Drift Velocities of Electrons in Cesium*

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The drift velocities of electrons in cesium vapor have been measured for E/p_0 values between 0.8 and 20 V/cm×Torr at temperatures between 566 and 725°K. The data were obtained from electron transit-time measurements using a pulsed-discharge technique. By obtaining differential transit times, injection and end-effect errors were minimized. The general variation of the drift velocity with E/p_0 was found to be comparable to that previously observed for some of the noble gases.

I. INTRODUCTION

CURRENT interest in alkali vapors has stimulated numerous experimental and theoretical investigations. Many of these studies have been directed towards an understanding of the interaction of electrons with cesium atoms. In view of the difficulties associated with experimental studies in cesium at high pressures, few measurements have been reported relating to electron and ion-drift parameters in pure cesium, the majority of the work having been performed[1,2] in cesium noble-gas mixtures. This paper reports measurements of drift velocities of electrons moving in cesium vapor for E/p_0 (electric field to normalized pressure ratio, $p_0=273p/T$) values from 0.8–20.0 V/cm×Torr. The measurements were performed with gas temperatures varying from 566–725°K.

II. APPARATUS

The technique used in the present study is a modification of a method[3] used previously to study ionic mobilities in a number of different gases. The method consists of generating a short duration discharge between the discharge electrode of the experimental tube and a grid maintained at ground potential. The discharge is created by application of a negative voltage pulse with a half-width[4] of 3×10^{-8} sec and amplitudes of approximately 1 kV. Some of the electrons created in this manner pass through the grid into the drift region where their motion under the influence of a constant applied electric field induces a current in the external circuit. From an analysis of the induced current, the electron transit times can be determined. The experimental tube used in present work is shown schematically in Fig. 1 and has been described in detail previously.[5] The experimental tube and all portions of the associated plumbing exposed to cesium vapor were constructed of cesium resistant materials; in particular, stainless steel, nickel, and high alumina ceramic were used. The drift and discharge distances could be varied externally to the ovens containing the tube, out to 5.0 and 2.5 cm, respectively, by means of micrometer-driven bellows assemblies, with an accuracy of 10^{-3} cm.

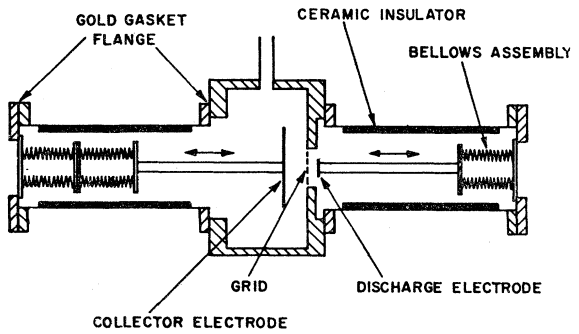

FIG. 1. Schematic drawing of the experimental tube.

Variable drift distances were necessary to enable differential measurements to be made free from injection errors. Thus if the electrons were injected through the grid with energies greater than their equilibrium drift energies (as will usually be the case), the initial portion of their transit would not be characteristic of their equilibrium motion. Use of a variable discharge distance permitted one to optimize the discharge characteristics over the range of parameters varied in the present study.

The experimental tube was mounted on a high-vacuum gas-handling station.[6] The cesium used in the measurements was 99.99%. Cesium pressures were measured using a capacitance type of manometer and were believed accurate to within 0.05 Torr. The gas temperatures were inferred from an extensive Chromel-Alumel thermocouple system and were believed accurate to within 5°C.

III. RESULTS

In the present studies, several techniques for measuring electron-drift velocities in cesium were evaluated before it was determined that the method described above was the most reliable. These techniques involved variations of the final method. Thus preliminary

* Work supported by U. S. Army Research Office, Durham, North Carolina.
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[2] C. L. Chen and M. Raether, Phys. Rev. **128**, 2679 (1962).
[3] M. A. Biondi and L. M. Chanin, Phys. Rev. **94**, 910 (1954).
[4] The width of the injected electron pulse was consequently at all times short compared to the transit times, which generally varied from 10–150 μsec.
[5] L. M. Chanin and R. D. Steen, Phys. Rev. **132**, 2554 (1963).
[6] D. Alpert, J. Appl. Phys. **24**, 860 (1953).

electron measurements were reported,[7] which were obtained from examination of composite electron and ion waveforms, resulting from the injection of ion pulses into the drift region. Under these conditions the electron component resulted from photoemission from the cesium-coated collector electrode, due to photons from the discharge region of the tube passing through the grid and striking the collector. Another method was evaluated in which only photons from the discharge region were allowed to pass through the grid. As in the previous method, the electron pulse was created by photoemission from the cesium-coated collector electrode. While both of these methods yielded drift-

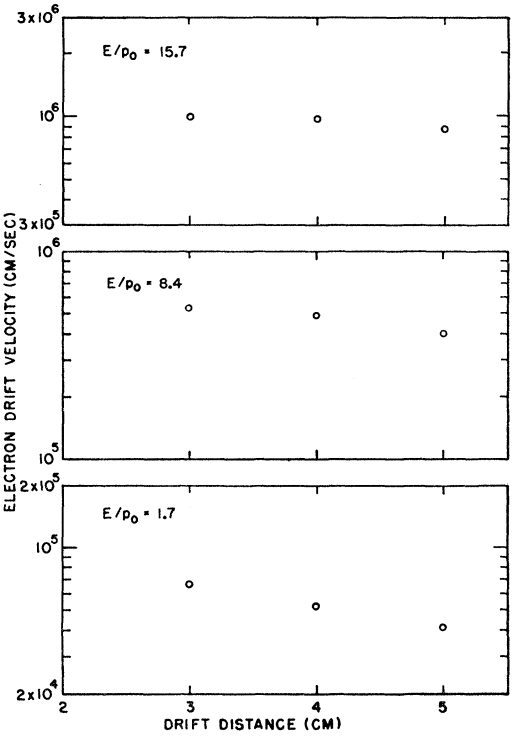

FIG. 2. Examples of the variation of direct drift-velocity values as a function of drift distance for the case of $E/p_0=1.7$, 8.4, and 15.7 V/cm×Torr. The data shown were obtained at $p_0=0.40$ Torr and $T=596$°K.

velocity values in rough agreement with the measurements obtained using the final technique (electron injection with the collector electrode maintained at a positive potential), the data were difficult to obtain and the experimental scatter was considerably greater. Several reasons for this behavior are apparent. First, the electron emission from the cathode would be quite sensitive to any changes in its work function; under the conditions of the experiment such changes would be expected to occur. Second, photon-delay processes such as imprisonment of resonance radiation, which

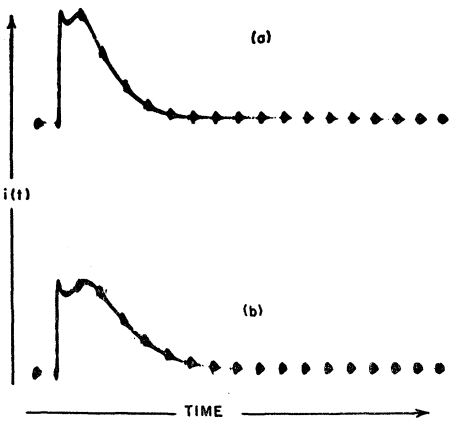

FIG. 3. Photographs of induced current versus time waveforms for the case of electron motion in cesium. The waveforms shown in Fig. 3 were obtained for drift distances of 4.0 and 5.0 cm (curves a and b, respectively), $E/p_0=4.93$ V/cm×Torr, $p_0=1.01$ Torr, and a gas temperature of 635°K.

are believed[8] to be important in cesium, would affect measured transit times. Finally for the case in which ions were injected into the drift regions, information regarding the initial portion of the electron transit is destroyed by the initial part of the ion component. The final method adopted is free of these difficulties and was found to give reliable results.

In all cases for a given value of E/p_0, pressure and temperature, drift times were measured for at least three different drift distances, in order to obtain differential transit times. Typical drift distances were usually 3, 4, and 5 cm. Figure 2 shows examples of measured direct drift-velocity values as a function of drift distances for the case of $E/p_0=1.7$, 8.4, and 15.7 V/cm×Torr. The data shown in Fig. 2 were obtained at $p_0=0.40$ Torr and $T=596$°K. From measurements of this type differential drift-velocity values were obtained. In general the 4- and 5-cm data were usually used to determine the differential values.

Figure 3 shows a photograph of an example of the observed current versus time waveforms. The waveforms shown in Fig. 3 were obtained for drift distances of 4.0 and 5.0 cm, $E/p_0=4.93$ V/cm×Torr, $p_0=1.01$ Torr, and a gas temperature of 635°K. The duration of the current pulse, measured between the midpoints of the leading and trailing edges, was interpreted as a measure of the transit time between the grid and collector electrode. In the actual experiment the transit times were measured by means of the delayed sweep of a 545A Tektronix oscilloscope. In general, at low E/p_0 values, the shapes of the electron waveforms were quite similar to that previously[3] observed for the case of ion motion, the initial current spike being attributed to back diffusion losses while the pulse was in the vicinity of the grid. The initial decrease may also result from the slowing down due to collisions of the electrons

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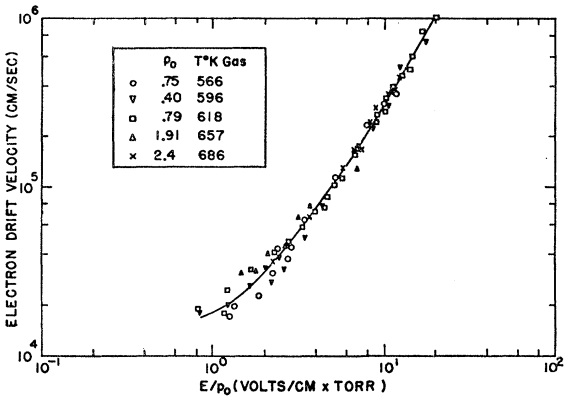

FIG. 4. The variation of the electron-drift velocity with E/p_0.

which were injected into the drift region with greater than their equilibrium drift velocities. As a result of the experimental limitation to moderately low cesium pressures caused by leakage resistance problems, diffusion broadening of the waveforms occurred; this may be noted in Fig. 3. The assumption that transit times are given by the differences in time between the leading and trailing edges, assumes that the effect of diffusion is to introduce a symmetric broadening of the pulse. The fact that experimentally at a given E/p_0 value, differential transit times were in agreement over a considerable range of pressures, implies that this assumption was essentially correct. From Fig. 3 it will be noted that following the initial current spike, the induced current was not constant as the electron pulse moved between the grid and collector but rather was observed to increase. The increase was believed due to electron multiplication as a result of ionization. This behavior is similar to that previously observed by Hornbeck[9] for the case of helium. In principle from a study of the current increase one could determine the electron ionization coefficient for cesium, as Hornbeck previously estimated for the case of helium. In the present studies such measurements were not undertaken.

Figure 4 shows a plot of the values of the electron-drift velocity as a function of E/p_0. For the purpose of clarity only a small portion of the total data obtained is shown in Fig. 4. In general, measurements were made every 25°K from temperatures of 566–725°K. For each gas temperature, differential data were obtained for at least three values of the pressure varying by at least a factor of 5. The reproducibility of the data was approximately 50%. The range of normalized pressures at which measurements were made varied from 0.24 Torr at 566°K to as high as 5.2 Torr at temperatures of 680°K.

For temperatures in excess of 725°K, reproducible data were difficult to obtain, due to the presence even for low E/p_0 values ($\sim$2 V/cm$\times$Torr) of a large ion component in the induced-current waveforms. The presence of this component seriously reduced the amplitude of the electron component thus making measurements unreliable. At the present time the source of this ion component, which was not observed at lower temperatures for moderate E/p_0 values ($<$8 V/cm$\times$Torr), is not understood.

IV. DISCUSSION

The technique used in the present study is not as accurate as some of the more sophisticated methods[10] developed in recent years for the measurement of electron-drift velocities. The special problems created by performing measurements at high cesium pressures, however, make the utilization of such methods extremely difficult. For performing measurements in cesium where at high pressures leakage resistance problems become severe, the present method possesses the virtue of simplicity as far as electrode connection requirements are concerned. Space-charge distortion of the applied electric fields was estimated to be within several percent under the most unfavorable conditions at low E/p_0 values. The requirement that the energy relaxation time be much smaller than the drift time has been used in previous electron-drift-velocity measurements.[10] This quantity can be easily estimated in the absence of inelastic collisions. In the present studies, however, the majority of the data given in Fig. 4 was obtained under conditions such that the electrons were believed to have undergone inelastic collisions. Since we observed good agreement between the various sets of differential drift times, we conclude that in the present studies the relaxation times were short compared to the drift times. The most serious error in the present studies was believed to result from the uncertainty in the drift times introduced by the waveform broadening due to diffusion; clearly this error is most pronounced at low E/p_0 values where the transit times are the greatest.

It will be noted from Fig. 4 that over the entire E/p_0 range investigated no drift-velocity variation with temperature was observed. Further it will be observed that at the lowest E/p_0 values the variation of the drift velocity with E/p_0 appears markedly different than at intermediate and high E/p_0 values. From Fig. 4 it will be noted that the drift-velocity variation can be approximately described by three different regions. For high E/p_0 values from 5.0–20.0 the velocity varies roughly to the power 1.7. For low E/p_0 values from 0.80 to approximately 2.5 the variation with E/p_0 is less than the power unity, while for intermediate E/p_0 values 2.5–5.0 the variation appears to be only slightly greater than unity. This drift velocity variation for $E/p_0 \leqslant 5.0$ is similar to that previously found for many of the noble gases. The interpretation of this variation

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has recently been discussed by Bowe.[11] According to this interpretation for intermediate E/p_0 values generally >0.1 but <1.0 V/cm×Torr where the average electron energy is many times the value of kT, the functional relationship between the drift velocity and E/p_0 is determined by the momentum transfer cross section for elastic collisions. If in this region the cross section does not decrease with energy, then the drift velocity varies with E/p_0 less than the power unity. With increasing E/p_0, a critical E/p_0 value is reached corresponding to the onset of inelastic collisions. As a result of the inelastic collisions tending to stabilize the random energy, a linear relationship between the drift velocity and E/p_0 is initially observed above the critical E/p_0 value. From Fig. 4, according to this interpretation, the critical E/p_0 value in cesium corresponding to the onset of inelastic collisions appears to be ~ 2.0 V/cm×Torr. Only for very low E/p_0 values, generally <0.1 V/cm×Torr, where the electrons are in thermal equilibrium with the gas atoms, should any gas temperature dependence[10] be observed. The extension of electron-drift-velocity data in cesium down into this interesting energy region must await further experimental investigation.

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Thermoluminescence of X-Ray and Ultraviolet Excited CsBr Crystals*

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Thermoluminescence produced both by x irradiation of uncolored crystals and by ultraviolet irradiation of additively colored single crystals of CsBr has been studied. Glow curves were obtained over the temperature range of 90–400°K and correlated with F-band absorption. A small amount of thermoluminescence was found in nonadditively colored crystals subjected to intense ultraviolet radiation. Glow-peak temperatures and activation energies are listed.

INTRODUCTION

MOST color-center studies have been concerned with face-centered cubic NaCl-type crystals.[1] Only quite recently have investigations been carried out on color centers in x-rayed and additively colored simple cubic CsCl-type alkali halides, in particular CsBr.[2–4] Thermoluminescence studies have been reported for KBr,[5] KCl,[5–7] and NaCl.[8]

The present work involved a study of glow curves obtained in x- and ultraviolet-irradiated CsBr single crystals over the range from liquid-nitrogen temperatures to above 400°K. The positions of the glow-curve peaks in CsBr crystals from three commercial suppliers, the nature of the luminescence, activation energies for some of the glow peaks, and correlations with F-band absorption were determined for the two modes of excitation.

EXPERIMENTAL PROCEDURES

For both thermoluminescence and optical absorption measurements, single crystals of CsBr were mounted in an evacuable cryostat (patterned in part after that described by Braner and Halperin[9]), placed between the monochromator and the photomultiplier housings of a Beckman DU spectrophotometer. Glow curves were obtained on a Varian recorder connected across a resistor inserted in the meter circuit of the spectrophotometer. For large signals the response of the recorder was quite nonlinear. Optical absorption measurements were made through quartz windows in the sides of the cryostat which were heated to a temperature somewhat above room temperature to prevent the formation of vapor on the quartz windows and to thermally isolate the photomultiplier from the crystal

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