SCIENCE

Vol. 103, No. 2671 Friday, March 8, 1946

The Neutron, the Intermediate or Compound Nucleus, and the Atomic Bomb[1]

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THE ATOMIC BOMB IS A MONSTER reared by war. A fact revealed by history is that the offense grows much more rapidly in power than the defense in its ability to cope with it. Indeed, this seems to be a natural law, since warfare was formerly restricted to the surface of the earth and was, therefore, two-dimensional. Now, it is rapidly rising above those limits of the atmosphere suitable to the life of man and is expanding in the third dimension. The offense can choose any portion of space thus made available, but it is impossible for the defense to cover every location in this space. Concomitant with this conquest of space is one of time, since jet propulsion makes it possible to exceed the velocity of sound.

Now, in addition to the conversion of space into the slave of war, nuclear energy is also enslaved. The danger here is one of mass and space. A few pounds of uranium 235 or of plutonium 239 carried in small packages may be put into such a form as to destroy a whole city, being set off by a time clock. The apparatus necessary to detonate the material would be much larger.

In the opinion of the writer, grave errors in connection with the bomb have imperiled the international situation. These need not be cited, but, the benefits to mankind of the energy made available are small compared to the uncertainty thereby introduced into human life. Man has not as yet attained the state of moral and intellectual development to make it safe to have such a weapon. Therefore, (1) no more bombs should be produced; (2) any uranium 235 or plutonium 239 now available should be distributed to universities or hospitals for scientific or medical work only; (3) a world association of scientists should be formed to oppose work on the bomb; (4) the United States should use its utmost influence to establish at once a temporary world organization, to be made permanent later, to suppress the use of the bomb.

Presumably this would require some type of World Government to control war. This might be associated with the United Nations Organization.

What has been written thus far refers to the bomb. However, nothing can stop progress in the use of the energy of fission for the development of power, but this should be under the control of the World Government to prevent its degeneration into the purposes of war. On account of the injurious effects of the radiations given off, the shielding essential to protect life necessitates large installations if human beings are near by. Thus, while ships might make direct use of this power, it is not suitable for automobiles.

While no mention of thorium is made in the paper which follows, it seems not unlikely that this element will be utilized more than any other. If this is done, it is probable that one method will be to convert this into uranium. To thorium of mass 232 a neutron would be added, thus forming thorium 233, which would then change into element 91 by loss of an electron and into element 92 (uranium) by the loss of another electron. Presumably, this isotope of uranium of mass 233 would undergo fission. Since thorium is more abundant than uranium 238, there is no lack of an abundant supply. If this comes true, uranium 233 and plutonium 239 would become the sources of industrial energy. Uranium 235 is less

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[1] This article had its origin in an attempt to answer many questions which arose after the first use of the atomic bomb and the publication of the Official Report written by H. D. Smyth. The only direct connection of the writer with this work was the building of the Chicago cyclotron, which was used in the Metallurgical Project at the university. An attempt has been made, without too much success, to avoid as much as possible topics discussed in the Official Report. Obviously, however, many of the topics considered there must be discussed here, if what is presented is made at all intelligible. For fifteen years, from 1913 to 1928, the writer and his collaborators were the only ones in America engaged in work on the structure of the nucleus of the atom. This involved the earliest use of the Wilson Cloud Chamber for the photography of what is commonly called nuclear disintegration. This work gave rise to an idea which may be expressed as follows: In what had been earlier considered as a direct disintegration of the atom the actual primary process is not the disintegration but the synthesis of an activated nucleus which disintegrates later, although after an extremely short life. It is the relations of this idea which are discussed in this article.

suitable on account of the necessity of at least partially separating it from uranium 238.

I. INTRODUCTION: DISINTEGRATIVE SYNTHESIS OF ATOMIC NUCLEI

There are certain relations discovered long ago and discussed here which are involved in the action of what has been designated as the atomic bomb, or, more properly, the nuclear bomb. Some of these may make it more simple to understand what occurs in the release of the extremely great amount of energy, as compared with the mass involved, when the bomb explodes.

The nucleus of the atom is an extremely minute body which may consist of only one particle, or of as many as 239 particles, very tightly bound together by nuclear forces. These primary particles are designated as the proton (nucleus of the hydrogen atom), with a mass of 1.00758 and unit positive charge of electricity, and the neutron, of mass 1.00893 without an electrical charge. The diameter of a single proton or neutron in any nucleus is about 3×10^{-13} cm.

Developments based upon the discovery of radioactivity by Becquerel in 1896 and the later discovery and separation of radium by Mme. Curie showed that the heaviest or radioactive atoms may disintegrate naturally to give off either negative electrons, which may even approach the velocity of light, or alpha particles, proved by Rutherford and Royds in 1909 to give gaseous helium when they are collected. Later it was shown that an alpha particle, which has a positive charge of 2, due to the two protons which it contains, is actually the nucleus of the helium atom. Each alpha particle contains two protons which would repel each other if they were not bound together by two neutrons. These alpha particles may have velocities as high as, or even higher than, 12,000 miles per second.

In 1919 Rutherford in a very remarkable and extremely simple experiment showed that he was able to obtain the disintegration of one of the lightest atoms, which he assumed to be that of nitrogen. This led to the idea that atomic nuclei may be disintegrated artificially, since the nuclei of the nitrogen atom which he used seemed to be split into two particles, one a carbon nucleus and the other a proton, by a mere, though excessively energetic, blow of a fast alpha particle.

Soon after this the writer came to the conclusion that the simplest method which could be used to determine whether or not a nucleus of the nitrogen atom is split in this way would be to use the Cloud Chamber of C. T. R. Wilson, a most remarkable apparatus which makes it possible to photograph the tracks of atoms as described later. From photographs obtained in this way the writer came to the conclusion that the primary action is not a disintegration but a synthesis of new nucleus, in the formation of which the nucleus used as a projectile is always captured by that used as a target (Fig. 1). The compound nucleus thus formed disintegrates later, after an *extremely* short life. Nevertheless, the life period is sufficient to make the disintegration of this nucleus, which is always in an excited state, an event entirely independent of its synthesis, since enough time elapses to distribute the energy introduced with the projectile through the whole nuclear system. Thus, the disintegration of this nucleus does not depend upon what nuclei have joined together to form it, *but only upon the state in which the excited nucleus exists.*

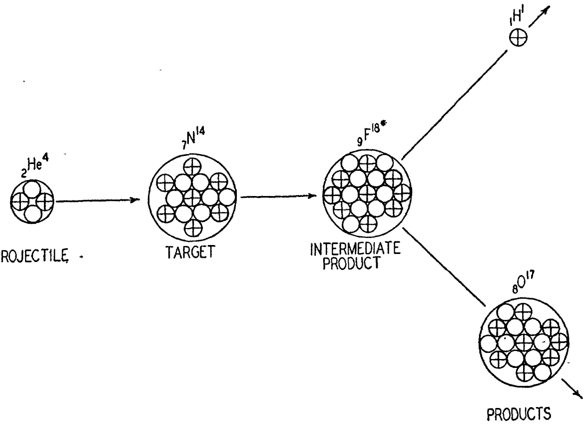

FIG. 1. Formation of oxygen 17 and hydrogen 1 by the disintegration of fluorine 18, the intermediate nucleus formed by the impact of helium 4 with nitrogen 14. Open circles = neutrons. Circles with plus signs = protons. At higher energies the excited fluorine nucleus disintegrates in two ways: (1) that given in the diagram, and (2) to give a neutron and positive electron in place of a proton (= hydrogen 1).

This greatly simplifies the consideration of nuclear transformations, since, as illustrated later, the same composition of the compound nucleus and essentially the same activated state may be obtained by the use of different projectiles. For example, carbon 12 (C^{12}) can be formed by the impact of hydrogen 1 (H^1) upon boron 11 (B^{11}), or of hydrogen 2 (H^2) upon boron 10 (B^{10}), but the excited carbon nucleus thus formed gives, in either case, as the final result of its disintegration, three alpha particles, *i.e.* three helium atoms. Thus, it is not the disintegration which is artificial, since this is entirely spontaneous, but it is the synthesis of the compound nucleus which may be brought about by artificial means.

While the writer's theory of the occurrence of nuclear reactions by the formation of an intermediate excited nucleus was accepted by a very few experimental physicists, it met with very strong opposition on the part of nuclear theorists during the years 1926–36, the period in which experimental evidence in favor of these ideas was being collected. This opposition was due to the fact that, whereas the nucleus consists of an aggregation of protons and neutrons bound together by an extremely strong interaction, giving a density so great that it is incomprehensible to ordinary human beings, theoretical physicists of the period treated it upon the basis of the Hartree formula, which in itself assumes a loosely bound aggregation (the free particle model of the nucleus). For example, Bethe (*1*), who favored the idea that the interaction between the particles in a nucleus is small, in a private conference in June 1936, stated that the existence of the intermediate nucleus, as demanded by the theory of the writer, is impossible. Reviews by other theoretical physicists in 1934 stated that the law of conservation of energy would have to fall before such an intermediate nucleus could exist. These ideas were based upon the fact that at that time nuclear physicists assumed the existence of a very much smaller number of nuclear energy levels than were considered by the writer to be present.

Evidence in favor of the theory of the writer is considered in more detail later, but here it may be mentioned that the reactions which occur in the atomic bomb proceed according to the theory. Thus, either uranium 235 or plutonium 239 is an entirely innocuous material, since the atoms of these substances are quite stable, having the type of stability found in radioactive atoms of moderately long life. It is not these which disintegrate by fission to give the excessively high energy of the bomb, but in each case it is the intermediate, or compound, nucleus uranium 236 or plutonium 240, which disintegrates by fission to give the energy. These relations are considered in more detail in a later section.

II. ENERGY OF THE BOMB

The effectiveness of the bomb is due to the fact that it develops an amount of energy which is enormous in comparison with the mass involved, in an exceedingly short space of time (of the order of a millionth of a second). This development of energy is accomplished by bringing about a nuclear reaction. A chemical reaction, such as the burning of coal or the explosion of an unstable compound, known as an explosive, may develop a large amount of energy. In general, a nuclear reaction which involves the same amount of mass develops from one to ten million times as much.

In 1897 Kaufman found that particles (in his experiments, negative electrons) have a higher mass when their velocity is high than when they are at rest. Eight years later Einstein developed a remarkably simple equation which the writer likes to consider from the following point of view. We may write an equation in which E represents energy in any form and m, mass in any form, as follows:

$$E = m$$

This equation may be said to be valid if both E and m are given in ergs, or both in grams, but in the use of this equation E cannot be expressed in ergs and m in grams. However, this can be done if the equation is written:

$$E = mc^2$$

which is Einstein's equation. The remarkable achievement of Einstein was that he showed that the transformation in units and dimensions involves a natural constant,

$$c^2 = (3 \times 10^{10})^2$$

which is the square of the velocity of light.

Others may prefer to write the equation as

$$-\Delta m \cdot c^2 = \Delta E.$$

This indicates that a decrease of mass of Δ m grams involves an increase in energy of Δ E ergs. That the energy developed in a nuclear reaction may be excessively large was shown in 1915 by Harkins and Wilson (*4*), who had been engaged in a consideration of the heat of the sun and stars. They found by the use of Einstein's equation that if 4 hydrogen atoms are by any series of processes converted into one atom of helium the energy liberated between the initial and final states is extremely large. Thus, a single pound of hydrogen by this "nuclear combustion" gives as much heat as the burning of *ten thousand tons*, or ten million pounds of coal. Here, the nuclear reaction gives ten million times the energy of the chemical reaction. Although later certain noted physicists considered that the reaction in which helium is formed occurs almost instantaneously, it was obvious that four exceedingly small protons could not meet and, in addition, lose two positive charges (the proton has a positive charge of one, and the helium nucleus or α-particle a positive charge of two) in a sufficiently minute time to give such a synthesis. Thus, the reaction must of necessity occur in steps, but a consideration of these steps is not involved in the calculation of the energy.

The mass of the hydrogen atom nucleus (proton) is 1.00758 and of the helium atom 4.0039. The mass of the helium nucleus is $4.0039 - 2 \times (0.000549$ mass of electron$) = 4.0028$. Now, four protons have a mass of $4 \times 1.00758 = 4.0303$, so $4.0303 - 4.0028 = 0.0275$ is the loss of mass. Consider these masses in grams; then the decrease of mass is -0.0275 g and $E = 0.0275 \times 9 \times 10^{20} = 2.475 \times 10^{19}$ ergs for the formation of 4.0039 g of helium from 4.0325 g of hydrogen (these masses now include the masses of the electrons outside the nucleus). This is 6.138×10^{18} ergs per gram = 1.467×10^{11} calories per gram = 6.654×10^{13} calories per pound, or 25.6 million electron volts.

The calculation of the energy developed in the fission of uranium 236 or of plutonium 240 would be just as simple as that for the energy of synthesis of helium given above, if the masses of all the final products of the fission were known. The problem is discussed later, but the energy given by one pound of the uranium isotope is equivalent to that produced in the burning of (about) 1,300 tons of coal (about 200 million electron volts). Thus, the *disintegration* of this heavy nucleus gives less than one-sixth as much energy per unit mass as the synthesis of helium.

In 1893 and later, Landolt, in a classical experiment which involved a long series of very accurate weighings, endeavored to determine the loss of mass in a chemical reaction which evolves heat. In connection with the calculations of nuclear energy changes, Harkins and Wilson found, by the use of Einstein's equation, that in the formation of 18 grams of water from hydrogen and oxygen the energy evolved is equivalent to only 3 *billionths of a gram,* which explains Landolt's failure to detect the loss of mass.

III. ELECTRIC CHARGE, THE PRINCIPLE OF ELECTRICAL NEUTRALITY AND ATOMS

One of the most fundamental laws of nature is that the electric charge of any "primary" particle may have a positive or negative sign, but the magnitude of the unit electric charge is invariable, *i.e.* the same (1.60 coulombs) for any single particle.

Furthermore, in any material body that we know, the number of negative charges is extremely closely equal to the number of positive charges. The departure of the earth as a whole from this principle of electrical neutrality is excessively small. Only extremely small bodies exhibit any considerable percentage variation from this principle. By definition any *atom* is electrically neutral: if it contains more negative than positive charges, it is designated as a negative ion, or with more positive than negative, a positive ion.

The nucleus of the atom, when it is free, as it may be at exceptionally high velocities, exhibits the greatest departure from electrical neutrality, since, according to our present philosophy, every charged particle which it contains is positive, *i.e.* a proton. A nucleus which is relatively "stable" may contain from one proton (hydrogen atom) to 92 protons (uranium atom) or even 94, since plutonium is moderately stable. The electrically neutral atom must then contain as many negatively charged particles (electrons) as the *number* of protons in the nucleus. This number (Z) is designated as the *atomic number,* though actually it is the *element number* in the periodic table of Mendelejeff.

The electron, or electrons, may be considered to move around the nucleus, where they form a cloud which is excessively tenuous, when considered in comparison with the high density of the nucleus. The mass of the proton is 1.672×10^{-24} grams. If this is contained in the 1.4×10^{-38} cc. considered as its volume, the density is 1.2×10^{14} grams or 130 million tons per cc. Thus, the whole earth would have a diameter of only 460 meters, or less than a third of a mile (0.286 miles) if its *whole mass* were present as protons and neutrons packed as they are in the nucleus of an atom. The presence of electrons, however, reduces the density from 1.2×10^{14} g per cc. to that of the earth (5.522 g per cc.) which is 20 million million times smaller.[2]

IV. ELEMENTS AND ISOTOPES

According to Section III, the number of electrons in an atom is equal to the number of protons in its nucleus. It was shown by Mendelejeff in 1868 that the chemical properties of the elements may be expressed as a periodic function of the atomic weight. In 1896, Rydberg and, later, van der Broek and, by direct experimental evidence, Moseley indicated that the relationship becomes more exact if the atomic number is considered instead of the atomic weight. According to more recent theory, the atomic number gives the positive charge on the nucleus, which is equal to the number of protons which it contains.

The atomic numbers of the elements thus far found in nature vary from 1 to 94 so it is often said that there are 94 elements. Of these, however, the nuclei with 61, 85, and 87 protons have not as yet been discovered in any known material. However, they have been produced by artificial means. It should be considered that there is also another element of zero atomic number which consists of neutrons. These carry no charge and thus its atoms contain no electrons and have no ordinary chemical properties. Elements 93 and 94, neptunium and plutonium, have now been produced artificially, and obviously it is possible with sufficient amounts of plutonium to push the artificially produced elements to still higher atomic numbers. When the chemistry and the spectrum of any of these becomes well determined, it is possible that some of them may be found to exist in nature.

Until the year 1907 it was considered that each known element is actually elementary, but in this year

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[2] The size of the nucleus is obtained by calculations made on the basis of the scattering produced in elastic collisions between nuclei and exhibits some variation with the velocities of the particles at the time of the collision.

McCoy and Ross, of the Department of Chemistry of the University of Chicago, made the remarkable discovery that there exist in thorium at least two varieties of this element. These have highly different stabilities, but the same chemical properties, and are now known as isotopes (*5*). The announcement of this discovery was made in the following simple statement: "In fact, it now appears doubtful whether it is possible by chemical treatment to separate any radiothorium from thorium." Both of these atomic species have the atomic number 90 and therefore belong to the same chemical element, although the atomic weights are 232 for thorium and 228 for radiothorium. It is now known that the element thorium consists of 6 isotopes. The known elements consist of from 1 to 10 isotopes, and the formation of these gives the existence of about 300 types of atoms (atomic species) in addition to the radioactive species of high atomic mass.

V. SEPARATION OF ISOTOPES

The separation of the isotopes of uranium of atomic masses 235 and 238 has been one of the most important problems in the production of the atom bomb. For some time after the discovery of isotopes it was considered that isotopes were inseparable. However, in 1919, Harkins and Broecker made the first separation of isotopes which was proved to be obtained. They obtained a partial separation of chlorine of atomic weight 35.46 into two isotopes of weights 35 and 37. A similar separation had been made in 1916 and early in 1917 by Harkins and Turner, but the war made it impossible to determine the atomic weights at that time.

The earliest detection (and determination of the mass) of isotopes by electrical means was entirely accidental. In 1913, J. J. Thomson, by deflection experiments on canal (positive) rays, found that there seemed to be two kinds, instead of one, of neon in a tube which contained this element. Although this is correct, the experiment did not appear to be entirely conclusive to Thomson or his co-workers, as indicated by a letter from the Cavendish Laboratory in 1919. In this year, Aston began an extensive series of determinations of the masses of isotopes in an improved apparatus commonly known as a mass spectrograph, and in a very long series of experiments determined the masses of a very large number of atomic species.

In the experiments of Harkins large quantities of dry hydrogen chloride gas were passed through a long series of porous porcelain tubes (churchwarden pipe stems obtained in Scotland). The ideal diffusion membrane is very thin, to reduce the time in passing through it, and has very fine pores. Later, Harkins and Mulliken found that sheets of filter paper are more efficient than the pipe stems, but the paper membrane could not have been used with hydrogen chloride.

The theory of the separation of gases by diffusion was given in 1896 by Lord Rayleigh and much more completely in 1922 by Mulliken and Harkins. The diffusion method has been used in the separation of the isotopes of uranium. Uranium, a metal which consists of 0.006 per cent 234, 0.7 per cent 235, and 99.3 per cent 238, was separated by the diffusion of its hexafluoride, which is a gas. Unfortunately, the change to the fluoride increases the molecular weights to 348, 349, and 352, but only the two latter need to be considered. Since the lighter molecules move faster than the heavier, more of the former pass through a porous barrier. The relationship for equal kinetic energies ($\frac{1}{2}$ m v^2) of the molecules is:

$$\tfrac{1}{2} m_1 v_1^2 = \tfrac{1}{2} m_2 v_2^2$$

or

$$\frac{v_1^2}{v_2^2} = \frac{m_2}{m_1}$$

so

$$\frac{v_1}{v_2} = \sqrt{\frac{m_2}{m_1}} = \beta$$

which is the enrichment factor, so, for uranium hexafluoride

$$\beta = \sqrt{352/349} = 1.0043.$$

Thus, if a very small amount of the uranium compound passes through a very fine porous wall, it contains, after the diffusion, under ideal conditions, 1.0043 times more uranium 235 than before, or 0.70301 per cent, if the initial percentage is 0.7. It is obvious that the separation is initially made much more difficult by the small percentage of uranium 235 present. The theory of the *increase* in the mean molecular weight (Δ M) of the heavy fraction is simpler, and is expressed by

$$\Delta M \alpha \frac{(M_1 - M_2)^2 x_1 x_2}{M}$$

Here, $A = (M_1 - M_2)^2 = 3^2 = 9$, which is a somewhat favorable factor for the separation of isotopes. However, M, the mean molecular weight, is about $352 = B$, which is very unfavorable, and x_1x_2, the product of the fractions present, $0.007 \times 0.993 = 0.007 = C$, is also extremely unfavorable. Thus, the molecules must pass through a very large number of porous barriers to obtain any considerable separation. When hydrogen chloride is diffused, $A = 2^2 = 4$, $B = 36.46$, and $C = 0.23 \times 0.77 = 0.177$. Here, for hydrogen chloride, only A is less favorable, while B and C are very much more favorable than with uranium as its hexafluoride.

When the percentage of uranium 235 in the light fraction becomes sufficiently high, the magnetic separation becomes more efficient than diffusion. The electromagnetic method is discussed somewhat fully in the official report and need not be considered here.

VI. THE NEUTRON

The neutron was discovered in 1932 by Chadwick. This discovery illustrates the advantage of having an idea that a particle exists before attempting to discover it. That a neutron exists was assumed by both Rutherford and Harkins independently early in 1920. This atom was assumed to have a zero charge and therefore an atomic number of zero. Its mass was assumed to be unity or, more definitely, close to that of the hydrogen atom. It was predicted that on account of its zero charge it would pass with practically no resistance through the outer part of atoms, but that it could collide with an atomic nucleus or be captured by it. A bullet may be shot from the muzzle of a rifle at a relatively small velocity, yet it may travel through air for one or two miles. The bullet can go this far, because it pushes the air away from it in its flight and does not pass through the atoms in the air. An alpha particle (a helium nucleus) may have an initial velocity as high as 12,000 miles a second. It might therefore be supposed that this particle would travel in air many thousand times farther than a rifle bullet. However, its entire range is only a few inches. This is because the alpha particle does not push the atom in the air aside, but its velocity is so great that there is no time for this to occur. Therefore, it has to go directly through the cloud of electrons in the outer part of each atom which it traverses. On account of the fact that it carries with it a positive charge of 2 or of 1 (after it has picked up a single electron) it attracts these electrons and pulls many of them out of the atoms to which they belong. This takes energy and uses up the kinetic energy of the alpha particle very rapidly. An atom or molecule from which one or more electrons has been taken is a positive ion, and one to which electrons have been added is a negative ion. Thus, the alpha particle in its passage through air leaves a narrow line of positive and negative ions, and this line may be considered as the track of the alpha particle. A fast proton gives a similar track which does not contain so many ions, since the proton has a charge of 1, which is less than that of the alpha particle. Other atoms of the higher charge leave more dense tracks. Any of these may be made visible if the moist air or other gas through which they have passed is cooled by a sudden expansion and is simultaneously illuminated by a brilliant light. This procedure is usually carried out in a cylindrical chamber, which is a part of the Cloud Track apparatus of C. T. R. Wilson.

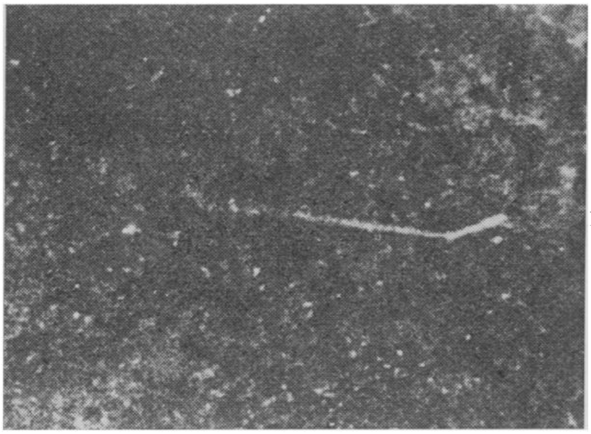

FIG. 2. First neutron found in America. Disintegration of nitrogen 15, the intermediate nucleus formed from nitrogen 14, by the impact of a neutron.

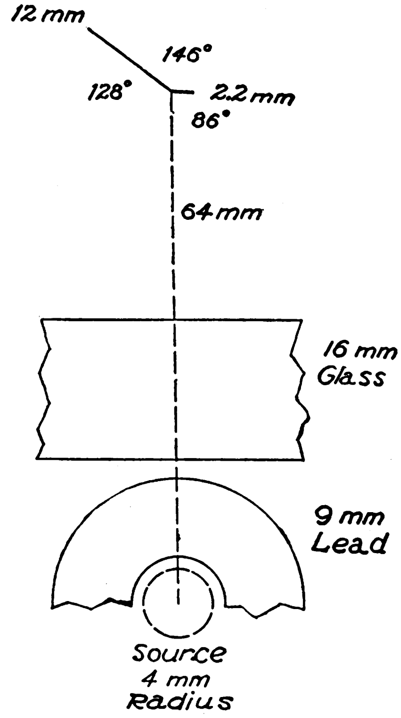

FIG. 3. Diagram of the nuclear transformation shown in Fig. 2. The neutron came from the action of a helium nucleus on beryllium in the source 4.4 mm. in radius. This passed through 9 mm. of lead, 16 mm. of glass, and, after a total range through solids and nitrogen gas of 64 mm., struck and united with a nitrogen nucleus of mass 14. The intermediate nucleus of mass 15 very quickly disintegrated into a helium nucleus of 12-mm. range and a boron 11 nucleus of 2.2-mm. range. The passage of the neutron through 9 mm. of lead and 18 mm. of glass, including the wall of the glass tube, illustrates the penetrating ability of a neutron.

Neutrons were obtained in 1930 by Bothe and Becker, when either beryllium or lithium was bombarded by alpha particles, and by Irene Curie and Joliot in 1932. Since neither of these pairs of investigators seemed to be aware that neutrons might exist, they assumed that very powerful gamma rays were involved and thus failed to discover their existence. Chadwick, however, believed uncharged heavy particles were involved and this was confirmed in 1932 by Feather, who used the Wilson Cloud Track apparatus. This was followed immediately by an even more extensive investigation by Harkins, Gans, and Newson (later also Kamen), who obtained results similar to those of Feather. Since the neutrons given off, for example, when beryllium is bombarded, do not ionize the gas through which they pass, the track is not visible in the Wilson Chamber. How, then, can the neutrons be observed? This is accomplished by means of the tracks of other nuclei which are produced by (1) elastic collections of the neutron with the nucleus; (2) inelastic collections in which the neutron is captured by the nucleus which it strikes. If, for example, this happens to be a nitrogen nucleus, a short track of a boron nucleus and a much longer track of a helium nucleus (alpha particle) are observed to originate at a single point.

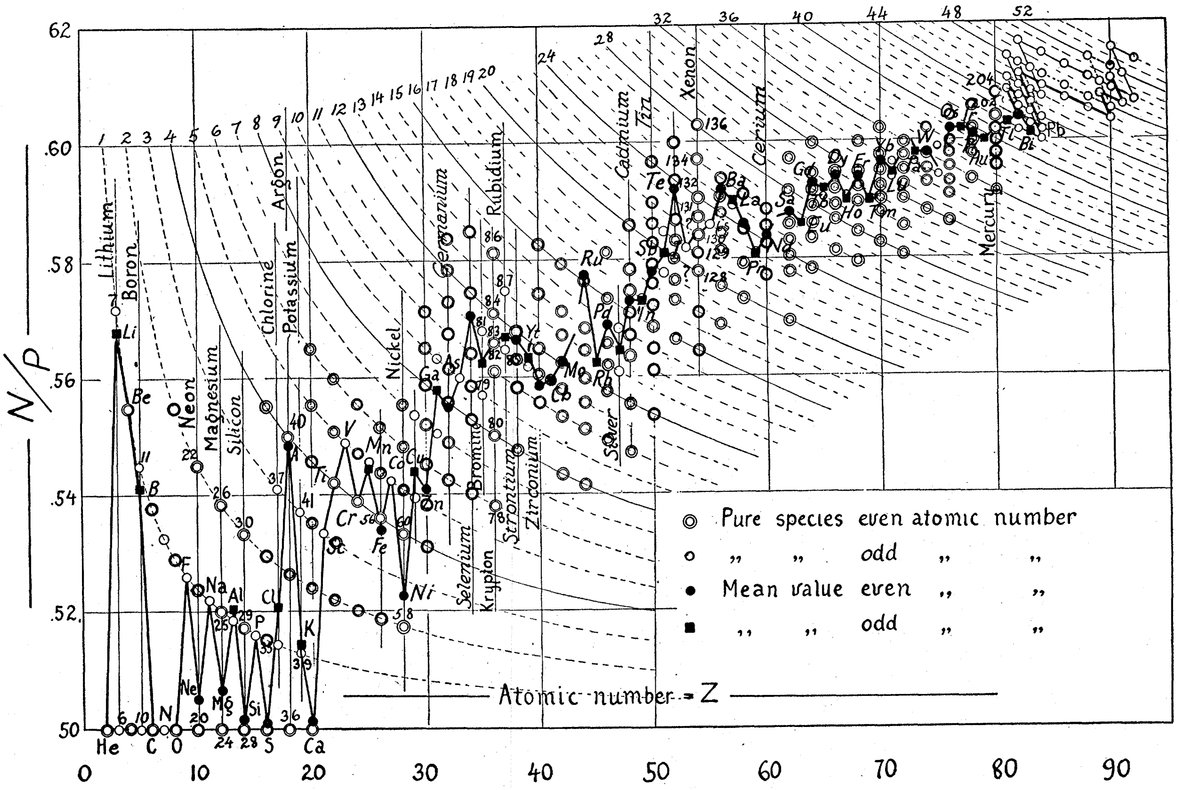

FIG. 4. Relationship between the *number of protons* Z in atomic nuclei and the *ratio of neutrons to total particles* (P.= protons plus neutrons). Only stable atoms are represented. The curves, nearly rectangular hyperbolae, are numbered to give the isotopic number of the species of atoms represented. The isotopic number gives the number of neutrons in the nucleus in excess of the number of protons. *Nearly all the atoms in the earth or the meteorites are represented by the short straight line at the bottom of the figure.* In these nuclei the number of neutrons is equal to the number of protons. The positions representing the atomic species indicate in a general way the band of stability. To indicate this properly a 3-dimensional plot is essential.

From the relations found in these and other photographs of atomic transformations the writer developed the theory of the existence of an intermediate, or compound, nucleus as presented in the introduction, and also in a later section.

VII. THE VALLEY OF STABILITY

While protons, aside from the effect of their charge, presumably exhibit some attraction for each other at extremely small distances, this is much less than the repulsion between their charges. This is overbalanced in the nucleus by the strong interaction between protons and neutrons. If the number of protons is small (20 or less), at least one neutron per proton is required to stabilize a nucleus. These relations became apparent to the writer in 1921 (*3*), in a paper which considered the effects of the number of protons and neutrons in atom nuclei upon their stability. However, as the number of protons increases above 20, their repulsion becomes so great that the nuclei are not stable unless the number of neutrons increases more rapidly than the number of protons.

The stability of atomic nuclei may be summed up in terms of (1) a general relation between the number of protons and of neutrons in the nucleus, and (2) special relations which involve whole numbers, as outlined in the next section.

The general relation may be considered to be represented by a valley in which the atoms are stable, surrounded by slopes where they are partly or wholly unstable. If considered as a relation between protons on one axis and neutrons on the other, the valley is narrow. However, it is broad (Fig. 4) if the number of protons, Z, is plotted on the X-axis and on the Y-axis the ratio N/P, where N is the number of protons and neutrons ($P = Z + N$).

Except for those atomic species represented on the X-axis, all the other species lie on 54 curves, each of which is nearly a rectangular hyperbola. These represent the isotopic number (I) which gives the excess in the number of neutrons over the number of protons. Any nucleus is represented by the formula:

$$(pn)_Z n_I$$

It may be considered that a deep canyon occurs at $(N/P) = 0.5$, or $I = \text{zero}$ (the straight line of the X-axis), since in 84.5 per cent of all the atoms on earth and 79.0 per cent of those in the meteorites the number of neutrons is exactly equal to the number of protons. That *almost* all (99.9 per cent on earth and 98.4 per cent in the meteorites) of the atoms on the earth or in the meteorites have isotopic numbers of 4 or less is shown in Table 1.

TABLE 1

Isotopic number	Earth	Meteorites
0	84.5	79.0
1	13.0	5.3
2	0.2	1.6
3	0.007	0.0
4	2.2	12.4
Sum	99.9	98.3

Thus, the valley is extremely deep at the lowest edge, rises to a ridge at $I = 3$, gives a deep valley at $I = 4$ and is shallow above this. Atoms in which N/P is too low for stability must increase N by the conversion of a proton into a neutron by giving off a positive electron. If, however, N/P is too high, a neutron must change into a proton by giving off a negative electron (β-particle).

VIII. Stability of Atomic Nuclei and the Abundance of the Elements

In 1913 the writer began a statistical study of the atomic weights then known. The results indicated several relations of interest. The atomic weights (actually mean values for the element) were found to be so close to whole numbers for elements 2 to 28 inclusive that several conclusions seemed inevitable, as follows:

(1) The masses of the atoms are extremely close to whole numbers, with the exception of that of hydrogen (Whole Number Rule). This was confirmed by Aston in 1919 and later.

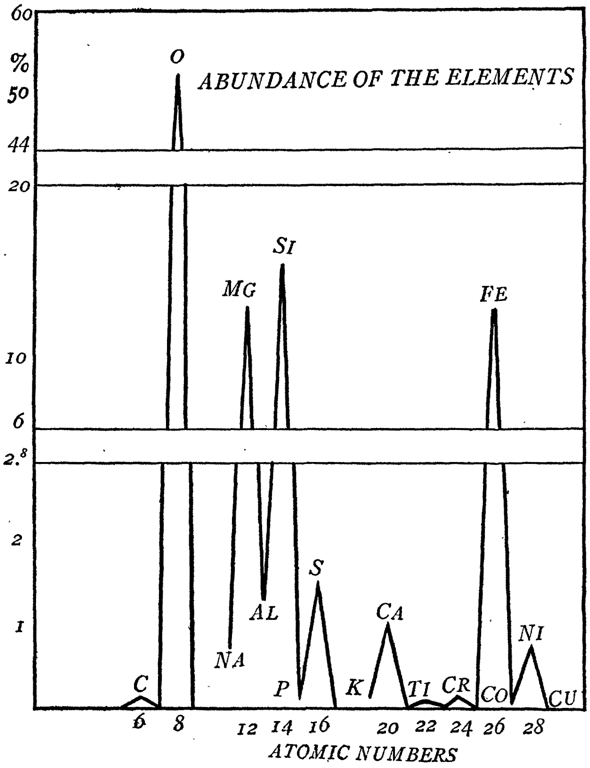

FIG. 5. Exhibits the high abundance of nuclei which contain an even number of protons. The figure gives the abundance in the meteorites. Neon (atomic number 10) and argon (atomic number 18) are gases and have escaped. In the stars, carbon, an element of even number, is extremely abundant as is also neon.

(2) Any considerable departure of the atomic weights (when correct) of the elements from a whole number was taken to indicate a mixture of isotopes. This conclusion was confirmed in the case of chlorine, atomic weight 35.46, by the separation of the element into isotopes.

(3) It was found that for elements of even atomic number above 26 (even number of protons in the nucleus) the atomic weights are no closer to whole numbers than they should be by chance. Thus, for each of these elements there should be many isotopes, while the odd elements were indicated as having only one, or very few, isotopes. Later, this also was confirmed by Aston.

The general theory of nuclear structure advanced at that time by the writer was sufficiently fruitful to give rise to several other predictions, which were verified later.

(4) Thus, the theory predicted that *elements* of even atomic number (P = even) should be much more abundant than those of odd atomic number. When this was investigated it was found that in the meteorites (Fig. 5) the elements of even atomic number are 70 times more abundant than those of odd number, while in the surface of the earth and the sun this ratio is about ten to one. Also, the stars in so far as they have been investigated seem to exhibit a decided preference for elements of even number. Thus, atomic nuclei which contain an even number of protons are much more "stable" than those in which the number is odd.

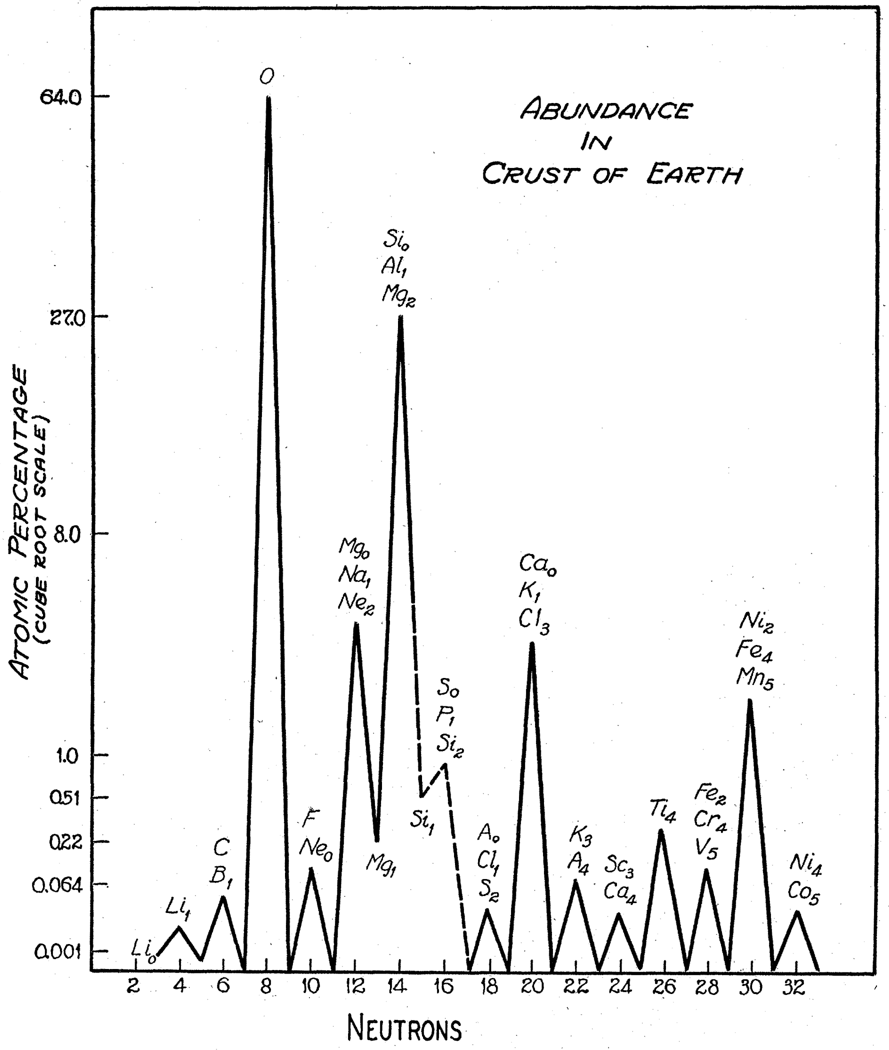

FIG. 6. Illustrates the excessively high abundance of atomic nuclei which contain an even number of neutrons, in comparison with the extremely low abundance when an odd number of neutrons is present. Note the cube root scale and that oxygen 16 (isotopic number equal zero) with the highest peak is about 100 times more abundant than the most abundant set of atomic nuclei for any single odd number of neutrons. The figures attached to the symbols of the elements are the isotopic numbers.

(5) An even more prominent relation is that in almost all "stable" nuclei the number of neutrons is even (Fig. 6). Thus, in so far as the abundance of atomic species has been determined, 99 per cent of all the atoms in the earth's crust have nuclei which contain an even number of neutrons. This relation became apparent to the writer in 1921, when he developed a formula for all nuclei as follows:

$$(pn)_Z n_I$$

in which p is a proton; n, a neutron; $\hat{z}$, the atomic number; and $\hat{I}$, the isotopic number. The isotopic number gives the excess in the number of neutrons above that for atoms whose nuclei contain equal numbers of protons and neutrons.

(6) Thus, there are almost no atoms whose nuclei are stable with an odd number of both neutrons and

protons: only about one atom in ten thousand on earth. This is an extremely remarkable relation.

IX. FUNDAMENTAL PARTICLES AND THE FORMATION OF PLUTONIUM

In nuclear reactions, particles other than protons and electrons, the two which are considered to exist inside the nucleus, are also involved. As stated in the last section, negative electrons (or β-particles) are given off from the nuclei of heavy (radioactive) atoms, if the particular species contains more neutrons than corresponds to stability. In such an event a neutron in the nucleus is converted into a proton by emission of an electron, or

$$\mathrm{n}_0^1 \rightarrow \mathrm{p}_1^1 + \mathrm{e}_{-1}^0$$

In such a change there is only a very small loss of mass. By this type of process U_{92}^{239} (formed by the addition of a neutron to U_{92}^{238}) changes into neptunium (N_{93}^{239}). Then, by emission of another electron this changes into plutonium (Pu_{94}^{239}), which is used in one of the two types of bomb. The whole series of reactions is as follows:

$$\mathrm{n}_0^1 + \mathrm{U}_{92}^{238} \rightarrow \mathrm{U}_{92}^{239} + \gamma$$

where γ represents gamma rays. Now, an electron is emitted with a half-life of 23 minutes:

$$\mathrm{U}_{92}^{239} \xrightarrow[\text{23 min.}]{} \mathrm{Np}_{92}^{239} + \mathrm{e}_{-1}^0$$

Neptunium also gives off an electron with a half-life of 2.3 days:

$$\mathrm{Np}_{93}^{239} \xrightarrow[\text{2.3 days}]{} \mathrm{Pu}_{94}^{239} + \mathrm{e}_{-1}^0.$$

In general, any second electron is lost more slowly than the first, and the species formed finally, *e.g.* Pu_{94}^{239}, when it disintegrates, gives off α-particles. Plutonium disintegrates very slowly and for practical purposes is stable.

Positive electrons are transient. They have the same mass as ordinary negative electrons and are given off from a nucleus when one of its protons changes into a neutron:

$$\mathrm{p}^{+1}_1 \rightarrow \mathrm{n}_1^0 + \mathrm{e}_{+1}^0$$

Such positive electrons disappear very rapidly, since, when they meet negative electrons, their mass takes on the form of radiation and no electron is left:

$$\mathrm{e}_{-1}^0 + \mathrm{e}_{+1}^0 \rightarrow \gamma.$$

The atomic mass of the electron is 0.0005486 or 9.1×10^{-28} gram, so, since both electrons disappear, twice this amount of mass appears in the form of radiation of a frequency 2.5×10^{20} vibrations per second, which is a wave length of 0.012 A.

Gamma rays (γ-rays), which are practically x-rays of higher energy and thus of higher frequency, are given off very frequently in nuclear transformations. In some cases this is the only "disintegration," by means of which an intermediate excited nucleus changes into its stable form, as with carbon:

$$\mathrm{C}_6^{12*} \rightarrow \mathrm{C}_6^{12} + \gamma$$

Gamma rays may also play the part of projectiles to form an excited nucleus, which then disintegrates. For example, this may occur with beryllium, with the emission of a neutron:

$$\mathrm{Be}_4^9 + \gamma \rightarrow \mathrm{Be}_4^{9*} \rightarrow (\mathrm{Be}_4^{8*} + \mathrm{n}) \rightarrow 2\,\mathrm{He}_2^4 + \mathrm{n}_0^1$$

It is pointed out in an earlier section that an alpha particle, when captured by a nitrogen nucleus, gives an unstable (excited) fluorine nucleus of mass 18. At *relatively* low, though high, energies this disintegrates into hydrogen and oxygen of mass 17. However, at higher energies the excited nucleus disintegrates also into a positive electron, a neutron, and oxygen 17. That the products of the disintegration of any compound nucleus are dependent upon its state of energy is illustrated also in the relations of uranium; *e.g.* uranium 239 is produced from uranium 238 by the capture of a neutron. At very high energies this undergoes fission, but if the production of plutonium is desired, the best yields are obtained if neutrons are used which are relatively slow but lie in the resonance region located somewhat above that of thermal energy —that is, above that of the molecules in the atmosphere. The best yield of fission of uranium 235 is, however, obtained by the use of thermal, or low-velocity, neutrons.

A stable nucleus may be considered as having a definite amount of energy. When more energy is present, it is said to be in an excited state. Such a state is restricted to definite amounts of energy, known as energy states, of which there are a very great number. If a particle which is approaching a stable nucleus has just the definite amount of energy, kinetic and potential, which, added to that of the stable nucleus, gives exactly the energy of one of the energy states or "levels" of the compound nucleus which would be formed by the union of the two particles, then the probability of the union of the two particles is extremely high. This phenomenon is known as *resonance*. As the energy departs from that of the energy level, the probability of the union of the two particles decreases rapidly. Different resonance levels have different widths: *i.e.* at some levels the variation of energy for capture (or for emission) is much greater than at others.

It is found that different elements, when used with all of their isotopes present, capture neutrons of certain velocity much more than those which have other velocities. A region of energy in which this capture is more apt to occur is a resonance region of one of the isotopes. For example, cadmium exhibits a very marked capture of neutrons which are very slow, with an energy of 0.01 volt. With silver this rises to 1 ± 0.03 volts; with rhodium, to 3 volts; with iodine, to 50–300 volts; and with bromine, to 100–500 volts. Thus, when neutrons are shot through a thin sheet of any of these elements, neutrons of the energies listed are greatly reduced in number, while most of the neutrons of other energies pass through. Relations of this type may be used to control the reactions in the bomb.

X. Discovery of the Trans-Uranium Elements

After the completion of the other sections of this paper the new elements 95 and 96 were announced on 16 November 1945, by G. T. Seaborg, the earlier discoverer of plutonium[3] (late in 1940). The first trans-uranium element, neptunium 239, was produced in May 1940, by E. M. MacMillan and P. H. Abelson, by the following procedure:

By a radiative capture of a neutron in uranium 236 an isotope of mass 239, (U^{239}) is formed. This emits a β-particle with a half-life of 23 minutes, giving neptunium of the same whole number mass 239 (since the loss of mass accompanying the emission of an electron is very small). Now, in general, in natural radioactivity the emission of one β-particle is followed by the emission of a second with a considerably longer life. In conformity with this relation the half-life of neptunium 239 was found to be 2.3 days, or 144 times longer than for the emission of the first β-particle. The first isotope of plutonium to be found was not that used in the atomic bomb, but was Pu^{238}.

First, U^{238} was bombarded in the cyclotron of E. O. Lawrence by the nucleus of heavy hydrogen (deuteron) of formula $(pn)^2_1$ and mass 2. Two neutrons escape, so the resultant effect is the addition of a proton:

$$U^{238}_{92} + (pn)^2_1 \longrightarrow Np^{239*}_{93} + n^1_0$$

$$Np^{238*}_{93} \longrightarrow Np^{238}_{93} + n^1_0$$

$$Np^{238}_{93} \xrightarrow[2.0\ \text{days}]{} Pu^{238}_{94} + e^0_{-1}$$

The isotope of plutonium thus formed emits α-particles with a half-life of about 50 years.

More important is the isotope Pu^{239}_{94} used in the bomb. This is formed by the emission of a β-particle (2.3 days half-life) from the nucleus of the Np^{239} described above.

Recently, as mentioned above, elements 95 and 96 have been discovered by Seaborg and collaborators (R. A. James, L. G. Morgan, and A. Ghiorso) in work at the Metallurgical Laboratory, University of Chicago. Both U^{238}_{92} and Pu^{239}_{94} were bombarded by high energy (40 Mev) helium ions in Lawrence's 60-inch cyclotron, as rebuilt by J. G. Hamilton.

Information as to what isotopes were found has not been released, but it is very simple to indicate what excited compound nuclei are formed.

$$U^{238}_{92} + He^4_2 \rightarrow Pu^{242*}_{94}$$

If this emits β-particles, then

$$Pu^{242*}_{94} \rightarrow X^{242}_{95} + \beta$$

$$X^{242}_{95} \rightarrow Y^{242}_{96} + \beta$$

With plutonium the excited compound nucleus would be formed as follows:

$$Pu^{230}_{94} + He^4_2 \rightarrow Y^{243*}_{96}$$

The chemistry of elements 93 to 96 is of extremely great interest. At the present time, 97 elements, including the element of atomic number zero (its atoms are neutrons), are known. Of these 1 to 96 have outer electrons and the associated chemical properties, while 0 has no electrons and no chemical properties.

Seaborg has revealed a few of the chemical relations of the trans-uranium elements, whose properties are, on the whole, somewhat similar to those of uranium. They form a transition series, and in this sense resemble the rare earths, but especially the lower numbers of the series are much more easily raised to higher oxidation states (above III) than the rare earths.

Seaborg finds that 10^{14} parts of pitchblende contain 1 part of plutonium. From this it may be calculated that there is in the earth's crust about 1 atom of plutonium to 10 billion-billion atoms of the other elements. In this work he was assisted by M. L. Perlman.

XI. Theory of the Intermediate or Compound Nucleus and the Fission of Uranium and Plutonium

It is pointed out in the introduction that in a nuclear transformation the first step is the formation of an excited nucleus, as follows:

$$P + T \rightarrow C^* \qquad (1)$$

Then C* must get rid of its excess energy by some type of change in which it loses energy, so:

$$C^* \rightarrow D + E.$$

If E is excited, a second disintegration occurs (Fig. 7). For the fission of uranium or of plutonium the first step is the formation of the excited nucleus which is to split into parts. This is done by the addition of a neutron (n^1_0), as follows:

$$U^{235}_{92} + n^1 \rightarrow U^{236*}_{92}$$

$$Pu^{239}_{94} + n^1 \rightarrow Pu^{240*}_{94}$$

Since the disintegration by fission of one of these is

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[3] Collaborators in the discovery of plutonium: E. M. MacMillan, A. C. Wall, and J. W. Kennedy.

a process of the same type as that of the other, only the fission of U^{236} is considered here.

In its fission the nucleus seems to split into two unequal parts of masses 127 to 154 for the heavier fragment and 115 to 83 for the lighter fragment. However, most of the masses lie between 134 to 144 for the heavier and between 90 and 100 for the lighter fragment. Inspection of Fig. 4 shows that for uranium 236 the ratio of neutrons to total particles in the nucleus is 0.61, while in the range of mass from 134 to 144 even the highest ratios are in general 0.6 or less, and for mass numbers 90 to 100 the highest ratios of any of the isotopes are about 0.584. Thus, if the two atoms formed in the end as the result of any fission have even the highest number of neutrons for stable isotopes, there are about five neutrons to be accounted for; if lower isotopes, more than five.

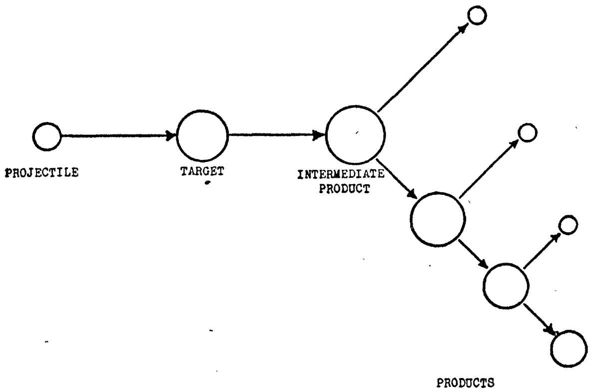

FIG. 7. A nuclear transformation in which several intermediate nuclei are involved.

The process of fission may be considered analogous to what would occur if the water drop in air were to be set into strong vibration. This would result in the separation of the drop into two parts, but initially with a neck, or cylinder, of water between them. This, then, segregates into several minute water droplets. In the fission of uranium 236 it may be assumed that the process is analogous and that the droplets formed are neutrons, 1 to 3 in number. The loss of this number is not sufficient to allow the two atoms formed as fragments to be stable. Therefore, these nuclei must expel neutrons, but the expulsion may be "delayed" for a period of moderate length. Another method of getting rid of extra neutrons is for the neutrons in the nuclei to lose negative electrons, thus converting neutrons in the nuclei into protons. It may be supposed that the "delayed" neutrons observed to be given off after the fission occurs are emitted after the emission of one or more negative electrons, since the life of atoms in electron emission is much greater in general than that for neutron emission. Although the water-drop model is used above to illustrate fission, nuclei in general seem to be more closely similar to minute crystals.

The history of the discovery of the fission of heavy atomic nuclei into two nearly equal parts is of extreme interest but cannot be related fully here. The lightest atoms such as the neutron, the hydrogen atom, or the atom of heavy hydrogen have masses higher than their respective whole numbers, in the case of the neutron by 0.9 per cent, and for hydrogen of unit mass by 0.8 per cent. The atomic weight of oxygen is a whole number by definition. As the atomic mass becomes higher, it falls below that of the corresponding whole number with extreme slowness, but when barium of masses 130 to 138 is reached it has fallen to about 0.08 units below the whole number. Above this, the negative deviation from a whole number becomes smaller, so that, when mercury of atomic weight 200 is reached, it is almost exactly at the whole number again (mass $200 = 200.016$). Above this, the positive departure from a whole number increases rapidly, and the mass of U^{236} may be given as 236.093.

Now, if U^{236} were to split into two parts, it would lose the excess over a whole number (.093) and also 0.08, the defect in the mass, or 0.173, which is the sum of these. However, on the average, two neutrons are lost in the process, and these have an excess mass of 0.018, so that the loss of mass experienced by any 235 grams of uranium used in the bomb would be 0.155. This multiplied by c^2 gives 1.4×10^{20} ergs, or 3.4×10^{13} calories. This amounts to 2.7×10^{20} ergs, or 6.6×10^{13} calories per pound. The temperature thus given by the bomb is many million degrees and the pressure many millions of atmospheres. However, the efficiency is not perfect, since not all of the uranium or plutonium atoms in the bomb undergo fission, and the temperature is so high that a considerable fraction of the energy may escape as radiation, which, although it gives pressure, is relatively ineffective as compared with the motion of the molecules.

Fermi became interested in the work on the disintegration of light atoms by neutrons, as presented in a paper by the writer at the Conference on Nuclear Physics at the University of Chicago in June 1933. In this paper Harkins, Gans, and Newson reported the discovery of the first artificially radioactive material ever produced, a nitrogen isotope of mass 16. A year later Joliot and Curie obtained a nitrogen isotope of mass 13, which they proved to be radioactive. Fermi had available at the University of Rome about fifty times more radium than was available at the University of Chicago, and was thus able to make a rapid survey of the effects of neutrons on a very large number of the heavier elements. This work gained him the Nobel Prize, which he merited on account of the discovery of the effects of slow neutrons and his earlier work in statistical mechanics. However, very unfortunately, the prize was granted for the discovery of the trans-uranium elements 93, 94, 95, and 96, the discovery of which is described in Section X of the present paper. What Fermi had actually found was the fission of uranium.

In all disintegration reported before 1939, one of the products was always a very light atom, for example, hydrogen of masses 1, 2, or 3, a neutron of mass 1, or helium of mass 4 (or 3). In January, 1939, however, Hahn and Strassmann described a repetition of Fermi's experiments on uranium. They obtained evidence, from the chemical nature and radioactive periods of the products, that one of the atomic species produced was barium with an atomic mass and number not far from half that of the uranium which disintegrates. Immediately after this, Frisch and Miss Meitner pointed out that this constituted the discovery of an entirely different type of nuclear reaction, in which the intermediate or compound excited nucleus splits into two parts of nearly equal mass.

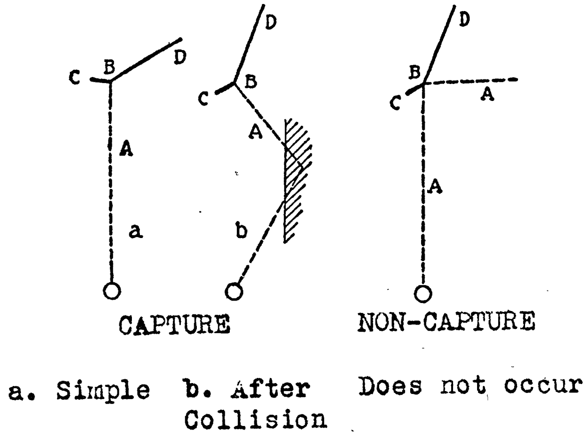

FIG. 8. Formation of an intermediate excited nucleus by capture of a neutron. In *b* the neutron is first deflected by an elastic collision with the nucleus of an atom. The right-hand section of the figure represents what would occur if, *according to the earlier ideas,* a disintegration were to occur by noncapture. *However, such a disintegration has never been found.*

Very shortly after this, numerous experiments by various investigators, Szilard, Zinn, Joliot, Halban, and Kowarski, combined to show that in each fission from one to three neutrons are liberated. This has been shown in an earlier section to agree with the relations presented in Fig. 4. However, it should be recognized that there is a second mechanism by means of which neutrons can disappear from an atomic nucleus, since, as shown earlier, when a negative electron is emitted by a nucleus a neutron in that nucleus is changed into a proton. The emission of negative electrons in this way is designated as artificial radioactivity, and the artificial radioactivity which occurs after the fission of a heavy nucleus is extensive.

During the years 1926–36 the writer obtained evidence, partly by experiment and partly from the literature, that the intermediate, or compound, nucleus is formed in all cases as a preliminary to disintegration. One of the first steps taken by Harkins and Gans in 1934 was to show that those disintegrations caused by neutrons assumed by members of the staff of the Cavendish Laboratory to occur by noncapture actually occur by capture (Fig. 8). By the development of a relativistic equation for disintegration by noncapture it was shown:

(1) That in none of the events assumed to occur in this way had there ever been enough energy to give a disintegration of this type. The simple form of this equation is presented here merely to show that the changes of mass involved in a disintegration must be considered:

$$V_A = \frac{\{M^2 + 2m_A[E_C + E_D + c^2(m_C + m_D - m_B)]\}}{2m_A M \cos \alpha}$$

Here V_A is the velocity of the projectile; M is the momentum; E is the kinetic energy; m, mass; c, the velocity of light; and A, B, C, and D are the nuclei involved.

(2) That the energies of the neutrons which were supposed to give noncapture disintegrations were found to lie on the same curve as those known to be of the capture type.

(3) That an intermediate compound nucleus is formed is shown clearly in events in which neutrons and protons are both given as the final products in two types of disintegration obtained from the same initial projectile and target. For example, if an intermediate, or compound, nucleus is formed by the addition of the helium nucleus to N^{14}, very few protons are emitted until the alpha particles have a somewhat high velocity, after which the number of protons emitted rises very rapidly with the velocity of the alpha particle and then quickly reaches a constant value, which, however, soon begins to decrease. Just as this decrease begins to appear, neutrons are found to be given off by the disintegration. The number of neutrons now increases at the same rate as the yield of protons decreases, which shows most clearly that in such transformation there is no direct coupling between the initial alpha particle and the protons and neutrons formed as the final products of the disintegration. The formation of protons and of neutrons are thus disintegrations of the compound nucleus, which compete with each other, the increase in one giving a decrease of the other.

One of the most prominent properties of the neutron, due to its absence of charge, is that it can pass through an enormous number of other atoms without deflection, unless it strikes a nucleus. Since, on the average, about two neutrons are emitted by each fission and only one is needed to produce it, and since, in addition, the reaction is exceedingly fast, the number of neutrons and also the number of fissions increases with extreme rapidity, provided no neutrons escape. However, unless the body is moderately large, so many neutrons escape that, on the average, less than one of the neutrons produced by a fission is effective in uniting with a nucleus to give another fission, so the reaction dies out. If the body is larger than this (known as the critical volume highly dependent upon the shape), the reaction proceeds. In such a case the term, chain reaction, has been employed, although this is somewhat different from the prior use of this term in chemistry.

The writer realized not very long after the beginning of the development of his general theory of nuclear transformation, in 1926, that the complete theory is of the quantum-mechanical type. Such an enlargement of the theory was developed in 1937 by Bohr and Kalckar (*2*). However, this was not done until the point of view of nuclear physicists in general was changed by experimental evidence, which demonstrated that the *primary* process is the formation of a nucleus, rather than its disintegration.

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Obituary

Thomas J. Maney
1888-1945

Last 12 October marked the passing of T. J. Maney, chief in pomology at Iowa State College. His death occurred at Rochester, Minnesota, where he had undergone an operation.

Maney was born at Geneva, New York, on 24 April 1888. He gained his inspiration for horticulture under the tutelage of Professor S. A. Beach and graduated from Iowa State College in 1912. He was employed by the college immediately following his graduation, in which relationship he continued for the past third of a century. He served as chief in pomology at this institution since 1917. His special field was hardy stocks for the pomaceous fruits. His genial fellowship and keen Irish wit will be missed by his college associates.

Mr. Maney is survived by his wife and three sons, one of whom is in the Army Air Corps.

A. T. Erwin

Iowa State College

Bruce Lawrence Clark
1880-1945

Dr. Bruce Lawrence Clark, associate professor of paleontology, emeritus, of the University of California and one of the country's outstanding authorities on invertebrate paleontology, died on 23 September 1945 at his home, 916 Euclid Ave., following a six-month illness. His death will be mourned by hundreds of his former students in all parts of the world, who held him in affectionate regard as a friend as well as an instructor.

Dr. Clark graduated from Pomona College in 1908 and received his Master of Arts degree and his Ph.D. degree at the University of California in 1909 and 1913, respectively. He joined the university faculty as a teaching fellow in 1909. He became an associate professor in 1923.

On the Berkeley campus, Dr. Clark developed a school of graduate students who went out to all parts of the world to develop the vast oil fields in Arabia, Sumatra, Java, Borneo, Colombia, Venezuela, and Mexico. He himself traveled extensively in Europe and Mexico visiting other scientists in his field.

His principal interest was in the invertebrate fossils of the Pacific Coast and he had recently discovered radiolarian deposits from the Eocene period in the region of Mount Diablo. He was a member of the American Association for the Advancement of Science, the Paleontological Society, the Geological Society of America, the California Academy of Sciences, the Faculty Club, and the First Congregational Church of Berkeley.

Dr. Clark was born in Humboldt, Iowa, on 29 May 1880. He is survived by his wife, Mrs. Delia E. Clark, a daughter, 2d Lt. Elizabeth Clark of the Army Nurse Corps at DeWitt General Hospital at Auburn, California, and a son, Bruce E. Clark, CM1/c USNR, now home from Okinawa.

Charles L. Camp

University of California, Berkeley