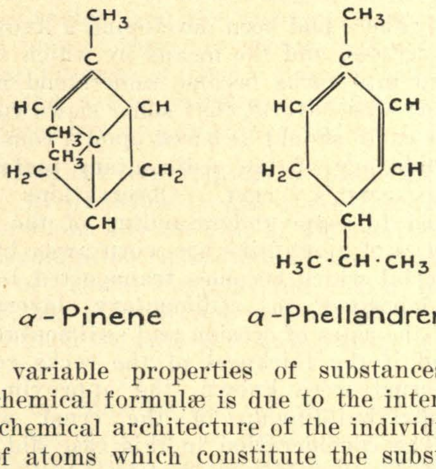
CHEMICAL FORMULÆ.

To those unacquainted with organic chemistry, it might appear strange that so many substances of diverse properties should possess identical chemical formulæ. Examples are $C_{10}H_{16}$, $C_{10}H_{16}O$, $C_{10}H_{18}O$, which appear in the preceding article.

These formulæ represent in the simplest possible manner the number of individual atoms of carbon and hydrogen, or carbon, hydrogen and oxygen constituting the molecule of substances, as for example:



α - Pinene α -Phellandrene

The variable properties of substances possessing similar chemical formulæ is due to the internal arrangement or chemical architecture of the individual atoms or groups of atoms which constitute the substance. It is the determination of the arrangement of the atoms or the variation in chemical architecture of a substance that makes organic chemistry such a fascinating study.

A.R.P.

THE AGE OF THE EARTH.

*By G. D. Osborne, D.Sc.

It would be difficult to think of an aspect of the development and history of the earth more fascinating than that of its age. Throughout the later history of man there have always been inquirers who have attempted to wrest from the earth the secret of her age. Many of the ancients wrote on this subject and, naturally enough, their views were intimately bound up with their ideas as to the mode of origin of the planet itself.

The age of the earth was often regarded as more or less the same as that of mankind. Religious beliefs and theological dogma had a great influence upon the minds of many regarding the beginnings and subsequent history of the earth, and the pronouncement by Archbishop Ussher to the effect that the creation took place in the year 4004 B.C. exercised great sway for a long time. It was not until towards the close of the eighteenth century that anything approaching scientific thought and method was brought into play upon this and other allied subjects.

Gradually there had been developing a knowledge of geological processes, and the means by which sediments were built up into rocks became understood more and more fully. It was natural that some views concerning the age of the earth should be based upon a consideration of the probable age of the sedimentary material constituting the earth's crust. Observations of keen naturalists led to some understanding of the cycle by which the rocks of mountains are worn away by erosion to form material which becomes transported to another zone and deposited in sedimentary layers. If a knowledge of the rates of erosion and sedimentation were available, and if the thickness of the rocks composing the earth's crust were known, the approximate time taken for the building-up of the crust would be calculable. The consideration in this case did not deal with the period antecedent to that in which sediments began to be developed.

As geological knowledge grew (and grew slowly against the conservatism of traditional beliefs) it was soon apparent that the period taken for the building-up of rocks and their subsequent elevation, sculpturing and final decay was of great length, and it was further seen that such a cycle of processes had occurred over and over again. It became clear that there was in the rocks a record of such length that ample provision could be made for the gradual unfolding of biological activities and the evolution of life.

Gradually there developed the conception of cycles in the history of the earth, and the testimony of the rocks has been very appropriately referred to as a great book of earth-history, or even a series of volumes, in which there are many chapters, each chapter being subdivided into many parts. These chapters represent the succession of geological periods, and the pages of the chapters can be read from the rocks, which, as Holmes says, are "historical documents". These interpretations have been made known by the patient labours of geologists, particularly during the last hundred years.

The problem of the age of the earth can be approached from different angles, namely, from the standpoints of astronomy, physics and geology. Astronomical investigations have given results for the age of the solar system rather than of the earth itself, but the genesis of the solar system and the assumption by the earth of its general present form are events that were separated by no great interval of time. Physics has contributed greatly to the astronomical calculations, and to age-determinations based upon radioactivity.

The geological contribution to the problem has been great and, in addition to the three purely geological methods, in which (*a*) the rate of sedimentation, (*b*) the rate of accumulation of sodium in the oceans, and (*c*) the series of crustal rhythms have been the bases of calculation, has played an important part in investigations based upon the rate of disintegration of radioactive minerals.

Before we consider any of the methods of determining the age of rocks, we must investigate something of the mode of origin of the earth in order to have a setting for the discussion of its age.

The tidal-disruption theory of the origin of the solar system from a great star by the pulling off of a filament of mostly gaseous material due to the near approach of another greater star is now regarded with a great deal of favour by physicists and astronomers, and may be taken in the present discussion as likely to be the best theory yet put forward for the origin of the earth in the solar system.

As developed by Jeans and Jeffreys, the theory postulates that the earth cooled down fairly quickly from a gaseous state, and before it became wholly liquid lost the moon through disruption under the influence of the parent sun upon the daughter earth.

During the cooling gravitational settling effected a zonal arrangement or distribution of the materials of the earth, and it appears that definitely lighter constituents of the composition of granite made up the continents and denser material of the composition of basalt made up the rest of the crust, *i.e.* under the ocean basins.

The central portion of the earth was composed of heavy metals such as iron and nickel, and this large central core was followed upward by zones with decreasing density, so that the crust of the earth was essentially siliceous. The original rock of the crust was probably entirely of igneous character, *i.e.* it had solidified from a molten condition. No doubt there were great irregularities on the primeval surface. Immediately below the siliceous crust there were substrata or shells of basic and ultra-basic rocks.

The investigation of the period of time which elapsed from the ejection of the earth from the sun to the time when it became solid has been carried out by Jeffreys. First the gaseous part of the earth-mass would liquefy and subsequently cooling would ensue, eventually giving a solid earth with the igneous crust just mentioned. Probably small pockets of molten rock would remain within the crust. Jeffreys points out that the moon would be formed at a time when conditions of resonance magnified the effects of solar tides and allowed a disruption to be effected. These conditions did not obtain until the earth had acquired practically its present diameter, and therefore the formation of the moon could only take place when the liquefaction of the earth-mass was nearly complete. For the time between the birth of the earth and of the moon Jeffreys gives the figure of approximately 10,000 years. Further considerations have led to the figure of about 15,000 years for the time taken for the earth to become solid after its birth.

After the earth became solid it still possessed no ocean, and therefore the major geological processes could not go on. So long as the sun gave out excessive heat the ocean could not form, and there is a difficulty here in connexion with assigning a figure to the time-interval between the solidification of the earth and the condensation of the ocean. Although the possibility of a long period must be recognised, physicists and astronomers at the present time are of the opinion that the period was a very small fraction of the total history of the earth.

Thus, to summarise, the earth cooled down from a fluid condition, becoming solid after a lapse of about 10,000 years, and a little later on (possibly not more than 20,000 years from its birth) received its oceans. The oceans would develop when the surface temperature was below 373° absolute, the boiling-point of water.

With the formation of the oceans the beginnings of the geological record come into the picture. At this time the sun had begun to decline and had passed through the giant stage. The geological record has been a very long sequence of events, which bring us right up to the present. Its actual beginnings, however, are shrouded in uncertainty, because we have not yet been able to discover the primeval crust of the earth. It is certain, however, that the early crust was of igneous rock, and mostly if not entirely of granitic composition. From that primary zone or crust the first sediments were developed by erosion carried out by the first rivers and streams which came into being with the first rains.

We may now proceed to consider some of the methods employed for the determination of the age of the earth, and the results obtained.

Astronomical and Physical Methods.

Lord Kelvin, some fifty or sixty years ago, calculated that the time since the earth was molten was probably about 40 million years. At the time Kelvin enjoyed a great reputation, and his prestige was such that respect for his pronouncement was maintained for a long time, in spite of the fact that geologists and biologists saw in this time-figure a most embarrassing restriction for the operation of the forces which they knew to be indicated in the rocks, and for the evolution of the life which those rocks revealed. At the time Kelvin's calculation was based upon what appeared valid premises, and although some of his opponents suspected a fallacy or flaw in his argument, it was only long afterwards that the need for abandoning Kelvin's figures developed, namely, with the discovery of radium and of radioactivity in certain rocks and minerals. Kelvin had assumed a simply-cooling earth, but the invalidity of this assumption followed the discovery of radium, and Kelvin's reasoning became obsolete.

Kelvin and Helmholtz, in the middle of last century, basing their investigation on the assumption that the output of energy and radiation by the sun was due to its contraction, gave the limits of 20 and 100 million years for the time of duration of the sun's heat as we know it to-day, and again this figure was in direct opposition to the probable order of magnitude of the age of the earth likely to be determined from purely geological evidence.

Other calculations by astronomers concerning the time-intervals for various sections of the history of the solar system have some bearing upon the age of the earth, and therefore some interest for us. Thus Dr. Harold Jeffreys has determined by an ingenious method the age of the solar system. This is based on the effect of a resisting medium upon the movement of the planet Mercury, whose orbit is the most eccentric of any of those of the planets. His result is of the order of 2,500 million years. Other modern astronomical methods, including one dealing with the origin of the moon and worked out by Jeffreys, have given values lying between 1,000 and 5,000 million years for the age of the earth, and in particular an age of about 4,000 million years for the solar system.

Geological Methods.

The purely geological methods are of two main types, those based upon the hour-glass principle, and that which recognises the existence of great cycles or rhythms in the history of the earth.

In the methods which employ the hour-glass reasoning, we have to take some set of processes which are characterised by the dual activity of a deletion or subtraction of material from one part of the earth's crust, and an addition or building-up elsewhere.

The two main methods are: (i) that based upon *Erosion and Sedimentation,* and (ii) that based upon the *Accumulation of Salt in the Ocean.*

Denudational Method.

Let us picture the sequence of major events which followed one upon the other in the unfolding of the geological record. We are struck at once with the rhythmic nature of the processes, and we see that forces which to-day operate upon the earth's surface were working upon the ancient landscapes. It is not clear, however, as to just at what rate the ancient erosive processes proceeded. In the past, as in the present, the rivers, aided by such agents as snow, glaciers, the sea and the wind, attacked the lands, carving them out, and transporting material to areas of deposition where masses of gravel, silt and sand were built up. The ceaseless attack of the sea modified the coastlines, and volcanoes and earthquakes were active from time to time, tending to change the face of the earth. Great movements of land and sea, involving submergence here and emergence there, also took place. The result of all these processes was to reduce the mountains to the state of plains, and to build up and fill in areas of deposition. This sequence of events went on time and again. It is considered, for example, that a land area such as Great Britain or New Zealand would be completely worn away to a rolling plain in the course of 1½ to 2 million years.

After a long period of stability when erosion and deposition could go on more or less uninterruptedly, a great revolution or catastrophe would occur within the crust, and land and sea areas would be much modified by major earth movements. These great revolutions were responsible for a great change in geography and in fauna and flora. Great mountains were built up by lateral stress and a new period of erosion and sedimentation was ushered in. Thus the cycle began again.

We thus have a series of great periods or chapters, throughout which proceeded a great pageant of events, and of the evolution and development of life-forms leading eventually to man himself.

Professor Joly, of Dublin, has provided science with a basis for understanding the rhythmic succession of the events of earth-history.

About 1½ to 2 million years ago there was initiated the last chapter or period of our great book, and we are still reading the pages of that chapter. Just prior to its opening, and at the conclusion of the previous period, the lands of the main continents were everywhere standing not very high above sea-level, and there were no great mountain-ranges. The opening of this last chapter saw the uprising of the Himalayas, the Andes, the Alps and other highlands, and great changes in sea and land were effected.

Now the conceptions of these periods, with their simultaneous wearing away of the hills and building-up of deltas, suggests the running of a great hour-glass. If we can discern the various chapters of our book, and if we can estimate the length of each period, we then have an approximate idea of the age of the geological record.

Geologists, especially those interested in stratigraphy, have attacked the problem of the rate of erosion and of sedimentation, and various more or less similar values have been obtained by independent workers for typical masses of sediment, and for erosion of areas of similar character under similar climates. One very important factor to be kept in mind is that of the rate of erosion in the past and the rate during the present, as based upon observation. It is considered that about one foot of the earth's surface is removed in 9,000 years. The rate at which sediments are built up has been determined by measuring the amount of sediment which is carried annually to the oceans by the larger rivers, and also the amount of material carried to the oceans in solution. From these calculations the time taken for the accumulation of the sediments in each geological period has been computed, and the general result obtained from the latest work indicates an age of 1,600 million years for the oldest sediments.

The Age of the Ocean.

The other geological method of "hour-glass" character is that which was used independently by Halley and Joly. This is based upon the rate of accumulation of sodium in the waters of the oceans, which, of course, were originally fresh. Salt is being constantly supplied to the oceans, and its rate of accumulation can be determined. From careful work a figure of 330 million years was obtained for the age of the oceans.

It is important to note that in both of the geological methods the question of the relative rates of the processes concerned, in the past and at the present time, is a most vital one. Modern geologists consider that it is erroneous to assume that the supply of salts to the oceans has been uniform throughout time, and it is now held that the figure of 330 million must be multiplied by a factor of five, bringing the age of the ocean to about 1,650 million years.

Methods Based Upon Radioactivity.

We must now turn to the most remarkable aspect of this study of the age of the materials composing the earth. This involves the determination of the age of radioactive minerals by considering their disintegration-history. The property of radioactivity has provided the most accurate method of computing geological time. The minerals possessing this property give out emanations regularly, and thus have been called natural chronometers or time-keepers, beating out pulses of time throughout the ages. Becquerel, in 1896, discovered that uranium salts and minerals give out radiations which are brought about by the disintegration of the mineral as it undergoes transformation through successive states. It is now known that uranium and thorium minerals are unstable, and disintegrate so as to produce a great series of daughter elements by losing helium atoms and other emanations. Amongst the daughter elements is radium, while the end product of disintegration is a stable substance, lead. This lead is not the same as ordinary lead. The simplest case of disintegration is that of Uranium to Lead with the discharge of Helium. Actually there are at least three entities in the emanations. Thus Rutherford found that these were: (*a*) *alpha rays* of electrically charged helium atoms; (*b*) *beta rays,* which are electrons with great velocity; and (*c*) *gamma rays*, similar to X rays.

In the change from Uranium to Lead, it was found that Uranium of atomic weight 236 lost eight Helium atoms and became Lead of atomic weight 206. Ordinary lead has an atomic weight of 207·2.

Now it is considered that the rate of Helium-discharge has been constant throughout time, and the rates of disintegration have been measured. Lord Rayleigh has been prominent in this connexion.

Coming now to the age-determinations of the minerals, it will be seen that if a mineral has existed for a certain time, and if the quantities of Lead and Uranium present can be accurately determined, then with a knowledge of the rate of disintegration of Uranium, the Lead/Uranium ratio of the mineral will be a measure of its age. In this way the ages of many radioactive minerals have been determined. This work involves very careful chemical analysis, as well as very careful selection of the material in the field, and precise determination of the field-relations of the rocks containing the radioactive mineral. It is in these latter phases of the work that the help of the geologist is essential. Indeed, it is very important to treat each occurrence as a separate case on its merits, and to make quite sure that the mineral has not been contaminated in any way, or suffered other forms of alteration besides its radioactive disintegration. It is important to determine whether there is any ordinary lead associated with the mineral. All these aspects call for expert geological advice.

In the manner explained above the ages of different terranes of rocks have been determined. The radioactive minerals have been in igneous rocks which have invaded sediments. The age-values have, of course, been assigned to the igneous rocks, but the relations of the associated sediments have been such as to assign to these latter some general age-value. The most heartening fact about this method is that minerals from widely separated areas, and in rocks that hitherto were thought to be of the same general age, have given approximately the same age-values. Gradually a time-scale based upon this method is being developed. It is most fortunate that most of the important radioactive minerals occur in the very old (Pre-Cambrian) rocks of the earth.

The figures for the oldest rocks vary, but are within the limits of 1,400 and 1,700 millions of years, the oldest authentic case being from Dakota. There is a record from Ceralia, Russia, giving an age of 1,800 million years, but some doubt has been cast on this case.

The oldest rocks we can see are not of the primary crust, so that the age of the earth has to be put beyond the highest values just considered.

A method based upon the quantities of uranium and actinium and thorium in the crust of the earth has been investigated, and a figure of 3,400 million years has been suggested for the upper limit of the earth's age.

Yet another interesting, but less reliable method, based upon the property of radioactivity, is that applied by Rutherford and Joly to the examination of certain mica specimens in which beautiful haloes due to the ionisation effects of alpha-particles in the mica have been studied and measured. Comparison with artificial haloes whose time-values are known leads to a computation of the age of the mica, and therefore of the rock in which it is found.

The various methods having been considered, it remains to be emphasised that in any convergence of evidence upon the various aspects of this problem there is the outstanding fact of the validity of the radioactive method, and the high status that it has in current thought. Thus we see that the oldest rocks examined by this method are of the order of 1,500 million years. The primeval crust of the earth must be yet older than this, but probably not very much older.

Purely geological methods indicate an age of the order of 1,600 million years, while astronomical calculations give the limits of 1,000 and 10,000 million years for the age of the solar system, and more closely a figure of about 2,500 million years for the age of the earth. *Taking all things into consideration, we can with confidence assign to the earth an age in round figures of approximately 2,000 million years.*

In conclusion we have to note that we are only dealing with the earth. There is yet the stupendous problem of the age of the sun and of the universe itself. But these are matters of events of almost inconceivable remoteness, and the veil of nature is lifting only very slowly. Astronomers have indeed to be very careful with regard to the bases on which they make their calculations, for the case of Kelvin's erroneous assumptions is a warning.

The long age of the earth emphasises the brief chapter in which man figures, and we note the insignificant fraction of the whole history which represents all man's history and pre-history, but we are surely able to agree with Professor W. W. Watts when he says (as quoted by Arthur Holmes), that the modern geological interpretation has given to man a worthy conception of the creation of the planet, and has filled him "with a reverence for the wondrous scheme which, unrolling through the ages, without haste, without rest, has prepared the world for man's dominion and made him fit to occupy it".