30 October 1959, Volume 130, Number 3383 SCIENCE

Current Trends in Linguistics

Though not a predictive science, linguistics has developed effective descriptive and historical methods.

Joseph H. Greenberg

The aim of the present discussion is roughly threefold: to distinguish the characteristic subject matter and methods of linguistic science, to discuss a few of the analytic concepts and substantive results of linguistics which are likely to be of interest to the nonlinguistic scientist, and, finally, to indicate certain recent developments, some of which concern areas of interdisciplinary interest which give promise of ultimate expansion into major subfields either of linguistics itself or of related sciences.

All disciplines are concerned in some fashion or other with linguistic problems. This is so with respect to fields as diverse as the natural and behavioral sciences, mathematics, history, and such humanistic pursuits as the study of literature. This is perhaps most readily evident in the last named instance, since the very data of literature are exclusively linguistic in nature, consisting of a certain body of written, or, in the case of folklore, of unwritten verbal materials. In the social sciences, likewise, there is a body of verbal behavior which is, however, not the exclusive subject matter of these sciences. In law, for example, there are written and unwritten constitutions, statute law, the records of past judicial decisions, and other materials, all of which are presented to the investigator as a corpus of concrete linguistic data. There are likewise the nonverbal acts of the criminal assaulting the victim or the condemned man being led to prison. The meaning analysis of verbal documents is therefore a task of the student of law as well as the relation between verbal and nonverbal acts.

Since only man speaks, the natural scientist does not include verbal behavior among the observational data of his science. This does not mean that the physical scientist does not share with other investigators a certain degree of preoccupation with linguistic matters. In all sciences hypotheses and results of observation can only be stated and communicated by means of a symbolic system, whether by natural language, in this case generally modified in certain respects (for example, through a technical terminology), or whether by a supplementary symbol system whose elements are ultimately defined in terms of natural language. The key role of this linguistic factor leads, in discussion of methodological problems, to an analysis of the language of science itself. Similar considerations obviously apply to the logico-mathematical disciplines and to analytic philosophy in which problems of metalogic and metamathematics are in large measure questions regarding the language of logical and mathematical statements.

Language, then, enters as a factor into all areas of the scientific enterprise. There is, however, one science, linguistics, which, as its very name implies, takes language as its primary object of investigation. Linguistics, however, differs from all other sciences not only in the centrality of its interest in language but also in the manner in which this subject matter is approached. All other sciences, insofar as they are concerned with language, are concerned with the specific content, that is, the meaning, of what is expressed in language, and this in a restricted fashion depending on its subject matter. Linguistics takes as its unique subject matter the structure of linguistic systems as such. Of course, linguistics, like any other science, is also interested in the language of its own subject, for example, problems of the terminology of scientific linguistics. In this aspect it does not differ in principle from any other science which deals with a subject matter other than language.

The two main fields of linguistics as traditionally practiced are descriptive and historical linguistics or, as they are frequently called, synchronic and diachronic. In the former, languages are studied as systems functioning in a single speech community at a single time, and in the latter, under their dynamic aspect of change through time. Although language descriptions are presupposed by historical linguists in that different time states of the same language or different languages which have issued from the same historical source (related languages) can only be compared after they have been described, it was the historical branch under the older name of comparative philology which first emerged as a science, at the turn of the 19th century. It was only in relatively recent times, roughly from 1920 onwards, that the problem of synchronic language description—the nature and requirements of an adequate description of a language—ceased to be taken more or less for granted and became a center of theoretical interest. A number of approaches which first emerged at about this time, and which have been called structural, all have in common an interest in interrelationships within a structure functioning on a single time plane, in contrast with the historical interests which predominated in the 19th century. This development within linguistics is doubtless to be viewed as related to similar contemporary movements in

The author is on the staff of the Center for Advanced Study in the Behavioral Sciences, Stanford, Calif.

neighboring fields, notably Gestalt approaches in psychology and functionalism in cultural anthropology.

The clear separation of synchronic and diachronic aspects is characteristic of linguistics as a science. This is possible because the rate of change in language is slow. Most of us probably have the impression that English has not changed in our own lifetime. On further reflection we will probably recall expressions which have become current in recent periods which did not exist earlier, or items which are no longer in active use. We will not have noticed, for example, the far slower drift in the pronunciation of certain sounds, a realm of linguistic events of which we are far less conscious than the use and meaning of words. As small as the changes in a language appear to be over a single lifetime, the accumulative effect becomes very considerable over a longer period. Thus we have to learn Anglo-Saxon, the form of English as spoken, say in the 11th century, as a foreign language which seems to be roughly as strange as German.

In describing a language for a given time period the linguist makes the assumption that the change in the speech of his informant during this time is negligible so that the system can be studied as an isolate, much as the astronomer studies the solar system as a system, disregarding the gravitational attraction of the stars. The description of a language obviously involves at least two levels, the phonetic and the grammatical. In the former we deal with the organization of the sound into units. In the latter we are concerned with the rules governing sequences of meaningful combinations of such units, for example, words or the smaller meaningful components of words known to the linguist as morphemes.

Phonemic Theory

The basic unit of that part of linguistic description which deals with the sounds of the language is the phoneme, the principle of which is foreshadowed in the prescientific invention of alphabetic writing. The nonlinguist so takes for granted the type of analysis into individual sound units which underlies alphabetic writing that he is unlikely to realize that there is a complex set of theoretic assumptions involved. He tends to believe that alphabetic writing simply renders each different sound by a different letter symbol. In fact, however, there are sound variations of which the naive speaker is generally unaware. For example, the average speaker of English, untrained in phonetics, is unlikely to have ever noticed that the sound spelled *t* in *stop* is unaspirated as compared with the aspirated *t* of *top*. But this difference is sufficient to distinguish separate forms in Chinese, Hindustani, and many other languages. If we approach another language naively we will respond only to those cues which are significant in our own language. On the other hand we will attribute significance to those differences which have a function in our own language whether they have a function in the language we are describing or not. Thus an untrained observer will arrive at essentially the same sound system for any language he describes and two untrained observers with different backgrounds will describe the same foreign language in different ways. Nor will phonetic training in itself overcome this difficulty. The ability to discriminate many sound differences not significant or not even present in one's own language is a necessary but not sufficient condition for success. In the prestructural period of descriptive linguistics the tendency became more and more prevalent, in the name of a naive empiricism, to transcribe phonetically in an attempt to reproduce as accurately as possible the actual sounds, thus producing what, from the point of view of the structure of the language studied, was an ever-growing mass of irrelevant detail. The use of instrumental phonetic apparatus hastened the realization that this type of analysis was a cul-de-sac, for it became apparent from such recordings that in the sound wave itself not even two repetitions of the "same" utterance in the same language are ever physically identical.

A fundamental assumption of linguistic analysis is that a phonetically trained observer will be able to distinguish those differences of sound which are functional in a given language. It seems plausible to assume that any sound distinction employed in a speech community will be fairly gross from the articulatory and perceptual point of view. Along with these distinctions the trained linguist will also note many others which will later turn out to be irrelevant. Since, however, he cannot know a priori which particular features of an utterance will be significant, he must be prepared to indicate them all at the beginning in what is known as a phonetic transcription.

In order to discover which of these sound differences are distinctive in the language investigated, several analytic principles are employed. One of these is that known as complementary distribution. By the distribution of any sound we mean the set of environments in which it occurs. For example in "stop the music!" the environment of the *t* is "s_op the music!" To say that two sounds are in complementary distribution is to say that we have discovered a rule concerning the environments of each which show that these are mutually exclusive. Assuming that the linguist describing English has noted the difference between the aspirated *t* of *top* and the unaspirated *t* of *stop*, further observation leads him to the hypothesis, never contradicted by later observations, that the environments of unaspirated *t* are all characterized by an *s* before the blank and those of aspirated *t* by never having an *s* before the blank. The environments are therefore mutually exclusive and the two sounds are in complementary distribution. Such variant sounds grouped as members of the same phoneme are called allophones.

The principle of complementary distribution is, however, not sufficient, as will be evident from further consideration of the example of aspirated and unaspirated *t*. Since it is also true that *p* (as well as certain other sounds) exhibits a parallel variation, that is, only unaspirated *p* occurs after *s* (as in *spin*, as opposed to the aspirated *p* of *pin*), this unaspirated *p* whose environments all contain an *s* immediately before *p* will likewise be in complementary variation with aspirated *t*. If we rely on complementary distribution alone, we have no way of choosing between unaspirated *p* and unaspirated *t* as the coallophone of aspirated *t*. If we choose both, then unaspirated *p* and unaspirated *t* will become members of the same phone as aspirated *t* and therefore coallophones with each other. But of course they are not in complementary distribution and so cannot by this same rule become allophones of the same phoneme. This example shows that an unconditional rule, stating that two sounds which are in complementary distribution are allophones of the same phoneme, leads to an undesired result. The same allophone will belong simultaneously to different phonemes, so that an unambiguous conversion of allophones to phonemes becomes impossible.

It is clear, then that another factor must be considered, namely, phonetic similarity. We match the unaspirated *p* of *spin* with the aspirated *p* of *pit* rather

than with the *t* of *ten*, although it is in complementary distribution with both. Although in this particular instance the choice is obvious, phonetic similarity is under certain circumstances a vague criterion. Can we always say that a particular sound *a* is more or less similar to two other sounds *b* and *c*?

The solution first arrived at by linguists of the so-called Prague School (*1*), and now quite generally accepted, runs somewhat as follows. Every sound is characterized by a set of simultaneous features, features some or all of which recur in other sounds in other combinations. For example, the English *b* sound has, among other features, that of bilabiality (being formed by articulation of both lips), stop closure, and voicing (vibration of the vocal chords). We then set up the requirement that all the allophones of the same phoneme have a set of features in common which are unique and separate it from every other phoneme. These features constitute, in effect, a definition of the phoneme in question. Features which do not figure in this definition are irrelevant. Thus, aspiration in the case of aspirated and unaspirated *t* is irrelevant but dental articulation is relevant for *t* since it is common to all the allophones and is not found in any of the allophones of *p*, which is bilabial. The example of English /h/ and /ŋ/ (the latter is the phonetic symbol for the final sound spelled *ng* in *sing*) will illustrate the application of this rule. These two sounds are in complementary distribution since /h/ is always syllable initial and /ŋ/ is always syllable final. Instead of saying merely that they are too dissimilar phonetically to be allophones of the same phoneme, we can state that the only phonetic feature common to both is mere consonantality, which is found in many other sounds in English and is not, therefore, unique.

The features of a phoneme may be considered the most elementary units of phonological description. The phonemes of any language may be resolved into combinations of a very limited number of such recurrent features, much smaller than the number of phonemes. Many features clearly involve a correlated pair of mutually incompatible articulations, for example, voicing versus nonvoicing, aspiration versus nonaspiration, and so forth. Jakobson and his associates have striven to reduce all significant features of all languages to 12 such pairs of binary features (*2*). It then becomes possible to derive a measure of relative efficiency of phonemic systems in terms of the utilization of binary features by a simple application of information theory mathematics, since its fundamental unit, the bit, is a single binary choice (*3*, pp. 156–7).

The principles of phonemic theory, though presented here at some length, have been necessarily somewhat simplified. This discussion has been designed to exhibit what is undoubtedly a first-rate achievement of contemporary linguistic science from two points of view: the isolation of a unit which is adequate for purposes of description, and the overcoming, by analytic techniques, of the particular observational bias of the observer, based on his own linguistic background.

Grammatical Theory

It might be maintained that the most significant advance in descriptive grammatical theory has been along similar lines, in the development of methods by means of which the actually functional grammatical categories of each language emerge in the place of a priori classifications derived from the traditional model of Latin grammar as applied to western European languages. More than any other single factor, the work of Boas and his students in the description of American Indian languages exposed the inadequacies of traditional grammatical analyses when applied to languages of very different structure.

The problem of grammatical theory may be most briefly characterized as the problem of generating the theoretical infinity of grammatically possible sentences in a grammar with a finite set of rules. If the number of grammatical sentences in any language were finite then there would be some one or more of these sentences of maximum length, whether reckoned by number of phonemes or by some grammatical unit such as the morpheme or word. But in fact we can always make a given sentence longer by an additional clause beginning with *and*, or in other ways. Although each sentence is of finite length, the number of sentences in any natural language is what is called by mathematicians a countable infinity. But the linguist deals with a necessarily finite corpus of actually recorded sentences. Grammatical theory is therefore necessarily predictive, in a certain sense, in that the rules of the grammar of a particular language enable us to project new grammatical sentences not contained within the corpus. It is likewise only such a theory that will do justice to the ability of the speakers of a language to produce sentences they have never spoken or heard previously and of their hearers to understand such sentences.

An infinitude of grammatically possible sentences can indeed be generated from a finitely large class of meaningful elements (for example, words) if there is limitless possible repetition of members of a particular class, for example, adjectives between the definite article and a noun. Again, the grammar would be vastly complex unless the possibility of combinations of meaningful elements is in terms of such classes whose members all enter into the same or highly similar combinations.

Traditionally grammar has dealt with such classes, or at least the most inclusive ones known as parts of speech, by definitions which involve meaning, as when a verb is defined in terms of activity or a noun as the name of a person, place, or thing. In fact, the inadequacy of such definitions has long been recognized in actual practice. Thus *lightning* is a noun in English, even though it names an activity, and if its nounness is called in question we resort not to meaning but to certain distributional facts, for example, the fact that just like *boy* it can be preceded by the article *the*. Now this means, in effect, that *lightning* is found in the same or similar environments as *boy*, using the term environment in the same sense as earlier in the discussion of phonemic theory, and this, in turn, means that one of the words can be often substituted for the other, as in "The lightning struck the man" and "The boy struck the man." Substitution therefore becomes a key operation in distinguishing grammatically useful classes. It turns out that this technique when applied to different languages will isolate different kinds of classes so that the traditional parts of speech, which do not fit even English very well, must make way for a far more complex typology of kinds of classes of meaningful elements in language.

The recent work of Chomsky (*4*) shows that simple substitution alone, such as described above, is by itself an inadequate, or at least an inconvenient, mechanism for generating the grammatical sentences of a language. A substitution such as that of the above example may be looked upon as a transformation by which, from the sentence "The lighting struck the man," we obtain the new sentence "The boy struck the man." However, it turns out that more com-

Table 1. Consonantal system of an earlier stage of Yiddish.

Mode of articulation	Point of articulation			
	Labial	Dental	Alveo-palatal	Velar
Unvoiced stop	p	t		k
Voiced stop	b	d		g
Unvoiced fricative	f	s	š	x
Voiced fricative	v	z		
Nasal	m	n		ŋ
	Liquids: r, l			

plex transformations are required to account adequately for such relations as that of passive to corresponding active sentences in English. These transformations are applied after the rules of formation of certain basic ("kernel") sentences have been described in a more elementary portion of the grammar ("phrase structure").

The role of meaning in contemporary linguistics has been the subject of much discussion and controversy. It should be emphasized that several quite different questions are involved. The rejection of semantic criteria as defining properties for grammatical classes does not involve necessarily the rejection of meaning itself as a proper subject of study for linguistic science. In fact, it cannot be avoided if linguistic descriptions of specific languages are to have any practical or scientific usefulness. The compilation of dictionaries is a necessary task and clearly falls within the province of linguistics. It is, however, that branch of linguistic description which up to now is the least developed from the theoretical point of view.

Sound Change

The development of structural approaches in synchronic linguistics has had its influence on the more traditional field of diachronic or historical comparative linguistics. Probably the chief effect has been a different manner of viewing change in language. This can be most readily illustrated from the area of changes in sound systems. Earlier descriptions of these changes were generally arranged in terms of each sound through time. For example, a history of the development of the sound system from Latin to modern French would have separate chapters on each vowel and consonant of vulgar Latin, tracing the changes through the course of time. Each sound was thus treated in isolation. The notion of the sounds of a language as a system of interrelated phonemic units leads to the view of change as change of state from one synchronic system to another of later date. Instead, then, of taking the history of the vowel *a* separately through time, we rather ask what was the entire system of sounds of the French language at, say, A.D. 1000, and then at A.D. 1200, and then we view the changes undergone by *a* or any other sound in the context of such systemic change.

The value of such a systematic view as a partial explanatory theory can be illustrated from the following example, which concerns certain changes in the phonemic system of Yiddish. To illustrate the principle involved, it will be sufficient to consider a portion of the consonantal system at a period previous to the changes to be considered. As relevant features in the sense mentioned earlier in our discussion of phonemic systems, we have (i) the contrast of voiced and unvoiced consonants, for example, *b* versus *p;* (ii) that of stop and fricative, for example, *p* versus *f;* (iii) a four-way contrast of point of articulation, for example, labial *p*, dental *t*, alveopalatal *š*, velar *k*; (iv) contrast of nonnasal and nasal, as *p* versus *m*. In addition, there were two liquids, *r* and *l*, which were isolated from the remainder of the consonant systems. The actual combinations of features that made up the relevant portion of the consonantal system can be seen from Table 1.

From the table we can see at least two obvious gaps in this system, representing possibilities for new sounds within the existing framework: a voiced partner for *š*, that is *ž* (as in French *journal*), and a voiced counterpart for *x* (the sound written *ch* in German *Dach*, "roof"). Such a voiced velar fricative would be represented in phonetic notation by γ. The phoneme *ž* came into the system largely through loan words from Slavonic and other languages. The second gap was filled by *r*, formerly a tongue tip trill, which, because of its phonetic structural isolation, was free to shift considerably without merging with any other sound. One variety of the so-called guttural or back *r* with considerable acoustic similarity to the front tongue-tip *r* is precisely γ. In many but not all dialects of Yiddish we then find the sound change $r > \gamma$, by which the formerly isolated *r* shifted backward and abandoned its former structural isolation to fill a gap in the system.

It should be emphasized that other factors beside those of sheer structural arrangement play a role in helping to explain linguistic change even in the case of phonetic change. The work of Martinet (*5*) in this area utilizes as an additional principle that of functional yield. This is the hypothesis that, other things being equal, the contrast between a pair of sounds is more likely to be preserved, the larger the number of different meanings distinguished by them. However, these principles are not sufficient to provide a complete explanation. We cannot, therefore, predict the changes in a linguistic system, although we can limit severely the types of possible changes.

Linguistic Reconstruction

Although linguistics is thus not a predictive science, except in a probabilistic sense, it can in a sense predict backwards in time. By comparing related languages, that is, languages which have developed by independent but regular changes from a single source language, linguists can, by a kind of triangulation known as the comparative method, reconstruct with a high degree of plausibility many features of extinct languages which have left no written records. The scientific status of linguistics is therefore much like that of geology, which can reconstruct but not predict.

In recent years a method has emerged which promises for the first time to furnish an absolute time scale for such reconstructions. This method is known as glottochronology, or lexicostatistics (*6*). If we compare related languages, we see that certain elements of vocabulary which stand for common items of human experience are extremely stable, in that they are not easily replaced by borrowed words from a foreign language, and are likely to persist over very long periods. Such are terms for low numerals, parts of the human body, water, fire, and so forth. The more closely languages are related, the more of such cognate (that is, related) items they will still have in common. For example, English will have more of these basic terms in common with German than with the more remotely related French. We assume that in a standard list of, say, 100 such items, replacement by new terms is random over time. Then if the proportion of retained items in some arbitrary fixed period of time, *t*, is some constant, *C*, which is to be determined,

then in the next period of equal length the same proportion of the remaining items will be retained so that for $2t$ the amount of survival from the original list is C^2, or, in general, $nt = C^n$. If we compare two related languages, rather than one language at two different times, we assume that the changes in the list for the two languages is independent and at this same rate. The value of the constant itself has been established empirically by considering languages for which there are written records over a considerable time span and noting the proportion of basic words which survive during this interval. The most recent determination of this constant on the basis of a standard list of 100 words is .864 ± .065 per millennium at the 5-percent confidence level. This means that a language retains approximately 86.5 percent of these 100 words over a period of 1000 years. By the use of this constant we can calculate the probable date of separation of two languages with a certain proportion of resemblance r in the list of 100 as t millennia by use of the formula

$$t = \log C / 2 \log r$$

where C is .864 as mentioned above. Although there are still difficulties to be overcome in the use of this method, it has already been applied to problems of prehistory with some success (*7*).

Other More Recent Developments

The topics already discussed all fall squarely within linguistics proper. A few of the more recent developments which concern somewhat peripheral areas, or which are chiefly of interdisciplinary interest, may be mentioned. One such topic is that of the application of statistical methods to the study of language. As has been seen, the standard model of grammatical description is nonquantitative. Its rules are adequate insofar as they allow us to decide whether a novel sequence is or is not grammatical. This is a yes-or-no decision which does not take into account the frequency of the sentence itself or of constituent elements, phonetic or grammatical, actually found in the use of the language by its speakers. The study of the properties of such frequencies by the use of samples of texts was largely pioneered by Zipf (*8*), who treated such problems as the proportional frequency of words as a function of their rank order of frequency within texts of given length. The most recent developments in this field have been along the general lines foreshadowed by Zipf.

The study of the acoustics of speech sounds, which may be considered a border area between linguistics and physics, with important bearings on the phonetic aspect of linguistics, has made important advances in the last decade or so, largely through the invention of the sound spectrograph, which permits a very exact study of the physical characteristics of the sound wave (*9*). The most important single result has probably been the discovery that the acoustic difference between vowel sounds depends fundamentally on the reinforcement of two basic frequency regions, called the first (lower) and second (higher) formants. These formants vary rather directly with two of the chief articulatory characteristics of vowels. The higher the tongue position, the lower the first formant, and the farther front the raising of the tongue the higher the second formant. Thus the high front vowel *i* has the lowest first formant and the highest second formant. The subsequent invention of a speech synthesizer, by which sounds are produced by means of hand-painted spectrograms as inputs, allows the manipulation of features of the sound wave, which is then judged perceptually by subjects so that the cues for the perception of speech sounds can be systematically studied. This line of experimentation has already produced interesting and significant results. It has been discovered, for example, that a basic cue for distinguishing one stop consonant from another is the transition to or from the formants of the vowel which follows or precedes respectively (*10*).

In the relatively unexplored area between linguistics and cultural anthropology known as ethnolinguistics, and that between linguistics and psychology known as psycholinguistics, the sharpest issues have been raised through the largely posthumous interest in the writings of Benjamin Whorf (*11*).

The Whorfian thesis, or linguistic Weltanschauung hypothesis, as it has been called, stated in extreme form, would be that the general manner in which the speakers of a language conceive the world is determined, or at least influenced, by the grammatical categories of their language. This manner of conceiving includes, in a global manner, culturally shared cognitive structures, value systems, and such psychological processes as individual perception, degree and accuracy of recall, choice of alternative principles of classification in matching experiments, and so forth. When stated in such over-all terms, the theory obviously suffers somewhat from vagueness. The Committee on Linguistics and Psychology of the Social Science Research Council has sponsored an extensive program in interdisciplinary research—involving linguists, psychologists, and anthropologists—among monolingual and multilingual speakers of Hopi, Navaho, Zuñi, Spanish, and English in the southwestern part of the United States. This project, which began in 1954, is known as the Southwest Project in Comparative Psycholinguistics. The basic design of the studies undertaken has been to obtain data by employing the same psycholinguistic experiments on speakers of different languages and on bilinguals with varying degrees of knowledge of the two languages they speak. In such studies the speaker's language is designed to be the only independent variable. As yet, only partial results have been published. An examination of these data and the unpublished reports of the project leads to the conclusion that agreement in fundamentals of human linguistic behavior far outweighs the idiosyncratic differences to be expected on the basis of the relativity hypothesis.

Finally, something should be said concerning the academic organization of linguistic science and some of its practical applications. Scientists whose chief field of specialization is linguistics are actually found in a variety of departments, including those devoted to specific foreign languages, English, speech, and anthropology. Several major universities have separate linguistics departments (for example, Columbia, California, and Pennsylvania), but even here linguists will be found in other departments. This disparity of departmental affiliations is largely overcome by the existence of linguistics clubs in all of the larger and many of the smaller universities, and by the existence of a general professional organization, the Linguistic Society of America, and of both general and specialized journals.

Linguistic science has made major contributions to the teaching of English as a foreign language, to the teaching of foreign, particularly exotic, languages to Americans, to the devising of orthographies, and to the problems of machine translation of languages. Such applications are bound to increase with the continuous widening of American inter-

est in remote portions of the world and the corresponding need for specialist training in the local languages. The present status of linguistics as a science is on the whole an encouraging one. Aided, no doubt, by a subject matter of transparently systematic type, it has been able to develop sophisticated and effective methods of descriptive analysis and historical reconstruction which give it a unique place among the sciences concerned with human behavior (*12*).

Reference

1. N. Trubetskoy, "Grundzuege der phonologie," *Trav. Cerc. Linguistique Prague*, 7 (1939).
2. R. Jakobson, C. G. M. Fant, M. Halle, *Preliminaries to Speech Analysis* (Acoustics Laboratory, Massachusetts Institute of Technology, Cambridge, 1955).
3. C. Osgood and T. A. Sebeok, Eds., *Psycholinguistics* (Waverly, Baltimore, Md., 1954).
4. N. Chomsky, *Syntactic Structures* (Moulton, 's Gravenhage, Netherlands, 1957).
5. A. Martinet, *Economie des changements phonétiques* (Francke, Berne, 1955).
6. S. C. Gudschinsky, *Word* **12**, 175 (1956); M. Swadesh, *Intern. J. Am. Linguistics* **21**, 121 (1955).
7. A. L. Kroeber, *Intern. J. Am. Linguistics* **29**, 113 (1955).
8. G. K. Zipf, *Human Behavior and the Principle of Least Effort* (Addison-Wesley. Cambridge, Mass., 1949).
9. R. K. Potter, G. A. Kopp, H. C. Green, *Visible Speech* (Van Nostrand, New York, 1947).
10. P. C. Delattre, A. M. Liberman, F. S. Cooper, *J. Acoust. Soc. Am.* **27**, 769 (1955).
11. J. B. Carroll, Ed., *Language, Thought and Reality: Selected Writings of Benjamin Lee Whorf* (Wiley, New York, 1956).
12. Other works of possible interest to the reader are: J. H. Greenberg, *Essays in Linguistics* (Univ. of Chicago, Chicago, Ill., 1957); C. F. Hockett, *A Course in Modern Linguistics* (Macmillan, New York, 1958); H. Hoijer, Ed., *Language in Culture* (Univ. of Chicago, Chicago, Ill., 1954).

Evolution of Enzymes and the Photosynthetic Apparatus

Primitive photochemistry and porphyrin catalysis after separate genesis join in modern photosynthesis.

Melvin Calvin

The basic idea of evolution can be applied to prebiological times as well as to the transformations that occurred after living organisms appeared on the earth. In order for biological types of processes to have functioned, it is clearly necessary that an independent mechanism be developed for the production of organic material on the surface of the earth by methods which do not depend on living things as we now know them.

A number of such methods are chemically conceivable and, in fact, some of them have actually been tried out experimentally (*1, 2*). Ultraviolet radiation, for example, was one of the earliest (*3*). Thermal energy was also among the early sources considered as a possible means of generating organic material (*3*). The first application of thermal sources involved the generation of heavy metal carbides and their hydrolysis to produce unsaturated hydrocarbons such as ethylene and acetylene (*3*). These latter substances could then undergo a variety of reactions, including polymerization, to produce large organic molecules.

More recently (*4*), a thermal step has been introduced at a later stage in the development of organic material, after the primary development of such molecules as the simple amino acids and keto acids, through the agency of ionizing radiation. This ionizing radiation might have been of several types —electrical discharge, cosmic radiation entering from outer space, or radioactivity on the earth itself. All three of these types of ionizing radiation have since been experimentally demonstrated to be capable of producing the kinds of molecules that were needed to begin the process of chemical evolution.

If one adds to this the recognition that the fundamental character of the important catalysts (enzymes) of present-day living organisms is the result of the evolutionary development of rudimentary catalytic powers present in the simple ions or molecules of the inorganic, or prebiological, environment, all the elements necessary for the ultimate appearance of living organisms are available to us.

Development of Rudimentary Catalysts

Even the most cursory examination of what is now known about the nature of present-day enzymatic mechanisms cannot fail to impress one with the apparent identity in kind between the enzymatic reactions and the reactions as they are known to the organic chemist in the laboratory. For example, glyoxalase, by which methyl glyoxal is converted to lactic acid, is nothing more or less than an internal Cannizarro reaction that is catalyzed by bases. Almost all of the hydrolytic reactions—those of esterase, proteases, phosphatases — have their nonenzymatic counterparts in the form of generalized acid or base catalysis, or more specialized catalysis by metal salts. For example, again in the case of the phosphatases, the freshly precipitated trivalent metal hydroxides are extremely effective, or manganese ion is effective as a rudimentary phosphotransferase (*5*).

One particular group of catalysts which is widely dispersed in present-day biological systems is that centered around the element iron—particularly catalase, peroxidase, and cytochrome. Here, a rather quantitative comparison can be made between the ability of the bare iron atom to perform some catalytic function and the ability of the iron atom to perform the same catalytic function as it has been developed in biological systems. Thus, in Fig. 1 one sees a comparison of the hydrated iron ion, the iron ion surrounded by a por-

The author is on the staff of the department of chemistry of the Lawrence Radiation Laboratory, University of California, Berkeley.

This article is adapted from a paper presented at the International Symposium on the Origin of Life on Earth, held in Moscow, 19-24 August 1957.