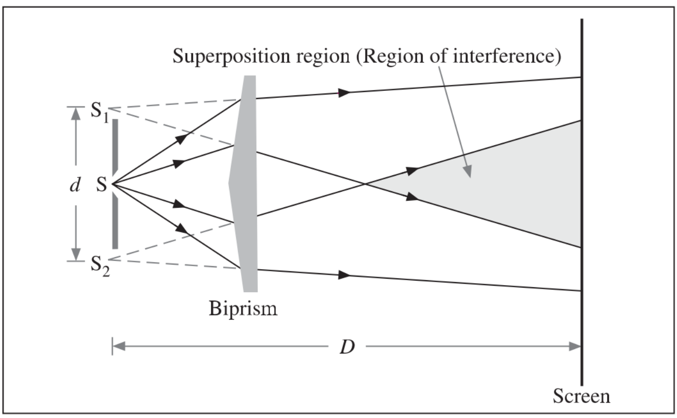
Question Set 11

INSTRUMENTS : CONSTRUCTION AND WORKING

Chapter 7. Wave optics

Q. 1. Describe the use of a biprism for obtaining two coherent sources of light. ***(2 marks)***

Ans. Fresnel's biprism is a single prism having an obtuse angle of about 178° and the other two angles of about 1° each. The biprism acts as a combination of two thin prisms of refracting angle of about 1° when a monochromatic source in the form of an illuminated narrow slit is aligned parallel to the refracting edge of the biprism. Cylindrical wavefronts of light from the slit falls on the biprism. The two halves of the biprism split every wavefront such that the light appears to come from two sources S_1 and S_2. These two virtual sources act as two coherent sources as they are derived from the same wavefront. The two split wavefronts, appearing to come



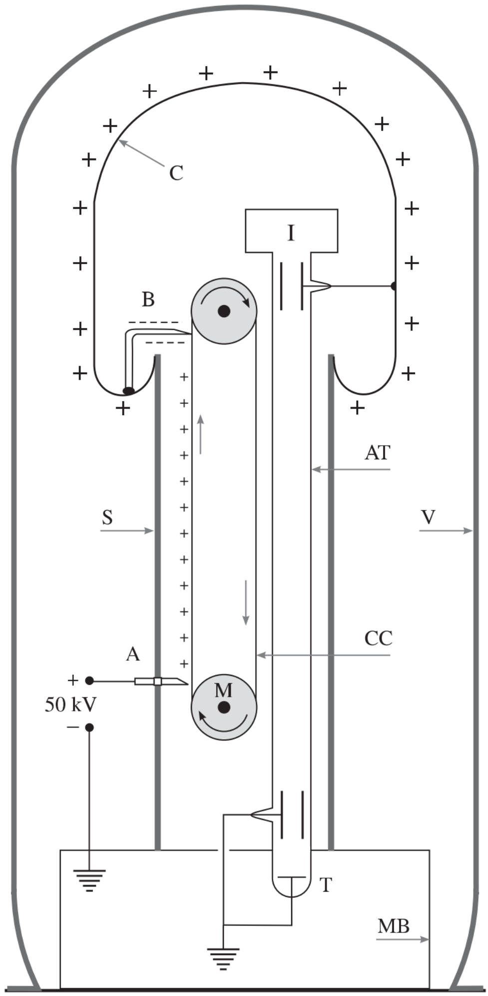
Fresnel's Biprism (Schematic diagram)

from S_1 and S_2 interfere under appropriate conditions and form interference fringes on a screen, far away from the biprism.

Chapter 8. Electrostatics

Q. 2. State the principle of working of the Van de Graaff generator. Describe its construction with a neat labelled diagram. ***(3 marks)***

Ans. Principle of working : The Van de Graaff generator works on the principles of corona or point discharge, that the charge on hollow conductor resides entirely on its outer surface and that the charge supplied to an insulated conductor increases its potential.



A, B : Spray combs, C : Conductor, I : Ion source,
M : Motor driven roller, S : Insulating support column,
T : Target, V : Pressurised vessel, AT : Accelerator tube,
MB : Metal base, CC : Charge-conveying insulating belt

The Van de Graaff generator

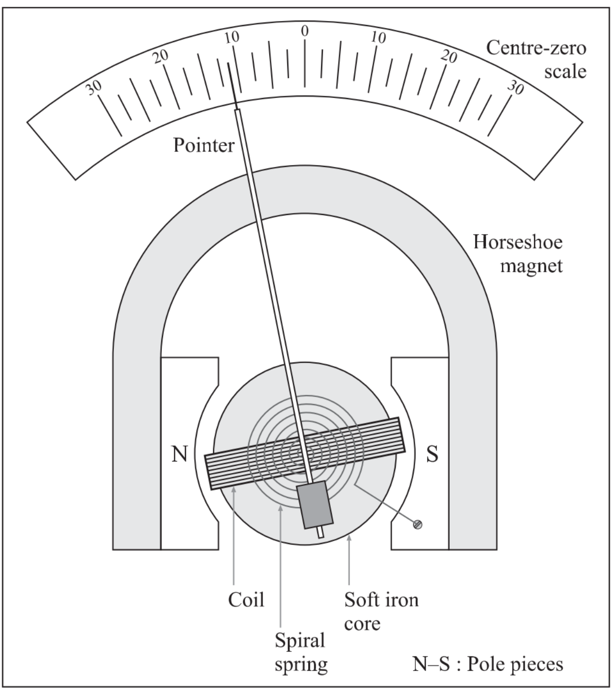
Construction : A hollow spherical conductor C is supported and insulated from the ground by a tower of ceramic insulators. A long, vertical, endless belt made of special insulating paper or fabric (rubberised silk) is continuously driven by an electric motor from the ground up to the inside of the conductor *(See figure)*. Near the ground, the belt passes close to a spraycomb A which is connected to a high-voltage source. The spraycomb consists of a set of sharp needle points. Another spraycomb collector B is connected inside conductor C at the top. The entire apparatus is usually enclosed in a pressurized vessel containing a gas such as nitrogen or Freon.

Housed inside the assembly is an evacuated tube through which positively charged particles may be accelerated from a source at the same potential as the conductor *C* to a target at the ground potential.

Chapter 9. Current electricity

Q. 3. Explain the basic construction of a pivoted-type moving-coil galvanometer with a neat labelled diagram. ***(2 marks)***

Ans. A table galvanometer consists of a coil of a large number of turns of fine insulated copper wire wound on a light rectangular aluminium frame. The coil has a pointer attached and is pivoted between cylindrically concave pole pieces of a strong horseshoe permanent magnet. The coil swings freely around a cylindrical soft iron core fitted between the pole pieces. The



A table galvanometer (Schematic diagram)

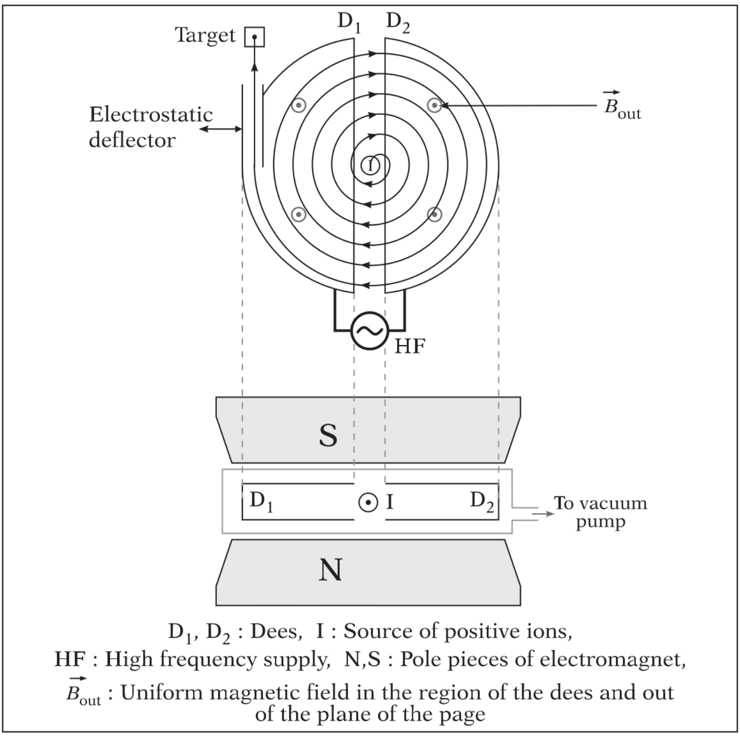
deflection of the coil depends on the current passing through the galvanometer (or the potential difference across it). The deflection of the coil is arrested by a spiral spring and is read with the pointer on a scale.

A galvanometer can be used as an ammeter or a voltmeter with a suitable modification.

Chapter 10. Magnetic fields due to electric current

Q. 4. State the principle of working of a cyclotron. Describe the construction with a neat labelled diagram. ***(3 marks)***

Ans. Principle of working : The cyclotron uses the principle of synchronous acceleration to accelerate charged particles which describe a spiral path at right angles to a constant magnetic field and make multiple passes through the same alternating p.d., whose frequency is the same as the frequency of revolution of the particles.



The cyclotron (schematic diagram)

Construction of the cyclotron : Two hollow D-shaped chambers that are open at their straight edges form the electrodes. They are called the dees. The dees are separated by a small gap, as shown in the figure, and a high-frequency (10^6 Hz to 10^7 Hz) alternating p.d. (of the order of 10^4 V to 10^5 V) is applied between them. The whole system is placed in an evacuated chamber between the poles of a large and strong electromagnet ($B \simeq 1$ T to 2 T).

The ions to be accelerated are produced in an ion source; a hydrogen tube gives protons, heavy hydrogen or deuterium gives deuterons while helium gives α-particles, etc. The positive ions are injected near the centre and are accelerated each time they cross the gap between the dees. At the edge of one of the dees, an electrostatic deflector at negative potential deflects the spiralling particles out of the system to strike a target.

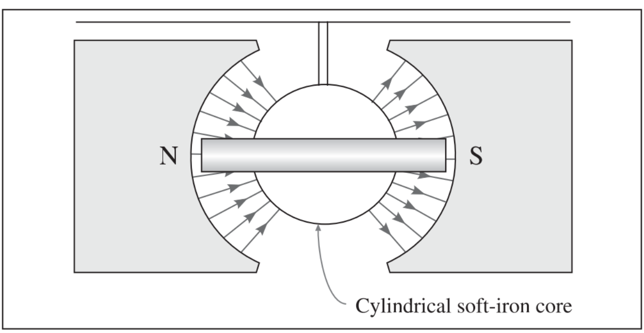
Q. 5. With the help of neat diagram, describe the working of a moving-coil galvanometer. ***(3 marks)***

Ans. Consider a rectangular coil – of length l, breadth b and N turns – carrying a current I suspended in a uniform magnetic field of induction $\vec{B}$.

The magnetic forces on the horizontal sides of the coil have the same line of action and do not exert any torque. The magnetic forces on the vertical sides constitute a couple and exert a deflecting torque. If the plane of the coil is parallel to $\vec{B}$, the magnitude of the deflecting torque is maximum equal to

$$\tau_d = NIAB \quad \text{... (1)}$$

where $A = lb$ is the area of each turn of the coil. This torque rotates the coil.



Top view of radial magnetic field

In a moving-coil galvanometer, the coil swings in a radial magnetic field produced by the combination of the cylindrically concave pole pieces and the soft-iron core. Hence, the plane of the coil is always parallel to the field lines, as shown in the figure. Therefore, the deflecting torque is constant and maximum as given by Eq. (1).

In a pivoted-type galvanometer, the rotation of the coil twists the helical springs which exert a restoring torque on the coil. The restoring torque is proportional to the angle of twist θ.

$$\tau_r = C\theta \quad \text{... (2)}$$

where C is the torque constant of the springs. C depends on the dimensions and the elasticity of the springs.

The coil eventually comes to rest in the position where the restoring torque equals the deflecting torque in magnitude. Therefore, in the equilibrium position,

$$\tau_r = \tau_d$$

$$\therefore \; C\theta = NIAB \quad \text{... (3)}$$

$$\therefore \; \theta = \left(\frac{NAB}{C}\right) I \qquad \therefore \; \theta \propto I$$

since N, A, B and C are constant. Thus, the deflection of the coil is directly proportional to the current in it.

Chapter 12. Electromagnetic induction

Q. 6. Briefly describe the construction of a simple ac generator. Obtain an expression for the emf induced in a coil rotating with a uniform angular velocity in a uniform magnetic field. Show graphically the variation of the emf with time (*t*). *OR*

Describe the construction of a simple ac generator and explain its working. ***(4 marks)***

Ans. AC generator construction : A simplified diagram of an ac generator is shown in Fig. 1. It consists of many loops of wire wound on an armature that can rotate in a magnetic field. When the armature is turned by some mechanical means, an emf is generated in the rotating coil.

Consider the coil to have N turns, each of area A, and rotated with a constant angular speed ω — about an axis in the plane of the coil and perpendicular to a uniform magnetic field $\vec{B}$, as shown in the figure. The frequency of rotation of the coil is $f = \omega/2\pi$.

Working : The angle θ between the magnetic field $\vec{B}$ and the area of the coil $\vec{A}$ at any instant t is $\theta = \omega t$ (assuming $\theta = 0°$ at $t = 0$). At this position, the magnetic flux through the coil is

$$\Phi_m = N\vec{B} \cdot \vec{A} = NBA \cos\theta = NBA \cos\omega t$$

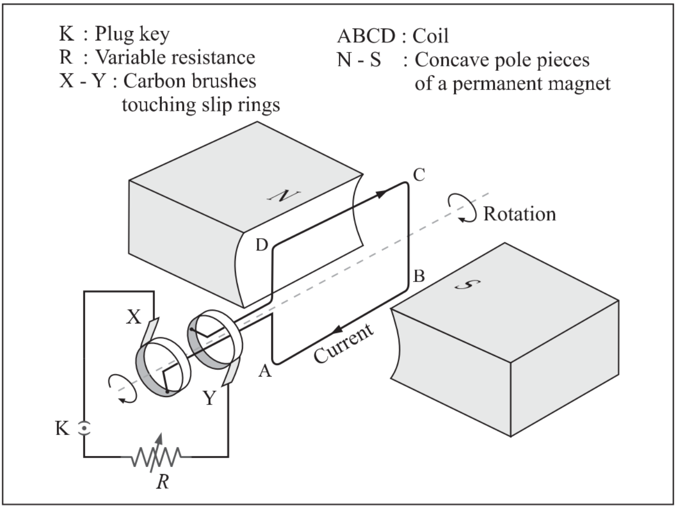


Fig. 1 : Coil of an ac generator rotating in a uniform magnetic field

As the coil rotates, the changing magnetic flux induces an emf in the coil given by

$$e = -\frac{d\Phi_m}{dt} = -\frac{d}{dt}(NBA\cos\omega t)$$

$$= -NBA\frac{d}{dt}(\cos\omega t) = NBA\omega\sin\omega t$$

$\therefore\ e = e_0 \sin\omega t$, where $e_0 = NBA\omega$.

Therefore the induced emf varies as $\sin\omega t$ and is called *sinusoidally alternating* emf. In one rotation of the coil, $\sin\omega t$ varies between $+1$ and -1 and hence the induced emf varies between $+e_0$ and $-e_0$. The maximum value e_0 of an alternating emf is called the peak value or amplitude of the emf.

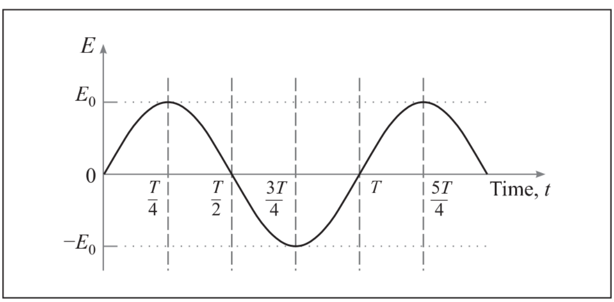


Fig. 2 : Variation of emf with time

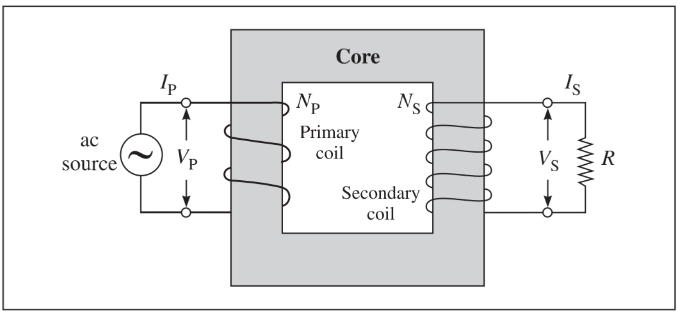
The sinusoidal variation of emf with time t is shown in Fig. 2. The emf changes direction at the end of every half rotation of the coil. The frequency of the alternating emf is equal to the frequency f of rotation of the coil. The period of the alternating emf is $T = \frac{1}{f}$.

Q. 7. Describe the construction and working of a transformer with a neat labelled diagram. ***(3 marks)***

Ans. Construction : A transformer consists of two coils, primary and secondary, wound on two arms of a rectangular frame called the core as shown in the figure.

(1) Primary coil : It consists of an insulated copper wire wound on one arm of the core. Input voltage is applied at the ends of this coil.

In a step-up transformer, thick copper wire is used for primary coil. In a step-down transformer, thin copper wire is used for primary coil.



Parts of a step-up transformer

(2) Secondary coil : It consists of an insulated copper wire wound on the other arm of the core. The output voltage is obtained at the ends of this coil.

In a step-up transformer, thin copper wire is used for secondary coil. In a step-down transformer, thick copper wire is used for secondary coil.

(3) Core : It consists of thin rectangular frames of soft iron stacked together, but insulated from each other. A core prepared by stacking thin sheets rather than using a single thick block helps reduce eddy currents.

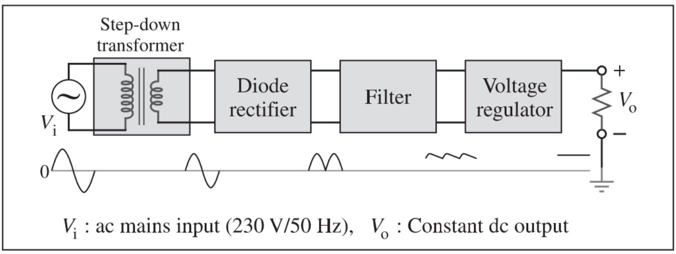
Working : When the terminals of the primary coil are connected to a source of an alternating emf (input voltage), there is an alternating current through it. The alternating current produces a time-varying magnetic field in the core of the transformer. The magnetic flux associated with the secondary coil thus varies periodically with time according to the current in the primary coil. Therefore, an alternating emf (output voltage) is induced in the secondary coil.

Chapter 16. Semiconductor devices

Q. 8. Draw a neat block diagram of a dc power supply and state the function of each part. *OR*

With the help of a block diagram, explain the scheme of a power supply for obtaining dc output voltage from ac line voltage. ***(3 marks)***

Ans. A consumer electronic system called a dc power supply produces a fairly constant dc voltage from ac supply voltage. The figure shows a functional block diagram of the circuits within a power supply.



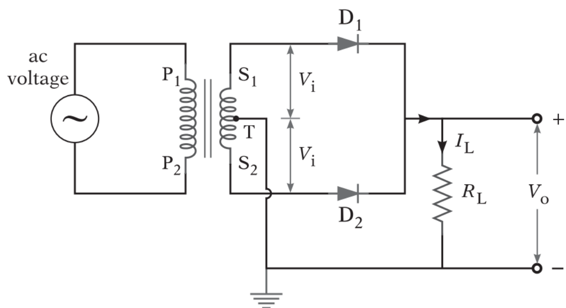
Block diagram of dc power supply with waveforms at each stage

The ac supply voltage is usually stepped-down by a transformer and its secondary voltage is converted to a pulsating dc by a diode rectifier. By the superposition theorem, this rectifier output can be looked upon as having two different components : a dc voltage (the average value) and an ac voltage (the fluctuating part). The filter circuit smooths out the pulsating dc. It blocks almost all of the ac component and almost all of the dc component is passed on to the load resistor. Figure shows the filtered output for a rectified full-wave dc. The only deviation from a perfect dc voltage is the small ac load voltage called *ripple.* A well-designed filter circuit minimizes the ripple. In this way, we get an almost perfect dc voltage, one that is almost constant, like the voltage out of a battery.

The regulation of a power supply is its ability to hold the output steady under conditions of changing input or changing load. As power supplies are loaded, the output voltage tends to drop to a lower value. Nowadays, an integrated circuit (IC) voltage regulator is connected between a filter and the load resistor, especially in low-voltage power supplies. This device not only reduces the ripple, it also holds the output voltage constant under varying load and ac input voltage.

Q. 9. With a neat circuit diagram, explain the use of two junction diodes as a full-wave rectifier. Draw the input and output voltage waveforms. ***(3 marks)***

Ans. Electric circuit : The alternating voltage to be rectified is applied across the primary coil (P_1P_2) of a transformer with a centre-tapped secondary coil (S_1S_2). The terminals S_1 and S_2 of the secondary are connected to the two *p*-regions of two junction diodes D_1 and D_2, respectively. The centre-tap T is connected to the ground. The load resistance R_L is connected across the common *n*-regions and the ground.



P_1P_2, S_1S_2 : Primary and secondary coils of transformer,
T : Centre-tap on secondary; D_1, D_2 : Junction diodes, R_L : Load resistance,
I_L : Load current, V_i : AC input voltage, V_o : DC output voltage

Fig. 1 : Full-wave rectifier circuit

Working : A full-wave rectifier rectifies both halves of each cycle of an alternating voltage.

During one half cycle of the input, terminal S_1 of the secondary is positive while S_2 is negative with respect to the ground (the centre-tap T). During this half cycle, diode D_1 is forward-biased and conducts, while diode D_2 is reverse-biased and does not conduct. The direction of current I_L through R_L is in the sense shown.

During the next half cycle of the input voltage, S_2 becomes positive while S_1 becomes negative with respect to T. Diode D_2 now conducts sending a current I_L through R_L is the same sense as before while D_1 does not conduct. Thus, the current through R_L is in the same direction, i.e., it is unidirectional, for both halves or the full-wave of the input. This is called full-wave rectification.

The output voltage has a fixed polarity but varies periodically with time between zero and maximum. Fig. 2 shows the input and output voltage waveforms.

Ripple frequency : The pulsating dc output voltage of a full-wave rectifier has twice the frequency of the input.

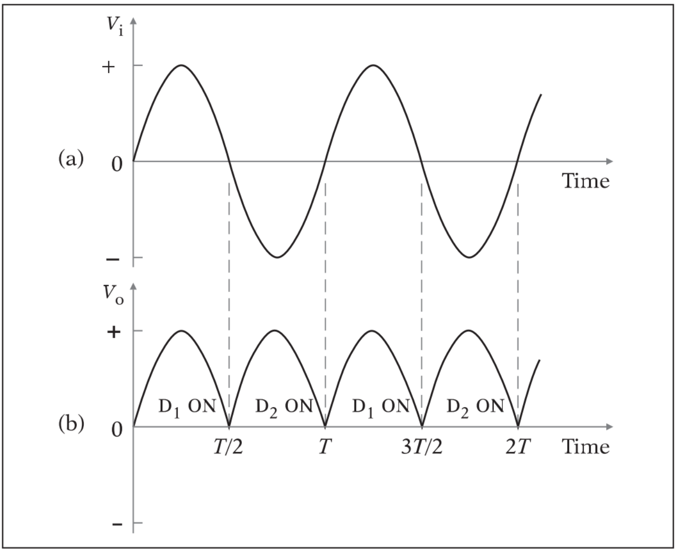
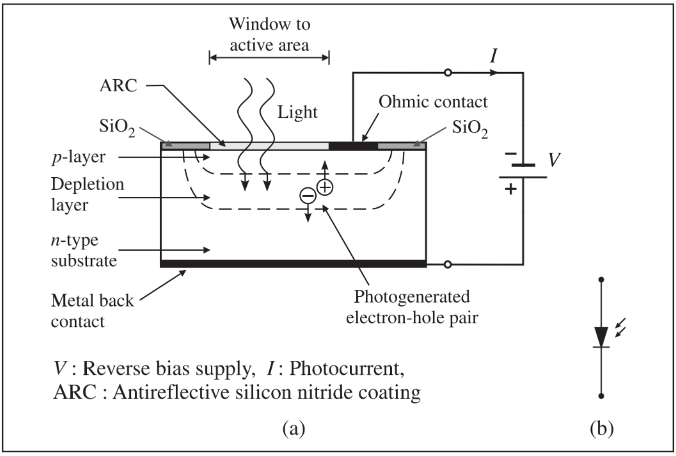


Fig. 2 : Voltage waveforms for a full-wave rectifier (a) input (b) output

Q. 10. Explain the construction of a photodiode with a neat diagram. ***(2 marks)***

Ans. Construction : A photodiode consists of an *n*-type silicon substrate with a metal electrode back contact. A thin *p*-type layer is grown over the *n*-type substrate by diffusing a suitable acceptor dopant. The area of the *p*-layer defines the *photodiode active area*. An ohmic contact pad is deposited on the active area. The rest of the active area is left open with a protective antireflective coating of silicon nitride to minimize the loss of photons. The non-active area is covered with an insulating opaque SiO_2 coating.

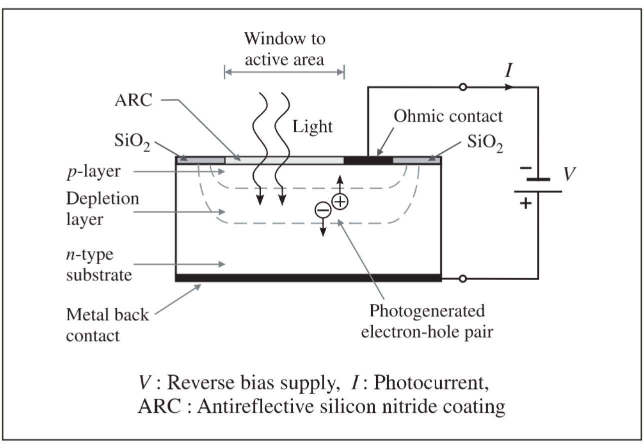


(a) Planar photodiode (b) Circuit symbol

Depending on the required spectral sensitivity, i.e., the operating wavelength range, typical photodiode materials are silicon, germanium, indium gallium arsenide phosphide (InGaAsP) and indium gallium arsenide (InGaAs), of which silicon is the cheapest while the last two are expensive.

Q. 11. Explain the principle of operation of a photodiode with a neat diagram. ***(2 marks)***

Ans. Working : In a semiconductor diode, photons or particles with energies greater than or equal to band gap energy E_G can transfer electrons from the valence band into the conduction band.



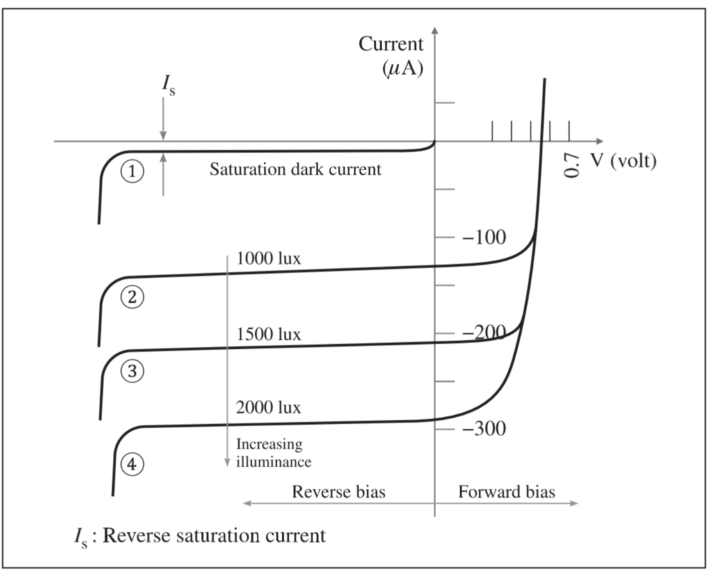
Planar photodiode

A photodiode is operated in the reverse bias mode which results in a wider depletion region. When operated in the dark (zero illumination), there is a reverse saturation current due solely to the thermally generated minority charge carriers. This is called the **dark current.**

When exposed to radiation of energy $hv \geqslant E_G$ (in the range near-UV to near-IR), electron-hole pairs are created in the depletion region. The electric field in the depletion layer accelerates these photogenerated electrons and holes towards the *n* side and *p* side, respectively, constituting a photocurrent *I* in the external circuit from the *p* side to the *n* side. Due to the photogeneration, more charge carriers are available for conduction and the reverse current is increased. The photocurrent is directly proportional to the intensity of the incident light. It is independent of the reverse bias voltage.

Q. 12. Explain the *I-V* characteristics of a photodiode. ***(2 marks)***

Ans. When a Si photodiode is operated in the dark (zero illumination), the current versus voltage characteristics observed are similar to the curve of a rectifier diode as shown by curve ① in the figure. This dark current in Si photodiodes range from 5 pA to 10 nA.



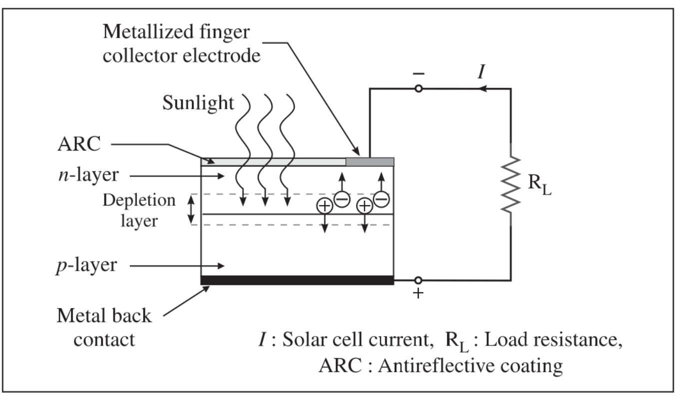
The *I-V* characteristics of a photodiode showing dark current and photocurrent for increasing illuminance

When light is incident on the photodiode, the curve shifts to ② and increasing the incident illuminance (light level) shifts this characteristic curve still further to ③ in parallel. The magnitude of the reverse voltage has nearly no influence on the photocurrent and only a weak influence on the dark current. The normal reverse currents are in tens to hundreds of microampere range.

The almost equal spacing between the curves for the same increment in luminous flux reveals that the reverse current and luminous flux are almost linearly related. The photocurrent of the Si photodiode is extremely linear with respect to the illuminance. Since the total reverse current is the sum of the photocurrent and the dark current, the sensitivity of a photodiode is increased by minimizing the dark current.

Q. 13. Describe with a neat labelled diagram the construction and working of a solar cell. ***(3 marks)***

Ans. Construction : A simple *pn*-junction solar cell consists of a *p*-type semiconductor substrate backed with a metal electrode back contact. A thin *n*-layer (less than 2.5 μm, for silicon) is grown over the *p*-type substrate by doping with suitable donor impurity. Metal finger electrodes are prepared on top of the *n*-layer so that there is enough space between the fingers for sunlight to reach the *n*-layer and, subsequently, the underlying *pn*-junction.



Sectional view of a solar cell

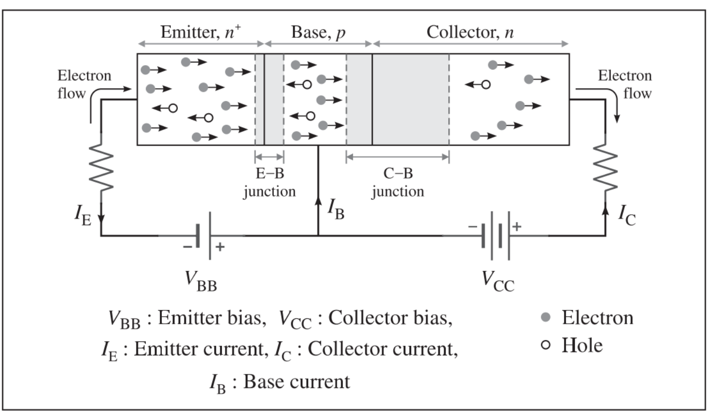
Working : When exposed to sunlight, the absorption of incident radiation (in the range near-UV to infrared) creates electron-hole pairs in and near the depletion layer.

Consider light of frequency v incident on the *pn*-junction such that the incident photon energy hv is greater than the band gap energy E_G of the semiconductor. The photons excite electrons from the valence band to the conduction band, leaving vacancies or holes in the valence band, thus generating electron-hole pairs.

The photogenerated electrons and holes move towards the *n* side and *p* side, respectively. If no external load is connected, these photogenerated charges get collected at the two sides of the junction and give rise to a forward photovoltage. In a closed-circuit, a current I passes through the external load as long as the solar cell is exposed to sunlight.

Q. 14. Explain the working of a junction transistor with a neatly labelled circuit diagram. ***(4 marks)***

Ans. For normal operation of a junction transistor, the emitter-base junction is always forward biased and the collector-base junction is always reverse biased. Figure shows the biasing of the junctions for an *npn* transistor connected as an amplifier with the common-base configuration, that is, the base lead is common to the input and output circuits. The emitter-base junction is forward biased by the battery V_{BB} while the collector-base junction is reverse biased by the battery V_{CC}. V_{BB} should be greater than the emitter-base barrier potential (the threshold voltage). The arrows of the various currents indicate the direction of current under normal operating conditions (also called the *active* mode).



Active mode biasing of an *npn* transistor and transistor action. Shaded regions show the depletion regions under biasing conditions.

Since the emitter-base junction is forward biased, majority carriers electrons in the n^+ emitter are injected into the base and holes (majority carriers in the *p*-type base) are injected from the base into the emitter. Under the ideal-diode condition, these two current components constitute the total emitter current I_E .

The emitter is a very heavily doped *n*-type region. Hence, the current between emitter E and base B is almost entirely electron current from E into B across the forward biased emitter junction.

The *p*-type base is narrow and the hole density in the base is very low. Therefore, virtually all the injected electrons (more than 95%) diffuse right across the base to the collector junction without recombining with holes. Since the collector junction is reverse biased, the electrons on reaching the collector junction are quickly swept by the strong electric field there into the *n*-type collector region, where they constitute the collector current I_C .

In practice, about 1% to 5% of the holes from the emitter recombine with holes in the base layer and cause a small current I_B in the base lead. Therefore, $I_E = I_B + I_C \approx I_C$.

Therefore, carriers injected from a nearby emitter junction can result in a large current flow in a reverse biased collector junction. This is the ***transistor action,*** and it can be realized only when the two junctions are physically close enough to interact as described.

If a *pnp* transistor is used, the battery connections must be reversed to give the correct bias. The conduction process is similar but takes place instead by migration of holes from emitter to collector. A few of these holes recombine with electrons in the base.

Assignments

1. With a neat labelled diagram, explain the construction and working of a sonometer. **(Ch. 6)** ***(3 marks)***
2. Describe the working and uses of the Van de Graaff generator with a neat labelled diagram. **(Ch. 8)** ***(4 marks)***
3. Draw the circuit diagram of a half-wave rectifier. Explain its working. What is the frequency of ripple in its output? ***(3 marks)***

   OR

   With the help of a neat circuit diagram, explain the working of a half-wave rectifier. **(Ch. 16)** ***(March '22)*** ***(3 marks)***
4. Describe with a neat diagram the construction of an LED. **(Ch. 16)** ***(2 marks)***
5. Explain the working of an LED. **(Ch. 16)** ***(Sept. '21)*** ***(2 marks)***
6. Draw a neat circuit diagram of a transistor CE-amplifier and explain its working. **(Ch. 16)** ***(3 marks)***