REFRESHER COURSE FOR GENERAL PRACTITIONERS

THE BASIC PRINCIPLES OF ATOMIC STRUCTURE

BY

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Correspondence in the *British Medical Journal* and remarks made to me personally following the two papers on isotopes in medicine published in the *Journal* of September 29 have made it evident that many members of the medical profession have difficulty in understanding modern atomic physics. This is very understandable when it is realized how recent is the growth of this subject, so that there must be many general practitioners and specialists who learnt their physics in the days when an atom was only an atom. Now it is becoming essential that, with the progress of medical treatment, they should have an elementary knowledge of the underlying principles of atomic structure. The literature is, however, so immense and the many textbooks are often so large and highly technical that general practitioners have neither the time nor the opportunity to study them. It is my belief, nevertheless, that by omitting all mathematical considerations and the lines of reasoning that have led to the conclusions, and by concentrating upon the actual experimental findings and the accepted results, an elementary knowledge of the facts can be given very simply and briefly. It is true that such a method tends to be too dogmatic, in that certain conclusions which are still under discussion, or even not accepted by many, have to be stated as facts, but this is a privilege which is granted to all elementary teachers and may not be unduly harmful.

The Atomic Theory

About 500 years B.C. the Greek philosopher Leucippus taught that the ultimate constituents of all things were empty space and atoms, which were infinite in number, indivisible, and always in motion. About 100 years later Democritus, who is usually credited with the atomic theory, developed this view and taught that atoms were the ultimate material of all things and, although not visible, were heavy and impenetrable. These views, which were purely theoretical, were forgotten for some 2,200 years, when in 1804 Dalton announced his famous atomic theory, in which he showed that atoms could be defined as the smallest particles in which an element can exist, that they could not be broken up by chemical means, and that they possessed definite weights which could be expressed by numbers relative to the atomic weight of hydrogen, which is the lightest known element. Alternatively, they could be defined as the smallest part of an element which could enter into chemical combination with another element.

In 1864 John Newlands showed that if the elements were arranged in the order of their atomic weights there was a recurrence of similar chemical and physical characters at every eighth element. This he described as the "law of octaves." In 1869 Mendeléeff developed this idea more fully and published a table with the elements arranged according to his periodic law. Since then many new elements have been discovered, and

their insertion in the position of the table indicated by their atomic weights has confirmed his views and fulfilled his predictions.

Structure of Atoms

In 1897 Sir J. J. Thomson found that by passing an electric current through a glass tube filled with an attenuated gas of any variety (Fig. 1) a luminous ray was given off in a straight line from the cathode. This cathode

FIG. 1.—Sir J. J. Thomson's apparatus for generating cathode rays.

ray could be deflected by electric and magnetic fields in a direction showing that it was made up of negatively charged particles which are known as *electrons*. They have a speed of approximately $1/10$ that of light, produce luminescence when they impinge on certain substances, cause the leaves of an electroscope to diverge, and have considerable penetrating powers. Since they come from any gas, they must be a constituent of all atoms. The electrical charge which each electron carries is taken as the unit charge. They have been estimated to have a diameter of only 10^{-5} of a hydrogen atom and to weigh only $1/1,840$ of its nucleus.

The fact that negative particles are obtainable from atoms suggested that similar positive particles must be present, as atoms are electrically neutral. Goldstein was able to demonstrate their presence, and in 1898 Wren proved that they were positively charged. Mosely was able to show, by x-ray spectroscopy, the actual number of these particles, which are known as *protons* and are grouped together to form a *nucleus*. Since each contains a unit positive charge and the total atom is neutral, they must equal the number of electrons. Their number in each atom is known as the *atomic number* of that atom. They weigh approximately 1,840 times the weight of an electron. It is the number of the protons which determines the nature of the element. In hydrogen there is only one, in helium two, and so up the scale to uranium with 92. If the number of protons is altered, as occurs naturally in radioactive substances or can be brought about artificially, the element is changed to another.

The fact that the atomic number is less than the atomic weight, except in the case of hydrogen, made it evident that other heavy particles must be present, and in 1931 Sir James Chadwick discovered the presence of *neutrons*, which are in the nucleus and have a like weight to the protons, they and the protons forming nearly the whole of the weight of the atom. Neutrons have,

however, no electric charge, and their presence therefore does not affect the number of electrons and the chemical properties. They steadily increase in number with the atomic number but not in the same ratio; deuterium, or "heavy hydrogen," contains one, helium two, bromine 45, and uranium 146. Together with the protons they give the atomic weight of the element.

In 1885 a Swiss schoolmaster named Balmer discovered that there was a definite mathematical relationship between the positions of the lines seen in the spectrum of the light from glowing hydrogen. Based largely upon this knowledge and upon the later brilliant work of the late H. G. J. Mosely on the wavelengths of the x -ray spectra of the elements, the Danish physicist Niels Bohr was able in 1913 to evolve his famous model of the atom. He showed that it consisted of a heavy central nucleus around which the electrons moved in ellipses in any plane; the ellipses formed shells placed at

FIG. 2.—Diagrams showing the arrangement of the electrons in atoms of helium, neon, argon, beryllium, magnesium, chlorine, and zinc. The diagrams are purely schematic: the orbits or shells are much further apart, and they are in the form of ellipses, not circles; also they may lie in any plane.

distances corresponding to the square numbers 4, 9, 16, 25, 36, etc., from the nucleus, the numbers of electrons in each shell being fixed for each atom. Hence by far the greater part of an atom consists of empty space. In hydrogen there is only one shell containing one electron, but on passing down the periodic table the numbers gradually increase (Fig. 2), the number in the individual shells being 2, 8, 18, 32, 18, 12, 2, this being the arrangement of electrons found in uranium, the heaviest known element. Generally speaking the electrons are more loosely attached in the outer shells, so that the inner shells are filled first. The total number of electrons corresponds to the atomic number. The outer electrons are those which are concerned in chemical reactions, and it is found that those elements which have similar chemical characters—that is, which are in the same columns of the periodic table—have a similar number of electrons in their outer shells, thus confirming Mendeléeff's views in a remarkable manner.

Ionization and Electrolytes

Electrons may be displaced from the outer shell of an atom, and, being free, will soon become attached to other atoms of a similar or different nature. The atom from which an electron has been displaced will have lost one unit negative charge and hence will be positively charged. It is known as a *positive ion*, or, since it is attracted to the cathode, as a *cation*. In the same way the atom which has gained an electron is negatively charged and is known as a *negative ion*, or, since it is attracted to the anode, as an *anion*. Certain simple salts

when dissolved in water separate into ions, when they are known as *electrolytes*, and, as Faraday showed early in the nineteenth century, can be separated by the passage of an electric current, a process known as *electrolysis*. The passage of a high potential electric charge or of rapidly moving atomic particles through a gas will knock off electrons, causing the gas to become ionized and to become an electrical conductor. Certain resins have the power of attracting different ions and thus bringing about their separation. This process is to-day largely used commercially, but it has also its medical application (ion-exchange resins).

Isotopes

It had long been known that certain elements showed varieties which, although identical in every chemical and in most physical characters, had different atomic weights: for example, when uranium breaks down completely it is converted into lead of atomic weight 206. The actinium series in breaking down ends as lead with the atomic weight 207, and that derived from thorium has an atomic weight of 208, but all three are lead in every sense of the word. To these elements Soddy in 1913 gave the name *isotopes*. The differences in the

FIG. 3.—Diagrams of two isotopes of carbon, C^{12} and C^{14} .

atomic weights are due to the number of neutrons, and, since they have no charge, the number of electrons and hence the chemical characters are unchanged. Mass spectrography has shown that the majority of elements have isotopes (Fig. 3), and the fact that many atomic weights are not whole numbers—for example, magnesium 24.32, chlorine 35.457, tin 118.70—is known to be because they are mixtures of isotopes with different atomic weights. The nature of the isotope is usually shown by an index number giving its atomic weight—for example, C^{11} , C^{12} , C^{13} of carbon, or P^{31} , P^{32} of phosphorus. Sometimes the atomic number is also indicated—for example, $^{12}_6C$, $^{13}_6C$, or $^{31}_{15}P$, $^{32}_{15}P$. One isotope of hydrogen is of double the atomic weight owing to the presence of a neutron in the nucleus: it is known as deuterium, and its nucleus as a *deuteron*; a still heavier isotope is tritium, with two neutrons and an atomic weight of three.

What Prevents Spontaneous Atomic Explosion?

Physicists had long been puzzled over why the protons in the nucleus did not repel one another and the atom spontaneously explode. In 1934 Yukawa suggested that negatively charged particles would be found within the nucleus. They have since been discovered and are known as μ mesons. They have a unit negative charge like an electron and a mass between that of an electron and a proton. There are probably at least four varieties having from 200 to 1,000 times the weight of an electron. They are produced naturally by cosmic rays in the upper air,

are capable of penetrating 20 ft. (6 m.) of lead, and have only a short existence. They were believed to bind together the protons by a reaction known as exchange attraction, which occurs only in minute structures of atomic dimensions, so that if once the protons are separated by a short distance they repel one another with great force and the atom is disrupted. Later work (*vide* Sir John Cockcroft, *Nature*, 1951, 168, 1060) has shown that the Yukawa hypothesis is no longer tenable, as the μ mesons discovered by Anderson and Neddermeyer scarcely interact with nuclei, and in 1947 Powell discovered the π meson or pion, which may be positively charged, negatively charged, or neutral, the positively charged meson π^+ having a very short life (10^{-8} of a second) and changing into a μ meson. They have a mass about 275 times that of an electron. There is also evidence that there are even other and heavier mesons.

In 1932 Anderson and Blackett discovered yet another particle which is produced when cosmic rays are stopped by collision with a metal plate. These particles were found to be positively charged and were called *positrons*. They have since been obtained by bombarding aluminium with α rays, or lead with γ rays (see definitions below). They have a mass approximately that of an electron. They are probably formed by the nucleus absorbing the energy of a γ ray and converting it into a positron and an electron. The life of a positron is very short—about 10^{-9} seconds in the air. It then disappears completely, probably by combining with another electron and being entirely converted into energy as a γ ray, thus supporting Einstein's contention that energy and matter are interchangeable.

An atom therefore consists of a compact nucleus in which is centred by far the greater weight and which contains positively charged protons and positrons, negatively charged mesons, and neutrons with no charge. The number of protons determines the nature of the element, and the combined weight of the protons and neutrons gives the atomic weight. Surrounding the nucleus at relatively great distances are a number of electrons, corresponding to the number of protons, moving in various planes in definitely placed elliptical shells around the nucleus. They are concerned with chemical changes only. The smaller atoms are estimated to be about 2×10^{-8} to 6×10^{-8} of a centimetre in diameter and the electron to be only 10^{-5} of the diameter of the atom of hydrogen in its normal state.

Radioactivity

In 1896, a year after Roentgen discovered x rays, Becquerel showed that a uranium salt gave off rays capable of affecting photographic plates. Further investigation has shown that these rays are of three sorts.

α Rays.—These are composed of the nuclei of helium—that is, of packets of two protons and two neutrons moving at great speed (2×10^9 cm. a second). They therefore contain two unit-positive charges but are deflected with difficulty. Because of their small mass they have but little penetrating power, but because of their high speed they tend to break up atoms in their path, leaving free ions and so ionizing the air.

β Rays.—These are electrons moving at prodigious speeds. They are easily deflected and are 100 times more penetrating than α rays.

γ Rays.—These are identical with x rays, and consist of electromagnetic waves with no mass. They have very short wavelengths, about 0.005 A, are extremely penetrating, and cause slight ionization, photographic, and fluorescent effects.

In searching for the source of these rays, the two Curies in 1898 extracted from pitchblende a number of radioactive substances, including radium, the most active of all. In 1902 Lord Rutherford showed that the emission of the rays was due to atomic disintegration, and that the seat of instability was the nucleus. It is the heavier atoms which show radioactivity, and it is present in all atoms with a higher atomic weight than bismuth. It would seem that nuclei containing large numbers of protons and neutrons are unstable. It is possible, therefore, that in the past there were elements of a higher atomic weight than those now known, but that they have completely degenerated.

Transmutation of Elements

In 1919 Rutherford exposed nitrogen to radium so that it was bombarded with α rays, and was able to convert some of the nitrogen into O^{17} , an isotope of oxygen, thus:

In 1932 Cockcroft and Walton were able to accelerate protons by very high voltages, and by their use were able to convert an isotope of lithium, Li^7 , into two α particles, thus:

By bombarding the isotope Li^6 with deuterons, a similar result was obtained:

but if Li^7 was bombarded with deuterons a neutron was also produced. It is reactions of this sort which are the basis of the hydrogen bomb. To-day large numbers of rapidly moving charged particles may be directed upon elements by the use of the cyclotron. This is a large and powerful machine consisting essentially of two electrodes for producing ions, and a high-frequency oscillating electromagnetic field for repeatedly accelerating the ions as they travel in an ever-widening flat spiral. After about a hundred revolutions the ions are drawn off their spiral track into a bombardment chamber, where they may be used to produce neutrons or electrically charged particles such as protons, mesons, and, to a lesser degree, electrons. The neutrons can be used to make radioactive isotopes artificially, but this is usually now done in an atomic pile (see below).

By these means, elements may be bombarded with protons, α particles, deuterons, or neutrons. When protons meet other nuclei the result will depend upon their energy resonance. If less than that of the nucleus they will bound off. If of similar resonance they will enter it and form a new element of greater atomic weight. In this way two new elements—neptunium and plutonium, both of atomic weight 239 but with atomic numbers of 93 and 94—have been formed. If of a higher resonance they will split up the nucleus, often with explosive force. Neutrons have similar effects, but if they enter the nucleus they form not new elements but isotopes, many of which are unstable and radioactive.

The Chain Reaction

The explosive effect of these bombardments may occur naturally, as in U^{235} . Here protons and neutrons driven off from one atom will explode the next atom, the so-called chain reaction. If the mass is sufficiently large (critical mass) to prevent the escape of the protons and neutrons the whole mass will explode with enormous violence and heat, as in the atomic bomb. The chain

reaction may be controlled, and the enormous energy utilized, by slowing down the protons and neutrons by passing them through material of low atomic weight, such as deuterium or graphite. This is the basis of the *atomic pile*.

Isotopes in Medicine

The isotopes prepared by these methods now number over 700, and, since many are radioactive, they are being used to an increasing degree in medicine. They are used either for treatment, by giving a radioactive element which may have a therapeutic effect, as upon a cancer with an affinity for the element—for example, the isotopes of iodine, I^{128} or I^{131} , for the treatment of some varieties of carcinoma of the thyroid—or to trace the metabolism of an element (or a compound containing it) in the body—for example, phosphorus by its isotope P^{32} . Their use may, however, be associated with danger, for, if their breaking-down period is long, the radioactivity may be carcinogenic rather than curative. Fortunately in the artificial isotopes the period to half-way disintegration (half-life) is usually short; according

FIG. 4.—Diagram of a Geiger counter.

to Wormald, for the isotopes of iodine and phosphorus it is 8 and 13 days and 14.3 days respectively. This is in marked contrast with uranium, for which it is about 500 million years.

The position in which the isotope is concentrated can be readily determined, if it is radioactive, by the use of the *Geiger counter* (Fig. 4). This consists essentially of a glass tube down the centre of which passes a fine tantalum wire. The centre of the wire is surrounded by a cylinder of thin copper, and the tube contains gas under a reduced pressure, usually argon and ethyl alcohol. The wire is positively charged and the cylinder negatively charged, with a maintained difference of potential such that a discharge will just not pass between them. If a fast-moving electron, proton, α particle, or even a photon of light passes between them, the gas is ionized and a momentary current will pass between the tantalum and copper. This minute rush of current is amplified by radio methods and emitted by a loudspeaker so that it is audible to a number of people standing around. The number of cracks or thumps may be counted or automatically recorded so that the radioactivity can be estimated. Saunders states that the instrument is so delicate that a match lit on the other side of the room gives a rush of such cracks.

"Music while you work" was one of the successful British ideas of wartime which was exported across the Atlantic. In one New York insurance company, employing thousands of clerks and machine operators, efficiency has been raised 19% since the provision of music over the hum of routine work. In department stores suitable music will make the customer linger at the cosmetic or hosiery counter and make a further purchase. And now dentists are offering patients music by headphone to distract them from the noise and vibration of the drill, while those undergoing plastic surgery under local analgesia are also thus diverted.

Reports of Societies

CORTISONE AND A.C.T.H. IN GENERAL PRACTICE

A meeting of the General Practice Section of the Royal Society of Medicine was held at No. 1, Wimpole Street, on December 19, 1951.

Dr. A. TALBOT ROGERS, who opened the discussion on "The Possible Future Use of Cortisone and A.C.T.H. in General Practice," described himself as a general practitioner with a special interest in rheumatic diseases. Being in charge of the physical medicine department of his local hospital, he had had the advantage of co-operating with Dr. E. N. Allott in his work on cortisone and A.C.T.H. (adrenocorticotrophic hormone) at Lewisham. He wanted to emphasize the words *possible* and *future* in the title of the discussion because he felt that there was not much hope that these substances would become widely available in the near future or that the cost of maintaining a rheumatic patient on either of them would soon be diminished from the present level of £10 to £20 a month. Because of this it was right that the supply of cortisone and A.C.T.H. should be limited to research centres; yet general practitioners should know about this type of treatment, as they would be responsible for sending the right type of patient for treatment and for helping to maintain treatment after discharge.

In a brief review of the scientific background of the subject Dr. Talbot Rogers recalled that the pituitary gland was under nervous control and when stimulated by bodily stress released varying amounts of A.C.T.H.; this in turn stimulated the adrenal cortex to produce its many hormones affecting salt and water metabolism, sugar and glycogen, protein metabolism and androgenic activity, in addition to cortisone. The diseases in which A.C.T.H. and cortisone could be used included rheumatoid arthritis and Still's disease: in these two diseases they offered the first really spectacular advance in therapy. In spondylitis deformans he had not experienced such a well-marked response, and, although this had been claimed by some American workers, he felt that this discrepancy was due to disagreement on what constituted spondylitis deformans. Of their activity in rheumatic fever he gave a guarded account, saying that, although they abolished symptoms and seemed to protect the heart, their effect was not yet certain. However, this was an excellent short-term use for cortisone, because the disease process eventually died out and indefinite maintenance doses were not necessary. Other diseases that benefited were acute lupus erythematosus, status asthmaticus, some cases of haemolytic anaemia, periarteritis nodosa, many eye conditions, exfoliative dermatitis, pemphigus, severe burns, and ulcerative colitis.

The Dangers

It was important that the general practitioner should know the complications that might arise from treatment with cortisone or A.C.T.H. The greatest danger with both was that they delayed healing, a serious matter with peptic ulcer or with active or recent pulmonary tuberculosis; septic conditions were masked and tended to spread silently without the usual pain and reddening—they could be detected only by increased swelling and a general rise of temperature. Because A.C.T.H. produced a general secretion of cortical hormones it was liable to produce disturbances in salt and water metabolism, with rise of blood pressure which was particularly dangerous in patients with heart disease. Diabetes could be precipitated and diverse psychotic changes could result—euphoria proceeding to mania or depression and insomnia. Cushing's syndrome was also liable to appear, with the characteristic "moon-face," hirsutism, amenorrhoea, acne, ecchymoses, flattening of the neck, and humping of the back and abdomen with deposits of fat.