Kinetic Ejection of Electrons from Tungsten by Cesium Ions*

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(Received April 29, 1957)

Measurements of γ_i (number of electrons per incident ion) for cesium ions on atomically clean tungsten surfaces are reported. Vacuum conditions were such that subsequent to heating the tungsten to 2400°K a monolayer of gas was formed on the surface in ~4 hours. Since measurements were taken within 30 seconds after heating the tungsten to this temperature, the surface contamination is <0.3% of a monolayer. The striking feature of these data is that the yields are smaller than previously reported. It was noted during the experiment that the yield increased if background gases were allowed to accumulate on the tungsten surface.

EXPERIMENTS have been made to measure γ_i (number of electrons ejected per incident positive ion), for cesium ions on clean tungsten. There are two distinct processes involved in the ejection of electrons from a metal. One is an Auger process[1] arising in the neutralization of the incident ion at the surface (termed "potential ejection"). The second arises from the distortion of the lattice upon impact, in which an electron is excited into the continuum from the conduction band.[2] (This is termed "kinetic ejection".) To obtain data for the yield resulting from either one of these processes, two conditions must be satisfied: (1) the contribution due to the other process must be negligible, and (2) the surface of the metal must be accurately known. With the use of modern vacuum techniques, it is possible to maintain metal surfaces with less than 5% of a monolayer of adsorbed gases for ten minutes after "flashing."[3] The data presented here isolate the "kinetic" process, since the ionization energy of cesium (3.87 ev) is less than the work function of clean tungsten (~4.5 ev).

Figure 1 shows the experimental arrangement schematically. The system is constructed of borosilicate glass. Tungsten strips which can be heated by conduction currents form both the ion source and the target. A three-element electrostatic lens system focuses ions created at the source onto a small portion of the target (~3 mm diam). A beam of cesium atoms enters the system through the side tube and is ionized at the source by surface ionization. Alternating current is used to maintain both the source and the target at ~1100°K. Center-taps at both the source and the target insure a minimum spread in the energy distribution of the incident ion beam and that the distribution is centered around V volts. A split cylinder forms the collectors. E_1 and E_2 are electrometers which record the current to each collector; positive charges leaving the target going to one collector, negative to the other.

High-purity cesium metal is sealed in a glass ampoule which can be opened after bakeout and outgassing of all metal surfaces. During the course of the experiment, the background pressure was $\sim 3\times 10^{-10}$ mm Hg. The measured monolayer adsorption time[3] is ~4 hours. The absence of any ions other than cesium is inferred from the attempt to operate the apparatus before the cesium ampoule is broken, which had negative results.

Because cesium drastically reduces the work function of tungsten, it is desirable to keep the surface of the target as free as possible from cesium during measurements. Maintaining the target at ~1100°K assured

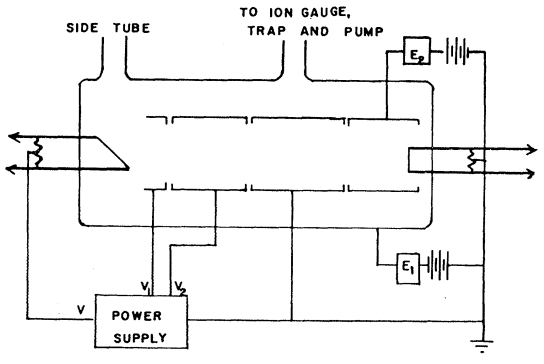

FIG. 1. Schematic diagram of apparatus.

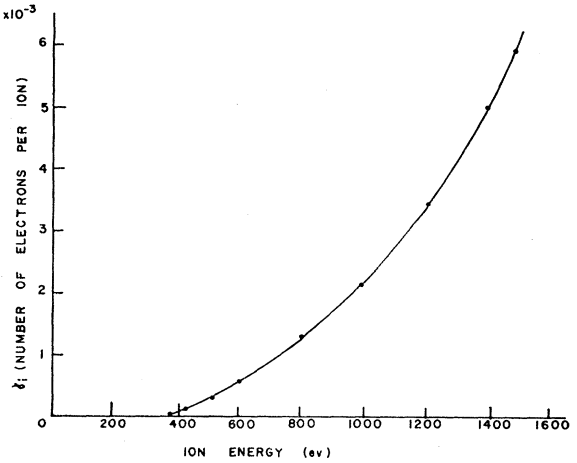

FIG. 2. Summary of results for cesium ions incident on clean tungsten.

* This work has been supported by the Office of Naval Research.
[1] H. D. Hagstrum, Phys. Rev. **96**, 336 (1954).
[2] O. von Roos, Z. Physik **147**, 210 (1957).
[3] H. D. Hagstrum, Phys. Rev. **96**, 325 (1954); **104**, 317 (1956).

that this condition prevailed except for the possibility of ions being trapped in the lattice. An additional electrometer placed in the circuit showed that the trapping probability is $<0.2\%$ in the energy range over which measurements were made (300–1200 ev).

Retarding potentials show that both ion and electron energy distributions are of the order of a few ev; hence small bias potentials are sufficient to provide satisfactory collector efficiencies without unduly disturbing the optics. The adjustment of these potentials to maximize the readings of the electrometers permitted a direct calculation of γ_i without additional corrections. (See Fig. 2.) The possibility of negative cesium ions being formed seems unlikely, since the ions apparently come into thermal equilibrium with the lattice before being re-emitted. Using the Boltzmann factor, we obtain for the ratio of negative ions to positive ions $\sim 10^{-11}$. The ratio of ions to neutral atoms leaving the target is $\sim 10^{3}$.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to Professor Leonard B. Loeb under whose direction and guidance this work was carried out, to Mr. Morley Corbett for the excellent glass blowing, and to the Office of Naval Research for their support during the progress of this work.

PHYSICAL REVIEW VOLUME 109, NUMBER 5 MARCH 1, 1958

Theory of Plane Elastic Waves in a Piezoelectric Crystalline Medium and Determination of Elastic and Piezoelectric Constants of Quartz

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(Received May 27, 1957)

Atanasoff and Hart made a series of elaborate experiments in order to determine dynamically the elastic constants of quartz. However, they reported that in the evaluation of the elastic constants from the experimental data, there was a small but not easily explained discrepancy between theory and experiment. Lawson pointed out later that the piezoelectric effect could not be neglected in the dynamic determination of elastic constants. The present writers became aware that in the case of a plane elastic wave in a piezoelectric crystalline medium, only the component of piezoelectric polarization in the direction of wave propagation produces a restoring force against mechanical strain, as far as the piezoelectric effect is concerned. Thus the writers could derive the equation of a plane wave in a piezoelectric crystalline medium in general and could further determine the elastic and piezoelectric constants, together with their temperature coefficients, from experimental data. Various experimental results reported by the foregoing authors, including Atanasoff and Hart, can now be adequately explained, even at high temperatures, so that there is no longer any discrepancy between theory and experiments.

I. INTRODUCTION

ALTHOUGH several authors have tried to determine dynamically the elastic constants of quartz from experimental data on the thickness vibration of a quartz plate, their results have not been in satisfactory agreement with each other. Atanasoff and Hart[1] found that, in the evaluation of the elastic constants from the expreimental data, there was a small but not easily explained discrepancy between theory and experimental results. Lawson[2] pointed out that the piezoelectric effect could not be neglected in the dynamic determination of elastic constants, but he did not clarify the question that Atanasoff and Hart had raised.

Needless to say, piezoelectric polarization is produced whenever an elastic wave is transmitted through a crystalline medium; but it is important to note that, in the case of a plane wave, only the component of piezoelectric polarization in the direction of wave transmission produces a restoring force against the strain, so far as the piezoelectric effect is concerned. Keeping this in mind, the present writers derived the equations for the plane wave in the following way.

2. GENERAL THEORY OF PLANE ELASTIC WAVE IN A PIEZOELECTRIC CRYSTALLINE MEDIUM

As the medium here is piezoelectric, the stress is composed of "electrical stress" as well as "mechanical stress." If the former be denoted by $\bar{X}_x, \cdots$, the latter by $X_x, \cdots$, and the displacements along the rectangular coordinate axes x, y, z by u, v, w, the equations of motion should initially be as follows:

$$\frac{\partial}{\partial x}(X_x+\bar{X}_x)+\frac{\partial}{\partial y}(X_y+\bar{X}_y)+\frac{\partial}{\partial z}(X_z+\bar{X}_z)=\rho\frac{\partial^2 u}{\partial t^2}, \quad (1)$$

etc.

[1] J. V. Atanasoff and P. J. Hart, Phys. Rev. **59**, 85 (1941).
[2] A. W. Lawson, Phys. Rev. **59**, 838 (1941).