The Relative Secondary Electron Emission Due to He, Ne, and A Ions Bombarding a Hot Nickel Target

MONICA HEALEA AND CHARLOTTE HOUTERMANS*
Vassar College, Poughkeepsie, New York

(Received June 17, 1940)

The number of electrons emitted per positive ion from a degassed Ni target bombarded by He, Ne, and A ions was measured. For He, in an energy range from 450 to 1650 ev the emission increased from 49 to 107 percent; for Ne having energies from 900 to 1275 ev the increase was 43 to 57 percent; for A of 680 to 1480 ev from 11 to 18 percent. These results confirmed those found earlier for H_2^+ and D_2^+ ions in showing a smaller emission for the heavier ion at the same energy. Similarly, the percentage of positive ions reflected increased with the energy of the primary ions and was smaller for the heavier ions.

SECONDARY electron emission from thoroughly degassed metal targets bombarded by positive ions of low energies has been little studied. Jackson's work,[1] in which beams of Na, Rb, and Cs, ions from Kunsman sources were used to bombard a Mo target, showed for Na^+ an electron emission of about 2 percent at 1000-ev ion energy, for Rb^+ no electron emission within experimental error, and for Cs^+ a secondary emission of about 9 percent. Oliphant[2] found that the He^+ ions impinging on a Mo target the emission varied with the energy of the ions from about 8 percent to 70 percent in an energy range from 80 to 1000 ev, with two decreases in slope of the emission-energy curve as the energy increased. Healea and Chaffee[3] obtained a nearly linear increase of emission with energy when a hot nickel target was bombarded by H_2^+ ions of energy ranging from 300 to 1000 ev, and one of the present authors,[4] in a comparison of the effect of using H_2^+ and D_2^+, found a smaller emission from nickel for the D_2^+ than for H_2^+ ions of the same energy in about the same energy range as that previously used.

On the other hand, A. G. Hill, W. W. Buechner, J. S. Clark, and J. B. Fisk[5] obtained results with H_1^+, H_2^+, and He^+ ions having energies in the range from 43 to 426 kev which indicated that for particles of the same energy in this high energy range the emission was nearly proportional to the mass of the bombarding particle. Further studies have therefore been undertaken with He, Ne, and A ions in the lower energy range.

APPARATUS AND PROCEDURE

The essential parts of the tube and the vacuum system were the same as previously described. A beam of ions, drawn from a discharge, was accelerated through a collimating canal and bent by an electric field to strike a target in a bulb whose platinized inner surface acted as collector for the secondary electrons and the reflected positive ions. The impinging ions were probably largely singly charged, since Oliphant who used a magnetic deflection method in conjunction with a similar tube reported his results as due to a He^+ beam. In the electrical circuit the batteries supplying the discharge and accelerating voltages were replaced by transformers, rectifiers and stabilizing devices. The discharge part of the circuit used three Westinghouse WL-706 stabilizing tubes, the accelerating part a circuit described by letter to the first of the present authors by Dr. R. W. Hickman of Harvard University and later reported in *The Review of Scientific Instruments*.[6]

The target box, containing as before a tungsten filament enclosed in a quartz tube, was kept at a bright red heat in the vacuum as near to the melting point as was considered safe for about two months. All thermionic emission of positive

* Research assistant in physics.
[1] W. J. Jackson, Phys. Rev. **30**, 473 (1927).
[2] M. L. E. Oliphant, Proc. Roy. Soc. **A127**, 373 (1930).
[3] Monica Healea and E. L. Chaffee, Phys. Rev. **49**, 925 (1936).
[4] Monica Healea, Phys. Rev. **55**, 984 (1939).
[5] Hill, Buechner, Clark, and Fisk, Phys. Rev. **55**, 463 (1939).
[6] F. V. Hunt and R. W. Hickman, Rev. Sci. Inst. **10**, 6 (1939).

ions then ceased and reproducible values of secondary emission for helium could be obtained. The final values of the emission were taken at a somewhat lower temperature. At the higher temperature, after a steady state had apparently been reached, there occurred a sudden and permanent increase of about 10 percent in the emission. This was probably caused by a change in the metal surface due to recrystallization. The temperature was lowered to reduce the chance of further change. Thereafter there was no evidence that the state of the surface was not constant during the observations on the three gases.

The difficulty previously encountered in maintaining a beam of H_2^+ and D_2^+ ions, due to the disappearance of the hydrogen, was certainly as great with helium, somewhat less in the case of argon, and much worse in the case of neon. These gases must therefore have a greater adsorbability at some surface in the vacuum system than is usually attributed to them.

Another difficulty arose in obtaining the values of the emission in the cases of neon and argon. When a new supply of gas was let in after each disappearance the emission of electrons rose sharply and then fell gradually to a minimum

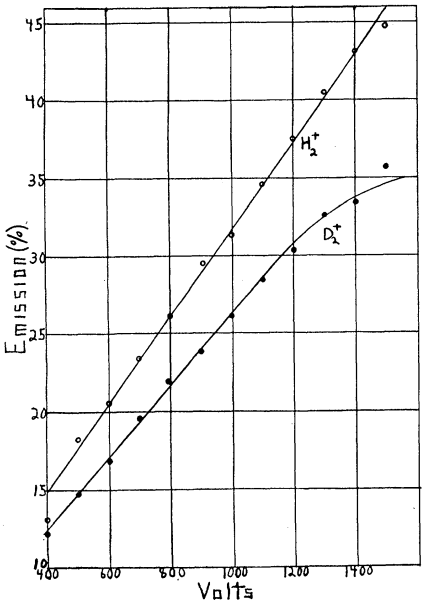

FIG. 1. Variation of the secondary electron emission with the positive ion energy expressed in volts. Values for He, Ne, and A.

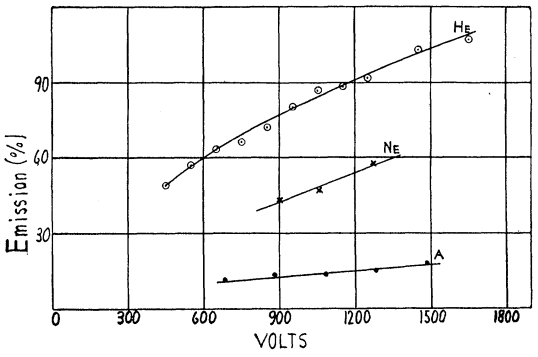

FIG. 2. Variation of the secondary electron emission with the positive ion energy expressed in volts. Values for H_2^+ and D_2^+.

value as readings were obtained at a constant ion energy. These minima could be accurately reproduced and the behavior was as if neon and argon were adsorbed even on the hot target and were knocked off by the beam until the minimum value obtained represented the emission from the metallic surface. This was surprising but it was difficult to attribute the effect to an impurity since the three gases, obtained as spectroscopically pure from the Linde Air Products Company, were let into the system in the same way and without any disturbance of the vacuum. Any foreign substance would have been present in the case of helium also. It is believed that further studies on the adsorption of noble gases on metals would be valuable.

Fewer values were obtained for neon and argon than for helium ions, partly because of the difficulty of maintaining a neon discharge, and partly because the resistance of the filament cathode of the discharge increased with use to such a marked degree that it was necessary to get a few data for these ions before the filament burned out. The conclusions to be drawn on the variation of the results with mass and energy of the ion are, however, unmistakable.

RESULTS

The curves showing the number of secondary electrons knocked out of the target per He, Ne, and A ion are shown in Fig. 1 plotted as percent against the energies of the ions expressed in electron volts. The deviations were nearly all well under 1 percent and the largest was 3 percent. In Fig. 2 are shown the curves for H_2^+

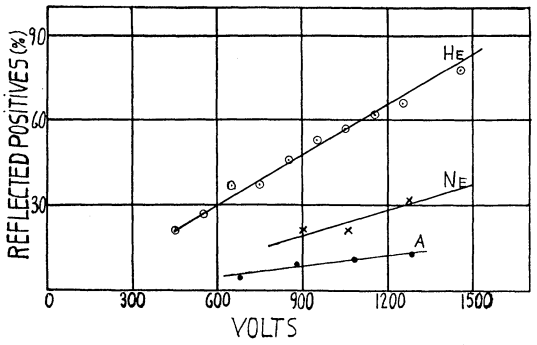

FIG. 3. Variation of the positive ion reflection with the primary positive ion energy expressed in volts. Values for He, Ne, and A.

and D_2^+ already reported in a letter to the *Physical Review*.[4] A rough test with a magnet showed that the beams in these cases consisted largely if not entirely of one kind of ion. Experience indicates that these ions are probably molecular. Clearly in all cases the emission caused by the lighter ion is greater at the same energy.

The values of the emission due to the noble gases cannot be compared with those due to the two hydrogens since different Ni targets were used in the two cases and their heat treatment was different. The choice of nickel as a target metal seems to have been an unfortunate one because of its anomalous behavior when heated. Miss Raines[7] has observed irregularities in the change of resistance of nickel with heat treatment unlike the behavior of other metals. Probably the change in emission after unusual heat treatment earlier reported[4] was due to recrystallization of the nickel and a consequent change in angle of impact of the ions on the target face. As stated above, however, no evidence was found for a change in the structure of the surface during either set of observations and the results show a comparison of the effect of different kinds of ions in each case.

When the percent emission is plotted against the velocities of the ions the helium curve lies between the one for neon and that for argon; when plotted against momentum, however, they lie in the same order as for the energy.

[7] Barbara Raines, Phys. Rev. **54**, 481 (1938).

The number of reflected positives plotted also as percent against the initial ion energy (Fig. 3) shows a similar trend, the number increasing with energy and a larger proportion of the lighter ions being reflected. The regularity of the increase in this case is to be compared with the more erratic results obtained for hydrogen[3] which were probably dependent on a varying small amount of hydrogen adsorbed on the surface.

DISCUSSION

Secondary emission curves may be compared in two respects, the shape of the curves themselves and the point at which they cut the emission axis. All of Jackson's work on the alkali ions showed a flattening of the curves similar to that due to primary electrons for which a maximum secondary emission is always found; it also showed no emission below a few hundred volts ion energy. Oliphant, on the other hand, found two changes in slope below 1000 volts and considerable emission at zero energy (extrapolated curve). The curves for the hydrogens, helium, neon, and argon show little if any departure from linearity, except that above 1000 volts both the He^+ and D_2^+ curves tend to flatten. Both the H_2^+ and D_2^+ curves when extrapolated show no emission below a certain value of the energy, but of course such an extrapolation is questionable. In this respect the results for He, Ne, and A are not at all definite. Hence no conclusions can be drawn as to the effect of the ionization energy of the ion in producing electrons.

No attempt is made to interpret the smaller emission of the heavier ions other than to say that it may be more difficult for a larger ion to penetrate the metal. Interpretation of results would probably be facilitated by using target surfaces formed by evaporation in the chamber in which measurements are made and by the use of a beam of ions of much lower energy. Further work along this line is contemplated.

The authors are indebted to Professor E. L. Chaffee of Harvard University for his continued interest in this work and to Professor Edna Carter of Vassar College for her interest and help at crucial moments.