tributions at sea level is remarkably good and the absorption coefficient is in good agreement with the value 0.16 deduced by Millikan and Cameron[4] from the portion of their ionization-depth curve adjoining sea level. For the Mt. Washington elevation there would seem to be a discrepancy between the observed intensities and those calculated from $\mu = 0.18$. There is, however, some uncertainty in the relative intensities as measured at the two different elevations arising from a change in the efficiency of the counters with counting rate. Although the change in efficiency was measured[1] the uncertainty of the measurement is sufficient to account for this apparent discrepancy. However, if the absorption coefficient increases with elevation as rapidly as indicated by the data of Millikan and Cameron, unaccountable differences appear between calculated and observed intensities both as regards angular distribution and relative values.

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[4] Millikan and Cameron, Phys. Rev. **37**, 235 (1931).

A Neutron of High Velocity, and Energy Relations for Nuclear Disintegration by Non-Capture

1. High velocity neutron

One of the photographs which we have obtained of the disintegration of N^{14}, by capture of a neutron from beryllium, into B^{11} and He^4 is remarkable with respect to the length of the track of the boron nucleus. The energy of the neutron which caused the disintegration is found by calculation to have been 16×10^6 electron-volts, which is about twice the value 7.8×10^6 usually[1] given for "fast" neutrons. The velocity of this neutron is found as 5.6×10^9 cm per sec. From the mass[2] 9.0155 of the beryllium atom, it is found that 6.9×10^6 electron-volts is the amount of energy given by the change of mass in the reaction with the incident α-particle, provided C^{12} is formed, or considerably less if the product is three α-particles. The α-particles used in the disintegration of the beryllium were those from Th C', which for the ordinary higher velocity have an energy of 8.8×10^6 electron-volts. Thus, if no γ-rays are emitted in the process of emission of the neutron, the total energy available is 15.7×10^6 electron-volts, or, making allowance for the kinetic energy imparted to the C^{12} nucleus, the maximum energy of the neutron should be 14.7×10^6 electron-volts. The fact that the energy found experimentally is greater by 1.3×10^6 electron-volts might be due to the action on the beryllium of a particle of higher velocity than that assumed, but is much more probably due to the fact that present knowledge of the range-velocity relations of B^{11} is not sufficiently exact to give a better agreement. The high energy found seems to indicate that the amount of energy which is transformed into γ-rays when the neutron is emitted is zero or very small.

2. Disintegration by non-capture

If the neutron is not captured, then the reaction may be:

$$N^{14}\rightarrow B^{10}+He^4,\qquad \Delta m=0.0077 \text{ mass units} \qquad (1)$$

$$N^{14}\rightarrow C^{13}+H^1,\qquad \Delta m=0.0038 \qquad (2)$$

$$N^{14}\rightarrow C^{12}+H^2,\qquad \Delta m=0.0091 \qquad (3)$$

However, (2) and (3) are excluded, at least in many of these events, by the fact that the track of the light atom has too great a line density of ions to be due to hydrogen.

The mass increase in (1) is 0.0077 as given by Aston's data. This corresponds to a gain of energy of 7.1×10^6 electron-volts. Thus the neutron must lose $(7.1\pm4.4)\times10^6$ electron-volts. The error of 4.4×10^6 electron-volts included here is the arithmetical sum of all of Aston's estimated errors, which are not likely to be all in one direction, so that the probable error is less than this.

The energy which must be supplied lies between 6 and

[1] I. Curie and F. Joliot, Nature **130**, 57 (1932).
[2] Bainbridge, Phys. Rev. **43**, 367 (1933).

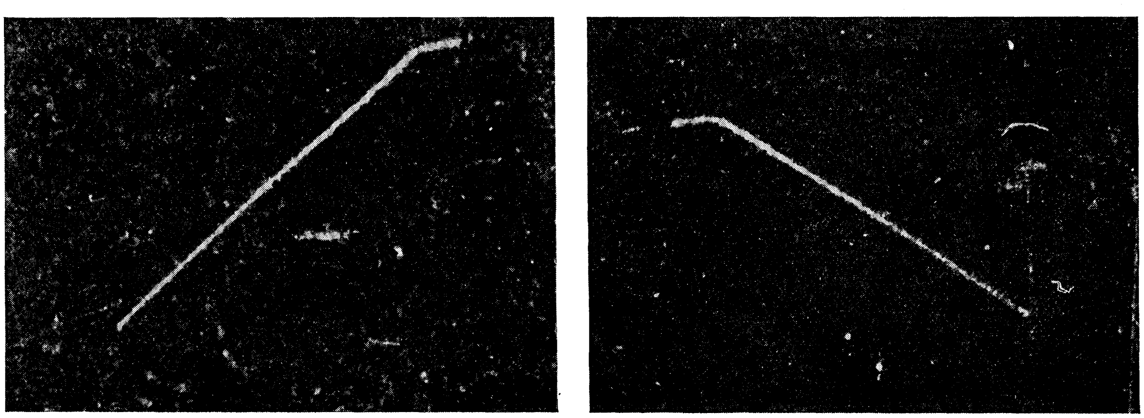

Fig. 1.

8×10^6 electron-volts if Aston's data are as accurate as is assumed by Chadwick.[3] In disintegrations of this type the kinetic energies of B^{10} and He^4 commonly amount to 1 to 3×10^6 electron-volts, so that in all about 9×10^6 electron-volts should be obtained from the loss of kinetic energy of the neutron. There is thus at present no good explanation from the energy standpoint as to how such disintegrations by non-capture are able to occur, particularly in the work of Feather, who used the comparatively slow α-particles from polonium, and thus obtained neutrons of energy 8×10^6 electron-volts.

Fig. 1 shows two views of a disintegration of a nitrogen nucleus, seemingly without capture of the neutron, since the plane of the event is such that the neutron could not have had a straight line path from the source if the event had occurred with capture.

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[3] Chadwick, Proc. Roy. Soc. **A136**, 692 (1932).

A New Kind of Radioactivity

The complexity of the process by which neutrons are produced and their energy measured invites a careful analysis of the data obtained. Such an analysis has bearing on several other problems but the present note will deal only with the application to the Be^9 nucleus. A more complete account will soon be published.

It appears that the experiments so far used to determine the upper limit to the range of protons produced by neutrons lead to an underestimate. The error may well be greater than twenty percent of the maximum range observed. It follows that Be^9 has more energy than two alpha-particles and a neutron.[1] From general considerations and especially on quantum theoretical grounds we are led to the conclusion that Be^9 should decompose spontaneously, giving off alpha-particles and possibly a neutron. If a He of mass five is temporarily stable no neutron would appear for awhile at least.

This matter has been investigated and the prediction verified. After a little trouble some radium-free Be was obtained. The activity was low enough to explain the failure of older workers to notice the effect. The contamination by the radium family as measured by radon content was less than enough to produce one percent of the activity. The thoron content showed, however, that the thorium family might have contributed twenty-five percent of the ionization measured. It can then be argued that the actinium family was also harmless. However, the question was decided definitely by range determinations with Al foils. The range proved to be about one centimeter in air and therefore quite easily distinguishable from the ordinary alpha-disintegrations.

The corresponding half-life turns out to be about 10^{14} years. This is in striking accord with the helium content of certain Beryls which has puzzled geologists since Rayleigh's[2] measurements. The explanation which has been offered for the abnormally high helium content of Beryls in terms of the radioactivity of Be^8 is now unnecessary and in fact certain strong objections can be offered against it. That is to say, we can estimate the mass of Be^8 from that of Be^9 or from the energy of the short range group of particles emitted in the bombardment of Li by protons. From these data it seems that the half-life of Be^8 would be extremely short and that this isotope could play absolutely no part in the chemistry of beryllium, it would have disappeared before any Beryl crystal could have been formed. The helium contained in Beryl may prove extremely interesting in connection with the existence of He^5. This isotope would exist in vanishing proportions in He from ordinary sources but might be a large fraction of the helium which results from the decomposition of Be^9.

Further investigations with counters and especially with the expansion chamber will, it is hoped, lead to results which will help to determine accurately the masses of the neutron and all the other light nuclei. Such information is essential to the development of the theory of the nucleus. In particular, alpha-disintegration can now be studied in an almost ideally simple case and defects in the present theory should be brought to light.

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[1] In an article which has just come to hand, K. T. Bainbridge (Phys. Rev. **43**, 367 (1933)) announces a mass-spectroscopic determination of Be^9. His value is rather higher than we predicted but it is conceivable that our present determination of range is off enough to account for the discrepancy.

[2] Cf. Bulletin of the National Research Council, *Physics of the Earth* IV, p. 405.

The Equilibrium Theory of the Abundance of the Elements

It is possible to consider by statistical mechanics an assembly containing radiation, atomic nuclei, electrons, and neutrons; when all possible transmutations of the nuclei occur without the "annihilation" of any ultimate particles. One can calculate the abundances of the nuclei of the various sorts in such an assembly, when it is in equilibrium, in terms of the atomic masses and packing fractions. The simplest procedure is possible if the nuclei

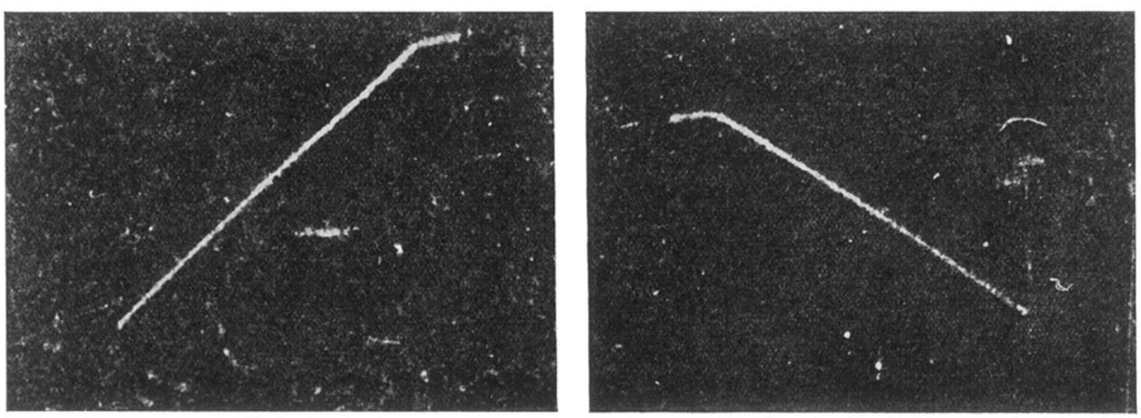

FIG. 1.