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27. Supported in part by AEC and NSF. We thank D. R. Herschbach, J. L. Kinsey, G. H. Kwei, and J. A. Norris for allowing the use of their recent work before its publication; R. B. Bernstein, D. R. Herschbach, and A. Persky for reading the manuscript; and the members of the chemistry department of the California Institute of Technology, particularly Prof. A. Kuppermann, for hospitality to E.F.G.

The Role of Systematics in Biology

The study of all aspects of the diversity of life is one of the most important concerns in biology.

Ernst Mayr

There are many ways of dealing with the topic that was assigned to me. One might give a history of the role which taxonomy has played in the development of biology; or one might concentrate on the present status of systematics in biology; or finally one might attempt, in a timeless and somewhat philosophical way, to delineate the niche which systematics occupies within the total conceptual framework of biology. Further thought makes it evident that the three approaches are interdependent to such a degree that one has to give due consideration to all three of them.

Let me start with the question, what do we mean by "systematics," the role of which I am to describe? To be able to answer this question meaningfully requires an excursion into the history as well as philosophy of biology. The ancient Greeks saw a natural order in the world which, they thought, could be demonstrated and classified by certain logical procedures. They tried to discover the true nature of things (their essences) and approached classification with the methods of logic. Indeed, Aristotle, the first great classifier, was also the father of logic. The underlying philosophy, now usually referred to as essentialism (from essence), dominated the thinking of taxonomists up to and including the time of Linnaeus. Taxonomic nomenclature and the so-called typological thinking of taxonomists right up to our day have been permanently affected by the Aristotelian heritage (*1*).

History of Taxonomy

During the early history of biology this was no great handicap. Botany and zoology, to state it in a highly oversimplified manner, arose from the 16th century on as applied sciences, attached to medicine. Botany started as a broadened study of medicinal herbs and early botanical gardens were herb gardens. With but one or two exceptions all the great botanists and herbalists from the 16th to the 18th century (Linnaeus included) were professors of medicine or practicing physicians. Zoology arose in connection with human anatomy and physiology. When botany and zoology became independent sciences, the first concern of the two fields was to bring order into the diversity of nature. Taxonomy was therefore their dominant concern, and indeed in the 18th and early 19th century botany and zoology were virtually coextensive with taxonomy. Moreover, by sheer necessity, taxonomy was essentially the technique of identification.

The middle third of the 19th century was a period of decisive change to which many separate streams of development contributed. Increasing professionalism was one, and increasing specialization was another, to mention just two. Taxonomy itself helped in accelerating the change by introducing several new concepts into biology. The greatest unifying theory in biology, the theory of evolution, was largely a contribution made by the students of diversity, as we might call the taxonomists. It is no coincidence that Darwin wrote his *Origin of Species* after encountering taxonomic problems dur-

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ing the voyage of the *Beagle* and after 8 years of concentrated work on barnacle taxonomy. The comparison of different kinds of organisms is the core of the taxonomic method and leads at the same time to the question how these differences originated. The findings of explorer taxonomists, paleotaxonomists, and comparative anatomists inexorably led to the establishment and the eventual acceptance of the theory of evolution.

One might have expected that the acceptance of evolution would result in a great flowering of taxonomy and its prestige during the last third of the 19th century. This was not the case, in part, one might say, for almost administrative reasons. The most exciting consequences of the findings of systematics were studied in university departments while the very necessary but less exciting operations of descriptive taxonomy, based on collections, were assigned to the museums. Furthermore, most taxonomists were satisfied to use evolutionary concepts for rather practical purposes, such as evidence on which to base inferences on classification. As a consequence, evolutionary biology did not contribute as much to the strengthening of the bridge between taxonomy and other branches of biology as one might have expected. The great contributions to biology made by taxonomists during this period, such as population thinking, the theory of geographic speciation, the biological species concept, and several others that I shall mention presently, were incorporated into biology anonymously and without taxonomy receiving due credit.

Biology is no exception to the well-known phenomenon that in science there is a continuous change of fashions and frontiers. Since the 1870's there has been one breakthrough after another, beginning with the improvements of the microscope and the exciting discoveries of cytology. Perhaps the dominant trend during this period was an increasing interest in biological mechanisms, and in the chemical-physical explanation of biological functions. This led to the flourishing of various branches of physiology, of endocrinology, of genetics, of embryology, of immunology, of neurophysiology, of biochemistry, and of biophysics. Taxonomy, the oldest and most classical branch of biology, inevitably suffered in competition with all these brilliant developments. Whenever there was an interesting new growing point in taxonomy, it quickly made itself independent and left a rather descriptive, static, and sometimes almost clerical residue behind. The older ones among us remember the days when taxonomy was regarded by most biologists as an identification service. Some of the best universities in this country refused to accept Ph.D. theses in the field of taxonomy. The Guggenheim Foundation was the only granting agency that considered taxonomy worthy of support. Under the circumstances it was not surprising that only the most dedicated naturalists would choose taxonomy as their life's work, and we must pay tribute here to some inspired teachers who attracted gifted youngsters into our field.

Even today systematists feel that they are not getting their full share of recognition, of adequate financial support, and of truly superior graduate students, yet one must recognize that the change for the better in the last 20 or 30 years has been quite dramatic. This change had many causes but for some aspects it is not easy to say what is cause and what is effect. Taxonomists played a decisive role in the development of the synthetic theory of evolution, and this is being increasingly recognized by the leaders of biology. Julian Huxley and others have emphasized that taxonomy is indeed a vital branch of biology. Simultaneously we have witnessed a steady improvement in the scientific training of taxonomists. In order to obtain a position it is no longer sufficient that the young taxonomist knows how to describe new species; he is now expected to have acquired an adequate training in, and understanding of, genetics, statistics, animal behavior, biochemistry, and other branches of experimental-functional biology. The bridge between museums and universities is being broadened and strengthened in most places and the strong barriers between a narrowly defined taxonomy and the adjacent branches of biology are being obliterated. This new generation of taxonomists is no longer satisfied to work on preserved specimens. This new breed of naturalist-taxonomists insists on studying taxa as living organisms and pursues such studies in the field and in the experimental laboratory, wherever such studies will be most productive.

The ultimate result of these developments has been the general recognition that the universe of the taxonomist is far greater than was previously envisioned. Taxonomists now take an ever-increasing interest in evolutionary, ecological, and behavioral research, and indeed have assumed leading roles in these fields. Up to recently the terms *taxonomy* and *systematics* were generally considered to be synonymous. In view of the recent developments it seems advantageous to restrict the term taxonomy to the theory and practice of classifying, more narrowly defined, and to make use of the term systematics for the study of organic diversity, more broadly defined. This new viewpoint is represented by Simpson's definition (*2*): "Systematics is the scientific study of the kinds and diversity of organisms and of any and all relationships among them." In short, *systematics is the study of the diversity of organisms.*

When I was assigned the topic of my presentation I took it for granted that I should adopt his broad definition. The lectures and discussions during this conference have confirmed that this is indeed the definition of systematics which is adopted by the current leaders in the field. But there is one additional reason why we should define systematics so broadly.

The Position of Systematics in Biology

When we look at biology as a whole we see that systematics occupies a unique position. Some years ago I pointed out that there are basically two biologies (*3*). One deals with functional phenomena and investigates the causality of biological functions and processes; the other one, evolutionary biology, deals with the historical causality of the existing organic world. Functional biology takes much of its technique and *Fragestellung* from physics and chemistry, and is happiest when it can reduce observed biological phenomena to physical-chemical processes. Evolutionary biology, dealing with highly complex systems, operated by historically evolved genetic programs, must pursue a very different strategy of research in order to provide explanations. Its most productive method is the comparative method, for which the taxonomists have laid the foundation. Indeed, I can hardly think of an evolutionary problem that is not posed because of some findings of taxonomy.

One can express these basic concerns also in a somewhat different manner. At one extreme of biology there is a preoccupation with the ultimate building stones and ultimate unit processes that are the common denominators throughout biology. This has largely been the concern of molecular biology from the structure of macromolecules to such functional unit processes as the Krebs cycle. As legitimate as the reductionist methodology is when applied to functional problems, it quickly carries us down to a level where we leave behind most of that which is most typically biological, and we are left with a subject matter that is essentially physical-chemical. This is surely true for the chemistry and physics of the ultimate building stones and unit processes of living organisms. If this were the only level of integration in biology, it would be quite legitimate to combine biology with chemistry or physics.

The other extreme is the preoccupation with that level of biology that deals with whole organisms, with uniqueness, and with systems. It is a matter of historical record that taxonomists are among those biologists who have been most consistently concerned with whole organisms and who have most consistently stressed the organismic, the systems approach to biology.

No one will question the immense importance of molecular phenomena but they are not the only aspect of biology. As Michael Ghiselin has stated it so perceptively, just as architecture is more than the study of building materials, so is biology more than the study of macromolecules. In systematics, in evolutionary biology, and in much of organismic biology, one normally deals with hierarchical levels of biological integration that are many orders of magnitude above the molecular level. Each level has its specific problems and its own appropriate methods and techniques. That there is such a difference in levels of integration is completely taken for granted in the physical sciences. No one would expect the aeronautical engineer to base the design of airplane wings on the study of elementary particles. But a uniqueness of role for each level is even more evident for the different levels of biological integration.

Lest I be misunderstood, there is no conflict between molecular biology and organismic biology (including systematics). But it must be emphasized that each level of integration poses its own specific problems, requires its own methods and techniques, and develops its own theoretical framework and generalizations. This has been clearly recognized and frequently stated by the foremost leaders of molecular biology. Consistent with this is the fact that faculty and curriculum in the areas of systematics, ecology, and evolutionary biology have recently been strengthened in several of the leading American universities, and as a result systematics has now become better integrated into biology than at any other time since the days of Darwin.

The role of systematics should now be quite clear: It is one of the cornerstones of all biology. It is the branch of biology which produces most of our information on the levels of integration, designated as natural populations and higher taxa. It supplies urgently needed facts, but more importantly, it cultivates a way of thinking, a way of approaching biological problems, which is alien to the reductionist, but which is tremendously important for the balance and well-being of biology as a whole.

Let me now turn to some of the concrete contributions made by systematics.

The Contributions of Systematics to Biology

The magnitude of the contributions made by systematics is not appreciated by many biologists. And yet these achievements are extraordinary indeed, even if we adopt the most narrow definition of taxonomy. They include the description of about one million species of animals and half a million species of higher and lower plants, as well as their arrangement in a system. This classification, much as we continue to modify it in detail, is on the whole amazingly logical, internally consistent and stable. It is an immensely useful system of information storage and retrieval. All the comparative work of morphologists, physiologists, and of phylogenetically inclined molecular biologists would be meaningless if it were not for the existence of the classification.

Taxonomists supply a desperately needed identification service for taxa of ecological significance and for the correct determination of fossil species needed for work in stratigraphy and geological chronology. In all areas of applied biology good taxonomy is indispensable, as in public health in the study of vector-borne diseases and of parasites; in the study of the relatives of cultivated plants and of domestic animals; and in the study of insect pests and their biological control. Much work in conservation, wildlife management, and the study of renewable natural resources of all kinds depends for its effectiveness on the soundness of taxonomic research. The faunas, floras, handbooks, and manuals prepared by taxonomists are indispensable in many branches of biology and also widely used by the general public.

As important as these descriptive and service functions of taxonomy are, they are only part of the contribution of systematics, and to many of us the least important part, even though a prerequisite of all the others. I have pointed out already that the founding of evolutionary biology was the work of taxonomists. They also supplied the solution of many individual evolutionary problems. This includes the role of isolation, the mechanism of speciation, the nature of isolating mechanisms, rates of evolution, trends of evolution, and the problem of the emergence of evolutionary novelties. Taxonomists (including paleontologists) have made more significant contributions to all these topics than have any other kind of biologists.

There is hardly a taxonomic operation during which the systematist does not have to face basic biological questions. In order to assign specimens to species he must study variability and particularly polymorphism, and quite often he has to undertake a rather complete population analysis including the study of life cycles. In the study of polytypic species he concerns himself with geographic variation and its meaning; he studies the adaptation of local populations and tests the validity of climatic rules. When studying the population structure of species, he examines isolates and belts of hybridization. Indeed, taxonomists have developed in the last two generations a veritable "science of the species," as cytology is the science of the cell and histology the science of tissues. At every step he must think about the adaptation of populations, their past history, and the magnitude of dispersal (gene exchange between populations).

Many new concepts arose out of this work of the taxonomist but have since diffused broadly into genetics, ecology, physiology, and other areas of biology. By far the most important of these, as I have often stressed in the past, is population thinking. Biology, as all other sciences, was permeated by typological thinking until late in the 19th century, and is still today. When the learning psychologist speaks of The Rat or The Monkey, or the racist of The Negro, this is typological thinking. The early Mendelians were pure typologists. A mutation changed The Wildtype, and the result was a new type of organism, according to De Vries a new species. I have pointed out elsewhere (*4*) that taxonomists began as early as the 1840's and the 1850's to collect large series of individuals, population samples as we would now say, and describe the variation of these samples. From this purely pragmatic operation emerged eventually a wholly new way of thinking which replaced typological essentialism. From taxonomy, population thinking spread into adjacent fields and was in part instrumental in the development of population genetics and population cytology. Population thinking has now spread into the behavior field, into physiology, and into ecology. This one conceptual contribution alone has been of such great benefit to vast areas of biology as to justify support for systematics.

As the interests of the systematists broaden, it is becoming more and more true that systematics has become, as stated by Julian Huxley (*5*), "one of the focal points of biology." Although he may not be able to solve these problems himself, it is the systematist who frequently poses the problems which are of concern to the population geneticist, the physiologist, the embryologist, and the ecologist. For instance, systematics poses the problems in that area of ecology which deals with the phenomena of diversity, the differences in the richness of faunas and floras in different climatic zones and habitats, and so forth. A succession of prominent taxonomists have been leaders in the study of problems of species competition, niche utilization, and structure of ecosystems.

Environmental physiology owes much to systematics. Zoological systematists like C. L. Gloger, J. A. Allen, and Bernhard Rensch have made major contributions to the discovery of adaptive geographic variation and the establishment of climatic rules. Up to the 1920's it was almost universally believed that geographic differences among populations of a species were nongenetic modifications of the phenotype and of no evolutionary interest. As it was stated, "the type of the species is not affected." It was zoologists with taxonomic interests or training who demonstrated the genetic basis for adaptive differences between geographic races. The stress of unique characteristics of individuals, the recognition of differences between populations, the emphasis on the phenotype as a compromise between multiple selection pressures, all this represents thinking which came straight out of evolutionary systematics but has exercised and is continuing to exercise a profound influence on environmental physiology.

Applying taxonomic principles to the interpretation of man's evolution, as was done by Simpson, LeGros Clark, Mayr, and Simons, has decisively added to our understanding of man's evolution and of hominid classification. The chaos of 29 generic and more than 100 specific names caused by the earlier typological approach was replaced by a biologically oriented classification in which three genera, *Paranthropus, Australopithecus*, and *Homo* (the latter with two species), are recognized.

Whole branches of biology are unthinkable without systematics. Biological oceanography is one example, and biogeography another. This field has traditionally been the domain of the taxonomists to such a degree that it is unnecessary to stress the contribution of systematics. Cytogenetics and bioacoustics are other areas of biology that derived much of their inspiration from systematics. Systematists have enormously contributed to ethology through their comparative behavior studies, particularly of insects.

There are two reasons why it is necessary to stress these contributions. One is that those who have come into biology from the outside (for example, from physics or chemistry) simply do not know this history. The second reason is that there has been a tendency even among those who know the situation to credit all the neighboring fields, population genetics, ecology, or ethology, even though the advances were made by practicing taxonomists and were made possible only by the experience they had gained as taxonomists. It is totally misleading to limit the labels taxonomy or systematics to the purely clerical, descriptive operations and to give a different label to all the broader findings and concepts that are the direct result of the more elementary operations. Regrettably, even some taxonomists have supported the myth that all the more biologically interesting activities and findings of the taxonomist are not part of taxonomy. In this connection it will be of some importance, in order to clarify the situation, to add a few words on the structure of systematics.

The Structure of Systematics

In the earlier part of my discussion I described how systematics, as we now understand it, emerged from essentialism and nominalism (by rejecting these concepts) and became based on the fact of evolution. It began to study organic diversity as the product of evolution. It recognized that every classification is a scientific theory with the properties of any scientific theory: it is explanatory, because it explains the existence of natural groups as the products of common descent; it is predictive, because with high probability it can make predictions as to the pattern of variation of unstudied features of organisms and the placing of newly discovered species. Finally, systematics established many new contacts with other areas of biology by adopting the thesis that the characteristics of the living organism are at least as important for classification as those of preserved specimens.

How did these profound changes in the science of systematics affect its working procedure? In some ways not at all, because the needs for sound classification have not changed. There is still the same need to order the diversity of nature into elementary units, biological species. Sorting variable individuals and populations into species (and naming and describing them) is sometimes referred to as alpha taxonomy. There is still need for some alpha taxonomy even in as mature a branch of systematics as bird taxonomy. New species, new subspecies, and all sorts of new taxa of birds are still being found. We still discover occasionally that a species of the literature is nothing but a variant of another species. In ornithology we still are in need of compilations, checklists, and descriptive works of various sorts that fall under the designation of alpha or beta taxonomy. And yet even in these relatively elementary procedures of taxonomy there is a drastic difference between doing them either in a typological (=essentialist) or in a biological-evolutionary fashion.

The typologist acts as if he were dealing with the "essential natures" of created types. He stresses morphotypes and discontinuities; variation is treated as a necessary evil to be ignored as much as this is possible. The biological systematist knows that he is dealing with samples of variable natural populations; he is interested in the biological meaning of this variation. He knows that he is dealing with living organisms and wants to study all their attributes whether they concern morphology, behavior, ecology, or biochemistry.

An understanding of the biological meaning of variation and of the evolutionary origin of groups of related species is even more important for the second stage of taxonomic activity, the sorting of species into groups of relatives ("taxa") and their arrangement in a hierarchy of higher categories. This activity is what the term classification denotes; it is also referred to as beta taxonomy. No matter how interested a taxonomist is in the evolutionary and ecological aspects of the taxa he studies, he will also devote a major share of his time to alpha and beta taxonomy, not only because so much work still remains to be done, but also because the more interesting biological problems are found only through research in alpha and beta taxonomy.

The Future of Systematics

I would feel rather pessimistic about the future of taxonomy if it were only an identification service for other branches of biology, as is thought by some of our less imaginative colleagues. But he who realizes that systematics opens one of the most important doors toward understanding life in all of its diversity cannot help but feel optimistic. Environmental biology, behavioral biology, and even molecular biology are all moving in our direction. The most exciting aspect of biology is that, in contradistinction to physics and chemistry, it is not possible to reduce all phenomena to a few general laws. Nothing is as typically biological as the never-ending variety of solutions found by organisms to cope with similar challenges of the environment. Nothing is more intriguing than the study of differences between related organisms and the challenge to explain these differences as the result of natural selection. Even in cases where the ultimate solution may come from genetics or biochemistry, it is the systematist who in almost every case is the one who poses the challenging questions. The opportunities for exciting research are virtually unlimited. This is becoming clearer and more widely appreciated every year.

These opportunities are not without obligations. Let us remember at all times that each and every taxonomist is a spokesman for systematics. He must carry out his activities in such a way as to reflect favorably on his field. Let us remember that taxonomy is not a kind of stamp-collecting but a branch of biology. Let us desist from all practices that are injurious to the prestige of systematics, as, for instance, by indulging in nomenclatural practices that lower the value of scientific nomenclature as an information storage and retrieval system. Finally, let us remember that in virtually every taxonomic finding certain generalizations are implicit that are of value and broad interest to biology as a whole. It will help our relations with other branches of biology if we make these findings known. They are sure to have a minor or major impact well beyond the bounds of systematics.

It is my sincere belief, to summarize my discussion, that systematics is one of the most important and indispensable, one of the most active and exciting, and one of the most rewarding branches of biological science. I know of no other subject that teaches us more about the world we live in than systematics, the study of the diversity of life.

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Metastable Atoms and Molecules

Measurements of their unusual properties in highly excited states reveal a new area for investigation.

E. E. Muschlitz, Jr.

An atom (A) or molecule (XY) is generally considered to be in a metastable state of electronic excitation if its lifetime for monomolecular decay is greater than 1 microsecond. Obviously, this is an arbitrary definition, for the entire range of lifetimes may be found. If ordinary electric dipole radiation is allowed, lifetimes of the order of 10^{-9} second are observed for the radiative decay process

$$A^* \rightarrow A + h\nu \qquad (1)$$

where $h\nu$ is Planck's constant times the frequency of the photon. Thus, for an atom or molecule to be in a metastable state, dipole radiation must be a forbidden transition. Chemical reactions of nonmetastable excited species are often not significant in the gas phase, since radiative decay may occur before a reactive collision takes place. On the other hand, a metastable species can survive a number of elastic collisions before reaction occurs. Perhaps the most prominent regions of the universe where metastable excited atoms and molecules play an important role are the upper atmospheres of the earth and other planets. In these regions, the particle density is so low that bimolecular collisions are relatively infrequent, and a significant amount of energy is stored in metastable species. On earth, atoms and molecules in electronically excited states are present in flames, shock waves, and electrical discharges.

The physical and chemical properties

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