

Experimental Studies on the Artificial Transmutation of Certain Light Elements Bombarded by Ions of Hydrogen and Heavy Hydrogen. I.*

(The Relative Probability of the Occurrence of the Two
Alternative Types of Disintegration of ${}^6_3\text{Li}$ and of ${}^{11}_5\text{B}$)

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I. Introduction.

The phenomena of Radioactivity had led us to believe in the occurrence of the spontaneous transmutations of atoms of some heavy elements into those of others, and hence the dynamical constitutions from elementary particles of atomic nuclei that may become unstable in course of time.

The accurate, electro-magnetic weighing of each atom by the method of positive ray analysis revealed the so called "whole number rule" that held good throughout the isotopes of all of the elements; the small deviations from this rule were taken as due to the different "packing effects" for the different constitutions of various atomic nuclei, and thus the mass m of the elementary particle of the construction was taken as decreased by being bound together by an amount calculated by the relativistic energy-mass relation

$$\Delta m = \frac{\Delta E}{C^2},$$

* Parts of the present paper were read at the meetings of the Japanese Association for the Advancement of Science held on December 24, (1934) and the Physico-Mathematical Society of Japan held on April 5, (1935) and April 4, (1936) respectively.

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where ΔE is the mean binding energy of the particles building the atom under consideration and may amount to the order of magnitude of some million electron volts (M. E. V.).

It was then natural to predict that the nucleus of an atom can be artificially disintegrated into pieces if we are able to impart sufficient energy to the constitution of the nucleus to destroy the union of the elementary, constituent particles, and especially that some of the light elements are relatively unstable and may easily be disintegrated by some means. The old experiments of RUTHERFORD and CHADWICK on the artificial disintegration of atoms of nitrogen and other light elements were undertaken by bombarding them with α -particles possessing high energies, and it was observed that a proton was ejected when the colliding α -particle happened to be captured by one of the atoms of the bombarded elements.¹⁾

This experiment, not only directly proved the existence of the proton as one of the building materials of atomic nuclei, but also, combined with the phenomena of anomalous scattering, led us to suggest that atomic nuclei carry in general a potential "hole" inside the "barrier" due to the Coulombian repulsion against the incoming α -particle, which may, according to classical mechanics, be considered to be captured when and only when the kinetic energy is sufficiently large as to be capable of surmounting the barrier, the process of disintegration being taken as one of the types of the liberation of energy due to the rearrangement of the configuration. According to the view of Wave-mechanics, however, it was predicted that a particle should be allowed to penetrate the barrier with a finite probability even though the kinetic energy is lower than the value corresponding to the maximum potential of the barrier.²⁾

The disintegration of atomic nuclei by bombarding them with high speed ions of entirely artificial origin was first achieved by COCKROFT and WALTON³⁾ and the prediction of Wave-mechanics was experimentally realised; namely that the accelerated positive rays of hydrogen of 100,000 E. V. or even of 20,000 E. V.^{3,4)} were sufficient of themselves to disintegrate the nucleus of a lithium atom (${}_3\text{Li}^7$)

with measurable probability while the height of the potential barrier of this isotope against a proton was estimated to be about 0.8 M.E.V.⁵⁾

Considerable work was subsequently done by many investigators in this field of research and a number of results were produced in the past few years.

Experimental studies on this subject have also been undertaken during the last two years in the physical laboratory of Taihoku Imperial University, and the relative probabilities of alternative types of disintegration of various light elements have been observed for the bombarding ions at relatively slow velocities.

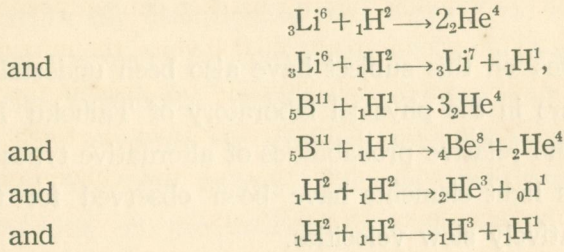
II. General Consideration.

It is generally believed⁵⁾ that the probability that a high speed particle will produce a disintegration of atomic nucleus on striking a target depends on

- 1) the effective nuclear collision cross-section that varies with (the square of the) varying de Broglie wave-length of the particle,
- 2) the range of the particle in the target,
- 3) the Wave-mechanical probability of the particle penetrating the nuclear potential barrier, (this chance reaches the unit when the kinetic energy of the particle exceeds the value of the potential barrier), and
- 4) the probability that disintegration will occur after penetration of the potential barrier has taken place. This may be considered to depend on the amount of the available energy, on the spin and angular momentum relations among the different nuclear particles relating the disintegration process, and on the chance of the particles escaping through the potential barrier.

The relative probability of different types of disintegration occurring on the bombardment by particles of the same kind the factor 2) is evidently indifferent. If the colliding particle is a proton, factors 1) and 3) are also ineffective. For cases of colliding deuterons, however, the matters seem sometimes to become very complicated.

In order to find, if possible, any prevailing law that may control the probability of disintegration, it seems convenient to observe the relative yield of disintegrations of different features caused by bombardment with particles of one kind, such as, for example,



etc. respectively.

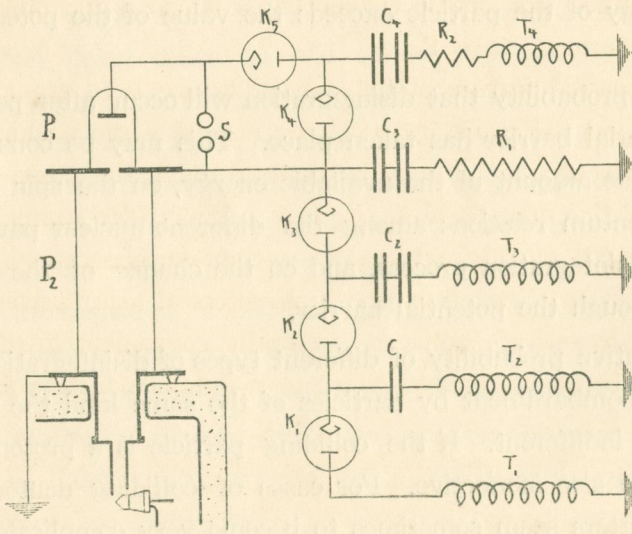
III. Experimental Procedure.

a) The High Tension Apparatus.

A compact source of high tension static voltage has been devised by using a system of kenotrons and condensers connected to a set of three equally constructed 60 K. V. X-ray transformers. (Fig. 1.)

The transformers T_1 and T_2 , the voltage of which may be independently regulated by a set of controlling autotransformers, are

Fig. 1.



excited in the opposite phase so that the voltage of the rectified side of the condenser C_1 comes, in a duration of time, to oscillate between V_1 and V_1+2V_2 where V_1 and V_2 are the maximum voltages of the transformers T_1 and T_2 respectively.

Since the kenotrons obtainable on the market can only endure, at most, up to a voltage difference of about 240,000 volts, the maximum value of V_1+2V_2 should not exceed 180,000 volts because, in the case of $V_1=V_2=60,000$ volts, the voltage of the transformer T_1 takes just the minimum value $-60,000$ volts while that of the condenser C_1 reaches then its maximum value of 180,000 volts.

So long as the transformers T_3 and T_4 are not in operation, all of the condensers C_2 , C_3 and C_4 are charged by means of the kenotrons K_2 , K_3 and K_4 up to this potential. When, however, T_3 is excited by A. C., just in the opposite phase to T_2 , (i. e. in the same phase with T_1 ,) the potential of the rectified side of the condenser C_2 alternates between 180,000 volts and 300,000 volts. The latter voltage is the highest limit obtainable, since the potential of C_1 takes the minimum value $+60,000$ volts when that of C_2 is 300,000 volts, which is the limit of the endurable voltage-difference of the kenotrons.

Actually, it was found that the static electricity of the various voltages up to 250,000 volts could be easily obtained by this method on the rectified side of the condenser C_3 which is the upper terminal of the accelerating tube P_2 .

The special feature of the present device is to provide the condenser C_4 and the transformer T_4 , by means of the pushing action of which an electric circuit may be made through the positive ray tube P_1 in the direction $C_3-K_4-C_4-K_5-P_1-C_3$. Since the running electrical apparatus with moving parts such as a motor-generator or inductor was entirely dismissed from the high potential side, it was found not only easy to operate but also essentially convenient to minimise the amount of brush discharge and so to maintain a high voltage by a

All of the condensers used in the present experiment are of oil-filled (O. F.) type (of 0.016 μ . F. capacity and 200 K. V. test voltage) manufactured by SUMITOMO SEISAKUSHO.

low power equipment such as this.

Each of the condensers, even on the earth side, was independently insulated from the earth for the highest voltage obtainable in the experiment, the earth sides of the condensers C_3 and C_4 being then earthed by means of the wide tubes of water resistances R_1 and R_2 respectively. The undue direct discharge against the earth due to the sudden change of the potential of any one of the condensers induced by an abrupt discharge through P_2 , which may otherwise often take place and strongly affect the counting system with amplifier and recorder, was found to be perfectly reduced and the experiment could be then carried out without inconvenience.

Fig. 2. a.

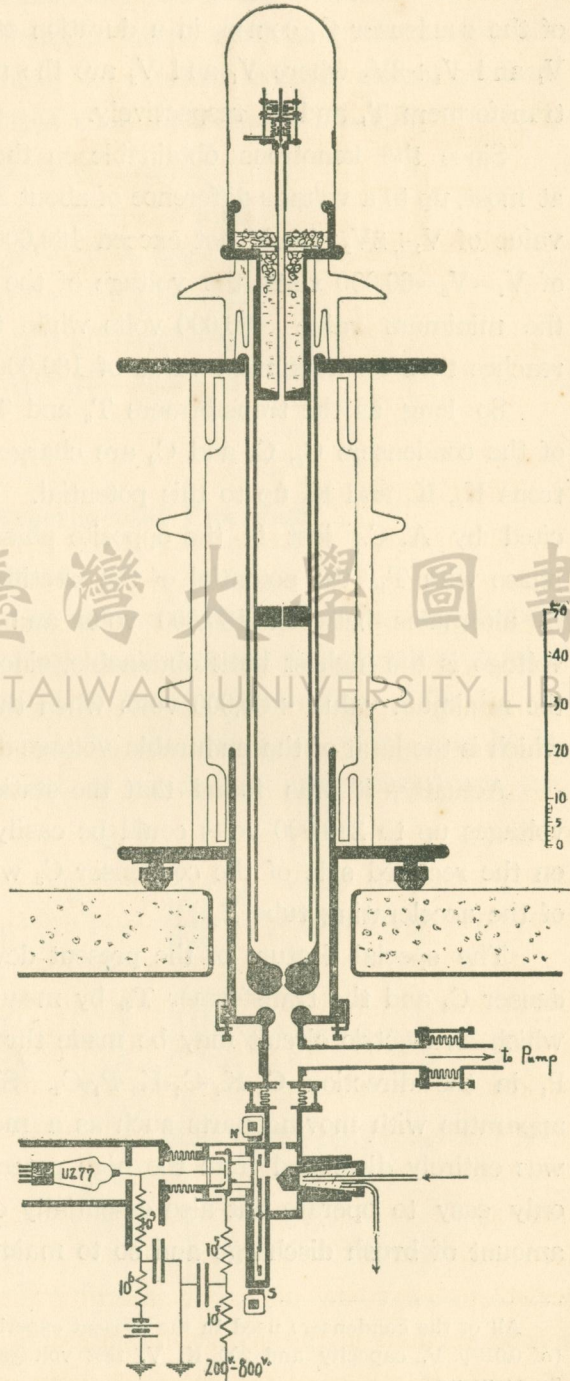


Fig. 2, b.

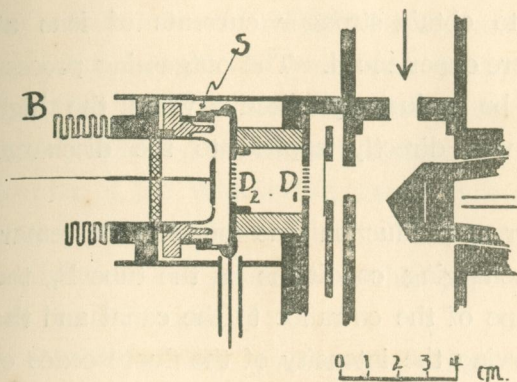
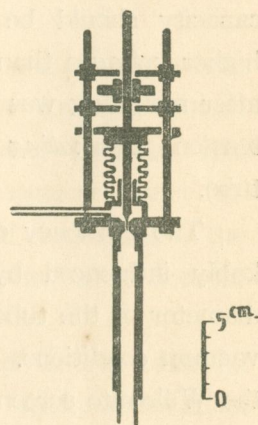


Fig. 2, c.



b) *The Positive Ray Tube.*

The positive ray tube used in this experiment is designed after OLIPHANT and RUTHERFORD⁹² and is especially intended that heavy currents of accelerated ions may run as short a distance as possible and be easily focused to the target. The dimensions and the setting conditions of the tube are as given in the annexed figure (Fig. 2). After the experimental conditions were well tested, the glass cylinder was replaced by a porcelain tube (one metre long and 37 cm across) specially designed as a protection against undue discharge, which otherwise frequently took place being caused by the bombardment of stray ions and electrons on the parts joined to the plates of electrodes.

In order to seal the joints the wax Apiezon Q was first used, but it was afterward found inconvenient for use in a tropical climate (34° C in summer) because the oil contained in the wax was slowly sucked out into the vacuum tube and it extended in a few weeks as a thin film over a considerable part of the electrodes and disturbed the favourable conditions of the tube by evolving a considerable quantity of carbon monoxide gas on discharge. Subsequently, therefore, each end of the porcelain tube P_1 (at least) was mechanically sealed to electrode plates by inserting a rubber ring. To maintain a good vacuum in the accelerating tube, a set of oil diffusion pump (P and Q in series) of the speed 20 liters per second was found con-

venient to use, it was also found, however, that a pump of larger capacity should be chosen to obtain stronger currents of ions at higher voltages than those here experienced. The outgassing process after mounting was found to be exclusively effective when the high tension, *alternating* current was directly applied to the discharge tube.

The efficiency of ion current production was found to be remarkably influenced by the discharging conditions of the tube P_1 , the diameter of the tube, the shape of the entrance to the canal and the vacuum conditions. By observing the intensity of the fluorescence of the Willemite screen or the deflection of the galvanometer connected to the Faraday box placed at the position of the target, it was found that, in the optimum condition, the pressure of the gas in the ionizing tube was relatively low, and the terminal voltage difference of this part was about 40,000 volts or more.

After the conditions had been well established, it was found that a current of 20 milliamperes or more could be conveniently allowed for producing ions in the ionizing tube P_1 and a current of ions of 10 microamperes was continually obtained in the accelerating tube.

It was arranged that, the accelerated ions should, in case of necessity, be analysed by an electromagnet which was capable of producing a field up to 20,000 gauss in a space of 1 cm distance between poles of an area of $3 \times 10 \text{ cm}^2$. In most parts in the present experiment, however, the magnet was dismissed, since, in the case of low accelerating voltage like this, the effective parts of the acting ions in causing disintegrations were taken to be atom ions and the relative probabilities of disintegration to be compared were those separately due to the bombardment of ions of hydrogen and heavy hydrogen respectively.

c) *The Counting System.*

At the stage of preliminary experiments in which the chief object was to become familiar with the general aspects of the artificial disintegration of various light elements, the scintillation method of

counting was adopted, since this method, though primitive and laborious, was found very reliable for beginners.

After experiments were made to test the function of the whole apparatus and the disintegration phenomena, this counting system was replaced by an ionization chamber with a linear amplifier and recorder of the WYNNE-WILLIAMS⁷⁾ type to which some necessary improvements have been added. Though the detailed description of the apparatus will be given in another paper, the following short account may be of interest.

Now the first troublesome thing encountered in this counting system is that it is very liable to be disturbed by slight mechanical shocks as well as by sound waves. The second is that it is naturally so disturbed by impulsive electric discharges, which may often take place in this kind of experiments, that the counting system may cease to be reliable (in its function).

These troubles, however, were shown to completely eliminated by the following precautions.

1) Each of the amplifying systems was encased in a separate box made of stout iron plates, 1 cm thick, and the rooms for tubes, coupling systems and stabilizing condensers, etc. respectively were separately provided for. All the tubes were supported by rubber belts.

2) The pentode tube UZ-77 was used in the first detecting stage, the grid of which was directly connected with the collector of the ionization chamber (Fig. 2) and its sensitivity being controlled by varying the voltage of the screen-grid in a range from 12 to 30 volts. This procedure was found very effective for the purpose. No natural back-ground fluctuation was detected on the "Zero" line of the oscillogram even when the sensitivity of the instrument was so adjusted that the kicks due to α -particles were 2 cm, the linearity of the amplifying function being maintained.

3) The most important improvement was that a "leak" of 10^9 ohms was inserted so as to lead the collector to the earth. It was found that not only no remarkable change of sensitivity was detected

by this means, but also the temporary damage to the counting function, which otherwise often took place and lasted for some seconds after an intense spark discharge had occurred somewhere in the high tension system, was entirely eliminated. The kicks due to the ordinary small sparks could be so reduced by this careful shielding and earthing device that they were scarcely observed on the oscillogram, except that a few large kicks of essentially different nature from that of ionizing particle, were sometimes observed accompanying large sparks.

One could, by this means easily count and record the number of disintegrated particles and analyse their kind with great ease even amidst noises and mechanical as well as electrical disturbances.

d) The Target System.

The target, a magnetically controlled rotating disc of aluminium absorbers, and the entrance attachment of the ionization chamber were composed in a set as shown in Fig (2).

The disintegration particles from target were often observed simultaneously from two sides at right angles to each other, one for the absorption measurement and the other for standardizing purposes, so that the change of the intensity of disintegrations due to the varying condition of the discharge tube was checked during the measurement which sometimes had a duration of time of about half an hour or more.

To avoid the undue broadening of zero lines of the oscillogram due to the electrical disturbance of the target on discharge, a perforated diaphragm D_1 was inserted between the target and ionization chamber. It was found effective even when no aluminium absorber was placed there.

It was possible to adequately modify the depth of the ionization chamber by means of a screw device at S, the cap of the chamber properly taking its position by the elastic nature of the bellows tube B. Sometimes, D_1 was covered by a thin sheet of mica and the space between two diaphragms D_1 and D_2 , the wall of which was of ebonite,

was filled by air and the pressure of this part was made controllable. The equivalent ranges of the absorbers used were first calculated by weighing and then experimentally checked by using 8.5 cm α -particles from ${}^7_3\text{Li}$ bombarded by protons.*

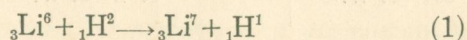
It was found that the counting system was well suited for counting α -particles when the depth of the ionization chamber was from 8 to 2 mm. the field of collecting ions being 100-150 volts per mm. For counting protons the depth should have been, at least, 5 mm to allow for a kick of about 6 mm at the end of its range on the oscillogram without losing the linearity of the amplification.

Throughout the experiment, thin targets of materials for disintegrations were used. For lithium, following the method first used by OLIPHANT and RUTHERFORD, the oxide was coated by exposing the target metal to the smoke of lithium burning in air. For boron, the thin film of borate was produced by strongly heating the target metal covered with a small quantity of borax.

IV. The Relative Probability of Different Types of Disintegration of ${}^6_3\text{Li}$ by Bombardment with Deuterium Ions.

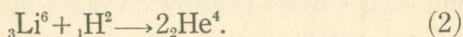
COCKCROFT and WALTON⁸⁾ reported that when a target of lithium hydroxyde was bombarded with a beam of deuterium ions accelerated by the potential of 500 K. V. the emission of a group of protons having a range of about 30 cm was observed. These particles were identified with the protons of a range up to 40 cm that had been previously observed by LAWRENCE, LEWIS and LIVINGSTON.⁹⁾

Being supported by the experiments of OLIPHANT, SHIRE and CROWTHER¹⁰⁾ on the disintegration of the separated isotopes of lithium, they suggested for the mechanism of the disintegration the reaction



* A polonium deposit, which was prepared by Mr. M. NAITO from Hokutolite an encrustation precipitated from the hot spring water of Hokuto in Taiwan, was subsequently used for the determination of the equivalent ranges.

By comparing the number of these protons with that of the well studied 13.2 cm α -particles¹¹⁾ emitted by the nuclear reaction



It was noticed that the relative probability of these different types of disintegration was not very different for deuterium ions having the energy of 500 K. E. V.

In the course of the experimental studies on the artificial disintegration of light elements by the bombardment of high speed ions, the present writers have carefully observed the variation in the relative number of these different groups of particles for a varying accelerating voltage of about 220 K. V.-100 K. V.

In the neighbourhood of this voltage the 30 cm particles were observed to be exceedingly reduced in number. At the voltage (120 K. V.) for which the 30 cm particles began to be measurably observed, the 13 cm particles were counted 20-30 times more numerous than the 30 cm particles and so the disintegrations of the type (2) were found to be 10-15 times more probable than those of this type (1).

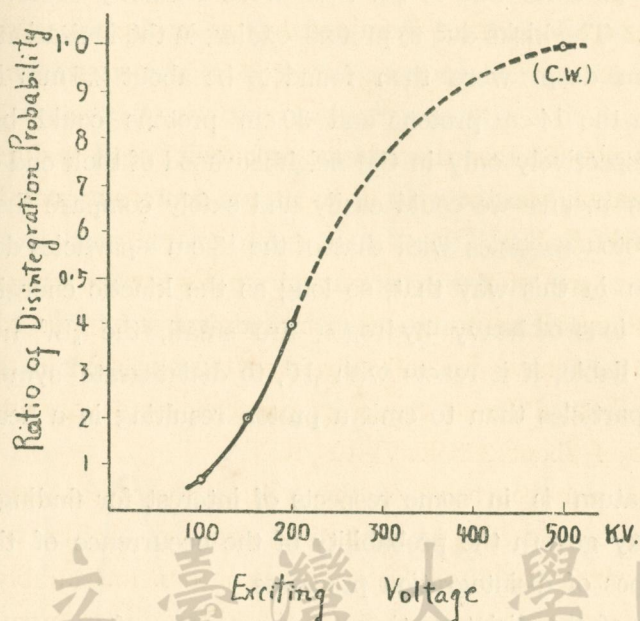
For increasing, accelerating voltages the ratio of the yields of particles was found gradually to decrease down to 5:1 at 200 K. V. (Table II).

Table II.

Exciting voltage (K. V.)	Number of 30 cm Protons	Ratio of the probability of disintegration
	Number of 13 cm α - particles	
100	1:30	0.07
150	1:10	0.2
200	1:5	0.3
.....
500 (C. W.)	1:2 (C. W.)	1.

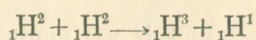
It seems, in this way, that the ratio may approach 1 at 500 K. V. as COCKCROFT and WALTON actually observed. Assuming this value, a curve showing the relation of the ratio of two disintegration probabili-

Fig. 3.

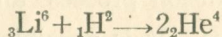


ties with the energies of the bombarding deuterons was presumptively traced as shown in Fig. (3).

On observation, special attention was paid to avoid miscounting the 14 cm particles^{12)a} due to the process



which sometimes copiously were emitted from the contaminated heavy hydrogen on the target exposed to ions for some duration of time, for the 13 cm particles due to the process



For this purpose, the disintegration phenomena of heavy hydrogen by the bombardment of ions of the same isotope was previously well studied,^{12)b} and the "kicks" on the oscillogram due to the protons were carefully observed for absorbers of various thickness.

The sensitivity of the counting system was then so adjusted that at about "9 cm" absorber the kicks of 14 cm protons due to ${}_1\text{H}^2 + {}_1\text{H}^2$ reaction could be scarcely observed on the oscillogram, while those of

the 13 cm α -particles due to ${}^6_3\text{Li} + {}^2_1\text{H}$ were distinctly observed (about 5 mm long). The kicks due to protons ending in the ionization chamber (about 7 mm deep) were then found to be about 2.5 mm in length, and so both the 14 cm protons and 30 cm protons could be clearly observed respectively only in the neighbourhood of their end of range.

By this means we could easily and safely compare the number of 30 cm proton particles with that of the 13 cm α -particles due to ${}^6_3\text{Li}$.

We see in this way that, so long as the kinetic energies of the bombarding ions of heavy hydrogen are small, the ${}^6_3\text{Li}$ nucleus is much more liable, if it reacts with ${}^2_1\text{H}$, to disintegrate symmetrically into two α -particles than to emit a proton resulting in a heavier isotope ${}^7_3\text{Li}$.

This datum is in some respects of interest for finding out any law that may govern the probability of the occurrence of these two different types of disintegration processes.

If, both of the disintegrating processes occur after an excited ${}^8_4\text{Be}$ nucleus was once made up, the law controlling the disintegration process may be considered to be either the law of maximum liberation of energy resulting in the most possibly stable atoms, or the disposition of equipartition of relativistic mass and momentum to the disintegrating particles.

Difficulties are, however, met if we want to account for by these considerations the equal probability of these two types of disintegration for higher accelerating voltages.

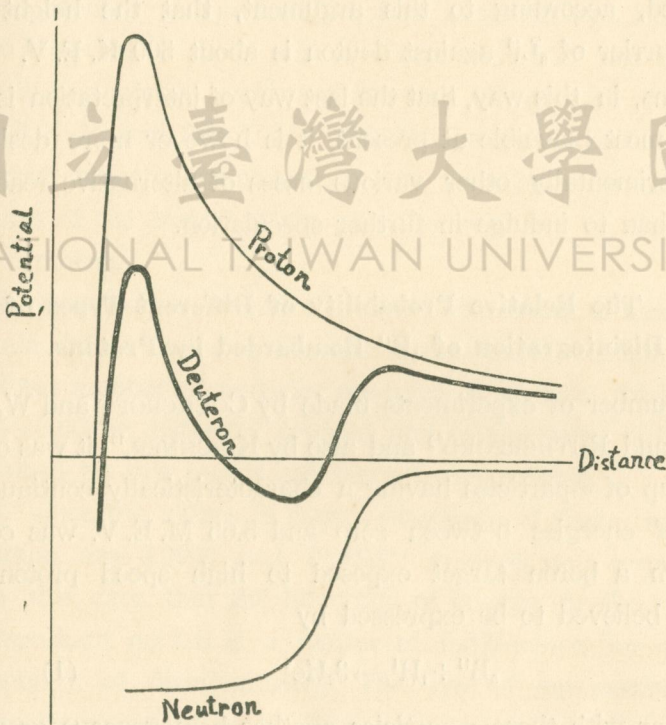
Another possible, controlling condition may be the angular momentum relation¹³⁾ in the collision process and the statistics obeyed by the disintegrating particles. It is possible, indeed, to put forward a hypothesis by presumably assigning an appropriate quantum number to the collision and disintegration process, but in the present state of knowledge, it is a thing to be reserved to the future.

Since the relative number of particles of these two different groups varies considerably with the accelerating voltages applied to bombarding ions, it may be considered that the two types of disintegration are already different in the capturing process. It seems then

that while the ${}_1\text{H}^2$ nucleus unites in the second case with ${}_3\text{Li}^6$ as a whole, once in ${}_4\text{Be}^8$, it is, in the first case, "polarised" in the nuclear field of Coulombian repulsion on the component proton and the strong attracting force on its neutron, and subsequently split up.

Indeed we know that slow neutrons are easily captured by ${}_3\text{Li}^6$ nuclei and that the cross section of a ${}_3\text{Li}^6$ nucleus for absorbing slow neutron is as large as the order of 10^{-22} — 10^{-23} cm^2 while¹⁴⁾ the radius of the potential hole for a proton is considered to be comparatively small (10^{-12} — 10^{-13} cm) and hence the proton is subject to strong repulsion up to this region.

Fig. 4.



If we show this relation in a presumptive diagram (Fig. 4) the potential curve for ${}_1\text{H}^2$ (as a whole) has a minimum in a region of relatively weak repulsion on protons and then rises once to its maximum and finally drops again into its hole.

For a relatively slow ${}_1\text{H}^2$ ion the attraction effect prevails over

the repulsion one and it unites if possible with ${}_3\text{Li}^6$ nucleus as a whole in a region in which the ${}_1\text{H}^2$ nucleus is scarcely polarised, so the probability of occurrence of the reaction in the type (1) is very small.

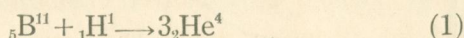
For particles of increasing kinetic energy the probability of being subject to "polarisation" becomes large and hence the probability that the neutron alone eventually will be captured into a stable state, liberating the excess of energy as the kinetic energy of the ejected proton.

For the particles of energies higher than the height of the potential barrier against ${}_1\text{H}^2$ the ratio of the probabilities of occurrences of the two types of disintegration should become stationary. It may be assumed, according to this argument, that the height of the potential barrier of ${}_3\text{Li}^6$ against deuteron is about 500 K. E. V.

It seems, in this way, that the last way of interpretation is among others the most plausible at present, it is however more desirable to study experimentally other various cases of alternative reactions of this kind than to indulge in further speculation.

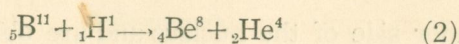
V. The Relative Probability of Different Types of Disintegration of ${}_5\text{B}^{11}$ Bombarded by Protons.

In a number of experiments made by COCKCROFT and WALTON,³⁾ OLIPHANT and RUTHERFORD⁸⁾ and also by KIRCHNER,¹⁶⁾ it was observed that a group of α -particles having a characteristically continuous distribution of energies between zero and 5.65 M. E. V. was copiously ejected from a boron target exposed to high speed protons. The reaction is believed to be expressed by



Together with these α -particles another homogeneous group of α -particles, having a range of about 4.5 cm (5.8 M. E. V. energy), was also observed in much smaller numbers (about $\frac{1}{200}$ of the total number of particles emitted from boron bombarded by protons).

It was explained by KIRCHNER that the latter group of α -particles was to be ascribed to the reaction



the mass of ${}_4\text{Be}^8$ having been then estimated to be 8.0074.

Now in the present experiment, which intends to observe the relative yield of the particles belonging to these two different groups, the number of α -particles was carefully counted for various thicknesses of absorbers by using an ionization chamber of 3 mm deep (and 0.75 cm² wide) with an improved linear amplifier and oscillograph system.

When the numbers were plotted against the thickness of the absorbers, curves of a character quite similar to that of OLIPHANT and RUTHERFORD were always obtained for various accelerating voltages.

The total number of α -particles (all of the kicks on the oscillogram were counted) counted with a 1 cm absorber was found to be about 150 times that of those with a 3.5 cm absorber. No remarkable variation in the relative yield was detected for voltages varying between 100 K. V. and 200 K. V. This fact suggests to us that these two different types of disintegration are probably due only to the mechanisms of the escape of the particles and not to the different ways of capturing.

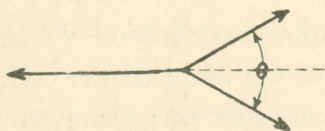
Since we could not selectively count the number of kicks superior to a certain definite amount, the distribution curve was not obtained. But the total number of particles observed at various thicknesses of absorbers could be distinctly counted and so the value of the relative yield obtained by this means are taken to be reliable.

Now, since the values of energy-liberation of these two types of disintegration are 0.0090 and 0.0091¹⁶⁾ in mass unit respectively, it seems in this case, that the liberation of energy (or the sum of the mass of resultant nuclei) is a matter of indifference for controlling the probability of disintegration. The law of equipartition of mass among the disintegrated particles seems to prevail in this case.

If we take, however, the disintegration of type (2) as a special case of the disintegration of type (1)—in which two α -particles commence to be emitted at a small angle in the opposite direction to the third one and then their relative velocities are so small that they can not escape from each other surmounting their mutual potential barrier

from the inner side of the nucleus and are obliged to remain united (probably temporally) into ${}_4\text{Be}^8$,—the probability of the occurrence of the type (2) may be interpreted as the integrated probability of the occurrence of type (1) in a region of limited angle for which the relation

$$M_\alpha V_\alpha^2 \sin^2 \frac{\theta}{2} \leq \text{Effective height of the mutual potential barrier of two } \alpha\text{-particles}$$

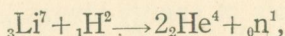


is satisfied.

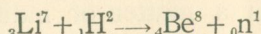
Assuming, as the experimental results of OLIPHANT and of KIRCHNER show, the maximum value of the angle $\theta/2$ to be roughly 45° ¹⁷⁾ and $\frac{1}{2} M_\alpha V_\alpha^2 = 5.5$ M. E. V., the height of the mutual potential barrier of the α -particles is to be estimated as about 5.5 M. E. V.

But since these hypothesis belong at present to no more than the field of speculation further argument is to be avoided.

It is, however, here to be noticed that investigations on the distribution of neutrons from a ${}_3\text{Li}^7 + {}_1\text{H}^2$ reaction¹⁸⁾ among various energies suggested that, besides the well-studied reaction



the reaction



took place with the relative probability of about 1%.

This fact seems closely related to the thing in the case under consideration.

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Description of the Plates.

Plate I.

- a: View of high tension equipment.
- b: Positive ray tube mounted on observation chamber. The inner surface of the chamber is completely lined with a lead plate of 1 cm thick.

Plate II.

- a: The oscillogram of the series of kicks of the disintegrated α -particles due to a ${}_{83}\text{L}^{210} + {}_1\text{H}^2$ reaction for various thicknesses of absorbers, from 8.3 cm to 15 cm air equivalent. The depth of the ionization chamber is 3 mm.

As is clearly shown, the amount of the "kicks", being equal for a definite thickness of absorber, gradually increases with the path of the particles got through. (6 mm at 11.5 cm abs.)

At 13.0 cm absorber all of the kicks of the α -particles suddenly disappear, while the kicks due to protons of a ${}_1\text{H}^1 + {}_1\text{H}^2$ reaction begin to be observed on the oscillogram. (3 mm for a 13 cm abs.)

At a 15 cm absorber no kick is observed.

- b: The oscillogram of the kicks due to 14 cm protons for the increased sensitivity of the counting system.

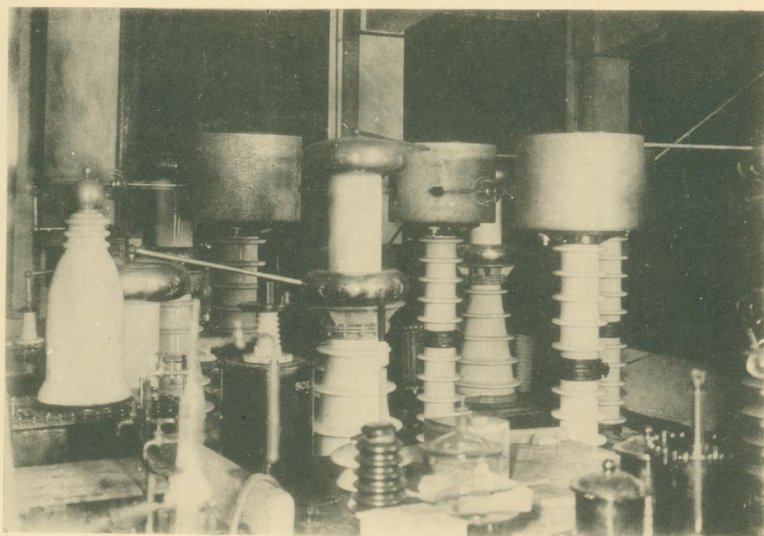
Plate III.

The oscillogram of the kicks of the disintegrated α -particles due to ${}_{10}\text{B}^{11} + {}_1\text{H}^1$ reaction. The depth of the ionization chamber is 5 mm.

- a: The comparison of the series of kicks for a 2 cm absorber for two extremely different thicknesses of boron target.
- b. and c: Number of kicks at various thicknesses of absorbers, for the exciting voltage of 200 K. V. and 120 K. V. respectively.

While the height of the kicks for a 2.5 cm absorber are clearly uneven (from 0-12 mm), all of the kicks for a 3.5 cm absorber are quite uniform (9 mm). This fact shows the existence of the perfectly homogeneous group of α -particles of the range between 3.5 cm and 4.5 cm., together with the continuous group of α -particles ending at about 3 cm.

(a)



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