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# Oxygen Isotopes in Nature and in the Laboratory

Harold C. Urey
*Institute for Nuclear Studies, University of Chicago*

THAT THE ELEMENTS CONSIST OF ATOMS having different atomic weights was discovered in 1911 by Fayans and Soddy as a result of the study of radioactive elements which occur in nature. It was found that two varieties of elements could be secured having different radioactive properties but otherwise chemically identical in every respect. The theory of radioactive disintegration of uranium and thorium showed that these varieties of atoms must have different atomic weights. In particular it was found, as a result of the very careful atomic weight determinations of Theodore Richards, that samples of leads from different parts of the earth's crust had different atomic weights and, in particular, that samples of lead isolated from thorium minerals had atomic weights approaching 208, whereas those isolated from uranium minerals had atomic weights approaching 206. Sir J. J. Thompson showed that charged atoms moving through cross electrical and magnetic fields should be separated if they have different ratios of charge to mass, and hence the isotopes of the elements should be separated by such a process. He determined that this was the case for the element neon, which is nonradioactive, and hence showed that ordinary elements also consist of mixtures of atoms of different atomic weights.

It is now known that there are more than 600 varieties of atoms which make up our 96 known elements. Most of these are radioactive and have been produced by artificial means. We have found that a few elements exist only in radioactive form and thus are constantly disappearing and have been doing so since the earth's crust was created. Some have completely disappeared from the earth's crust and therefore must be made in our laboratories today. In this discussion I shall largely limit myself to one of the ordinary elements, namely, oxygen. Table 1 shows a very limited number of these varieties of atoms, those for the first 10 elements of the present periodic system. The stable isotopes are printed in heavy type and the radioactive ones in light type. These elements are very important indeed, since they contain several of the elements necessary for living processes. Also, oxygen is the most abundant element in the surface layer of the earth, namely, the layer with which we come most in contact.

The interest in these varieties of atomic species is of several kinds. In the first place, there are the purely physical properties which physicists are studying today. During the last 25 years particularly it has been possible to unravel the laws governing the behavior of the electrons in the outer shells of the atom, and at the present time the center of the stage of physics is held by the questions dealing with the structure of the nucleus of atoms. How are the fundamental parts held together, and what are the energy relations? The properties which are important in connection with this are the lifetimes of the radioactive nuclei, the energy of binding of the elementary particles, the nuclear spins or nuclear angular momenta, and the magnetic moments. Physicists are interested in the relative abundances of those atoms which are stable, how these varieties of atoms were produced, and what was the origin of the universe.

TABLE 1

ISOTOPES OF THE FIRST 10 ELEMENTS

| Symbol | Atomic No. | Masses |
|---|---|---|
| H(D) | 1 | 1, 2, **3** |
| He | 2 | 3, 4, **6** |
| Li | 3 | 6, 7, **8** |
| Be | 4 | **7,** 9, **10** |
| B | 5 | 10, 11, **12** |
| C | 6 | **10, 11,** 12, 13, **14** |
| N | 7 | **13,** 14, 15, **16** |
| O | 8 | **15,** 16, 17, 18, **19** |
| F | 9 | **17, 18,** 19, **20** |
| Ne | 10 | **19,** 20, 21, 22, **23** |

## USES OF ISOTOPIC SPECIES

But there are many uses of these isotopic species for other sciences and such uses have been discussed many times in recent years. The use as tracers or indicators was discovered by Prof. Hevesy over 30 years ago, and the general outlines of the possible uses of such elements were made by him using naturally radioactive elements. It is, of course, natural that the many recently discovered artificial radioactive elements should be useful in this connection, especially in view of the fact that effective radioactive tracers for many of the common elements have now been discovered. There are few for which there are no satisfactory tracers of this kind, but it has been possible to separate the stable isotopes in the case of those ele-

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ments for which no radioactive tracers are known, and hence tracers for these elements, hydrogen, nitrogen, oxygen, and carbon, are also available. The use of these tracers is particularly valuable in the case of the study of living processes. We have in living organisms an enormous complexity of chemical substances and chemical reactions, and every possible method that can be devised is of value if we are to understand these processes. During recent years we have heard particularly of the use of such tracers of hydrogen, carbon, nitrogen, and oxygen, since these are especially important elements in living organisms, as well as phosphorus, sulfur, iodine, sodium, potassium, and iron, which are present only in comparatively small amounts but which are nevertheless very important for the vital processes taking place.

There are other uses to which isotopes have been put besides those which we have indicated. The radioactive isotopes occurring in nature have been useful in establishing the geological time scale on a quantitative basis. Uranium and thorium decompose into lead and helium, and it is possible to measure the rate of this transformation. Uranium produces lead of an atomic weight of 206 and thorium of lead of 208. Thus, if we measure the amount of thorium and the amount of lead 208 in a mineral containing thorium, it is possible to calculate the time required for the amount of thorium present to produce the amount of lead present, and the age of the mineral could not be longer than the time so calculated. On the other hand, if we measure the amount of uranium and lead 206 in a uranium mineral, it is possible to calculate how long it would have taken for the uranium to produce the amount of lead which is present. This again would be of maximum time for the age of that mineral. Of course, if ordinary lead were present in the mineral to a small extent at the time it was deposited, an error would be made and a correction for the amount of such lead must be made. In this way a geological time scale has been established which has enabled us to date the geological periods of time with very considerable precision. The work has been done very carefully, for there are, of course, many possible errors which can be made. The analysis must be made with high precision, and the amounts of the various lead isotopes present in the samples must also be determined precisely. The oldest rocks on the surface of the earth are 1,800,000,000 years old, and ages in years of the geological periods are reasonably well known.

It is possible to calculate an upper limit for the age of the earth. The lead isotope 207 is produced from the uranium isotope 235 (the isotope of atomic bomb fame). This lead is produced more rapidly than any of the isotopes produced from thorium and uranium. If all the lead 207 in the crust of the earth was produced from uranium 235, and none was present at the time the elements of the earth were formed, then, knowing the amount of uranium 235 and lead 207 in the crust of the earth now and the rate of transformation, we can calculate the maximum time which has elapsed since the creation of our elements as somewhat greater than 5,000,000,000 years.

Prof. A. O. Nier, of the University of Minnesota, has shown that the carbon in nature varies in isotopic composition. Living organisms, plants, and animals together with all of their probable geological remains, namely, petroleum, natural gas, and coal, contain less carbon 13 than does limestone. The origin of this fractionation of carbon isotopes is not exactly known. Differences in chemical properties of the isotope were first detected in the case of neon and the hydrogen isotopes. It was shown during the 1930s that differences in the thermodynamic properties of isotopic compounds should exist because of the differences in vibrational frequency of molecules, depending upon whether they contain one isotope or another. The early observation that the chemical properties of isotopes of elements were identical is only approximately true. Very careful measurements have shown that there are slight differences in chemical properties and that these are to be expected upon the basis of our modern knowledge of the physical properties of such molecules. It is probable that the fractionation of the carbon isotope in nature as obtained by Nier has its origin partly in such effects. It may also be that this effect is partly due to the kinetics of chemical reaction. Recently we found that algae, very simple one-celled plants, grown in Prof. Franck's laboratory, contain 2.97% less carbon 13 than the carbon dioxide in the solution in which the plants grew.[1] It may be that the chemical reaction taking place as the plant fixes the carbon of its body from the carbon dioxide in the solution favors the lighter isotope, thus producing the concentration of carbon 12 in the plant. This particular type of study has made it possible to show in other cases that deposits of carbon were due to living organisms rather than those of mineral origin and thus that life existed in the pre-Cambrian period, 600,000,000 or 700,000,000 years ago. This type of isotopic data has made a notable contribution to geological study of this kind and promises to be very fruitful in the future.

## Studies of Oxygen Isotopic Composition

With this rather long introduction to the subject I wish to come to the main object of this discussion,

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[1] The normal ratio of $C^{13}$ to $C^{12}$ is 1/90, and hence this statement that the ratio for the algae carbon was .983/90 if that in the solution is 1/90.

namely, to present some recent results which my colleagues and I have secured at the University of Chicago during the last year.[2]

The element oxygen is the most abundant in the crust of the earth. It composes about 78% of the atmosphere, about 89% of the water, and approximately 51% of the inorganic crust of the earth. Water is the liquid in which all living processes take place. The energy which is used by all living organisms, of course, comes from the sun in the form of radiant energy. Plants are able to convert carbon dioxide and water into oxygen on the one hand and compounds of carbon on the other and thus store up chemical compounds in their tissues. These plants in turn are used by animals on the surface of the earth and burned by the aid of oxygen to produce the energy which they use in their living processes. Thus, the element oxygen, as well as carbon, is of primary importance in the living process.

The particular processes which we have been studying are those involving the deposition of oxygen in chemical compounds of the inorganic type in the earth's crust. Our study to date has been limited to calcium carbonate deposited by animals. It is to be expected that studies similar to those which I shall describe can be made on the oxygen isotopic composition in phosphates and silica, which are also deposited by animals and plants.

The ratios of the oxygen isotope in different chemical compositions as we find them in our chemical laboratories are not the same. The normal abundance of the oxygen 18 isotope is taken as very closely as 1 in 500 of the much more abundant isotope 16. But it is possible to find samples of oxygen which vary in their isotopic ratios as much as 4 or 5%; that is, from 1 part in 500 to 1.04 or 1.05 parts in 500. This is not a very large variation, though it does result in a change in the atomic weight of oxygen, as it is found in chemical substances in our laboratories, by as much as two units in the fourth decimal place. Since oxygen is the standard of atomic weight and is taken as having an atomic weight of 16, we see that this standard is not constant if we are interested in the precision of the fourth decimal place. Other elements vary in atomic weights just as oxygen does. One of the most interesting among these is chlorine, which, according to calculations which have not yet been confirmed experimentally, may vary in atomic weight by as much as 0.03 atomic weight units, *i.e.* by 1 part in 1,000 of the atomic weight of chlorine.

The origins of these differences in chemical properties are understood in detail in many cases. The energy and entropy and hence the free energy of chemical substances depend on the vibration frequencies of the molecules, and these depend on the masses of the atoms. Without going into the details of the mathematical calculations, we may say that the observed differences agree exactly with calculations where these are possible. If calcium carbonate is crystallized slowly in the presence of water at 0° C, the calculations show that the ratio of the oxygen isotopes in the calcium carbonate should be 1.026 to 500 if the ratio of the isotopes in the water is 1 to 500, *i.e.* oxygen 18 is very slightly concentrated in the calcium carbonate in relation to the water. On the other hand, if the temperature is 25° C, the oxygen isotopes will be concentrated only to the extent of 1.022 as compared with 1 in 500 in water. This shows that there is a slight temperature coefficient for the abundance of $O^{18}$ isotope in the calcium carbonate as compared with that in the water. In fact, the amount of this fractionation is so slight that the atomic weight of oxygen in the calcium carbonate will be changed by only 0.0000007 atomic weight units as the temperature is changed by 1° C. A change in temperature from 0° to 25° will change the atomic weight of the oxygen by only 0.00002 atomic weight units.

Calculations of this kind were first made some 15 years ago by Dr. Greiff and myself, and during the 1930s my research group succeeded in showing that it was possible to separate the isotope of the elements by chemical methods due to small differences in the chemical properties of this kind. These methods have been used for the separation of the hydrogen, boron, carbon, nitrogen, and sulfur isotopes and are, in fact, the most effective methods for the isolation of these particular elements—the most effective in the sense that if one wishes to produce the isotopes in substantial quantities, they can be separated most cheaply by these methods. Dr. Robert White, of the University of Michigan, is engineering a chemical process for the oxygen isotopes which have previously been concentrated by distillation methods.

The temperature coefficient for the abundance of the oxygen isotope in calcium carbonate makes possible a new thermometer of great durability, which may have been buried in the rocks for hundreds of millions of years after recording the temperature of some past geological epoch and then having remained unchanged to the present time.

It is evident that, if an animal deposits calcium

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[2] My colleagues in this case who have been partners with me in these researches over the past year are Mr. Charles McKinney, Mr. John McCrea, and Dr. Samuel Epstein, who have worked steadily on these subjects with me. Articles covering the scientific details will be published under our joint names, and this therefore is only a preliminary presentation of the scientific article which will appear in the *Bulletin of the Geological Society of America.*

carbonate in equilibrium with water in which it lives, and the shell sinks to the bottom of the sea and is buried securely in the earth and remains unchanged from that time to this, it is only necessary to determine the ratio of the isotopes of oxygen in the shell today in order to know the temperature at which the animal lived. This particular application of the chemical differences in the processes of isotopes occurred to me a year and a half ago, and since that time my colleagues and I have been trying to solve the several difficult problems encountered in making such measurements of paleotemperatures. I wish to relate some of the difficulties encountered in this problem.

## IMPROVEMENT OF MASS SPECTROMETERS

The calculated differences in the ratio of oxygen 18 to oxygen 16 for 1° C difference in temperature amounts to only .0176% in that ratio. As the ratios of isotopes of this kind have not been reported in the literature with higher precision than .1%, it is immediately necessary to increase the precision of determination of these isotopic abundances by a factor of 6. In view of the excellent work which has been done on mass spectrometer in this country particularly, this is a very difficult assignment. In measurements of the ratio of isotopes the element is based upon the principle first used by Sir J. J. Thompson and Aston in England and developed particularly in this country by Prof. Dempster, of the University of Chicago, and Prof. Nier, of the University of Minnesota. Electrons are accelerated through electric fields of some 50 v and collide with gaseous molecules producing positively charged ions, which are then accelerated in a well-defined beam through high electrical fields and pass through a magnetic field. Ions having different masses but the same charge are separated from each other and can be collected on electrodes at different points. Prof. Nier has devised an instrument which collects ions of different masses on separate electrodes. The electric current produced by these ions is small, but sufficient for accurate measurement. These currents must be amplified by electronic devices in order to make measurements possible. After amplification of these small currents, the two currents are compared by means of what is essentially a Wheatstone bridge. In the work which I am describing Nier's instrument has been changed very slightly. The mass spectrometer tube (Fig. 1) has not been changed, though the electronic equipment has been quite completely redesigned. The tube which has been designed by Nier is capable of high ion beam intensity, which makes possible very precise comparisons of these ion currents. Our amplifiers are not completely satisfactory, but for limited periods of time they are sensitive and stable. The state of balance of the bridge is recorded on a Brown potentiometer, which makes it possible for us to show the stability of the instrument over a period of time and enables us to tell whether the instrument works satisfactorily.

The second modification of the instrument which we have made consists of a rapid method of changing from one sample to another. A sample of carbon dioxide gas is confined behind a very small capillary through which it leaks into the mass spectrometer. We have arranged two leaks with different samples of gas behind them, with a valve which sends one sample to the mass spectrometer and the second to a waste vacuum line and then reverses the flow of the two samples. In 10 sec it is possible to shift from one sample to another. The method of operation consists in recording the state of balance on the one sample for 2 min and then switching to the other sample. The Brown potentiometer pen records the displacement from balance for first the one sample and then the other. Fig. 1 shows such a trace where the total difference is 1.2/mil of the ratio of the oxygen isotope between the two samples. This represents a difference of 4 millionths in the atomic weight of oxygen. It will be seen from the figure that it is possible to get the instrument to record small differences in isotopic abundance with very great precision.

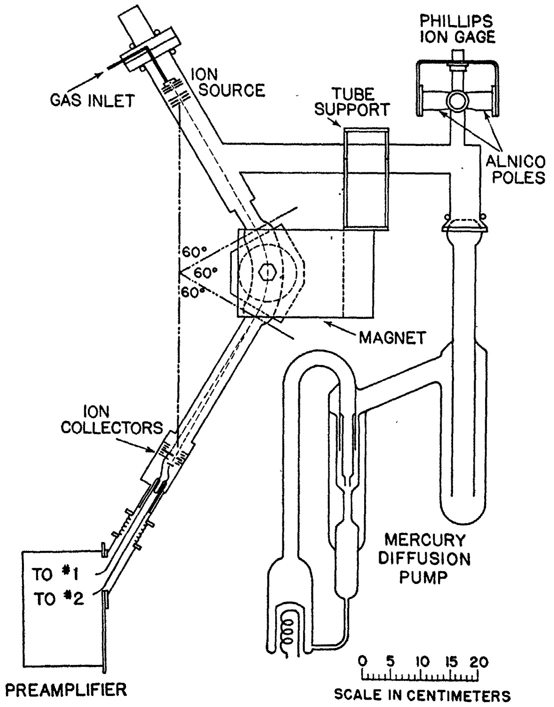

FIG. 1

## Preparation of Gas Samples

If one wishes to analyze a sample of carbon dioxide with this precision, it is necessary to prepare pure samples of the gas from calcium carbonate which may be contaminated by the organic remains of the animals which secreted the calcium carbonate. In order to have a precision of 1° C it is necessary to measure the ratio of the isotopes to 0.0176%, and this means that impurities must be removed from the gas to a high degree. We use carbon dioxide as our working gas measuring masses 44 and 46. Since the 46 mass is 1/250 as abundant as 44 and we wish to secure this within 1 part in 6,000, it is necessary to remove any impurity of mass 46 to the extent of 1 part in 1,500,000. As we have found during the past 6 months, it is difficult to prepare carbon dioxide of that purity. It would be much less difficult to prepare such pure carbon dioxide if there were not the problem of preventing other oxygen from becoming mixed with the sample being investigated. The glass apparatus in which one customarily handles gases and the chemical substances which are normally used to remove impurities contain oxygen which may become mixed with the sample. In addition, the compounds of carbon and hydrogen which seem to be present in all laboratory apparatus are difficult to remove. The carbon isotopes can be handled much more easily, since laboratory apparatus does not contain this element, and impurities can be easily removed by combustion.

After trying many methods for the preparation of pure carbon dioxide we have found that a mixture of phosphoric acid and phosphorus pentoxide reacts with calcium carbonate, producing carbon dioxide of great purity and with no mixing of the oxygen of the calcium carbonate and of the phosphoric acid. All the carbon dioxide does not leave the solution immediately, but we have found that there is no fractionation of oxygen isotopes in the first sample produced as compared with the last sample. Great care must be used in placing samples in the mass spectrometer if slight fractionation of the isotopes is to be avoided. We have not been able to find impurities in a carbon dioxide prepared by this process from animal shells, from mineral calcite, and chemically prepared calcium carbonate. The most sensitive method of investigation is the mass spectrometer itself, though it is not possible to use it to test for that substance which will produce an ion of mass 46 or mass 44, the two in which we are directly interested. We are, however, able to show that the gas is pure with respect to substances which will produce ions of lower and higher mass than carbon dioxide. Finally, we have shown that samples of gas prepared in this way, when analyzed on our sensitive mass spectrometer, give very close agreement. Table 2 shows a comparison of analyses secured by this method of preparation on the mass spectrometer which I have described. If check analyses show a difference of 0.2 per mil, the analysis is not satisfactory; the mass spectrometer is not operating satisfactorily or some error has been made in preparing the samples. In this case the analysis is repeated.

TABLE 2

DIFFERENCES IN OXYGEN ISOTOPIC RATIOS IN PARTS PER MIL BETWEEN *Haliotis rufescens* FROM MONTEREY BAY (t = 13°C) AND OTHER SPECIMENS

| | Sample 1 | Sample 2 |
|---|---|---|
| *Haliotis rufescens,* Monterey Bay ..... | −0.02 | ..... |
| *Pecten,* Bering Strait ............... | 1.32 | 1.08 |
| *Allopora boreo-pacifica,* Sea of Okhotsk | 0.35 | 0.36 |
| *Pectunculus,* Spermonde Archipelago .. | −2.92 | −2.92 |
| Coral, Jamaica ..................... | −2.88 | −2.90 |
| Globigerina ooze, Pacific south of New Zealand ....................... | 2.14 | 1.85 |
| *Arca,* Spermonde Archipelago ........ | −3.06 | −2.90 |
| *Belemnitella,* Upper Cretaceous, Hampshire Co., England ............... | −1.12 | −1.39 |
| | −1.35 | ..... |
| *Balanophyllia,* Monterey Bay ........ | −2.67 | −2.55 |
| | −2.72 | ..... |

## Empirical Temperature Scale

We turn now from the problem of a satisfactory method of analysis to the much more difficult problem of paleotemperatures. Has the ocean kept the same ratio of oxygen isotope throughout all geological time? If it has not, errors in temperature will be made. We ask what might have changed this isotope abundance. The earth began as a molten ball with oxides floating on the surface. It solidified, and rain began the erosion process. The oxygen of the water and the rocks perhaps had the same initial isotopic composition. As time went on, the igneous rocks were crumbled and carried by the rivers to other positions and were deposited as sand, clay, and limestone in other parts of the earth, and great thicknesses of these materials have accumulated. It is estimated that the oxygen in these sedimentary rocks is equal in amount to all the oxygen in the ocean and perhaps is three times as great. If the concentration of $O^{18}$ in the igneous rocks is not the same as in sedimentary rocks, the difference must have been supplied from the ocean, and its isotopic composition must be changed. I think it probable that the oxygen of sandstone and much of that of shale has not been changed much in this weathering process. It is a subject which we shall investigate, but for the purpose of my present discussion the total time from the Cretaceous to the present is only 60,000,000 years, or only a small fraction of the total time that erosion has taken place. Simple calculations show that not much change in isotopic composition could have occurred in that time.

We are investigating the shells of living organisms which have a capacity to fractionate chemical elements to a high degree. Some plants, for example, concentrate iodine from the sea water in concentrations that are very much greater than exist in the sea. Some animals concentrate copper or vanadium from very low concentrations of these elements in sea water. It is always possible that an animal will fractionate the oxygen isotopes, and we fully expect to find some cases of this kind. But it does seem probable that such effects will be rare in the case of inorganic deposits such as calcium carbonate.

Let us assume that an animal does lay down its calcium carbonate in equilibrium with the sea and now enquire into what happens as the animal is buried and becomes converted to a fossil. It is possible, and I think probable in some cases at least, that the oxygen of the shell will exchange places with the water surrounding the shell. This should not be a very fast process, since it depends on the rate of diffusion of the oxygen through the solid matter. Estimates as to the velocity of this process have led me to the conclusion that the process will take place in the finest material in a matter of years to thousands of years, but in the case of coarse crystals it will not occur within a time of the order of 1,000,000 to 1,000,000,000 years. In any case we wish to secure heavy, thick, massive crystals of calcium carbonate for our study in order to increase our probabilities of success. We have found cases in which these diffusion effects have occurred but also, we believe, cases in which they have not.

In order to get a temperature scale it is necessary to establish empirically a relationship between the isotopic composition of the shells of the present-day animals and the temperatures at which they live, since the theory is only approximately applicable. To do this, it is necessary to use animals which have lived in sea water of full salinity in order to avoid the possibility that fresh water, which may have an isotopic composition different from that of sea water, has changed the isotopic ratio of the oxygen of the water in which the animal lived so that the isotopic ratio would not be characteristic of the temperature alone. It proves difficult to discover such places on the earth's surface at the present time, since most of the shallow seas of the world are brackish to a large degree. It is also difficult to be sure of the temperatures of the water in which the animal lived, since temperature of the sea fluctuates and most animals wander from one temperature zone to another. Many people have helped us to secure specimens of animals. Dr. L. F. de Beaufort and Dr. de Jong, of Amsterdam, have secured samples from the Dutch East Indies; The Chicago Museum of Natural History, from Hawaii; Dr. H. S. Brown, from Jamaica; Dr. L. R. Blinks, of the Hopkins Marine Station, from Monterey Bay; and Dr. Robert S. Dietz, from Bering Strait and from the bottom of the Pacific Ocean south of New Zealand and Australia. We also received a sample from Dr. Blinks from the Sea of Okhotsk. Dr. Austin H. Clark, of the Smithsonian Institution, supplied us with some samples of his crinoids taken from various parts of the world. We have not as yet investigated all the samples of this kind which we have received. Fig. 2 shows the plot of the recorded temperature against the isotopic composition for a number of specimens.

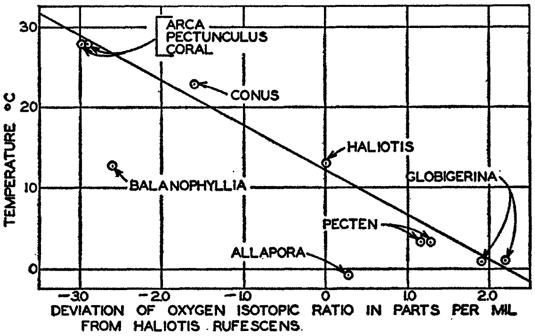

FIG. 2. The specimens included are from Spermonde Archipelago, Dutch East Indies (*Arca* and *Pectunculus*); Hawaii (*Conus striatus*); Monterey Bay, California (*Haliotis rufescens* and *Balanophyllia elegans*); the bottom of the Pacific, latitude 60° 13′ S, longitude 147° 45′ E (globigerina ooze); Bering Strait (*Pecten*); and the Sea of Okhotsk (*Allapora boreo-pacifica*).

The latter is given in parts per thousand of the ratio of $O^{18}$ to $O^{16}$ compared to an abalone (*Haliotis rufescens*) from Monterey Bay, the temperature of which is taken as 13° C. It will be noted that a number of the points on this curve follow rather well on a straight line, the slope of which is very close to the calculated slope, 4.4 per mil between 0° C and 25° C. The Bering Strait samples do not fall well on the curve, but the Bering Sea is slightly brackish and reasonable estimates in regard to the isotopic deviation expected would move this point toward the curve. The specimen from Hawaii falls above the curve, indicating that this animal (a gastropod, *Conus striatus*) lived perhaps at a lower temperature than is assumed. The points for the coral from Monterey Bay do not fall anywhere near the curve, and at present no certain explanation of this difficulty is possible. It may be that such finely divided materials as corals exchange their oxygen with water of the air in a reasonable length of time. In general, every compact shell which we have investigated lies on the curve, and every point off the curve is that of an organism having a loose structure and collected some 50 years ago. All of the crinoids investigated to date belong to this group, and it is well known that they have an extremely porous structure in their skeleton. Our conclusion from this curve is that many organisms do fit the theoretical curve expected on the assumption that the calcium carbonate deposited is in equilibrium with the sea water.

The fact that we have such great difficulty in finding suitable specimens for investigation today means that similar difficulties would have been encountered in past geological periods. However, since the land surface of the earth is exceptionally large at the present time, we may expect that brackish water will be a far more common occurrence on the surface of the earth today than in the past. In general, we must attempt to select our specimens from those deposits which from all geological evidence indicate fully marine conditions. A study of the various types of animals which might fit these conditions early led us to consider two types as particularly worthy of study. The first was the crinoids, which belong to the echinoderms, which are entirely marine in their habits though some specimens do live in quite brackish water but never in fresh water. Since the skeletons of the crinoids are very porous, consisting of a three-dimensional, lace-like structure, these appear to be unsatisfactory on these grounds. The second group of animals which we consider are the cephalopods, which are entirely marine animals and among which the belemnites seem to be particularly suitable. The belemnites, which lived during the Mesozoic era, are cephalopods similar in general structure to the modern squid. They had an internal skeleton of calcite. A typical specimen would be perhaps as large as a cigar and of somewhat the same shape, with a rather wide flaring cone in one end. Its transverse section shows that it consists of crystals of calcite arranged radially from the center of the specimen. This is a characteristic arrangement of the crystals and a well-preserved specimen is always translucent, sometimes nearly the color of honey and grading to darker shades of yellow and brown. It would appear that this deposit of calcite is the original deposit (with about as high degree of certainty as can be expected in matters of this kind). We have, then, a marine type of animal with a heavy, substantial skeleton well suited for the preservation of the original isotopic composition of the shell.

## Temperature of the Upper Cretaceous of Hampshire County, England

Dr. Stubblefield, of the London Geological Museum, to whom we are much indebted, supplied us with a number of specimens of belemnites, oysters, and brachiopods from the upper Cretaceous of England, nicely classified, arranged in the order in which they were deposited in geological time. In fact, it has only been necessary for us to determine the isotopic ratios and fit them into the outline of the research supplied by him. Our work to date has completed the study of the belemnites, and work is continuing on the oysters and brachiopods as well as the chalk in which they were embedded. The temperatures so secured (Table 3) range from 17° or 18° C to 27° C. There is a trend in these results, but this trend cannot be taken seriously on so few specimens. One could hardly judge the climatic condition in any sea of the earth at the present time by the investigation of a single or even a few specimens of the animals that live there now, and since we have only some half-dozen specimens to record the climatic conditions of approximately 10,000,000 years, it will be easily seen that no very serious conclusions can be drawn. The results of our measurements, however, are in accord with the views of the geologists deduced from the kinds and types of animals living in the Cretaceous as to the probable temperature of that part of the earth during this period.

TABLE 3

Temperatures of Belemnites From the Upper Cretaceous of Hampshire County, England

| Zone | Specimen | Analysis | Avg. | Temp. | Chalk analysis |
|---|---|---|---|---|---|
| Upper Chalk<br>*Ostrea lunata* | *Belemnitella mucronata* | −1.26<br>−1.08<br>−1.07 | −1.14 | 18.8 | −2.64 |
| Upper Chalk<br>*B. mucronata* | *B. mucronata* | −1.39<br>−1.35<br>−1.12 | −1.29 | 19.7 | −3.38 |
| Upper Chalk<br>*Actinocamax quadratus* | *Actinocamax quadratus* | −1.71<br>−1.76 | −1.73 | 22.1 | ..... |
| Upper Chalk<br>*Offaster pilula* | *Actinocamax* sp. | −2.18<br>−2.25 | −2.21 | 24.7 | ..... |
| Upper Chalk<br>*Marsupites testudinarius* | *Actinocamax* sp. | −2.57<br>−2.52 | −2.54 | 26.5 | ..... |
| Lower Chalk<br>*Holaster subglobosus* | *A. plenus* | −0.91<br>−0.92 | −0.91 | 17.5 | ..... |

The data thus far secured are not sufficient to draw extensive and varied conclusions in regard to past geological temperatures, but they are sufficient to lead us to believe that at least some measurements of past temperatures can be made, and hence a quantitative basis for past climatic conditions of the earth secured. We cannot expect that every fossil which has been or will be found on the surface of the earth can be tested by our methods for the temperature at which it lived. We do hope, however, to find a small fraction of such fossil remains preserved to such a degree that such measurements can be made and at least a limited exact knowledge in regard to these matters secured. These studies can be compared to the radioactive time scale which I referred to previously. That method is very simple in principle, but the actual carrying out of the research which established the time scale involved very careful work covering many years. What will be remarkable, if these ideas are substantiated by further work, will be that such a transient physical quantity as temperature will prove to have been recorded in the rocks in a sufficiently durable form to allow us to read this thermometer at the present time.

# *NEWS and Notes*

**Albert E. Whitford** has been appointed director of the Washburn Observatory, University of Wisconsin, succeeding **Joel Stebbins,** who retired on July 1.

**Z. I. Kertesz,** professor of chemistry at the New York State Agricultural Experiment Station, Cornell University, Geneva, has been granted a sabbatical leave and has accepted a joint invitation from the Division of Food Preservation and Transport, CSIR, the Australian Chemical Institute, and the Food Technology Association to study for 6 months the biochemical aspects of food production and processing in Australia. Dr. Kertesz leaves Geneva early this month. His headquarters will be at the Chemistry Department, Sydney Technical College, Ultimo, Sydney, N.S.W.

**Stanley D. Miroyiannis** has resigned as professor and chairman of the Department of Biology at Northeastern University, Boston, to accept the position of professor of advanced biology in the Graduate School of the Massachusetts College of Pharmacy, Boston.

**Robert Simha,** consultant for the Division of Organic and Fibrous Materials, National Bureau of Standards, is spending four months in Europe studying the status and trends of high-polymer research in government, academic, and industrial institutions. In September he attended the International Rheological Congress in Holland; in October he lectured at the Institute of Physical Chemistry, Basel, Switzerland; and he is now lecturing at the University of Stockholm.

**Theodore L. Jahn,** who has been associate professor of zoology at the State University of Iowa, is now professor of zoology on the Los Angeles campus of the University of California. In addition to teaching general physiology and physiology of the Protozoa, Dr. Jahn will continue his research on the physiology of vision.

**Robert W. Dougherty,** who was formerly associated with the College of Veterinary Medicine, State College of Washington, has recently been appointed professor of veterinary physiology at the New York State Veterinary College, Cornell University.

**Adam G. Bøving,** research associate in zoology, Smithsonian Institution, has been elected a member of the Royal Academy of Sciences and Letters of Denmark.

**Elmer L. Sevringhaus,** director of endocrine and metabolic clinical studies at the Medical Center, Jersey City, and director of clinical research for Hoffman-La Roche at Nutley, New Jersey, has also been appointed clinical professor in the Department of Medicine of the New York Medical College, with teaching and clinical duties at the Metropolitan Hospital in connection with endocrine and nutritional work.

**C. H. Hardin Branch,** formerly executive director of the Institute of Pennsylvania Hospital at Philadelphia, has been appointed professor and head of the newly formed Department of Psychiatry at the University of Utah College of Medicine.

**Keith T. Swartz,** formerly with the Research Department of the Continental Can Company, Chicago, has recently joined the staff of the Animal Products Branch, Quartermaster Food and Container Institute for the Armed Forces, Chicago. Dr. Swartz will be engaged in developmental work on canned meat items for use by the Armed Forces.

**Harold A. Zahl,** who has been associated with the Signal Corps in research and development work since 1931, has just been made director of research for the SC Engineering Laboratories, Fort Monmouth, New Jersey.

**Horace W. Stunkard,** professor and head of the Department of Biology, New York University, recently returned from sabbatical leave at the Scripps Institution of Oceanography, La Jolla, California. During his leave, **W. W. Cort,** of Johns Hopkins University, served as chairman of the Editorial Committee and managing editor of the *Journal of Parasitology.* Volume 34 (1948) is now complete, and manuscripts intended for publication in the journal should henceforth be sent to New York University, University Heights, New York City 53.

## Visitors to U. S.

**Torbjoern O. Caspersson,** director of medical cell research and genetics at the Medical Nobel Institute, Karolinska Institute, Stockholm, is to present the Salmon Memorial Lectures this fall. Dr. Caspersson's lectures, on ''Cell Function and Cell Growth in Normal and Pathological Conditions Studied by Quantitative Cytochemical Procedures,'' will be given November 8, 9, and 10, at 8:30 P.M. in Hosack Hall of the New York Academy of Medicine, 2 East 103rd Street, New York City.

**Two German agricultural scientists,** William Rudorf, director of the Kaiser Wilhelm Research Institute at Voldagsen, and Alfred Koenekamp,