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
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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.

[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.

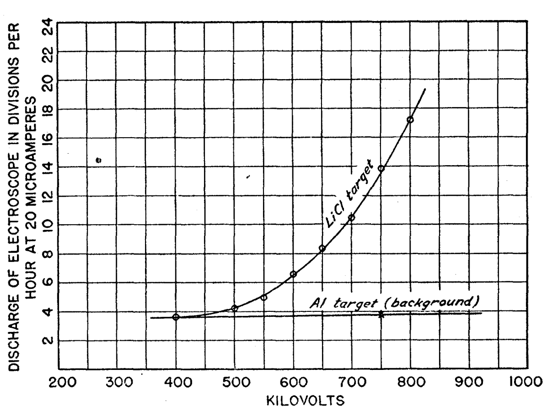

Fig. 1. Yield of neutrons from the disintegration of lithium by protons as a function of voltage

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.

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

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

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

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

Cockroft and Walton and others,[2] and the second has recently been reported by Curie and Joliot.[3] Taking, for the purpose of calculation, the mass of the neutron to be 1.0065, and the other atomic masses

Li^6	6.0145	He^4	4.0022
Li^7	7.0147	H^1	1.0078
B^{10}	10.0137	H^2	2.0136

we find that the second reaction requires 3×10^6 electron-volts energy. However, each of the α-particles produced by the first reaction has an energy of about 8.5×10^6 electron-volts, so it is to be expected that the second reaction takes place with a rather high efficiency. The efficiency of the first reaction at 800,000 volts can be obtained from the results of Henderson,[2] and is about 5×10^{-8}. The overall efficiency of the double process at the same voltage is about 10^{-11}, assuming that the factor between neutrons and recoil particles is 10^{-3}. This gives an efficiency of 2×10^{-4} for the second reaction.

A reaction suggested by Oliphant and Rutherford[2] in which lithium could give neutrons when bombarded with protons is

$$Li^7+H^1\rightarrow He^4+He^3+n^1 \quad (3)$$

although there has so far been no evidence of He^3. Since this is a three particle disintegration, the energy could be distributed at random, and each of the three products would have a continuous range of velocities. The process might therefore be used to account for some of the low energy α-particles which have been reported by several investigators, and for which there seems to be as yet no explanation except the assumption that a γ-ray sometimes accompanies the two α-particles.

In the production of neutrons from lithium by deutons, where the heavy hydrogen used to produce the deutons is very much diluted with ordinary hydrogen, the intensity of neutrons contributed by the above double process cannot in all cases be neglected. Also, in addition to the reaction

$$Li^7+H^2\rightarrow 2He^4+n^1(+16\times10^6 \text{ e.v.}) \quad (4)$$

there must be a double process involving deutons

$$Li^6+H^2\rightarrow 2He^4(+22\times10^6 \text{ e.v.}) \quad (5)$$

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

Finally, for the sake of completeness, it must be mentioned that the α-particles produced in reaction (4) are effective in contributing some neutrons by means of reaction (2).

The experimental data available at the present time on the disintegration of lithium seem entirely too meager to allow anything definite to be concluded about the various ways in which neutrons might be produced from it. An experiment which would shed considerable light on the subject would be a study of the disintegration of targets of the individual isotopes, Li^6 and Li^7.

H. R. Crane
C. C. Lauritsen

Kellogg Radiation Laboratory,
California Institute of Technology,
October 14, 1933.

[2] Cockroft and Walton, Proc. Roy. Soc. **A137**, 229 (1932). Lawrence, Livingston and White, Phys. Rev. **42**, 150 (1932). Oliphant and Rutherford, Proc. Roy. Soc. **A141**, 259 (1933). Henderson, Phys. Rev. **43**, 98 (1933).

[3] Curie and Joliot, J. de Physique **4**, 278 (1933).

The Production of High Velocity Ions and Electrons

Previous methods of producing high velocity electrons and ions may roughly be divided into two general classes, one in which the electron or ion is given its acceleration by falling through a single potential drop applied to the terminals of a discharge tube, and the second in which ions are accelerated by sending them by various means through several fields so arranged as to be in the correct direction at the proper time. In this note we wish briefly to describe a method that belongs to another class[1] in which the electron or ion is accelerated by a field which is so adjusted as to move with the same velocity as the ion or electron.

In the first method referred to above in which the ion receives its acceleration in a single electric field the upper limit to the velocity of the ion is usually set not only by the trouble of producing sufficiently high voltage but also by the difficulty of maintaining this voltage across a single discharge tube. The second class of methods avoids this difficulty as has been so beautifully shown by Lawrence and his collaborators. Up to the present time, however, these latter methods have been highly successful only in the case of ions and not in the case of electrons. The method to be described here also avoids this difficulty with the first class of methods and may be used to accelerate electrons as well as ions.

It is well known that an electrical surge will travel along an artificial transmission line with a virtual velocity that depends upon the constants of the line and may be made to vary over large ranges. For a straight parallel wire transmission line the velocity approaches to approximately that of light. If the artificial transmission line is connected to a series of electrodes in a long vacuum tube in such a way that the travelling potential fall is applied successively to the electrodes an ion or electron moving with the approximate speed of the surge or potential fall on the line will be continuously accelerated and thus may reach very high velocities.

Our preliminary apparatus consisted of a discharge tube of about 3 cm diameter and 160 cm length containing 15 ring electrodes spaced at intervals of 10 cm. The tube was terminated by a bulb partially coated with willemite on the inside for detecting the electron beam. A pair of Helmholz coils was used to measure the electron velocities by the magnetic deflection method. The electron beam was produced by applying a negative empulsive potential of approximately 28 kv between the first and second electrodes from a condenser sparkgap circuit, the second electrode remaining at ground potential. The next nine electrodes were connected to the elements of the artificial transmission

[1] A method somewhat similar to that here to be described was discussed by one of the authors (L. B. S.) with Dr. K. H. Kingdon about two years ago.