training, it will thus be at least six years before a normal supply of young professionals will again be available to our laboratories. Can we afford to wait any longer?

This is a situation of national concern which needs to be carefully watched lest when the war is won we may find that we have gained a Pyrrhic victory, having lost so much of our technical strength that we shall be unable to carry on the great task of world leadership which we now see before us.

It remains for those who follow me on this program during the next weeks to explain how the growth of science will bring to us life of greater human value. Increased cooperation and concern for each other's welfare, greater attention to education for everybody, fresh consideration of the goals of living worthy of our great new powers, such human developments are sure consequences of the emphasis that science places on specialized skills and on coordinated effort in learning and using knowledge. But more of this later.

What I want to bring to you to-day is the fact that greatly increased emphasis on science is a "must" for our nation's safety and future welfare. If a wise course is followed with regard to training and in other support of science, our nation is in favorable position to lead the world in the scientific age that lies ahead.

THE CONCEPT OF INTEGRATIVE LEVELS AND BIOLOGY[1]

By Dr. ALEX B. NOVIKOFF

DEPARTMENT OF BIOLOGY, BROOKLYN COLLEGE

THE concept of integrative levels of organization is a general description of the evolution of matter through successive and higher orders of complexity and integration. It views the development of matter, from the cosmological changes resulting in the formation of the earth to the social changes in society, as continuous because it is never-ending, and as discontinuous because it passes through a series of different levels of organization—physical, chemical, biological and sociological.

In the continual evolution of matter, new levels of complexity are superimposed on the individual units by the organization and integration of these units into a single system. What were wholes on one level become parts on a higher one. Each level of organization possesses unique properties of structure and behavior which, though dependent on the properties of the constituent elements, appear only when these elements are combined in the new system. Knowledge of the laws of the lower level is necessary for a full understanding of the higher level; yet the unique properties of phenomena at the higher level can not be predicted, *a priori*, from the laws of the lower level. The laws describing the *unique* properties of each level are qualitatively distinct, and their discovery requires methods of research and analysis appropriate to the particular level. These laws express the new organizing relationships, *i.e.*, the reciprocal relationships of elementary units to each other and to the unit system as a whole.

The concept of integrative levels recognizes as equally essential for the purpose of scientific analysis both the isolation of parts of a whole and their integration into the structure of the whole. It neither reduces phenomena of a higher level to those of a lower one, as in mechanism, nor describes the higher level in vague non-material terms which are but substitutes for understanding, as in vitalism. Unlike other "holistic" theories, it never leaves the firm ground of material reality. Integration does not imply, as Lillie has recently maintained, "special vital factors"[2] or "something of the mental or psychic."[3] Both parts and wholes are material entities, and integration results from the interaction of the parts, as a consequence of their properties. The concept points the need to study the organizational interrelationships of parts and whole. This full recognition of both units and whole leads to a more adequate understanding of the whole.

The different levels of matter, while distinct, are not completely delimited from each other. No boundary in nature is fixed and no category air-tight. "Mesoforms" are found at the transition point of one level of organization to the next. Between the highest level of organization of non-living, the crystal, and the lowest level of unicellular organisms are protein paracrystals, the viruses, with some of the internal structure and behavior of living substance. Between the single-cell organism and the multicellular organism are the colonial organisms. Yet the absence of rigid demarcation between two levels does not make the difference between them any less clear or fundamental. Mesoforms, "the more clearly we understand them, will all the more clearly serve to bring out the essentially new elements of (the) higher order."[4]

There is both continuity and discontinuity in the evolution of the universe; and consideration of one

[1] Contribution No. 62.

[2] Ralph S. Lillie, *The American Naturalist*, 72: 414, 1938.

[3] Ralph S. Lillie, *Philosophy of Science*, 7: 327, 1940.

[4] Joseph Needham, *The Modern Quarterly* (London) 1: 30: 1938.

to the exclusion of the other acts to retard the development of biological and sociological sciences. Knowledge of the general qualities of development common to all levels of organization of matter will aid in the analysis and description of the concrete attributes of each level. But it can not be a substitute for such analysis or for the determination of the qualitative uniqueness of each level and the characteristic laws which govern it.

Physico-chemical and Biological Levels

The concept of integrative levels does not regard living organisms as machines made of a multitude of discrete parts (physico-chemical units), removable like pistons of an engine and capable of description without regard to the system from which they are removed. Its approach is one which biochemists are adopting more and more: living cells present problems not to be encountered in the test-tube or flask. The structural pattern of the cell plays a decisive role in many of the chemical reactions which constitute metabolism. The ordering, as well as speed, of the chemical reactions in the cell are largely the result of the distribution and activity of colloidal enzymes. Korr[5] has indicated that even simple colloidal systems "represent a much higher level of integration . . . and that, because of the quantitative and qualitative modification which interfaces and their molecular groupings impose, there emerge new classes of phenomena for which there are no analogies in homogeneous systems, and which, therefore, require new sets of rules." Commoner[6] has discussed the increased dependence of enzyme function on structural factors in the living cell. The degree of dependence of a particular enzyme system on protoplasmic structure or physico-chemical organization can be revealed by changes in this structure, both natural and experimentally produced.

It has been the great contribution of the "organicists" that they have demonstrated the error of the mechanistic reduction of the biological organism to the physico-chemical. It is therefore unfortunate that "organicism" has been marred by non-material concepts. Organicists fail to picture the "whole" as developing through the integration of individual units of matter into a single system; they omit a discussion of the organizing relationships of the parts. They try to describe the behavior of the organism solely in terms of the higher level, the whole. As a result, the impression is created that no material basis exists for the part-whole relation.

Almost all the text-book definitions of physiology reduce phenomena of living matter, a highly complex and integrated system, to the level of free molecules and atoms. Certainly chemical and physical forces are operative in cells, yet defining physiology as "the physics and chemistry of life processes" overlooks the fact that the cell organization imposes a new and higher order on physico-chemical change, and that tissues, organs, organ-systems and organism impose a higher order on cell activity. Physiology rightly concerns itself also with the activities of the higher orders: cellular organization and function as well as chemistry and physics in the narrow sense; the tissue, organ, organ-system as well as the cell. No matter how complete our knowledge of the chemistry and physics of living systems becomes in the future, living substance must still be recognized as matter on a higher level, with new, unique properties which have emerged on combination of the lower-level units. When molecules become part of a highly integrated system, protoplasm, it is important to know the properties of the molecules, but protoplasmic behavior needs description in terms and laws which have no meaning for molecules, in specifically biological terms and laws.

Biological Levels

Within the biological level, there are a series of other integrative levels.

I

In the multicellular organism there is a hierarchy of levels—cells, tissues, organs, organ-systems and organism. Viewed in terms of integrative levels, Heilbrunn's assertion that "general physiology thus becomes cellular physiology" and that "the ultimate mechanism responsible for any form of vital activity lies inherent in the individual cells"[7] is one-sided. A full understanding of the organism is not possible without complete knowledge of the activities of its cells. But knowledge of "the individual cells" does not exhaust the problems of organism physiology; the activity of the individual cell is greatly influenced by the products of activity of other cells in tissue, organ, organ-system and organism.

The inadequacy of a cell concept in which the cell is considered an independent unit of activity is clear from the work of experimental embryologists. The embryo is not a collection of unrelated portions developing independently of each other; on the contrary, the development of any cell is dependent not only on its own constitution but also on the nature of the surrounding materials outside the egg or produced in adjacent cells of the embryo. If ectoderm cells which normally form belly skin were removed from a salamander embryo and transplanted over the mouth organizer of a frog embryo, they would develop into

[5] Irvin Korr, *Cold Spring Harbor Symposia*, 7: 74, 1939.

[6] Barry Commoner, *Quarterly Review of Biology*, 17: 46, 1942.

[7] L. V. Heilbrunn, "An Outline of General Physiology," pp. 3, 4. Philadelphia, 1943.

salamander structures—of the mouth; they would form teeth and not belly skin.

Similarly, in the adult organism, plant or animal, the behavior of a cell is influenced by the activity of other cells of the body. Thus, the hormone, auxin, produced in the apical cells of a plant, will cause the elongation of stem cells, inhibit the growth of cells of lateral buds, influence the course of differentiation of root cells and stimulate the growth of cambium cells. Chiefly through such hormones, the cells of the plant body are integrated into an organism. In animals, the activity of cells is under the integrating influence of nerve impulses, hormones and other cell products like carbon dioxide. Activity of cells of the salivary glands is dependent upon stimulation by nerve impulses begun elsewhere in the body. The behavior of uterine cells depends not only on its own constitution, but also on hormones produced by cells of pituitary and ovary. Carbon dioxide produced by muscle cells in the legs will influence the behavior of the respiratory center cells in the medulla.

Just as cells do not exist in isolation in the organism, neither do organs or organ-systems. Thus, the functioning of the heart (the rate and force of its beat) is not unrelated to the pressure of the blood in the aorta and carotid arteries, the diameter of the arterioles or the amount of blood returning through the veins; nor is the circulatory system unaffected by or without effects on the nervous, endocrine, muscular or respiratory systems. Coghill,[8] using embryos, and Lashley[9] and Goldstein,[10] studying adult animals and men, have demonstrated the weakness of an atomistic approach to the activity of the nervous system and have emphasized that it functions as an integrated whole.

II

Populations constitute a distinct level of integration, higher than that of the individual organism. Schneirla, in his excellent studies on the interrelations between individual behavior of the army-ant and the population unit or colony, stresses this point. "Any social organization represents a qualitatively new emergent level not equivalent to that which might be attained through a mere summation of the properties of its constituent individuals."[11a] It is solely the reactions of the individual ant which are responsible for the highly organized mass behavior; yet "strictly speaking, the Eciton worker has no behavior pattern outside the social sphere."[11b]

Dobzhansky, in his authoritative work on population genetics, similarly describes populations as higher levels of integration. The fate of a newly-arisen genetic variant depends not alone on its effect on the individual organism but also upon the "dynamic regularities of the physiology of populations." Thus, it is the effective size of a population which may determine whether a useless or even deleterious mutant will, through chance recombinations, become incorporated into the constitution of the group. The smaller this population size the less effective is selective pressure in evolution. Dobzhansky emphasizes that evolutionary changes are changes in the genetic constitution of groups—of populations. Through natural selection, migration, and isolation, biological groups are produced whose genetic structure is molded in relation to the environment. The laws of population genetics which describe these evolutionary changes are on a higher level than those of the genetics of the individual. "The rules governing the genetic structure of a population are, nevertheless, distinct from those governing the genetics of individuals, just as rules of sociology are distinct from physiological ones, although they are in fact merely integrated forms of the latter."[11c]

The concept of integrative levels stresses the need to study living organisms at all levels—cells, tissues, organs, organ-systems, organisms and populations. It is not "organicist"; always the reciprocal relationship of elementary units to each other and to the unit system as a whole must be studied. It is not mechanistic; the detailed methods of study at higher levels will include not only some used at lower levels but new methods peculiar to the higher levels; the laws of one level will be expressed differently from those of the others.

BIOLOGICAL AND SOCIAL LEVELS

According to the concept of integrative levels, man's social relationships represent a new level, higher than that of his biological make-up. Man's behavior differs from that of other animals because of his possession of body structures, notably, the highly developed nervous system, which make thought and speech possible and whose functioning is profoundly affected by social or cultural influences. Man possesses a unique head and hand, and is able to confront nature not only with his body but with tools devised and wielded by him. The crude tools of primitives give way to the more complex technology characteristic of modern society. As the technological forces change, the social and economic relations of men change, and, with them, man's behavior. Socio-economic or cul-

[8] G. E. Coghill, SCIENCE, 78: 131, 1933.

[9] K. S. Lashley, "Brain Mechanisms and Intelligence," Chicago, 1929.

[10] Kurt Goldstein, "The Organism." New York, 1939.

[11] (a) T. C. Schneirla, *Psychological Review*, 48: 465, 1941; (b) *idem, The Journal of Comparative Psychology*, 29: 447, 1940; (c) Theodosius Dobzhansky, "Genetics and the Origin of Species," p. 11. New York, 1941; (d) Francis H. Bartlett, "Sigmund Freud," p. 80. London, 1938.

tural forces thus come to dominate biological factors in directing man's actions.

In a penetrating analysis of Sigmund Freud's failure to recognize the inseparability of the biological and the cultural forces which determine man's behavior, Bartlett writes,

> The biological organism, by its existence in society, has become a "new biological species." . . . The biological organism is transformed; it no longer exists as a biological phenomenon, strictly speaking. Under the influence of society, the biological has become the psychological. New laws of motion have come into being which are neither biological nor sociological, but the subject of study of a different science, psychology.[11a]

The concept of integrative levels, as it stresses the need to study the interrelationships between the biological and sociological, emphasizes the fact that the two constitute two distinct levels. Blurring this distinction leads to anthropomorphism and to mystical, often dangerous, statements about society.

Anthropomorphism—endowing animals, and even plants, with human attributes, psychical and social—transports the higher level (social) bodily into the lower level (biological). In doing so, it presents a wholly erroneous picture of the animal. The aspects of behavior common to man and animals are studied in comparative psychology, just as comparative cytology studies the uniformity of structure of diverse cells and comparative biochemistry the fundamental chemical changes common to all cells and organisms. Often, the significance of certain aspects of man's behavior (*e.g.*, instincts) can be illuminated by studies on lower animals where the problem may be analyzed more directly. And in the anthropoid apes, it is possible to investigate the beginning of reflective thought and of social influences on behavior.

Yet the study of animal behavior can not be a substitute for the study of man's behavior. As we establish the likenesses in behavior of animals and men, we must simultaneously investigate the fundamental qualitative differences between them. Except in certain pathological conditions, man's behavior is as unique as the organs which he, alone of all animals, possesses; thought, speech, labor are impossible without a highly developed brain and a hand. It is his unique biological constitution which makes possible the development of truly social relations among men. Many investigators studying the integrated animal populations, the so-called societies of animals, appear to have overlooked the fact that animal societies never rise above the biological level, that only man's society is truly sociological.

Any one who has tried to teach biological change to college students knows the barriers to learning which have been created by the identification of animals with men throughout the student's lifetime. Every phenomenon is approached by them in terms of human experience. There is no time scale other than the clock, calendar or century. Yet important biological change can be expressed only in a "non-human" time scale. For each living organism travels at two enormously different speeds of life.[12] The comparatively rapid one is easy to comprehend because the changes can be observed; the birth, growth and death of the body, the movement of the plant on the window sill, and even the less obvious chemical changes of cells and organisms. But only the end results of changes over many thousands of centuries can be seen in the diverse plants and animals, each almost perfectly adapted to its environment. A species, in high-speed terms, is constant; but in low-speed terms, it is changing.

Thinking in high-speed terms of these low-speed phenomena leads almost inevitably to teleological conceptions, ascribing these phenomena to a divine purpose in nature. The terrestrial mammal has no gills because the air, containing little water, would dry out the exposed soft tissues; the earthworm has no eyes because it has no need for them, buried as it is in the ground. Such teleological reasoning is carried over even to changes which are directly observable. The heart beats in order to bring food-laden blood to all cells of the organism. The leaf bends to the light in order to intercept more energy for photosynthesis. There is no awareness that ascribing such purposive behavior to the heart or the plant imparts the ability to reason and to look into the future, in one case to a small individual part of the organism, and, in the other, to an organism which lacks a nervous system, let alone a brain!

The history of biology demonstrates that teleology explains nothing, and, worse still, hampers the search for explanations and causes. You do not study the causal development of eyes in worms if you believe their absence in earthworms is explained by the statement that underground worms need none. Nor do you trouble to analyze the causes of cardiac muscle contraction or the distribution of plant growth hormones if it suffices to say that the heart beats to pump blood and the leaf bends to get light. You do not study the causes of evolution or the explanation of mutual adaptation of organism and environment if you assert, as Gerard has recently, that the "selection or creation of these particular mechanisms" is volitional or purposive.[13] Only when purpose was excluded from descriptions of all biological activity except rational behavior of human beings, could bio-

[12] Henry Collier, "An Interpretation of Biology," Chapter 5. London, 1938.

[13] Ralph W. Gerard, "Organic Freedom," p. 425, in "Freedom, Its Meaning," edited by R. N. Anshen. New York, 1940, *Scientific Monthly*, 50: 349, 1940.

logical problems be properly formulated and analyzed.

CRITIQUE OF SOME BIOLOGICAL LITERATURE ON INTEGRATIVE LEVELS

In a recent volume devoted to the concept of integrative levels,[14] a number of serious errors occur. These errors stem from a tendency to concentrate exclusion of any consideration of the uniqueness of ter from low to high levels. While the "organicists" concentrate their attention exclusively on the uniqueness of the biological level ("the organism as a whole") without relating it to the lower levels, this tendency is preoccupied with the general similarity of organizational development in evolution to the exclusion of any consideration of the uniqueness of each level. This overemphasis of the continuity of evolution leads to the confusion of biological and sociological levels.

A. E. Emerson acknowledges the distinction between biological and social sciences but then says, "Society is surely a manifestation of fundamental life attributes which are shared with other biological systems and the division between the social and non-social is not sharp."[15] Elsewhere, he maintains that "the evolution of human social and ethical characteristics is governed by the same forces which have been directing organismic evolution through the ages."[16] However, the material in Emerson's articles reveals the basic difference between the forces making for change in human society and those producing changes in "organismic evolution." There has apparently been no important change in the society of insects in the thirty-five million years since the Oligocene period. Since insects possess neither intelligence nor the ability to transmit the results of experience to others, change is dependent on the slow process of germinal change (mutation) and their society is therefore relatively fixed. On the other hand, in the seven or eight thousand years of recorded history, man's society has continually changed; because of the transmission of experience symbolized by tools, language, printing, photography, etc., there is social-cultural inheritance as well as biological inheritance. It is the plasticity of man's intelligence which brings ethics into being.

While man's social relations have undergone marked transformation, his biology has remained essentially unchanged. What small biological change has occurred (*e.g.*, increased mean length of life) has been the result and not the cause of social development. The "forces . . . governing . . . human social and ethical characteristics" have been not biological but social, the relation of man to changing technological and economic relations. The "forces . . . governing . . . organismic evolution through the ages" have been biological (mutation, etc.). That is why whatever similarities one notes in animal and human societies must be purely formal and therefore meaningless.

Gerard accepts the old analogy between society and the living organism and, by what Simpson has aptly described as the "most reckless, unjustified, and nonscientific extrapolation,"[17] he draws a great many parallels between aspects of society and organisms. Thus, he equates scientists with receptors,[18] the formation of an army by a nation with the fusion of slime molds in the face of "emergency conditions,"[19] altruism of men with "service and mutual helpfulness seen in the interplay of cell nucleus and chloroplast,"[20] and so on. It is unnecessary to enumerate all the parallels. In every one of them, the social activities for which Gerard finds biological counterparts are not of biological origin but are the results of long processes of social development. We can not overlook the fact that the origin of social integrations of rational men in society is fundamentally distinct from that of biological integration of masses of protoplasm in the living organism. Aside from its refinement in terms of modern biological data, the organism-society analogy of Gerard is the same as that of Herbert Spencer in which, Needham has pointed out, instead of seeking the economic basis of social relations, he "elaborates to a degree sometimes almost fantastic the analogy between animal and social organisms."[21]

Just as the striking but fundamentally misleading analogy between living organisms and non-living engines has stimulated both mechanical and vitalistic biology, so this organism-society analogy leads to erroneous and dangerous social conclusions as well as to anthropomorphism.[22] Because he fails to distinguish the social from the biological, Gerard[23] is led

[14] Biological Symposia, VIII. "Levels of Integration in Biological and Social Sciences," edited by R. Redfield. Lancaster, 1942.

[15] Alfred E. Emerson, "Basic Comparisons of Human and Insect Societies," p. 173, in Redfield, *op. cit.*

[16] Alfred E. Emerson. Abstract 21423, in *Biological Abstracts*, vol. 16, 1942.

[17] George G. Simpson, *Journal of the Washington Academy of Sciences*, 31: 18, 1941.

[18] R. W. Gerard, "Higher Levels of Integration," p. 79, in Redfield, *op. cit.*

[19] *Idem*, "Higher Levels of Integration," p. 81.

[20] *Idem*, "A Biological Basis for Ethics," p. 108. *Philosophy of Science*, vol. 9, 1942.

[21] Joseph Needham, *The Modern Quarterly* (London), 1: 38, 1938.

[22] Needham, Huxley and Simpson have noted that even the formal aspect of the organism-society analogy is erroneous because it overlooks the fundamental differences between organism and society in: (1) the degree of concentration of consciousness in specialized parts, (2) the degree of differentiation arising during reproduction (of individuals in society and of cells in organisms), (3) the mode of reproduction and inheritance, and (4) the degree of subordination of individual parts to the whole.

[23] R. W. Gerard, "Higher Levels of Integration," pp. 83–85.

to formulate a single principle to govern the entire historical process from the origin of molecules to the development of human society, the progressive growth of cooperation and altruism. By oversimplifying phenomena and divesting each level of organization, among organisms and in society, of its specific characteristic qualities, a metaphysical statement is produced, to the effect that society will inevitably—because it is an organism—progress toward a cooperative state. "The ultimate future of society, however dark it may look to the contemporary sociologist or even to the historian, appears in the eyes of the biologist, sighting down the long perspective of organic evolution, as bright with hope."

It should be remembered that even in the biological world, evolution is not always in the direction of progress—witness the "regression" of the tapeworm. We can not afford to take refuge in Gerard's idea of a mysteriously operating "organizing trend"[24] which will insure the steady march of progress for man's society. Such evolutionary fatalism is unsound science, and dangerous social advice for it leads only to inaction. Fortunately, the United Nations are not guided by such fatalism; they are relying not on any "trend," but on their armed might, in order to defeat fascism and keep society on the road of progress.

Despite occasional backward movements and many blind alleys, biological evolution has moved in the direction of progress—towards more and more highly integrated and efficient organisms in which there is an increasing independence of and control over the external environment. This is to be explained on the basis of phenomena such as genetic mutations and natural selection. We may agree that, despite more or less temporary setbacks, society will develop eventually to a high level of cooperation. But it will do so not because of "organizing trends," mutations or natural selection. Discussion of social evolution in terms of natural selection as it applies in the biological world is no more meaningful than metaphysics, for, as we have indicated, without a study of man's socio-economic relations, it is impossible either to explain the past history or to indicate the prospects for the future development of society. Progress in social development is basically different from progress in organic evolution; the latter does not involve conscious activity, the former, depending on scientific and technological advance, is the result of conscious activity of men and is directed by experience of life and study of history. Progress in organic evolution occurs without a set plan or direction; social progress rests upon planned activity of men. As Huxley says, human progress "is not inevitable; man . . . must work and plan if he is to achieve further progress for himself and so for life."[25]

Needham[26] has demonstrated that the most dangerous aspect of the reduction of social phenomena to the biological level, at the present historical moment, is the basis it provides for fascist "philosophy." The central point in this "philosophy" is the thesis that man's biology decides his social behavior, and ruthless oppression of certain groups of people is justified because these groups are for all times fixed as "inferior" by their biology. Gerard's view gives indirect support to this thesis, by making biological principles the guide for social thought and action.

A sharp separation of the two levels—biological and social—must precede a fruitful discussion of how man's society can be kept free and democratic. That discussion must be based on a study, by means appropriate to the level, of the social forces making for change. Only a scientific analysis of these forces will enable man to speed social progress.

It is perhaps not surprising that Gerard's one-sided view of evolution—which ignores the qualitative differences of successive levels of integration and the specific part-whole relationships in each—should lead him to embrace the concept of purpose.[27] The retarding influence of teleological thinking on the advance of biological science has already been referred to. Here we add our agreement with Huxley that any "apparent purpose" in evolution is "just as much a product of blind forces as is the falling of a stone to earth or the ebb and flow of the tides. It is we who have read purpose into evolution, as earlier men projected will and emotion into inorganic phenomena like storm or earthquake. If we wish to work towards a purpose for the future of man, we must formulate that purpose ourselves. Purposes in life are made, not found."[28]

CONCLUSION

The concept of integrative levels describes the progress of evolution of the inanimate, animate and social worlds. It maintains that such progress is the result of forces which differ in each level and which can properly be described only by laws which are unique for each level. Since higher level phenomena always include phenomena at lower levels, one can not fully understand the higher levels without an understanding of the lower level phenomena as well. But a knowledge of the lower levels does not enable us to predict, *a priori*, what will occur at a higher level. Although some may have validity for the higher level, laws of a

[24] *Idem*, "A Biological Basis for Ethics," p. 108.

[25] Julian Huxley, "Evolution, The Modern Synthesis," p. 578. New York, 1942.

[26] Joseph Needham, Foreword to Prenant, "Biology and Marxism." New York, 1938.

[27] See references, note 13.

[28] Julian Huxley, *op. cit.*, p. 576.

lower level are inadequate to describe the higher level. The laws unique to the higher level can be discovered by approaches appropriate to the particular level; to do otherwise is invalid scientifically and, in some instances, dangerous socially.

By stressing the material interrelationships of parts and whole and the qualitative uniqueness of each level of integration, the concept is of genuine help to biologists. Its dialectical approach avoids "organicism," "fatalism" and mechanical "atomism," and helps attain a fuller understanding of such problems as the interrelations of cellular structure and metabolism, of cell and organism in ontogeny and in adult physiology, of individual and population biologies, of biological and social factors in the development of man's behavior; and the mechanisms responsible for organic evolution. By avoiding teleology, the concept aids the search for causes of biological phenomena.

The concept of integrative levels indicates to research biologists the crucial aspects of their problems, the solution of which puts the known facts into proper perspective by revealing the decisive element, the element imparting the uniqueness to the phenomena under study. It emphasizes the importance of studying the "mesoforms," matter at the point of transition from one level of organization to the next, so as to deepen our understanding of the unique qualities of the higher level. For example, it would indicate that an intensive study of the transition region between the chemical and biological levels, between protein and protoplasm, will help reveal the organizing relations unique to living matter and fundamental to vital activities.

As biologists become more familiar with the concept, a greater number will recognize its value both as an aid in the understanding of biological data already accumulated and as a reliable guide for research. Such recognition of its value will, however, be delayed by any presentation which creates the erroneous impression that it is metaphysical, teleological or mystical. This article has pointed to shortcomings in the presentation of the concept in some recent biological literature, with the hope that this may help make future references to the concept more reliable.

OBITUARY

SIR ARTHUR EDDINGTON

THE death of Sir Arthur Eddington deprives astrophysics of its most distinguished representative and the philosophy of science of its most notable expositor.

Appointments to major scientific posts in England have been made with a very high average of success. The electors have shown excellent judgment in picking the ablest men and courage in putting them, while young, into positions which gave them adequate opportunities. They never did better than when a young man of twenty-four was appointed chief assistant at the Greenwich Observatory in 1906. His early work—a series of papers dealing with the motions of the stars and the dynamics of star-clusters—was notable for the thorough insight into the problems and skill and elegance in their mathematical discussion which marked his later work. It may not be as well remembered that he was also a very competent observer. A floating photographic zenith telescope (supported by a mercury bath) had failed to give results of the anticipated precision. Eddington took on this discouraging problem, and found that the errors could be eliminated by changes in the details of observing methods. The instrument was thus started on a program of almost thirty years of successful operation, interrupted only by the present war.

In 1913 Eddington was elected, at the age of thirty-one, to the historic Plumian professorship at Cambridge. Again the judgment of the electors was fully vindicated.

His interest in physical problems now became predominant, and he entered upon the most notable period of his career, with his studies of the internal constitution and radiation of the stars.

These form a contribution of the highest order to the progress of physical science. When he began, a large number of properties of the stars were known, from the observations of the preceding decades, and the properties of atoms were also fairly well understood. By analysis of remarkable incisiveness and skill, he established the relations between the two, and ended by showing that the stars had to be what they were, just because they were composed of atoms. He proved that only large masses—exceeding fifty thousand times that of the earth—could shine brightly enough to be seen at distances of even a few light-years, and that all larger masses must inevitably so shine, with a brightness depending mainly, though not entirely, upon the mass, and increasing very rapidly with it. These conclusions were fully confirmed by the observed data, and the era of secure interpretation, rather than empirical study, of the properties of the stars began.

The greater part of this work is presented in "The Internal Constitution of the Stars" (1926). This volume marks an epoch in the progress of astrophysics. It is no less admirable as an example of the