application of affinity chromatography does not show a stabilization tendency. By the end of 1976, the number of citations to the papers in which Cuatrecasas was the first author amounted to more than 5.5 thousands, whereas to the paper of Axén et al.[82] 8 times less! To the paper of Porath et al.,[83] 467 citations were made by the end of 1976. This comparison does not show that the citation rate of the papers of Swedish authors is not high. In spite of this, the absolute number of citations to the two papers[82,83] is tremendous. The growth of citations reflecting the applications of the two variants of the method is shown in Figure 50.

In the first stage of the spread of affinity chromatography, when the authors cited the original papers, most of the citations refer to the authors of both variants. Consequently, in order to determine the true popularity of one or the other variant, half of the citations should be subtracted from the scores of both variants. It is easy to see that this would increase the relative difference between the citation levels of the U.S. and Swedish authors.

The diffusion of the Swedish variant of the method is characterized in Figure 50 by the

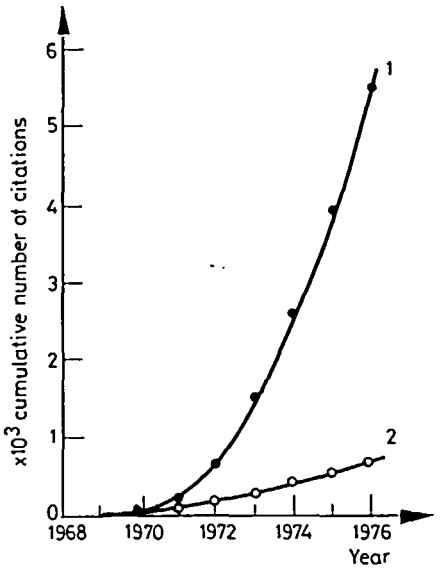

FIGURE 50. Growth rate of citations to the papers of Cuatrecasas (curve 1) and Axén (curve 2). (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya*, Ser. 1(1), 7 (1979). With permission.)

citations to Reference 82, not including the further papers of the authors. This is motivated by the fact that the scientific attention of the authors, if it is judged correctly from the titles of their post-1968 papers, had shifted to another field (immobilized enzymes), and a large number of citations refer to papers that are not related to affinity chromatography. Even if these citations were added, the parameters of Curve 2 of Figure 50 would not change substantially. The works of Axén published after Reference 82 received a total of 365 citations in the whole period up to 1976.

Then what is the explanation of this enormous difference between the propagation of these two, so similar variants? The difference, as it appears, is even more surprising since the paper of the Swedish authors was published 1 year earlier in a first-class periodical, and one of its authors was Porath, who had become known world-wide for being one of the creators, of the gel-filtration method. As can be seen from Figure 45, the papers[82,83] were widely cited immediately after their publication. The differences appearing later can be explained by the fact that Cuatrecasas, unlike the Swedish authors, took part personally and very actively in the use of affinity chromatography for solving of a wide variety of problems. This author assisted several researchers working in various fields of chemistry and biochemistry in solving the difficulties of learning the method that were mostly psychological in nature. He demonstrated the efficiency of the method and organized centers which accelerated the diffusion of the new method. Cuatrecasas played the role of "innovation champion", key figure indispensable in the introduction of a new method. The necessity of such a figure was postulated by Schön,[85] and proved by an extensive investigation of scientific-technical innovation processes. The *Science Citation Index* makes it possible to assess the proportions of the scientific links of Cuatrecasas. Figure 51 shows the "contact map" of the authors of the original paper, not only those researchers with whom Cuatrecasas, Anfinsen, and Wilchek co-authored a paper, but also some prominent co-authors of the co-authors. The basic concept of the map is that the co-author of a co-author is already in the field of the scientific contact of a

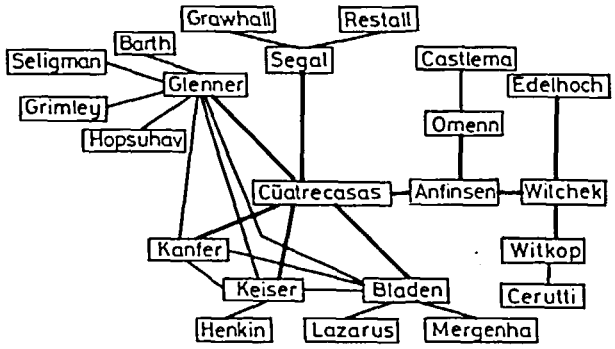

FIGURE 51. Map of scientific connection of Cuatrecasas et al.[84] in 1968. Thick line connects direct co-authors. A single line binds the co-authors of Cuatrecasas, Wilchek, and Anfinsen. (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya,* Ser. 1(1), 7 (1979). With permission.)

Table 44
SCIENTISTS ON THE PROFESSIONAL CONNECTION MAP OF THE AUTHORS OF PAPER 82

Name	Subject field	No. of co-authored papers (1968)
Glenner, G.	Histochemistry	21
Keiser, H.	Antibiotics	6
Bladen, H.	Bioorganic chemistry	4
Kaufer, J.	Lipids	5
Segal, S.	Transport processes	15
Crawhall, J.	Medicine	7
Restall, C.	Anesthesiology	4
Barth, W.	Connective tissues	6
Seligman, A.	Histochemistry	16
Grimley, P.	Cytology, virology	8
Hopsuhav, V.	Enzymology	10
Henkin, R.	Endocrinology (corticosteroids)	9
Lazarus, G.	Connective tissues	6
Mergenha, S.	Polysaccharides (endotoxines)	12
Castlema, B.	Medicine	49
Witkop, B.	Bioorganic chemistry, organic chemistry	27
Cerutti, P.	Bioorganic chemistry	6
Edelhoch, H.	Bioorganic chemistry	6

From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya,* Ser. 1(1), 7 (1979). With permission.

scientist, since they may easily be contacted personally through their common acquaintances. It can be seen in Figure 51 that between Cuatrecasas' co-authors excellent scientists of very diverse research fields can be found. This follows from the data of Table 44, in which the specialties of these scientists and the number of papers they published in 1968 are given. This "co-author map" contains important pieces of information on the connection of the two variants of affinity chromatography. Among the 1968 co-authors

Table 45
PUBLICATION ACTIVITY OF CUATRECASAS AFTER 1969

	Number				
Year	Papers	Total after 1969	Co-authors	New co-authors[a]	Total no. of new co-authors
1970	10	10	12	4	4
1971	21	31	17	6	10
1972	15	46	13	8	18
1973	28	74	15	10	28
1974	22	96	21	9	37
1975	23	119	14	5	42
1976	16	135	16	3	45

[a] Co-authors with whom Cuatrecasas did not co-author papers after 1968.

From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya,* Ser. 1(1), 7 (1979). With permission.

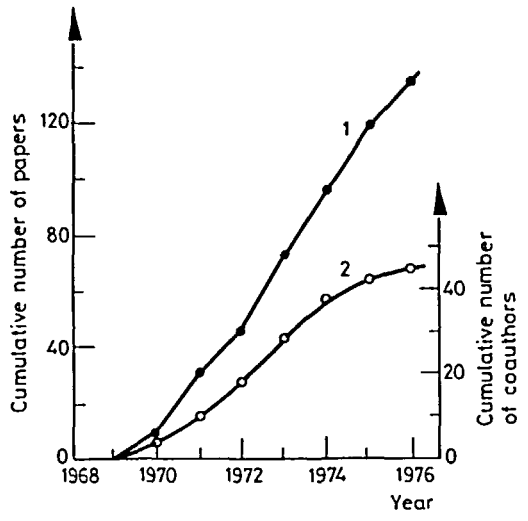

FIGURE 52. Publication activity and scientific links of Cuatrecasas after 1969. Curve 1, papers; curve 2, co-authors. (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya,* Ser. 1(1), 7 (1979). With permission.)

of Wilchek, one can find Witkopf, an expert of bio-organic and organic chemistry who was in 1966 and 1967 co-author of Porath, Axén, and Ernback, the Swedish discoverers.

The 1968 data shown in Figure 51 and Table 44 are enough to characterize the research style of Cuatrecasas, who maintained intense contact with a large number of research groups, which in itself promotes the dissemination of a method. In 1967 he published 13 papers with 15 co-authors. Nevertheless, his activity after 1968 was directed to the diffusion of affinity chromatography in cooperation with several research groups, and publication of numerous papers, with co-authors frequently changed.

Table 45 shows the amount, co-authors, and new co-authors of the publications of Cuatrecasas. Figure 52 shows the growth of papers and new co-authors after 1969.

Although the number of Cuatrecasas' new co-authors is large, of course it is too low to

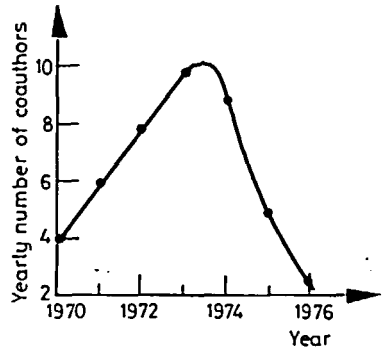

FIGURE 53. Dynamics of Cuatrecasas' scientific links between 1970 and 1976. (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya*, Ser. 1(1), 7 (1979). With permission.)

be processed statistically. The curve shown in Figure 53 reflects the tendency to believe that the number of new co-authors has passed its maximum and in the last years it is decreasing. This is easy to explain; by now the method can be regarded as well known in all basic fields of applications, it is described in detail in handbooks, and is even in the program of undergraduate laboratory practice. The author already has nothing to do with its diffusion.

The activity of the Swedish authors developed in a completely different way. Their publication activity does not change after 1967. During 9 years (1967 to 1976) Axén published 22 papers, many of them in co-authorship with Porath. The latter published 50 papers, but only 16 of them deal with affinity chromatography, the rest of his work is directed mostly towards finding new ways for "anchoring" macromolecules to carriers.

The fact that Axén, Porath, and Ernback published so little on the extension of the application sphere of the method explains why the citation dynamics of their original paper[82] are so different from the pattern shown in Figure 46 and the characteristic of the papers of the American authors. The citation level of this paper[82] increases almost linearly up to 1975 (Figure 54). This is in relation with the fact that all scientists who learned and apply the given variant of the method may cite the paper of Axén et al.[82] only, since there is no paper on the application of the Swedish variant of the method on fields closer to one or another research group, unlike the American variant.

It can be assumed that if a scientist with a broad research profile had introduced the Swedish variant of the method to various fields, the citation of the original paper[82] would have reached saturation. In this case the "propagation agency" of the innovation takes the relay baton from the creators of the method.

It is noted by Laitinen and Ewing[86] that "a method's utilization needs commercial instrumentation for success, regardless of the method's inherent capabilities". This is completed by us with the remark that this not only holds for instrumentation but also for the special reagents, adsorbents necessary for a method. Had the column filling of affinity chromatography not been produced and marketed commercially, the method would not have been applied so widely.

It is worth noting here two other investigations. In one of them Orient[89] deals with citation analysis by the relative efficiency of books dedicated to analytical chemistry. In the other,[90] the same author investigates the scientific legacy of the prominent late Soviet analyst A. K. Babko by scientometrics, primarily citation analysis.

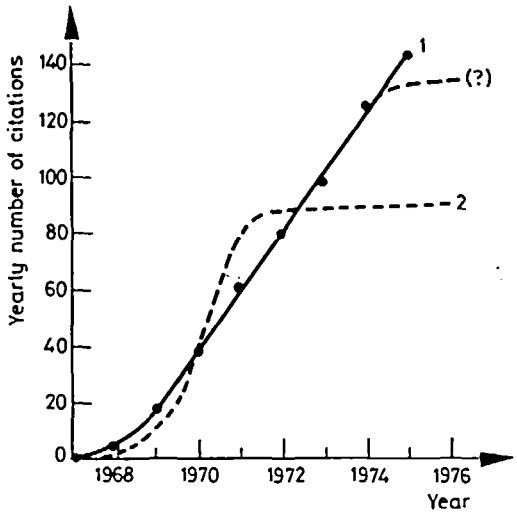

FIGURE 54. Citation dynamics of the first two papers on affinity chromatography. Curve 1, Axén et al.,[82] curve 2, Cuatrecases et al.[84] (From Kara-Murza, S. G., *Nauchn. Techn. Informatsiya*, Ser. 1(1), 7 (1979). With permission.)

C. Citation Classics*

In a 1978 paper, Belcher[91] stated that "at least four chemists have been awarded the Nobel prize for the development of analytical techniques, but it is significant that in each instance the particular technique chosen accelerated the progress of biochemistry."

The correctness of this statement also transpires from two studies by Garfield[92,93] in which a list is compiled of the 100 papers most cited in the *Science Citation Index* for 1961 to 1972. The list, broken into two parts containing 50 papers each, can be seen in Tables 46 and 47. Papers related to analytical chemistry are marked with circles in the lists. We consider it extremely significant that although the list is completely interdisciplinary, i.e., pertains to the entire field of science, 47% of the papers are on the subject of analytical chemistry. We cannot imagine better proof for the support of viability and importance of this subject field.

ACKNOWLEDGMENTS

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* As per the definition of the Institute for Scientific Information (Philadelphia), a "citation classic" is a highly cited publication, as indicated by the *Science Citation Index*. Of course, citation rates differ for each discipline. The number of citations which would make a publication a classic in botany, a small field, might be much lower than the number required to make a classic in a large field like biochemistry. However, one can appreciate the relative impact of each classic by considering that the average article published in a journal covered by *SCI* in 1973 received 5.7 citations, 1973 to 1976.

Table 46
MOST-CITED JOURNAL ARTICLES 1961—1972, NOS. 1—50

Rank	Times cited	Bibliographical data
①	29,655	Lowry, O. H., Rosebrough, N. J., Farr, A. L., and Randall, R. J., Protein measurement with the Folin phenol reagent, *J. Biol. Chem.*, 19 (3), 265, 1951.
2	6,281	Reynolds, E. S., The use of lead citrate at high pH as an electron opaque stain in electron microscopy, *J. Cell Biol.*, 17, 208, 1963.
③	5,825	Fiske, C. H. and Subbarow, Y., The colorimetric determination of phosphorus, *J. Biol. Chem.*, 66, 375, 1925.
4	5,273	Luft, J. H., Improvements in epoxy resin embedding methods, *J. Biophys. Biochem. Cytol.*, 9, 409, 1961.
⑤	5,054	Folch, J., Lees, M., and Sloane Stanley, G. H., A simple method for the isolation and purification of total lipides from animal tissues, *J. Biol. Chem.*, 226, 497, 1957.
⑥	4,932	Bray, G. A., A simple efficient liquid scintillator for counting aqueous solutions in a liquid scintillation counter, *Anal. Biochem.*, 1, 279, 1960.
⑦	4,376	Spackman, D. H., Stein, W. H., and Moore, S., Automatic recording apparatus for use in the chromatography of amino acids, *Anal. Chem.*, 30, 1190, 1958.
8	4,367	Sabatini, D. D., Bensch, K., and Barrnett, R. J., Cytochemistry and electron microscopy; the preservation of cellular ultrastructure and enzymatic activity by aldehyde fixation, *J. Cell Biol.*, 17, 19, 1963.
⑨	3,967	Gornall, A. G., Bardawill, C. J., and David, M. M., Determination of serum proteins by means of the biuret reaction, *J. Biol. Chem.*, 78, 751, 1949.
10	3,621	Lineweaver, H. and Burk, D., The determination of enzyme dissociation constants, *J. Am. Chem. Soc.*, 56, 658, 1934.
⑪	3,464	Davis, B. J., Disc electrophoresis. II. Method and application to human serum proteins, *Ann. N. Y. Acad. Sci.*, 121, 404, 1964.
⑫	3,406	Burton, K., A study of the conditions and mechanism of the diphenylamine reaction for the colorimetric estimation of deoxyribonucleic acid, *Biochem. J.*, 62, 315, 1956.
⑬	2,903	Scheidegger, J. J., Une micro-methode de l'immuno-electrophorese. *Int. Arch. Allergy*, 7, 103, 1955.
14	2,770	Duncan, D. B., Multiple range and multiple *F* tests, *Biometrics*, 11, 1, 1955.
⑮	2,740	Nelson, N., A photometric adaptation of the Somogyi method for the determination of glucose, *J. Biol. Chem.*, 153, 375, 1944.
⑯	2,620	Reed, L. J. and Muench, H., A simple method of estimating fifty per cent endpoints, *Am. J. Hygiene*, 27, 493, 1938.
17	2,293	Dole, V. P., A relation between non-esterified fatty acids in plasma and the metabolism of glucose, *J. Clin. Invest.*, 35, 150, 1956.
18	2,230	Marmur, J., A procedure for the isolation of deoxyribonucleic acid from micro-organisms, *J. Mol. Biol.*, 3, 208, 1961.
19	2,226	Moorhead, P. S., Nowell, P. C., Mellman, W. J., Battips, D. M., and Hungerford, D. A., Chromosome preparations of leukocytes cultured from human peripheral blood, *Exp. Cell Res.*, 20, 613, 1960.
20	2,054	Warburg, O. and Christian, W., Isolierung und Kristallisation des Garungsferments Enolase, *Biochem. Zschr.*, 310, 384, 1941.
21	1,976	Jacob, F. & Monod, J., Genetic regulatory mechanisms in the synthesis of proteins. *J. Mol. Biol.*, 3:318-56, 1961.
㉒	1,905	Martin, R. G. and Ames, B. N., A method for determining the sedimentation behavior of enzymes: application to protein mixtures, *J. Biol. Chem.*, 236, 1372, 1961.
23	1,887	Watson, M. L., Staining of tissue sections for electron microscopy with heavy metals, *J. Biophys. Biochem. Cytol.*, 4, 475, 1958.
㉔	1,885	Bartlett, G. R., Phosphorus assay in column chromatography, *J. Biol. Chem.*, 234, 466, 1959.
25	1,849	Palade, G. E., A study of fixation for electron microscopy, *J. Exp. Med.*, 95, 285, 1952.

Table 46 (continued)
MOST-CITED JOURNAL ARTICLES 1961—1972, NOS. 1—50

Rank	Times cited	Bibliographical data
㉖	1,841	Smithies, O., Zone electrophoresis in starch gels: group variations in the serum proteins of normal human adults, *Biochem. J.*, 61, 629, 1955.
㉗	1,814	Barker, S. B. and Summerson, W. H., The colorimetric determination of lactic acid in biological material, *J. Biol. Chem.*, 138, 535, 1941.
㉘	1,767	Warren, L., The thlobarbituric acid assay of sialic acids, *J. Biol. Chem.*, 234, 1971, 1959.
㉙	1,737	Trevelyan, W. E., Procter, D. P., and Harrison, J. S., Detection of sugars on paper chromatograms, *Nature*, 166, 444, 1950.
㉚	1,695	Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., and Smith, F., Colorimetric method for determination of sugars and related substances, *Anal. Chem.*, 28, 350, 1956.
31	1,662	Eagle, H., Amino acid metabolism in mammalian cell cultures, *Science*, 130, 432, 1959.
32	1,628	Litchfield, J. T., Jr., and Wilcoxon, F., A simplified method of evaluating dose-effect experiments, *J. Pharmacol. Exp. Ther.*, 96, 99, 1949.
33	1,398	Ellman, G. L., Tissue sulfhydryl groups, *Arch. Biochem. Biophys.*, 82, 70, 1959.
34	1,387	Bardeen, J., Cooper, L. N., and Schrieffer, J. R., Theory of superconductivity, *Phys. Rev.*, 108, 1175, 1957.
35	1,384	Andrews, P., Estimation of the molecular weights of proteins by Sephadex gel-filtration, *Biochem. J.*, 91, 222, 1964.
㊱	1,384	Schmidt, G. and Thannhauser, S. J., A method for the determination of desoxyribonucleic acid, ribonucleic acid, and phosphoproteins in animal tissues, *Biochem. J.*, 161, 83, 1945.
37	1,344	Jaffe, H. H., A reexamination of the Hammett equation, *Chem. Rev.*, 53, 191, 1953.
38	1,333	Venable, J. H. and Coggeshall, R., A simplified lead citrate stain for use in electron microscopy, *J. Cell Biol.*, 25, 407, 1965.
39	1,324	Karnovsky, M. J., Simple method for staining with lead at high pH in electron-microscopy, *J. Biophys. Biochem. Cytol.*, 11, 729, 1961.
40	1,317	Karplus, M., Contact electron-spin coupling of nuclear magnetic moments, *J. Chem. Phys.*, 30, 11, 1959.
41	1,305	Gell-Mann, M., Symmetrics of baryons and mesons, *Phys. Rev.*, 125, 1067, 1962.
㊷	1,297	Ornstein, L., Disc electrophoresis. I. Background and theory, *Ann. N.Y. Acad. Sci.*, 121, 321, 1964.
㊸	1,294	Chen, P. S., Jr., Toribara, T. Y., and Warner, H., Microdetermination of phosphorus, *Anal. Chem.*, 28, 1756, 1956.
㊹	1,292	Moore, S., Spackman, D. H., and Stein, W. H., Chromatography of amino acids on sulfonated polystyrene resins, *Anal. Chem.*, 30, 1185, 1958.
㊺	1,278	Schneider, W. C., Phosphorus compounds in animal tissues. I. Extraction and estimation of desoxypentose nucleic acid and of pentose nucleic acid, *J. Biol. Chem.*, 161, 293, 1945.
46	1,239	Mancini, G., Carbonara, A. O., and Heremans, J. F., Immunochemical quantitation of antigens by single radial immunodiffusion, *Immunochemistry*, 2, 235, 1965.
47	1,226	Yphantis, D. A., Equilibrium ultracentrifugation of dilute solutions, *Biochemistry*, 3, 297, 1964.
48	1,214	Dulbecco, R. and Vogt, M., Plaque formation and isolation of pure lines with poliomyelitis viruses, *J. Exp. Med.*, 99, 167, 1954.
49	1,209	Weber, K. and Osborn, M., The reliability of molecular weight determinations by dodecyl sulfate-polyacrylamide gel electrophoresis, *J. Biol. Chem.*, 244, 4406, 1969.
㊿	1,207	Mandell, J. D. and Hershey, A. D., A fractionating column for analysis of nucleic acids, *Anal. Biochem.*, 1, 66, 1960.

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Table 47
MOST-CITED JOURNAL ARTICLES 1961—1972, NOS. 51—100

Rank	Times cited	Bibliographical data
(51)	1,204	Smithies, O., An improved procedure for starch-gel electrophoresis: further variations in the serum proteins of normal individuals, *Biochem. J.*, 71, 585, 1959.
52[a]	1,171	Arnon, D. I., Copper enzymes in isolated chloroplasts; polyphenoloxidase in *Beta vulgaris*, *Plant Physiol.*, 24, 1, 1949.
(53)	1,158	Moore, S. and Stein, W. H., A modified ninhydrin reagent for the photometric determination of amino acids and related compounds, *J. Biol. Chem.*, 211, 907, 1954.
(54)[b]	1,156	Somogyi, M., Notes on sugar determination, *J. Biol. Chem.*, 195, 19, 1952.
(55)	1,152	Hanes, C. S. and Isherwood, F. A., Separation of the phosphoric esters on the filter paper chromatogram, *Nature*, 164, 1107, 1949.
(56)[b]	1,149	Van Handel, E. and Zilversmit, D. B., Micromethod for the direct determination of serum triglycerides, *J. Lab. Clin. Med.*, 50, 152, 1957.
57	1,145	Monod, J., Wyman, J. and Changeux, J. P., On the nature of allosteric transitions: a plausible model, *J. Mol. Biol.*, 12, 88, 1965.
(58)	1,130	Friedemann, T. E. and Haugen, G. E., Pyruvic acid. II. The determination of keto acids in blood and urine, *J. Biol. Chem.*, 147, 415, 1943.
59[a]	1,116	Millonig, G., Advantages of a phosphate buffer for OsO_4 solutions in fixation. *J. Appl. Phys.*, 32, 1637, 1961.
(60)	1,103	Dische, Z., A new specific color reaction of hexuronic acids, *J. Biol. Chem.*, 167, 189, 1947.
(61)	1,100	Hoffman, W. S., A rapid photoelectric method for the determination of glucose in blood and urine, *J. Biol. Chem.*, 120, 51, 1937.
(62)[b]	1,087	Bligh, E. G. and Dyer, W. J., A rapid method for total lipid extraction and purification, Can., *J. Biochem. Physiol.*, 37, 911, 1959.
(63)	1,066	Poulik, M. D., Starch gel electrophoresis in a discontinuous system of buffers, *Nature*, 180, 1477, 1957.
64	1,063	DeDuve, C., Pressman, B. C., Gianetto, R., Wattiaux, R., and Appelmans, F., Tissue fractionation studies. VI. Intracellular distribution patterns of enzymes in rat-liver tissue, *Biochem. J.*, 60, 604, 1955.
(65)	1,061	Bratton, A. C. and Marshall, E. K., Jr., A new coupling component for sulfanilamide determination, *J. Biol. Chem.*, 128, 537, 1939.
66	1,059	Boyden, S. V., The adsorption of proteins on erythrocytes treated with tannic acid and subsequent hemagglutination by antiprotein sera, *J. Exp. Med.*, 93, 107, 1951.
(67)	1,044	Van Slyke, D. D. and Neill, J. M., The determination of gases in blood and other solutions by vacuum extraction and manometric measurement, *J. Biol. Chem.*, 61, 523, 1924.
68	1,029	Millonig, G., A modified procedure for lead staining of thin sections, *J. Biophys. Biochem. Cytol.*, 11, 736, 1961.
69[a]	1,023	Shapiro, A. L., Vinuela, E., and Maizel, J. V., Jr., Molecular weight estimation of polypeptide chains by electrophoresis in SDS-polyacrylamide gels, *Biochem. Biophys. Res. Commun.*, 28, 815, 1967.
70	1,022	Coons, A. H. and Kaplan, M. H., Localization of antigen in tissue cells. II. Improvements in a method for the detection of antigen by means of fluorescent antibody, *J. Exp. Med.*, 91, 1, 1950.
71	1,012	Caulfield, J. B., Effects of varying the vehicle for OsO_4 in tissue fixation, *J. Biophys. Biochem. Cytol.*, 3(5), 827, 1957.
72	1,010	Sever, J. L., Application of a microtechnique to viral serological investigations, *J. Immunol.*, 88, 320, 1962.
73	1,006	Ahlquist, R. P., A study of the adrenotropic receptors, *Am. J. Physiol.*, 153, 586, 1948.
74	1,001	Porter, R. R., The hydrolysis of rabbit gamma-globulin and antibodies with crystalline papain, *Biochem. J.*, 73, 119, 1959.
(75)	994	Dole, V. P. and Meinertz, H., Microdetermination of long-chain fatty acids in plasma and tissues, *J. Biol. Chem.*, 235, 2595, 1960.

Table 47 (continued)
MOST-CITED JOURNAL ARTICLES 1961—1972, NOS. 51—100

Rank	Times cited	Bibliographical data
(76)	990	Sperry, W. M. and Webb, M., A revision of the Schoenheimer-Sperry method for cholesterol determination, *J. Biol. Chem.*, 187, 97, 1950.
(77)	984	Boyer, P. D., Spectrophotometric study of the reaction of protein sulfhydryl groups with organic mercurials, *J. Am. Chem. Soc.*, 76, 4331, 1954.
78	968	Seldinger, S. I., Catheter replacement of the needle in percutaneous arteriography: a new technique, *Acta Radiol.*, 39, 368, 1953.
(79)	961	Abell, L. L., Levy, B. B., Brodie, B. B., and Kendall, F. E., A simplified method for the estimation of total cholesterol in serum and demonstration of its specificity, *J. Biol. Chem.*, 195, 357, 1952.
(80)	960	Boas, N. F., Method for the determination of hexosamines in tissues, *J. Biol. Chem.*, 204, 553, 1953.
81	955	Nirenberg, M. W. and Matthaci, J. H., The dependence of cell-free protein synthesis in *E. coli* upon naturally occurring or synthetic polyribonucleotides, *Proc. Natl. Acad. Sci. U.S.A.*, 47, 1588, 1961.
82	949	Bowden, K., Heilbron, I. M., Jones, E. R. H., and Weedon, B. C. L., Researches on acetylenic compounds. I. The preparation of acetylenic ketones by oxidation of acetylenic carbinols and glycols, *J. Am. Chem. Soc.*, p. 38, 1946.
83	944	Hirs, C. H. W., The oxidation of ribonuclease with performic acid, *J. Biol. Chem.*, 219, 611, 1956.
(84)	928	Sweeley, C. C., Bentley, R., Makita, M., and Wells, W. W., Gas-liquid chromatography of trimethylsilyl derivatives of sugars and related substances, *J. Am. Chem. Soc.*, 85, 2497, 1963.
85	924	Bloembergen, N., Purcell, E. M., and Pound, R. V., Relaxation effects in nuclear magnetic resonance absorption, *Phys. Rev.*, 73, 679, 1948.
(86)	919	Allen, R. J. L., The estimation of phosphorus, *Biochem. J.*, 34, 858, 1940.
(87)	915	Reitman, S. and Frankel, S., A colorimetric method for the determination of serum glutamic oxalacetic and glutamic pyruvic transaminases, *Am. J. Clin. Pathol.*, 28, 56, 1957.
88[b]	908	Cromer, D. T. and Waber, J. T., Scattering factors computed from relativistic Dirac-Slater wave functions, *Acta Cryst.*, 18, 104, 1965.
89[a]	906	Parlser, R. and Parr, R. G., A semi-empirical theory of the electronic spectra and electronic structure of complex unsaturated molecules, *J. Chem. Phys.*, 21, 767, 1953.
90[a]	903	Karnovsky, M. J., A formaldehyde-glutaraldehyde fixative of high osmolality for use in electron microscopy, *J. Cell Biol.*, 27, A137, 1965.
91[b]	896	Higgins, G. M. and Anderson, R. M., Experimental pathology of the liver. I. Restoration of the liver of the white rat following partial surgical removal, *Arch. Pathol.*, 12, 186, 1931.
92[b]	896	Hoffmann, R., An extended Huckel theory. I. Hydrocarbons, *J. Chem. Phys.*, 39, 1397, 1963.
93	894	Clarke, D. H. and Casals, J., Techniques for hemagglutination and hemagglutination-inhibitions with arthropod-borne viruses, *Am. J. Trop. Med. Hyg.*, 7, 561, 1958.
94[a]	894	Davis, B. D. and Mingioli, E. S., Mutants of *Escherichia coli* requiring methionine or vitamin B_{12}, *J. Bacteriol.*, 60, 17, 1950.
95[a]	890	Hales, C. N. and Randle, P. J., Immunoassay of insulin with insulin-antibody precipitate, *Biochem. J.*, 88, 137, 1963.
(96)	875	Peterson, E. A. and Sober, H. A., Chromatography of proteins. I. Cellulose ion-exchange adsorbents, *J. Am. Chem. Soc.*, 78, 751, 1956.
97[a]	871	Roothaan, C. C. J., New developments in molecular orbital theory, *Rev. Mod. Phys.*, 23, 69, 1951.
(98)	869	Bush, I. E., Methods of paper chromatography of steroids applicable to the study of steroids in mammalian blood and tissues, *Biochem. J.*, 50, 370, 1952.

Table 47 (continued)
MOST-CITED JOURNAL ARTICLES 1961—1972, NOS. 51—100

Rank	Times cited	Bibliographical data
99	867	Farquhar, M. G., and Palade, G. E., Junctional complexes in various epithelia, *J. Cell Biol.*, 17, 375, 1963.
(100)	865	Yalow, R. S. and Berson, S. A., Immunoassay of endogenous plasma insulin in man, *J. Clin. Invest.*, 39, 1157, 1960.

[a] These articles achieved their highest citation rate in 1971.
[b] These articles achieved their highest citation rate in 1972.

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21. **Orient, I. M.,** *Zavodsk. Lab.*, 41 (9), 1071 (1975); *Ind. Lab. U.S.S.R.*, 41, 1327 (1975).
22. **May, K. O.,** *Science,* 154, 1672 (1966).
23. **Holt, Ch. C. and Schrank, W. E.,** *Am. Doc.*, 19, 18 (1968).
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29. **Cole, P. F.,** *J. Docum.*, 19, 1 (1963).
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