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

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

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

$$Li^7+H^2\rightarrow 2He^4+n^1(+16\times 10^6 \text{ e.v.}) \qquad (4)$$

there must be a double process involving deutons

$$Li^6+H^2\rightarrow 2He^4(+22\times 10^6 \text{ e.v.}) \qquad (5)$$

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

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.

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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.

line, the last four electrodes were grounded. A negative impulse of 15 kv was applied to this line from an auxiliary condenser sparkgap circuit. This impulse was timed to occur after the glow discharge between the first and second electrodes had started. This insured the presence of an electron beam inside of the line electrodes.

The artificial line was of the low pass filter type having inductance as the series impedance and capacitance as the shunt impedance. This type of line has a virtual velocity of current propagation of $1/(LC)^{\frac{1}{2}}$ sections per second where L and C are respectively the lump values of inductance and capacitance. The constants were chosen to give approximately the correct velocity of voltage propagation per electrode. The line was terminated by a resistance of such a value that reflections from the end of the line were negligible. It would obviously produce better results to vary the line constants in such a way that the time between sections is decreased as the wave passes down the line, but for this preliminary work the constants were approximately the same although the inductance was progressively decreased to some extent.

With this arrangement we have obtained electrons with a maximum velocity of between 80 and 90 kv. Assuming that the electrons entered the first line electrode with a velocity corresponding to 28 kv this represents a threefold multiplication. Since the glow discharge current was limited by a high resistance it is very probable that the electron beam velocity was much lower than the maximum potential appearing between the first and second electrodes, and that consequently the line was producing an even greater multiplication.

These rough preliminary experiments lead us to believe that there is no inherent difficulty in obtaining a multiplication factor of 10 or more. Since it is not very hard to construct a tube capable of withstanding surge potentials of several hundred kilovolts this method should be capable of easily producing electrons having velocities corresponding to several millions of volts. We hope to continue these experiments using voltage sources of much higher potential. It would obviously be much easier to work with positive ions rather than with electrons due to the lower velocities and correspondingly longer time intervals between sections. We have not as yet performed an experiment of this kind.

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The Faraday Effect at High Frequencies

In view of the general interest in the work of F. Allison,[1] in which the results obtained were attributed to differential time lags in the Faraday effect for isotopes of certain elements, it seemed worth while to see if such effects could be detected using continuous oscillations. The work here reported is the result of some preliminary experiments with apparatus already on hand in the laboratory. A 210 tube was used as an oscillator, followed by an 852 as an amplifier. This fed two more 852 amplifiers in parallel which were made as symmetrical as possible. The plate inductances of these surrounded cells of carbon disulphide which were placed in the optical path in the manner described by Allison. The relative phase of the magnetic fields in the two coils was adjustable over a small range near 180° by varying the coupling arrangement between the first amplifier and one of the final amplifiers. The optical arrangement was similar to Allison's except that a continuous source of light, generally Hg 5461, was used.

Since the time lags reported by Allison are small compared to the period of any feasible oscillatory circuit, conditions would appear to be more favorable at high frequencies. For this reason a frequency of 7.5 megacycles was used at first. This is about five times the resonant frequency of Allison's apparatus as computed from his published data. If we assume that the eye integrates light received over an interval as long as 1/60 of a second, and that the light transmitted by a nicol is proportional to the square of the angle of rotation from the position of extinction, we should have observed, when only one cell was in position, a brightening of the field of about the same order as that found by Allison. However no brightening could be observed. This was probably due to a departure from the square law for transmission by the nicol at small angles. The circuit constants were then changed making the frequency about 1.7 megacycles and increasing the peak rotation to be expected to about 10°. Under these conditions a definite brightening of the field was observed with either cell singly. With both cells in, the field was dark. Within the amount of phase shift available, which corresponded to a motion of the trolleys of Allison's apparatus of about 5 meters, no sudden variations in intensity were observed. This result is not considered conclusive since the rotation produced by the individual coils may have been too small.

It is considered, however, that the feasibility of the general method of investigating the effect with continuous oscillations has been established. It has the advantages of steadiness of operation and greater flexibility, for the currents in the coils may be varied independently to allow for differences in the Verdet constant, and the phase of the currents may be varied without changing their magnitude. The work is being continued by the construction of more powerful amplifier tubes which should be capable of giving greater rotation. With these we hope to investigate further the Faraday effect at high frequencies, and also the possibility that the phenomenon may be due to some type of Kerr effect as suggested by Webb and Morey[2] or to the presence of a longitudinal electric field.

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[1] F. Allison, J. Chem. Ed. **10**, 71 (1933) and references there cited.

[2] Webb and Morey, Phys. Rev. **44**, 589 (1933).