The Emission of Electrons by Swiftly Moving Mercury Ions

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Various metal targets bombarded by swiftly moving ions emit from 7 to 20 electrons per incident ion. The majority of these secondary electrons have energies less than 10 electron volts. The commonly used metals such as nickel, copper, molybdenum, aluminum, tungsten, silver, tin, magnesium and cadmium differ but little from one another in emission of electrons. The emission is an increasing function of the ionic energy in the range 0.7 to 2.35 mv. Targets of molybdenum and tungsten heated in vacuum have shown a decreased emission but the effect is temporary. Freshly formed films of the alkali metals show a steadily increasing emission for some time after formation. In the case of lithium the effect is extremely rapid and the emission reaches values as high as 50 electrons per incident ion.

ASIDE from its general interest, the emission of electrons by impact of swiftly moving ions is important in the theory of high voltage breakdown, and hence in the design of high voltage vacuum tubes. Previously published work with very energetic particles has always dealt with alpha-rays, and therefore it seems desirable to study the problem with various other energetic ions. Fortunately these fast ions can now be obtained in a number of ways. In the present work mercury ions were accelerated to energies up to 2.35 mv by a method due to Sloan and Lawrence,[1] and extended by Sloan and Coates.[2]

APPARATUS

Singly-charged mercury ions are produced in the plasma of a hot-cathode mercury arc and drawn through a canal tube into the high frequency oscillating system, which accelerates them to a high velocity. The high frequency system is constructed in the following way; alternate members of a series of 36 short coaxial copper cylinders act as a capacity and are connected to opposite ends of a small inductance. The length of the Nth tube is the product $L_1(N)^{\frac{1}{2}}$, where L_1 is the length of the first accelerator; this allows charged particles to be accelerated through the series of tubes in synchronism with the oscillating field and to emerge with 36 times the energy acquired by crossing a single gap. Inasmuch as the capacity is fixed, the synchronizing potential and hence the energy of the ions is varied in practice by changing the value of the inductance. The ionic energy can be determined quite accurately by a kinematical relation between the frequency of oscillation and the geometry of the accelerating system.

Precaution must be taken to keep the collected beam free of x-rays and electrons. Therefore the beam is electrostatically deflected through a small angle and into a collimating tube in which x-rays are absorbed by a series of slitted stops. All x-rays and electrons in the main body of the tube except those following the beam can be stopped by a grounded lead ring at the end of the accelerating system, and those remaining electrons which are with the beam are stopped by electrostatic and magnetic deflection. There will be secondaries formed in the collimating tube wherever the ion beam may strike, but these are slow electrons that can be stopped by a 45 volt retarding potential indicated in Fig. 1.

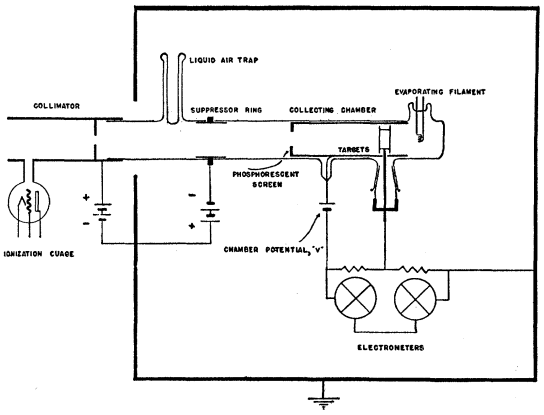

FIG. 1. Collector. (The vertical line representing a lead from the targets should have been drawn on down to join the direct connection between the two electrometers.)

[1] D. H. Sloan and E. O. Lawrence, Phys. Rev. **38**, 2021 (1931).

[2] D. H. Sloan and W. M. Coates, Phys. Rev. **46**, 539 (1934).

The Collector

Proper alignment of the collector is assured by the presence of a phosphorescent screen on the collector front which remains dark only if the beam does not strike it. Two targets are mounted on a ground joint, and fresh films can be evaporated upon them from a metallic pellet heated by a conical filament. Variations of the apparatus have included distilling tubes for the generation of alkali metal films, and a filament and circuit to heat a single target of a refractory metal by electron bombardment. Good vacuum conditions are secured by the presence on the collector of a liquid air trap and ionization gauge. A negative potential of 45 volts on the suppressor ring prevents slow electrons from leaving the collector. The collector and associated circuits are insulated to prevent leakage currents.

The General Effect

The space current between the chamber and the target is the sum of several components, the most important of which are listed as follows:

A. Current originating on the target.
   (1) Secondary electrons.
   (2) Photoelectrons.
B. Current originating on the chamber.
   (3) Photoelectrons.

A soft radiation produced at the target by the ion bombardment[3] is the cause of the photocurrents, and these two currents must be of almost equal magnitude since the target and the chamber subtend equal angles at the source of radiation. The ratio of the space current i, and the ion current I, is dependent upon the potential of the chamber with respect to the target. This dependence is shown in Fig. 2. If the potential is sufficiently positive the photoelectrons generated on the chamber will be almost completely suppressed and the space current will consist of components (1) and (2) which are indistinguishable experimentally. It has a saturation value for chamber potentials more positive than V_s. For potentials more negative than V_p the current is made up of photoelectrons from process (3) with the other components practically

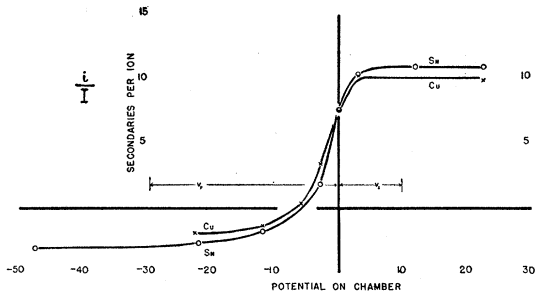

FIG. 2. Ratio of space current to ion current as a function of chamber potential, with 1.32 mv ions.

suppressed. The magnitude of these ratios is noteworthy.

These slow electron currents are the source of other currents of slow electrons of about 30 percent of the primary intensity,[4] but these secondary currents are suppressed by the saturation potentials and therefore do not affect the saturation values of i/I. These electrons with the more plentiful components (1), (2) and (3) will all be present when the chamber potential is between V_s and V_p and this complexity makes an accurate measure of the distribution in energy of any component quite impossible. It appears that the average energy of the electrons from the target is about 3 volts and about 10 percent have energy definitely greater than 10 volts. About 30 percent of these target electrons are photoelectrons.

Efficiency of Secondary Production

The average number of secondaries per ion is roughly reproducible from one sample to another of a given metal. The commonly used metals such as nickel, copper, molybdenum, aluminum, tungsten, silver, tin, magnesium and cadmium do not differ greatly one from another in efficiency if they have been well cleaned mechanically and observed under good vacuum conditions. Thus the emission from targets of these metals is likely to fall in the range of about 7 to 20 electrons per ion when they are bombarded by mercury ions in the energy range 0.7 to 2.35 mv.

[3] W. M. Coates, Phys. Rev. **46**, 542 (1934).

[4] H. E. Farnsworth, Phys. Rev. **31**, 405 (1928).

Dependence upon Experimental Conditions

The dependence of emission upon the energy of the mercury ions is shown in Fig. 3, which is a plot of the average number of secondaries per ion against the energy of the bombarding ions.

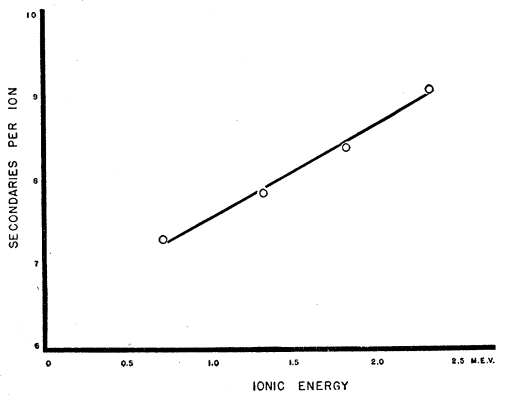

FIG. 3. Dependence of emission upon ionic energy.

Other data taken over the same energy range have shown the slope of increasing emission to be as much as three electrons per ion per million electron volts, so the only definite conclusion to be drawn from the rather meager data is that the emission does definitely increase with ionic energy.

Surface conditions

Although the surface conditions of a target cannot be very well known, there are certain treatments a target can be given to alter its emission properties and allow fairly reproducible results. These experiments have included the outgassing of targets, and the evaporation of fresh films. By means of electron bombardment a target of molybdenum or tungsten could be heated to an orange glow for many minutes until the evolution of gas had become very weak. Observations were begun about four minutes after heating was stopped, and the emission was from 50 to 75 percent of the values found for targets which had not been heated, but cleaned only mechanically or chemically. It rose steadily and after 20 or 30 minutes had reached a constant value only slightly lower than the emission from targets not heated.

Freshly formed alkali metal films

These targets were formed by distilling the alkali through a number of constrictions and thence onto the target, which could be seen during the formation of the film; the films appear to be thick, shiny, and sometimes a bit granular. The pressure was about 5×10^{-5} mm of Hg during evaporation, and fell to about 5×10^{-6} in three or four minutes after evaporation ceased. Fig. 4 shows the average emission per ion as a function of time after the film was formed. The nickel curve was taken simultaneously with the sodium curve, and is a standard of comparison.

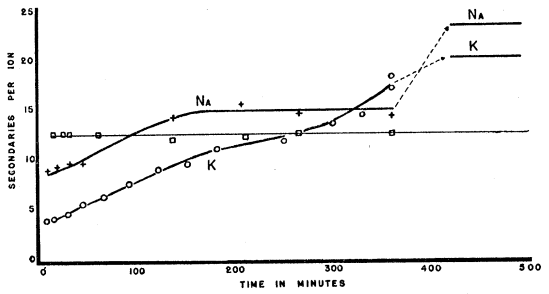

FIG. 4. Effect of elapsed time on freshly formed targets of alkali metals, with 1.32 mv ions.

The lithium targets were formed by evaporation from a pellet which was heated by a conical tungsten filament. The pellet with its oxide coating was outgassed for a considerable time at a fairly low temperature, then the temperature was gradually raised until the oxide coating cracked and rapid evaporation began. The pressure of about 10^{-4} mm of Hg during evaporation fell rapidly to 5×10^{-6} as in the case of the other alkalis. The appearance of the lithium films was thick and shiny, but somewhat darker than the others. The experimental values for the emission from lithium were somewhat higher than those given in Fig. 5, and have been reduced using nickel as a standard.

Discussion of Results

The rapid increase of emission with elapsed time and the differential effect with the pressure as shown in Fig. 5 indicate a relation between emission and gas pressure which is evidence for an adsorption theory as the explana-

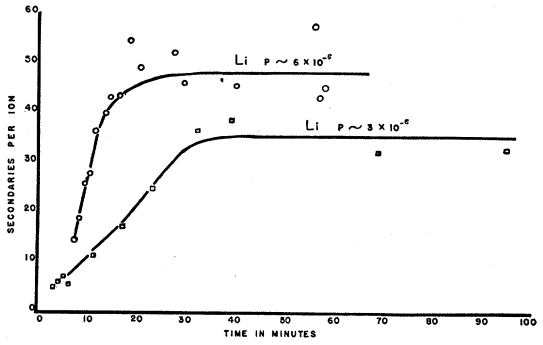

FIG. 5. Effect of elapsed time on freshly formed lithium targets, with 1.32 mv ions.

tion of the effect. In the light of the high values and the great speed of the lithium reaction as compared to the others it seems likely that the surface change is neither a modification of properties that is directly proportional to the thickness of the adsorbed layer, nor a simple replacement of the lithium by a gas film as the emitter.

The action of the alpha-rays has been studied by Thomson,[5] Logeman,[6] Bumstead and McGougan,[7, 8] Becker[9] and others, and it has been found that the number of secondaries per alpha-particle is of the order of 10, but depends upon experimental conditions. The energies of the secondaries lie in the range zero to two or three thousand electron volts with the great majority having a value of only a few volts; these energies are compatible with the theory that the maximum velocity a secondary can have is twice the velocity of the incident alpha-particle. This allows a maximum energy of about 10 volts for the secondaries produced by 1.32 mv. mercury ions, but about 10 percent of the electrons leaving the target have greater energy. It seems likely that these more energetic particles are photoelectrons. In this connection it should be pointed out that Coates[3] has found that x-rays of several thousand volts energy are produced by the swiftly moving mercury ions.

The author takes pleasure in expressing his gratitude to Professor Ernest O. Lawrence who suggested the problem and has been an inspiration and the source of invaluable suggestions.

[5] J. J. Thomson, Proc. Camb. Phil. Soc. **8**, 49 (1904).
[6] W. H. Logeman, Proc. Roy. Soc. **A78**, 212 (1906).
[7] H. A. Bumstead, Phil. Mag. **26**, 233 (1913).
[8] H. A. Bumstead and A. G. McGougan, Phil. Mag. **24**, 462 (1912).
[9] A. Becker, Ann. d. Physik **75**, 217 (1924).

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The Effect of Pressure on the Electrical Conductivities of the Alkalies

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The observed effects of pressure on the resistance of lithium and of sodium are explained by taking into account the change of binding of the conduction electrons of these metals with pressure. A method of interpreting the experimental results is given and it is shown that from the theoretical calculations of Slater and of Millman one can predict the observed behavior of these metals. Thus no special assumptions are necessary to explain the "abnormal" behavior of lithium.

INTRODUCTION

IT is well known that the alkalies in common with most other metals become better conductors of electricity when compressed, with the notable exception of lithium, which becomes a poorer conductor under pressure than at zero pressure. Besides lithium, calcium and strontium also display an abnormal pressure coefficient of resistance, but these elements are divalent and this abnormal behavior can readily be explained.[1] The normal effect has been qualitatively explained by Grüneisen[2] as follows: When a metal

[1] See N. F. Mott, Proc. Phys. Soc. **46**, 691 (1934).
[2] Grüneisen, Verh. d. D. physik. Ges. **15**, 186 (1913).