Research Comparisons

Some limitations of international comparisons of research and development expenditures are considered.

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Originally introduced as a technical term in international trade theory (*1*), the expression *technological gap* has passed into general use as a loose description of the disparities in scientific and technical resources and attainments, or in the levels of technology in use, between Western Europe and the United States (*2*). Interest in this subject was stimulated by the first systematic measurement of research and development manpower and expenditures in the principal West European countries, for the period 1955–1962. I and two of my colleagues at the National Institute of Economic and Social Research (NIESR) used these data to make an experimental comparison between the scale of organized research and development in the United States and in a group of West European countries (Belgium, Britain, France, Germany, and the Netherlands) (*3*). This study was supported and published by the Directorate for Scientific Affairs of the Organization for Economic Cooperation and Development (OECD), which had taken the initiative in stimulating measurement of scientific activities in Europe and in attempting the standardization of definitions and methods (*4*). We also attempted in the experimental study to make comparisons with the Soviet Union, and in this work we cooperated with R. W. Davies, director of the Centre for Russian and East European Studies in the University of Birmingham (England), and two of his colleagues.

We were at pains to point out the provisional nature of our estimates and the numerous pitfalls involved in making international comparisons of this sort. Moreover, we emphasized that our figures related only to *inputs* into research and development activities, and that no satisfactory measures existed for the *outputs* of R & D. We did not ourselves use the expression *technological gap*, although we did emphasize the considerable disparity between the resources committed to R & D respectively in the United States and in the group of five West European countries. This was indeed the principal conclusion of the survey. European and American economists had long since established the existence of very large disparities between per capita productivity in U.S. and West European industry, and large disparities in fixed assets per man employed. But until the 1960's the lack of usable statistics had made it impossible to obtain any systematic confirmation of large disparities in R & D inputs between European countries and the United States. The evidence of these disparities did not in general surprise economists or industrialists, but it did excite considerable political interest (*5*).

Our experimental comparison related to the year 1962, but since then more reliable data have become available and the OECD has organized the International Statistical Year for Research and Development. This will make available, for more than a dozen countries, comprehensive statistical data much more firmly based than the data of our experimental study. Since the results obtained during this International Statistical Year will be published within a few months, it would be pointless to make detailed unofficial estimates, which would necessarily be less accurate and less complete than the OECD data. However, enough is known from information already published by member countries to justify the view that the figures for 1964–65 essentially confirm the order of magnitude of our experimental estimates for 1962.

If the new comparison of the situation in the U.S. and West Europe is based on data for the same group of five European countries that we considered in our experimental comparison, then the U.S. expenditures at official exchange rates are found to be approximately four times as great as the West European expenditures. If the comparison is based on data for the countries of the European Economic Community (EEC) (that is, with Italy and Luxembourg added to our original group and with Britain excluded), then the U.S. expenditures are found to be about six times as great as the West European expenditures. Even if all the European Free Trade Association (EFTA) countries and all the EEC countries are included in the comparison, the U.S. expenditures are found to be more than three times as great. The population of the United States in mid-1965 was 194.6 million as compared with 179.4 million for the EEC countries and 97.8 million for the EFTA countries.

However, a number of important qualifications must be considered, especially in relating R & D comparisons to more general technological and economic data. Comparisons made at official exchange rates overstate the real differences in resources committed, because some factor inputs are cheaper in Europe than in the United States, especially scientific manpower. From the limited data available, and with the assistance of international firms experienced in R & D operations on both sides of the Atlantic, we estimated "research exchange rates" for the principal European countries and the United States (*3*, p. 91). These suggested that the cost of performing R & D in European countries was between half and two-thirds of the cost in the United States. This difference has diminished since 1962, but R & D costs are probably still about one-third lower, on the average, in Western Europe than in the United States. If allowance is made for this difference, then the disparity ratio for inputs from the United States and Western Europe would be about 4 (for the comparison based on EEC data) or 2 (for the comparison based on EEC data plus EFTA data).

Second, a large part of the R & D expenditures in both the United States and Europe are actually oriented primarily not toward economic growth but toward other policy objectives: mili-

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tary, prestige, welfare, and cultural goals. The proportion of total R & D directed toward military and prestige objectives is much higher in the United States than in Europe, and we have no satisfactory measures of "spin-off" effects on the economy.

Third, R & D inputs are not necessarily related to R & D outputs, and even if they are related, there may be major differences in the "productivity" or "efficiency" of R & D between different countries, as there undoubtedly are between different firms.

Fourth, it is obvious that a firm, an industry, or a country which starts from rather primitive levels of technology can make fairly rapid economic advances by assimilating and applying what is already well known in more advanced countries. Intercountry differences are so great that this process of assimilation may continue for decades. Adaptive R & D can be relatively cheap as compared with work at the world frontiers of science and technology, although some R & D is needed even for "absorption." Thus the technological level already attained and the economic maturity of each country will be major factors affecting both the opportunities and the needs for R & D. Finally, there are many conditions for economic growth which must be satisfied, of which technical progress is only one, and there are many conditions for technical progress, of which adequate research and development is only one.

Consequently, to describe or to understand a "technology gap," one must go beyond comparisons of R & D inputs, valuable though these may be. Many aspects of these complex relationships between R & D, technology, and economic growth have been analyzed by Carter and Williams in the United Kingdom (*6*), and, more recently, by Nelson, Peck, and Kalachek in the United States (*7*). Here I concentrate on clarification of a few selected aspects and on the direction of future research.

"Input" and "Output" of Research and Development

All science policy is concerned in some sense with optimizing the "output" or "effectiveness" of resources committed to scientific and technical activities. Thus the relationship between "input" and "output" is a critical question for policy makers at all levels. Every scientist and engineer is familiar with stories of "accidental" discoveries and inventions and with examples of major scientific and technical advances achieved with very small resources. There are also examples of massive resources squandered with very little tangible result. It is tempting to generalize from these examples and to conclude that rationality in the allocation of resources to research and development is an unattainable goal. If the relationship between input and output is completely arbitrary, then the measurement and comparison of inputs has little relevance for policy making. It must be admitted that very little progress has been made in measuring or even defining the output of research and development.

But, as Machlup has pointed out (*8*), there are some good reasons for rejecting a completely skeptical or nihilistic attitude toward what he describes as the "production function" for inventive activity. All economists are familiar with production functions involving very wide deviations from the norm. Agriculture is a classic example. Soil conditions, climatic conditions, pests, and many other factors may result in output variations per unit of input which are enormous from farm to farm, from year to year, and from country to country. But it by no means follows that it is impossible for farmers to pursue a rational strategy in relation to their inputs of labor, land, fertilizers, and capital equipment. Luck plays its part, but so does good management. Second, it is evident that many managers of research and development behave "as if" they were farmers. These include policy makers, who are obliged to operate almost entirely on criteria of profitability and survival. Science policy or the management of research and development are much younger arts than agriculture, but they are already beginning to get results which justify the assumption of some degree of rationality. Thus, Mansfield, who has made perhaps the most thorough empirical investigations of industrial R & D in the United States, concluded (*9*):

> Although the pay-out from an individual R and D project is obviously very uncertain, there seems to be a close relationship over the long run between the amount a firm spends on research and development and the total number of innovations it produces.

Carter and Williams, who made several studies of industrial R & D in the United Kingdom, also concluded (*10*):

> Given reasonable skill and judgment, it is very broadly true that the more resources you devote to R and D the more results you will get out.

It is important to bear in mind that the "output" of research and development is seldom wanted for its own sake. Strictly speaking, the output of R & D is a flow of ideas, information, models, and prototypes. Only where science is being supported as a cultural end in itself or for some prestige purposes is this sufficient for the policy maker. But, generally, society supports science for other, more utilitarian ends, which may be economic, welfare, military, or prestige goals. If the output of R & D simply remains at the stage of research papers, blueprints, or models, then it is almost useless for most of the purposes of science policy. To move from discoveries and inventions to innovations (whether in the economic, military, or welfare fields), a whole series of further steps is necessary. So far as economics is concerned, we owe this distinction between "invention" and "innovation" primarily to Schumpeter. It is an extremely inportant one. In Schumpeter's sense, "innovation" occurs only when the first commercial transactions involving the new product or process have taken place. It is obvious that the role of the entrepreneur (whether in a private or a public organization) is crucial in moving from invention to innovation. Theoretically, it is clearly possible to have a highly productive R & D system but a disproportionately small flow of economically successful innovations and a slow rate of diffusion. This could occur, for example, if the standard of scientific and technical competence was high but the quality of business management was low. It could occur if the scale of enterprises was inappropriate to the R & D results and possibilities, or if the production, investment, and marketing functions were divorced or remote from the R & D activities. This might itself be the result of bad management. But it might also be the result of institutional barriers. Therefore, in relating R & D comparisons to technological and economic progress it is necessary to take into account the innovation and imitative process as a whole and to measure as many aspects as possible. Let me give two examples.

The Examples of the U.S.S.R. and the United Kingdom

Part of the following analysis is necessarily speculative, but there are good grounds for believing that, both in the Soviet Union and in Britain (though for rather different reasons), the flow of profitable innovations and the speed of their diffusion has been somewhat disappointing, in relation to the input of resources into growth-oriented R & D and probably also in relation to the "output" of R & D. In our experimental study we made two estimates for Soviet R & D inputs, of which the higher figure was greater than the figure for the United States, in absolute terms (*3*, sec. III and appendix II). It now seems probable that even the higher figure was an underestimate, due to insufficient allowance having been made for the amount of research and development at plant level, in design organizations, and in technological institutes. This would mean that the Soviet Union had the largest R & D system in the world, both in relation to population and national income and in absolute terms. It may be that a very large proportion of the total resources are committed to military, space, and nuclear research and development. So far as can be guessed, the efficiency in this sector is fairly high. But there is evidently considerable dissatisfaction among Soviet scientists and economists over the performance of the civil R & D system in relation to the economy. Increasingly, this criticism has focused on the inadequacy of the innovation process. Until recently, not only have there been some strong disincentives for innovation on the part of plant management but there have also been major problems of communication between the specialized industrial institutes, in which development and new design are concentrated, and the enterprises which they serve. Many examples have been cited in the Soviet press of R & D "output" which could not or did not find application in the economy, or which did so only after inordinately long delays. A systematic comparison of development lead times between the United States, the U.S.S.R., and other European countries would be difficult to make, but the available evidence suggests that, outside the military-space complex, Soviet lead times compare unfavorably with lead times for the other countries. Both Soviet sources and Boretsky's study (*11*) have shown that there has been very slow progress in the diffusion of many important technological innovations. In the last 2 years a number of reforms have been carried out with the object of improving communication throughout the R & D innovation system and of strengthening the incentives to make innovations at plant level (*12*).

Table 1. Nobel prize awards in natural science. [From M. Macioti (*17*)]

Period	U.S.	U.S.S.R.	United Kingdom	Germany	France	Italy	Japan
1901–1920	3	2	8	21	11	2	
1921–1940	11		14	16	5	1	
1943–1965	52	7	23	10*	3	2	2
Total	66	9	45	47	19	5	2

* West Germany only.

In Britain, while the resources committed to research and development are higher both absolutely and relatively than those in any other West European country, the performance of the economy has been disappointing. For reasons explained above, there is no simple or direct relationship, and it is quite possible to explain the relatively slow rise in productivity in terms of factors which are only distantly related to R & D input or output. Kaldor (*13*) has laid great stress on the limited elasticity of supply of manpower for manufacturing industry, while Beckerman (*14*) has pointed mainly to the damaging effects on investment of low demand expectations arising from the deflationary remedies repeatedly used to deal with the balance of payments problem. Other economists have pointed to the excessive overseas military expenditure and overseas investment as important contributory factors in the balance-of-payments constraint. Some sociologists and economists, such as Barna (*15*), have emphasized the shortcomings of British marketing and management; others (*16*), the inadequate supply of technologists and technicians, and deficiencies in their training. The process of economic growth is so complex that there is probably some degree of truth in all of these explanations. They are not mutually exclusive. They would explain Britain's relatively slow growth even if her research and development were extremely efficient.

In fact British achievements in fundamental research do seem to have been remarkably good. While the award of Nobel prizes is not a satisfactory measure of "output" of fundamental research, it does provide a very rough (and reasonably impartial) guide to the most outstanding achievements. Britain is the only large West European country which has consistently improved her performance in this respect over the past 60 years, and while the rise of the United States as a recipient of Nobel prizes has been even more remarkable, British attainments still exceed those of the United States in relation to the country's size and resources (Table 1). It is often suggested that there is a marked contrast between British achievements in fundamental research and her performance in technology (*17*). There is strong evidence of a relative neglect of technology over the past hundred years, particularly in the educational system (*18*). There have been several major reforms since World War II, such as the development of the Colleges of Advanced Technology and their integration into the university system. More recently there has been the establishment of a strong Ministry of Technology. But these reforms have been belated, and there has been a persistent shortage of qualified technologists and technicians, and generally too low a priority for technology.

However, it would be wrong to write off British postwar technological achievements. There is no award equivalent to the Nobel prize in the area of technology to serve as a measure of achievement, but it would be difficult to construct a representative list of technological innovations in which Britain did not rank fairly high. Among her outstanding technological achievements have been advanced nuclear reactors, vertical-takeoff aircraft, hovercraft, jet engines, marine and aircraft radar, automatic landing systems, computer-controlled machine tools, several important new chemical processes and products, the float glass process of plate-glass manufacture, and, most recently, the revolutionary spray process of steel-making. Several of these achievements were ahead of anything else in the world at the time of their introduction.

Partly as a result of this, Britain has a small surplus in her "technological balance of payments" (*19*)—the difference between her receipts for technological know-how and licenses and her outgo. It has been said that Britain spends too little on foreign know-how (*20*), but there is not a great difference between the amounts spent, respectively, by Britain, France, Germany, and Japan. British receipts are larger than receipts of any of these countries. Nevertheless, the commercial profitability of major innovations has often been disappointing, and an early lead in design and in first deliveries has often been lost within a few years or at the time of the "second-generation" products. The failure appears to have been more in exploitation and in follow-through than in original design and development. The inquiries made into the electronic capital goods industry and the plastics industry at the National Institute of Economic and Social Research threw some light on the reasons for this weakness (*21*). These inquiries investigated the scale of the British firms' research and development in relation to the total innovation process, including export performance, of the other principal manufacturing countries. The electronics study showed the weaknesses in integration of development, production, and marketing in some British firms—weaknesses reflected in longer lead times and poor marketing strategy. It also showed the great importance of economies based on large-scale operation (economies of scale) for some complex engineering products. These economies arise not so much in production as in marketing and in development, especially second-generation development. For other new products, such as plastics, economies of scale in production may also be very important.

Jewkes and others (*22*) have shown that, in the early stages of the invention process, small teams and even single individuals often make major advances. At this stage there is often little to be gained by large-scale operations, but once a new product or a new model moves to full-scale development, trial production, and marketing, economies of scale may be of critical importance. The new small innovating firm often has an initial advantage of a stock of scientific capital and know-how brought by individuals from another environment. But this is soon used up and must be replenished by organized R & D. Like the 19th-century entrepreneur, the advanced small firm today often has the advantage of well-integrated management which may be lost by the specialization involved in separation of R & D and technical departments in the larger firm. If the management of innovation is not well integrated, then it is quite possible for those concerned with one stage of the process to ignore or disregard the needs, the advice, and the scale requirements of those concerned with the later stages. The NIESR inquiry revealed several examples of electronic developments, in Britain and in other European countries, which, although successful from a technical point of view, were completed with an almost total disregard for the subsequent marketing and technical service requirements and opportunities. Not surprisingly, they were commercial failures (*23*). Cottrell has maintained (*24*) that there has been a general tendency in British R & D to invest in projects somewhat too large for the available resources, and that an appropriate strategy for Britain would be concentration of resources on smaller and medium-sized projects. Others, including the Prime Minister, have emphasized the need for a wider European market and for joint European-scale R & D for some science-oriented industries (*25*).

Patterns of Innovation

These examples illustrate the need for quantitative analysis not only of R & D inputs but of many other aspects of the innovation and diffusion process. In order to make R & D data more useful as a basis for science policy, and to understand "technological gaps," it is necessary to measure a variety of related scientific and technical activities and to link the R & D information more systematically with other data affecting the policy goals which are being pursued, whether by firms or governments. The social and economic framework in which the R & D system is operating must always be considered. This point was forcefully made by Sir Solly Zuckerman in his Science of Science Foundation lecture (*26*). He pointed to the relatively greater success of American firms in "that part of the innovation process which comes after the research and development has been done."

Successful innovations often demand management qualities of a high order. Not only must the innovating entrepreneur (whether public or private) calculate and assume a variety of risks beyond those of normal business investment, he must overcome many resistances to changes, both within his organization and outside it. He must be prepared for systematic education and training, both of his own staff and of the staffs of his customers; he must often provide technical services and assistance far beyond those normally offered; he must deal with quite novel problems of standards, specifications, and codes; he must often design and install new equipment to produce a new product; he must cope with the inevitable "bugs" which attend any major new development; he must deal with security, patenting, and licensing problems; and he must coordinate closely the work of the development, production-engineering, marketing, and other divisions, which may not easily work together.

Ben-David (*27*), in an interesting secondary analysis of Jewkes's data on major 20th-century inventions, provides supporting evidence for the view that American industrial management has been generally stronger than European in moving from invention to successful innovation. Of those inventions which could be attributed almost entirely to work in one country, 19 were made in the United States and ten in either Britain, France, or Germany—a "disparity" between the U.S. and Europe of about two to one in major inventions. But of the innovations flowing from these inventions, 22 were successfully made in the United States and seven in the European countries—a "disparity" of three to one. There may be objections to choice of this particular sample of inventions, but this type of quantitative approach is necessary for resolving some of the issues involved in the complex chain leading from research to innovation (*28*). Among the many factors which may help to explain the U.S. competitive advantage in innovation are (i) the economies arising from greater availability to the innovating firm of specialized manpower, components, and equipment, and (ii) the elasticity of demand for many new products, resulting from high per capita income. Some European firms have found it more profitable to launch new products first of all on the American market, because the requirements for specialized manpower could be more easily met in the United States and because the higher level of per capita incomes created a much greater possibility of rapid expansion of sales. The highly developed U.S. "research-innovation" system in the military sector has been well analyzed by Krauch (*29*); this system has probably helped to raise the professional standards of "innovation management."

Some scientists have stressed "social need" and the "demand" side very strongly in their treatment of both scientific research and innovation, and, among economists, Schmookler has made an outstanding contribution on the influence of demand on patterns of patenting and invention (*30*). But he has been careful to emphasize (*31*) the interdependence of the "two blades of a scissors," and the need to take into account the supply side as well as market demand. The history of economic thought provides examples of the limitations of a one-sided analytical framework concentrating exclusively on either demand or supply factors. Case studies of inventions and innovations provide evidence of the critical importance of factors such as the scale of effort, the enthusiams and other personality traits of scientists and inventors, advances in knowledge in related fields of effort, and normative forecasting and planning by entrepreneurs. Marx pointed out that what distinguishes the worst of architects from the best of bees is the faculty of erecting in the imagination what is subsequently constructed in the real world. The study of invention and innovation cannot ignore the human imagination and the human will, however difficult measurement may seem in this field.

Conclusion

In concluding, I will make some personal value judgments explicit. No value judgments need enter into a comparison of inputs, nor need they intrude into comparisons of technological progress and economic growth, except in the choice of these themes for investigation, but value judgments are inevitably involved in the consideration of policy measures which may flow from such comparisons. Insofar as it represents a conscious political decision, the scale of R & D activity and support for science in any particular country reflects a variety of policy goals, only some of which are economic. Moreover, the balance of "home" R & D and "imported" science and technology must also partly reflect political and cultural, as well as more narrowly conceived economic and technological, goals. My personal preference is for a more research-oriented society, both in Britian and in Europe, but for very different policy goals than those pursued in the U.S. and the U.S.S.R. I regard the proposals being canvassed in Britain for drastically cutting back the rate of growth of fundamental and applied research as shortsighted both culturally and economically, and I believe that the real possibilities of acquiring and using American know-how will depend increasingly on strengthening Europe's own R & D capacity. But wherever the balance may lie, all countries benefit to a very considerable extent from scientific and technological exchanges. Autarchy is inefficient, both for the world economy and for world science and technology.

However, most economists have recognized that extreme economic inequalities between regions and countries may call for some deliberate measures of redress, which are not consistent with free play of market forces. The same may well be true of extreme inequalities in scientific and technical resources. Whether or not the "technological gap" is an imbalance of this type is an extremely complex issue, for reasons which have been explained. In my judgment, the really important gap, both economic and technological, is that between the poorer underdeveloped countries of the world on the one hand and the richer industrialized countries on the other (*32*). While self-help must be the foundation for success, this gap does, in my view, also require action by all the wealthier countries on a massive scale. Such aid should not only be economic and technical but should also deliberately aim to build up and strengthen an independent "problem-solving capacity" (R & D system) in each country, appropriate to the local circumstances. This view is consistent with the traditional internationalism of science, not with proprietary attitudes toward knowledge. Radical institutional reforms may be needed to increase dissemination of know-how. Policy should also aim to prevent the frustration of educational investment in these countries through net emigration of scientific and technical manpower, while increasing the total international flow of scientific manpower and enabling developing countries to take full advantage of educational and research facilities in more advanced countries.

While some of these considerations apply also to the "gaps" between West Europe and the United States in technology and R & D inputs, these gaps seem to me to be relatively less important and to be largely a matter for the European countries themselves to attend to. International organizations may play a useful role in finding cooperative solutions, where these are appropriate, and in preventing this issue from becoming a cause for ill will. In some cases the existence of "gaps" stimulates friendly emulation, and this seems to me to be a healthy reaction. But whatever may be the development of science policy in West European countries, there is no need for this to become a divisive issue either with the United States or with the U.S.S.R. Some of the fears expressed on this point are, in my view, quite groundless and unnecessarily alarmist. All countries benefit from improvements in world science and technology and from rapid diffusion of new knowledge. Just as the U.S. or any other economy benefits from world prosperity, so too would U.S. and Soviet science and technology benefit from increased contributions from other European countries. All of them will benefit still more as the developing countries begin to make a major contribution. As the dodo said, in this race all can have prizes.

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28. The Science Policy Research Unit at the University of Sussex is embarking on a long-term study (Project SAPPHO) which aims to identify, quantify, and record the circumstances surrounding a large number of successful *and* unsuccessful research projects, inventions, and innovations in various countries, and to deduce patterns which will be useful for predictive as well as descriptive purposes. Information will be fed into a computerized data bank—for example, information from biographical profiles of individual scientists and managers, or from case studies of individual inventions and innovations, whenever this material is met with in the other projects inside the unit or is specially gathered to provide a broad base for pattern finding. We shall try to develop procedures to establish the existence of "best" descriptive patterns of the data, or of subsets of the data, and sampling procedures will then be used to find "sibling" or control data elsewhere in the data bank, so that the observed descriptive pattern can be gauged logically as a predictive pattern. To be effective, SAPPHO will need a large volume of data. For this reason we would welcome case studies of discoveries, inventions, and innovations from scientists and engineers in any country, including material on unsuccessful projects (which is rarely published). We would also welcome comments and views on the most significant features of the research-innovation process. We shall try to link biographically oriented data on scientists, inventors, and entrepreneurs with information which is "event-oriented." The traditional compartmentalization of fields of knowledge is inadequate for this kind of study, and for this reason we have deliberately brought together both natural and social scientists to work on these problems.
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NEWS AND COMMENT

Nobel Prize: Three Named for Medicine, Physiology Award

Three scientists, George Wald, Ragnar Granit, and Haldan Keffer Hartline, were named last week to share the 1967 Nobel prize in medicine or physiology. Wald is professor of biology at Harvard University. Granit is retired director of the Neurophysiological Institute of the Royal Medical School in Stockholm; at present he is serving as a visiting professor at St. Catherine's College in Oxford. Hartline is professor of biophysics at Rockefeller University. The following are appreciations and descriptions of Wald's work by John E. Dowling and of Granit's and Hartline's work by Floyd Ratliff.

George Wald

Nobel prizes have generally been awarded either for a single great contribution or for sustained contributions over a period of many years. In the work that brought the award this year to George Wald, both criteria are met. Wald's greatest contribution, of course, was the discovery of the role that vitamin A plays in vision, as precursor to retinene (vitamin A aldehyde), the chromophore of all the known visual pigments. Wald's discovery provided one of the first identifications of the biochemical function of a vitamin, and today this is still the only specific biochemical function known for a fat-soluble vitamin.

Beyond this important discovery, Wald has made innumerable contributions to our knowledge of the biochemistry of vision. This work includes extensive studies on the chemistry of the rod pigment, rhodopsin; the extraction and characterization of the first known cone pigment, iodopsin; and the discovery and tracing in nature of visual pigments synthesized with vitamin A_2, the porphyropsins. Wald and his collaborators discovered the role of *cis-trans* isomerization in the visual process, demonstrating for the first time that such molecular transformations play a role in biology. In addition he and his co-workers have provided important information on vitamin A deficiency, visual adaptation, color vision, and the cone pigments in primates. No one has contributed more to our understanding of the visual pigments and their relation to vision than George Wald.

Wald was born in 1906 in New York City and grew up there. He was graduated from Washington Square College in 1927, and from there he moved to Columbia, where he received his Ph.D. in 1932. At Columbia he was a student of Selig Hecht, who introduced him to visual physiology, where Wald's principal interests have resided for the past 40 years. Wald was profoundly influenced by Hecht and, when accepting the Proctor medal in 1955, spoke of him thus: "Hecht was a great teacher and physiologist. Also he was one of those rare persons who sets a standard both at work and at leisure. I was fortunate in having his instruction and later his friendship. I saw too little of him after leaving his laboratory but I felt his presence always. What I did or said or wrote was in a sense always addressed to him."