the assumption of close packing of spheres is given by $a=1.33(M/\rho)^{\frac{1}{3}}$ where M is the molecular weight ρ the density and a is in Angstroms. At smaller angles the intensity should drop, approaching a finite value as $\phi\rightarrow 0$.

With this in mind filtered Mo $K\alpha$ radiation has been scattered from nitrogen at a pressure of 1270 lbs./in.^{2} at 21°C. This corresponds to a density of 0.10 g. cm^{-3}. According to Eq. (1) ϕ_m should be about 5° 45′ at this density. A very definite angle of scattering was obtained by the use of crossed Soller slits in both the primary and scattered beams, giving a maximum angular divergence of about 0.5°. This, of course, greatly reduces the intensity. A further difficulty is the fact that for the windows of the scattering cell to be strong enough to withstand the pressure they must also be so thick that the scattering from the windows is comparable in intensity with that from the gas, and as the scattering from the windows can enter the ionization chamber at small angles the background is rather large.

Although the intensity was excessively weak it has been possible to show that there definitely is a rather flat maximum at about 6° below which the scattering decreases somewhat, apparently approaching a finite value at very small angles, in (at least qualitative) agreement with Debye's theory. The scattering has not been measured below 1.5°.

The work is being continued and more complete details will be given later with, it is hoped, data at both higher and lower pressures.

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May 15, 2934.

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The Acceleration of Electrons to High Energies

The general method of accelerating ions to high velocities[1] by means of electrical fields that effectively move with the same speed as the ion has been adapted to the special case of the acceleration of electrons. In the previous work the ions were accelerated with "moving fields" obtained by connecting a series of short cylindrical electrodes, mounted in a long evacuated discharge tube, to points on a transmission line in such a way that a potential surge travelling on the transmission line was applied to the electrodes in succession. The transmission line was so designed that the electric field, produced between each pair of electrodes in succession by the potential surge on the line, travelled with effectively the same speed as the ion being accelerated along the axis of the tube. By this means protons with energies corresponding to several million volts have been obtained without the use of very high electrical potentials.

The acceleration of electrons by this method presents a somewhat unique problem because of the very high speed they attain in falling through comparatively modest potentials. For example, a 10^5 volt electron moves 1.65×10^{10} cm/sec. while a 10^6 volt electron moves over 94 percent the velocity of light. Therefore after the energy of the electron has attained say a million volts a transmission line should be used that will permit the potential surge to travel with almost the velocity of light. This of course necessitates a line with very small "loading" or "tapering." Attempts are under way in this laboratory to test the feasibility of this general type of line. Fortunately there exists a quite obvious and simple extension of the above method that can make an electric field "move" down the discharge tube with an effective velocity even greater than the velocity of light if such were desirable. Instead of applying the potential surge to the electrodes in the discharge tube in succession by a single transmission line the potential may be applied by means of a number of different transmission lines of increasing lengths each attached to a separate electrode. In our present apparatus 4 cylindrical aluminum electrodes 5 cm long and 1 cm internal diameter are mounted along the axis of a glass tube 2.2 cm in diameter at intervals of 60 cm. One end of the tube is sealed by a metal cap in which is mounted a tungsten filament heated by an insulated storage battery. The electrons from the hot filament (field emission might also be used) are accelerated along the axis of the tube through the 4 electrodes and into a grounded chamber where they impinge upon a fluorescent screen. Their velocity is measured by their deflection in a uniform magnetic field. The McLeod gauge showed a "sticking vacuum." The source of potential consisted of a small Van de Graaff generator constructed according to a design of Tuve. This generator applies a potential across a condenser, one side of which is grounded, until a discharge occurs between two metal spheres 25 and 40 inches in diameter (it may be noted that a Marx or impulse generator should serve equally well for the source of potential). The electric impulse or surge produced by the discharge between the spheres is applied simultaneously to five transmission lines. The end of the first transmission line is attached to the metal cap in which the hot filament is mounted while the ends of each of the 4 other lines are attached to the respective remaining cylindrical electrodes. A negative potential surge upon its arrival at the end of the first line lowers the potential of the filament and produces a field that accelerates the electrons toward the first cylindrical electrode. When the "blast" of electrons reaches the first cylindrical electrode the negative potential surge on the second transmission line is made to arrive at this same electrode. This in turn produces a field between the first and second cylindrical electrodes so that the electrons are again accelerated. The remaining three transmission lines were so adjusted that the potential surge was applied to the second, third, and fourth cylindrical electrodes,

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[1] Beams and Snoddy, Phys. Rev. **44**, 784 (1933); **45**, 287 (1934); Ham and Beams, Washington Meeting, 1934.

respectively, at the proper times to give the moving electrons maximum acceleration. The end of the last line was grounded through a resistance to prevent "floating" while the ground wires were attached to the grounded side of the condenser. By means of the above arrangement with a spark gap distance between the spheres corresponding to 300,000 volts we have obtained electrons with energies of 1.3×10^6 volts, i.e., each transmission line effectively adds 260,000 volts to the energy of the electrons or 86 percent of the spark gap voltage. In view of these first results we believe that with an extension of this method in which a larger number of transmission lines are used it may be possible to secure electron energies of many times that already obtained. However, it should not be overlooked that the potential surge or wave produced by a spark in air has a finite slope and that the total effective surge impedance of the lines decreases with increasing number of lines so that for the present condenser spark gap system the number of lines cannot be advantageously increased beyond a certain limit. Yet on the other hand the potential increases at reflection at the end of each line. Also some recent measurements made by Mr. J. W. Flowers in this laboratory indicate that potential surges many times steeper than those produced by an ordinary spark in air can be obtained.

It is a pleasure to record our indebtedness to Dr. L. B. Snoddy for many helpful discussions and to the Virginia Academy of Sciences for a grant that made possible the construction of the Van de Graaff generator.

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H. Trotter, Jr.

Rouss Physical Laboratory,
University, Virginia,
May 17, 1934.

The Mass of the Neutron from the Nuclear Reaction $H^2+H^2\rightarrow He^3+n^1$

In recent experiments by Oliphant, Harteck and Rutherford,[1] and by Dee,[2] compounds containing H^2 were bombarded with deutons of energies up to 0.1 m.e.v. In addition to two groups of charged particles, neutrons were observed in large numbers. This neutron emission was best accounted for by assuming the process

$$H^2+H^2\rightarrow He^3+n^1. \tag{1}$$

The He^3 was not detected; however momentum considerations based upon the measured neutron energy lead to an expected range for the He^3 particles of only 5 mm, a range too short to be observable in these experiments.

One notes that the mass-energy relation of Eq. (1) may be used for a determination of the mass of the neutron. Thus:

$$n^1=2H^2-He^3+T(H^2)-T(He^3)-T(n^1). \tag{2}$$

The mass of He^3 has been obtained[1, 3] from the reaction

$$Li^6+H^1\rightarrow He^3+He^4. \tag{3}$$

Hence, if we assume the validity of process (1), the measurement of the mass of He^3 from (3), the absence of gamma-ray emission in both (1) and (3), and an accurate measurement of the neutron kinetic energy, reaction (1) yields an accurate value for the mass of the neutron.

However, Oliphant, Harteck and Rutherford obtained two different values of the He^3 nuclear mass;

(a) $He^3=3.0155$ if the Li^6 nuclear mass equals 6.0129 ±0.0003 as obtained by Bainbridge,[4]

(b) $He^3=3.0167$ if the Li^6 nuclear mass equals 6.0141[5] as obtained from the data[6] of the reaction

$$Li^6+H^2\rightarrow 2He^4. \tag{4}$$

The maximum neutron energy was measured by Oliphant, Harteck and Rutherford, and by Dee as about 2 m.e.v. From momentum considerations, neglecting the impulse of H^2, the kinetic energy He^3 equals 0.7 m.e.v. The mass of H^2 is 2.0131; its kinetic energy is 0.1 m.e.v. The mass of the neutron is, therefore,

(a) 1.0079 if Bainbridge's Li^6 is used,

(b) 1.0067 if the Li^6 is taken from (4).

The emission of gamma-radiation from lithium bombarded by protons has been observed.[7] If this is associated with (3), the mass of He^3 may be lowered and that of the neutron raised. No study of gamma-ray emission for (1) has yet been reported.

The purpose of this letter is not to stress the specific values of the neutron mass above, but to point to the likelihood that reaction (1) may lead to a reliable value of the neutron mass.

H. H. Goldsmith
Victor W. Cohen

Columbia University,
New York, New York,
May 17, 1934.

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[1] Oliphant, Harteck, and Rutherford, Nature **133**, 413 (1934): Proc. Roy. Soc. **A144**, 692 (1934).

[2] Dee, Nature **133**, 564 (1934).

[3] Wu and Uhlenbeck, Phys. Rev. **45**, 553 (1934).

[4] Bainbridge, Phys. Rev. **44**, 56 (1933).

[5] The probable error is not given by *O*, *K*, *R*, but we estimate it from their data to be about ±0.0002 m.u.; hence we retain both values of the mass of He^3 in the calculation.

[6] Oliphant, Kinsey, Rutherford, Proc. Roy. Soc. **A141**, 722 (1933).

[7] R. v. Traubenberg, Eckardt, and Gebauer, Naturwiss. **21**, 694 (1933); Crane and Lauritsen, Phys. Rev. **45**, 63 (1934).