Lecture Notes of B.Sc.(HONS.) PHYSICS ,Part-II, Paper -IV

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TOPIC:-------Aston's Mass Spectrograph

Mass Spectrograph—It is an instrument which is used to determine the mass of atoms or molecules in which a beam of charged particle is passed through an electromagnetic field that separates particles of different masses. The result of distribution of spectrum is recorded on photographic plate .

Components of Mass Spectrograph:

1. **Ion Source-** All mass spectrograph starts with an ion source to be detected. The ions are produced either by electron-bombardment of gases or by heating the suitable coated filaments.

2. **Energy, Momentum and Velocity Filter—**The positive energy ions are given energies by accelerating them through a potential difference V,so that their energy qV is much greater than initial ion energies. To have beam of same momentum and mass the ions are then passed through electric and magnetic fields which may act as momentum and velocity filters.

3. **Evacuated Chamber—**This chamber is evacuated and provides the path to ion-beam to be detected. Usually a strong magnetic field is applied perpendicular to ion beam for its deflection to circular path.

4. **Detector—**It may be a photographic plate or an electrometer. The typical Mass Spectrograph are Bainbridge's, Aston's and Dempster's Mass Spectrograph. Now we will discuss the Aston's Mass Spectrograph in detail.

Aston's Mass Spectrograph

It uses electric and magnetic fields which are mutually perpendicular.The isotope beam is subjected perpendicular to electric field. The apparatus is shown in fig.(1) The given stream of positive ions is rendered into a fine beam by passing it between two narrow slits S_1 and S_2. This beam enters the electric field of strength (E) between

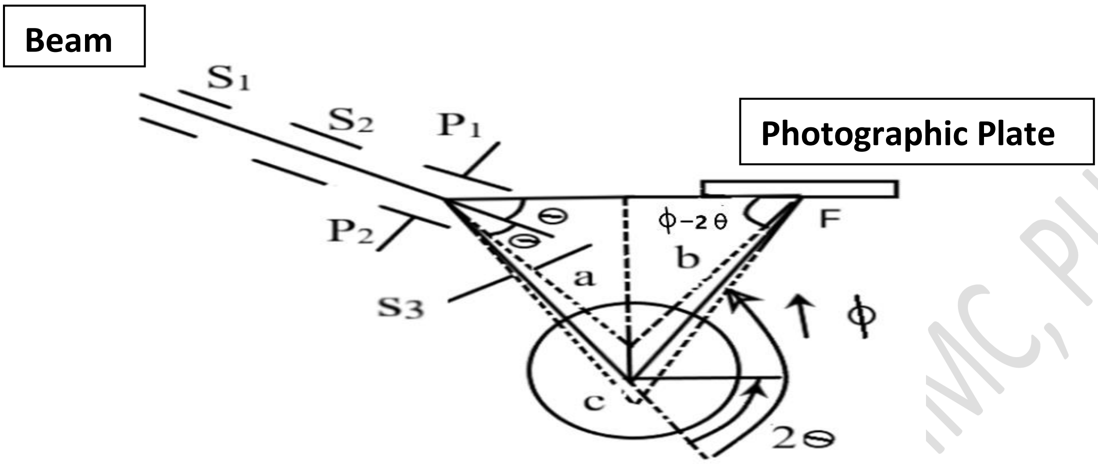

fig.(1) Experimental setup for Aston's Mass Spectrograph

metal plates P_1 and P_2. Due to action of electric field all positive ions having the same value of specific charge (q^+/M) (where q^+ is positive charge on ion and M is its mass) are not only deflected by an angle θ from the original path towards negative plate but are also dispersed by an angle $d\theta$ due to their different velocities. The beam is then allowed to pass through slit S_3 and enter a magnetic field of strength B arranged perpendicular to electric field so as to deflect the beam in opposite direction and converge it to a single point F on photographic plate. The magnetic field deviates the beam through an angle $\emptyset$ and reconverges them by an angle $d\emptyset$.

Theory : Condition for Focussing:

Consider a beam of ions having the same value of q+/M but moving with different velocities. Let θ and $\emptyset$ be the mean angles of deviation of beam in electric and magnetic fields in opposite directions. Let $d\theta$ be dispersion angle due to electric field and $d\emptyset$ be the convergence angle due to magnetic field. Let v be the velocity of an ion ,L_1 the length of electric field and l_1 the transverse displacement of an ion from its path due to electric field ,

then acceleration of ion , $a_1=(q^+E/M)$ and

Time by ion to transverse electric field $=L_1/v$

Transverse deflection in electric field,

$$l_1=\frac{1}{2}\ a_1{}^2 t_1{}^2 = \frac{1}{2}\left(\frac{L_1}{v}\right)^2 \frac{Eq^+}{M}$$

Angular deviation of ion beam, $\theta = \frac{l1}{\boldsymbol{L_1}} = \frac{1}{2}\left(\frac{\boldsymbol{L_1}}{\boldsymbol{v}^2}\right)\frac{Eq^+}{M}$

Angle of dispersion of beam in electric field ,

$$d\,\theta = \frac{1}{2}\left(\frac{\boldsymbol{2dv}}{\boldsymbol{v}^3}\right)\frac{q^+}{M}\,EL_1 = \frac{\boldsymbol{dv}}{\boldsymbol{v}^3}\frac{q^+}{M}\,EL_1$$

$$\frac{d\,\theta}{\theta} = \frac{2d\boldsymbol{v}}{\boldsymbol{v}} \quad \text{……………………………………………..(1)}$$

If l_1 is transverse deflection of an ion beam in magnetic field of strength L_2,then in a similar manner,

$$l_2 = \frac{1}{2}\left(\frac{\boldsymbol{L_2}}{v}\right)^2\frac{Bvq^+}{M} = \frac{1}{2}\frac{Bq^+}{Mv}\boldsymbol{L_2^2}$$

(since acceleration of ion in magnetic field B is $a_2 = (q^+ vB/M)$

The deviation produced by the magnetic field is in opposite direction

$$\emptyset = \frac{l2}{\boldsymbol{L_2}} = \frac{1}{2}\left(\frac{\boldsymbol{L_2}}{v}\right)\frac{Bq^+}{M}$$

Convergence $d\emptyset = \frac{1}{2}\left(\frac{\boldsymbol{-dv}}{\boldsymbol{v}^2}\right)\frac{q^+}{M}\,BL_2$

$$\frac{d\emptyset}{\emptyset} = \frac{-d\boldsymbol{v}}{\boldsymbol{v}} \quad \text{……………………………………………..(2)}$$

Comparing eqn.(1) and eqn.(2) we get ,

$$\frac{d\,\theta}{\theta} = \frac{2d\emptyset}{\emptyset}$$

$$\Longrightarrow \frac{d\emptyset}{d\theta} = \frac{\emptyset}{2\theta}$$

Let a=OC=distance between two fields ,Then width of ion at C= a$d\theta$

Let CF=b=distance of magnetic field and photo-plate. If there had been no magnetic field , the width of ion beam after travelling a further distance b would have been =(a+b) d θ

Therefore magnetic field produces convergence $d\emptyset$ in a distance b.

Thus width of converged beam= b $d\emptyset$

Thus the condition of focussing becomes :

$(a+b)\, d\theta = b\, d\emptyset$

$$\Longrightarrow \frac{a+b}{b} = \frac{d\emptyset}{d\theta} = \frac{\emptyset}{2\theta}$$

$$\Longrightarrow \frac{b}{a} = \frac{2\theta}{\emptyset - 2\theta}$$

This gives the distance at which the photographic plate should be placed to record the beam and also the deflection caused by magnetic field as compared to the electric field.

Detection of isotopes:

To determine the masses of isotopes of an element ,the element is mixed with a number of other elements of known atomic masses. The traces of all of them are obtained on the same photographic plate. The distance of the traces of known masses are measured from a given reference point on the plate. A calibration curve is then drawn between known atomic masses and distance of traces from a given point. By measuring the distances of the traces of isotopes of elements from the same reference points, the atomic masses are obtained from calibration curve.

Advantages:

1. All particles having same (q^+/M) are focussed on a single point of photographic plate unlike ,Thomson's method where they spread out in the form of a parabola. Hence lines on photographic plates in Thomson's arrangement are feeble.

2. The intensity of a line obtained on photo-plate is proportional to the total no. of particles of the mass. Thus the relative intensities of various lines give the idea of relative abundance of different isotopes of an element.