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**Determination of the Ionization Potential of Argon**

Francis A. Brhely

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DETERMINATION of the IONIZATION POTENTIAL of ARGON

by

Francis A. Erhely

Experimental data submitted to the Faculty of the
College of Liberal Arts, Marquette University
in partial fulfillment of the requirements
for the degree of Bachelor of Science

Milwaukee, Wisconsin

February 1951
The introduction and discussion of a gas filled thyatron, with data and graphs determining the ionization potential of argon.
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The argon-filled tube is a positive-grid control type tube. The grid, a fine wire, is surrounded by the grid from a given anode. The positive anode potential is unable to cause electrons emitted from the cathode and the operating current must be supplied to the tube.

If a positive anode voltage is applied, some of those electrons may travel over to the anode, and if the voltage is sufficient, they will cause ionization by collision producing positive ions.

If the grid is not sufficiently positive, then electrons are prevented from passing to the anode preventing ionization by collision. But if the grid is less positive or the plate is made more positive, an anode current will flow, and ionization by collision will result.

The positive ions travel to the cathode and neutralize the negative space charge. The reduction in opposing space charge makes it easier for the electrons to flow to the anode. Therefore, large currents can flow from the cathode to the anode with a relatively small voltage drop. The low voltage drop makes an efficient tube, because the internal heat losses are low.

It is important to know that the grid can control at the instant at which current starts to flow from the cathode to the
The Argon filled tube is a positive grid control type tube, that is the grid must be positive before discharge starts. The cathode is completely shielded by the grid from a given anode voltage. Therefore, the positive anode potential is unable to influence the electrons emitted from the cathode and the operation of the tube. A positive current must be supplied to the tube before it conducts.

In a gas filled tube electrons are given off by a hot cathode. When no positive anode voltage is applied, the electrons form a negative space charge about the cathode. If a positive anode voltage is applied, some of these electrons may be drawn over to the anode, and if the voltage is sufficient, they will cause ionization by collision producing positive ions.

If the grid is not sufficiently positive then electrons are prevented from passing to the anode preventing ionization by collision. But if the grid is less positive or the plate is made more positive, an anode current will flow, and ionization by collision will result.

The positive ions travel to the cathode and neutralize the negative space charge. The reduction in opposing space charge makes it easier for the electrons to flow to the anode. Therefore, large currents can flow from the cathode to the anode with a relatively small voltage drop. The low voltage drop means an efficient tube, because the internal heat losses are low.

It is important to know that the grid can control at the instant at which current starts to flow from the cathode to the
anode, but as soon as the current once starts, the grid losses control, and the grid potential has no further effect on the current to the anode, within operating limits.

The reason is as follows: After ionization, the positively charged grid is in a region of equal numbers of positive and negative ions. The positive grid repels the slow moving, massive positive ions, and attracts the highly mobile negative electrons. Therefore, a negative ion sheath is formed around the positive grid. The negative electric field from this sheath neutralizes the positive field of the grid, preventing the grid from further influencing the operation of the tube.

The grid continues to be ineffective until the tube deionizes and the anode current ceases to flow. After deionization occurs the grid is again able to determine the value of the anode voltage at which the tube breaks down and conducts.

T is a 225, 8-pin, argon filled thyatron.
Efficient filament voltage is 2.0 volts.
Efficient filament amperage is 1.4 amps.
Peak anode voltage is 300 volts.
Maximum anode milliamperage is 300 ma.
Operating milliamperage is 15 ma.
Grid resistance is 10,000 ohms.
E is a 22½ volt E battery.
P is a 15,000 ohm potential divider.
V is a 0-30 volt voltmeter.
NA is a 0-600 ma milliammeter.
G is a center tapped transformer. The 110 volt primary is stepped down to 3.3 volts. Since the maximum effective voltage of the filament is 2.5 volts, the transformer was connected to a
CIRCUIT DIAGRAM FOR IONIZATION POTENTIAL

Fig. 1

T is a 385, 5 pin, argon filled thyatron.
Efficient filament voltage is 2.5 volts.
Efficient filament amperage is 1.4 amps.
Peak anode voltage is 350 volts.
Maximum anode milliamperage is 300 ma.
Operating milliamperage is 75 ma.
Grid resistance is 25,000Ω.
E is a 22½ volt E' battery.
P is a 15,000Ω potential divider.
V is a 0-30 volt voltmeter.
MA is a 0-600 ma milliammeter.
G is a center tapped transformer. The 110 volt primary is stepped down to 6.3 volts. Since the maximum effective voltage of the filament is 2.5 volts, the transformer was connected to a
variac, and the voltage was stepped down by the variac until
the secondary supplied the necessary 2.5 volts.

The tube should be heated at least fifteen minutes before
potential is applied to it, allowing the filament to expel a sufficient amount of electrons to validate the readings shown on the meter.

Since the grid and the plate are tied together, the tube is essentially a diode, and most of the electrons given off by the filament will pass to the plate without being hindered by a grid voltage.

Various voltages applied to the plate are controlled by the potentiometer. As the voltage is increased, a greater velocity is imparted to the electrons and more will reach the plate, thereby increasing the plate current. In the vicinity of 15 volts, it will be noticed that a sudden increase in plate voltage will cause a rapid increase in current. Fig. 2 should be taken that the milli-

ameter is connected to a higher scale when readings are taken in this and 5 are filament heater supply pins.

rise in 2 is the plate supply pin. The rapid rise in 3 as the grid supply pin. The rapid rise in the current, the intersection will be the value of the ioniza-
tion potential of the gas.
The tube should be heated at least fifteen minutes before potential is applied to the plate. This will allow the filament to expel a sufficient amount of electrons to validate the readings shown on the meters.

Since the grid and the plate are tied together the tube is essentially a diode, and most of the electrons given off by the filament will pass to the plate without being hindered by a grid voltage.

Various voltages applied to the plate are controlled by the centimeter. As the voltage is increased a greater velocity is imparted to the electrons and more will reach the plate, thereby increasing the plate current. In the vicinity of 15 volts, it will be noticed that a minute increase in plate voltage will cause a rapid increase in current. Care should be taken that the millimeter is connected to a higher scale when readings are taken in this region, since the current increase is very large. The rapid rise in current denotes that the ionization potential of the gas has been reached.

The values of current to the 2/3 power are plotted as functions of plate potential. If the gradual slope of current is extended to intersect at a point with the slope of the rapid rise in the current, the intersection will be the value of the ionization potential of the gas.
Name: Ionization Potential

Date: 12-4-50

Tube: 885 Thyratron

Element: Argon

Result from graph: 15.06 Volts

Circuit Constants

Effective voltage 2.5 V.

Warm up time: 1 hour

\[ R_1 = 15,000 \, \Omega \quad R_n = 2 \, \Omega \]

\[ E = 22\frac{1}{2} \, V. \quad R_v = \frac{100 \, \Omega}{\text{volt}} \]

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IONIZATION POTENTIAL
DETERMINED WITH
386 Argon Thyatron
at
Marquette University
12 - 4 - 50
Result: 15.06 volts

$V_p \text{ (volts)}$
**Name:** Ionization Potential  
**Date:** 12 - 7 - 50  
**Tube:** 885 Thyratron  
**Element:** Argon  

**Result from graph:** 15.3 Volts  

**Circuit Constants**  
- **Effective voltage:** 2.5 V.  
- **Warm up time:** 45 min.  
- **R₁ = 15000 Ω**  
- **Rₓ = 2 Ω**  
- **E = 22\frac{1}{2} V.**  
- **Rᵧ = \frac{100}{\text{volt}}**

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IONIZATION POTENTIAL
Determined by
885 Argon Thyatron
at
Marquette University
12 - 7 - 50
Result: 15.3 volts

12 \sqrt{I/3} (ma)
(Flate Current)
**Name:** Ionization Potential

**Date:** 12 - 11 - 50

**Tube:** 885 Thyatron

**Element:** Argon

**Result from graph:** 15.3 Volts

**Circuit Constants**

- Effective voltage: 2.5 V.
- Warm up time: 30 min.
- \( R_1 = 15,000 \Omega \)
- \( R_a = 2 \Omega \)
- \( E = 22\frac{1}{2} \) V.
- \( R_v = 100 \Omega \)

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IONIZATION POTENTIAL
determined with
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at
Marquette University
12 - 11 - 50
Result: 15.3 volts
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The tube was operated as a gas filled diode. The principles behind the operation is similar to that already explained in the introduction, except there is no grid.

From the graphs it is obvious that within the vicinity of the ionization potential a large current is produced for very small values of voltage drop.

The ionization potential itself seemed to remain fairly constant as compared to various warm up periods. But there seemed to be a slight deviation in the value obtained when the filament was pre-heated for one hour. This may be due to experimental error, such as inaccurate readings of the meters, decrease in plate resistance due to some defect of the tube, or the gas pressure of the argon was affected by the temperature change due to the prolonged heating effect of the filament and therefore varied the characteristics of the tube.
BIBLIOGRAPHY


The discussion and theory of the measurement of the a/m for electrons, using a No. 223 a/m tube manufactured by the W. H. Welch Scientific Company, Chicago, Illinois.

PART II
The discussion and theory of the measurement of the e/m for electrons, using a No. 623 e/m tube manufactured by the W. M. Welch Scientific Company, Chicago, Illinois.

Development of the e/m Formula
Development of the e/m Value
Circuit Diagram for Filament Current and Accelerating Potential
Circuit Diagram for Magnetizing Current
Cutaway Diagram of the e/m Tube
Description of the Physical Constants
Experimental Procedure
Bibliography
Approval
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Edison discovered in 1883 that glowing filaments of carbon give off electricity. If a cathode is heated to a fairly high temperature electrons will flow from the cathode to a cold anode for the smallest potential differences. This fact is demonstrated by the incandescent lamp. Inside the glass bulb a fast metal plate is insulated from a glowing filament which is connected by a wire sealed in the glass. When the plate is positive compared to the filament, a current flows through the vacuum. There is no current flow when the plate is negative.

The various phenomena occurring in the experiment may be explained with the help of diagrams (A) and (B). In diagram (A) the cathode is heated electrically by a heater coil (H) placed high inside it. Practically both electrodes may be made cylindrical, with the cathode placed on the inside or the heater coil itself is made to act as cathode in place of (C). The high temperature
of the cathode evaporates electrons from the metal, and an electron cloud forms above the surface of the cathode.

Since electrons repel each other, but are attracted to the surface of the cathode by the positive charges which they induce in that surface, this cloud is denser close to the cathode surface than it is any other place, and only those with the most velocity will escape the surface. Existing coils inside.

Therefore if (E) is charged positively it attracts electrons to itself, and an electron current flows through the tube. This current depends on the potential of (E) as demonstrated by the following curve.

A straight glowing filament in motion small metal cylinder and an insulated row slit parallel to the axis of emission a narrow ray of electric charges shooting out in a straight direction has the function of making the electrons free of electric fields, and the voltage is placed between magnetic coils and a straight direction without affecting the emission.

Low voltages affect only the outer electrons of the cloud and the current is small. Higher voltage will affect more electrons in the cloud, until a voltage is reached which will draw all the electrons to (E) as fast as they are emitted from (C). Further increase in voltage produces little effect in current and the current is said to be saturated. (C) on the graph illustrates that the saturation current is reached at a lower voltage for a lower cathode temperature.

The emission depends also upon the nature of the surface of the cathode. Tungsten was used because it could be heated to high temperatures without disintegration.

Further discovery showed that tungsten in which a small amount of thorium oxide was added while the tungsten was still dissolved,
would emit more electrons at much lower temperatures.

This emission is due to a mono-molecular layer of thorium atoms covering the surface of the tungsten filament.

The cathode is always heated electrically by a separate low voltage battery or transformer. It may be in the form of a filament through which the heating current flows directly, or it may be a metal box or cylinder with heating coils inside.

These phenomenon were utilized by K. T. Bainbridge*. The diagram of the tube used in this experiment is essentially that used by Bainbridge. The experimental method is described in later pages.

A straight glowing filament is mounted along the axis of a small metal cylinder and is insulated from the cylinder. A narrow slit parallel to the axis of the cylinder along its wall, emits a narrow ray of electric charges coming from the filament, shooting out in a straight direction. The space outside the slit is free of electric fields, and the low pressure mercury vapor has the function of making the electric beam visible. The bulb is placed between magnetic coils so that the electric beam can be bent in a circular path.

It is not true that the filament gives off only negatively charged particles. There is observed a weak emission of positively charged particles which are detected when the polarity of the filament is reversed with respect to the plate.

Determining e/m of these particles show they consist of positive ions of sodium or chemically related elements. This

---

* American Physics Teacher, 6, 35, (1938)
emission is only apparent in filaments carrying impurities. Generally the positive ions are exhausted after a short time and the positive current stops.

\[ \frac{I}{I_0} = 1 \]

\[ H = \frac{E}{I} \]

\[ \frac{1}{2} \rho \frac{d}{L} \]

\[ \frac{1}{2} I \]

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FIELD STRENGTH DUE TO HELMHOLTZ COILS

1. From fundamental experiments Ampere had shown that the following relationship is true.

\[ H = \frac{i \, dl \, \sin \theta}{R^2} \]

where:

- \( H \): resultant field strength
- \( i \): current
- \( dl \): element of length
- \( \theta \): angle
- \( R \): distance of the element of the circuit to the point at which \( H \) is to be found
- \( \sin \theta \): sine of the angle

2. The field at (A): Where \( \theta = 0 \)

\[ H = \frac{i \, dl}{R^2} \]

3. But the coil consists of \( n \) turns sufficiently close together so that a mean radius of negligible error may be taken.

\[ \text{From: } R = 2 \pi \alpha a \]

4. But \( r = x^2 + a^2 \) and \( x = (r^2 + a^2)^{1/2} \)

5. Then: \( H = 2 \pi \text{ln} \frac{a}{x} \)

6. Then: The field strength at a point on the axis is the greatest at the center of the coil because there

\[ H = 2 \pi \text{ln} \frac{a}{x} \]

As you move from the center, the field becomes 0 when \( x = 0 \)

7. The rate of change of the field from point to point along

\[ \frac{dH}{dx} = 2 \pi \text{ln} \frac{a}{x} \]

Figure (E) shows that the Helmholtz coils are so constructed that their radii are equal, and that the distance between the coils is also equal to the radius of either coil.

In regard to figure (C), the field due to \( dl \) of the circle.
must be considered in order to find the strength of a magnetic field at a point on the axis of the circular coil at a distance \( x \) from the center of the circle.

2. The field at \((A)\): Where \( i \) = current in the coil in the direction \((AB)\) at right angles to the plane containing \((r)\) and \((dl)\).

\[
\begin{align*}
\text{from 1.} \quad \sin \theta = \frac{a}{r} ; \quad dl = 2\pi a \\
\text{then:} \quad H = \frac{i \cdot 2\pi a}{r} \cdot \frac{a}{r} = \frac{2\pi a^2 i}{r^3} \\
\end{align*}
\]

3. But the coil consists of \( n \) turns sufficiently close together so that a mean radius of negligible error may be taken.

\[
\text{then:} \quad H = \frac{2\pi n a^2 i}{r^3} \\
\]

4. But \( r^2 = x^2 + a^2 \) and \( r = (x^2 + a^2)^{1/2} \)

\[
\text{then:} \quad H = \frac{2\pi n a^2 i}{(x^2 + a^2)^{3/2}} \\
\]

6. then: The field strength at a point on the axis is the greatest at the center of the circle, because there

\[
\begin{align*}
x &= 0 \\
\text{then:} \quad H = \frac{2\pi n a i}{a} &= \frac{2\pi n i}{a} \\text{As you pass from the center, the field becomes 0 when} x = 0 \\
\end{align*}
\]

7. The rate of change of the field from point to point along the axis is

\[
\begin{align*}
\frac{d}{dx} \left[ \frac{2\pi n a^2 i}{(x^2 + a^2)^{3/2}} \right] \\
\end{align*}
\]

Let \( y = \frac{d}{dx} \left[ \frac{2\pi n a^2 i}{(x^2 + a^2)^{3/2}} \right] \)
If the rate of change of \( y \) becomes constant,
\[
\frac{dy}{dx} = 0 \quad \text{or} \quad \frac{d^2 y}{dx^2} \left[ \frac{2\pi n a^2 i}{(x^2 + a^2)^{3/2}} \right] = 0
\]

8. \( 2na^2i \) is a constant, therefore it can be omitted in the following differentiations.

9. \[
\frac{1}{(x^2 + a^2)^{3/2}} = (x^2 + a^2)^{-3/2}
\]

10. \[
\frac{d}{dx} (x^2 + a^2)^{-3/2} = \frac{3}{2}(x^2 + a^2)(2x) = -3x(x^2 + a^2)^{-5/2}
\]

11. \[
\frac{d^2}{dx^2} (x^2 + a^2)^{-3/2} = \frac{d}{dx} (-3x)(x^2 + a^2)^{-5/2}
\]

then: \[
\frac{d^2}{dx^2} (x^2 + a^2)^{-3/2} = \frac{5}{2} (x^2 + a^2)(2x)(-3x) (x^2 + a^2)^{-5/2} \quad (3)
\]

12. \[
\text{then: } - (x^2 + a^2)^{-5/2} - 5x^2(x^2 + a^2)^{-7/2} = \frac{dy}{dx} = 0
\]

13. divide (12) by \(-3(x^2 + a^2)^{-5/2}\)

then: \[
0 = -1 \quad 5x^2(x^2 + a^2)^{-1}
\]

14. \[
x^2 + a^2 = 5x^2 \quad \text{then: } 4x^2 = a^2, \quad \text{and} \quad x = \frac{a}{2}
\]

15. Conclusion:
At a point on the axis whose distance from the plane of the circle is \( a/2 \), the rate of change of the field as you pass along the axis becomes constant.

16. Therefore in the Helmholtz system of double coils; the two coils are placed co-axially at a distance apart equal to the radius of either coil. The rate of change of field is most uniform at a point \( a/2 \) or midway between either coil. Thus any decrease in the field at a point due to one coil as the distance from \( a/2 \) is increased, is compensated for by an equal increase in the field due to the other coil, since the rate of change for the two coils is constant and occur-
17. Substitute \( \frac{x}{2} \) in the expression \( H = \frac{2\pi na^2}{(x^2 + a^2)^{3/2}} \) to find the field due to the Helmholtz coils. Then:

The field due to the Helmholtz coils may be expressed as:

\[
H = (2)^2\pi na^2 = (2)2\pi na^2 = 4\pi na^2 \frac{(a^2 + a^2)^{3/2}}{4} = (\frac{3\pi}{4}a^2)^{3/2} \]

Then: \( H = 4\pi na^2 = 32\pi ni \cdot \frac{(125)^{3/8}a^3}{8} \) for the medium in the tube.

The apparatus must be so arranged that \( v \) is perpendicular to the magnetic field if equation (1) is to be used.

2. \( F \) is constant in magnitude and perpendicular to \( v \); therefore the electrons will move in the arc of a circle of radius \( a \).

Then: \( F = \frac{m v^2}{a} \) where: \( m \) mass of electrons in grams.

Then: \( F = \frac{m v^2}{a} \)

3. \( A = \frac{1}{n} \)

4. The kinetic energy of the electrons at the slit of the cylinder equals \( \frac{1}{2}mv^2 \). But the potential energy \( V_e \) of these electrons as they leave the filament equals their kinetic energy.

Then: \( \frac{1}{2}mv^2 = V_e \) where: \( V \) the potential difference in volts between the filament and the cylinder.

5. \( x^2 = \frac{2Ve}{m} \) and: \( v = \frac{(2Ve)^{1/2}}{m} \)

6. Substitute equation (5) into equation (3)
CALCULATION OF e/m FOR NO. 623 e/m TUBE

Manufactured By W.M. Welch Scientific Company

1. The magnetic field exerts a force \( F \) on each electron, then:
\[
F = e B v
\]
where:
- \( B \) = magnetic flux density in gauss
- \( \mu \) = magnetic permeability of the medium
- \( e \) = charge on the electron in ab.
coulombs
- \( v \) = speed of the electron in cm./sec.

Note: \( \mu = 1 \) for the medium in the tube.

2. \( F \) is constant in magnitude and perpendicular to \( v \), therefore the electrons will move in the arc of a circle of radius \( R \), then:
\[
F = \frac{m v^2}{R}
\]
where:
- \( m \) = mass of electrons in grams

then:
\[
E v = \frac{m v^2}{R}
\]

3. \[
\frac{e}{m} = \frac{v}{BR}
\]

4. The kinetic energy of the electrons at the slit of the cylinder equals \( \frac{1}{2} m v^2 \). But the potential energy \( (V_e) \) of these electrons as they leave the filament equals their kinetic energy.
then:
\[
\frac{1}{2} m v^2 = V_e
\]
where:
- \( V \) = the potential difference in abvols between the filament and the cylinder.

5. \[
v^2 = \frac{2 V_e}{m} \quad \text{and:} \quad v = \left( \frac{2 V_e}{m} \right)^{\frac{1}{2}}
\]

6. Substitute equation (5) into equation (3)
\[
\frac{e}{m} = \left( \frac{2 V_e}{m} \right)^{\frac{1}{2}}
\]

\[
\frac{e}{m} = \left( \frac{2 V_e}{m} \right)^{\frac{1}{2}}
\]

\[
\frac{e}{m} = \left( \frac{2 V_e}{m} \right)^{\frac{1}{2}}
\]

\[
\frac{e}{m} = \left( \frac{2 V_e}{m} \right)^{\frac{1}{2}}
\]
The terms on the right side of equation (6) are all measurable. $V$ can be read on the voltmeter $(V_a)$ shown in figure 1. $R$ is computed from the known values of the distances from the filament to the top of the bars. $B$ can be computed from equation (17) of the previous proof.
DEVELOPMENT OF UNITS USED IN THE e/m FORMULA

1. unit of charge = 1 abscoulomb

2. potential = joule/coulomb where: 1 joule = 10^7 ergs

3. charge = current * time where: \( Q = \text{charge in coulombs} \) \( I = \text{current in amperes} \) \( T = \text{time in seconds} \)

4. magnetic field = force/unit pole where: \( m_p = \text{unit pole} \)

5. force = mass * acceleration where: \( M = \text{mass in grams} \) \( a = \text{acceleration in cm. per sec.}^2 \)

6. dyne = gram-centimeter \( = \frac{ML^2}{T^2} \) \( \text{second}^2 \)

7. erg = dyne-centimeter \( = \frac{ML^2}{10^6 \text{ergs}} \) \( \text{per coulomb} \) \( = \frac{10^6 \text{ergs}}{10 \text{coulombs}} \)

8. From equation (4)

9. Substitute equation (5) into equation (8)

10. From equation (4), where \( H = \text{magnetic field strength} \)

11. Substitute equations (5) and (9) into equation (10)
12. From previous proof:

\[ H = I \cdot \text{constant} ; \quad \text{where: } I = \text{current} \]

\[ a = \text{distance} \]

then: \( I = aH \)

13. Substitute equation (11) into equation (12)

\[ I = L \cdot M^{1}L^{-1}T^{-1} = M^{1}L^{-1} \]

14. From equation (3) and equation (1)

\[ I = \text{charge} = 10^{-1} \text{abscoulomb} \]

\[ \text{time} = \text{second} \]

15. Substitute equation (13) into equation (14)

\[ \text{then: } 10^{-1} \text{abscoulomb} = 10^{-1}M^{1}L^{-1}T^{-1} \]

and: \( 1 \text{abscoulomb} = M^{1}L^{-1} \)

16. From equation (2)

\[ \text{volt} = \text{joule} \]

\[ \text{coulomb} \]

But the volt must be transposed into electro-magnetic units.

\[ \text{then: volt} = \text{joule} \cdot \frac{10^{7} \text{ergs}}{\text{coulomb}} \cdot \frac{10^{8} \text{coulombs}}{\text{joule}} \cdot \frac{10^{8} \text{coulombs}}{\text{abscoulomb}} \]

\[ \text{volt} = 10^{8} \text{abvolts} = 10^{8} \frac{\text{ergs}}{\text{abscoulomb}} \]

17. Substitute equations (7) and (15) into equation (16).

\[ \text{then: } 10^{8} \frac{\text{ergs}}{\text{abscoulomb}} = 10^{8} \frac{M^{2}L^{2}T^{-2}}{M^{1}L^{1} \cdot 10^{8} \frac{M^{2}L^{3/2}T^{-2}}{M^{1}L^{1/2}} \cdot 10^{8} \frac{M^{2}L^{3/2}T^{-2}}{M^{1}L^{1/2}} \]

18. From previous proof:

\[ \frac{m}{e} = \frac{V}{E \cdot R^{2}} ; \quad E = \mu H ; \quad \text{where } \mu = 1 ; \quad \text{then: } E = H \]

19. Substitute equation (12) into equation (18).

\[ \text{then: } \frac{m}{e} = \frac{V}{L^{2} \cdot L^{2}} \cdot \frac{V}{I^{2}} \]

20. Substitute equations (15) and (17) into equation (19)

\[ \text{then: } \frac{m}{e} = \frac{10^{8} M^{1/2} L^{3/2} T^{-2}}{10^{-2} M L T^{-2}} = 10^{10} \frac{M^{1/2} L^{3/2} T^{-2}}{M} \]
21. Substitute equation (15) into equation (20)

then: \( e = 10^{10} \text{ aboulombs} \)

\[ m \quad \text{gram} \]
WIRING DIAGRAM FOR FILAMENT CURRENT AND ACCELERATING POTENTIAL

Fig. 1

- PO
- E
- Va
- A
- M
- MA
- G
- D
- C
- L
- F
- S
- R
**WIRING DIAGRAM FOR MAGNETIZING CURRENT**

![Wiring Diagram](image)

**Fig. 2**

- **B** is a group of five storage batteries connected in series.
- **R₁** is a rheostat controlling current passing through the Helmholtz coils.
- **M** is a 0 - 15 amp. ammeter.
- **C₁, C₂** are Helmholtz coils consisting of 72 turns of No. 14 copper wire per coil. Mean radius of each coil is 33 cm.

---

**CUTAWAY DIAGRAM OF NO. 623 e/m TUBE**

![Cutaway Diagram](image)

**Fig. 3**

- A copper cylinder 6" in diameter by 12" long. It is kept at a positive potential with respect to the filament (Y).
The distance (D) from the filament to the top of each bar can be determined from the following diagram. The bars are indicated in figure 3 as a series of dots placed on the center line (P).

Following the evacuation a small amount of mercury was distilled into the bulb and the bulb was sealed off from the vacuum system. Mercury is present in the bulb at a saturated vapor pressure determined by the temperature of the glass of the bulb. Mercury is a heavy metal and it is made of nickel 0.050" in diameter. Mercury is a nickel wire staff with cross bars at a measured distance from (S) which is at the same potential as (F).

M is a 0-15 volt milliammeter.
Va is a 0-15 volt voltmeter.
M is a 0-10 amp ammeter.
A is a 6 volt battery supplying heating current to (F), controlled.

The electrons are subject to such forces that they will describe a controlled arc of a circle as shown in figure 3. The radius (R) is subject to the constant values shown in figure 4. Since the values shown in figure 4 determine the diameters of the various circles, the radius (R) is determined from the formula; 

\[ R = \frac{D}{2} \]

where (D) is the diameter.

Figure 1 is a detailed drawing of the filament and cylinder assembly shown in figure 3. Figure 3 is drawn at right angles to figure 1. The definition of the letters shown in figures 1 and 3 is the following.

C is a carbon cylinder \( \frac{1}{8}" \) in diameter by \( \frac{1}{8}" \) LONG. It is kept at a positive potential with respect to the filament (F).
F is a straight tungsten filament 0.008" in diameter and \( \frac{5}{8} \)" long. S is a slit in the side of (C) 0.032" wide and 7/16" long. Electrons emerge from (F) through this slit.

LL insulates (C) from (F).

E is a spherical bulb of 3 liters volume. The bulb is evacuated. Following the evacuation a small amount of mercury was distilled into the bulb and the bulb was shut off from the vacuum system. Mercury vapor is present in the bulb at a saturated vapor pressure determined by the temperature of the glass of the bulb.

GG are lead wires to (F). They are made of nickel 0.060" in dia.

P is a nickel wire staff with cross bars at a measured distance from (S) which is at the same potential as (C).

MA is a 0-15 ma milliammeter.

Va is a 0-100 volt voltmeter.

M is a 0-5 amp ammeter.

A is a 6 volt battery supplying heating current to (F), controlled by the rheostat (R) and read on (M).

E is a group of three 45 volt B' batteries connected in series, supplying accelerating potential to the electrons.

PO is a 15,000- \( \Delta \) potentiometer controlling the voltage across (E), read on the voltmeter (Va).

D is the lead wire for (C) made of 0.060" nickel.
**EXPERIMENTAL PROCEDURE**

**Adjusting the Magnetic Field**

The tube should be set in its housing so that its axis is in a magnetic north and south direction. Thus a beam of electrons which is emitted from the slit due to the heated filament, may travel perpendicular to a controllable magnetic field.

The Helmholtz coils must have their magnetic field parallel to the earth's magnetic field but in an opposite direction.

A dip needle is used to measure the influence of the earth's magnetic field at the place of experiment. The apparatus is set at an angle which is the complement of the dip angle. The current is then sent through the coils in such a direction that the magnetic field is opposite to that of the earth's field.

**Filament Warmup**

The voltage should be set at a convenient value, about 50 volts. Then turn on the filament switch and adjust the rheostat (R) until the milliammeter reads about six milliamperes. The usual filament current required for the above reading is from 3 to 4.5 amperes. As the tube is used the filament current required for a 6 ma emission will decrease. This decrease is due to increased activation of the filament. The tube should be warmed for about fifteen minutes before any readings are attempted.

**E/M Measurement**

As the filament is heated electrons are given off which are ejected through the slit in the carbon anode by the accelerating
potential. If the electrons have a sufficient kinetic energy, they will collide with the mercury atoms and a portion will be ionized. When these ions recombine with stray electrons, the characteristic mercury arc spectrum is emitted, which is bluish in color. The beam is more clearly visible if observed in a semi-darkened room. If loose in energy, circles of smaller radius are the result.

Care should be taken that the slit in the cylinder is set parallel to the axis of the Helmholtz coils. Then the current is increased in the coils until the beam describes a small circle. If the slit is parallel to the axis of the coils, this beam will travel in a cork-screw spiral upward or downward. The cork-screw path is due to the magnetic field of the filament current.

The spiral effect is removed by rotating the tube on its axis until the center of the electron beam strikes the back of the cylinder at its center point.

The beam is then adjusted by the current through the coils so that the outside edge of its beam strikes the outside edge of one of the cross bars. Thus for various accelerating potentials as shown on (Va), and various currents controlling the size of the circular beam, the e/m of the electrons can be measured from the previously computed formulae.

Readings should be taken for values of V from 20 to 100 volts on each of the five cross bars.

Discussion

The outside edge of the electron beam is used because electrons of the highest velocity form the outer arc. Electrons which leave the negative side of the filament fall through the greatest
potential and thus have the greatest velocity. This is the potential read by the voltmeter \((V_a)\). When an electron makes an ionizing collision with a mercury atom some energy is lost to the atom, which reduces the velocity, therefore the magnetic field bends this electron into a path of smaller radius. Further ionizing collisions will produce greater losses in energy, circles of smaller radius are the cause of the haze of light seen inside the circle. Thus the electrons in the outside edge of the beam have made their first ionizing collision and are the only phenomenon applicable to the conditions of the experiment.

**Second Method of Determining the Earth’s Magnetic Field**

It can be seen that the electron beam is deflected by the magnetic field of the earth when no current is sent through the Helmholtz coils. Observe the beam in relation to a straight edge held above the tube with one end above the slit. Adjust the current in the coils so that the beam appears straight in comparison with the straight edge. Then increase the current in the coils until the beam shows a curvature and note the current. Decrease the current in the coils until the beam just curves in the opposite direction. An average of the two values is the value of the current necessary to straighten the beam. Substitute this current value into the formula for the magnetic field and the earth’s magnetic field is determined at the place of experiment.


