

DISTILL OR DROWN: THE NEED FOR REVIEWS

The information explosion sparks a need for creative synthesis of facts and ideas. For efficient access to good science literature we must devise new schemes for compression.

CONYERS HERRING

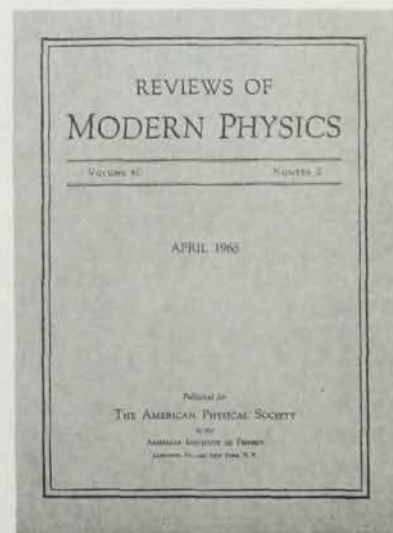
By now there can hardly be a physicist who has not been jolted by the challenge of the information explosion. Some men have been so overcome that they have given up subscribing to *The Physical Review* for lack of shelf space. The widespread concern about this challenge has been reflected in a number of recent articles in *PHYSICS TODAY* and in similar discussions in magazines of other fields and other countries. Among the great bulk of physicists diverse attitudes prevail: Some remain happy in a speciality narrow enough so that they can feel "in the swim" if they keep in touch with a few colleagues and read a highly specialized journal; others rationalize with

the comment that most of the literature is garbage anyway; a few pin their hopes on the vast improvements being made by their documentalist colleagues in the science of indexing and retrieval.

I would like to argue that in most cases such attitudes represent little more than wishful thinking, but that even so the situation is still far from hopeless. Specifically, the theses to be presented are as follow: Today's information crisis is indeed qualitatively different from anything in the past; it threatens to slow the progress of science significantly; creative synthesis and compaction of facts and ideas are essential if this threat is to be parried;

the manpower—or brainpower—needed to do a worthwhile amount of this synthesis in physics could be made available without major disruption of the lives and careers of physicists.

Some of these points have been made before by highly respected persons.^{1,2} But the ideas have usually emerged only as opinions of able and experienced men, and such opinions are likely to be shrugged off by those who are indifferent or disagree with them. What I shall attempt here is to put at least a part of the argument on a roughly quantitative basis. Hopefully this approach will stimulate more thought and better discussion in the physics community. Such thought



and discussion are urgently needed if we are to find effective ways to improve production and use of reviews.

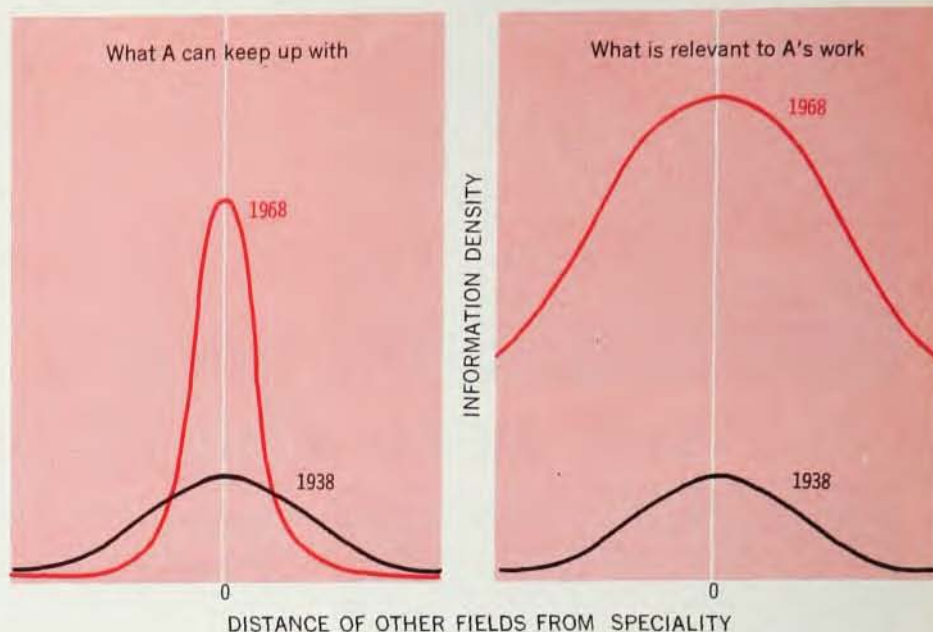
Times have changed

Let us begin with a look at how the amount of available literature in fields close to a given man's speciality has changed in the last three decades. The total amount of such literature that this man—call him "A" for short—can skim through, in a month for example, probably has not changed very much because there are still only 24 hours in a day, 30 days in a month. But the distribution will, in most cases, have changed greatly, as shown schematically by the two curves in the left-hand part of figure 1: Since there is now five to ten or more times as much literature published in most fields as there was 30 years ago, most workers have had to narrow greatly the range of topics they keep abreast of. Thus the full curve for 1968 is much higher and narrower than that for 1938, though of roughly the same area.

So what? In 1900 the curve was much lower and broader than in 1938, in 1850 much more so, and so on. Scientists and scholars have always complained of their inability to keep up with new developments that interest them. Why should we think our difficulties today are any different from those of earlier generations? The answer is that these curves must not be



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DISTRIBUTION OF INFORMATION. Left, various fields of information that "A" can keep in contact with. Right, information relevant to "A's" work. —FIG. 1

considered by themselves: They must be compared with another set of curves giving the amount of information available in each subfield that is relevant to A's work. Such curves are shown, again schematically, as the two curves at the right of figure 1. Here there is no conservation of area. The colored curve for 1968 is not only higher than the one for 1938, but also wider because different fields of science are becoming more interrelated. As a few familiar examples of recent interrelationships, one can cite nuclear matter and superconductivity, neutrino detection and astrophysics, and ultrasonics and Fermi surfaces. It is clear how today differs from the past: The colored curve (for most A's) has become much narrower than the black one.

Garbage or gold?

The concepts related to figure 1 of course need a great deal of refining. For example, it is one thing to state that there is a huge amount of material in print with some sort of relevance to A's speciality, and quite another to say that A needs to know about most of this material to do his work effectively. We are thus led to ask the next question: How valuable is the physics literature now being published, and how long will its value last? In particular, how much is wrong, how much is trivial, and how soon is the rest outdated by improv-

ed measurements or better theories?

It is quite possible to find quantitative answers to these questions. For example, one can take a random sampling of papers published at any particular time and ask one or more very qualified experts to classify a paper into one of the categories listed in figure 2, which range from "wrong" through "trivial" to "classic." If the experts are well chosen and are not asked to evaluate their own work or that of their close associates, the resulting distribution should be fairly meaningful, though perhaps with a little bias to the low side.

I have made a small-scale study of this sort in solid-state physics. The study suggests distributions over the scale of value roughly of the form shown by the curves of figure 2. At the time of publication a small proportion of papers are wrong (and therefore deserve a negative rating on the scale of value), a somewhat larger number have nearly zero value, and the majority make an identifiable positive contribution to the advancement of science. As time passes, nearly all regress in value towards zero: Papers of negative value become less harmful (and therefore less negative) as their fallacies become increasingly apparent; those of positive value lose some of their value as they become more and more outdated. Thus the distribution of a given set of papers over the scale

of value changes as indicated by the evolution of the black curve of figure 2 into the colored curve. The shape becomes more peaked about a point near zero, but the area, by definition, remains the same. (In fact, the areas of the positive and negative portions remain individually almost unchanged.) The important point, however, is a semiquantitative one: According to the evidence from my solid-state sample, nearly half of all papers published retain significant value—that is, are not out of date or superseded—even after 5 years have passed. It is likely that a similar figure applies to most other areas of physics, though apparently there are a few areas where the yield is lower or the gold is rarer.

Thus the literature is not all garbage: There is a lot of gold in it. True, many a paper containing valuable information also contains some nonsense or presents its case very poorly. This fact is perhaps the source of the widespread contempt physicists have for the writings of the bulk of their fellows. But the good stuff is nevertheless there, and there is a lot of it. To do our work with optimal efficiency, we ought to be able to make contact with the fraction—still quite vast—of this which is relevant to our own work. How?

Limitations of the grapevine

The scientific grapevine (personal conversations, correspondence, preprint exchanges, etc.) is frequently cited as the research worker's most efficient

tool for information exchange. It has even been argued³ that formal publication is far less important as far as actual communication of ideas is concerned and is necessary only to satisfy needs for prestige, self-satisfaction and so forth. Although it appears to me that this view grossly misrepresents the present situation in physics, one must concede that the grapevine is remarkably effective and often very quick, thanks to its informality. But it has obvious shortcomings. For one thing, it is not equally accessible to all. The junior worker or the man at a small institution is likely to miss out because of his limited contacts. Worse yet, the specialist in one field has difficulty making contact with the grapevine of another area; this difficulty impedes the interdisciplinary activity that is so greatly needed now, as revealed in the width of the colored curve in figure 1.

But these shortcomings are not all. The documentation literature contains indications that the grapevine falls far short of optimal effectiveness, though it is relied on more and more as scientists become discouraged with the torrent of published literature. About as good an illustration of this as I know is provided by an experience of my own, which, as I have discovered, closely matches similar experiences of some of my colleagues on the American Institute of Physics Reviews and Compilations Subcommittee (see box). A few years ago the pressure of other duties forced me to suspend, for about

a year, my usual habit of browsing through the current literature. A year or so afterward I started to go back over the journals I had missed. Out of the few hundred articles whose titles were of most interest to me, a sizable majority had not come to my attention through any other channel during the year or two subsequent to their appearance. Moreover a large proportion of the ones I had learned about had come to my attention from citations in more recent papers rather than from preprints or word of mouth.

The experience described above can undervalue the grapevine a little because the figures referred to published papers with interesting titles rather than to ideas evaluated as especially important. However, several other kinds of evidence suggest that the undervaluation is not by a large factor. Thus I feel reasonably certain that in most areas of physics even a well known scientist with many friends would miss a large amount of potentially valuable information if he relied solely on the grapevine.

Retrieval systems

Fortunately most good physicists do not try to rely on the grapevine alone. They scan titles of a large number of articles, either in the journals themselves or in current-awareness publications like *Current Papers in Physics* and *Current Contents*; to extract information from the past or to develop competence in a fresh field they track down citations and consult treatises, compilations, review articles and bibliographies. These two types of activities, which the documentalists call, respectively, "current awareness" and "retrospective searching" have so far been rather separate from each other, except for their intertwining through the grapevine. Subject indexes (for example, those of *Physics Abstracts* and *The Physical Review*) have played only a minor, though by no means negligible, role in the retrospective search activities of most physicists; the new tool provided by citation indexes is only beginning to be used. Exciting new developments are foreseeable in the near future, however, both in the intellectual structure of indexes⁴ and in the extremely rapid and flexible coupling of user to file that electronic computers make possible.^{4,5} These developments can be applied not only to retrospective

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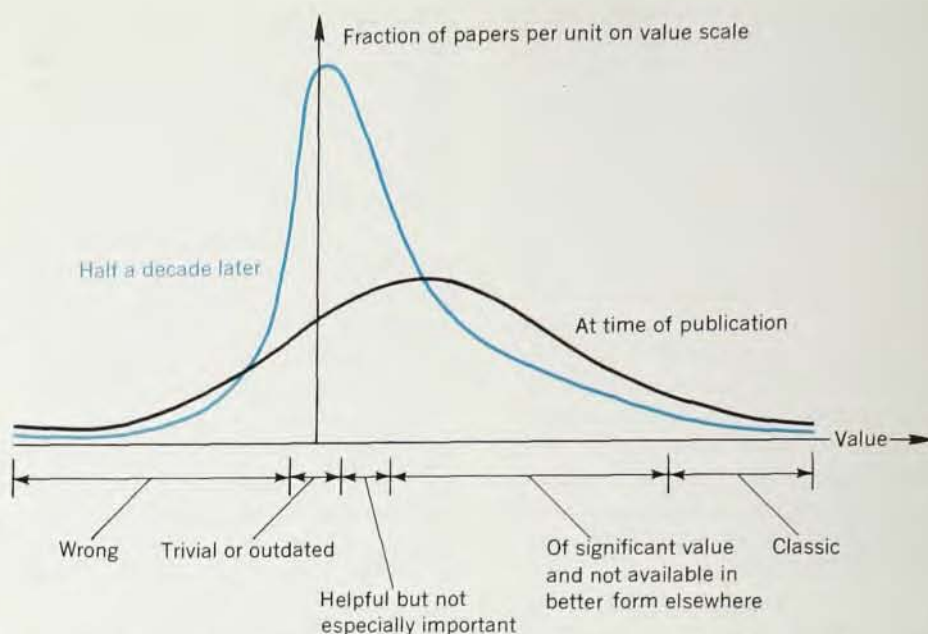
The Advisory Committee on the AIP Information Programs was set up early in 1967 to advise AIP regarding its various information-directed activities. The Advisory Committee has three subcommittees including the Subcommittee on Reviews and Compilations. Members of the Advisory Committee include Richard B. Bernstein, *The American Physical Society (Division of Chemical Physics)*; Sanborn C. Brown, *Chairman (American Association of Physics Teachers)*; Philip M. Morse, *APS (Division of Electron and Atomic Physics)*; Francois N. Frenkiel, *APS (Division of Fluid Dynamics)*; David W. McCall, *APS (Division of High Polymer Physics)*; Thomas Lauritsen, *APS (Division of Nuclear Physics)*; Arthur H. Rosenfeld, *APS (Division of Particles and Fields)*; Jay L. Hirshfield, *APS (Division of Plasma Physics)*, and Conyers Herring, *APS (Division of Solid State Physics)*. Other members include Edward E. David, Jr., *Acoustical Society of America*; Marshal H. Wrubel, *American Astronomical Society*; Robinson Burbank, *American Crystallographic Association*; Lucien Biberman, *Optical Society of America*, and Ronald S. Rivlin, *Society of Rheology*. Members of the Subcommittee on Reviews and Compilations are Conyers Herring, *Chairman*,* Edward L. Brady, Robinson Burbank,* Francois N. Frenkiel,* Thomas Lauritsen,* Howard N. Reiss, Ronald S. Rivlin,* Stephen J. Smith and Katharine Way.

*Members of the Advisory Committee and the Subcommittee

searching, but also to current awareness by automatically calling to the user's attention articles that match his interest profile.

Can such measures solve the problem posed by the flood of information? I am hopeful that they can help a great deal, though many difficulties are yet to be overcome before we have an operational system that will take adequate account of the diversity of individual interests and real-life situations. But even if these document-retrieval measures can be made to work perfectly, they will provide the user with no more than a set of papers relevant to a particular topic of interest. If there are only a few such papers (and none has been missed), fine. But what if there are hundreds that often disagree with one another?

Let me take an example from a recent experience of my own. A topic of considerable interest to me is that of quantum transport theory in high magnetic fields, that is, electronic transport in metals and especially in semiconductors, in magnetic fields large enough to make the Landau-level spacing of the order of thermal energy or larger, so that the use of a semiclassical Boltzmann equation is not valid. The number of existing papers on this topic is by now quite large, close to 150. A typical paper consists of a dense texture of commutators, Green's functions, Laplace transforms and other formal devices; it may take a competent theorist hours or even days to see what the author is trying to do. Some of the papers are wrong, and others duplicate one another but conceal the duplication with different terminologies and notations; yet most of them contain some contribution of value, and in fact it is impossible to select any small subset of the 150 whose members between them cover all valuable contributions of the entire set. These contributions are of interest not only to theorists, but also to experimentalists. How are they to be made accessible? Clearly they will never be fully accessible to the great bulk of potential users until they are evaluated, condensed, and presented simply. This is, in fact, quite possible to do: Practically all that is of value in the 150 papers could be presented, *ab initio* and understandably, in something like a tenth the total pages of the original items. (Two or three recent reviews illustrate this



VALUE OF PUBLISHED PAPERS ranges over a scale that includes wrong, trivial and classic work. Papers that are wrong have negative value. —FIG. 2

fact, though only for a portion of the material.)

Although the example cited may be extreme, it is illustrative of the basic limitation of retrieval systems, a limitation that will become more and more painful as the literature continues to expand: The user may be presented with so many items relevant to his interest that he cannot digest them.

Creative synthesis

Thus an essential ingredient is lacking both from the grapevine and from retrieval systems: *No set of information tools is going to enable the scientist to make full use of our information output unless it includes some means for digesting, evaluating and above all condensing the scattered bits of valuable material into coherent and comprehensible packages.* Concepts, as well as facts, must be retrieved. This service can only be provided by treatises, review articles and critical compilations. Even these publications can do the task adequately only if their authors invest a great deal of thought—and really *creative* thought—in their preparation. There is a genuine intellectual challenge in this kind of activity: After all, science consists in the creation of simplicity out of the complexity of nature, and it is scarcely less of a feat to create new simplicity out of the complexity of the literature. More physicists need to devote more

time to the problems of synthesis, however, and they need to learn how to make the product more accessible and useful to its users. Let me turn, therefore, to a semiquantitative survey of the prospects for progress in this direction.

Present review literature

I should start, of course, with a look at the present review literature of physics. How much of it is there? A scholarly treatment of this question would require elaborate definitions of the boundaries between physics and other disciplines and of those between reviews and popularizations or elementary texts. This task would be too great for this article. Fortunately, however, the issues of interest to us require no more than rough figures. Some estimates, derived from article listings in *Physics Abstracts*, from book listings in *PHYSICS TODAY* and *Nature* and from rough corrections for omissions in these listings, are shown in the left-hand half of figure 3. It will be seen that the review literature of interest to research workers amounts to about 70 000–80 000 pages a year, that is, almost a third as many pages as the primary literature. About two thirds of this review literature consists of treatises (books giving unified treatment of a single subject); over half of the remainder is taken up by review articles in hardcover or paperback col-

lections; compilations account for about a tenth of the total and review articles in periodicals for the final tenth. Omitted from the figures, though not of negligible impact, is the review material often put in the introductions of research papers.

One's first reaction to such figures is likely to be, "If there's so much review literature, why plead for still more?" Actually, however, the type of review most needed—that which is both comprehensive and critical—comprises only a small fraction of the present page total. Although material below the level of utility to research workers has already been omitted from the figures, what remains still includes lectures for graduate students, brief reviews at conferences, unevaluated summaries of annual progress in special fields and so forth. Each of these types of review has its place because there are many kinds of users with different needs. Thus each area of research must be reviewed in several different ways; overlap is unavoidable, but a given scientist should be able to cover a given area at the level appropriate to his needs by reading only a fraction of the total review literature in this area.

Page-bulk figures alone, of course, do not tell us much about the adequacy of today's review literature. What we really need to know is how well it retrieves and describes to its users the really significant items that abound in the primary literature. I have tried to study this question with a few experiments in solid-state physics. I shall not discuss these studies in detail here; suffice it to say that they suggest that our present review literature is considerably, but by no means hopelessly, deficient in its coverage. On the one hand, the review literature falls considerably short of being a substitute for, or even an infallible guide to, the important ideas and facts in primary literature more than five years old. On the other hand, it does at least refer to nearly all the important ideas by the time they are this old and gives reasonable discussions of a great many of them. Thus one can hope that review literature can be made reasonably adequate with a moderate expansion of its total bulk if it can be more efficiently distributed over the different levels and kinds of reviews needed by different classes of users. An important element of the

picture is the accessibility of the review literature. Even if there is a 90% probability that some item of interest to a user is discussed somewhere in the review literature, the situation is not very satisfactory if there is only a 30% chance of his finding such a discussion in any of the places that he thinks to look. Although I have no figures to present on this question, my feeling is that it is serious, and that upgrading of our review literature is as much a problem of improving accessibility and redirecting efforts now being expended as it is a problem of increasing quantity. Some evidence in support of this view will emerge from the studies of use discussed below.

Patterns of use

How, then, do physicists use their review literature? What are the characteristics of the reviews that are most widely used? Of those reviews that are found most useful, who uses them? One can obtain partial answers to these questions from citation studies, interviews and so forth but one must not dismiss the possibility that books and reviews that are not widely cited, perhaps not even widely read, can nevertheless exert a considerable influence by way of the grapevine.

Bearing this limitation in mind, let us look at the pattern of citations of different types of review material. The right half of figure 3 shows how the citations to the different types of review literature in solid-state physics were distributed in a sample of solid-state articles in *The Physical Review*. Some interesting conclusions are suggested by comparison of the relative numbers of citations to the different categories with the relative amounts of material in these categories (roughly the same for solid-state physics as shown on the left of the figure for the whole of physics). Although treatises are cited most often, their preponderance is not as great as might have been expected from their extreme dominance of the page bulk. Instead the ratio of numbers of citations to treatises and to articles is roughly the same as the ratio of numbers of primary articles cited in these two types of review literature. This ratio differs from the page ratio because the average number of citations per page is about a third as great for treatises as

for articles. A potentially more important conclusion is suggested by a comparison of citation rates for different types of review articles. Relative to the total existing bulk of articles of different types, there are many more citations to review articles in review journals (most notably *Reviews of Modern Physics*) than to such articles in other journals, and many more citations to review articles in books of standard "progress" series than to those in conference reports or one-of-a-kind books. These differences do not appear to be due to differences in density of references in the various types of review articles.

Two other studies confirm this user preference for review articles in review journals or in "progress" series. One is a study of citations, in the world literature, of review articles in various categories written by one and the same author. The other study is a set of replies that I have obtained from a number of my colleagues in answer to the question, "What books or reviews have you found especially useful as sources for information about developments in your field during the last decade?" So the effect is real enough. Doubtless it is due largely to the greater conspicuousness of material published in review journals or "progress" series; in addition, however, it may well reflect a preference of users for the more thorough and scholarly type of article. In any event, there appears to be ground for the exhortation: *Authors of review articles should try to avoid wasting their time preparing sketchy reviews for publication in out-of-the-way places.*

Authors are not overloaded

Expanding the quantity of review literature will require a greater investment of time by many good scientists; so will an improvement of quality. Thus it is pertinent to ask how much effort is currently being put into the preparation of treatises and review articles, and whether a significant expansion of this effort would cut seriously into research productivity. I recently interrogated a sample of about two dozen solid-state physicists, who were fellows of the American Physical Society, concerning treatises and reviews that they had written in the last two decades. If one counts all such material that the authors regard as having value to research workers, the

average production rate of this group of authors is 16 pages of review material per man per year. A comparison of the total number of pages of such solid-state review material produced annually in the US (about 10 000) with the number of solid-state physicists over 30 who are fellows or are destined to become fellows suggests, however, that the average production rate of this potential author population is rather smaller than the figure of 16 pages per year. One must conclude that review writing is still far below the level that would constitute a serious drain on the time of the entire population of people who have the technical expertise required for such writing.

One must recognize, of course, that not all physicists who are competent in research make good writers of reviews. But even competent writers do not appear to be grossly overworked. In my sample there were several authors whose review articles were extremely widely cited; yet the only author of the whole sample who had averaged more than 50 pages per year was a young man who had written a book in the few years of his activity included in the study.

Making time available

Despite the rather small average amount of time that physicists invest in review writing, most workers who

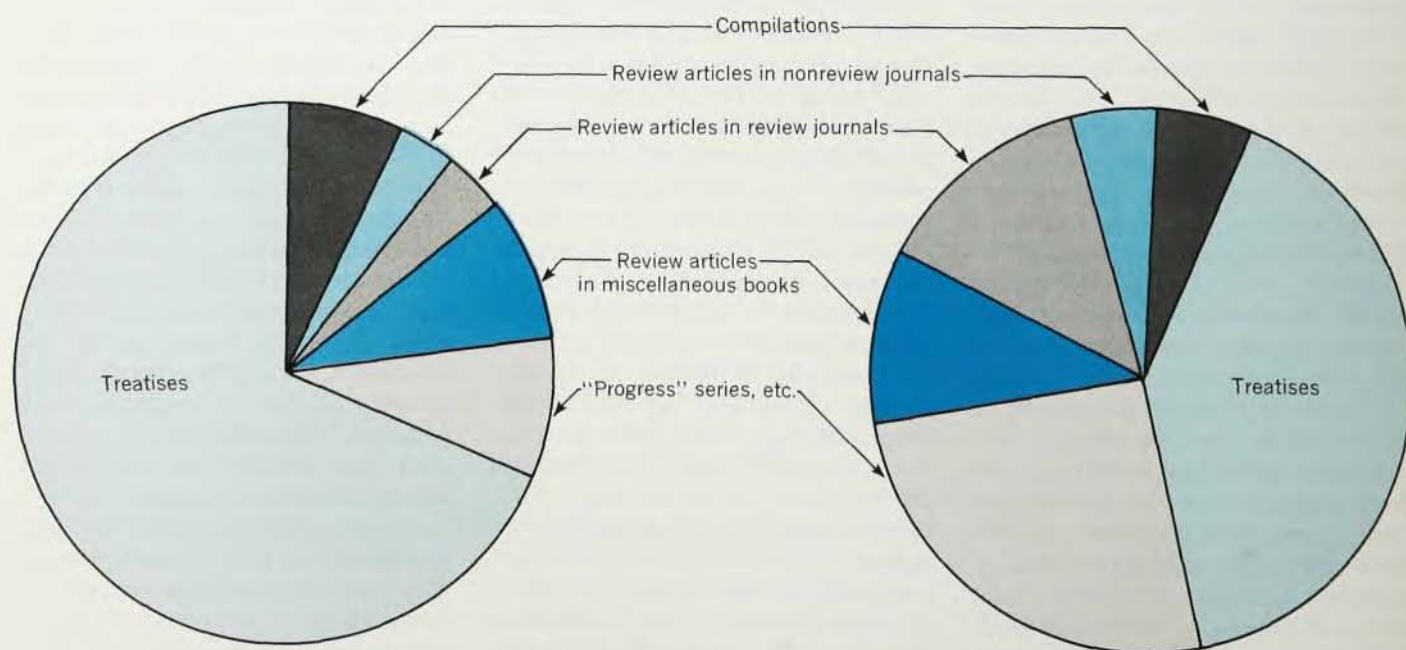
are active in research are reluctant to undertake it. They usually feel that a given amount of work invested in review writing earns less reward, in terms of prestige, than the same amount invested in original research. Also, it is difficult to interrupt research activities for a period of several months or more, especially if one is working closely with colleagues or students. Yet if physics is to avoid being drowned in its own products, ways *must* be found to clear away these impediments to review writing.

Though there is certainly a need for daring innovations and large-scale projects (if workable) directed to this end, the possibilities of modest and gradual measures should not be ignored either. The prestige of review writing will increase as the use of reviews increases. Use, in turn, can be improved by education of potential users (in graduate schools and elsewhere) and especially by training authors and editors of review publications to construct review writings in a way that will make use easy and rapid. To ease the burden on authors, all possible steps should be taken by editorial offices, scientific societies and information-analysis centers to relieve authors of bibliographic and clerical routine, even to the extent of subsidizing assistants working at the authors' institutions.

Direct subsidy of authors has been

much discussed. Money talks, of course. But subsidy funds, governmental or private, are going to be very limited until they can be augmented by direct financial support from users. Among physicists with whom I have talked there is a strong feeling that to obtain the most results for the fewest dollars one should direct the subsidy at the author's time and prestige. One appealing suggestion that is actually being tried in some other areas of science is the awarding of fellowships for review preparation. Awards can be made by a distinguished board as a recognition of especial merit. The honor thereby conferred can encourage the recipients' institutions to relieve them of other duties or permit them to take a sabbatical elsewhere. Another suggestion, probably worth implementing though of limited scope, is that prizes be awarded for outstanding reviews.

Most exciting to me would be the development of ways whereby a senior author possessing both critical judgment and expository skill could draw on the detailed expertise of a number of his colleagues to review a wider area than he would be able to cover all by himself. Since writing would be done by the senior author, one would have to provide the colleagues with adequate credit for their contributions as well as with financial support.



1966 REVIEW LITERATURE in all fields of pure physics is distributed on the left. Right, distribution of citations in a sample of solid-state papers in *The Physical Review*. —FIG. 3

An interesting suggestion, made to me recently by Simon Pasternack, is that graduate schools might make a practice of awarding a PhD for a comprehensive critical review of some field that is prepared under the supervision of a mature scientist and contains a significant amount of really creative synthesis.

Information-analysis centers

A key role, both in the channeling of support for review writing and in the direct preparation of reviews and compilations, can be played by specialized information-analysis centers. Such a center consists of one or more active specialists whose task is systematically to collect, index and store published literature and other information in a given field and then to analyze and evaluate the contents in appropriate ways. Over a hundred such specialized information centers are already being sponsored by various technical agencies of the federal government⁶ in government laboratories, universities and other places; a significant fraction for these centers is in areas relating to physics. Other such centers operate under entirely private sponsorship. In most cases literature resources of the center are available for specialists outside the center.

These centers already produce critical reviews, evaluated data compilations, indexed bibliographies and other special products. Many of them provide an ideal working situation for scientists from other institutions who may work on their premises temporarily during preparation of reviews and compilations; they may even support such scientists financially. Although we are still far from the day, envisaged in the report of the Weinberg panel,⁷ when specialized information centers are the prime retailers of information to scientists, the role of these centers in synthesis and compaction is sufficiently promising to merit vigorous support.

Readers are human

It is not enough, of course, to put reams of review literature on library shelves. It must be used. To this end one must educate scientists in its use, one must make it easy for the user to find review material of value to him, and above all one must see that each book or review article is organized for quick and efficient use.

User education must not only inform users about the value of reviews and about how to find and read them; it must also teach the users to recognize and consciously reduce the large hysteresis that occurs in the adaptation of their habits to changing situations. (An example of this hysteresis is that American solid-state physicists cite reviews in *Soviet Physics—Uspekhi* much less often than the ones in *Reviews of Modern Physics*, though there is more material in the former journal, and, according to my own judgment and that of several colleagues, it compares favorably in quality. The time delay in translation appears not to be a factor.)

More important, however, is the education of authors and editors; for it is they who are responsible for making reviews useful and economical of time for their readers. There is room for improvement in many directions: writing abstracts, prefaces or opening paragraphs that clearly state the scope of the review and the audience to which it is addressed; thorough cross referencing from one review to other reviews; optimal organization of primary papers cited. Especially important is recognizing that *most users of books and reviews use them piecemeal*: They do not read them from beginning to end but seek out for perusal portions pertaining to the topic that interests them at the moment. Probably much of the present underutilization of review material is because of the difficulty of quickly extracting useful information from the middles of books and articles.

Our responsibility

Considering the tremendous need for distilling valuable knowledge from the vast flood of primary literature and resynthesizing it into more compact and usable form, the present level of effort in this direction appears inexcusably puny. I shall take one final example from my own field. The Pake Report⁸ estimated that in 1964 the total of public and private funds spent on research (excluding technological applications) on the physics of solids and other condensed matter was in excess of \$180 million. By contrast, the total value of authors' time plus supporting services (loaded salaries) invested in the production of review literature in the US in this year probably did not exceed \$1 million.

This figure is, in fact, only a fraction of the estimated cost of the mere mechanics of composing, printing and mailing the 50 000 or so annual pages of US primary literature in the field.

Surely, salvaging intellectual content merits a higher proportion of the total investment. Not only funding agencies and university and industrial administrators, but also the great bulk of physicists must realize that *the support society gives to the conduct of research is justifiable only insofar as there is acceptance of the obligation not only to publish the results as they are found, but also to boil down these results and consolidate them into usable syntheses*. Many types of people, with various roles, will have to contribute many ideas, big and small, if this obligation is to be fulfilled.

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This article owes its genesis to many discussions of the review-literature problem with members of the subcommittee on reviews and compilations of the Advisory Committee to the American Institute of Physics information program, with members of the AIP staff and others. Distill or Drown is being published simultaneously in the Bulletin of the Institute of Physics and the Physical Society.

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