ABSTRACT. Considerable progress has been made in bacterial systematics, particularly in characterization and in approaches to determining the relationships of bacteria. Nonetheless real progress is difficult because much of the older literature is inadequate in terms of the present state of knowledge and because original strains do not exist wherewith sense can be made out of the older literature. It is felt that bacterial systematics could be placed on a firm foundation if the following steps were taken: 1) revise the Bacteriological Code so that in order for a name to be validly published a prescribed minimal description would be required as would deposition of the type strain in a culture collection from which it would be available; 2) establish a date in the future as the starting date for names of bacteria, conserving, however, those names of recognizable taxa for which there are adequate descriptions and type strains (if the organism is cultivable), and 3) where indicated, acquaint authors and editors with the requirements for valid publication and with sound taxonomic practices.

Bacterial systematics embraces the characterization, classification, identification and naming of bacteria. In these areas a great deal of progress has been made from the time bacteria were first discovered to the present, especially during the past twenty-five years. However, despite the advances that have been made, the current state of bacterial systematics leaves much to be desired, and the situation becomes increasingly worse as new taxa are described and named and as more and more invalid statements appear in the literature. In that which follows, some mention will be made of recent advances in the systematics of bacteria, but the emphasis will be on the obstacles to real progress and on the ways in which these obstacles can be removed or circumvented.

Great strides have been made not only in the equipment and methods used to determine the characteristics which have been routinely used in taxonomy but also in the search for new attributes to better show the relationships of the bacteria. Among the latter are the presence or absence of a nuclear membrane, the cytoplasmic membrane system, the number and arrangement of flagella, the chemical composition of the cell wall, the appendages on spores, metabolic pathways and products, the DNA base ratio, DNA homology, and comparative chemistry of enzymes with identical functions.
In addition to more and improved data on the characteristics of the bacteria, computers are now available to facilitate our handling of these data. Regardless of whether or not we want to weight certain characters, programs can be written which will enable us to compare in a consistent fashion large numbers of strains and taxa. It should be stressed here that, as applied to bacterial classification, the computer is a tool, not a concept or a philosophy. It so happened that the first use of the computer in bacterial classification was in connection with the application of Adanson's theory, proposed in the latter half of the 18th Century, which maintains that each characteristic is of equal weight in determination of relatedness. Unfortunately there are many taxonomists who equate the computer with Adansonian theory, and who, not subscribing to this theory, will have nothing to do with the computer. They should realize that the computer can be an extension of their minds and can include all the bias they wish and that, if they are dealing with large numbers of strains or large volumes of data, the function of the computer is to expedite their work. One of the contributions computer taxonomy has made is that most taxonomists now realize that in order better to "see" bacteria and to visualize their relationships, bacteria should be looked at in terms of a large number of attributes rather than from the narrow viewpoint of a few characteristics with which a taxonomist may be enamored; a much better perspective of the bacteria is obtained by looking at their total biological picture rather than at a few arbitrarily selected characteristics just as the astronauts obtained a much better perspective of the planet Earth, indeed of man himself, when they recently viewed the Earth from the proximity of the moon.

Now regardless of whether or not one supplements his inbuilt, biological computer with a mechanical one to facilitate his computations and to analyze his data, it is, of course, necessary that the data be comparable if valid conclusions are to be reached. If one uses his own data, there should be no problem. If, however, one is using information obtained from a variety of sources, then valid comparisons might become difficult, if not impossible, to make. Clearly many of the older descriptions of bacteria are extremely confusing and create great difficulty not only because of insufficient information when compared to modern descriptions but also because it is very difficult to assess the reliability of the data. Valid comparison of data becomes possible, and a great deal easier, if detailed descriptions of or suitable references to the methods used to obtain the data are given.

In addition to being reliable, it is essential that the data on the characteristics of a bacterium be sufficient to permit the identification of the bacterium. Enough information should be given, 1) to place the organism in its proper taxonomic niche, and 2) to separate it from closely related organisms. Unless information of this type is provided in the description of a newly named species, it may be impossible to determine to which organism the name applies, and the name would then be illegitimate as a nomen dubium. It probably would be helpful if, in those cases where possible, the inclusion in the description of each newly named bacterium of a minimal list of characteristics significant to the classification of bacteria were made part of the requirements for the valid publication of names. Such a list might include the Gram and acid-fast reactions, morphology, mode of reproduction, mode of motility, if any, number and position of flagella, if any, relationships to oxygen, temperature and salt, and the type of energy-yielding metabolism. In connection with this, it is
interesting to note that nearly 6 years ago a list of characteristics recommended for inclusion in the description of streptomycetes which appear in patent applications was published in the International Bulletin of Bacteriological Nomenclature and Taxonomy, 13(3):169-170 (1963).

In the absence of adequate descriptions, cultures on which the original descriptions were based are invaluable in helping taxonomists to understand the literature; these cultures are also very useful in updating older descriptions. However, one disadvantage with maintaining bacteria in serial subculture is that as actively growing cells they are subject to mutation and selection; furthermore, the more subculturing required, the greater the chances for contamination to occur.

Fortunately it was discovered many years ago that bacteria can be preserved in a viable and stable condition for long periods by freeze drying; however, it was not until the 1940's that this method of preserving bacteria gained wide acceptance. Within the past 10 years it has been found that bacteria can be preserved more effectively when frozen and stored at the temperature of liquid nitrogen than when maintained in the freeze-dried state.

Now the fact that bacteria can be preserved in a viable and stable condition for long periods has great implications in bacterial systematics. It means that living cultures can serve as fixed standards, i.e. as nomenclatural types, for taxonomic groups. For many years the bacteria were regarded as plants, and their nomenclature was governed by the Botanical Code. Plants are classified and identified primarily on morphological grounds, and dead specimens of plants serve adequately as representatives of nomenclatural types; living specimens, which are subject to change, were not permitted by the Botanical Code to serve as representatives of nomenclatural types. However as the science of bacteriology developed, it soon became apparent that living cultures were indispensable to the complete characterization and to the classification and identification of bacteria. It was primarily for the reason that the Botanical Code did not permit living cultures to serve as nomenclatural types that bacteriologists formulated a code of nomenclature for the bacteria, which was published initially in 1947. To be sure, the Bacteriological Code is not perfect. However, during the past 10 years Dr. R. E. Buchanan and his staff have put the Code through rigorous paces while preparing the text of the Index Bergeyana and supplementary material, and most of the problems and deficiencies are recognized. It now remains for the International Committee on Nomenclature of Bacteria to effect a suitable revision of the Code, and towards this end an ad hoc committee was constituted a little over 6 months ago by the Judicial Commission of the International Committee on Nomenclature of Bacteria.

In addition to revising the Bacteriological Code, there is another step that, if taken, should aid considerably the efforts to improve bacterial systematics. It would appear that many of the problems in systematic bacteriology could be avoided if editors of biological journals were reminded of or made aware of the nomenclatural-type concept and the requirements for the valid publication and legitimacy of names of bacteria. It is suggested, therefore, that a committee or committees of qualified individuals be formed to assist editors of biological journals by providing them with information and guidelines relating to bacterial nomenclature and perhaps by offering their services on reviewing papers on systematics.
Regardless of how highly we regard modern descriptions of bacteria, it is conceivable that in the future some of them may be quite inadequate because of the lack of certain bits of information. It is, therefore, essential that cultures of type strains be available so that descriptions can be updated and valid comparisons made. Many, if not most of the problems in bacterial systematics would disappear if cultures of the type strains of all of the named species were available. It seems reasonable, therefore, to make one of the requirements for the valid publication of a species or subspecies name the designation of the type strain and the deposition of a culture of the type strain in a culture collection from which the strain would be available. For organisms which cannot be cultivated, adequate descriptions or illustrations would have to suffice. Currently one of the requirements for the establishment of a neotype strain is that the strain be deposited in a culture collection from which it would be available; this requirement should now be made part of the conditions for the valid publication of new species and subspecies names.

Perhaps the most important and useful concept in bacterial systematics is that of the nomenclatural type. It is by means of the nomenclatural type that we are able to determine the application of names. The nomenclatural type is that constituent element of a taxon to which the name of the taxon is permanently attached. The nomenclatural type of a genus is a species and that of species or subspecies is a strain, which may be represented by a living culture or by a description or an illustration. A type strain must be one of the strains on which the original description was based. If none of the original strains is extant, then a later isolate which agrees with the original description may be designated as a neotype. According to the nomenclatural type concept, a named species can be described as consisting of the type strain together with all other strains which closely resemble the type strain. If at some time it is decided to divide the strains which comprise a named species into two or more groups and to recognize each group as a named species, the group which contains the type strain of the original species must retain the name of this species; for each of the other groups a new species name must be given and a type selected from the included strains. Furthermore any study or any statement about a named taxon must take into consideration the nomenclatural type of that taxon. For example if one wanted to discuss the genus Corynebacterium, the type species, C. diphtheriae, cannot be ignored for it is the species to which the generic name Corynebacterium is permanently attached, and it is the only species which belongs to the genus Corynebacterium without question.

Nomenclatural types are useful in the determination of synonymies. Names based on the same type are objective synonyms; names based on different types, which types are regarded as similar enough to belong to the same taxon, are subjective synonyms. For example, when a species is transferred from genus to genus, the resultant names are objective synonyms. In the case of two independently named species, each with its own type, synonymy of the two names is determined by comparison of the types; if the types are regarded as similar enough to belong to the same species, the names are regarded as subjective synonyms because the relatedness of the types is a personal opinion.

The main purpose, therefore, of nomenclatural types is to provide a fixed reference point for scientific names so that a given name will always refer to the same taxonomic group. Clearly "species" is a man-made
concept, and the limits of species are constantly in a state of flux due not only to evolutionary processes but also to the many differences in human opinion. It is easy to see how the concept of a given species could change over the years if there were not some fixed point to relate the name to. There are, in fact, several documented cases where the species description applied to a name eventually changed so much that the modern description does not agree at all with the original description; in addition, there are instances where a name has been used with so many different meanings that complete confusion has resulted.

The primary purpose of type strains, then, is to serve as fixed references to which the names of species are permanently attached. Type strains have the special function of determining the applications of names, and they are not intended to be typical of the species; in fact it is quite difficult to determine exactly what is a typical or average strain of a species. Even if a typical strain of a species could be determined, it could only relate to a given population at a given time; changes in the population are constantly occurring, and we would be faced with the impossible task of selecting a never-ending series of typical strains. Suffice it to say that a typical strain, if indeed it can be recognized as such, has a function different from that of a type strain: whereas the former is intended as an example of the kind of strain most frequently encountered in a population, the latter serves as a permanent, fixed standard in the application of names. Both type strains and typical strains can serve adequately as points around which other strains can be clustered. However, the type strain holds the advantage because it does not change with time.

As stated previously, one aspect of bacterial systematics is nomenclature. When an author wishes to recognize a new taxon he must give a scientific name to the taxon in accordance with the internationally accepted rules of nomenclature. According to the rule of priority, the earliest available name or specific epithet must be used. It is incumbent then for an author of a new name, indeed for any author who uses a scientific name, to determine whether there are any earlier names or specific epithets for the taxon he is dealing with. If done properly, this entails an enormous amount of work, for there are thousands upon thousands of species names which appear in the literature. Furthermore, the task is completely frustrating because of the generally inadequate descriptions applied to most of these names. The only reasonable solution seems to be to establish a new and very recent starting date for the acceptance of names of bacteria, as has been suggested many times in the past, and to require adequate descriptions as well as designation and deposition of type strains as part of the requirements for the valid publication of new names. Exceptions to the new starting date would be made for named taxa which are adequately described and recognizable and for which cultures of type or neotype strains are available; for organisms which are unique but which cannot be cultivated, an adequate description or illustration would serve as the nomenclatural type; the names of these taxa could be retained or accepted with credit given to the original authors of the names. The intent of this action is to avoid making authors spend their valuable time searching through ambiguous literature merely for the purpose of determining the earliest name of the taxon they are concerned with and then, as in most cases when older synonyms are discovered, having to conserve the later name or reject the earlier name.
The work involved in updating the descriptions and designating type or neotype strains of three, four or even five hundred species is considerably less than that entailed in determining the adequacies of thousands upon thousands of descriptions and rejecting thousands upon thousands of names as nomina dubia.

In summary, considerable progress has been made in bacterial systematics, particularly in characterization and in approaches to determining the relationships of the bacteria to each other. Nevertheless the present state of bacterial systematics is, frankly speaking, not good, primarily because much of the older literature is inadequate in terms of present-day knowledge and because type or neotype strains of most of the named species are not available. The disorder and confusion that exist are difficult to understand in light of man's remarkable scientific achievements. However in all fairness it must be pointed out that much of systematics is subjective, and it is the great difference in human opinion that is the source of much of our difficulty. It is felt, however, that if certain admittedly arbitrary steps were taken, bacterial systematics could be placed on a solid foundation and taxonomists could at least operate on common grounds even if they do not agree with each other. These steps are:

1) require, as a condition for the valid publication of the name of a bacterium, a) that where practical original descriptions of bacteria contain information on a basic list of characteristics; certain characteristics would be required for all bacteria, and additional characteristics would be required for organisms placed in specific families or genera, and b) that a type strain be designated and that cultures of the type strain be deposited in a culture collection where the strain would be available; in those cases where the organism cannot be cultivated, this requirement would not pertain,

2) establish a very recent date, perhaps even one in the future, as the beginning date for valid publication of the names of the bacteria; the present starting date is May 1, 1753; those names of recognizable taxa which should be retained because of common usage could be retained with authorship credited to the original authors, and

3) in order to promote sound practices in bacterial systematics, establish, probably through the International Committee on Nomenclature of Bacteria, through national microbiological societies, or through the Conference of Biological Editors, a committee or committees of qualified individuals to assist editors of microbiological journals by providing them with information relating to the requirements for the valid publication and legitimacy of names of bacteria and to the nomenclatural-type concept and perhaps by reviewing papers on systematics submitted for publication.