THE TRANSMUTATION OF ENERGY AND MATTER

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The idea of mass becoming a function of energy was a direct result of the relativistic theories by Einstein in 1905. Little must he have thought at the time how momentous his theories and their practical applications were to become within the same half-century. The exploding of the atom bomb over Hiroshima and Nagasaki in 1945 heralded a new era for homo sapiens and, incidentally, a serious challenge to contemporary medical science. Einstein's calculations, first based on the results of observations on the characteristics of light, demonstrated the rather startling fact that the mass of a particle increased with its velocity.

The change in mass with velocity was confirmed by the experiments of Kaufmann, who proved that a charged particle emitted from the disintegration of radioactive substances increased in mass as the velocity increased. This increase in mass of a charged particle is actually an increase of energy in the surrounding magnetic field. From the above consideration of the transmutability of mass and energy, we proceed to the study of matter itself and consider the energy residing in the atom as mass.

The original idea that an atom consisted of a round marble-like core, surrounded by smaller marbles, revolving like the planets around the sun, has not been held for some time, but it served its purpose as a stepping-stone to new and
rather more logical conceptions. First and foremost, the hydrogen atom is now thought to be the "brick" of the Universe, and from which all other elements are composed, as all other atomic structures seem to be just multiples of the fundamental hydrogen atom. This atom comprises a nucleus, or a positively charged particle called a proton and an extra-nuclear negatively charged particle called an electron. The charge on the proton is exactly equal and opposite to that of the electron, thus giving the atom a state of electrical equilibrium. However, the mass of the proton is nearly 1,840 times that of the electron. Thus, although one may form a mental picture of the atomic structure according to the individual sense of imagination, science is just as imaginative, for the fact is, that a true mental picture has not yet been formulated, and it is doubtful if one ever will be, as the hope of being able to form such a picture seems to be receding as more knowledge is gained.

![Diagram of atomic structures](image)

**Fig. 2**

Although the electron does possess mass, the weight of the hydrogen atom is taken as the weight of its nucleus, or proton, the difference in mass being so great. Thus for convenience the weight of the hydrogen atom is taken as unity. Scientific research during the past few years has discovered that in a quantity of hydrogen 99.98 per cent. of the atoms consist as stated, of a proton nucleus and an extra-nuclear electron, but what of the other 0.02 per cent.? This small fraction has
been found to consist of atoms possessing one extra-nuclear electron, but of mass twice that of the majority of hydrogen atoms. As these atoms are stable, that is, in electrical equilibrium, the nucleus must contain one proton, yet their mass is such that "something extra" must be in the nucleus. This "something extra" has been shown by Chadwick to be particles of mass equal to that of the proton, but possessing no electric charge whatsoever, and, aptly, they are called neutrons.

One may ask if the atom of hydrogen which contains this extra mass is so much different from the hydrogen atom which does not, and the answer is that chemically there is practically no difference, but physically there is a great difference. A very important fact can now be stated—that is that the extra-nuclear electrons (and not the nucleus) decide the chemical characteristics of the atom. This "heavy" hydrogen atom possesses but one electron and one proton and so its "atomic number" is unity, although its atom weight is 2. This brings us to atomic numbers, which are easily understood when it is seen that the number of charges in the nucleus or the number of extra nuclear charges in the stable atom give the atomic number. Thus the atomic number of hydrogen is unity; the atomic number of oxygen is 8, oxygen possessing 8 protons or 8 extra-nuclear electrons, and so on right up the atomic table to uranium, which has an atomic number of 92. Symbolically the atom of hydrogen is given as _\text{H}^1_, that of oxygen as _\text{O}^{16}_8_, the suffix at the foot of the symbol being the atomic number, and the superfix at the head being the atomic weight.

To return to "heavy" hydrogen, it is hydrogen, and acts chemically like hydrogen. In fact, right up the atomic scale it is found that other elements possess these heavier "brothers." For example, oxygen possesses three, _\text{O}^{16}_8_, _\text{O}^{17}_8_, and _\text{O}^{18}_8_, whilst the uranium family is very large. These varieties of the same element are called "isotopes," and in fact the isotope of hydrogen _\text{H}^2_ has even got a special name—"deuterium."

Helium, which possesses a nucleus consisting of two protons and two neutrons and of course two extra-nuclear electrons, is symbolically _\text{He}^4_2_, whilst the heaviest atom of all, uranium, of atomic weight 238 and number 92, possesses...
some 146 neutrons. The nucleus of this atom is exceedingly unstable and continually flings out particles consisting of two protons and two neutrons; in fact, helium nuclei, an exceedingly stable formation, given the name of alpha particles, which leave the nucleus with tremendous velocity. This activity of the nucleus is common to all the elements with a higher atomic number than 82. Actually this activity, called “radio-activity,” is a highly complicated procedure involving interchanges of energy inside the atomic nucleus, and we will not dwell too much upon its ramifications except to note the external manifestation of nuclear energy. It should be noted that the atomic nucleus consists of positive charges and neutrons and that “like” charges repel each other (consistent with the law of electrostatics). How then is the atomic nucleus held together, usually with such tremendous force? The answer to this must await further investigation into atomic structure.

If these alpha particles emitted by radio-active substances are utilized to bombard nitrogen gas, the nitrogen atom is disintegrated as follows:

\[ ^7\text{N}^{14} + ^2\text{He}^4 \rightarrow ^1\text{H}^1 + ^8\text{O}^{17} \]

—and two different elements, hydrogen and an isotope of oxygen, are formed. Nuclear transmutations may be achieved by any atomic particles possessing the requisite energy. Positive ions (or protons) may be given tremendous energy by means of a device called a “cyclotron.” This device consists of sending the charged particles through strong magnetic fields which apply the requisite resonant “push” at intervals, thus imparting to the particle a tremendous velocity. By bombarding various elements by these particles, fast or slow transmutation may be made to take place, and some elements may be made into isotopes of a new element which are unstable and radio-active; these may be used in many ways by both industry and medico-biological research in the form of “tracers.” This, however, is a digression.

By means of an instrument called a “mass spectroscope,” a mass spectrograph may now be obtained which, on interpretation, indicates differences in atomic weights compared with those values previously held. The results are of interest, and the relative masses of the elements computed show that the atomic weight of hydrogen relative to oxygen (16.0000) now becomes 1.0080, that of helium 4.003, and so on to uranium of atomic weigh 238.07. Suppose that we could take two atoms of heavy hydrogen or deuterium and build, up an atom of helium, then, taking the atomic weight of deuterium to be 2.01418 on our new scale and the atomic weight of helium to be 4.003 in the same scale, we have a discrepancy:

\[ 2 \times 2.01418 = 4.02836 \text{ and not } 4.003. \]

This discrepancy is too large for it to be due to experimental error and, in fact, similar discrepancies occur if we theoretically make up oxygen from our hydrogen isotope. This difference in mass (in the above case 0.02536 atomic mass units) can be calculated in terms of energy from Einstein’s equation, \( E = mc^2 \), where \( E \) is the energy represented in ergs, \( m \) the mass in grams, and \( c \) the velocity of light \( (3 \times 10^{10} \text{ cms. per sec.}) \). (See Appendix.) To gain some idea of the
amount of energy represented by even a small mass, such as 0.001 grams, the substitution of 0.001 grams in the energy equation gives a value:

$$E = 9 \times 10^{17} \text{ ergs}.$$  

This value is approximately equivalent to 33,000 horse-power hours, whilst one gram of matter is equivalent to $9 \times 10^{20}$ ergs, or approximately 1,000,000 horse-power for 33 hours (the total output of Niagara Falls for 33 hours). Oxygen atoms consist for the majority of eight neutrons, eight protons, and eight extra-nuclear electrons, yet the mass of the oxygen atom is less than four times as heavy as the helium atom. The explanation in short is that as hydrogen atoms are built up into more complex structures, a rearrangement of the electrical field inside the atom must take place; this is known as the "packing effect." Mass is given up as energy, and the mass converted into energy gives us some idea of the binding energy of the nuclei. For example, if we wished to dissect a helium atom and make two deuterium atoms from it, we should have to use the amount of energy represented by that mass lost in the building of the helium atom—i.e. 0.02536 atomic mass units, per atom.

![Diagram of mass spectroscopy](image)

**FIG. 5**

**Mass Spectroscope.**

The earth is continually being bombarded by a radiation from outer space given the name "cosmic radiation," the exact origin of this radiation being at the moment a matter of speculation, but the energy of this radiation is such that nothing short of the building of a universe could explain it. If, under certain conditions, hydrogen is being built up into complex atoms in some remote "building plot" in space, the mass difference released as energy is awe-inspiring even to modern science. In the sun and stars, hydrogen is probably being transmuted into helium and into elements of still higher atomic weight and number, the release of "mass energy" being responsible for the continued radiation of electro-magnetic origin. Scientific progress has recently brought us to the conclusion that if we could emulate the sun and manufacture helium from hydrogen, a new and vast store of energy could be released. The transformation of hydrogen into helium, or even into oxygen (with still greater mass release),
would take place if the conditions were propitious. These conditions are, in effect, heat and pressure equivalent to that of the sun's interior, a rather ambitious project, but evidently not too ambitious for the modern scientist.

In 1939 Hahn and Meitner found that when the uranium atom is bombarded with neutrons, the nucleus splits up into roughly two equal parts with great release of energy. As a matter of fact, neutrons are very convenient "bullets" for this bombardment, because, being electrically neutral, they are not attracted or repulsed by positive or negative charges and, of course, their mass is equal to that of the proton. Now, if the uranium nucleus is split, what happens? Where does the energy come from and what remains? Natural uranium contains two main isotopes, 238 and 235—that is, the isotope 235 possesses 3 neutrons less than uranium 238. As the nuclei split there occurs a discharge of energy, the "binding energy," of the particle, manifested in the discharge of heat radiation, fast neutrons, alpha particles, beta particles (negative charges) and a radiation of photons (or quanta of electro-magnetic energy) of great power called "gamma radiation." It was discovered that the isotope 238 was disintegrated by fast neutrons and not by "slow" neutrons, whereas the isotope 235 was disintegrated by either fast or slow neutrons. Now, if the uranium atomic nucleus is split by the bombardment of neutrons, more neutrons are generated, but these neutrons will not in their turn disintegrate the nuclei of isotope 238, but will disintegrate the nuclei of the 235 isotope. Suppose that the 235 isotope be separated from the 238 isotope, then what happens? This is exactly how the research progressed. A salt of uranium was vaporized and passed through the powerful magnetic field of a huge cyclotron, the particles being made to describe a circular path by the electro-magnetic forces acting. The heavier isotope, 238, described a different path from that of the 235 by reason of its different mass, and was collected. The 235 isotope was now bombarded with neutrons of "thermal speeds" (or speeds comparable with those of heated gas molecules), these speeds being obtained by allowing the neutrons to make collision with the lighter atoms of deuterium (or heavy hydrogen). A "chain reaction" was initiated; that is, as bombarding neutrons disintegrated the uranium nuclei, other neutrons were liberated, which in turn disintegrated other nuclei and so on. As the isotope \(^{235}\text{U}\) split, it formed two more isotopes, \(^{138}\text{Ba}\) (Barium) and \(^{86}\text{Kr}\) (Krypton), which accounts for 132 neutrons; but the isotope 235 contains 143 neutrons. The extra 11 neutrons split other nuclei, releasing 11 at every reaction and so on. The artificial separation of the 235 and 238 isotopes of uranium is a long and slow process and has other disadvantages, but it was found that if \(^{238}\text{U}\) was bombarded with neutrons, another isotope—\(^{239}\text{U}\)—was obtained. This isotope is radio-active (as are all elements of high atomic weight) and gives off a "negative" charge called a "beta particle," an interchange of energy in the nuclear field causing a radiation to acquire negative characteristics. This discharge of negativity causes the positive charge of the nucleus to increase by 1, thus giving us a new element, for another extra nuclear electron will attach itself to the atom—i.e. 

\[ \text{\textit{U}}^{239} \rightarrow \text{\textit{Np}}^{239} \]

The Np stands for neptunium, a new element to which the above name has been
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given. Now neptunium, also radio-active, in its turn gives off a beta particle, and we get a new element again, called plutonium ($^{93}_{92}$Pu$^{239}$).

\[ _{93}^{239}\text{Np} \rightarrow _{94}^{239}\text{Pu} \]

The plutonium, as is seen, collects an electron from the surrounding matter, there being plenty of free electrons (or ions) in all matter. Actually, in the latter transformation gamma rays are emitted as the nuclear field reorientates itself. Now this element plutonium can be separated from uranium by chemical means (for after all it is an element in its own right), and so is relatively easy to obtain.

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If plutonium is bombarded with neutrons, a chain reaction acting in practically instantaneous time causes such a rapid release of energy that it constitutes a violent explosion. However, another difficulty arises, for in the sphere of plutonium the amount of neutrons generated in the mass of the sphere will vary with the cube of the radius (volume of a sphere being $\frac{4}{3}\pi r^3$), whilst the loss of neutrons being emitted from the surface is proportional to the square of the radius (area of a sphere being $4\pi r^2$).

Thus if the sphere is too small, the loss of neutrons will be greater than their generation, and if the sphere is too large, the absorption factor becomes too great, and so the correct size of mass must be obtained if nuclear fission is to be effected satisfactorily. This size is called the “critical size,” and two particles, together making the critical size, can be brought together at any desired time to cause the instantaneous reaction and explosion. The speed of each fission neutron is in the order of $10^{10}$ cms. per second (about one-third that of light), and the time taken to cause considerable disintegration of the mass is in the order of millionths of a second. Every gram disintegrated releases an energy equivalent to thousands of tons of T.N.T., with consequent heat emission of millions of degrees and pressure of many millions of atmospheres. Therefore the heat and pressure required for the building up of helium, nitrogen or oxygen from hydrogen or lithium can be obtained. In fact, science now possesses the “fuse”
for the release of unimaginable energy, and it is perhaps ironic that the first use made of this energy should be in the form of a "hydrogen" or "oxygen" bomb.

The energy emission from this "bomb" would be in the form of heat, light or radiation, the radiation being, it is presumed, of very penetrating gamma rays, but not as penetrating as cosmic rays, whose energy would presumably be in ratio to the building up of heavier atoms. However, these gamma rays would be of such penetrability that the protection factor against radiation would assume a greater significance than hitherto, and in fact it must be a matter of grave speculation if any surface protection could be efficiently devised. The heat energy emitted would cause instantaneously a blast of hot gases extending for a radius of several miles—the height above the ground for the explosion of the bomb being calculated so that the blast would have a maximum tangential force. The extent of the energy release could presumably be made to vary—in fact, the main limiting factors at the moment must be the engineering facilities necessary for the production of the components and the obtaining of the necessary heat-resisting materials. Graphite is probably utilized, but even this element sublimates at 3,500° C. However, in the not so distant future, when heavier elements are built by artificial means, the tremendous energy release may be utilized for more constructive purposes, but again that is another story.
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APPENDIX

The transmutation of mass and energy was anticipated by J. J. Thompson, Heaviside and Larmor, but it was the experimental observations of Michelson and Morley which gave Einstein the basis for his calculations on the special theory of relativity.

During the course of experiments with light, it was found that any change in the motion of an observer did not produce any change in the velocity of light as measured by the observer.

FitzGerald contended that the apparatus measuring or recording a change in the relative velocity of the light contracted by the ratio \( \sqrt{1 - \frac{v^2}{c^2}} \) where \( v \) is the velocity of the apparatus and \( c \) that of light. This ratio is known as the "FitzGerald contraction."

The mathematics defining the theory of the matter energy transformation involve the conception of a four-dimensional vector, but, using the results of a simple integration, the following can be readily understood:

Let \( m \) represent the mass of a particle at velocity \( v \), and \( m_0 \) the mass of the particle at rest, then if \( c \) is the velocity of light (at a constant value of \( 3 \times 10^{10} \) cms. per second).

\[
m = \frac{m_0 \sqrt{1 - \frac{v^2}{c^2}}}{c^2}
\]

It can be seen from this equation that as the velocity of a particle approaches that of light, the mass of the particle approaches infinity, and, again, it demonstrates the fundamentality of the velocity of light. Substituting relativistic functions in Newtonian dynamics: Let \( W \) be the work done on a particle of mass \( m \), then it can be demonstrated that—

\[
W = mc^2 = K \text{ (constant)}
\]

When the body is at rest, \( W = 0 \), \( m = m_0 \), so that \( K = m_0 c^2 \)

\[
\therefore W = c^2 \left( m - m_0 \right)
\]

From the first equation,

\[
W = m_0 c^2 \left( \sqrt{1 - \frac{v^2}{c^2}} - 1 \right)
\]

In the case where \( v \) is relatively small \( \sqrt{1 - \frac{v^2}{c^2}} = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}} \)

Using the Binomial Theorem \( \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}} = 1 + \frac{v^2}{2c^2} + \frac{3v^4}{8c^4} + \ldots \)

Neglecting \( \frac{v^4}{c^4} \) and higher powers,

\[
W = \frac{1}{2} m_0 v^2
\]

Now \( W \) can be considered to be the kinetic energy of the particle, and an increase in kinetic energy can therefore be regarded as an increase in mass \( (m - m_0) \).

\[\therefore E = mc^2, \text{ where } E \text{ is the energy in ergs and } m \text{ the mass in grams.}\]