

University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

Papers from the University Studies series (The University of Nebraska)

University Studies of the University of Nebraska

1921

An Experimental Study of the Cathode Fall in Helium and Argon with Wire Cathodes

L. G. Raub

Follow this and additional works at: <https://digitalcommons.unl.edu/univstudiespapers>



Part of the [Arts and Humanities Commons](#), [Atomic, Molecular and Optical Physics Commons](#), [Electrical and Computer Engineering Commons](#), and the [Engineering Physics Commons](#)

This Article is brought to you for free and open access by the University Studies of the University of Nebraska at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Papers from the University Studies series (The University of Nebraska) by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

UNIVERSITY STUDIES

VOL. XXI

JANUARY-OCTOBER, 1921

Nos. 1-4

AN EXPERIMENTAL STUDY OF THE CATHODE FALL IN HELIUM AND ARGON WITH WIRE CATHODES

BY L. G. RAUB

It was recognized rather early in the study of the phenomena of discharge of electricity through gases that the ordinary laws of conduction as found in solid and liquid conductors are not applicable to gases. It was shown by Zeleny¹ and independently by Child² that Ohm's law by no means represents the distribution of potential between electrodes in an ionized gas, but that the potential gradient is large in the vicinity of the electrodes, and not uniform throughout the space between them.

When the pressure of the gas surrounding the electrodes is reduced to one or two millimeters and a current passed between the electrodes, part of the intervening gas becomes luminous and part does not show any luminosity. In this case the potential gradient through the gas is decidedly irregular.

Covering the surface of the cathode is a thin, luminous layer of gas called the "cathode glow." Beyond the cathode glow is a layer of non-luminous gas known as the Crooke's dark space followed by a layer of luminous gas, the negative glow. At the surface of the anode is a layer of luminous gas, the positive column, the extent of which depends upon the length of the tube and the pressure of the gas—the length of the positive column being made shorter either by lowering the pressure of the gas or making the tube shorter. Between the negative glow and the

¹ Zeleny, *Phil. Mag.*, Vol. 46, p. 120, 1898.

² Child, *Wied. Ann.*, Vol. 65, p. 152, 1898.

positive column is a second layer of non-luminous gas known as the Faraday dark space.

The extent of the cathode glow is not materially changed by a change of pressure or current. However, the negative glow and the Crooke's dark space increase in length as the pressure is reduced. If the exhaustion is carried to an extreme limit as in an X-ray bulb, the Crooke's dark space fills the entire tube and the glass walls begin to fluoresce.

The electric intensity varies greatly in the different parts of the tube and has been investigated by Hittorf,³ Graham,⁴ Skinner,⁵ Wilson,⁶ and many others. The usual method of measurement is to insert a small wire electrode in the gas and measure the potential at that point. From the potential difference between one electrode and some point in the gas or between two points in the gas the electric intensity may be determined.

Investigation has shown that there is a large potential drop between the cathode and the edge of the negative glow amounting in general to rather more than two hundred volts. This relatively large drop of potential is known as the cathode fall.

When the current density is small enough so that the glow does not entirely cover the cathode, the cathode fall is independent of the current and is known as the normal cathode fall. As the current is increased the glow covers more of the cathode surface—and the cathode fall remains constant—until it is entirely covered, after which any further increase of current causes an increase in the cathode fall.

In the luminous negative glow the potential gradient is very small, gradually rising as one progresses from the negative glow through the Faraday dark space to the positive column, in which the gradient becomes fairly uniform up to a point relatively close to the anode, at which a second abrupt potential fall—by no means as large as that at the cathode—is found which is termed the anode fall.

The cathode fall has been the subject of much research and no

³ Hittorf, *Wied. Ann.*, 20, p. 705, 1883.

⁴ Graham, *Wied. Ann.*, 64, p. 49, 1898.

⁵ C. A. Skinner, *Wied. Ann.*, 68, p. 572, 1899.

⁶ H. A. Wilson, *Phil. Mag.*, 49, p. 505, 1900.

explanation has been entirely satisfactory. It has been found to consist of two distinct, but interdependent, parts: (a) the potential difference between the surface of the cathode and a point in the gas very near the cathode, this point being marked by the outer edge of the cathode glow; and (b) the potential difference between this point and the negative glow, or point of minimum potential gradient. Of these quantities (a) the polarization potential difference due to the accumulation of positive ions at the surface of the cathode is, in general, the larger quantity and increases with increasing current density. The cathode glow, within which this drop occurs, is about .2 mm. in thickness and does not seem to vary appreciably with the current density. The magnitude of (a) appears to be proportional to the potential gradient of the positive ions just before they enter the polarization region.⁷ The difference in potential between the cathode glow and the negative glow can not be explained as readily, and it is the explanation of this potential difference in which we are interested.

Stark⁸ has given a theory connecting the cathode fall for any current density with the normal cathode fall, the normal current density—i.e., the current density which is just sufficient to cause the glow to cover the surface of the cathode—the gas pressure, the cathode area, the current, and the absolute temperature. This theory is fairly satisfactory, but does not at all explain the drop of potential through the Crooke's dark space.

In 1915 Skinner⁹ published a theory of the cathode fall in which he obtained expressions for the upper and lower limits, giving the difference of potential between the cathode and a point in the gas between the cathode and the point of minimum potential gradient. In a later article he obtained a simpler and more exact theory¹⁰ which is applicable to both plate and wire cathodes.

A description of the process which is conceived to go on between the cathode and outer edge of the negative glow will give us a basis for the theory obtained. Under the bombardment of

⁷ C. A. Skinner, *Phys. Rev.*, IX, pp. 97 and 314, 1917.

C. A. Skinner, *Phys. Rev.*, XII, p. 136, 1918.

⁸ J. Stark, *Ann. d. Physik*, 12, p. 1, 1903.

⁹ C. A. Skinner, *Phys. Rev.*, V, p. 483, 1915.

¹⁰ C. A. Skinner, *Phys. Rev.*, XII, p. 143, 1918.

the positive ions the cathode liberates a small electron current—of the order of 10^{-8} amp. per cm^2 . Driven by the intense electric field these electrons double in number at every ionizing collision, producing at the same time an equal number of positive ions. The negative current, then—since we may safely assume no recombination of ions—at any point in the gas is determined by the number of electrons produced per second from the cathode up to that given point in the gas. Likewise, the positive current at any point is determined by the number of positive ions per second entering from the negative glow, plus the number of positive ions produced per second by the collisions of the electrons between the point considered and the negative glow. Conditions in the negative glow allow a relative evaluation of these two currents. The potential gradient in the negative glow being very small, the density of charge is practically zero, which means that the volume charge of electricity of both signs have equal density. Since the potential gradient is very small, the mobilities of the positive and negative ions may be assumed equal. Equal densities of charge and equal mobilities give equal positive and negative currents.

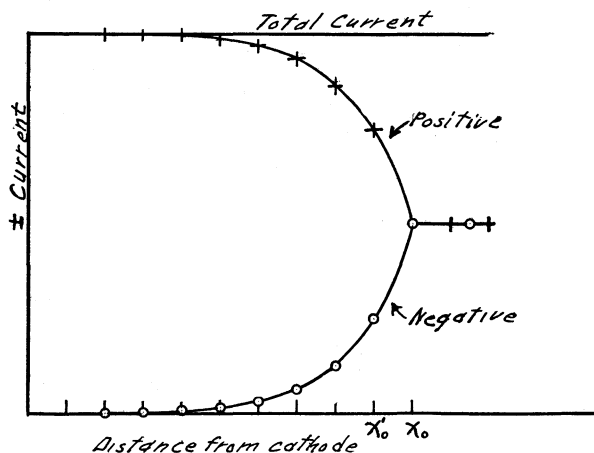


FIG. 1

Figure 1 illustrates what we may conceive to occur in an ideal case where the ionizing intervals are equal and the negative glow

is considered to be the sole source of ions. In the negative glow where the positive and negative currents are equal the horizontal portion of the curves represents the value of the current due to either type of ions. If X_0 is assumed as the source of ions, then at one ionizing interval toward the cathode, X'_0 , the negative current will have dropped to one-half its original value, or one-fourth the total current, and the positive current will be three-fourths the total current. At two ionizing intervals the negative current will be one-eighth the total current, while the positive current will be seven-eighths, and so on until the positive ions are carrying practically all the current.

Assuming the negative glow to be the sole source of ions leads to the development of a relatively simple theory of the potential at different points in the gas, between the cathode glow and the negative glow. The results of the theory obtained agree very closely with the experimental measurements made.

THEORY OF THE POTENTIAL FALL

If we assume the source of positive ions, X_0 , to be an infinite equipotential plane surface, and that between it and the polarization region, X_a , of an infinite plane cathode, there is a uniform current density, j , of positive ions, with the potential gradient $\delta V/\delta X$ at X_0 equal to zero, Poisson's Law for density of charge, since the planes are parallel, gives

$$\frac{\partial^2 V}{\partial X^2} = -4\pi ne, \quad (1)$$

where n is the number of positive ions per c.c. and e the ionic charge. From the law of the mobility of the ions we have the current density

$$j = -neU \frac{\partial V}{\partial X}, \quad (2)$$

where U is the mobility, or velocity of the ions in cm. per sec. for a potential gradient of one volt per cm.

If the source of ions and the polarization region are infinitely long, concentric cylindrical surfaces, the Poisson equation becomes

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial V}{\partial r} \right) = -4\pi ne, \quad (3)$$

where r is the radius of the equipotential surface having the potential V .

If now we substitute the current per unit length of cathode,

$$I_1 = 2\pi rj$$

for j in (2) we obtain an expression for the difference of potential between the cathode and a point in the gas between the source of ions, r_0 , and the cathode glow, namely,

$$I_1 = -2\pi rneU \frac{\partial V}{\partial r}. \quad (4)$$

Equation (3) is expressed in electrostatic units; in practical units it becomes

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial V}{\partial r} \right) = -3.6 \times 10^{12} \pi ne. \quad (5)$$

Solving for $\delta V/\delta r$ by use of (4) and (5) and making use of the fact that if $r \equiv r_0$, $\delta V/\delta r = 0$, we have

$$\frac{\partial V}{\partial r} = 1.34 \times 10^6 \left(\frac{I_1}{U} \right)^{1/2} \left[\frac{r^2 - r_0^2}{r^2} \right]^{1/2} \quad (6)$$

This equation requires that I_1 be negative, as it should be, for the direction of flow of the positive electricity is in the direction of decreasing gradient. However, for convenience we wish to use I_1 as a positive quantity, and (6) becomes

$$\frac{\partial V}{\partial r} = 1.34 \times 10^6 \left(\frac{I_1}{U} \right)^{1/2} \left[\frac{r_0^2 - r^2}{r^2} \right]^{1/2} \quad (7)$$

Solving (7) for V and making use of the fact that when $r \equiv r_0$, $V = V_0$, we have

$$V_0 - V = 1.34 \times 10^6 \left(\frac{I_1}{U} \right)^{1/2} \left[r_0 \log \frac{r_0 + \sqrt{r_0^2 - r^2}}{r} - \sqrt{r_0^2 - r^2} \right], \quad (8)$$

where V is the potential at any radius r between the source of ions r_0 and the polarization region at the cathode.

The purpose of the present investigation is to test the above theory—which is a simpler mathematical expression of Skinner's theory—in the monatomic gases helium and argon.

Apparatus.—The apparatus used was similar to that used by Skinner.¹¹ It consisted of a cylindrical tube 3 cm. in diameter with a wire cathode K lying in its axis (Fig. 2). The cathode

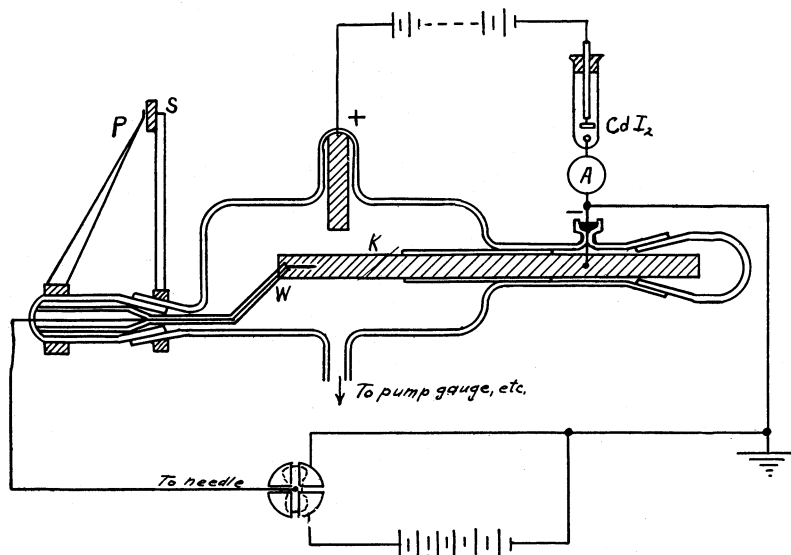


FIG. 2

was partly covered by a glass sheath which confined the discharge to a definite area. The anode was an aluminium wire placed in a side tube as shown in the figure. The potentials in the gas were measured by means of the probe-wire, W , which could be shifted to any position in the gas, since its axis of rotation is parallel to K . The probe was sheathed by a glass tube except for the short part of its length parallel to K . The diameter of the circle described by the probe is 20 mm. and its position is obtained by the pointer P moving over a circle of reference S —having a diameter of 30 cm. S is so adjusted that its zero corresponds to the center of K , and thus the distance from the center of K , or the radius of the equipotential surface, is given directly by readings on S .

¹¹ C. A. Skinner, *Phys. Rev.*, XII, No. 2, p. 143, 1918.

Certain systematic errors arise in measuring the distance from the center of K to the probe. One is due to the impossibility of determining when the probe passes through the axis of the cathode. This was obtained as accurately as possible by drawing K back until the probe would rotate past the end and adjusting S while the probe-wire was held at the center of the cathode. A second error arises from the impossibility of making the probe exactly straight and exactly parallel to the axis of the cathode. These errors were made sufficiently small to be negligible except at points very near the cathode surface. However, the deviations found at the edge of the polarization region are consistent and would seem to arise from these errors.

A third error which is not systematic and has a greater effect upon the computed results arises from the difficulty in locating the point of minimum gradient, r_0 , of equation (8). This value, which has a great influence on the computed potentials, is not well marked by the luminosity in the gases used. It was determined, approximately, by taking several readings in this region and plotting observed potentials against distances, or radii of the equipotential surfaces. The most probable values of r_0 and V_0 were then taken from this curve and substituted in equation (8), together with the values of two or three other equipotential surfaces not too near the negative glow. The value of the factor $1.34 \times 10^6 (I_1/U)^{1/2}$ was then computed, and those values of r_0 and V_0 which gave most nearly a constant value for this factor were taken as corresponding to the point of minimum gradient. The average of the values obtained by the above computation for the factor $1.34 \times 10^6 (I_1/U)^{1/2}$ was then used in computing the values of V recorded in the tables.

The current was furnished by a battery of small lead storage cells and measured by a Weston milliammeter (Fig. 2). The difference of potential between the cathode and the probe was measured by a well-insulated quadrant electrometer of the Dolazalek type with a phosphor-bronze needle suspension. The cathode was an aluminium wire carefully cleaned and polished.

The apparatus for generating and purifying helium is shown in Fig. 3. Dry, powdered cleveite was placed in flask A , and granular

potassium hydrate and phosphorus pentoxide in the bulbs *B* and *C*, respectively. The system was evacuated and the cleveite in *A* was heated over a sand bath. The increase in pressure was measured

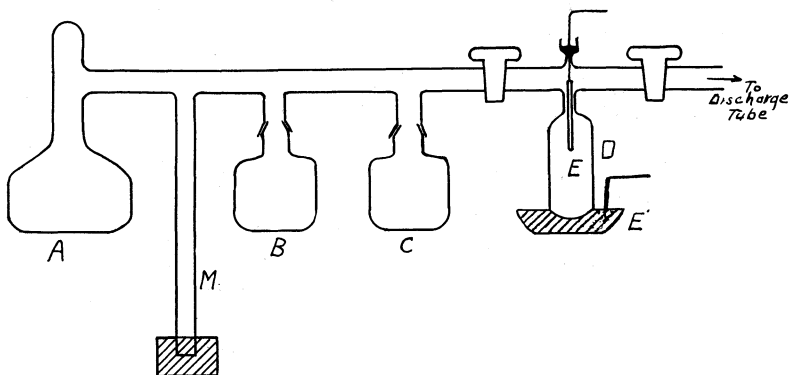


FIG. 3

by the manometer, *M*. The gas thus generated, which is mainly helium with hydrogen, oxygen, nitrogen and water vapor as impurities, was allowed to stand for at least twenty-four hours in the drying bulbs *B* and *C*.

Having removed the water vapor from the gas, it was allowed to enter the purifying chamber *D*. This was a discharge tube with an aluminium wire, *E*, as one electrode and an alloy of metallic potassium, sodium, and mercury for the second electrode, *E'*. *E'* was heated to about 300° C., at which temperature the glass becomes sufficiently conducting so that potassium and sodium were passed through the glass into the chamber by electrolysis. The current was then reversed and a glow current maintained in the tube using the alloy, *E'*, as cathode.¹² According to Mey,¹³ this treatment eliminates nitrogen, oxygen, and hydrogen, leaving only argon as an impurity. The writer was able to remove all traces of oxygen and hydrogen so that spectroscopic examination failed to show any trace of either gas. Nitrogen, however, was

¹² Much trouble was encountered in the purification because the glass deteriorated and cracked while the current was passing through it. Several samples of helium were lost in this way.

¹³ K. Mey, *Ann. d. Physik*, (4) 11, p. 127, 1903.

not completely eliminated, and after the current had been passed for several hours spectroscopic observations always revealed, more or less faintly, the characteristic flutings of nitrogen, with the helium lines standing out strong and sharp. According to Ramsay,¹⁴ one-hundredth of one per cent. of nitrogen is still visible in

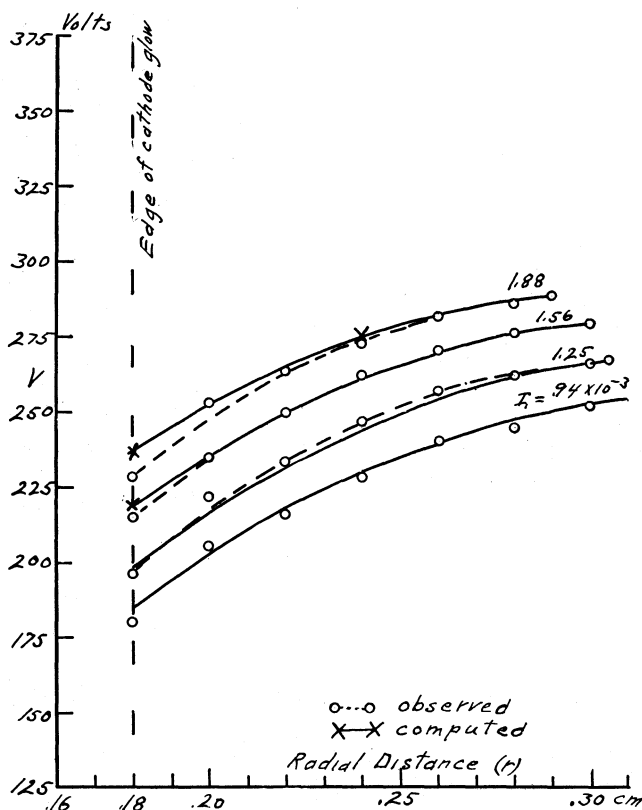


FIG. 4

helium, so that it seems probable that in the samples used there were only a few hundredths of one per cent. of nitrogen at the most present as an impurity.

¹⁴ Ramsay, *Proc. Roy. Soc.*, 59, p. 325, 1896.

EXPERIMENTAL RESULTS

Helium.—Table I gives the observed potentials at different distances from the axis of the cathode and the corresponding values of the potential computed from the theoretical formula (8), for helium at a pressure of 2.55 mm. for four different current densities. These are shown graphically in Fig. 4. The values of r_0 and V_0 , the value of V at the bottom of each column, were determined as described above. In the first column is given the distance of the equipotential surface from the axis of the cathode. The observed values of the potential are in reasonably good agreement with the computed and none of them could be called distinctly unsatisfactory except the one for the point nearest to the cathode for the greatest current density. Since nearly all the measurements at that position have shown a considerable error, it seems probable either that the errors due to the orientation of the probe make these readings unreliable or that the setting for that position is slightly within the polarization region. Confidence in

TABLE I
Aluminium Wire Cathode

Diam., 3.2 mm.; exposed length, 3.2 cm.; Helium pressure = 2.55 mm.

Dist.	$I_1 = .94 \times 10^{-3}$ Amp.		$I_1 = 1.25 \times 10^{-3}$ Amp.		$I_1 = 1.56 \times 10^{-3}$ Amp.		$I_1 = 1.88 \times 10^{-3}$ Amp.	
(r)	V		V		V		V	
Cm.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
.18 . . .	180.0	184.9	196.1	197.9	214.5	218.6	228.5	237.3
.20 . . .	205.3	202.8	221.5	216.4	234.6	234.9	252.7	252.6
.22 . . .	216.5	217.8	233.4	231.3	249.7	249.2	263.5	265.0
.24 . . .	228.0	230.6	246.5	244.5	262.1	260.5	272.5	275.0
.26 . . .	239.9	240.2	256.7	254.6	270.3	269.5	281.5	282.6
.28 . . .	244.7	248.1	262.2	262.0	276.0	275.6	286.0	287.3
.29 . . .	.....	.....	.....	.....	.....	.....	288.5	288.5
.30 . . .	252.0	253.4	266.2	266.4	279.0	279.0		
.305 . . .	.....	.....	267.1	267.1				
.31 . . .	254.2	254.2						
U	3.56×10^3		4.23×10^3		6.14×10^3		8.04×10^3	
U ₁ . . .	9.7×10^3		10.79×10^3		15.66×10^3		20.5×10^3	
*								

the probable truth of the latter suggestion is strengthened when it

is noted that in the great majority of instances the observed values at this point are lower than those calculated.

In Table II are given the observed and calculated potentials in helium at a pressure of 1.55 mm., with a graphical representation in Fig. 5. The results show a reasonably good agreement except

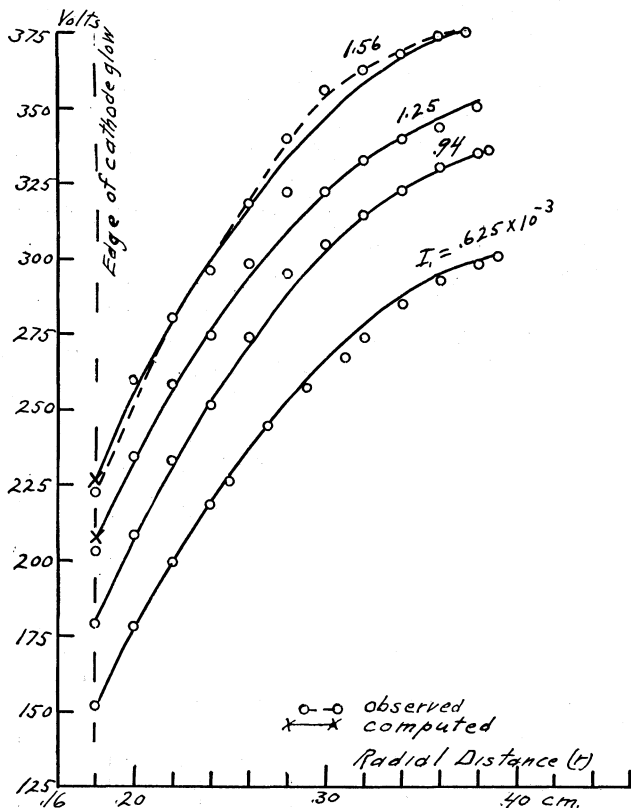


FIG. 5

for one reading in the next to the highest current density.

DETERMINATION OF MOBILITY OF POSITIVE IONS

The theoretical formula may also be used to determine values of mobility of the positive ions, U , of the gas in the discharge tube.

Using the measured values of r_0 and V_0 , the measured potential, V , of one other equipotential surface, near the cathode glow, but not directly at the edge of the cathode glow, and the current I_1 , and solving the equation for the value of U , we can obtain the value of the mobility for each current density.

TABLE II

Aluminium Wire Cathode

Diam., 3.2 mm.; exposed length, 3.2 cm.; Helium pressure = 1.55 mm.

Dist.	$I_1 = .625 \times 10^{-3}$ Amp.		$I_1 = .94 \times 10^{-3}$ Amp.		$I_1 = 1.25 \times 10^{-3}$ Amp.		$I_1 = 1.56 \times 10^{-3}$ Amp.	
(r)	V		V		V		V	
Cm.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
.18....	151.7	150.3	179.0	179.7	203.0	206.7	222.5	226.3
.20....	178.0	176.6	208.5	207.2	236.8	232.7	259.8	255.2
.22....	199.2	200.3	233.0	232.7	258.5	255.6	280.3	279.1
.24....	218.5	219.7	251.5	253.4	274.6	276.4	296.2	299.2
.25....	226.2	228.6						
.26....	.....	.....	274.0	272.3	298.3	294.3	318.4	317.2
.27....	244.5	245.8	.....	.....	.....	.....
.28....	.....	.....	289.9	288.3	321.8	308.8	339.8	333.5
.29....	256.2	260.2						
.30....	.....	.....	304.7	303.1	322.0	321.6	355.8	346.4
.31....	267.3	273.1						
.32....	273.5	278.6	314.2	314.1	332.2	332.7	362.5	357.6
.34....	285.0	287.6	322.5	323.8	339.8	340.7	367.7	366.3
.36....	292.5	295.2	330.0	330.2	343.5	347.4	373.2	372.2
.375...	.....	.....	.....	.....	.....	.....	374.5	374.5
.38....	298.0	299.4	334.8	335.5	350.5	350.5		
.386...	.....	.....	336.0	336.0				
.39....	300.8	300.8						
U.....	2.01×10^3		2.68×10^3		3.84×10^3		4.17×10^3	
U1.....	3.11×10^3		4.15×10^3		5.95×10^3		6.46×10^3	

When the mobilities are thus computed the values obtained at the different current densities are not found to be in agreement as might be expected from the theory, but the value of the mobility obtained increases as the current density is increased. The suggestion occurs that this may be due to the nitrogen present as an impurity. Since the ionization potential of nitrogen is lower than that of helium, it might be expected that at the lower currents the

nitrogen ions would carry a relatively higher proportion of the current, and as the current is increased the more mobile helium ions carry a larger percentage of the current, thus giving higher average mobility. Spectroscopic examination of the glow tends to support this explanation, since the helium lines become relatively much more intense as the current density is increased.

The law that the product of the mobility times the pressure is constant is found to hold at higher gas pressures. In order to compare mobilities obtained at different pressures, the value, U_1 , of the mobility at 1 mm. pressure was computed for each case on the basis of the above law. The values of U_1 in the two tables

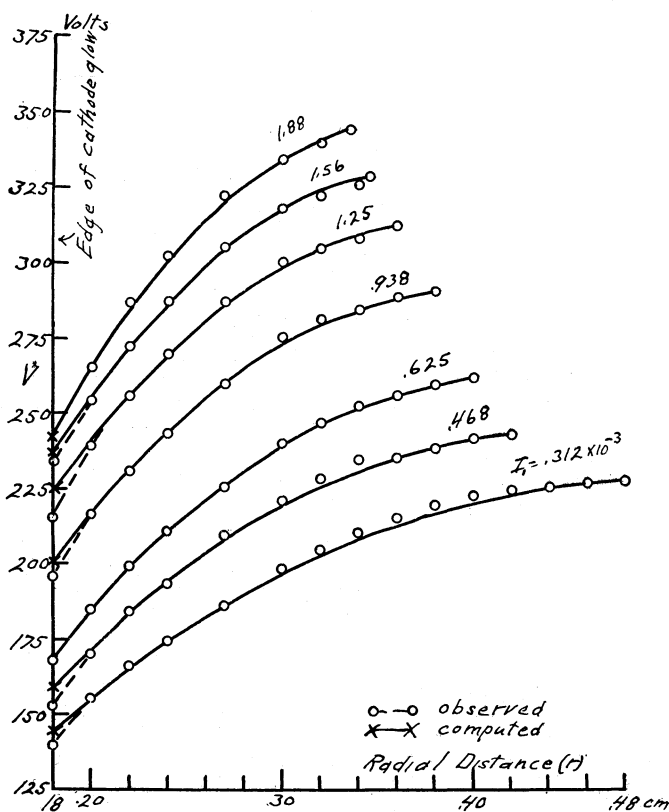


FIG. 6

do not agree. All, except one, are higher than the mobility of helium, 3.9×10^3 , computed from measurements of Franck and Pohl made at atmospheric pressure,¹⁵ the highest value obtained being approximately five times as high as their value.

Argon.—The argon used was from a bulb obtained from the Linde Gas Products Company and contained a trace of nitrogen as an impurity. The argon was introduced into the discharge tube without any further purification except drying—the tube being “washed out” by repeated fillings and evacuation. The results are incorporated in Tables III, IV, and V, and are shown graphically in Figs. 6, 7, 8.

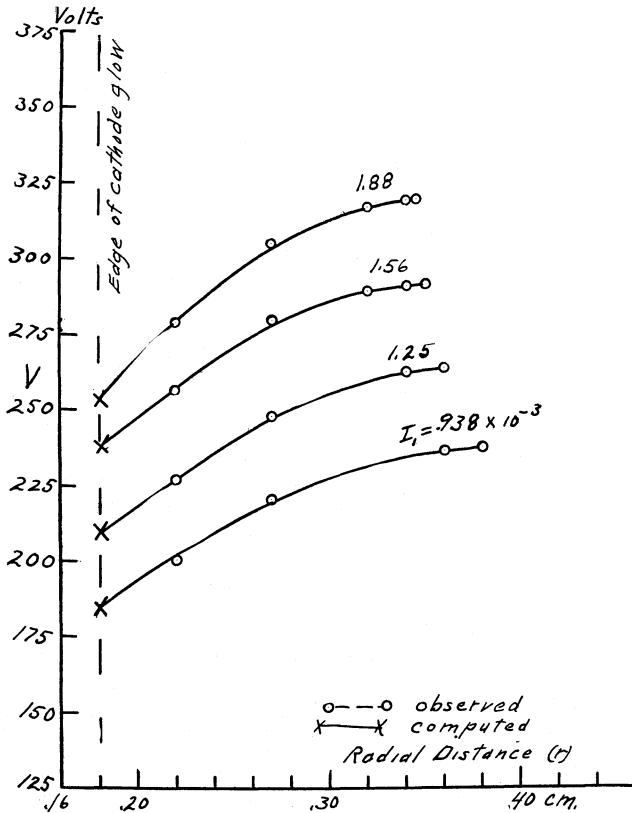


FIG. 7

¹⁵ Franck & Pohl, *Verh. d. D. Phys. Ges.*, 9, p. 194, 1907.

The results in Table III were taken immediately after filling the apparatus from the argon bulb. They show an excellent agreement between the observed and calculated potentials, sub-

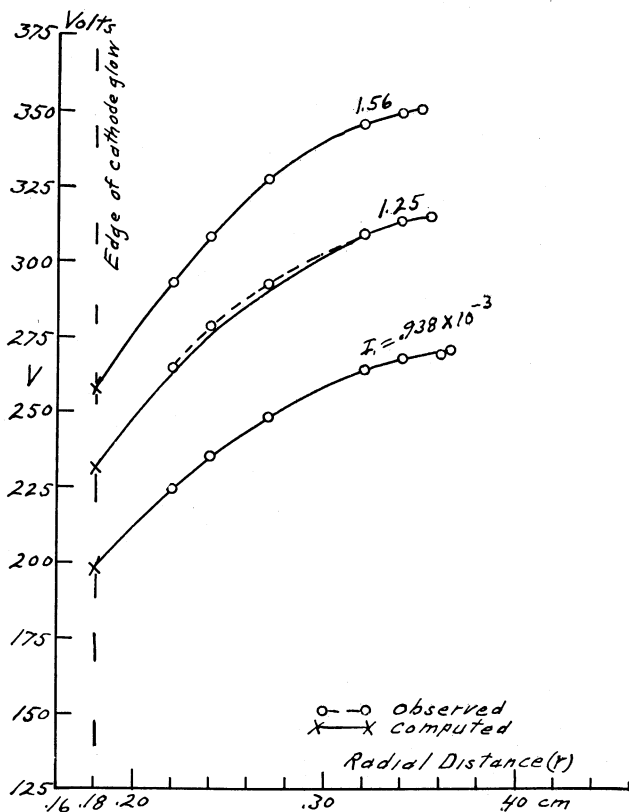


FIG. 8

stantiating the theory very satisfactorily. None of the values could be considered unsatisfactory except one or two at the distance .18 cm., the edge of the polarization region, where the observed values of the potential are markedly lower than the computed values. As explained previously, this is believed to be due to the setting of the probe slightly too close to the cathode.

The values of the mobility computed from these data are in fair

TABLE III

Aluminium Wire Cathode

Diam., 3.2 mm.; exposed length, 3.2 cm.; Argon, pressure = .75 mm.

Dist.	$I_1 = .312 \times 10^{-3}$ Amp.*		$I_1 = .468 \times 10^{-3}$ Amp.		$I_1 = .625 \times 10^{-3}$ Amp.		$I_1 = .938 \times 10^{-3}$ Amp.		$I_1 = 1.25 \times 10^{-3}$ Amp.		$I_1 = 1.56 \times 10^{-3}$ Amp.		$I_1 = 1.88 \times 10^{-3}$ Amp.	
(r)	V		V		V		V		V		V		V	
Cm.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
.18.....	140.8	143.7	152.5	158.2	167.7	168.3	195.6	199.2	215.3	223.7	228.0	236.4	234.0	241.7
.20.....	155.2	155.2	170.2	172.2	184.9	184.5	216.5	216.5	239.0	241.4	254.0	255.6	265.5	265.5
.22.....	166.1	165.0	184.0	183.8	199.0	198.5	230.5	230.7	255.6	256.2	272.2	272.7	286.6	284.4
.24.....	174.3	173.0	193.3	194.2	210.5	210.3	243.2	243.6	269.3	269.6	287.0	287.3	302.0	301.4
.27.....	186.0	186.0	209.4	208.4	225.9	226.1	259.5	259.4	286.6	285.7	305.2	304.6	322.5	321.5
.30.....	198.3	196.2	221.1	218.6	240.2	238.9	275.0	272.4	300.0	298.3	317.7	317.6	334.0	335.2
.32.....	204.5	202.0	228.2	225.3	247.2	245.8	281.0	279.4	304.0	304.6	322.2	324.6	339.8	341.4
.335.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	344.0	344.0
.34.....	210.0	207.2	234.5	230.3	252.3	251.8	284.3	284.1	307.8	310.2	326.0	327.5		
.345.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	328.5	328.5		
.36.....	215.2	212.1	235.3	235.1	256.0	256.4	288.5	288.4	311.7	311.7				
.38.....	219.4	216.5	238.4	239.5	259.2	260.0	290.5	290.5						
.40.....	222.4	219.9	241.5	241.5	261.7	261.7								
.42.....	224.3	223.0	243.0	243.0										
.44.....	226.0	225.5												
.46.....	227.2	227.2												
.48.....	228.0	228.0												
U.....	9.13×10^3		7.10×10^3		6.07×10^3		7.16×10^3		7.52×10^3		5.92×10^3		5.56×10^3	
U ₁	6.85×10^3		5.33×10^3		4.55×10^3		5.37×10^3		5.64×10^3		4.44×10^3		4.17×10^3	

Average value of $U_1 = 5.19 \times 10^3$.

agreement and do not show the marked variations with change of current density that was found with helium. However, the actual values of mobility are found to be about five times as large as the value,¹⁶ 1.04×10^3 , obtained by computation from Franck's measurements made at atmospheric pressure.

TABLE IV
Aluminium Wire Cathode

Diam., 3.2 mm.; exposed length, 3.2 cm.; Argon, pressure = .75 mm.

Dist.	$I_1 = .938 \times 10^{-3}$ Amp.		$I_1 = 1.25 \times 10^{-3}$ Amp.		$I_1 = 1.56 \times 10^{-3}$ Amp.		$I_1 = 1.88 \times 10^{-3}$ Amp.	
(r)	V		V		V		V	
Cm.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
.18....	.....	183.6	.....	208.4	.....	235.8	.....	251.8
.22....	200.5	201.9	226.5	227.8	255.7	256.8	277.7	277.9
.27....	219.5	218.8	246.8	246.3	278.0	275.6	303.0	301.2
.32....	.....	.....	.....	.....	288.0	287.7	315.4	315.4
.34....	.....	.....	260.6	260.8	290.0	290.0	318.0	318.0
.345...	.....	.....	.....	.....	.....	.....	318.2	318.2
.35....	.....	.....	.....	.....	290.6	290.6	.....	.....
.36....	236.0	235.8	262.2	262.2	.....	.....	.....	.....
.38....	237.0	237.0	.....	.....	.....	.....	.....	.....
U.....	21.0×10^3		20.0×10^3		20.5×10^3		15.4×10^3	
U ₁	15.75×10^3		15.00×10^3		15.35×10^3		11.55×10^3	

The values shown in Table IV and Fig. 7 were taken with the same sample of gas as the readings of Table III, but after it had been standing in the apparatus several days. The computed and observed potentials are in good agreement, but markedly lower than the values found in Table III. This was not surprising, since it is a well-recognized fact that a slight change in the cathode surface may produce a marked change in the total potential fall, but this does not involve any change in the potential gradient in the Crooke's dark space, nor would it have any influence on the values of the mobility in that region. A comparison of Figs. 6 and 7 shows that the curves of Fig. 7 are flatter than those in Fig. 6, the drop of potential through the Crooke's dark space being

¹⁶ J. Franck, *Ber. d. D. Phys. Ges.*, 8, p. 291, 1910.

smaller than with the fresh filling. The comparison of the mobilities in the two cases shows that the mobility has been increased to a remarkable degree by allowing the gas to stand in the apparatus.

To make certain that this increase in mobility was not accidental the system was thoroughly evacuated, washed out with fresh argon

TABLE V
Aluminium Wire Cathode

Diam., 3.2 mm.; exposed length, 3.2 cm.; Argon, pressure = .75 mm.

Dist.	$I_1 = .938 \times 10^{-3}$ Amp.		$I_1 = 1.25 \times 10^{-3}$ Amp.		$I_1 = 1.56 \times 10^{-3}$ Amp.		
(r)	V		V		V		
Cm.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	
.18.....	.....	198.1	.....	231.3	.....	257.7	
.22.....	224.2	224.3	264.5	262.8	292.5	293.2	
.24.....	235.2	235.1	278.5	275.6	308.0	307.9	
.27.....	248.3	248.2	292.0	290.4	327.4	325.1	
.32.....	264.0	263.9	309.0	309.2	345.5	345.5	
.34.....	268.0	268.0	313.4	313.2	349.0	349.6	
.35.....	.....	.....	.....	.....	350.5	350.5	
.355.....	.....	.....	314.8	314.8			
.36.....	269.7	270.2					
.365.....	270.7	270.7					Average
U.....	8.92×10^8		7.72×10^8		7.12×10^8		
U ₁	6.69×10^8		5.79×10^8		5.34×10^8		5.94×10^8

from the bulb to remove, as far as possible, the impurities from the apparatus, and refilled with fresh argon at the same pressure—.75 mm. A set of readings were taken immediately and are given in Table V, with a graphical representation in Fig. 8. The curves show nearly the same form as the curves of Fig. 6. The mobilities show a reasonable agreement with the mobilities found in Table III.

The gas was then allowed to stand for several days and another series of readings were taken. These gave values of U practically identical with those found in Table IV, showing that the mobility increases if the gas is allowed to stand in the apparatus. If this increase were caused by impurities, as is believed, the impurities must originate in the apparatus and be relatively minute in volume,

for in no case was there any change in the pressure as read on the McLeod gauge which could detect a change of about five-tenths of one per cent.

If this is true, the value of the mobility must be very sensitive to impurities in the gas, since they would be given up very slowly, and the values found for the gas after a fresh filling may be higher than the true value of U for argon, since it is not strictly pure. Franck¹⁷ found that the negative ion was very sensitive to impurities, but he did not find that impurities seemed to show any influence on the mobility of the positive ions. However, measurements made by this method might well be more sensitive to the effect of impurities—at least to the presence of hydrogen if Skinner's¹⁸ value for the mobility of hydrogen is correct—than measurements made by the ordinary methods.

SUMMARY

It has been shown that in the negative glow there are equal positive and negative currents. Assuming, then, that the negative glow is the source of positive ions, and that the negative ions originate from the extremely small electron current caused by the bombardment of the cathode by the positive ions, it has been shown that at a distance of one ionizing interval toward the cathode from the negative glow the positive ions carry three-fourths of the current, at the distance of two intervals seven-eighths, and so on, so that at a comparatively short distance the positive ions carry practically all the current.

From this assumption a theory has been developed for the potential at any point in the gas between the point of minimum gradient and the polarization region for wire cathodes.

This theory is tested for an aluminium cathode in the monatomic gases, helium and argon, and is found to correspond very satisfactorily with the experimental results.

The values for the mobility in helium, which was not entirely pure, computed from the theoretical equation (8), were not constant for different current densities, and the values of the mobility

¹⁷ J. Franck, *Ber. d. D. Phys. Ges.*, 8, p. 291, 1910.

¹⁸ C. A. Skinner, *Phys. Rev.*, XII; p. 143, 1918.

at 1 mm. pressure, U_1 , did not agree when computed from the two pressures used.

Two fresh fillings of argon gave mobilities which checked quite well and there was not any decided variation in the mobility when the current density was changed. However, the mobility is about five times as large as the value found by Franck with measurements made at atmospheric pressure and increased by three or four times its original value if the gas was allowed to stand in the apparatus for several days. This makes it extremely doubtful whether the value of mobility obtained is the value that would be found if the argon were pure when the first measurements were made.

If the value found is larger than would be found for pure argon, then this is a reliable method for measuring mobilities, and Skinner's suggestion that in the case of hydrogen the high mobility which he found—about twelve times as high as the values which ordinary methods of measurements give—is due to an atomic ion would be supported. This can be determined only by using pure argon, which the writer was unable to secure for the purpose of the present investigation, but hopes to be able to obtain for later work.

However, if the pure monatomic gases give abnormally high mobilities, it seems probable that the form in which the mobility factor enters the theoretical formula must need be modified, presumably by the introduction of another constant factor.

THE DIATOMS (BACILLARIOIDEAE) OF NEBRASKA

BY CLARENCE J. ELMORE

OCCURRENCE

Diatoms are found practically in all places where there is water—in lakes, rivers, creeks, ponds, tubs, troughs, tanks; and on damp ground, rocks, walls, or boards. All water, from the ocean to the smallest puddle caused by the tracks of cattle's feet, provided the puddles persist for a few days, is almost certain to contain diatoms. When unmixed with other substances they present a brownish color. Often the entire bottom of a stream may be covered to a thickness of an inch or more with a brown mass of diatoms. But the greater number occur mixed with other algae, in which case their brown color is hidden by the green of the algae.

Diatoms are also found in the fossil state. In this condition they are called Diatomite by geologists, or Kieselguhr in commerce. The name Infusorial Earth has also been applied to them, but this is incorrect, for diatoms are not Infusoria.

Diatoms differ from other plants in that their cell walls are thoroughly infiltrated with silica, or quartz of the opal variety. The form of the cell is often likened to a pill box or a telescope, one-half fitting over the other. The statement made in practically all of the textbooks is that when a cell divides the two valves, ends of the cell, separate slightly and a new valve grows inside of each, thus forming two new cells. Thus each new cell has one of the original valves of the mother cell and a new valve formed inside of the girdle of the old one. Hence it would appear that one of the new cells is the exact size of the mother cell and the other slightly smaller, the reduction in size going on with each cell division. This process continues until a certain minimum size is reached, when an auxospore is formed. The necessity for auxospore formation arises from the fact that the cell walls of diatoms are silicified and so can not grow, together with the fact that they become smaller with each division.

Volume 8, The Nebraska Geological Survey published by the University Studies, Volume 21