would correspond to no exchange), and casts some doubt on the surmise that the coupling should be positive, in the alpha-model. Since both models agree that the ground state of N_{15} is a ^2P, which is, experimentally, a $^2P_{\frac{1}{2}}$, its magnetic moment is $(2\mu_L-\mu_S)/3$. This is $-0.3\mu_N$ in the central model[3a] with $g_L=1$, and about $-0.6\mu_N$ in the alpha-model (near the "former extreme") with $g_L\approx 1/2$, and $\mu_S=\mu_\pi$. Since, furthermore, the data on the odd-proton nuclei indicate a tendency[18] for μ_S to be rather near μ_π, especially for the lighter nuclei, and for g_L to be almost unity, one should expect at least to find the N^{15} magnetic moment rather small and negative.

The theory of spin-orbit coupling and the consequent nuclear magnetic moments in the alpha-model will be the subject of a future paper by Sachs, Goeppert-Mayer and Teller.

Thanks are due especially to Professor Rabi, Drs. Zacharias and Kellogg, Professors Wood and Dieke for advance experimental information and to Professors Breit and Teller for discussions.

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The Emission of Secondary Electrons from Metals Bombarded with Protons

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A study has been made of the yield of secondary electrons from various metals bombarded with protons. For metals that have not been outgassed the secondary electron-proton ratio was about three for protons having energies between 48 and 212 kev. The ratio from outgassed targets of C, Cu, Ni and Pt was about two for protons of the same energies as above. Be gave a yield of about 7.5 electrons per proton. The secondary electron yield was found to be proportional to the cosecant of the angle between the proton beam and the target.

Introduction

In recent years little work has been done on the emission of secondary electrons from metals bombarded with protons. Healea and Chaffee[1] have investigated the secondary emission from thick Ni targets bombarded by protons having energies up to 1600 electron volts. For a hot target the secondary electron-proton ratio increased with the energy of the protons and reached a value of about 22 percent at 1600 volts. Moreover, the ratio increased to 90 percent for targets that had not been outgassed by heating. Schneider[2] has investigated the energy distribution of the secondary electrons ejected by the passage of protons through very thin films of Au and Al. The secondaries produced by 23 and 53 kev protons had a continuous energy distribution with a broad peak at about 20 to 40 electron volts. The total number of electrons ejected from thick targets of Au, Cu and Al placed at an angle of 90 degrees to the proton beam was also determined. The secondary electron-proton ratio for the three metals had a value of approximately four. This ratio did not change as the energy of the protons was varied from 23 to 53 kev. These targets were not outgassed by external heating, but merely by the local heat produced by the proton beam hitting the metal surface.

Because of the lack of information concerning the electron yields from outgassed metals bombarded by protons of greater energies a study was made of the emission from various metals that could be outgassed by heating.

Apparatus

A transformer-kenotron set supplied voltages up to 250 kev to a five-section accelerating tube described by Williams, Wells, Tate and Hill.[3] A resistance-type voltmeter was used to measure the accelerating voltages. After magnetic analysis the proton beam passed through a number of slits into the long Faraday cage shown in Fig. 1. The end of this cage was covered with a glass

[1] Monica Healea and E. L. Chaffee, Phys. Rev. **49**, 925 (1936).
[2] G. Schneider, Ann. d. Physik **11**, 357 (1931).
[3] J. H. Williams, W. H. Wells, J. T. Tate and E. L. Hill, Phys. Rev. **51**, 434 (1937).

plate so that the position of the proton beam could be seen by the pale blue fluorescence caused by the protons striking the glass. In order to prevent the collection of surface charges the glass was covered by a coarse mesh, copper screen.

The target was a Ni cylinder, one inch in length, and having a square cross section with the sides $\frac{5}{8}$ inch wide. By means of a tungsten coil inside this cylinder the target could be heated to a bright red color. Targets other than Ni were hung on the forward surface of the cylinder. Both the secondary and primary currents were measured by the same galvanometer, *G*. When the double-throw switch was thrown to the right, the target and the Faraday cage were connected together and the proton current alone was measured. With the switch to the left the net electron current from the target to the collecting cage was measured.

The accelerating tube was operated at a pressure of approximately 5×10^{-5} mm of Hg. The fact that the observed ratios did not change when this pressure was tripled indicated that the pressure was sufficiently low. The position of the proton beam on the target could be adjusted by moving the Faraday cage and target with respect to the main accelerating tube until the beam did not show on the glass end of the tube. It was possible to focus the beam sharply enough to make a spot $\frac{1}{8}$ inch in diameter on the glass plate at the end of the tube. For most of the measurements proton currents of from two to three microamperes were used.

Results

Before attempting to measure the yield of secondary electrons from various metals it was necessary to determine whether or not the voltage between the collector and the target was sufficient to remove all the secondaries from the

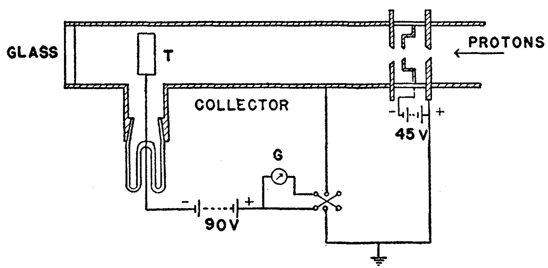

FIG. 1. Diagram of the target assembly.

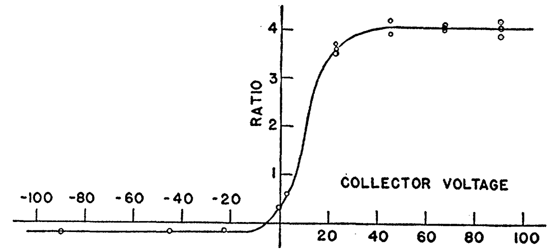

FIG. 2. The secondary electron-proton ratio from Al as a function of the collector potential. The energy of the protons was 120 kev.

target. This was done by keeping the proton current constant and recording the current to the collector as this voltage was varied. Fig. 2 shows the relation between the collector potential and the ratio of the collector current to the proton current for a target of sheet Al. The target was not outgassed, but was bombarded until consistent readings were obtained. It is evident that when the collector was 45 volts positive with respect to the target, a saturation current was produced. The measured collector current was the difference between the number of electrons leaving the target and the number of protons either scattered from the target or missing the target and consequently reaching the collector. By making the collector sufficiently negative to return all electrons to the target, the positive current from the target to the collector was measured. According to Fig. 2 this was about 20 percent of the proton current. However, this current was the sum of the number of protons from the target and the number of electrons going from the collector to the target. Later results showed that about three electrons were ejected by every proton hitting the collector. Thus, the measured positive current to the collector was at least four times the actual current of protons. Thus the number of protons scattered from the target or missing the target was about five percent of the proton current bombarding the target. When the switch was in the position necessary for recording the proton current to the target, both this current and also that to the collector was actually measured. Consequently, it was necessary to correct the observed values by subtracting about five percent.

As a preliminary investigation, the yields of secondaries from targets of Be, C, Al, Cu, Ni and

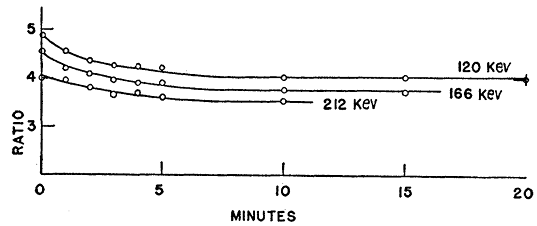

FIG. 3. The variation with time of the secondary electron-proton ratio from a Ni target that had not been outgassed. The proton currents were held constant at three microamperes.

Pt that had not been outgassed were determined. In each case the target was a circular disk placed at an angle of 45 degrees to the proton beam. By means of a ground joint the target could be rotated so as to present a fresh surface to the beam. Fig. 3 shows the variation of the yield with the time that the target had been bombarded. The decrease in the yield during the first ten minutes is typical of all the metals studied. This was caused by the local outgassing of the target by the proton beam. All the metals studied showed a similar decrease with time. The yield showed a slight increase with decreasing energy of the protons. Within the experimental error, all the metals studied had a secondary electron-proton ratio of about four for protons of 120-kev energy.

Since the yield appeared to depend strongly upon the amount of outgassing undergone by the metal, it was considered important to investigate targets that were well outgassed. The target arrangement shown in Fig. 1 was used. The targets were heated to a bright red color and readings taken after the pressure in the system had returned to its normal value. For all metals studied other than Be the yield dropped during the first ten minutes of heating and did not change appreciably after continued heating. The secondary yield from Be rose to about 7.5 after it had been brought to a red color for ten minutes. Prolonged heating did not alter this value. The Be targets were formed by evaporation of the metal in a vacuum onto sheets of copper or nickel. The same yield was obtained from a plate of solid Be ground flat and merely polished with fine emery cloth before it was introduced into the vacuum system. The carbon targets were formed by coating a piece of sheet copper with Aquadag. Table I gives the secondary electron-proton ratio for targets perpendicular to the beam. The ratio appeared to be independent of the energy of the protons in the range between 48 and 212 kev. Some rough measurements for protons having energies as low as 20 kev indicated that the ratio had not changed appreciably at this voltage.

TABLE I. *The secondary electron-proton ratio from outgassed targets placed at an angle of 90 degrees with the proton beam.*

Proton Energy kev	Be	C	Cu	Ni	Pt
48				1.7	
72	7.3	2.3		1.8	
120	7.6	2.3	1.8	1.7	2.4
166	7.5	2.1	1.8	1.7	2.2
212	7.8	2.0	2.1	1.9	2.1

In order to study the yield of secondary electrons as a function of the angle between the proton beam and the surface of the target, the target shown in Fig. 1 was replaced by one of sheet nickel one inch long and $\frac{7}{8}$ inch wide. This target could be rotated through a ground glass joint. Since it was impractical to heat the metal, the target was bombarded at each angular position until the secondary yield reached a constant value before readings were taken. It was found that for angles less than 20 degrees the effective width of the target was so small that an appreciable amount of the beam showed upon the glass at the end of the tube. Consequently no readings were made at angles smaller than this value.

Figure 4 shows the secondary yield as a function of the angle between the proton beam and the surface of the target. The solid circles represent the experimental values while the open

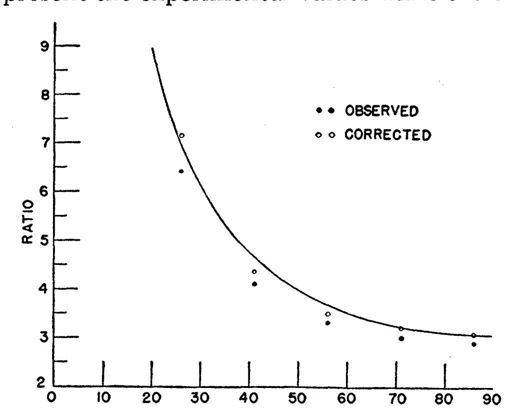

FIG. 4. The secondary electron-proton ratio as a function of the angle between the proton beam and the surface of the target. The energy of the protons was 120 kev.

circles represent the values corrected for the fraction of the beam of protons that either missed the target or were scattered from it. The curve is a plot of the function $R=3 \csc \theta$, where θ is the angle between the proton beam and the surface of the target.

Conclusion

The disagreement between the value of three obtained in the present experiment and that of four obtained by Schneider as the value of the secondary electron-proton ratio from thick targets perpendicular to the proton beam probably may be explained by a difference in the outgassing of the targets. If a very small proton current were used, the ratio would decrease very slowly with time and thus would remain near the value obtained when the metal was first exposed to the beam.

The high yield obtained from Be after a short heating is similar to the results obtained recently by Kollath[4] for Be bombarded by electrons. He investigated very carefully the effects of heating and oxidizing upon the secondary electron-primary electron ratio. The value of 0.5 or 0.6 obtained for this ratio from a freshly evaporated target was raised to about 5.5 when the target had been heated at a temperature of about 700 degrees centigrade for a few minutes in a good vacuum. The same results were obtained by heating the metal in an atmosphere of oxygen. Kollath attributed the increased yield not to the formation of a layer of oxide upon the surface, but to a change in the crystal structure of the surface.

The variation of the yield with the angle between the target and the proton beam may be explained at least qualitatively by assuming that the secondaries that are able to reach the surface are produced along a part of the proton path near the surface in the metal. Then the efficiency of the production of the secondaries will be constant for this very short distance. As the angle is decreased, more and more of the total path of the protons becomes effective in producing secondaries according to a $\csc \theta$ law. This is true only if the penetration of the incident particles is much greater than that of the secondaries which is clearly true in the present case. Müller[5] gives a similar explanation for the angular dependence of the yield of the secondaries created by electrons having energies of a few thousand volts.

In conclusion, the author wishes to express his gratitude to Professor J. H. Williams for placing the facilities of the nuclear research laboratory at his disposal and for many helpful discussions during the course of this investigation.

[4] R. Kollath, Ann. d. Physik 33, 285 (1938).

[5] H. Müller, Zeits. f. Physik 104, 475 (1937).

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The Scattering of Slow Neutrons by Gaseous Ortho- and Parahydrogen: Spin Dependence of the Neutron-Proton Force

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Room temperature and liquid-air neutrons have been scattered by gaseous ortho- and parahydrogen at 90°K. The results check with those of Brickwedde, Dunning, Hoge and Manley for liquid hydrogen if reasonable allowances are made for the Doppler effect of the motion of the scattering H_2 molecules.

I. Introduction

As Teller[1,2] has pointed out, the different orientations of the protons in ortho- and parahydrogen must affect the scattering of slow neutrons by these molecules if the neutron proton scattering is dependent on the relative orientations of the spins of the neutron and the proton. A second point is that the absolute magnitude of the elastic scattering cross sections must also

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[1] E. Teller, Phys. Rev. 49, 420 (1936).

[2] J. Schwinger and E. Teller, Phys. Rev. 52, 286 (1934).