have made more progress in the treatment of non-homogeneous models of the universe which may well be necessary for a better understanding of the actual universe. The development of relativistic thermodynamics to include an appropriate treatment of fluctuations might also be attempted with the help of the statistical methods introduced by Gibbs himself. The effect of fluctuations on the behavior of cosmological models might be specially important at certain stages of their history.

In trying to estimate the significance of the applications of relativistic thermodynamics that have already been made, we must not misjudge the nature of the two applications to cosmological models that were described in the foregoing. It should be emphasized that the homogeneous cosmological models which we now consider are not only very highly simplified and idealized, but at best are constructed to agree throughout their entire extent with that small sample of the actual universe which lies within the range of some 10^8 light years. Furthermore, it must be remembered that among the different possible kinds of homogeneous cosmological model, there is a class which would expand never to return as well as the class that could undergo an unending succession of expansions and contractions; and we do not now have sufficient data so that we could assign the actual universe to either class. Hence we must be very careful, in extrapolating to the actual universe any conclusions that we may draw as to the behavior of our conceptual models.

The dangers of long-range extrapolation were specially emphasized to you by Professor Bridgman in his beautiful Gibbs memorial lecture of last year, and these dangers, as we see, are specially present in cosmological speculations, based on the observation of a small fragment of the total universe for an inappreciable time span. Nevertheless, it certainly seems significant that conceptual models of the universe can be constructed, which are permitted by the principles of relativistic thermodynamics to exhibit behavior in serious conflict with the classical conclusions, that reversible processes could never take place at a finite rate, and that the end result of irreversible processes would necessarily be a stationary condition of maximum entropy. Hence at the very least it would now seem desirable to extrapolate to a cautious position, in which we no longer dogmatically assert that the principles of thermodynamics necessarily require a universe created at a finite time in the past and fated for stagnation and death in the future. Indeed, the chief duty and glory of theoretical science is certainly, not merely to describe in complicated language those facts that are already known, but to extrapolate—as cautiously and wisely as may be—into regions yet unexplored but pregnant with human interest.

ACTIVE IRON

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IN the year 1806 the Bergrat Johann Georg Lenz named a natural iron oxide hydrate "goethite," in honor of the celebrated naturalist and poet, Johann Wolfgang von Goethe. This mineral had already been known in the literature previously under the name ruby mica (Rubinglimmer).[1] Although comparatively rare, it is found in good crystalline form in Siegen, in Westphalia. The splendid crystals, one to two millimeters long, indeed resemble rubies in their beautiful color and luster. The crystals or powder made from them are non-magnetic, but if one dehydrates the powder by heating it a magnetic iron oxide, Fe_2O_3, is obtained. This interesting observation was described as early as 1838 in the book "Grundzüge der Mineralogie" by Franz von Kobel (published in Nürnberg in 1838). The names ruby mica and goethite are used interchangeably for this macro-crystalline brown iron ore in the "Manual of Mineralogy" by Robert Allan (Edinburgh, 1834). It is seen, therefore, that historically the names ruby mica and goethite properly apply to the natural iron oxide hydrate which becomes magnetic on heating.

In the year 1848, Plücker made a magnetic study of the natural and artificial iron oxides and oxide hydrates, and observed that an iron oxide hydrate prepared in a certain way gave a magnetic iron oxide on dehydration. He found it almost a hundred times stronger magnetically than the original hydrate from which it was prepared, and remarked that the powdered material could be picked up by even a small horseshoe magnet. Robbins mentioned a magnetic iron oxide in *Chemical News* in the year 1859.

Malaguti in 1863 (*Compte Rendus*) published more exact chemical and physical data on the properties of magnetic iron oxide. He obtained the oxide in various ways, as, for example, by explosion of magnetite with potassium chlorate and by heating ferrous salts of organic acids in the air. In France the magnetic iron oxide is also known under the name Malaguti-oxide.

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[1] J. F. L. Hausman, ''Handbuch der Mineralogie,'' Göttingen, 1813.

The fact that this magnetic iron oxide contained iron only in its completely oxidized state (ferric), was definitely established by Hilpert in 1909. Until this time all samples had contained varying amounts of incompletely oxidized iron (ferrous).

To turn again to the iron oxide hydrates, it must be noted that our view-points on these important iron compounds, which occur so abundantly in nature, have been fundamentally changed. Formerly on a basis of chemical analysis and superficial characterization, the natural iron oxide hydrates were classified as to water content. Thus, iron oxides combined with 3, 2, 1½, 1, ¾ and ½ molecules of water were classed as separate species. These distinctions did not recognize the fact that part of the total water present is chemically linked and part only absorbed. Consequently, the majority of the older chemical formulas assigned to iron oxide hydrates are meaningless.

More exact studies, in particular x-ray analyses, have proved that there is only one definite chemical combination between iron oxide and water, namely, the monohydrate, $Fe_2O_3 \cdot H_2O$. This is known to exist in two different modifications, both of which exist in nature and may be prepared synthetically. Since the oxides prepared by dehydration of the two monohydrates are genetically related to the natural dimorphous aluminum oxides, diaspore and bauxite, according to a proposal of Haber (*Naturwissenschaften,* 1925) they were named α and γ hydrates and oxides. This designation has been adopted not only by chemists and physicists but by mineralogists as well.

There are two common differences between the α and γ hydrates. Each has a distinct x-ray spectrum. Also they may be more easily distinguished by their magnetic properties. The α hydrates on dehydration yield a non-magnetic α oxide (hematite), while the γ hydrates yield a strongly magnetic (ferromagnetic) γ oxide. Since goethite, as we have seen, becomes ferromagnetic on dehydration it belongs to the γ hydrate class.

The various natural iron oxide hydrates formerly mentioned are merely micro-crystalline aggregates of α $Fe_2O_3 \cdot H_2O$ (Böhm, 1928; Albrecht, 1929). The differences depend partly on a chemical reaction (polymerization) of the molecules, and partly on the difference in the arrangement, form and size of the crystallites (clusters of sub-microscopic crystals). The different shades of color depend mainly on the particle size.

For the more detailed study of the structure (fine and hyper-fine structure) which remains to be carried out, it is necessary first of all to have pure materials. It is important to prepare iron oxide hydrates and iron oxides which are free from electrolytes, since such impurities may greatly influence the magnetic and surface properties. This we have succeeded in doing, through the use of organic bases, for example, pyridine and aniline. The purest obtainable iron, that prepared from iron pentacarbonyl, serves as starting material. It is dissolved in hydrochloric acid and autoxidized in the presence of pyridine to a very pure γ iron oxide hydrate, with the study of which we are now concerned. This γ hydrate gives on dehydration a ferromagnetic ferric oxide which is free from all impurities of electrolytes.

There now remains only to report briefly of the progress that has been made with γ oxide since the work of Hilpert, and how our study in this field has brought us to designate the concept "active iron."

The fundamental discovery which led to the introduction of the concept "active iron" into biology was that of Welo and Baudisch[2] concerning the interesting and peculiar behavior of ferromagnetic ferric oxide. We found that the lattice of ferromagnetic ferric oxide, Fe_2O_3, is cubic, whereas hematite, Fe_2O_3, is rhombohedral, as was already known. The paramagnetic modification corresponding to hematite is stable, while the ferromagnetic modification is unstable and can pass over, with loss of energy and loss of ferromagnetism, into the stable form. The surprising observation that magnetite retains its spinel crystal structure on oxidation and first passes to the rhombohedral hematite structure on strong heating led us to designate the ferromagnetic gamma oxide as "active" in contrast to the inactive form corresponding to hematite. The strikingly different physical and physico-chemical behaviors of these chemically identical iron oxides led us to compare their biological actions. The experiments of Webster and Baudisch showed, in fact, that the two oxides had different biological effects. The designation "active iron" therefore assumed biological significance.

Since, in the medical literature, the term "active iron" has often been completely distorted and confused in relation to and in comparison with the sense in which we use it, it seems necessary to include a further discussion of the development of the problem. The original identification of the two forms of ferric oxide (alpha and gamma), became, one might say, only an introduction to further study and further knowledge of the topochemistry and the magnetic properties of iron oxides. The designations "active" and "inactive" had, later, to be expanded and developed.

It has been mentioned that by x-ray analysis one can determine only the type of arrangement, while by magnetic measurements one can at least detect

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[2] SCIENCE, 62: 1605, 311–312. 1925.

finer structural anomalies and consequent surface irregularities. We therefore made detailed magnetic studies of magnetite and several ferromagnetic iron oxides prepared in different ways. This was done, as is usual in the study of ferromagnetic materials, by taking the magnetization curves for increasing and decreasing magnetizing fields; that is, we determined the hysteresis loops. The four constants characteristic of ferromagnetic materials may be obtained from these curves. They are: the permeability (simply related to susceptibility), which is a measure of the magnetization; the hysteresis loss, which is a measure of the resistance to orientation of the elementary magnets and hence appears as a transformation of electromagnetic energy into heat; the remanence, which is the residual magnetization after the field is removed, since orientation, when once attained, may persist in varying degree; and finally, the coercive force, which is the field that must be applied in the opposite direction to demagnetize the substance. Both remanence and coercive force are secondary features of the hysteresis phenomenon. If the hysteresis loss is large, both the remanence and the coercive force are large. For example, in steel hysteresis loss, remanence and coercive force are large, while in soft iron all three of these quantities are relatively small.

The result of these studies was that while the several oxides differed somewhat as to permeability, they differed enormously as to the constants associated with hysteresis. But after the several differently prepared oxides had been annealed at high temperatures they gave nearly the same values for the hysteresis loss, remanence and coercive force. It is this fact which is the basis for our conclusion that it is the crystal quality (lattice perfection and absence of atomic deformation) which is markedly affected by changing the method of preparation. The magnetic investigation, therefore, gave us a means of tracing the finer structural features which occur in regions of too small dimensions or are for other reasons not accessible to x-ray analysis. In other words, while we can establish the fine structure of ferromagnetic iron oxides by the x-ray, it becomes possible by magnetic analysis to establish the existence of a still finer one—a hyperfine structure.

To these exact physical methods of investigation the biological methods joined themselves naturally and it was found that the latter were not less but rather more sensitive than the magnetic methods to hyperfine structural differences. By combination of these methods one can gain an insight into biological phenomena that would otherwise be quite impossible.

Our investigations, as they have been briefly described in the foregoing, have given rise to a whole array of researches in the field of the metal oxides, especially those of iron. Chemists, physicists, engineers, mineralogists, geologists, pharmacologists and medical men have repeated the experiments and supplemented them in various directions, according to their particular fields of interest.

SCIENTIFIC EVENTS

THE JUNIOR SCIENCE CLUBS OF THE AMERICAN INSTITUTE

THE Junior Science Clubs of the American Institute were the guests, on the morning of March 25, of the Museum of Science and Industry and the American Museum of Natural History.

Museum Day was planned by the American Institute as a new departure in its program of science educational projects for children. Recently the institute, a century old organization, has associated hundreds of science clubs made up of young people all over the city into its new branch, the Junior Science Clubs. The members of these clubs represent some seven or eight thousand children, all under eighteen years of age.

The meeting at the Museum of Science and Industry was open to all member Physical Science Clubs. The group was divided into two sections, one going directly to the main exhibit hall and one to the museum theater. In the main exhibit hall, Robert P. Shaw, of the Museum of Science and Industry, spoke on "The Story of Electricity." The hall was darkened and a spotlight was thrown on the various exhibits as they illustrated Mr. Shaw's talk. In the museum theater, the second group was shown the following series of science motion pictures: "The Romance of Power"; "Dynamic America"; "A. B. C. of Electricity," and "Finding His Voice." The groups then changed places and the program was repeated.

To the American Museum of Natural History meeting members of the Biological Science Clubs were invited.

At the meeting at the museum Paul B. Mann, chairman of the department of biology of Evander Childs High School, spoke on "The Museum's Part in Exploration," illustrated with motion pictures taken by Roy Chapman Andrews.

The group was then broken up into five sections, each of which visited one of the various museum trails. Members of the museum's staff were stationed in the different halls, where they gave short talks on the contents of each. The children then, under the guidance