## 1-3 Collisions:-

The incessant interchange of energy between the particles of a gas takes place mainly by collisions, of which we may distinguish differentypes: ① elastic collision and ② inleastic collision.

### 1-3-1 Cross-Section:-

One of the best ways of describing the probability of various types of collision is to define an effective cross-Section for collision, by analogy with spherical particles. The probability of a particle making a collision in unit distance of its path is simply the reciprocal of its (m.f.p) $\lambda$. Hence, using the approximate eq(4), and putting $q = \pi d^2$, we have;-

$$P = nq \qquad (19)$$

Here ($q$) is the effective cross-section of a particle for collision with another, since we have seen ($\pi d^2$) to be the area through which the centre of a colliding particle must be pass.

For collision by an electron, the cross-section of a gas particle is from eq (7)

$$P = \frac{1}{\lambda_e} = nq$$

$$q = \frac{\pi d^2}{4} \qquad (20)$$

When the type of collision considerd is between unlike particles, the cross-section of one is determined by the m.f.p of the other. To avoid ambiguity, we may, for a collision of type X between particles of types 1 and 2, defined the cross-section $q_{2X}$ of a type 2 particle as;

$$q_{2X} = \frac{1}{n_2 \lambda_{1X}} \quad (21)$$

Where ($n_2$) is the concentration of type 2 and $\lambda_{1X}$ the mean free path of type 1 between collisions X.
A cross-section ($q_{tot}$) for any collision irrespective of type can be defined; more specifically ($q_i$) for ionization ($q_{ex}$) for excitation or ($q_{el}$) for elastic collisions are usual. If necessary excitation, or ($q_{el}$) can be subdivided into $q_{ex1}$, $q_{ex2}$ .... for different levels of excitation, or $q_{el}$ into cross-sections for particular angles of scattering particular amounts of momentum transfer and so on.
In any case, since every collision must fall into one of the chosen categories we can write for a certain type of particle colliding with another type:

$$q_{tot} = \sum_X q_X \quad (22)$$

or, since $n$ is constant;

$$P_{tot} = \sum_X P_X \quad (23)$$

The ratio $P_X/P_{tot}$ or $q_X/q_{tot}$ gives the proportion of all collisions which are of type X, for ionization $q_i/q_{tot}$ is the probability of ionization at a collision.
The actual value of ($q$) is not a <u>constant</u> for a particular type collision; it depends very much on the relative

kinetic energy of the particles before they collide.
The kinetic energy of relative motion of two particles of masses $m_1$ and $m_2$, which is their combined kinetic energy less that corresponding to the motion of their centre of mass, can be shown to be:

$$E_r = \frac{1}{2} \frac{m_1 m_2}{m_1 + m_2} V_r^2 \qquad (24)$$

where $V_r$ is the relative velocity. If $m_1 \ll m_2$

$$E_r = \frac{1}{2} m_1 V_r^2 \qquad (25)$$

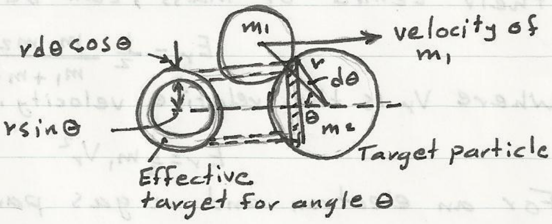
For an electron and a gas particle, $V_r$ is approximately the velocity of the electron, since the heavier particles are much slower; hence the kinetic energy of relative motion is virtually that of the electron. The quantity $m_1 m_2/(m_1 + m_2)$ is known as the reduced mass of the pair.

It is possible to calculate cross-sections for certain types of collision by the methods of quantum mechanics but in gas discharge work experimental data are widely used.

## 1-3-2 Elastic Collision:

is one in which the energy exchanged is translational kinetic energy only. In gases under normal conditions and in many gas discharges, the majority of collisions are elastic. The fact that only kinetic energy is involved implies that the atomic or molecular structure is unchanged.

For the spherical particles of the kinetic theory, the results of an elastic collision can be predicted from the laws of conservation of energy and momentum. Fig(1) shows the colliding spheres.




Fig(1) Colliding spheres.

If a stationary particle of mass ($m_2$) is struck by a particle of mass ($m_1$) and kinetic energy ($E_1$) it can be shown that the energy transferred to the former is given by

$$\Delta E = E_1 \cdot \frac{4 m_1 m_2}{(m_1+m_2)^2} \cos^2\theta \qquad (25)$$

The maximum fraction of energy transferred is therefore:

$$\delta_{max} = \frac{4 m_1 m_2}{(m_1+m_2)^2} \qquad (26)$$

for a central collision ($\theta = 0$).

For a particle of radius ($r$) this projected area is;

$$dA = r d\theta \cdot 2\pi r \sin\theta \cdot \cos\theta$$
$$= \pi r^2 \cdot \sin 2\theta \, d\theta$$
$$= A \sin 2\theta \, d\theta \qquad (27)$$

Where (A) is the total projected area or actuall cross-section. The average fraction of energy transferred in all collisions is therefore;

$$\delta = \frac{4m_1 m_2}{(m_1+m_2)^2}\int_0^{\pi/2} \cos^2\theta \cdot \sin 2\theta \, d\theta$$

$$= \frac{2m_1 m_2}{(m_1+m_2)^2} = \frac{1}{2}\delta_{max} \quad (28)$$

If $m_1 \ll m_2$

$$\delta = \frac{2m_1}{m_2} \ll 1 \quad (29)$$

Hence electrons, colliding with even the lightest of atoms, lose only a very small part of their kinetic energy on each collision.

From energy transfer we are led to consider momentum transfer. Consider again the case $m_1 \ll m_2$; clearly only a very small velocity will be imparted to $m_2$, so the relative velocity will be ~~that~~ that ~~small~~ of $m_1$ at an angle $\phi$, say, to its original direction; this is the angle of scatter. For $m_1$, then, all values of $\phi$ are equally probable, and we have symmetrical or <u>isotropic</u> scattering. Momentum transfer by electrons in actual elastic collisions is rather less than total; that is, there is generally forward scatter as opposed to the isotropic scattering of the elastic-sphere theory. Then the effective cross-section for momentum transfer can be defined as:

$$q_m = q_{el}\overline{(1-\cos\phi)} \quad (29)$$

## 1-3-3 <u>Inelasitic Collisions</u>:

An inelastic collision involves the interchange of the internal energy of excitation or ionization (or, in a molecular gas, dissociation), and the kinetic energy of translation. An electron can excite or ionize an atom provided that its kinetic energy is sufficient to provide the necessary energy difference between electron level. Excitation and ionization can also be produced by the impact of positive ions or neutral atoms. The cross-sections for this process are much smaller than for electron impact except for high energies, of order of 200ev and above, when the relative velocity becomes comparable with that of typical electrons.

* If a gas is sufficiently hot, the random energy of an atom may occasionally be sufficient to ionize another upon collision. This process is called <u>thermal ionization</u> and is important in high pressure arc discharge.
* In <u>chemi-ionization</u>, which occurs in flames, the energy is provided by chemical exchange.
* For <u>cumulative ionization</u> is possible, where several successive collisions give sufficient energy, through various stages of excitation, finally to ionize an atom. Cumulative ionization can occur at high pressure and temperature.
* <u>Auto-ionization</u>; is a process involving a doubly-excited atom; that is, an atom in which successive collisions have transferred two valency electrons to higher levels. It is possible for one electron to fall back and the other to be released, provided that the total excitation

energy is greater than that for ionization.

x <u>Surface or contact ionization</u>; is the process by which a neutral particle impinging on a metallic surface may give up an electron to the surface and leave as a positive ion.

1-3-4 <u>Charge Transfer; the Penning Effect</u>;.

An important class of inelastic collisions of the second kind between atoms or ions is that where potential energy is transferred from one to the other. A limiting case of this is charge transfer. An ion and a neutral atom collide and exchange positive charge, the ion takin an electron from the atom.

Excitation energy can also be exchanged between neutral atoms. In particular, an excited atom can ionize by viture of its excitation energy, if the latter is larger than the required ionization energy. Such a process is made more probable if the excited atom is in a metastable state and has thus a longer lifetime in which to undergo a collision. The process is then known as the <u>Penning effect</u> and can be an important ionizing agent for discharges in mixtures containing the <u>raregas</u>, the atoms of which have metastable states of high energy.

1-3-5 <u>Attachment and Emission of Radiation</u>:.

The process in which an electron, colliding with a neutral particle, forms a negative ion is called attachment. The most familiar example is oxygen; the halogen gases also are strongly electronegative.

Of a similar nature to attachment is random recombination sometimes called <u>recombination</u> to distingusih it from other neutralization process. Recombination can occur when a positive ion collides with eith an electron or a negative ion. The probability of each process is influnced by the electrostatic force of attraction. Electron-ion recombination is usually much less probable than ion-ion, because of the relatively high electron velocity.

The rate of recombination is obviously directly proportional to the concentrations of both positive ions and negative ions, or electrons. Writing these as $n_+$ and $n_-$ gives;

$$\frac{dn_+}{dt} = \frac{dn_-}{dt} = \alpha n_+ n_- \qquad (30)$$

Where $\alpha$ is the recombination coefficient

For the common case in which $n_+ = n_- = n$, we have

$$\frac{dn}{dt} = \alpha n^2 \qquad (31)$$

↔

## 1-4. Absorption and Emission of Radiation

An excited atom may lose its potential energy of excitation in a collision of the second kind with another particle, but there is also a probability that the electron will fall back spontaneously into a lower orbit - not necessarily directly into the lowest - with the emission of a quantum of radiation. The average time elapsing between excitation and such spontaneous emission in the absence of collisions is the lifetime $\tau$ of that particular excited state. For most states $\tau$ is of the order of $10^{-8}$ s, but for metastable states can be $10^{-3}$ s or more, there is a high probability that an excited atom will emit spontaneously before colliding. Metastable atoms are much more likely to lose energy in a collision.

When the spontaneous transition from a level m is predominantly to a level n, so that transitions from m to another lower level are rare, $\tau$ is easily related to the transition probability of the mn transition.

Induced or stimulated emission can also take place in which the transition occurs with a probability proportional to the density of radiation already existing in the vicinity of the atom at the appropriate frequency.

The reverse process to spontaneous emission is photoexcitation in which an atom absorbs a photon and is raised to a higher energy level.

Photoionization occurs when an absorbed photon has sufficient energy to ionize an atom; if the latter is in the grounded state and has ionization potential $V_i$ the photon frequency $f$ must be such that;

$$hf \geq eV_i$$

The reverse process to photoionization is radiative recombination where the potential energy and relative kinetic energy of a recombining electron-ion or ion-ion pair are released a quantum of radiation. Radiative attachment produces a similar effect.

The probability of gas particles being excited or ionized by the absorption of radiation is most easily described in terms of an absorption coefficient $\mu$ for the gas. defined by the relation:-

$$I = I_0 e^{-\mu x}$$

Radiation can be emitted by free electrons as brehmsstrahlung in encounters with positive ions where the electron remains free gives up kinetic energy (a free-free transition). This is an important energy loss from highly ionized plasma at high temperature.

## 1.5 Mobility

An electron, of charge $e$ and mass $m$ in an electric field $E$, experiences a force $Ee$ and an acceleration $Ee/m$ in the negative E-direction. The average kinetic energy is then constant and so also is the average directed velocity, the value of which is then known as