DEPARTMENT OF PHYSICS,

INDO – AMERICAN COLLEGE, CHEYYAR

BPH 52

ATOMIC PHYSICS AND SPECTORSCOPY

UNIT – I :

DISCHARGE PHENOMENON THROUGH GASES

Moving of a charge in transverse electric and magnetic fields – specific charge of an electron – Dunnington’s method – Magnetron method – Positive rays – Thomson prabola method – Aston and Dempster’s mass spectrograph.

Books for study:

1. Modern physics by R Murugesan, S Chand & Co., New Delhi - 2004.
2. Atomic and Nuclear physics by N Subramanian and Brij Lal, S Chand & Co. - 2000.
3. Atomic physics by J B Rajam.
4. Spectroscopy by Gupta & Kumar
5. Spectroscopy by Banewell
6. Laser Fundamentals, by William T. Silfvast , Cambridge University Press.

UNIT - I

DISCHARGE PHENOMENON THROUGH GASES

Moving of a charge in transverse electric and magnetic fields:

Motion of a charged particle in the simultaneous presence of both electric and magnetic field has a variety of changes ranging from straight line motion to the cycloid and other complex motion. Both electric and magnetic fields produce acceleration to the charged particle.

Magnetic field relates only to the change of direction of motion and always normal to the velocity of the particle tends to move the particle about a circular path. On the other hand, electric force is along electric field and is capable to bring about change in both direction and magnitude depending upon the initial velocity of charged particle with respect to electric field.

Applications:

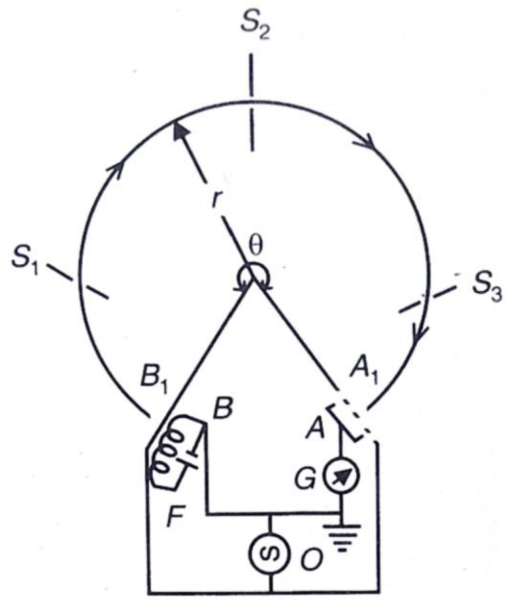
- Motion of a charged particle in electric and magnetic fields.
- Measurement of specific charge of an electron.
- Acceleration of charged particles.

Specific charge of an electron:

Dunnington's Method:

A crystal oscillator 'O' is used to produce an alternating voltage at a constant high frequency is applied simultaneously to the two pairs of electrodes 'AA_1' and 'BB_1'.

Electrons from the hot filament 'F' are accelerated towards B, during positive half cycle and emerge through a fine opening B_1. The electrons are then bent into a circular path by a magnetic field 'B' can pass through the slits S_1, S_2 and S_3.



The radius of curvature and velocity of the electron is 'r' and 'v' and satisfies the relation,

$$Bev = mv^2 / r$$

The speed of the electron in its circular path,

$$Bev = mv^2 / r$$

$$v = Ber / m \qquad (1)$$

After the electrons are turned through an angle θ, they enter the Faraday's chamber 'A' through a grid A_1 and produce a deflection in the galvanometer 'G'. The electrodes and the slits are enclosed in an evacuated glass envelope. The grid A_1 is connected to the same oscillator which accelerated the electrons. The period of the oscillator is 1/f for an angle θ, then the electrons will lose all their energy in overcoming the opposing potential difference between A_1 and A and will fail to reach A. Then the galvanometer indicates zero deflection. Distance travelled by the electron from B_1 to A_1 = r θ

The time taken for travelling this distance = n / f

$$v = \text{distance} / \text{time} = r\,\theta / (n / f)$$

$$v = r\,\theta\, f / n \qquad (2)$$

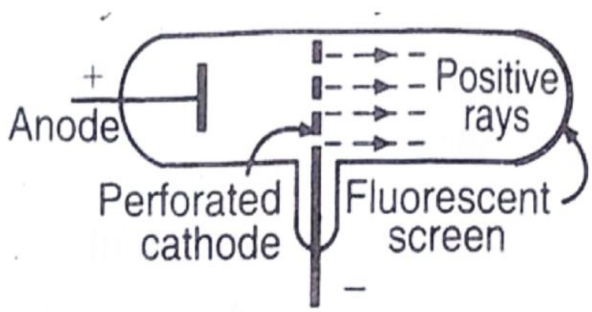
From (1) and (2),

$$Ber / m = r \theta f / n$$

$$\mathbf{e / m = f \theta / n B}$$

Thus, e / m is calculated, the value of $e / m = 1.7597 \times 10^{11}$ C / kg.

Positive Rays:

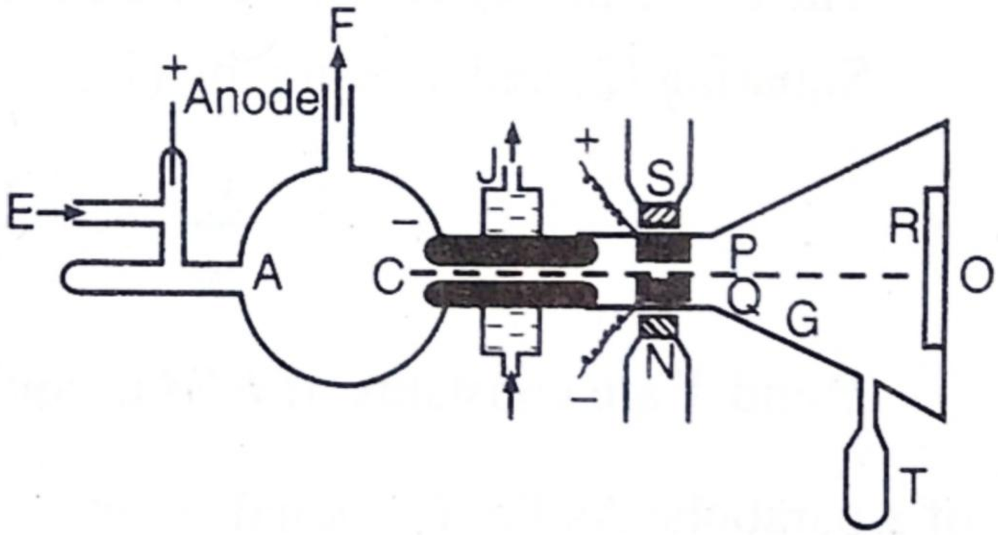


In a discharge tube if the cathode is perforated luminous rays are observed behind the cathode. These rays travel opposite to cathode and produce fluorescence, when they strike the fluorescent screen. The direction of deflection is opposite to cathode. This shows that they are positively charged and hence it is called as positive rays or canal rays.

Properties of Positive rays:

- These rays affect photographic plate.
- They are deflected by electric and magnetic fields.
- The velocities of all positive ray particles are not the same. The velocities range from 10^5 to 10^6 m s^{-1}.

Thomson's Parabola Method – Positive Ray Analysis:



E – Capillary tube, F – pump, A – Discharge tube, C – Perforated cathode, J – Water Jacket, P and Q – Electric field, N and S – Magnetic field, G – Camera, T - Air trap, R – Photographic plate, O – Un deflected spot.

1. Experimental Description:

Thomson determined the charge to mass ratio of positive ions. It consists of a discharge tube (A) in which the pressure of the gas is about 10^{-5} m of mercury. The anode is held in a slide tube.

A steady stream of the gas is allowed to flow in through a capillary tube (E) and after circulating in A and pumped off at F.

The cathode C is perforated and it is cooled by the water – jacket (J). The positive ions produced in A fly towards straight and emerge from the opposite end of the cathode. An electric field is applied between plates P and Q. N and S are strong poles of electromagnet.

After passing these two fields, the beam enters a highly evacuated camera G and is received on a photographic plate (R). A liquid air – trap (T) helps to keep the pressure in G quite low, even though pressure in A is comparatively large. From the photographic plate, it shows a series of parabola.

2. When no field is applied:

When no electric and magnetic field is applied, the positive ion strikes the plate at O. This is called the “un deflected spot”.

3. Action of electric field:

Let an electric field of strength X act over a length l of the path of the ion.

Displacement of the ion passing through the electric field,

$$S = 1/2(X\ E/M)(l/\ v)^2$$

After leaving the field, the ion moves in a straight line and hit the plate at x from O. x α S

$$x \propto 1\ /\ 2\ (X\ E\ /\ M)\ l^2\ /\ v^2$$

$$x = K_1 X\ E\ /\ M\ v^2 \qquad (1)$$

$$K_1 = l^2\ /\ 2$$

Where, K_1 is a constant

4. Action of Magnetic field:

Suppose a magnetic field B acts in the same length the ions deviates and strikes the photographic plate at y from x.

Displacement of the ion passing through the magnetic field,

$$S' = 1/2\ B\ E\ v/M\ (l^2/\ v^2)$$

$$S' = 1\ /\ 2(B\ E\ l^2\ /\ M\ v)$$

$$y \propto S'$$

$$y \propto B\ E\ l^2\ /\ 2\ M\ v$$

$$y = K_2\ B\ E\ /\ M\ v \qquad (2)$$

Where, K_2 is a constant

5. Action of electric and magnetic fields:

The combined effect of the two fields of the two fields is found by eliminating v from (1) and (2), Squaring (2) and divide by (1),

$y^2 = K_2^2 (B^2 / v^2) (E / M)$

$x = K_1 X E / M v^2$

$y^2 / x = [K^2_2 / K_1 . B^2 / x] E / M$ (3)

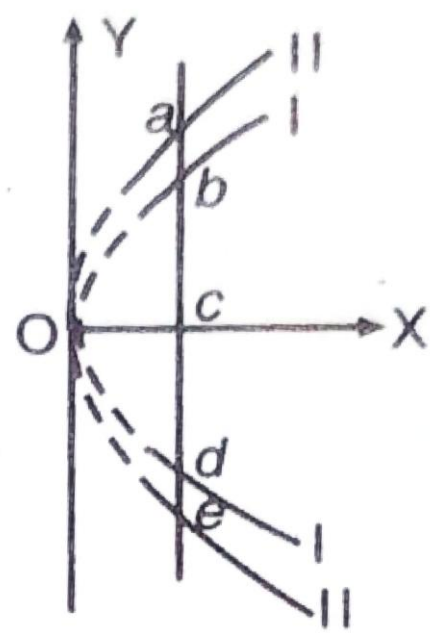
B and x are constants. If E / M is constant then (3) y^2/x = constant. This is the equation of parabola. The ions having different E / M will lie along the different parabolas.

6. Determination of E / M:

E/M value is determined by knowing the B and x values, evaluating K_1 and K_2 and measuring co – ordinates x and y point of the parabola.

7. Determination of Mass:

Hydrogen gives outermost parabola in all elements. let I and II represents the parabolic traces due to ions of mass M_1 and M_2 of hydrogen ions.



Let ac and bc represents the two values of y corresponding to a constant value of x on the parabolas. Let us assume that both ions have the same charge, then from (3),

$(ac)^2/x = [K^2_2/K_1 . B^2/x] E/M_1$

$(bc)^2/x = [K^2_2/K_1 . B^2/x] E/M_2$

$M_2/M_1 = (ac)^2/(b\ c)^2 = (ae/bd)^2$

$\mathbf{M_2 = (a\ e\ /\ b\ d)^2\ M_1}$

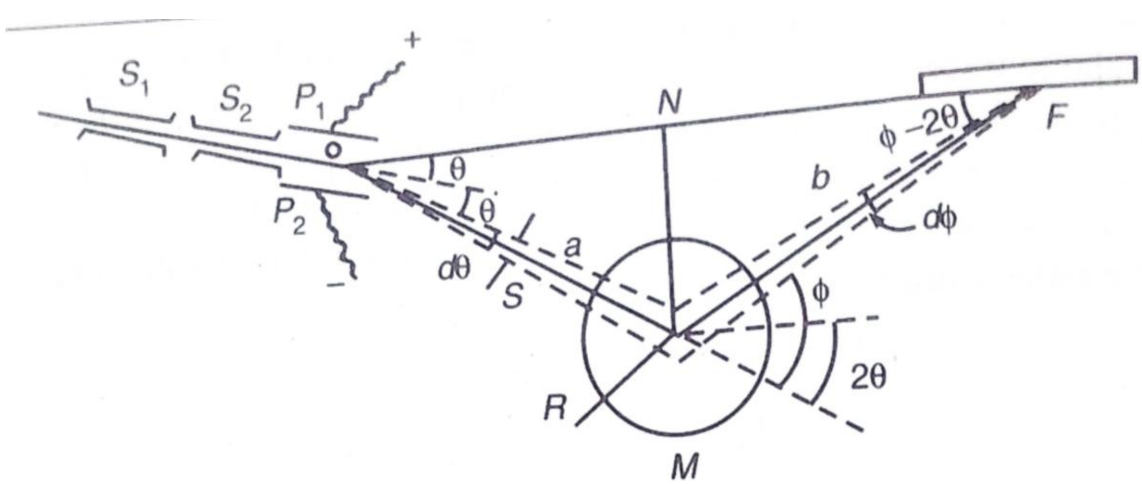
8. Discovery of stable isotopes:

Thomson obtained two isotopes of neon gas of first ones mass = 20 and the others mass = 22, with intensity ratio of 9:1.

9. Limitations of the parabola method:

- ♣ Due to velocity dispersion, each parabola trace is low intensity.
- ♣ There is no definite edge and hence accurate measurements are not possible.
- ♣ The influence of secondary rays makes analysis difficult.

Aston's Mass Spectrograph:



Description:

A stream of positive ions obtained from a discharge tube is allowed to pass as a fine beam between two narrow slits S_1 and S_2. This beam enters the electric field between the metal plates P_1 and P_2.

Due to the action of electric field (X) all positive ions having the same value of E/ M are not only deviated by an angle 'θ', also dispersed by an angle 'd θ' due to their different velocities.

The beam is then allowed to pass through the magnetic field (M) acting right angles to the field. The magnetic field deviate the particle by an angle 'φ' and re converge them by 'dφ'.

Even though differing in their velocities, they are brought to focus at one point 'F'.

Theory:

Consider a group of ions having the same value of E / M, but with different velocities, then,

1. $d_1 = 1 / 2 (X E l^2 / M v^2)$

Deviation $(\theta) = d_1 / l_1 = 1 / 2 X E l^2 / M v^2$ (1)

[Arc length = Radius (l_1) × angle (a)]

Where,

θ – Angle of deviation by electric field.

d θ – angle of dispersion by electric field

X – Strength of electric field

E – Charge of the ion

M – Mass of the ion

v – Velocity of the ion

l_1 – Length of the electric field

d_1 – linear displacement of the ion

Differentiating (1),

$$(\text{Dispersion})\ d\theta = -XEl_1 / M \times dv / v^3 \quad (2)$$

$$\{1 / v^2 = -2\,dv / v^3;\ v^{-2} = -2\,v^{-2-1} = -2\,v^{-3}\,dv = -2\,dv / v^3\}$$

$$d\theta / \theta = -XEl_1 / M \times dv / v^3[2Mv^2 / XEl_1]$$

$$d\theta / \theta = -2dv / v \quad (3)$$

2. Similarly, d_2 is the displacement of the ion due to magnetic field of strength B,

$$d_2 = 1 / 2\,BEv / M \times l^2{}_2 / v^2$$

$$\text{Deviation } (\Phi) = d_2 / l_2 = 1 / 1\,BE / M \times l_2 / v \quad (4)$$

Where,

Φ– Angle of deviation by magnetic field

d Φ– Angle of dispersion by magnetic field

B – Magnetic induction

l_2 – Length of magnetic field

Differentiating (4)

$$\text{Dispersion } (d\Phi) = -1/2\,(BEl_2 / M) \times dv/v^2 \quad (5)$$

$$[1 / v = v^{2}]$$

$$d\Phi / \Phi = -1 / 2\,(BEl_2 / M) \times dv / v^2\,(2Mv / BEl_2)$$

$$d\Phi / \Phi = -dv / v \quad (6)$$

$$\mathbf{d\Phi / d\theta = \Phi / 2\theta} \quad (7)$$

The width of the ions at R = a dθ. The width of the group after travelling a further distance b would be (a + b) dθ. The magnetic field produces a convergence dΦ brings the ions to focus at a distance RF = b.

The condition of focusing is given by, $(a + b)\, d\theta = b\, d\varphi$

$$(a + b) / b = d\Phi / d\theta$$

From (7),

$$d\Phi / d\theta = \Phi / 2\theta$$

$$(a + b) / b = \Phi / 2\theta$$

$$(a / b) + 1 = \Phi / 2\theta$$

$$a / b = (\Phi / 2\theta) - 1$$

$$a / b = (\Phi - 2\theta / 2\theta)$$

$$\mathbf{b / a = 2\theta / (\Phi - 2\theta)} \qquad (8)$$

If $\Phi = 2\theta$, the ray do not converge. However if $\Phi = 4\theta$, $b = a$, then convergent beam can be easily photographed.

Detection of Isotopes:

The mass of isotopes of an element is found out by drawing a calibration graph connecting the distances with atomic masses.

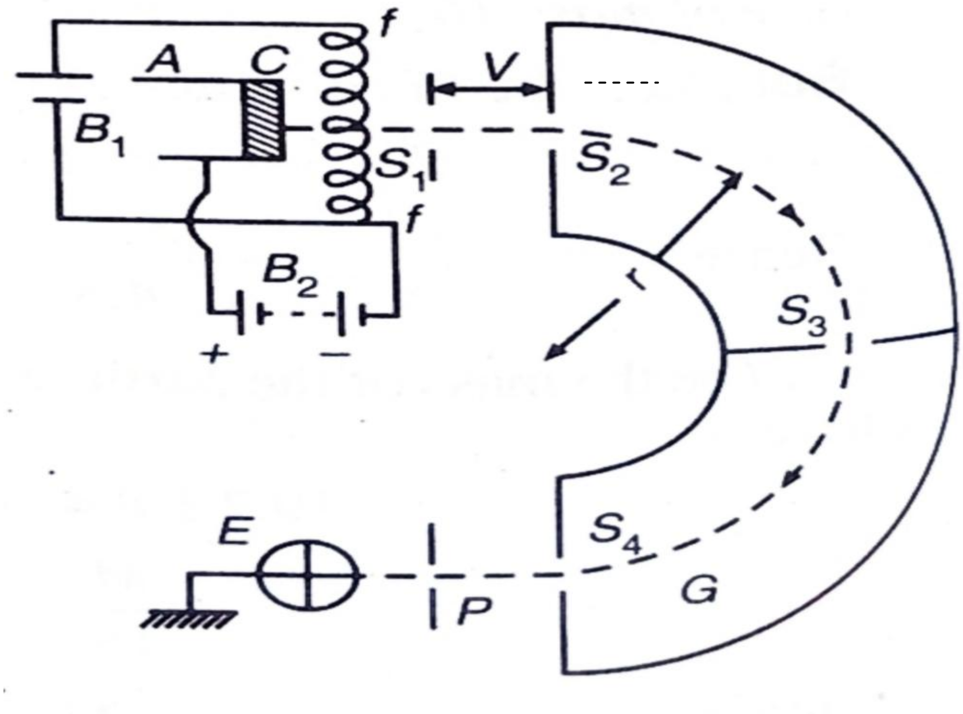
Advantages:

- ❖ Particles having same E / M value are focused at a single point. But in Thomson's method they are spread out onto a parabola.
- ❖ Intensity of the lines is very large. But in Thomson's method intensity is very feeble.
- ❖ Intensity is proportional to total number of particles of that mass.

Limitations:

- The mass scale is not linear.
- The traces are not straight but slightly curved.

Dempster's Mass Spectrograph:



A filament is electrically heated by the battery B_1 emits electrons and the anode is a metal cylinder 'A' with its front surface 'C' coated with the experimental salt and heated electrically.

By maintaining the filament at a potential difference of about 50 volts with respect to 'A' by using another battery B_2, the electrons are made to bombard the heated salt which emits the positive ions. These ions are collimated into a narrow beam by the slit 'S1', and then the positive ions are accelerated towards 'S_2'.

We know that when ions of mass 'm' and charge 'e' are accelerated through a potential difference 'V' and acquire a velocity 'υ' is given by,

$$1 / 2 \, m \, \upsilon^2 = e V$$

$$\upsilon^2 = 2 e V / m$$

$$\upsilon = \sqrt{2 e v / m} \qquad (1)$$

The ions are then entered into the vacuum chamber 'G', and then the ions are subjected to a magnetic field of flux density B. The ions are deflected through a semi circle towards the slit S_4.

The magnetic flux density 'B' and mass of the ion 'M' with radius and velocity 'r' and 'υ' given by,

$$B\ e\ \upsilon = M\ \upsilon^2 / r$$

$$r = M\ \upsilon / B\ e \qquad (2)$$

From (1),

$$\upsilon = (2\ e\ \upsilon\ /\ m)^{1/2}$$

$$r = M\ /\ B\ e\ (2\ e\ \upsilon\ /\ M)^{1/2}$$

$$r = [2\ M^2\ 2\ e\ \upsilon\ /\ B^2\ e^2\ M]^{1/2}$$

$$r = (\sqrt{M}\ \sqrt{M}\ /\ \sqrt{B}\ \sqrt{B}\ \sqrt{e}\ \sqrt{e})\ (\sqrt{2}\ e\ \upsilon\ /\ M)$$

$$r^2 = (M\ /\ B^2\ e).\ 2\upsilon$$

$$r = (2\ M\ \upsilon\ /\ B^2\ e)^{1/2}$$

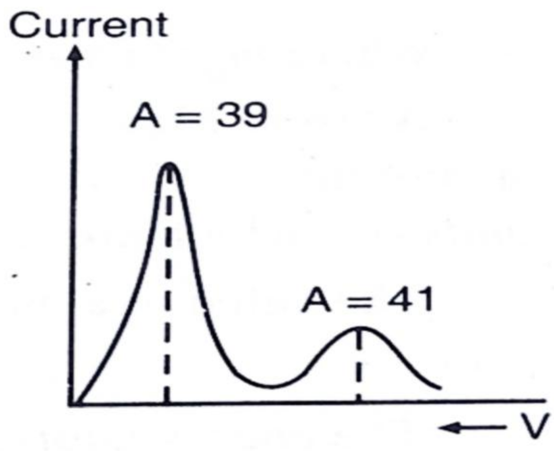
$$e = 2\ M\ \upsilon\ /\ B^2\ r^2$$

$$\mathbf{e\ /\ M = 2\ \upsilon\ /\ B^2\ r^2} \qquad (3)$$

From the equation $r = (2\ M\ \upsilon\ /\ B^2\ e)^{1/2}$, it is clear that if $(M\ /\ e)$ $(\upsilon\ /\ B^2)$ is kept constant, the radius 'r' of the path of these ions will remain unchanged. Hence ions of different e / m can be made to circular path of fixed radius by adjusting 'υ' and 'B'.

Determination of mass of the Isotope:

By using the magnetic field (B) constant, a plot is drawn between ionic current (I) and the values of (υ). The peak of the curve denotes the mass numbers of the isotopes as 39 and 41.



Uses of Mass Spectrograph:

- Mass spectrographs are used to determine the isotopic masses of elements. By using the mass spectrographs more than 300 different isotopes are discovered from the nature.

- To produce nuclear power and production of atom bombs from uranium 235. It is used to separate the pure isotopes of small quantities.

Model Questions

1) What are positive rays?
2) Mention the limitations of Aston's mass spectrograph.
3) What are the properties of positive rays?
4) Define the specific charge of an electron.
5) What are the applications of mass spectroscopy?
6) Discuss the motion of a charged particle in a uniform magnetic field.
7) Describe the experimental arrangement of Thompson's parabola method to determine the charge to mass ration of positive ions. Also discuss its drawbacks.
8) Describe the Aston's mass spectrograph.
9) Describe the construction and working of Dempster's method.
10) Describe the Dunnington's method of measuring e/m of an ion.