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ZOOLOGICAL SCIENCES IN THE FUTURE[1]

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I. INTRODUCTION

As far back as we can follow human records the relations of man and animals have been intimate. The Cro-Magnons in France of 50,000 or more years ago have left accurate and spirited records of animal groups, showing careful observation, that may have been born of the chase but which also displayed imaginative interest that extended beyond physical needs. Primitive man was largely dependent upon wild animal life for food and clothing. How far back the history of domestication of animals goes is still uncertain. The early use of totems and of animal names for families and clans testifies to a feeling of affinity. The satisfaction of needs, the stimulus to artistic impulse and the feeling of a kind of animal brotherhood created the first human understanding of animal life.

Aristotle, who so preeminently embodied the Greek feeling for natural law, is sometimes called the father of zoology, for he was the first great systematizer of animal lore, including not only that handed down, but also his own observations and reflections. He wrote a general "Historia Animalium," and also works on anatomy and physiology of animals, the famous "De Partibus Animalium," on the movements and locomotor organs of animals, "De Motu Animalium" and "De Incessu Animalium"; he wrote also to some extent on the behavior of animals, and all his philosophy is permeated by his zoological reasoning. Thus over 2,000 years ago the principal subdivisions, the philosophical implications and the social significance of zoology were delineated.

The evolution of zoology since may be traced in the enlargement of data, increase of accuracy in determination of facts accompanied by specialization, in the development of theories, in the application of techniques derived largely from other sciences, in economic

[1] Address before the American Association for the Advancement of Science in the conference on Science and Society, Ottawa, June 28, 1938.

and other human uses and in cultural development generally, both as donor and recipient.

The future of the zoological sciences must be founded on the course of their evolution up to the present. If we are to venture a guess as to where we are going, we must know the places at which we have arrived.

II. THE EVOLUTION OF ZOOLOGICAL THEORY

It is customary to divide the general theories of biology, which apply equally to botany and zoology, into those relating to the succession of organisms in time, the theory of organic evolution, those relating to their cellular structure, the cell theory and those relating to their physico-chemical constitution.

(1) *The Evolution Theory.* We shall not follow the history of the evolution theory. It is, as you know, since the publication of Darwin's "Origin of Species" in 1859 the basis for the development of the descriptive zoological disciplines: taxonomy, comparative anatomy, paleontology, embryology and geographical distribution. These studies reciprocally constitute and continually extend the evidence for organic evolution.

There is a strong tendency among zoologists at the present time, especially those devoted to experimental methods, to believe that these subjects have played their main role already in the development of zoology; and so in many places these fields of zoological education are neglected. The consequent failure, where such a situation exists, to appreciate the richness and interrelationships of animal life, the perfection of adaptations and the immensity of time in the geological ages that have gone into their creation is a grave defect in the education of the zoologist.

The basic descriptive disciplines of zoology are, moreover, live subjects for research. The rapid progress of paleontology, for instance, displays no features of senescence; one need only allude to the advance in mammalian paleontology and the extraordinary pictures it affords of adaptive radiation of orders and families or to the light thrown on human ancestry by discoveries of fossil human and sub-human remains. Comparative anatomy, descriptive embryology, taxonomy and geographical distribution require much more systematic work. Moreover, new view-points constantly appearing through experimental and analytic work demand reexamination and extension of the bases of observation, and it is necessary that experiment and observation proceed hand in hand.

Darwin's deepest interest, however, was not so much the demonstration that evolution is the method of origin of species and of adaptations, as the search for the causes of the evolutionary process. It was indeed the reasonableness of his theory of natural selection, or the survival of the fittest in the struggle for existence, that accounted for the rapid acceptance of the general theory. The selection theory aroused much interest as a matter of speculation during the latter part of the nineteenth century; but it has been only within the present century that an accelerating interest has developed in a statistical and experimental analysis of the subject. The progress of genetics, as is well known, is mainly responsible for this movement.[2] It is certain that factors of importance in the evolution process are being uncovered and appraised, in regard to the transmission of hereditary characters, the mechanisms of the action of genes in individual development and the consequences in the composition of populations. These topics belong to the division of the subject that Dobzhansky has aptly called micro-evolution, *i.e.*, evolution within experimentally available limits of time. Such investigations are still in their infancy, and as a first forecast I venture to predict a productive future for micro-evolution.

We think it reasonable to believe that the same causes operative throughout the whole period of evolution are operative to-day, and that it should therefore be possible to detect their presence experimentally. At the present time the theory of the gene enjoys a certain preeminence, for causes other than genetic affecting the heritable composition of individuals and populations have not been satisfactorily demonstrated in spite of much research. But it does not follow that the whole subject of micro-evolution is necessarily comprised within the theory of the gene.

It is difficult for the taxonomist and the paleontologist to believe that the gene theory is capable of explaining macro-evolution, the great trends covering geological ages; and the embryologist does not even attempt to use the gene theory in the analysis of the life history. Perhaps the solution of these difficulties may be met by some as yet unimagined extension of genetic theory, perhaps by some entirely different kind of discovery. But a gradual advance of understanding, rather than a quick solution, is to be anticipated in the theory of the causes of evolution, the most comprehensive of all scientific questions.

(2) *The Cell-Theory.* Since its establishment in 1838–39 by Schleiden and Schwann, the cell-theory has undergone a development that was unpredictably extensive and rapid. It led quickly to a complete rejuvenation of microscopical anatomy, physiology, pathology and embryology. To-day the cell still occupies its place as the unit of structure, function and development; no simpler unit has been discovered. All biological problems lead back to the cell; but we do not mean to assert either that they stop there or that cell-aggregates and composites may not display prop-

[2] The books of R. A. Fisher on "The Genetical Theory of Natural Selection" (1929) and of Theodosius Dobzhansky on "Genetics and the Origin of Species" (1937) are recent summaries of this movement.

erties unpredictable from those of the units. The cell has indeed become a sort of half-way house through which biological problems must pass, going or coming, before they complete their destiny. This being so, it is simpler to deal with this association in other connections.

(3) *The Theory of the Physico-Chemical Constitution of Organisms.* I hope that, since the decline of the mechanical view in physics has been so authoritatively announced,[3] the choice between being a mechanist or a vitalist in biology may soon cease to be regarded as the only alternatives. Biology is indeed committed to a thorough-going physico-chemical analysis of organic structure and function, but it is not committed to a reduction of its concepts to physico-chemical levels. Biology is an autonomous science in the sense that its problems concern the level of attainments, both historical and functional, of living organisms.

Evolution has not taken place in terms of increasing chemical or physical complexity, but in terms of organization. One has only to turn to the chemistry of the simplest organisms, best known perhaps for the bacillus of tuberculosis,[4] to realize that there is but little increase relatively in chemical complexity of organisms above this simple level, whatever stage of evolution may be examined. One may also say the same thing about the fundamental physical processes involved in the functioning of organisms. Students of biophysics turn by choice to single cells or microorganisms for material, and find that their results are applicable to the highest organisms.

That which characterizes organisms above all else is their anatomical and functional organization, and the regulations and correlations, both internal and external, which condition their wholeness and their capacity to survive in the struggle for existence through appropriate behavior.

The physical and chemical mechanisms, which we are increasingly learning to know, to understand and to apply in experiment, are to be regarded as mechanisms of control of structure and function on the biological level. Their rôle has not up to the present been shown to transcend this range. It is therefore fallacious to conclude that the organism is nothing more than a "physical-chemical-mechanical conglomerate."

When we attempt an analysis of biological organization, we must remain on the biological level. Hence the autonomy that we predicate for the biological sciences. It is true that the specifically biological factors are dependent on the "constancy of the physical units and physical modes of action," as R. S. Lillie has well said in a recent address,[5] but as he says further, they possess "a 'creative' side shown in a tendency to depart from routine and to produce novel action or organization," for which we have at present no physical analogy. The creative side is best shown in evolution, in individual development and in the course of experience, behavior and education.

[3] Einstein and Infeld, "The Evolution of Physics," Simon and Schuster, New York, 1938.

[4] H. G. Wells and Esmond R. Long, "The Chemistry of Tuberculosis," The Williams and Wilkins Co., Baltimore, 1932.

It would be footless to inquire into the relative importance of research on the physico-chemical and biological levels, for both are necessary, and all physico-chemical analyses must be referred back to the organism as test-object or indicator. Many such investigations go astray or are incomplete because of an inadequate preceding biological analysis; and the reference back usually discloses a different or more complex biological situation than was postulated. The direction of biological research must thus always remain in the hands of the biologists and can not be assigned. But there will continue to be action and interaction between the sciences concerned.

The evolution of organisms as we know it is a historical process in terms of geological time. This statement, if fully apprehended, fairly poses the difficulty of a physico-chemical analysis of organization. What is more impressive than the duration of frail living matter, showing a stability far greater than the physiographic features of the earth's surface, unless it be the richness of its evolution within the period of its duration! These are the essential biological problems, and with respect to them the biological sciences are still in a period of early infancy.

III. The Development of Techniques

The history of the sciences may be presented primarily as a history of ideas; but there would be no such richness of ideas in science as we actually possess without richness of technique. I am sure that a very profitable philosophical treatise could be written about the relation of technique to ideas. Though tempted, I shall not essay to provide an outline for this treatise. Suffice it to say that in the present state of the scientific world, all techniques are available to the zoologist: mathematical, chemical and physical. A single old example may serve to place the interrelation of technique to ideas before us.

Following the earliest anatomical techniques, the first great technique that fashioned the zoological sciences was that of magnification, the invention of the compound microscope about the end of the sixteenth century and its subsequent development. A new world of life was discovered in the latter part of the seventeenth century: protozoa, bacteria, spermatozoa and

[5] Ralph S. Lillie, "The Nature of Organizing Action," *Am. Nat.*, 1938.

tissue elements; and ideas ran riot as a consequence in the eighteenth century. The subsidiary techniques that have developed, of sectioning, staining, etc., fill volumes. That curiosity of the opticians in the seventeenth and eighteenth centuries remade biology, a fact worth mentioning because it is so commonplace as to emphasize very emphatically the dependence of science upon technique.

We could not have modern biology without mathematical, chemical and physical techniques. In general, the techniques of the higher, or more complex, sciences tend to be derived from those of the simpler sciences, and this in itself promotes conceptual resemblances, as fruitful associations always do. But when technique outruns ideas, we tend to have a relatively sterile association. It should not be held that on account of its dependence on physical and chemical techniques, biology is reducible to physics and chemistry. This would be an overestimate of the rôle of technique in the progress of ideas.

Ideas proceed from felt needs, material or intellectual, and they are acted out through the scientific method by techniques, the results of which in their turn produce the discovery of new opportunities for advance, and hence the feeling of new needs; there follow new ideas and new techniques or applications of techniques. It is a circular process. The discovery of x-rays was not immediately related to the problem of cancer; but when the connection between the application of x-rays and the retardation of cancerous growth was discovered, what a host of new ideas arose in the biological field, and how important the whole subject of radiant energy in relation to the organism has become!

Among fruitful conceptual resemblances in zoology to the simpler sciences are the experimental method in general and the use of mathematical language and tools. Certainly the method of experiment as contrasted with direct observation was developed earlier and more completely in the physical than in the biological sciences. Its application in certain of the zoological sciences, *e.g.*, embryology and behavior, lies within my own life-span, and as yet experiment has barely entered the taxonomic field.

Experiment and mathematical analysis are bound to play an increasing rôle in the progress of zoology. The prospects for productiveness of such procedures imply a sharp definition of data and of units; otherwise deductions are faulty or we are left with empty formulae. The rôle of intelligent and accurate observation as basis for experimental and mathematical treatment will always be crucial. The fact that this requirement has not always been met is merely a sign of immaturity of the subject and not any indication of limits. The attempt to create a mathematical biophysics that will play a rôle of prediction and suggestion, as does mathematical physics, is in the spirit of the times; and the endeavor to apply the principles of modern field-physics to problems of biological organization is promising.[6]

We can not predict what the next great technical advances in the study of zoology may be, but we confidently expect that there will be such; and the results may even be revolutionary. We are, however, far from complete utilization of the possible techniques that recent advances in physics and chemistry have placed in our hands; and it will be a long time before we have exhausted these possibilities.

IV. Zoology and Cultural Development

Sciences develop not only in the realms of ideas and techniques, but also in a changing social and cultural environment, and these necessarily interact. Though strictly inseparable, there is an attempt to estimate separately the influence of science upon society and the impact of society upon science. At the present time the estimates largely concern the influence of science upon society. It is regarded on the one hand as "the living source of all progress" and the basis of intellectual freedom, or on the other as a "Frankenstein monster that will slay its own master."[7] Moulton, from whose citations in the introductory address to the present series of conferences I take these estimates, ventures the remark, "Perhaps the way forward lies in a great extension of the scientific spirit."

Dr. Moulton presumably means an extension of the scientific spirit and its methods beyond the field of the natural sciences, in which its native home is established, into the fields of social phenomena. The scientific spirit consists, as Dr. Moulton also says, in deriving conclusions from facts. This no doubt means as distinguished from the drawing of conclusions from *a priori* principles, such as those enunciated in the preamble to the Declaration of Independence, or, let us say, in the "Wealth of Nations." In operation, this requires knowledge of the ways of ascertaining facts, and of distinguishing and using those that are significant. When fact and principle are in disagreement, it is the principle that must yield and submit to modification. If this be admitted, it emphasizes that being certain of our facts is a tremendous responsibility, which rises in proportion to the status and significance of the principle controverted. There can surely be no valid objection to the extension of such method in the social sciences.

We are accustomed in our free society to hold that the development of all science is good; in certain coun-

[6] Burr and Northrop, *Quar. Rev. of Biology*, 10, 1935.
[7] H. G. Moulton, SCIENCE, 1938.

tries less free it is ruled that only those aspects of science that contribute to their special national ideologies are good. But there is agreement on the thesis that in science is power. A free society in a world containing societies that are not free could neglect science only at its peril; and they also may suffer peril who neglect or distort part of it.

The scientific world as a whole has always, to the best of its ability, asserted freedom on its own behalf in research and in teaching; and conversely, has been willing to grant freedom to others. It has thus been a strong influence for democracy. It has often had to fight its way. In the zoological sciences the battle for evolution that so stirred the world in the latter part of the nineteenth century occasionally needs to be fought again, as in the famous trial in Tennessee a few years ago. Freedom in animal experimentation is periodically assailed, threatening the fight against disease; restrictions are placed on the teaching of the facts concerning human reproduction. In other countries than ours, free teaching of the principles of heredity, especially in its human aspects, is impeded. It should not be forgotten that freedom is never permanently attained; it may be won, but requires always to be defended.

The democratic assumption that all science is good does not mean that all that is good is science. It is impossible to say what a society wholly devoted to science would be like, for we have never had such a society on any national scale; but certainly the love of truth and freedom that characterizes science, and the training of the imaginative qualities demanded, would favor all that is best in literature, art, music, philosophy and religion.

Apart from such general considerations, we must deal with the very complex question concerning the part that the zoological sciences play in the welfare of mankind. This confronts us immediately with the problem of determining what, for our purposes, should be considered as zoological sciences. There is no such problem on the side of botany, for everything concerning plant life is included; but man unfortunately belongs in the zoological system, and yet the development of man is specifically reserved to the fifth conference, and this is only the second! It happens also that man is the most interesting zoological species, and that students of man and his needs have systematically picked out of the zoological sciences all that is most interesting to them; nor do they stop here, for they also pick out promising zoologists and graft them on to their own departments of anatomy, embryology, physiology, bacteriology and parasitology, vital statistics, entomology, animal husbandry, fisheries, forestry, etc. Zoologists also cooperate in the work of clinical medical departments in various places. This is in itself sufficient evidence of the human interest and value of zoology and, I hope, sufficient excuse if the boundaries of the present conference should be overstepped.

It is especially difficult to define in a few words the relationship of the zoological sciences to medicine. All advanced medical schools require general zoology, comparative anatomy of vertebrates and embryology as an introduction to the conventional medical courses. Anatomy and physiology are usually organized as departments distinct from zoology, but they overlap and are frequently manned to a considerable extent by zoologists of special interests and training; the same thing may be said of bacteriology, with which the zoological discipline of parasitology is frequently united. Such relationships have developed very rapidly in the modern period of scientific medicine, and it is safe to predict that this tendency has not run its full course. Direct relationships of clinical medicine with zoology are also found: for instance, application of results in the field of physiology of reproduction to obstetrics and in the increasing attention to the application of the principles of genetics to hereditary diseases and diatheses.

The economic uses of zoology are very important. Consider, for instance, the control of insect pests: in 1915 it was estimated that in the United States they caused an annual money loss of over $1,212,000,000 to cereals, hay and forage, cotton, tobacco, sugar, fruits, forests, animal products, products in storage, etc. This estimate has recently been raised to about $3,000,000,000. Whether more or less, the damage is very great. The federal and state governments employ large staffs of entomologists engaged in the study and control of these pests. The study and control of parasitic worms, liver flukes, tapeworms, trichinae, hookworms, filariae, etc., engage the attention of numerous other zoologists within and without the government services. Fisheries industries employ many zoologists; shellfish industries likewise. The regulation of the fur seal industry is based on studies of a zoological commission.[8] Such subjects as the fouling of ships' bottoms and destruction of marine structures by boring mollusks likewise come to the zoologist for study and advice. This is a very incomplete list of the economic uses of zoology.

V. ZOOLOGICAL SCIENCES IN THE FUTURE

There are approximately 850,000 species of animals already described; the number may easily run up to 1,000,000 before the descriptive labors of the taxonomists are through. This is a relatively simple and safe prediction.

But I take it that we are mainly interested in general theory and social effects. For these purposes it

[8] *Bull.*, U. S. Bureau of Fisheries, 1914.

is simplest to assume the most favorable social and political conditions for the continued evolution of the zoological sciences, leaving the evolution of social environments themselves to the subsequent conferences.

The most general trends that we have already noticed are a steady progress in the application of the methods of experiment to zoological problems and a rising state of consciousness of social, as contrasted with merely intellectual, responsibility. The background is occupied by the descriptive and systematic observational disciplines, which need and continue to receive constant attention, if only in the service of experimental investigations which require increasingly exact observational bases.

It has been argued that biology, especially animal biology, holds more for the improvement of conditions of living than the physical sciences. Some even go so far as to say that we need no more "gadgets of civilization" of a physical kind, and hence should center our efforts in science on the organism for the sake of which "gadgets" are designed, man himself. The organism *is* in a way more significant than its environment and should be equal to its opportunities. It is unfortunately true that many humans are poorly equipped, biologically or economically, to make the best avail of the resources of civilization, and so long as this is true it constitutes a good argument for special attention to the biological and the social sciences. However, the interdependence of the sciences would render it hazardous to neglect the inorganic sciences for the sake of the sciences of the living, and any such attempt would probably defeat its own ends.

The advance of the zoological sciences requires enlarging support for the advancing technologies and for access to properly controlled materials. The best materials for experiment are not to be found everywhere. In the progress of development of experimental zoology, university and other laboratories have been forced to make provision for the maintenance and breeding of animals and in some cases to establish farms for these purposes. The great importance of marine animals for experimental work has favored the development of marine laboratories, which in some cases have become national and international centers for study. At the Marine Biological Laboratory at Woods Hole, Massachusetts, over 350 investigators gather in the summer, representing about 110 American universities and laboratories, and approximately 10 foreign institutions. There the workers are supplied with the living material they require and facilities for keeping it in good condition, with a great variety of chemical and physical supplies and apparatus, with access to a very excellent working library, and living accommodations. The effect of this institution upon the progress of zoology and general physiology in America during the period of fifty years has been very great. A variety of favorable influences have radiated from it. The maintenance of such institutions along our coasts is needed to provide the conditions under which the zoological sciences may prosper. Stations at other points in the interior, on the lakes, great and small, in the mountains and other special ecological territories, are now doing good work and should be supported. The zoological sciences require such special provisions.

When a problem is discovered and accurately defined by observation, experiment is then the method *par excellence* for deeper understanding of the mechanisms of control in which we are interested; and so zoology has tended more and more in the last half century to become an experimental science. The modern zoological laboratory must be provided with means for maintaining and breeding different kinds of animals; and, for experimenting with them, a great variety of chemical and physical facilities must be available. The principal divisions of experimental zoology—genetics, experimental embryology, ecology and behavior and cellular physiology—depend for their progress on such provisions.

No single speaker is able to do justice to the whole field of experimental zoology nor would there be time for a systematic survey. In a necessarily preferential selection, one must follow his own interests in illustrating the possibilities and the limits of prediction.

From about 1915 to 1920 I was interested in a purely zoological problem, *viz.*, the fact that a female calf born twin to a bull calf was sterile in about 90 per cent. of the cases, and was, as a matter of fact, in its internal anatomy in such cases predominantly male. This phenomenon had long been known, and in some remote period of English history the sterile females had been denominated free-martins. Embryological analysis showed that in all such cases the circulations of the twins were joined in early fetal life and that each individual continued to receive blood from the other until birth. The inference that the malformation of the female was due to influence of its brother's blood was inescapable, and inasmuch as the malformation primarily concerned the reproductive system it seemed probable that it was due to a sex-hormone secreted by the male.

This led to other investigations and to a request from the Sex Research Committee of the National Research Council in 1922 to present a program of investigation in the biology of sex. Among other topics, I presented that of the sex hormones. Nothing was known at that time of the chemical nature of the substances, the existence of which was postulated on certain influences of the gonads transmitted through the circulating blood. I wrote at that time: "It will be the province of the chemist to endeavor to identify, isolate and ultimately synthesize the sex hormones. The possibility of an ultimate ready control of sex characters and behavior within the limits discovered to be possible by the biologist must depend on the chemist working in close cooperation with the biologist."

About this time, owing to other discoveries, events began to move very rapidly; the first real discoveries on the chemistry of the female and male sex hormones were made in St. Louis and in Chicago within a year or two. As there is no copyright on ideas in science, the investigations spread to Germany, Holland, Switzerland, England, Scandinavia and other countries, also to numerous centers in America; various unforeseen lines of work developed from it. The sex hormones themselves were gradually purified and obtained in pure crystalline form in 1929; then synthesized, modified in various ways, used in extraordinary animal experiments, and their clinical utilization is being explored. The relationships with carcinogenic compounds is now being tested among other things, and the subject is leading into quite unexpected fields.

Thus a program involving a prediction that I never expected to see finished in my lifetime was brought to completion, as far as stated, within a period of less than fifteen years; and as always happens, the unexpected has also emerged and the way ahead opened up.

I mention this from my own experience to illustrate the possibility of short-term predictions. Every program of investigation involves the principle of prediction, because after preliminary observation and preparation it starts out from an hypothesis—"either, or"; advance is through a series of subsidiary hypotheses. Every investigator tends to favor "either" or "or" if he starts out with a prepared mind; but, if he be a good investigator, he abides loyally by the result and learns from it. So it would be possible to present an almost unlimited series of short-term predictions.

Long-term predictions can concern only very general trends, and they lose in probability as they concern specific questions. To illustrate: following the example I have already chosen, there can be no reasonable doubt that our knowledge of the gonadal and hypophyseal hormones will grow rapidly, including their chemical synthesis in some additional cases at least, and hence ready availability; in such cases the production of allied chemical compounds by well-established principles, the testing of the physiological effects of such compounds, and so on. But what the effect of such increase of knowledge may be on regulation of sex ratios, on control of the reproductive cycles, on the physiology of pregnancy, and the radiating effect on social customs and development, it is impossible to foresee. The effects certainly will be important.

Zoology, in the more conventional sense, will in my opinion continue to occupy a privileged position with reference to fundamental and long-time programs of research. It is the only one of the sciences of animal biology not directly attached to programs of immediate social significance, and that is not more or less confined and restricted by such relations. It still has its place in the academic field, as contrasted with the professional fields. It is important that this place be preserved and that free rein be given to the imaginative faculty and the development of theory. We may venture to predict that under these circumstances in the future, as in the past, conceptions of social significance will continue to emerge.

The zoologist should know the wealth of animal life for its suggestiveness and for the opportunities, often unique in specific animal forms, for successful experiment. In the course of the age-long struggle for existence, nature has discovered the mechanisms most apt for each species to meet the conditions of survival. These methods are often different for the same problem in different species, sometimes apparently quite radically different. The animal kingdom is a great storehouse of information concerning ways to solve animal and human problems, which we have only begun to explore.

When any fundamental discovery is made in the zoological sciences, no matter where—*e.g.*, parthenogenesis in sea-urchins, heredity and its relation to chromosomes in the fruit-fly, embryonic organizers in salamanders, the hydrogen ion concentration in slime moulds, sea-urchin or frog eggs, colloidal properties of protoplasm anywhere, permeability of cell-membranes in plants and animals, the independent life of cells in tissue culture or of organs under suitable conditions, balance of salts required by marine eggs or the frog's heart, electrical properties of nerves in frogs or squid, and so on indefinitely—there is repercussion throughout the entire realm of the biological sciences, and especially in the complex of zoological sciences that we call medicine, so alive now to everything that may affect the well-being of the human individual.

Essentially new discoveries proceed in the long run from fundamental research conceived in intellectual terms. The social use will eventually appear, and organization for its exploitation is sure to be effected by various interested agencies. There should be large provision for free research. There is a real danger to the progress of the zoological sciences in placing too much emphasis on economically or socially useful types of investigation; and there is already a pronounced tendency in that direction, even in our universities, by the relative ease of securing funds for such research, thus diverting the talents of investigators away from more fundamental work. Granted that a sharp line can not be drawn and that economically motivated research may lead into problems of fundamental theoretical significance, nevertheless free research constitutes the greatest long-term asset of society in the field of science.

It is more than a little illogical for society to hold on the one hand that the results of science, developed under a system of freedom of research for which it has been necessary constantly to fight, constitute the greatest economic asset of nations, and on the other hand to maintain that science will do better in the future if its direction is taken over by social agencies. The problem of social agencies is not so much to direct the course of science as to make good use of its results.

Lest I may seem to be deprecating organized research let me say that this is not in the least my intention, nor has it been my past example. Organization of research has increasing importance, illustrated by so many productive examples as to require no defense. It has existed as long as our universities, academies and scientific associations and societies. It has been strengthened more recently by industries, technical schools and governments. Almost every scientific man is as a matter of course a member of one or many such organizations. I am, however, much concerned about the auspices of the organization of research and the freedom of the members of such organizations. Most scientific men work best in an organized program. This, I think, has to be recognized. But there is food for thought in a remark once made to me jokingly by one of the best-known American physicists, now dead: "I propose," he said, "to organize a Committee of One Hundred to write the best American poem." The limitations of organization for creative work are thus suggested.

In some cases the results of science in our own time are not yet put to their full social uses; there is an inevitable social lag or even active social resistance. A good example of retardation due to social resistance, now in the course of breaking down, is the present campaign against syphilis. Ever since the discovery of the causative organism (*Treponema pallidum*) by a zoologist, Schaudinn, in 1905, the way was open to its control, which was realized, through the pioneer work of Ehrlich on the chemo-therapy of arsenic compounds, by a whole host of investigators; but it has remained for the years 1937–38 to inaugurate an effective campaign for the suppression of this destructive disease in our own country.

In other cases groups of people organize to promote applications of biology to the social organism when both biological and sociological opinion is divided. The most striking example is in the field of eugenics, the improvement of the inborn qualities of the population. Biological opinion is divided because our knowledge of human heredity is quite rudimentary as compared, for instance, with our knowledge of heredity in fruit-flies or guinea pigs. Even if we felt sure that our knowledge of the principles of heredity in lower animals is theoretically fully applicable to mankind, we would not know how to apply it energetically except in most general terms, for there are no pure lines in human inheritance for one thing, and for another, we have few animal analogies to the human qualities of character that we most need in the social process. Biological opinion is divided even on the subject of negative eugenics, the elimination of the unfit, not so much on the general desirability of the principle as on the definition of unfitness, the determination of standards and the methods to be employed. Sociological and political opinion is also divided sharply, on the question of the trends of existing social, economic and political selective processes as they affect population, and the desirability of applying such a sharp instrument as radical eugenics to society before the possibilities of social amelioration in other ways are more fully explored. Under these conditions we should have institutes specially devoted to human genetics for the sake of the medical as well as of the social problems involved.

One sometimes feels tempted to despair of the social coordination of scientific knowledge for the increase of the well-being and happiness of mankind. But faith in the progressive evolution of mankind is stronger, in the scientific world at least. I have the conviction that the ethical principles of Christianity are wide-spread among the masses of mankind and that they will prevail. But the processes of evolution are slow, and we may have to wait a long time.

OBITUARY

HENRY HERBERT DONALDSON

HENRY H. DONALDSON was born at Yonkers, New York, on May 12, 1857, and died at his home in Philadelphia on January 23, 1938. He prepared for college at Phillips Academy, Andover, Mass., and graduated from Yale in 1879 with the degree of B.A. The following year he did advanced work at Sheffield Scientific School and conducted research with Professor Russell H. Chittenden "On the Detection and Determination of Arsenic in Organic Compounds"; this was published jointly with Professor Chittenden as his first scientific paper. During the year 1880–81,