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THE IONIZATION OF MERCURY VAPOR BY ELECTRON IMPACT

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Abstract

Quantitative measurements have been made of the total number of positive charges per electron per centimeter path at a definite pressure and temperature in mercury vapor as a function of the energy of the impacting electrons out to 750 volts. The maximum efficiency 19.40 occurs at about 85 volts.

"*Ultra-ionization potentials*" were found at 10.60, 10.76, 10.88, 11.06, 11.27, 11.40, 11.55, 11.70, 11.78, 11.92, 12.00, 12.06, 12.17, 12.28, 12.40, 12.77, 13.55, 18.20, 19.36, 20.40, and 29.50 volts. Most of these agree with those previously observed.

A METHOD has recently been described[1] for measuring the total number of positive charges formed by electron impact in gases at low pressure. The results in helium, neon, and argon have been reported. The present paper gives a description of the results of a study of mercury vapor.

Compton and Van Voorhis,[2] T. J. Jones,[3] and Bleakney[4] measured the efficiency of ionization of mercury vapor by electron impact and obtained values which agree qualitatively. Lawrence,[5] and Hughes and Van Atta[6] have observed by indirect methods sharp increases, near the ionization potential, in the number of ions formed by electrons as their energy was increased. Haupt,[7] and Nielsen and Potter,[8] by more direct methods, also observed several of these critical potentials which Lawrence has called "ultra-ionization potentials."

The writer has redetermined the efficiency of ionization of mercury vapor and has observed a number of abrupt changes in the slope of the efficiency curves. The potentials at which these new modes of ionization set in agree quite well with those previously observed and several of the new ones found account for some of the apparent discrepancies between those found by Lawrence and by Hughes and Van Atta.

Apparatus and Procedure

The apparatus, Fig. 1, was constructed entirely of tantalum. The more essential parts were insulated with quartz. The metal parts were baked out at a yellow heat before they were sealed into the Pyrex tube.

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[1] P. T. Smith, Phys. Rev. **36**, 1293 (1930).

[2] Compton and Van Voorhis, Phys. Rev. **27**, 724 (1926).

[3] T. J. Jones, Phys. Rev. **29**, 450 (1927).

[4] W. Bleakney, Phys. Rev. **34**, 157 (1929); **35**, 139 (1930).

[5] E. O. Lawrence, Phys. Rev. **28**, 947 (1926).

[6] A. L. Hughes and C. M. Van Atta, Phys. Rev. **36**, 214 (1930).

[7] C. R. Haupt, 167th Meeting of the American Physical Society.

[8] W. M. Nielsen, Phys. Rev. **37**, 87 (1931).

The filament, *F*, was a thin tungsten ribbon about 0.075 cm wide and placed within 1 mm of the hole, S_1, which was about 0.034 cm in diameter.

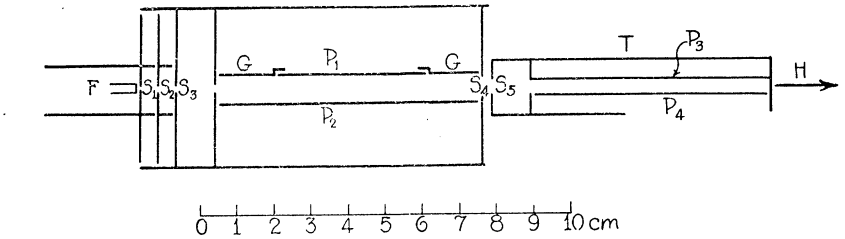


Fig. 1. Diagrammatic sketch of the apparatus.

The *IR* drop across this 0.034 cm length of the filament was less than 0.02 volt so that the velocity distribution of the electrons was determined almost entirely by the temperature of the filament.

The positive end of the filament was connected to S_1, which in turn was maintained about 7 volts negative with respect to S_2. The velocity of the electrons was determined by a variable potential between S_2 and S_3.

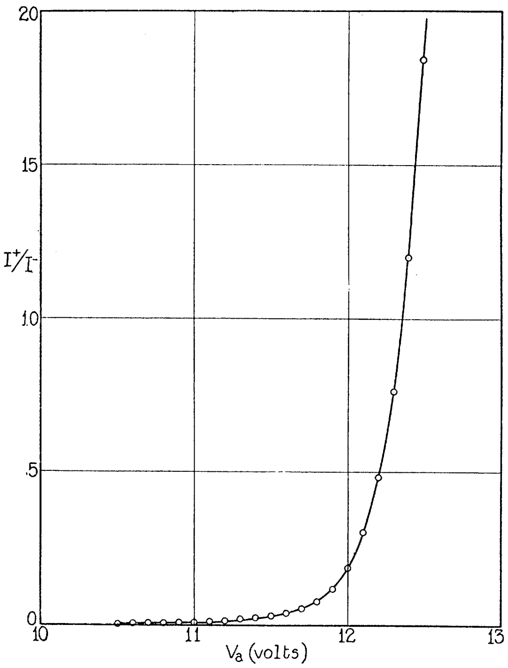
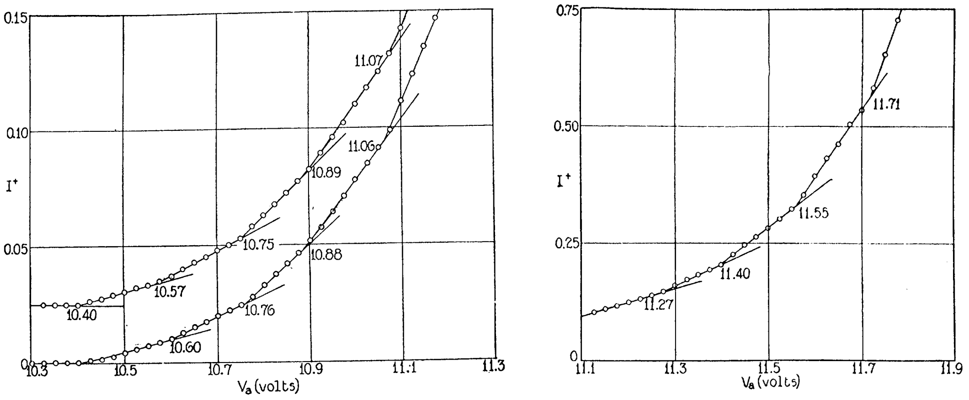
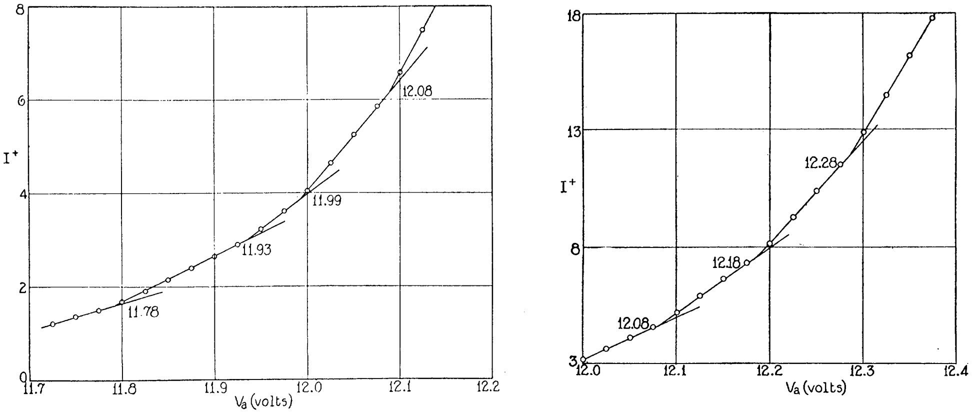


Fig. 2. The efficiency of ionization by electron impact of Hg vapor near the ionization potential. The ordinates represent the efficiency in arbitrary units.

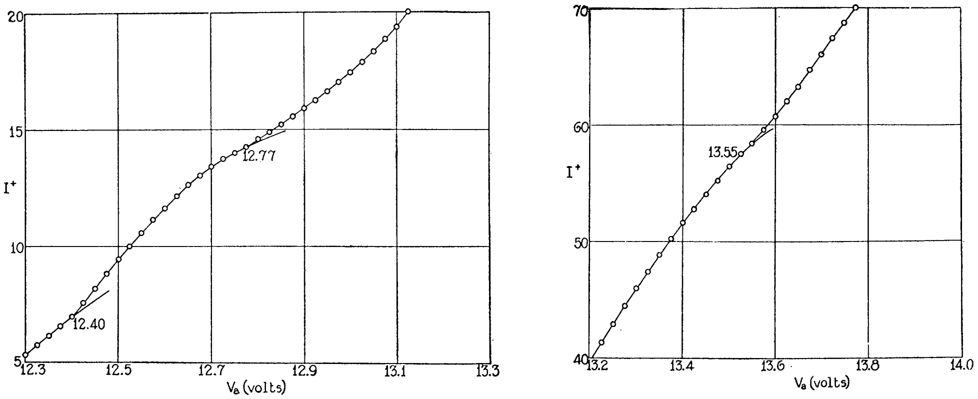
This arrangement gave an electron beam whose magnitude was quite independent of the field between S_2 and S_3 and insured a voltage correction which was independent of the speed of the electrons.



Figs. 3 and 4. The ionization of Hg vapor by electron impact from 10.4 to 11.7 volts. I^+ is proportional to the efficiency of ionization.



Figs. 5 and 6. The ionization of Hg vapor by electron impact from 11.7 to 12.3 volts. I^+ is proportional to the efficiency of ionization.



Figs. 7 and 8. The ionization of Hg vapor by electron impact from 12.3 to 13.8 volts. I^+ is proportional to the efficiency of ionization.

The holes S_2 and S_3 were about 0.18 cm in diameter, whereas S_4 and S_5 were 0.6 cm and 0.5 cm in diameter, respectively. The plates P_3 and P_4 were about 6 cm long and 3 cm wide. Plate P_4 was 0.5 cm below P_3 and was maintained 300 volts positive with respect to P_3. With the magnetic field, H, equal to 300 gauss, it is quite improbable that an electron will leave the trap, T, once it has entered, as both experiment and theory show.

RESULTS

Fig. 2 shows the efficiency curve for the first 2 volts above the ionization potential. The ordinates are proportional to the efficiency of ionization. The curve indicates that the ionization does not rise sharply at the ionization potential, the rapid rise occurring almost a volt above this potential. Curves obtained with a poor velocity distribution did, however, show a more rapid rise at 10.40 volts.

Figs. 3–8 show the efficiency curve plotted on a large scale. (They are not all plotted to the same scale.) The accuracy with which the breaks could be reproduced is shown in Fig. 3 where two independent sets of data have been plotted.

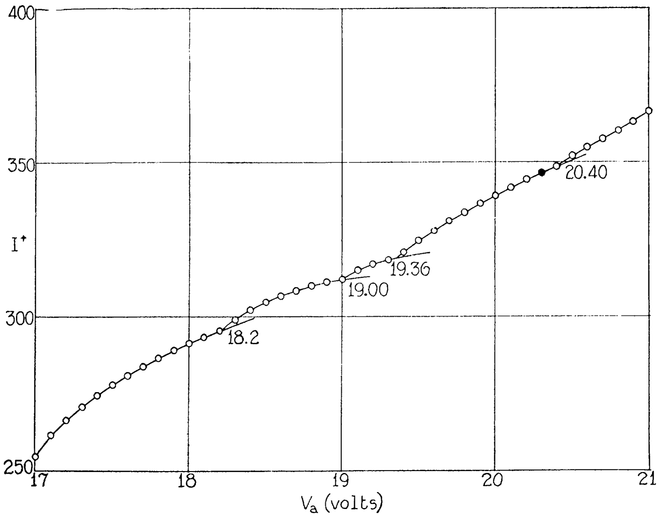


Fig. 9. The ionization of Hg vapor by electron impact from 17 to 21 volts. I^+ is proportional to the efficiency of ionization.

From 13.8 to 18 volts the curves were smooth and showed no obvious discontinuous changes in the slope. Fig. 9 shows the curve from 17 to 21 volts. The four breaks in this interval could be reproduced very accurately. Beyond 21 volts evidences of breaks were observed but the experimental errors in the measurements were greater than the deviations from a smooth curve, so that no satisfactory results were obtained although it is believed that several critical potentials do exist beyond 21 volts. However, at 29.5 volts a definite in-

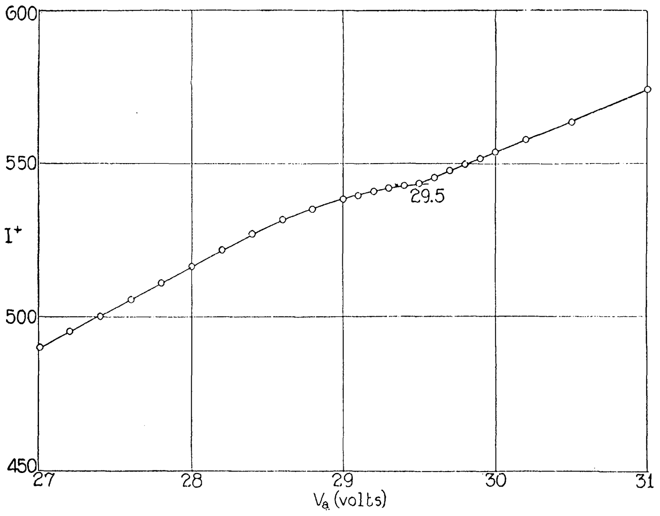


Fig. 10. The ionization of Hg vapor by electron impact from 27 to 31 volts. I^+ is proportional to the efficiency of ionization.

TABLE I. *The "ultra-ionization potentials" in Hg vapor.*

Lawrence	Hughes and Van Atta	Haupt*	Nielson and Potter	Author
10.40	10.40	10.40	10.40	10.40
10.60	10.62			10.60
			10.66	
				10.76
	10.88			10.88
			11.00	
				11.06
11.29				11.27
	11.40		11.41	11.40
				11.55
11.70			11.72	11.70
	11.77			11.78
				11.92
				12.00
12.06			12.06	12.06
	12.16			12.17
		12.30		12.28
			12.40	12.40
		12.45		
	12.76		12.80	12.77
		12.85		
		13.20	13.25	
				13.55
				18.20
				19.36
				20.40
				29.50

* Haupt reports that he also observed those found by Lawrence.

crease was always observed, which may be attributed to the formation of Hg^{++}. Fig. 10 shows a typical set of data in this region.

A list of the critical potentials reported by the various investigators, together with those found by the writer, is given in Table I. The values given in the same row were assumed to correspond to the same critical potential. The agreement is in general very good.

An "ultra-ionization potential" at 11.06 volts has not been previously reported, but as Fig. 3 shows, it apparently represents the minimum energy necessary for some quite efficient mode of ionization. It is of interest to note that in a study of the electron energy losses in mercury vapor, Castle W. Foard[9] found a pronounced peak which corresponded to a loss of 11.07 volts of energy. He was unable to account for this loss on spectroscopic grounds. This loss of energy can probably be associated with the ultra-ionization potential at 11.06 volts if we assume that ionization can result as a consequence of the simultaneous excitation of the two valence electrons. This would require a quantized energy loss.

The measurements of the positive ion current were made with a Compton electrometer having a sensitivity of about 3700 mm per volt. The electron current used in obtaining the data for the curves shown in Figs. 3–10 was about 5×10^{-8} amperes and for some of the work was measured with a galvanometer having a sensitivity of 2.70×10^{-11} amperes per mm deflection by employing a suitable balancing-out arrangement. With this sensitive measuring device, very small variations in the electron current could be detected. A very careful study showed that there was no correlation between any observed deviations in the electron current and the observed critical potentials.

TABLE II. *Efficiency of ionization, ϵ expresses as number of positive charges per electron per cm path per mm pressure at 0°C for various electron velocities.*

V_a (volts)	ϵ	V_a	ϵ	V_a	ϵ	V_a	ϵ
15	3.43	75	19.33	175	17.55	475	11.45
20	8.14	80	19.38	200	16.90	500	11.05
25	11.51	85	19.40	225	16.30	525	10.70
30	13.68	90	19.38	250	15.70	550	10.45
35	15.37	95	19.32	275	15.15	575	10.15
40	16.42	100	19.25	300	14.60	600	9.88
45	17.38	105	19.17	325	14.10	625	9.63
50	17.90	110	19.07	350	13.55	650	9.36
55	18.51	120	18.83	375	13.05	675	9.12
60	18.85	130	18.64	400	12.55	700	8.90
65	19.05	140	18.40	425	12.15	725	8.70
70	19.25	150	18.15	450	11.77	750	8.55

The pressure used ranged between 3×10^{-5} and 1.85×10^{-4} mm mercury. The data shown in Fig. 11 and in Table II were taken with a pressure of 8×10^{-5} mm of mercury and agrees very closely with data taken at different pressures. The ordinates represent the total number of positive charges per electron per cm path reduced to a pressure of 1 mm of Hg at 0°C. The posi-

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[9] C. W. Foard, Phys. Rev. **35**, 1187 (1930).

tive ion current for these data was measured with a galvanometer having a sensitivity of 2.70×10^{-11} amperes per mm deflection. The electron current used was about 6×10^{-7} and was measured with a galvanometer having a sensitivity of 8.00×10^{-10} amperes per mm deflection.

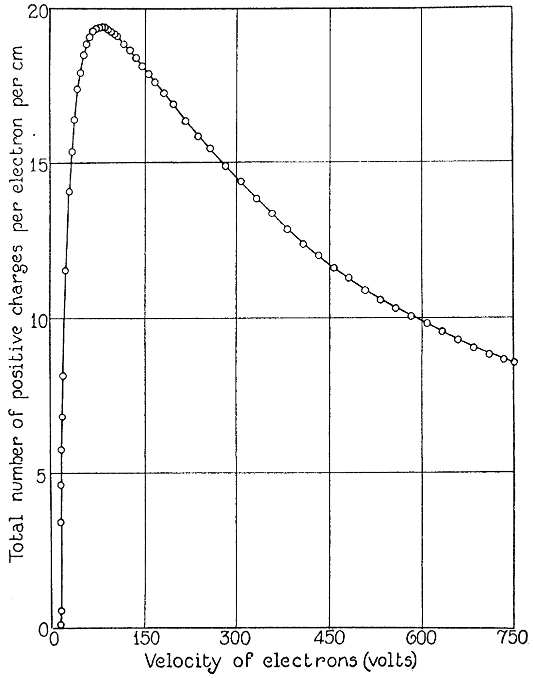

Fig. 11. The total number of positive charges per electron per cm path at 1 mm pressure and 0°C plotted as a function of the velocity of the impacting electrons in volts.

Discussion

It is very difficult to reconcile the values for the efficiency of ionization of mercury vapor given here with those obtained by Bleakney and by Jones, both of whom employed the same method. The present work was carried out with a better vacuum and a very careful study of all of the characteristics of the apparatus failed to reveal any objectionable features in the apparatus, method, or procedure. It is interesting to note that the copper apparatus, used in the study of helium, neon and argon, gave essentially the same values for Hg vapor as those given here.

The author takes this opportunity to acknowledge the constant interest and many suggestions of Professor John T. Tate.