of energy is released in the disintegration process. From this it is accordingly calculated that the mass of the neutron is about 1.0006 rather than 1.0067 as estimated by Chadwick.[2]

Recognizing that our lower value for the mass of the neutron has profound theoretical implications, we have meanwhile continued our experiments with the express purpose of proving or disproving the hypothesis of the instability of the deuton. Obviously the strongest additional evidence we could obtain would be the observation of the neutrons presumably produced in the process.

This we have done. First we counted the number of disintegration protons with an ionization chamber and linear amplifier and then, with a 1/8 inch lead screen coated with paraffin in front of the ionization chamber, observed recoil protons due to neutrons from the target. From a brass target (with some wax also in view of the deuton beam) 18 cm protons entered the ionization chamber at the rate of 40,000 per minute while with the lead-paraffin screen we observed 12 recoil protons per minute. Now it has already been established by the observations of neutron-proton collision cross sections of previous workers that in a paraffin lined ionization chamber such as ours, one in several thousand of the neutrons passing through gives rise to a betectable recoil proton. Consequently, the number of recoil protons observed per minute corresponds exactly with expectations on the hypothesis that the deutons disintegrate with the production of equal numbers of neutrons and protons. In other words, the present experiments do more than support the deuton disintegration hypothesis in qualitative fashion by demonstrating the production of neutrons in the process. A quantitative check is afforded in that the yield of neutrons is as expected.

The brass-wax target (we have not as yet determined what constituent of the conglomerate target is most effective) yielded 2 disintegration protons per 10^7 deutons. Calcium fluoride and platinum gave about 4 protons per 10^8 deutons while Be gave only 1 proton per 10^8 deutons.

We raised the energy of the bombarding deutons from 1.2 MV to 3.0 MV* and were rather surprised to find that the observed proton yield did not increase a great deal. However, the range of the disintegration protons did increase quite according to expectations. From the considerations outlined above it was to be expected that they would have an energy of 2.4 MV more than the bombarding deutons, i.e., 5.4 MV. Our observations indicated a range of 33 cm corresponding to 5.2 MV which, for the present experimental accuracy, constitutes agreement.

All of these observations corroborate the view that the deuton disintegrates with the release of about 4.8 MV of energy and consequently that neutrons produced in the process have a mass of about 1.0006 mass units.

We are much indebted to Professor G. N. Lewis who collaborated with us last spring, not only for providing a generous supply of deuterium but also for his continued close association with the experiments. We acknowledge also with pleasure the assistance of Commander T. Lucci. We are especially grateful for grants from the Research Board with the approval of the President of the University and from the Research Corporation and the Chemical Foundation.

M. Stanley Livingston
Malcolm C. Henderson
Ernest O. Lawrence

Radiation Laboratory,
Department of Physics,
University of California,
October 7, 1933.

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

* These are the most energetic atomic projectiles that have ever been produced artificially in the laboratory. It is of some interest to record here also that we have recently increased the intensity of the beam of swiftly moving protons generated by our apparatus to 0.2 microampere.

Neutrons from Beryllium Bombarded by Deutons

In our recent experiments (preceding letter) we found, as a few days earlier had been observed by Lauritsen, Crane and Soltan (private communication), that Be yields many more neutrons than can be accounted for alone by deuton disintegration. With a current of 10^{-8} amp. of 1.3 MV deutons we observed 240 recoil protons per minute in an ionization chamber subtending at the Be target a solid angle of $\pi/10$. From this we estimate (assuming 3 recoil protons for every 10,000 neutrons, as indicated by the observations from the brass target) that about 500,000 neutrons were produced per sec., i.e., about 10 neutrons per 10^6 deutons. Since the proton yield is a thousand times smaller it must necessarily be concluded that the neutrons result from the disintegration of Be.

Last spring we not only observed protons from Be bombarded by deutons, but also one alpha-particle of 3.3 cm range per 10^7 deutons.[1] These we supposed resulted from the disintegration of Be^9 without capture of the deuton, resulting in the production of two alpha-particles and one neutron. But this process also does not account for the large number of neutrons observed in the present experiments.

So it appears that in this instance the neutrons result from the disintegration of Be^9 with capture of the deuton to form B^{10} and a neutron. By assuming that the mass of the neutron is 1.0006 and that no gamma-radiation is given off in the process, it is calculated that these neutrons have about 14 MV of kinetic energy. We are planning in the near future to observe the ranges of the recoil protons and thereby determine whether at least some of them have this much energy.

We found also that the yield of neutrons from Be increases linearly with the range of the deutons for deuton ranges extending from 1 cm to 9 cm. This means that the

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[1] Lewis, Livingston and Lawrence, Phys. Rev. **44**, 55 (1933).

probability that a deuton will disintegrate the Be nucleus on collision is independent of deuton energy over the observed range and that the increase in yield of neutrons with deuton range is due only to the increase of the frequency with which deutons make nuclear collisions.

It is hardly necessary to emphasize the importance of this disintegration process as a source of neutrons for nuclear research. Though the rate of production of neutrons in the present experiments exceeds considerably that of any heretofore used radioactive source, we intend to increase our deuton current to 10^{-6} amp. and thereby increase this neutron yield a hundred-fold.

Again we acknowledge our indebtedness to Professor G. N. Lewis for furnishing deuterium, to Commander T. Lucci for his assistance, and to the University Research Board, the Research Corporation and the Chemical Foundation for their financial support.

M. Stanley Livingston
Malcolm C. Henderson
Ernest O. Lawrence

Radiation Laboratory,
Department of Physics,
University of California,
October 7, 1933.

An Unusual Nitrogen Tube

Further study of the unusual nitrogen discharge described last December,[1] has led to a great improvement of the tube. In the present tube, the first negative bands are much more intense in relation to the first positive bands than they were last year. At least twelve new members of the Lyman bands of nitrogen have been discovered in this tube showing that one of the properties of the tube is a remarkable enhancement of very high vibrational levels. The Lyman bands, it may be recalled, are the $a^1\pi \rightarrow X^1\Sigma$ bands of N_2. High vibrational levels of the $B^3\pi$ level are also enhanced, and the first positive bands arising on these are present in the spectrum with a far greater relative intensity than in ordinary tubes. One of the most striking characteristics of the tube is a strong nitrogen afterglow in which bands arising on the very high vibrational states of the $B^3\pi$ level have been visually observed. The heretofore reported afterglows in nitrogen consist of bands chiefly from the B_{10}, B_{11} and B_{12} levels. Visual observation indicates that in this new afterglow, strong bands appear which originate on levels around B_{18}. Since no photographs of the afterglow have been obtained so far, the actual origin of these new bands is not accurately known. It is certain, however, that the afterglow is considerably different from the heretofore reported afterglows of nitrogen. This tube also has characteristics which are of value in auroral studies, but these will be discussed in a more detailed communication.

Joseph Kaplan

University of California at Los Angeles,
October 9, 1933.

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[1] Kaplan, Phys. Rev. **42**, 807 (1932).

On the Production of Neutrons from Lithium

It was mentioned in a previous letter to the *Physical Review*[1] that lithium, when bombarded with protons gave a measurable intensity of neutrons. The effect has since been investigated further, and a curve plotted of the yield of neutrons as a function of voltage from 400,000 to 800,000 volts, with an ion current of 20 microamperes. As in the previous measurements of neutrons, an electroscope, the inner walls of which were coated with paraffin, was used as a detecting device. The electroscope was enclosed in a lead cylinder with 5 cm walls, through which the neutrons were obliged to pass. To determine whether the effect observed was due to neutrons or to γ-rays, a measurement was made with the paraffin removed from the electroscope. The deflection without the paraffin was less than half the deflection with the paraffin, indicating that the greater part of the effect was due to recoil hydrogen particles ejected from the paraffin by neutrons. The effect observed without the paraffin is not to be attributed entirely to γ-rays, because the neutrons are capable of producing some ionization by means of recoil oxygen and nitrogen atoms produced in the air in the chamber.

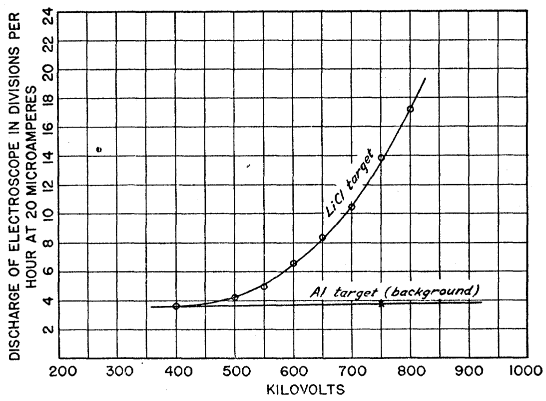

Fig. 1. Yield of neutrons from the disintegration of lithium by protons as a function of voltage

No simple and plausible reaction, which gives a neutron from lithium and a proton, suggests itself, so we have considered a double reaction in which the α-particles produced by protons and Li^7 in turn bombard Li^7 with the production of neutrons.

$$Li^7+H^1 \rightarrow 2He^4(+17\times10^6 \text{ e.v.}) \qquad (1)$$

$$Li^7+He^4 \rightarrow B^{10}+n^1(-3\times10^6 \text{ e.v.}). \qquad (2)$$

The first of these reactions is well known from the work of

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[1] Crane, Lauritsen and Soltan, *Production of Neutrons by High Speed Deutons*, Phys. Rev. **44**, 692 (1933).