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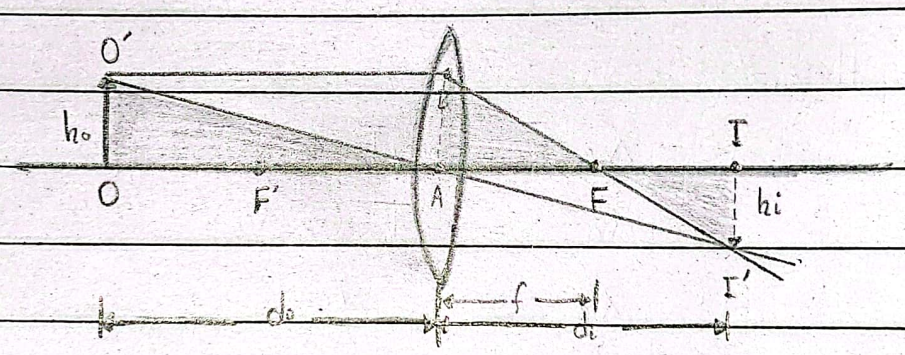
Thin Lens Equations

We now derive an equation that relates the image distance to the object distance and the focal length of a thin lens. Let d_o be the object distance from the center of lens, and d_i be the image distance, the distance of image from center of lens.



Let h_o and h_i refer to the heights of the object and image. The right triangles FI'I and FBA are similar because angle AFB and IFI' are equal, so

$$\frac{AB}{II'} = \frac{AF}{IF}$$

$$\because \left(\frac{AB}{AF} = \frac{II'}{IF} \right)$$

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$$\frac{h_o}{h_i} = \frac{f}{IA - AF}$$

$$\frac{h_o}{h_i} = \frac{f}{d_i - f} \longrightarrow \text{(i)}$$

Also, the right triangles OAO′ and IAI′ are also similar. so,

$$\frac{OO'}{OA} = \frac{II'}{AI}$$

$$\frac{OO'}{II'} = \frac{OA}{AI}$$

$$\frac{h_o}{h_i} = \frac{d_o}{d_i} \longrightarrow \text{(ii)}$$

Comparing equ (i) and (ii)

$$\frac{d_o}{d_i} = \frac{f}{d_i - f}$$

$$d_o(d_i - f) = d_i f$$

$$d_o d_i - d_o f = d_i f$$

$$d_o d_i = d_i f + d_o f$$

$$d_o d_i = f(d_o + d_i)$$

$$\frac{1}{f} = \frac{d_o}{d_o d_i} + \frac{d_i}{d_o d_i}$$

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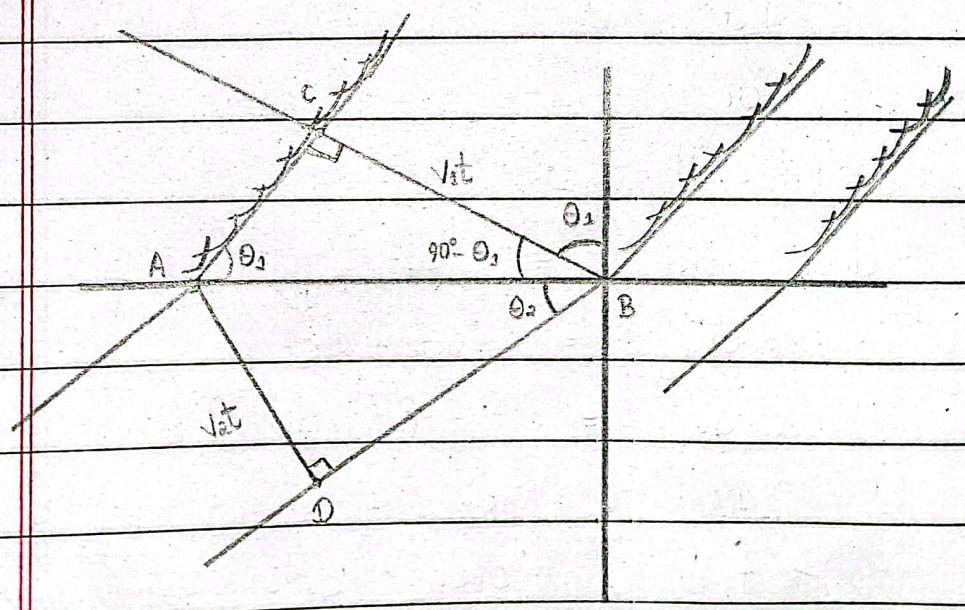
$$\boxed{\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}}$$

Snell's Law

When light passes from one transparent medium into another with a different index of refraction, some or all of the incident light is reflected at the boundary. If a ray of light is incident at an angle to the surface, the ray changes direction as it enters the new medium. This change in direction of light ray is called refraction.



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$$\sin\theta_1 = \frac{BC}{AB} = \frac{V_1 t}{AB} \longrightarrow (i)$$

$$\sin\theta_2 = \frac{AD}{AB} = \frac{V_2 t}{AB} \longrightarrow (ii)$$

Dividing equ (i) by (ii)

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{V_1 t}{\cancel{AB}} \times \frac{\cancel{AB}}{V_2 t}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{V_1}{V_2}$$

As we know that

$$n = \frac{c}{v}$$

$$v = \frac{c}{n}$$

Thus,

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{c/n_1}{c/n_2}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

$$\boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$$

CamScanner

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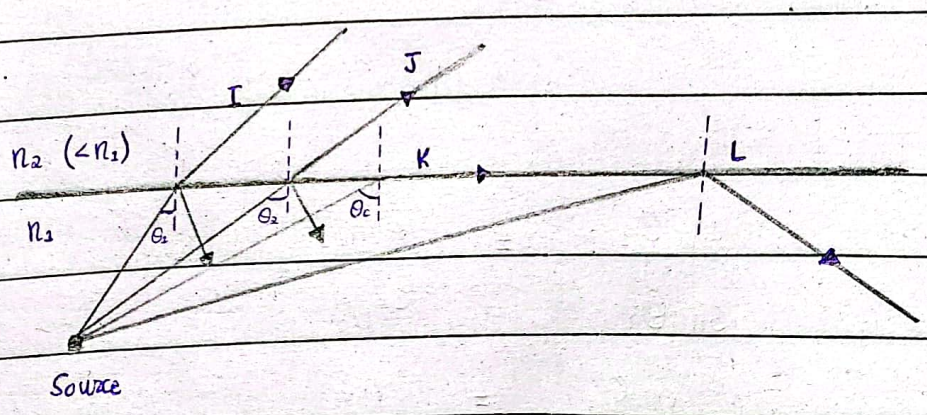
Total Internal Reflection

When light passes from one material into a second material where the index of refraction is less (say, from water into air), the refracted light ray bends away from the normal. At a particular incident angle, the angle of refraction will be 90°, and the refracted ray would skim the surface (ray K). The incident angle at which this occurs is Critical angle, θ_c.



From Snell's law, the critical angle θ_c is given by

$$\sin\theta_c = \frac{n_2 \sin 90^\circ}{n_1} = \frac{n_2}{n_1}$$

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For any incident angle less than θ_c, there will be a refracted ray, although part of the light will also be reflected at the boundary. However, for incident angles θ_1 greater than θ_c, Snell's law would tell us that $\sin\theta_2$ $(= n_1 \sin\theta_1 / n_2)$ would be greater than 1.00 when $n_2 < n_1$. Yet the sine of an angle can never be greater than 1.00. In this case there is no refracted ray at all, and all of the light is reflected. This is called total internal reflection.

* TIR occurs only when the light strikes a boundary where the medium beyond has a lower index of reflection.

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Semiconductors

Semiconductor diodes and transistors are essential components of modern electronic devices.

At the interface b/w an n-type and a p-type semiconductor, a pn junction diode is formed. Separately the two semiconductors are electrically neutral. But near the junction, a few electrons diffuse from the n-type into p-type semiconductor, where they fill a few of the holes. The n-type is left with a +ve charge, and the p-type acquires a net -ve charge. The "junction" is actually a very thin layer b/w the charged n and p semiconductors where all holes are filled with electrons. This junction region is called the depletion layer.

Forward biased

If a battery is connected to a diode with the positive terminal to the

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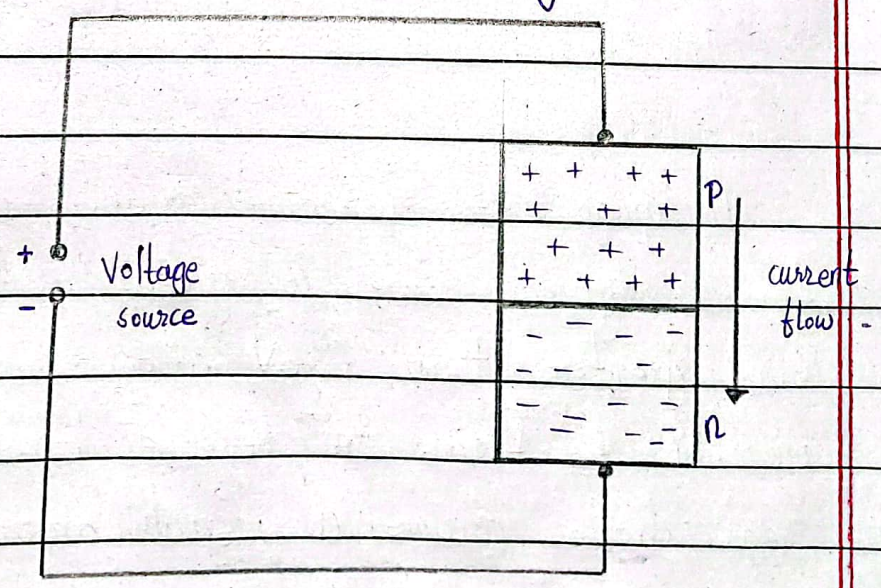
p side and the negative terminal to the n side, the externally applied voltage opposes the intrinsic P.D and the diode is said to be forward biased.

If the voltage is great enough about 0.6V for Si at room temperature, it overcomes that intrinsic P.D and a large current can flow. The +ve holes in the p-type semiconductor are repelled by the +ve terminal of battery, and $\bar{e}$ in the n-type are repelled by -ve terminal of battery. The holes and $\bar{e}$ meet at the junction and $\bar{e}$ cross over and fill the holes. A current is flowing.



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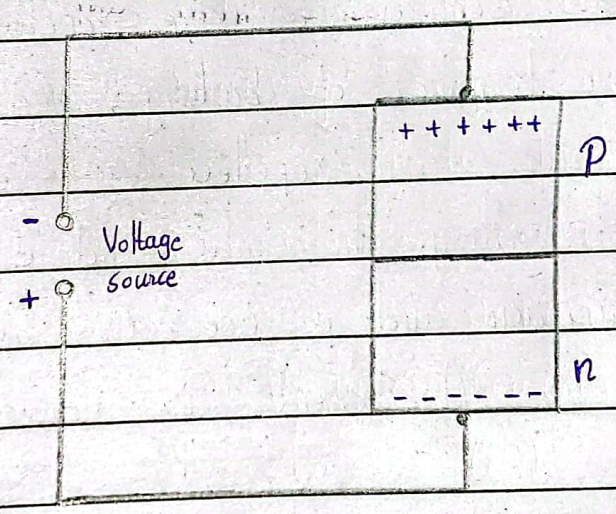
Reverse biased

when the diode is reverse biased the holes in the p end are attracted to the battery's -ve terminal and the $\bar{e}$ in the n end are attracted to the +ve terminal. Almost no current carriers meet near the junction and ideally no current flows.



A graph of current versus voltage for a typical diode is given. A forward bias greater than 0.6V allows a large current to flow. In reverse bias, a real diode allows a small amount of reverse current to flow; for most practical purposes, it is negligible

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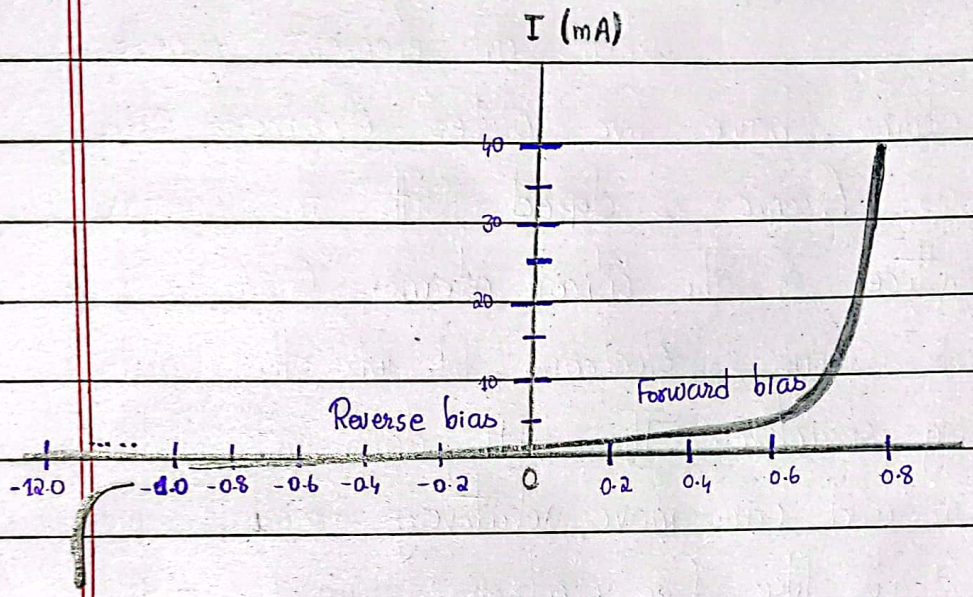
The symbol for diode is



Doping

An atom of Silicon has four outer electrons (G4 of Periodic table) that act to hold the atoms in the regular lattice structure of the crystal. Si acquires properties useful for electronics when a tiny amount of impurity is introduced into the crystal structure. This is called Doping the semiconductor.

Two kinds of doped semiconductor can be made, depending on the

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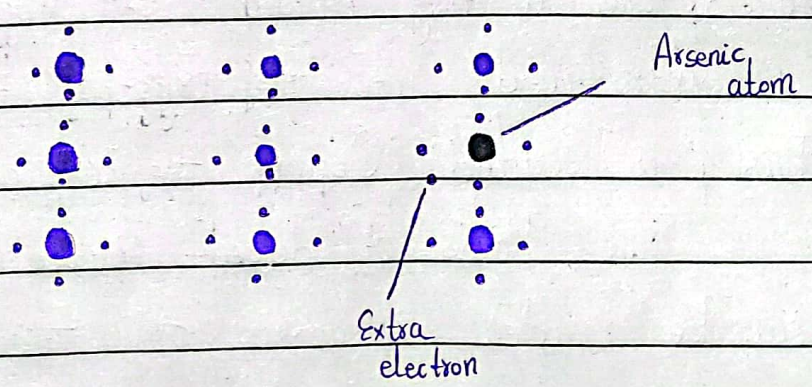
type of impurity used.

i) n-type Semiconductor

When an element whose atoms have five outer electrons such as Arsenic is doped with the crystal lattice of the silicon atoms. Only four of arsenic's electrons fit into the bonding structure. The fifth does not fit in and can move relatively freely, somewhat like free electrons. Due to these free e^-, a doped semiconductor becomes slightly conducting. An arsenic-doped silicon crystal is an n-type semiconductor because -ve charges (e^-) carry the electric current. Thus, the n-type semiconductor behaves as a donor.



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ii) p-type semiconductor

When an element whose atoms have three outer electrons (G3 in Periodic table) such as boron are doped in the lattice structure of the element like Silicon then there would be a hole in the lattice structure near a boron atom because it has only three outer electrons. An $\bar{e}$ from a nearby Si atom can jump into this hole and fill it but this leaves a hole where that $\bar{e}$ had previously been. In this way, there are holes always next to a Si atom due to vast majority of atoms. Since Si atoms require four outer electrons to be neutral, this means there is a net +ve charge at the hole.

This type of semiconductor is called p-type because it is +ve holes that carry the electric current. Note, however, that both p-type and n-type semiconductors have no net charge on them.

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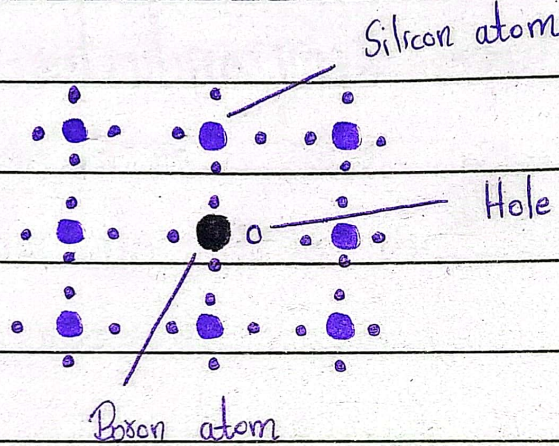

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Energy Band Theory

Forbidden Energy Gap

In b/w two consecutive permissible energy bands, there is a range of energy states which can't be occupied by electrons. These are called forbidden energy states, and its range is termed as forbidden energy gap.

Valence Band

The $\bar{e}$ in the outermost shell of an atom are called valence electrons and the energy band occupying these $\bar{e}$ is known as valence band. It is obviously the highest occupied band. It may be either completely filled or partially filled with $\bar{e}$ and can never be empty.

Conduction Band

In conduction band, $\bar{e}$ move

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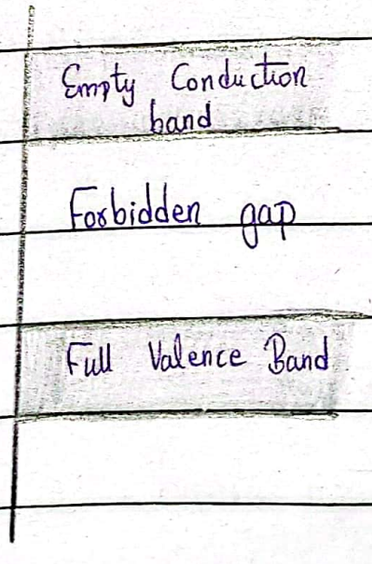
freely and conduct electric current through solids. That is why the e^- occupying this band are known as conductive electrons or free electrons. Any e^- leaving the valence band is accommodated by this band.

Insulators

Insulators are those materials in which valence e^- are bound very tightly to their atoms and are not free. In terms of energy bands, it means that an insulator has

1) an empty conduction band (no free e^-).
2) a full valence band
3) a large energy gap (several eV) b/w them.



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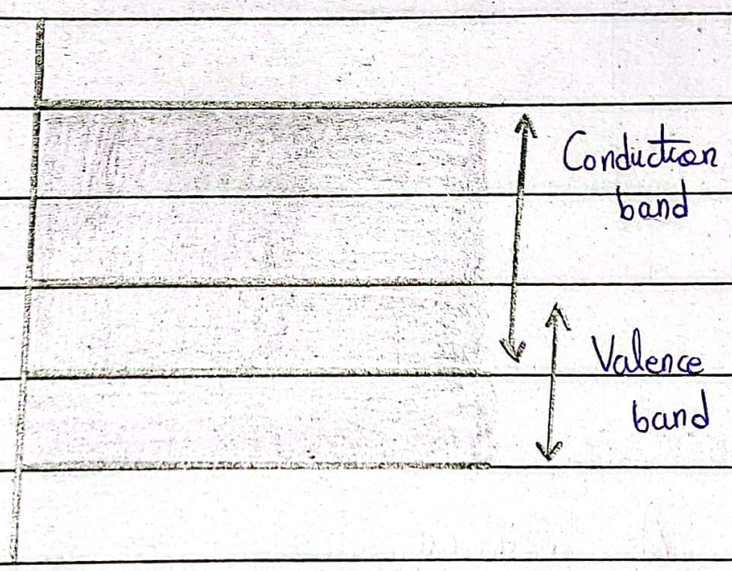
Conductors

Conductors are those which have plenty of free e^- for electrical conduction. In terms of energy of conduction bands largely overlap each other. There is no physical distinction b/w the two bands which ensures the availability of a large no. of free e^-.



Semiconductors

In terms of energy bands, semiconductors are those material which at room temperature have

1) partially filled conduction band
2) partially filled valence band

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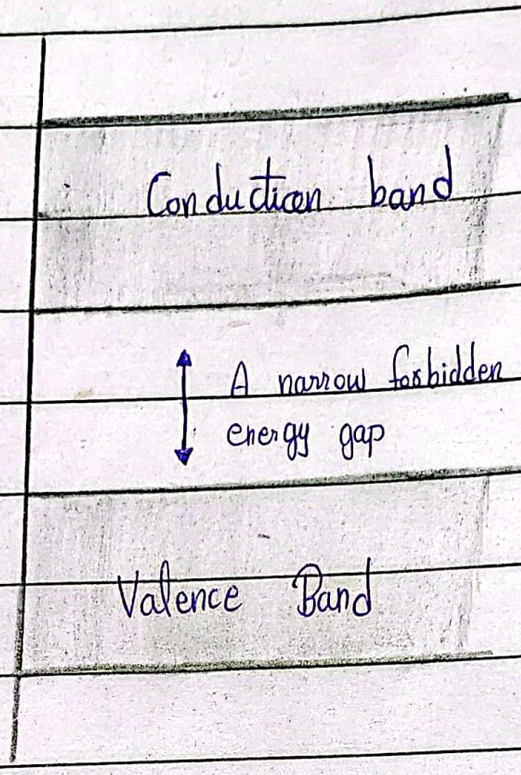
3) a very narrow forbidden energy gap (of the order of 1eV). b/w the conduction and valence bands.



Intrinsic Semiconductors

A semiconductor in its extremely pure form is known as an intrinsic semi-conductor.

Extrinsic Semiconductors

The doped semi-conducting materials or impure semiconductors are known as Extrinsic Semiconductors.

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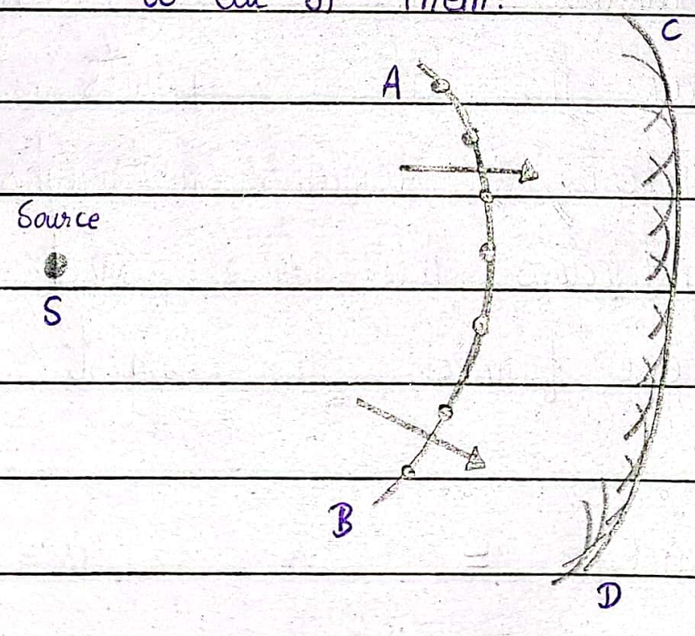
Huygen's Principle

Huygen's principle can be stated as given below

- "Every point on a wave front can be considered as a source of tiny wavelets that spread out in the forward direction at the speed of the wave itself." The new wave front is the envelope of all the wavelets — that is, the tangent to all of them."



- "The new position of the wave-front after a certain interval of time can be found by constructing a surface that touches all secondary wavelets."

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Young's Double Slit Experiment

The experimental arrangement consists of a screen having two narrow slits which is illuminated by a beam of monochromatic light. The portion of wave-front incident on slits behaves as a source of secondary wavelets. The secondary wavelets leaving the slits are coherent. Superposition of these wavelets result in a series of bright and darks bands (fringes) which are observed on a second screen.

The wavelets arrive at the screen in such a way that at some points crests fall on crests and troughs on troughs resulting in constructive interference and bright fringes are formed. The bright fringes are

$$d\sin\theta = m\lambda \quad , \quad m = 0, 1, 2, \ldots$$

There are some points on the screen where crests meet troughs giving rise to destructive interference and dark fringes

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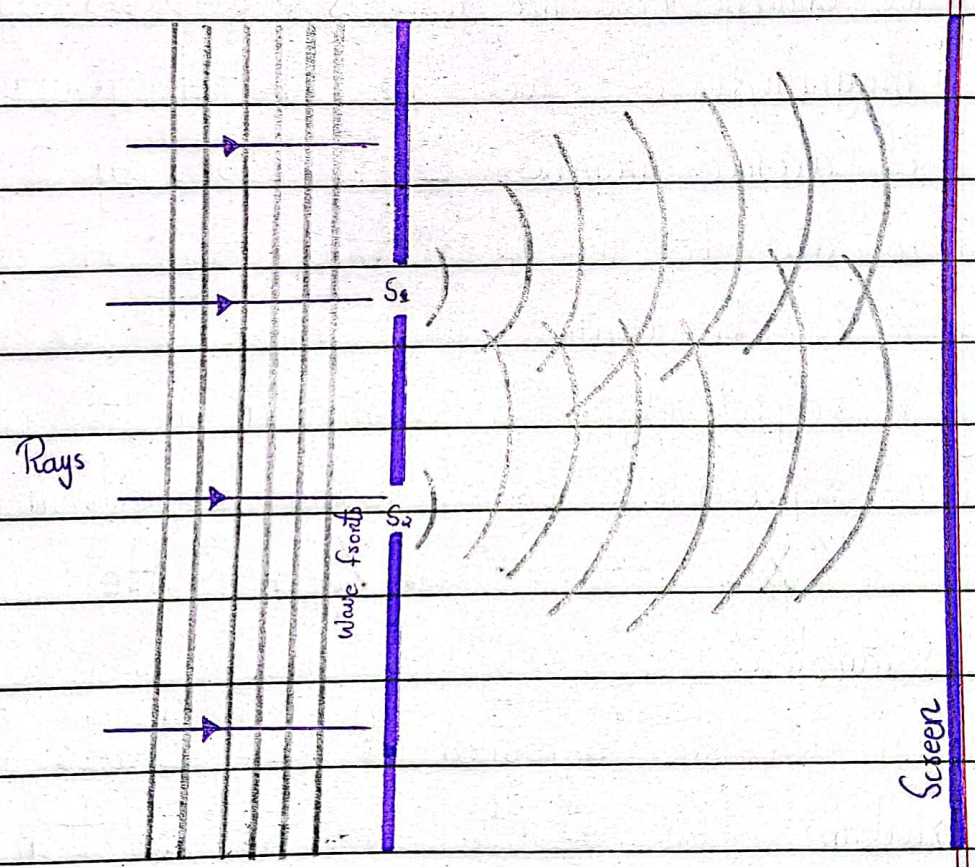
are thus formed. These fringes are given as

$$d\sin\theta = \left(m + \frac{1}{2}\right)\lambda$$

$$m = 0, 1, 2, \ldots$$



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α Decay

When α particle is emitted out of any nucleus then due to law of conservation of matter, the mass number A of the nucleus decreases by 4, and due to law of conservation of charge, the charge of the nucleus decreases by a magnitude of 2e i.e. the charge number of atomic number Z, decreases by 2. It is due to the fact that the A and Z of the emitted particle α is 4 and 2 respectively. The emission of α-particle is represented by following equation

$$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

Example:

The emission of α-particle from radium $^{226}_{88}Ra$ results in the formation of radon gas $^{222}_{86}Rn$.

$$^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$$

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β Decay

When a β - particle is emitted out of any nucleus, then its mass number A does not change but its charge number Z increases by one. The emission of a β - particle from any element X is represented by the following equation.

$$^{A}_{Z}X \longrightarrow ^{A}_{Z+1}Y + ^{0}_{-1}e$$

Negative β - particle is an electron and as there is no electron present in the nucleus, this emission of $\bar{e}$ from the nucleus can be thought of as a neutron emitting an electron and becoming a proton. This means that the β - particle is formed at the time of emission. That is why at the time of emission of a β - particle the Z of nucleus increases by one but no change in its A takes place. The transformation of $\bar{e}$ at the moment of its emission is given as

$$^{1}_{0}n \longrightarrow ^{1}_{1}H + ^{0}_{-1}e$$

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Example:

It has been observed that thorium $^{234}_{90}Th$ is transformed into protactinum $^{234}_{91}Pa$ after the emission of β- particle.

$$^{234}_{90}Th \longrightarrow ^{234}_{91}Pa + ^{0}_{-1}e$$

γ Decay

When a γ-radiation issues out of the nucleus then neither the charge number Z not the mass number A of the nucleus changes. It is due to the fact that a γ-radiation is simply a photon that has neither any charge nor any mass. Its emission from nucleus has same resemblance with the emission of a photon of light from an atom. As any e^- when absorbs energy, it jumps from ground to higher energy state and becomes excited and after returning to its ground state, it emits the absorbed energy in

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the form of photon. The same is the case with nucleus. When nucleus gets excited it emits α and β particle. This excited state of nucleus is unstable state, in coming back to ground state it emits γ- radiation.

The emission of γ- radiation from a nucleus is represented as

$$ {}^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + \gamma \text{ radiation} $$

Tunneling

Consider a model of a nucleus that has an alpha trapped inside it. The potential energy "seen" by the α- particle would have a shape like shown ~~below~~ in figure. The potential energy well (square) b/w $r = 0$ and $r = R_0$ represents the short Range attractive nuclear force. Beyond the nuclear radius R_0, the Coulomb repulsion dominates (since the nuclear force drops to zero) and we

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see the characteristic $1/r$ dependence of the Coulomb potential. The α particle, trapped within the nucleus, can be throught of as moving back and forth b/w potential walls. Since the potential energy beyond $r = R_0$ is greater than the energy of α particle (dashed line), the α particle could not escape the nucleus if it were governed by classical physics. But according to quantum physics/mechanics, there is a non zero probability that the α particle can tunnel through the Coulomb barrier from point A to point B. The height and width of barrier effect the rate at which nuclei decay. Because of this barrier, the lifetimes of α-unstable nuclei can be quite long, from a fraction of a microsecond to over 10^{10} years. The Q-value in figure represents the total K.E when α particle is far from the nucleus.

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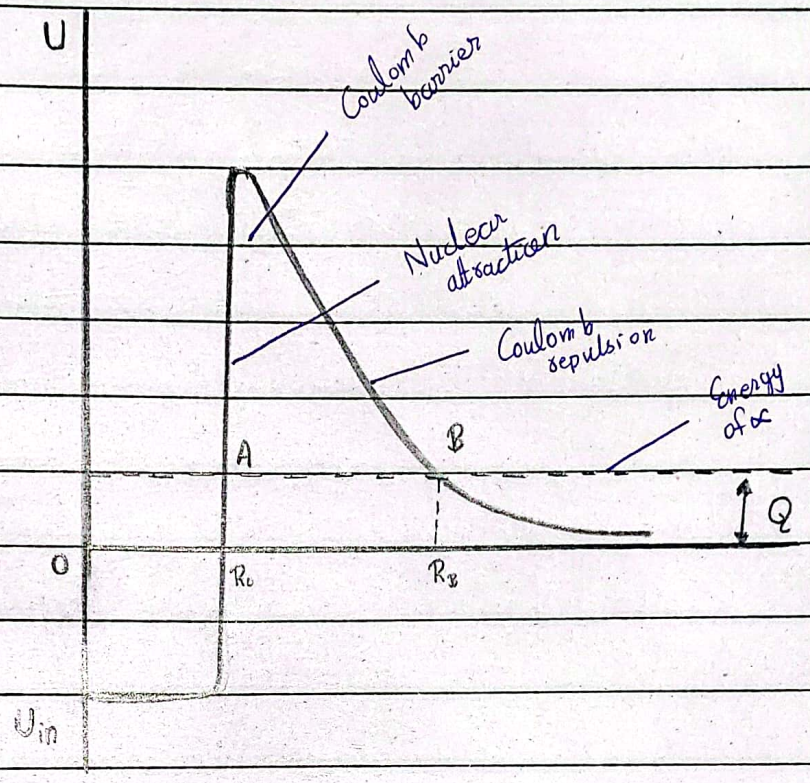

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Potential Energy Diagrams

Potential Energy diagram is useful to analyze the interaction b/w two atoms or molecules. P.E diagram is a plot of the P.E versus the separation distance b/w the atoms or molecules.

For the simple case of two point charges q_1 and q_2, the P.E U is given by

$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

where r is the distance b/w two charges, and the constant $(1/4\pi\epsilon_0)$ is equal to $9 \times 10^9 \ Nm^2C^{-2}$.

For Like charges (+ve) P.E ↑

If the two charges have the same sign, the potential energy U is positive for all values of r, and a graph of U versus r in this case is shown. The force b/w charges is repulsive (the charges have same sign) and the curve rises as r decreases; this makes sense because

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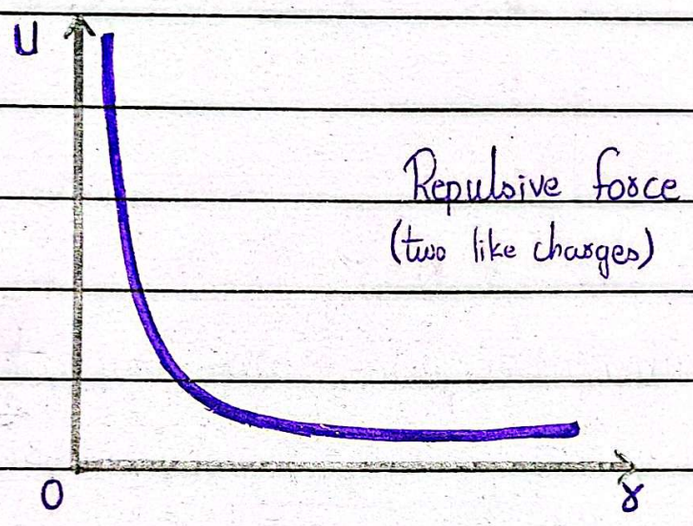
work is done to bring the charges together, thereby increasing their potential energy. (+ve)



For unlike charges P.E ↓ (-ve)

When two charges of opposite sign are considered, the potential energy is negative because the product $q_1 q_2$ is negative. The force is attractive in this case, and the graph of $U (\propto -1/r)$ versus r looks as given. The potential energy becomes more negative as r decreases.

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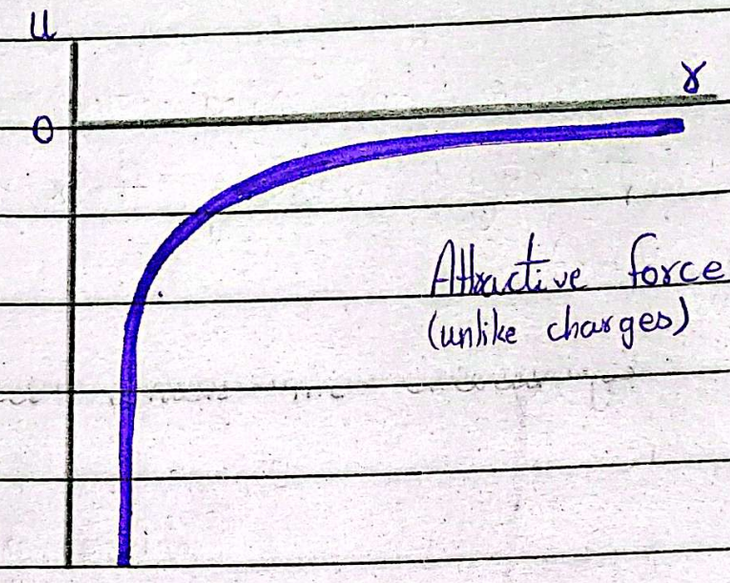

To summarize we can say that

- When P.E is +ve (increasing curve) then the net force b/w atoms is repulsive and thus atoms repel each other.
- When P.E is -ve (decreasing curve) then the net force is attractive and thus atoms attract each other.

Potential Energy Diagram for the formation of H_2 molecule

Let us look at the potential-energy diagram for the formation of a covalent bond, such as for hydrogen molecule H_2. The potential energy U of one H atom in the presence of other is plotted.

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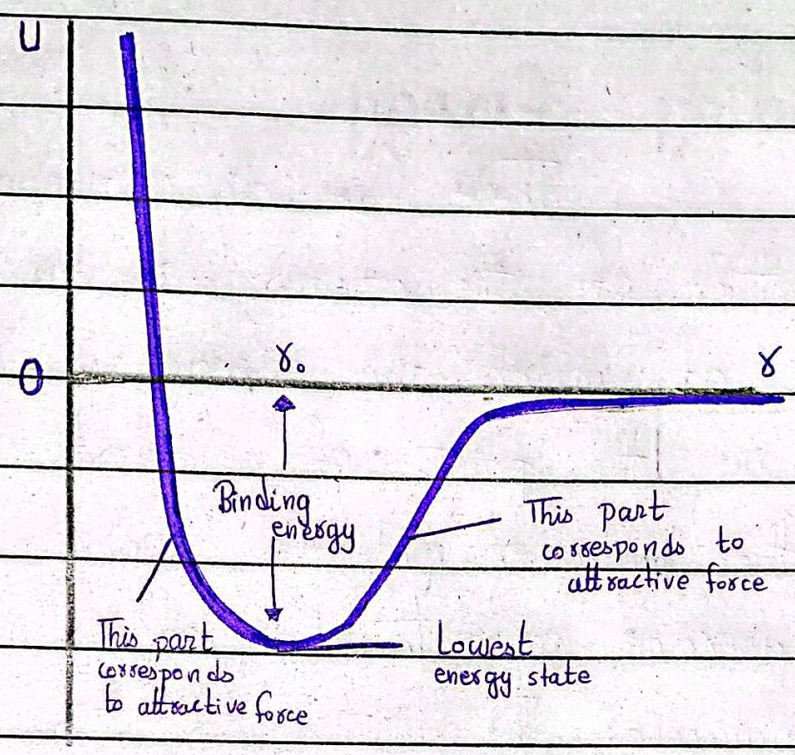

Starting at larger r, U decreases as the atoms approach, because the electrons concentrate b/w the two nuclei, so attraction occurs. However, at very short distances, the electrons would be squeezed out — there is no room for them b/w the two nuclei. Without the e^- b/w them, each nucleus would feel a repulsive force due to the other, so the curve rises as r decreases further.

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Binding Energy

There is an optimum separation of the atoms, r_0 in the figure, at which the energy is lowest. This is the point of greatest stability for the hydrogen molecule, and r_0 is the average separation of atoms in the H_2 molecule. The depth of this "well" is called the binding energy. This is how much energy must be put into the system to separate the two atoms to infinity, where $U = 0$. For the H_2 molecule, the binding energy is about 4.5eV and $r_0 = 0.074$ nm.

Activation Energy

When the atoms approach from a large distance, the force is initially repulsive rather than attractive. The atoms thus do not spontaneously form a bond. Some additional energy must be injected into the system to get it over the

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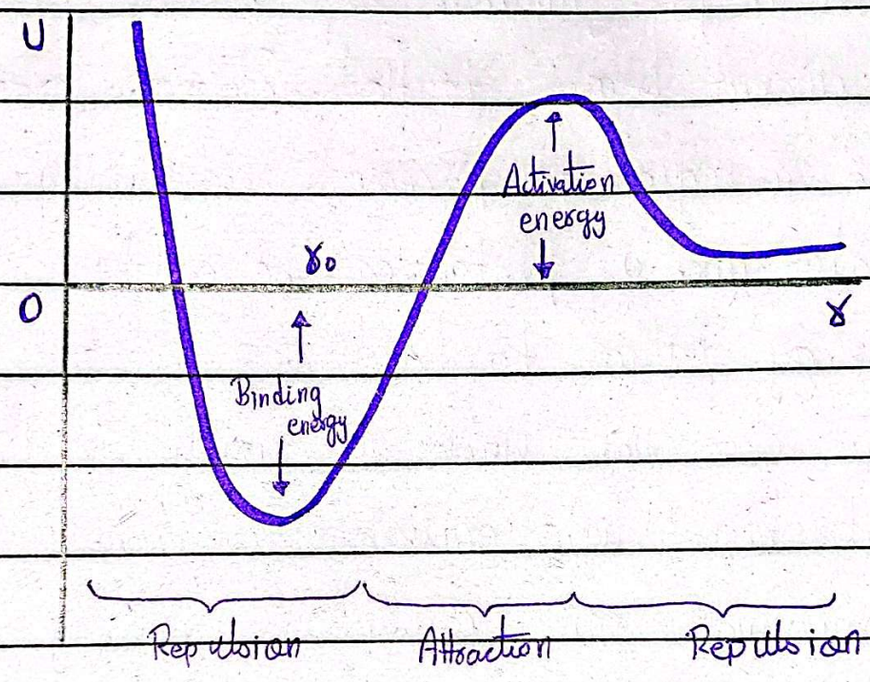
"hump" (or barrier) in the potential-energy diagram. This is required energy called Activation Energy.



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LED

A light Emitting Diode (LED) is a sort of the reverse of a photovoltaic cell. When a pn junction is forward biased, a current begins to flow. Electrons cross from the n-region to p-region, recombining with holes and a photon can be emitted with an energy equal to band gap energy Eg. This does not work well with Si diodes. But high light-emission is achieved with compound semi-conductors, typically involving a group III and a group V element such as Gallium and Arsenic (Ga, As).

The first visible-light LED, developed in early 1960s was made of a semiconductor compound of gallium, arsenic, and phosphorus (= GaAsP) which emitted red light.

LED "bulbs" are also used in flashlights, street lighting, traffic signals, car brake lights and large display screens at stadiums.

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In YDSE, the distance of the mth bright fringe from the central maximum (Y) is given as:

$$Y = \frac{m\lambda L}{d}, \quad m = 0, \pm 1, \pm 2, \pm 3, \ldots$$

In YDSE, the distance of the mth dark fringe from the central maximum (Y) is given as

$$Y = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d} \quad m = 0, 1, 2, 3, \ldots$$

The distance b/w two adjacent bright fringes (or dark fringes) is known as the fringe width Δy and it is given as

$$\Delta y = \frac{\lambda L}{d}$$

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Polarization

An important and useful property of light is that it can be polarized. Polarization can exist only for transverse waves, and not for longitudinal waves such as sound.

Let us examine waves traveling on a rope. A rope can oscillate in a vertical plane or in a horizontal plane. In either case, the wave can be said to be linearly polarized or plane-polarized — the oscillations are in a plane. If we now place an obstacle containing a vertical slit in the path of the wave, a vertically polarized wave passes through the vertical slit, but a horizontally polarized wave will not.

Maxwell's theory of light as EM waves prescribed that light can be polarized since an EM wave is a transverse wave. The direction of polarization in a plane-polarized EM wave is taken

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as the direction of the electric field vector $\vec{E}$. Light is not necessarily polarized. It can also be unpolarized, which means that the source has oscillations in many planes at once.

Polarization by Absorption

Plane-polarized light can be obtained from unpolarized light using certain crystals such as tourmaline. Or more commonly, we use a Polarized sheet which consists of long complex molecules arranged parallel to one another. Such a polaroid acts like a series of parallel slits to allow one orientation of polarization to pass through nearly undiminished. This direction is called the **transmission axis** of the polaroid. Polarization $\perp$ to this direction is absorbed completely by the Polaroid.

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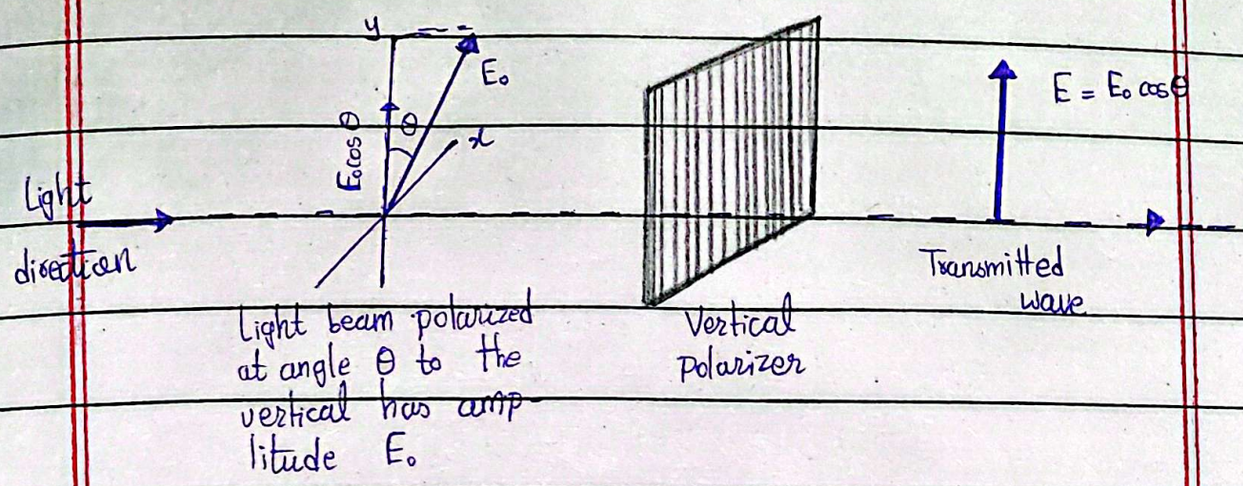
Absorption by a Polaroid can be explained at molecular level. An electric field $\vec{E}$ oscillates ∥ to the long molecules can set e^- into motion along the molecules, thus doing work on them and transferring energy. Hence, if $\vec{E}$ is ∥ to the molecules, it gets absorbed. An $\vec{E}$ perpendicular to the long molecules does not have this possibility of doing work and transferring its energy, and so passes through freely.

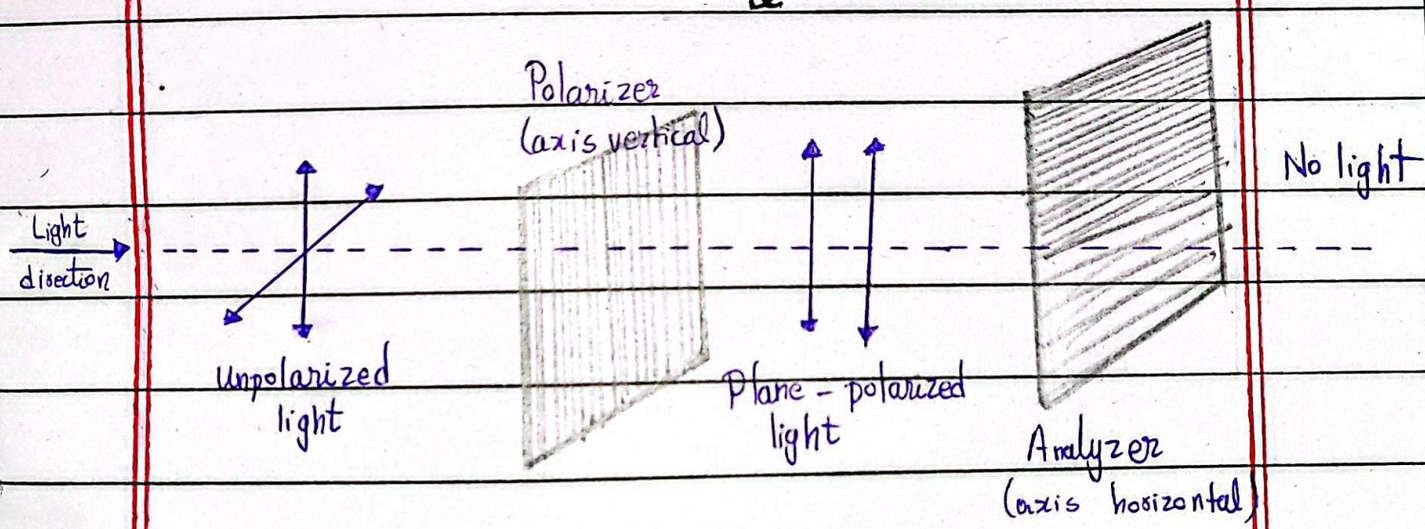
Because the intensity of light I is proportional to square of the amplitude, the intensity of a plane-polarized beam transmitted by a polarizer is proportional to $(E_0 \cos\theta)^2$, a relation called Malu's law

$$I = I_0 \cos^2\theta$$

where I_0 is the incoming intensity and θ is the angle b/w polarizer transmission axis and plane of polarization of incoming wave.

Date: Day:



* Intensity of initially unpolarized light after passing through polarizer is given as

$$I = \frac{1}{2} I_0$$