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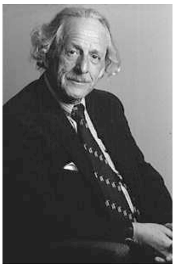

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More Than a Mere Physical Attraction: The 100 Most-Cited Papers from the *Reviews of Modern Physics*

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In celebrating the periodical's 60th anniversary, the 100 most-cited papers from the *Reviews of Modern Physics* are examined. By using ISI® data from the *Science Citation Index*® and *Journal Citation Reports*®, the journal's centrality to the physics literature is detailed. Some of the topics covered include a historical synopsis of the journal's origins and its editors, information on Nobelist authors, as well as multiple authorship and scientific institutions that are represented among the 100 papers.

In October 1928 a letter was sent to 53 prominent American physicists from John Torrence Tate, then editor of the American Physical Society's *Physical Review*. Tate wanted their views on starting a supplement to the journal, which would focus on review papers in the field of physics. Of the 48 correspondents who replied, 46 agreed that such a review publication was necessary.[1] Those who replied included Percy Williams Bridgman (Nobel Prize, physics, 1946), Edward Uhler Condon (codiscoverer of the 1926 Franck-Condon principle of molecular spectroscopy), Irving Langmuir (Nobel Prize, chemistry, 1932), Robert A. Millikan (Nobel Prize, physics, 1923), Robert S. Mulliken (Nobel Prize, chemistry, 1966), and J. Robert Oppenheimer (best known for his role in the development of the atomic bomb).

In July 1929 the first issue of the *Physical Review Supplement* was launched. In 1930 it was renamed the *Reviews of Modern Physics*. For nearly 60 years the publication has been one of the best sources of broad-ranging review articles in physics. According to information scientist and physicist Michael Moravcsik:

> [*Reviews*] has quite frequently during its long existence—most certainly since I have been following it since the 1950s—published "classic" review articles that were instrumental to the development of many of the present high-interest and high-activity physics fields.... [*Reviews*] is definitely one of the top five physics review journals in the world.[2]

The original concept of what a review journal should be has evolved somewhat since the founding of *Reviews*. In the early years, the primary function of the journal was archival. Fields of physics in which there were questions, controversies, or conflicting theories yet to be tested were considered not "ripe" for review and had no place in the journal. However, the explosion of knowledge and the emergence of new and exciting fields of research in the late 1950s and 1960s—too new to be considered proper for an old-style scholarly review—were powerful lures that drew both readers and potential writers away from archival publications.

The size and readership of *Reviews* were in serious decline when the present editor, David Pines, took over the editorship of the journal in 1973. When the journal's board members first invited him to consider the position, he refused, saying that he could hardly be editor of a journal to which he had just cancelled his own subscription. But the members of the board who had invited him convinced him that this was exactly why he was needed.[3] A new policy dealing with publishing scholarly reviews was instituted. In an editorial in April 1974, Pines announced that the editorial board would solicit

> articles on frontier topics in physics which are intended to convey to graduate students, and to physicists in other fields, a sense of why that topic is of great current interest, what progress has been made recently, and what are its likely future directions.[4]

Today, over 10,000 subscribers (nearly 2,600 are library subscriptions) on six continents receive the quarterly journal.[5] The journal has published over 2,000 review papers. On occasion, topics of interest to readers who are not physicists are covered. These have included the safety of light-water nuclear reactors,[6] the feasibility of the Strategic Defense Initiative,[7] and studies relevant to DNA.[8]

Journal Editors

In its almost six-decade history the journal has had a number of influential editors. The first, Tate (1929-1941, 1947), headed the Office of Scientific Research and Development division on antisubmarine warfare during World War II. J. William Buchta (1941-1946, 1948-1951), an expert on metallic crystals, served on the Advisory Committee on Government-University Relations for the National Science Foundation in 1954-1955. Samuel Abraham Goudsmit (1951-1957) was a codiscoverer of the spin of the electron in 1925 and, as chief of the Science Intelligence Mission in Europe, appraised German nuclear-weapon capabilities in 1944-1945. Condon (1957-1968) worked on the Manhattan atomic bomb project and during the mid-1960s worked on a US Air Force project to investigate the UFO phenomenon. Lewis McAdory Branscomb (1968-1973), an atomic and molecular physicist, was active in the late 1960s and early 1970s with CODATA (the Committee on Data for Science and Technology), an International Council of Scientific Unions agency for worldwide data evaluation. Pines, whose career has included pioneering work in quantum plasma theory, condensed matter, neutron stars, and compact X-ray sources, as well as being a past chairman of the National Academy of Sciences (NAS)-Nuclear Regulatory Commission Committee on US-USSR Cooperation in Physics, has been editor since 1973.

Branscomb is well known in the field of information science and science policy. He has indeed had a distinguished career. His *curriculum vitae* includes a 19-year stint at the National Bureau of Standards (NBS), Washington, DC, which included 4 years as director (1969-1972). Other positions include vice-president of research at IBM Corporation, member of the President's Science Advisory Committee (1965-1968), and chairman of the Commission on Scholarly Communications with the People's Republic of China (1977-1980) for the NAS. He now serves as professor of science, technology, and public policy at the John F. Kennedy School of Government at Harvard University, Cambridge, Massachusetts.

In addition to Branscomb, one of the more colorful of the editors was Condon. He began his career as a journalist in 1918, reporting on the development of organized labor for the *Oakland* [California] *Enquirer*. In 1921 he entered college at the University of California, Berkeley, and five years later earned his doctorate in physics.[9]

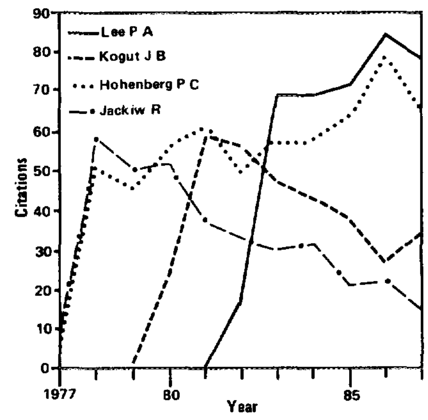
In the early postwar years Condon was a major influence on, as well as an outspoken advocate for, the civilian control of atomic-energy development. His outspokenness made him the target of the House Un-American Activities Committee (HUAC) beginning in 1948, leading to several investigations into his security clearance. American scientists—in a show of support—voted Condon president of the American Association for the Advancement of Science in 1953. In late October 1954 he lost his security clearance because of the activities of HUAC and its partisans, among them then Vice-President Richard M. Nixon.[10] The US Department of Defense reinstated Condon's security clearance in 1965.[11]

In 1957 Condon was appointed editor of *Reviews*, a position that he held for 11 years. In the last issue of *Reviews* for which he was editor, Condon expressed his strongly held beliefs on the importance of review journals:

> There is a special art to the writing of a good literature review paper. I believe that it is not being cultivated as much as it should be in our graduate schools. Every student when he starts on his thesis work ought to have to search the literature, *read* the papers he so retrieves (ridiculous word!) and prepare a critical summary of the present state of the field in which his research is to be done. Later when he reaches post-doctoral status or becomes a young assistant professor he ought to undertake a wider and more sophisticated review of his field. From the best of such materials would be generated a stream of papers which would make the *Reviews of Modern Physics* a much more useful journal than in the past. This...must be regarded as a personal responsibility to be worked on by every physicist who would like to be regarded as part of the research team of the world.[12]

It is hard for me to understand why I was unaware of Condon's strong feelings about reviews—not only when I discussed the importance of reviews in *Current Contents*® 10 years ago,[13] but also in the 1950s when I first explored their special role in knowledge accumulation. I remember well how this "physics" journal was singled out by the advisory committee to the *Genetics Citation Index* project as being important to the emerging field of molecular biology. This multidisciplinary aspect of modern genetics epitomized the policies for journal coverage in the *Science Citation Index*® (*SCI*®).

Figure 1: *Year-by-year citations to the four most recent* papers in the 100 most-cited *Reviews of Modern Physics* papers, 1955-1986 *SCI*®. Articles graphed are: Hohenberg P C. *Rev. Mod. Phys.* 49:435-79, 1977 (522 cites 1955-1986 *SCI*, 65 cites 1987 *SCI*); Jackiw R. *Rev. Mod. Phys.* 49:681-706, 1977 (341 cites 1955-1986 *SCI*, 15 cites 1987 *SCI*); Kogut J B. *Rev. Mod. Phys.* 51:659-713, 1979 (295 cites 1955-1986 *SCI*, 35 cites 1987 *SCI*); and Lee P A. *Rev. Mod. Phys.* 53:769-806, 1981 (308 cites 1955-1986 *SCI*, 78 cites 1987 *SCI*).



Impact and Half-Life Data Confirm Journal's Preeminence

Since 1929 *Reviews* has published about 2,000 papers. For this study, we have identified and examined its 100 most-cited papers as reflected in the *SCI* from 1955 to 1986. (See Bibliography.) Their citation frequencies range from 289 to 2,506, with a median of 527—making them all *Citation Classics*®. Five percent is indeed a very large number of papers to be classified in this category. Ordinarily, one would expect about 1 percent of a journal's output to achieve this distinction. However, it is not unusual for review journals to produce a better-than-average number.

The oldest article in the Bibliography is by Hans A. Bethe, Department of Physics, Cornell University, Ithaca, New York, who won the Nobel Prize in physics in 1967. His 1937 article, "Nuclear physics. B. Nuclear dynamics, theoretical," has been cited nearly 350 times since 1955. (He is, of course, the author of many other *Citation Classics*.)

The most recent paper in the list, "Extended x-ray absorption fine structure—its strengths and limitations as a structural tool," is by Patrick A. Lee and colleagues, Bell Laboratories, Murray Hill, New Jersey. It appeared in 1981 and is the only paper in the Bibliography published in the 1980s. Figure 1, a graph of annual citation accumulations for the four most recent papers in the list, includes this review article.

The citation-frequency distribution for the 655 *Reviews* articles cited at least 50 times in the *SCI* from 1955 to 1986 is shown in

Table 1: Citation-frequency distribution for the 655 articles published in the *Reviews of Modern Physics* with 50 or more citations, 1955-1986 *SCI®*.

Citation Level	Number of Items at Level	Percent of Total Items
≥2,500	1	0.2
1,250-2,499	2	0.4
950-1,249	3	0.5
750-949	6	0.9
600-749	12	1.8
450-599	21	3.2
350-449	22	3.4
300-349	29	4.4
250-299	32	4.9
200-249	52	7.9
150-199	61	9.3
100-149	138	21.1
50-99	276	42.1

Table 1. Since the papers listed are based on only 32 years of cumulated *SCI* data, some older papers that were mainly cited prior to 1955 did not turn up. (The *SCI* for 1945-1954 will be published later in 1988.) Nevertheless, 24 percent of the papers listed were published in the two decades before 1955. Table 2 provides a chronological breakdown. The peak is between 1960 and 1964.

Another way of viewing the long-range influence of a journal is to examine impact and half-life. Impact is a measure of the frequency with which the "average article" in a journal is cited during a specified period of time. The 1986 impact factor for *Reviews* is 27.0, the second highest in the *SCI*. (The *Annual Review of Biochemistry* is first, with an impact of 31.6.) The 1986 impact factor measures how often the average article published in 1984 and 1985 was cited in 1986.

Table 2: Chronologic distribution of publication dates for the 100 most-cited articles from the *Reviews of Modern Physics*, 1955-1986 *SCI®*.

Publication Year	Number of Papers
1935-1939	2
1940-1944	1
1945-1949	8
1950-1954	13
1955-1959	14
1960-1964	21
1965-1969	14
1970-1974	15
1975-1979	11
1980-1985	1

While a journal's impact is an indication of its current influence in the literature, its half-life reflects the pace of obsolescence. Since *Reviews* publishes reviews, one would expect continued citations to its articles over a long period, and thus a relatively long half-life for this journal would not be surprising.

Indeed, in the 1986 *Journal Citation Reports®*, we do find this to be the case. *Reviews* has a long half-life: both with respect to cit*ed* and cit*ing* papers (>10 and 7.4, respectively)—longer than the cited and citing average for the entire *SCI* (6.8). In comparison, *Physical Review Letters*—a journal that publishes brief communications quickly—had 1986 cited and citing half-lives of 4.4, and the *Annual Review of Biochemistry*, 5.6 and 3.9 years, respectively. Cit*ing* half-life refers to the median age of papers that the review articles cite; cit*ed* half-life refers to the median age of the review papers cited by other journals.

Concerning the half-life data for *Reviews*, Branscomb expresses the opinion that

> Your data (7 to 10 years) suggest that something less than immortality but considerably more than fleeting notice can be had by authoring a first-class review. Perhaps scientists should remember that when [*Reviews*] editors are pleading with them to write.[14]

Research Fronts

Probably the most remarkable aspect of these review papers is the continuing role they play in identifying current research-front activity. I cannot help but think of the "Daedalus effect" that Baruch S. Blumberg, 1976 Nobel Prize winner in physiology or medicine, discusses in a recent interview in *THE SCIENTIST®*.[15] As Blumberg notes, science often raises more questions than it answers. This is perhaps most evident in Nobel-class work and in a critical, provocative review article. So it would not be surprising for these classic articles to be cited decades after publication. In Table 3 we have listed the research fronts having three

Table 3: The 1987 *SCI®/SSCI®* research fronts that include three or more citing papers published in the *Reviews of Modern Physics*. (The relatively low citing threshold is due to the small number of papers the journal publishes each year.) Over 400 other research fronts were cited by *Reviews* in 1987. A = number of *Reviews* articles citing the core of each front. B = total number of citing documents. C = total number of core documents.

Number	Name	A	B	C
87-0329	Universal conductance fluctuations, quantum interference in small metallic rings, Aharonov-Bohm oscillations, and disordered conductors	4	353	32
87-0665	Excited weak vector bosons, particle physics at hadron colliders, and standard model	4	218	16
87-0593	Heavy-fermion systems, Anderson lattice model, anisotropic superconducting state, large-N expansion for dilute magnetic alloys, Kondo resonance	3	526	49
87-1525	Neutrino oscillations, exponential solar density profile, and nonadiabatic resonant conversion	3	237	25
87-1757	Lattice QCD, dynamical Wilson fermions, and stochastic quantization simulation of ϕ^4 theory	3	244	22

or more citing papers published in *Reviews* in 1987.

Clearly, even a key journal like *Reviews* could not cover in one year all the myriad topics that physicists investigate. Indeed, it is one of the stated objectives of the *ISI Atlas of Science®* series to use our objective data, in combination with expert opinion, to help our own and other review-journal editors identify the areas most in need of up-to-date reviews.

For it was that special intellectual challenge that my colleagues and I took up over 20 years ago—before it was called artificial intelligence—to combine the use of the human brain with the machine to create not just automatic indexing of the individual document but also a synthesis of the collective output of the invisible colleges. Word processing and electronic publishing have revolutionized the way in which all journals have been produced. But the creative use of the artificially intelligent machine represents the real challenge to and opportunity for the review editor of the future. Two essential ingredients in the selection and creation of timely and relevant topics to review are our compact disc read-only-memory (CD-ROM) version of the *SCI* (*SCI CD Edition*)[16] and the research-front database derived from the *SCI* each year.

The Five Most-Cited Papers

The 5 most-cited papers from *Reviews* have already been identified in our study of the 1,000 most-cited articles in the *SCI*, 1961-1982,[17,18] and include 1 by Chandrasekhar (1943), 2 by Roothaan (1951 and 1960), as well as a paper by Alder and colleagues (1956) and 1 by Lane and Thomas (1958). Five other papers in the Bibliography also appeared in that study—namely, those by Bambynek and colleagues (1972), Bearden and Burr (1967), Burbidge and colleagues (1957), Kadanoff and colleagues (1967), and Kisslinger and Sorensen (1963).

Chandrasekhar

The most-cited paper in the Bibliography, with just over 2,500 citations, is by Subrahmanyan Chandrasekhar, Laboratory for Astrophysics and Space Research, University of Chicago, Illinois. The paper describes "Stochastic problems in physics and astronomy." It is now over 40 years old but continues to be cited frequently. It received about 100 citations in 1987. (Chandrasekhar was awarded the 1983 Nobel Prize in physics, an event we covered in a previous essay.[19]) In a letter commenting on his classic paper, Chandrasekhar states that:

> In 1941 I became convinced that a proper treatment of stellar encounters must be along the lines of the theory of Brownian motion. With this application in view, I began an earnest study of the classical papers of Smoluchowski, Einstein, Planck, Langevin, and others. And since I could find no extant account dealing with all these matters coherently and systematically, I wrote an account for myself; and while writing the account I thought that

I was able to generalize existing treatments and discover new relations—albeit minor. I was not sure whether my account should be published; but John von Neumann, to whom I showed the account, strongly encouraged me to do so. And that was how the paper came into being. And it is satisfying to know that the efforts one takes in science to learn for one's self can also be helpful to others.[20]

Roothaan

Clemens Carel Johannes Roothaan, Department of Physics, University of Chicago, wrote "New developments in molecular orbital theory" in 1951. Since 1955 the paper has been cited in over 2,400 papers and continues to be quoted today—45 times in 1987.

A graph of the citations to Chandrasekhar's and Roothaan's most-cited papers appears in Figure 2. Roothaan's other paper, the fifth most cited in the list, "Self-consistent field theory for open shells of electronic systems," has been cited in 1,165 articles since its publication in 1960.

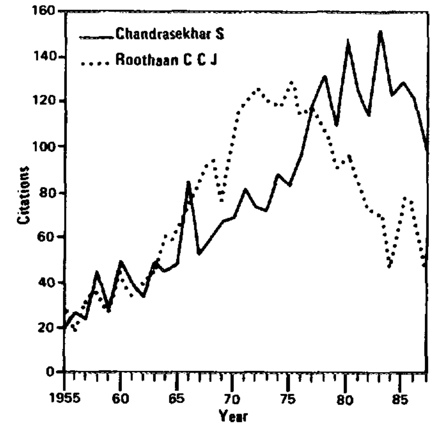
Alder and Colleagues

The third most-cited paper is a multiauthored work that was published in 1956. Kurt Alder, Aage Bohr (1975 Nobelist in physics), Torben Huus, Ben Mottelson (1975 Nobel laureate, physics), and A. Winther, CERN Theoretical Study Division, Geneva, Switzerland, and Institute for Theoretical Physics, University of Copenhagen, Denmark, authored a "Study of nuclear structure by electromagnetic excitation with accelerated ions." Citations to this paper have reached 1,320.

Lane and Thomas

The fourth most-cited paper, "R-matrix theory of nuclear reactions," is by Anthony M. Lane, Theoretical Physics Division, Atomic Energy Research Establishment, Harwell, UK, and R.G. Thomas, formerly of the Los Alamos Scientific Laboratory, New Mexico. Published in 1958, it has been cited in over 1,230 subsequent publications.

Figure 2: Year-by-year citations to the two most-cited *Reviews of Modern Physics* papers, 1955-1986 *SCI*®. **Solid Line**=Chandrasekhar S. *Rev. Mod. Phys.* 15:1-89, 1943 (2,506 cites 1955-1986 *SCI*, 102 cites 1987 *SCI*). **Broken Line**=Roothaan C C J. *Rev. Mod. Phys.* 23:69-89, 1951 (2,430 cites 1955-1986 *SCI*, 45 cites 1987 *SCI*).



Nobel Author Information

Studies at ISI have demonstrated that Nobel Prize winners consistently publish one or more classic papers. The record for *Reviews* confirms this. Among the authors of these 100 works are 15 Nobelists—11 from the US, 2 from Denmark, and 1 each from the People's Republic of China and the UK. The oldest paper by a laureate in the journal (which is also in the Bibliography) is the 1937 piece by Bethe, mentioned earlier. The most recent paper by a Nobelist is by Kenneth G. Wilson (physics, 1982), Cornell University, which was published in 1975. It has been explicitly cited in over 435 publications. Richard P. Feynman (physics, 1965), who died earlier this year, was an author of two of the papers in the Bibliography. He was also a member of the commission that investigated the space shuttle *Challenger* accident in 1986. It should be added that *Reviews* publishes the acceptance address of every Nobel laureate in physics, a practice that was instituted by the current editor in 1973.

Several readers have written to me to complain that our *Citation Classics* selections are biased in favor of older papers. But the fact is that, more often than not, the year of publication is biased *against* the selection of older papers. As the literature grows, the number of papers that reach a given threshold increases. A modern "equivalent" to the papers published by Bethe and others will have to be cited four or five times as often. Back in 1950, a *Citation Classic* might have been cited only 100 times, whereas today we find thousands of papers at that frequency. It is not unusual that some of the "golden oldies" will not be cited even 100 times in the *SCI*—not only because we do not yet have the citation information for the postwar years, but also because some of these papers were affected by the "obliteration phenomenon."[21] In other words, they became part of the common wisdom and did not require formal citation each time the phenomenon was mentioned or discussed.

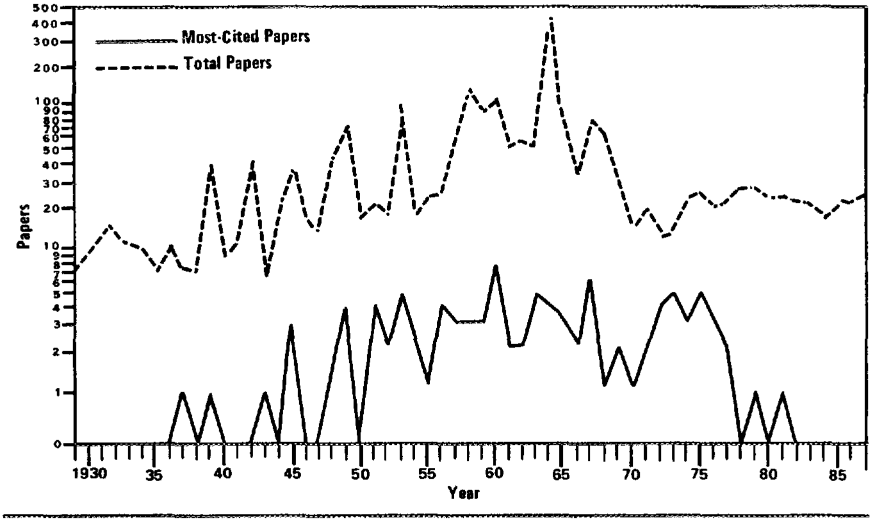
Table 4: The number of authors per paper for the 100 most-cited articles from the *Reviews of Modern Physics*, 1955-1986 *SCI*®.

Number of Authors per Paper	Number of Papers
10	1
8	2
6	1
5	1
4	3
3	8
2	33
1	51

Multiple Authorship and Age of Papers

In the past 20 years various scholars have noted a growing trend toward multiple authorship of scientific papers. In the field of physics, multiple authorship is becoming more and more common as scientific projects involve larger and larger numbers of researchers. For example, the average number of authors for the most-cited articles in the physical sciences for 1983 and 1984 was 11.3[22] and 8.9[23] per paper, respectively. In this study, however, the average is less than two—51 papers had one author. Only a few of the rest had more than five or six authors. (See Table 4.) The average of 1.9 for review papers is significantly lower than the typical

Figure 3: Year-by-year publication of *Reviews of Modern Physics* papers. **Solid line**=number of most-cited papers. **Broken line**=total number of items published in *Reviews*. Conference proceedings account for the high publication rates in peak years, such as 1958 (141 items), 1960 (117 items), and 1964 (425 items).



research paper in physics and other fields. This is because the aim of a review is to give a unified overview of a subject, a goal best accomplished by one person. For *Reviews*, the policy is that, generally, papers are solicited from a single author, who is left free to choose collaborators if desired. Frequently, a theorist will choose an experimentalist, or vice versa, to cover the side of the literature that he or she is less familiar with.

Publication dates for the majority of the papers in the Bibliography are clustered rather heavily into just 15 years, with nearly half (49) of the articles published between 1955 and 1969. A graphic depiction of the distribution of the 100 papers by year against the total number of papers published annually by *Reviews* appears in Figure 3.

Geographic and Institutional Information

There are 73 unique institutions listed as affiliations by the authors of the 100 most-cited papers. The top six are, in descending order (with the number of occurrences in parentheses): the Murray Hill facility of Bell Laboratories (10); the University of Chicago (10); Cornell University (6); the Argonne National Laboratory, Lamont, Illinois (5); the NBS (5); and the University of California (represented by three campuses—Berkeley, 3; Irvine, 1; and San Diego, 1). According to Branscomb, the fact that the Argonne and Bell laboratories are in the top six indicates that scientists there believe it is either their moral duty or it is important to their work to write good reviews.[14] He comments further that

> I believe both are true. Much university work is forced into a series of quick reconnaissance missions, about the size of a PhD thesis. With a brilliant faculty member and a clever student, wonderful things can happen. But the great new syntheses of knowledge do not often happen that way.... At places like the [NBS] scientists are encouraged to be very thorough and very careful, and select long-range goals worthy of the effort. A review may play a significant role in such a strategy.[14]

Table 5: Geographic areas represented by the institutional affiliations given by authors in the Bibliography, listed in descending order by the number of papers produced (column A). B = number of papers coauthored with researchers affiliated with institutions in other countries. C = national locations of institutions listed by coauthors.

Geographic Location of Institutions		A	B	C
United States		85	8	Belgium, Canada, FRG, Japan, UK, Switzerland
Illinois	19			
New Jersey	15			
New York	15			
California	13			
Massachusetts	7			
Washington, DC	6			
Connecticut	5			
Maryland	5			
Pennsylvania	3			
Colorado	2			
Ohio	2			
Oregon	2			
Tennessee	2			
Arizona	1			
Georgia	1			
Iowa	1			
Michigan	1			
Minnesota	1			
Missouri	1			
Nebraska	1			
New Mexico	1			
Oklahoma	1			
Rhode Island	1			
Texas	1			
Wisconsin	1			
UK		8	3	Australia, US
Canada		3	1	US
Denmark		3	0	
FRG		3	2	US
Switzerland		3	1	US
Japan		2	1	US
Australia		1	1	UK
Belgium		1	1	US
France		1	0	

The 73 institutions represented are located in 10 countries. (See Table 5.) The US accounts for the vast majority of papers—85. However, the gap between it and the two next most-listed countries—the UK and Canada—is not consistent with population and other factors. About 35 percent of the reviews published today are from non-US authors, and the geographical spread is broader than that of the 100 most-cited papers, including good representation from the USSR.[24]

Conclusion

The *Reviews of Modern Physics* has clearly played a major role in the development of modern science. While it would seem that fewer experimentalists these days find the time and energy to write for review journals, writing reviews continues to be an increasingly important activity for the scientist with a more global view of his or her discipline.[25]

* * * * *

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