CHAPTER II

THEORY

2.1 Motion of Charged Particles in a Certain Arrangement of Electric and Magnetic Fields.

When charged particles are subjected to both electric and magnetic fields, their motion will be confined. If a particle, having charge e and mass m, is accelerated from rest through an electrostatic potential V, the kinetic energy acquired by the particle is equal to the workdone on it.

$$\text{Kinetic energy } \frac{1}{2}mv^2 = \text{work done } eV \qquad (2.1)$$

If a positively charged particle in a uniform magnetic field of flux density B, has a velocity v in a direction at right angle to the field, the magnitude of Lorentz's force acting on it will be evB where Z is equal to unity.

$$\text{Lorentz's force } \vec{F} = e\vec{v} \times \vec{B} \qquad (2.2)$$

The directions of the force and the velocity will have changed continually, but the magnitude of the force remains constant. In other words, the particle moves under the influence of a force whose magnitude is constant but whose direction is always at right angles to the velocity of the particle. The orbit of the particle is therefore a circle with constant tangential speed v, the force F being the centripetal force. Since the centripetal acceleration is $\frac{v^2}{R}$, and from Newton's second law of motion, it is obvious that

$$evB = \frac{mv^2}{R} \tag{2.3}$$

and the radius of the circular orbit is $R = \frac{mv}{Be}$ (2.4)

2.2 The Calculation of the Atomic Mass, the Resolving Power and the Probable Error of Quantities Measured Experimentally.

2.2a The Calculation of the Atomic Mass of the Positive Ion.

The positive ions with a charge e, will acquire energy equal to eV when passing through the electric field. After passing through the same field, all singly charged ions will possess the same kinetic energy $\frac{1}{2} mv^2 = \frac{eV}{300}$. The light ions will move with a high velocity and the heavy ions with a low velocity.

When the ions enter the magnetic field in a direction perpendicular to the magnetic line of force, they will be subjected to a force perpendicular to both the direction of the field and the direction of their motion. The magnitude of this force depends on the field strength and on the charge and the velocity of the ions. The ions are thereby forced to travel in a circular arc, the radius of which depends on their mass and energy. The centrifugal force $\frac{mv^2}{R}$ of an ion moving in the circular arc is equal exactly to the magnetic force $\frac{Bev}{3 \times 10^{10}}$, by which the ion is deflected.

$$\frac{Bev}{3 \times 10^{10}} = \frac{mv^2}{R} \tag{2.5}$$

The energy gained by a charged particle falling through the potential difference V is

$$\frac{1}{2}\,mv^2 \quad = \quad \frac{eV}{300} \qquad (2.6)$$

It is obtained from the two equations that

$$m \quad = \quad 4.82 \times 10^{-5}\,\frac{B^2R^2}{V} \qquad (2.7)$$

where m is the mass of the particle in a.m.u.

B is the magnetic flux density in gauss

R is the radius of curvature of the path in cm.

V is the ion accelerating voltage in volt.

The product B^2R^2 is the characteristic of the particular instrument used.

2.2b The Calculation of the Resolving Power.

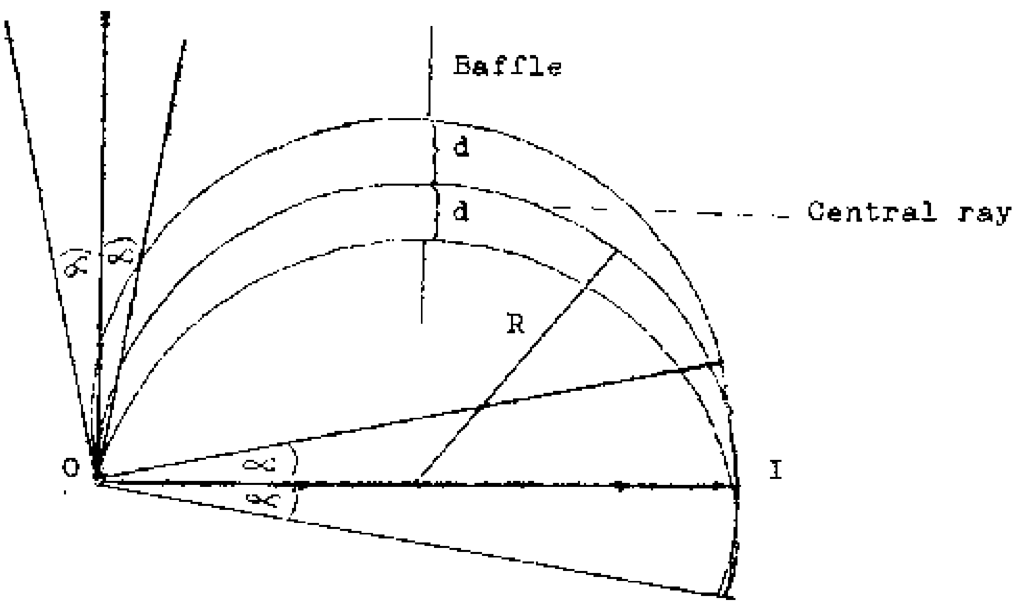

Fig.2 The Circular Path of Positive Ions.

If the object is treated as a point source with the emergence angle α, one can determine the widths of Slit S_2 and Slit S_3 by drawing a picture using the principle of geometry as shown in Fig.2.

The ion beam forming the central ray, deflects through the distance 2R, while the beam taking α^{0} to the central ray deflects through the distance 2R cos α. Thus the separation of two images is $R\alpha^2$ obtained by expending cosα and eliminating the terms with higher power of α. In the arrangement in which the object and image lie symmetrically with respect to the magnetic field, the image width is $R\alpha^2$. The image also has the width corresponding to the object width.

$$\text{Total image width} = \text{object width} + R\alpha^2 \qquad (2.8)$$

If the detector slit width is incorporated, the effective image width is equal to the total image width plus the detector slit width. Ions' peaks are usually said to be resolved when the separation of two images is equal to the effective image width.

The width of slit S_2 can be computed by assuming α very small, not greater than 10 degrees.

$$\text{From Fig.2} \quad \sin\alpha = \alpha = \frac{d}{R} \text{ radian} \qquad (2.9)$$

$$\text{The width of slit } S_2 = 2d \text{ cm.} \qquad (2.10)$$

The atomic mass of a positive ion can be calculated from the equation (2.7)

$$m = 4.82 \times 10^{-5} \frac{B^2R^2}{V}$$

Differentiating, we get

$$\Delta m = 4.82 \times 10^{-5} \frac{B^2R}{V} \cdot 2\,\Delta R$$

Hence $$\frac{\Delta m}{m} = \frac{2\,\Delta R}{R} \qquad (2.11)$$

One can see that ions differ in mass by Δm, their paths in the magnetic field differ in radius by ΔR. In the case of 180° deflection in the magnetic field, it is obvious that $2\,\Delta R = \Delta x$; where Δx is the separation of two images formed by the two types of ions.

Thus $$\frac{\Delta m}{m} = \frac{\Delta x}{R} \qquad (2.12)$$

Resolution is the separation of adjacent peaks of a mass spectrum by a mass spectrometer, while the resolving power is the highest value of the ratio $\frac{m}{\Delta m}$ for the complete separation of the mass spectrum lines differing by Δm in mass.

Therefore. Resolution $$\frac{\Delta m}{m} = \frac{\Delta x}{R}$$

Resolving power $$\frac{m}{\Delta m} = \frac{R}{\Delta x} \qquad (2.13)$$

Δm is the smallest variation in mass that can be detected when ions of mass m are focussed.

However, one can see that by differentiating Eq. (2.7), it becomes

$$\Delta V = 4.82 \times 10^{-5} \frac{B^2}{m} \cdot 2R\Delta R$$

Hence $\frac{V}{\Delta V} = \frac{R}{2\Delta R}$

In other words, the resolving power is

$$\frac{m}{\Delta m} = \frac{R}{2\Delta R} = \frac{V}{\Delta V} \tag{2.14}$$

With the application of Rayleigh criterion, it is obvious that ΔV is the half width at the base of the peak resolved.

2.2c <u>The Probable Error as a Function of Quantities Measured Experimentally</u>.

So far, the atomic mass of positive ion is calculated from Eq. (2.7). The value of each quantity B,R and V has its own probable error due to physical measurements. The probable error of the result (Δm) can be obtained from the relation below.

$$(\Delta m)^2 = \left(\frac{\partial m}{\partial B}\right)^2 (\Delta B)^2 + \left(\frac{\partial m}{\partial R}\right)^2 (\Delta R)^2 + \left(\frac{\partial m}{\partial V}\right)^2 (\Delta V)^2$$

However, for convenience it can be calculated from the formula

$$\left(\frac{\Delta m}{m}\right)^2 = 4\left(\frac{\Delta B}{B}\right)^2 + 4\left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta V}{V}\right)^2 \qquad (2.15)$$

Where ΔB is the probable error of the magnetic field strength.

ΔR is the probable error of the radius of the semicircular path of the ion.

ΔV is the probable error of the accelerating voltage.

In order to obtain the ratio $\frac{\Delta B}{B}$, the method of determination of the magnetic field strength is now considered. The calculation of the magnetic field strength by the search coil is achieved by using the formula

$$B = \frac{MI}{\pi r^2 N} \frac{\alpha}{\beta} \qquad (2.16)$$

where B is the magnetic field strength in gauss.

M is the mutual inductance in henry.

I is the current through the calibrating circuit in ampere.

r is the radius of the search coil in cm.

N is the number of turns of the search coil.

α is the deflection in cm. on the scale of the galvanometer in flipping the search coil through 180 degrees.

β is the deflection in cm. on the scale of the galvanometer resulting from changing the current in the primary circuit of the mutual inductance.

Similarly, the probable error of magnetic field strength (ΔB) is calculated from the formula

$$\left(\frac{\Delta B}{B}\right)^2 = \left(\frac{\Delta M}{M}\right)^2 + \left(\frac{\Delta I}{I}\right)^2 + \left(\frac{\Delta \alpha}{\alpha}\right)^2 + 4\left(\frac{\Delta r}{r}\right)^2 + \left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta \beta}{\beta}\right)^2 \qquad (2.17)$$

where ΔM is the probable error of M

ΔI is the probable error of I

$\Delta \alpha$ is the probable error of α

Δr is the probable error of r

ΔN is the probable error of N

$\Delta \beta$ is the probable error of β.

Thus, the ratio $\frac{\Delta B}{B}$ is obtained.

2.3 The Effect of Positive Ions Impinging on a Solid Surface.

The detection of positive ions has been accomplished by means of a cylindrical collecting electrode and an electrometer. The ion collector is made of brass. When a beam of positive ions is incident on a solid surface, it may give rise to a variety of phenomena.

In the first place secondary electron emission may occur. Such emission takes place largely in the backward direction. Many positive ions striking a solid surface, will simply be scattered back with loss of energy. Such reflected positive ions are observed at all angles of reflection. The energy of the reflected ions depends on the angle of reflection.

When the positive ions are incident normally on the target, the positive ion reflection coefficient has been found to be very small in the case of alkali ions. It was found that ions from a source of a Kunsman type emitting K^+, Cs^+, Li^+ ions were incident on a target, the values of the reflection coefficient were about 0.004 - 0.028.

2.4 The High Frequency Electrodeless Discharge.

When a closed tube containing gas or vapour at a pressure which may vary between 0.001 and 10 m.m. of mercury, is brought close to a coil through which high frequency oscillations are passing (10^5 cycles per second and upwards.), the low pressure gas glows. No internal electrodes are required and it has been suggested that the action is occurred by the fact that the lines of magnetic field produced by the oscillations in the coil effectively form closed loops of changing magnetic flux. The initial ions in the rarefied gas can therefore be set in motion by the induced electric field and ionize by collisions, resulting in an intense glow.

The high frequency electical energy may be coupled to the discharge tube either magnetically, by inserting the tube within the oscillator coil, or electrostatically. Electrostatically coupling may be made by wrapping metal foils around extreme limbs of the tube and connecting these directly to the opposite ends of the oscillator coil.

The sensitivity of the discharge to small quantity of organic impurity makes it useful as a means of testing for even very small leaks in a vacuum system. A leaky system invariably shows a red glow which is largely due to the band spectrum of nitrogen. The leak position is sought out by applying to suspected points a cotton-wool pad soaked in benzene. When the leaking system is covered with benzene vapour, the entry of a minute amount into the tube immediately turns the discharge gray. Strong glow may persist down to a pressure of 10^{-5} mm. of mercury, it is a good evidence of a high vacuum having been achieved if a high frequency discharge can not occur at all. In other words, a high vacuum system is obtained when no glow occur when the high frequency oscillation is applied to.

2.5 The Properties of Materials

2.5a The Property of the Heating Material.

The heating unit is composed of the salt of an alkali metal coated on the tungsten filament. With salts of alkali metals, the metallic atom can evaporate in the ionized state, when they are heated together with the tungsten filament on which they are coated. The substance with a higher affinity for electrons will ionize the other one, in other words the tungsten filament has high work function relative to the ionization potential of material coated on it. When the filament is raised to a high temperature, ions of the source material are formed. The efficiency of this ionization process which also includes the re-emission as ions of metallic atom striking the hot filament, has been shown theoretically to depend exponentially upon the difference between the work function of the filament and the ionization potential of the evaporated atom according to the relationship

$$N_{+} = N_{o} \exp. \left[\frac{e(w - \phi)}{kT} \right] \qquad (2.18)$$

where $\frac{N+}{N_o}$ is the ratio of the evaporated atoms and the total amount of atoms containing in the salt.

w is the work function of the filament.

ϕ is the ionization potential of the evaporated atom.

e is the magnitude of electronic charge.

k is the Boltzmann's constant.

T is the absolute temperature of the filament.

2.5b Some Properties of the Material Used.

Glass to metal seals are in common use for high vacuum systems. In many processes, it is possible to produce a desired motion inside the vacuum chamber by means of magnetic forces. The usual procedure is to place a permanent magnet or an electromagnet outside a portion of the vacuum chamber. It is clear that the vacuum envelope in the region where this motion is to be produced must be constructed of non - magnetic material. Brass and glass are the most commonly used materials for construction of small vacuum systems.

Certain openings must be provided in a device for the insertion and removal of materials for a given process. During operation these openings must be sealed vacuum tight by appropriate covers. Rubber is widely used as a gasket material where temperature and loads permit, since this material offers far more reliable sealing than any other. For high vacuum service, leaks must be as much as possible eliminated. Rubber, both synthetic and natural, have certain important qualities. It is an incompressible material. Deformation in one direction must be suitably allowed for in other directions so that the total volume of the gasket may remain constant. It experiences a certain amount of permanent set resulting from flow when stressed over a long period of time.