DATING THE PAST WITH RADIOCARBON

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ONE of the most striking manifestations of the underlying unity of all knowledge is the way in which a discovery in one branch of science often finds fruitful application in another. A recent example of this is the development by Professor Libby in America of a new method of dating archaeological samples using the techniques of nuclear physics. The basic fact underlying the method is that all archaeological specimens containing carbon also contain a small amount of radioactive carbon, or radiocarbon, which becomes progressively less in quantity as time goes on. The fraction of radiocarbon present can be measured, and hence the age of the sample deduced. To explain this in more detail, it is necessary to explain what is known as the carbon cycle and then to discuss some of the radioactive transformations which take place in the earth's atmosphere.

The chemical element carbon, which plays an essential part in all vital processes, continually takes part in a cyclic series of interchanges between the earth and its atmosphere. Plants obtain the carbon they need to grow by absorbing carbon dioxide from the air and, with the aid of sunlight, build up complex chemical compounds containing carbon by the process known as photosynthesis. Some carbon is also absorbed by roots from the soil, where it is present as a weak solution of carbonic acid. When a plant dies it is often burned, and the complex compounds are broken up and the carbon returned to the atmosphere as carbon dioxide. Sooner or later this carbon dioxide is used by another plant and so the process continues. This is the simplest form of the carbon cycle.

There are, of course, many other possibilities. The plant may be eaten by an animal and used to build up its own tissues. In this case, the carbon will not be returned to the atmosphere until the animal dies and is itself burnt. Or, again, the plant may decay and eventually form coal which may not be burnt for many millions of years. But whatever happens to a particular carbon atom, the essential fact is that much of the carbon on the earth's surface is continually being converted into atmospheric carbon dioxide,

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which is in turn re-absorbed by plants. There is consequently a continual interchange of carbon between the earth's atmosphere and its vegetation.

The earth's atmosphere is constantly bombarded by a stream of particles from outer space called the cosmic radiation. These particles collide with the atoms in the atmosphere and initiate a complex series of atomic transformations which result in the production, among many other things, of uncharged particles called neutrons. Each of these neutrons can enter the nucleus of a nitrogen atom in the atmosphere, forming an unstable structure which soon breaks up into a nucleus of radiocarbon and a nucleus of hydrogen. The neutrons therefore effectively convert a small fraction of the nitrogen in the atmosphere into radiocarbon. This radiocarbon behaves chemically in exactly the same way as ordinary carbon, and so takes part in the carbon cycle.

Radiocarbon atoms have, however, one important difference from ordinary carbon atoms. This difference is that they are slightly unstable and, after a certain time, they shoot out a small charged particle called an electron. We cannot predict when a particular atom will break up in this way, but we do know that, if we take a large number of radiocarbon atoms, one half of them will have broken up after about five thousand six hundred years.

The electron is emitted from the disintegrating carbon atom with a high velocity and can easily be detected by the sensitive instruments used in nuclear physics. Consequently, the proportion of radiocarbon in a piece of carbon can be determined by counting the number of electrons emitted from it in a measured interval of time.

We can now understand the new method of dating archaeological specimens. Since the average time of circulation of a carbon atom in the carbon cycle, estimated at about five hundred years, is very much shorter than the average lifetime of a radiocarbon atom, a typical radiocarbon atom will complete several cycles before it breaks up. As a result, the radiocarbon is evenly distributed, and all the carbon in the cycle, including that in living organisms, contains the same proportion of radiocarbon.

If a tree or plant dies and is not burnt, the radiocarbon in it is no longer replenished by the radioactive transformations taking place in the atmosphere. The radiocarbon slowly breaks up and so the proportion of radiocarbon in a piece of dead wood con-

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tinually diminishes. Thus the wood from a Pharaoh's tomb will have much less radiocarbon in it than a similar piece of newly-cut wood. Since the radiocarbon can be easily measured, this provides a way of finding the age of the specimen.

Great care is necessary in performing and interpreting these measurements. In the first place, the carbon must be very pure, as any radioactive impurities would vitiate the results. The sample of wood is therefore reduced to charcoal and purified chemically before the measurements are made. Again, the sample must not be contaminated by wood of more recent date.

It is important to remember that the method determines the date on which the tree died, and not the date on which it was used to build a tomb or make a statue. Strictly speaking, therefore, this method only allows us to say that a tomb cannot be earlier than a certain date. But it is usually reasonable to suppose that the wood was cut not long before it was used and so the date of the wood gives a good estimate of the date of the tomb. In general, however, the results of the radiocarbon method have to be supplemented by more conventional archaeological considerations.

In order to test this method, it has been applied to a number of specimens of known date. The radiocarbon results have, in almost every case, shown excellent agreement with the known dates, thus confirming the validity of the method. Such a test is necessary because the method depends on certain assumptions, such as the constancy of the intensity of the cosmic radiation, which, although they are very probable, cannot be established otherwise.

The dates found by these measurements are not absolutely precise, but are subject to a certain margin of error which depends on the size of the sample available and on the number of electrons counted. The results of a measurement are accordingly quoted, for example, as A.D. 300 $\pm$ 50, where the uncertainty in the date is fifty years. This does *not* mean that the sample certainly has a date between A.D. 250 and A.D. 350, but that there is a *probability* of about seventy per cent that this is so. In other words, if we measure a large number of samples originating in the year 300, seventy per cent of these will give measured values lying between the years 250 and 350, while the remaining thirty per cent will give values lying outside these limits. The errors of measurement are prohibitively large for samples having ages differing from the lifetime of radiocarbon by more than about a factor of ten.

Many possible applications of this new method immediately come to mind. Among those that may be noticed here is its use to determine the age of relics. Owing to the prevalence of spurious relics, it is desirable to have some independent check on their authenticity. The method described here would be of some value, but its limitations must be borne in mind. The most important of these is that, as pointed out above, it only gives an upper limit to the age. Thus it cannot authenticate a relic, since it could easily have been made recently out of old wood. But it could show if the wood was of recent date, in which case the relic is spurious.

Another disadvantage is that it can only be used for relics containing a considerable fraction of carbon, and, still more serious, at least a large part of the specimen is effectively destroyed in the process of purification. In general, this would not be appreciated by the owners of the relic. To sum up, one might be able to say that the relic was certainly faked but not that it was certainly genuine.

This is not very helpful, but there still remain cases where the method would be of great value. Suppose, for example, some old manuscripts, suspected of being early copies of the Scriptures, were found in such a condition that, apart from one or two fragments, there was no possibility of deciphering them. They could then be destroyed without loss, and it would certainly be of importance to be able to establish, for example, that the plants from which the paper was made died in the first century. The upper limit to the age obtained by the radiocarbon method may in these cases be supplemented by a lower limit derived from archaeological considerations, and a reliable estimate of the age obtained.

An opportunity of applying the method occurred quite recently when the Zadokite fragments were found in a cave in Palestine. Measurements have dated some of the fragments to within the first decades of our era, with an uncertainty of about two hundred years.

It may be confidently anticipated that this method, at present in its infancy, will be refined and developed, and will find increasing application in many fields. There is surely something very satisfying in the way in which Nuclear Physics, one of the newest and most vigorous of the sciences, has come to the aid of Archaeology, the study of the antiquity of mankind.