45. Semiconductors and Semiconductor Devices

Short Answer

Answer.1

One mole of sodium vapor has 6.02×10^{23} atoms (Avogadro's number). A sodium atom has atomic number 11. The electronic configuration of sodium is $1s^2 2s^2 2p^6 3s^1$.

Therefore, there are $2\times 6.02 \times 10^{23} = 12.04 \times 10^{23}$ (number of electrons occupying a state × Avogadro' s number) 1s energy states in one mole of sodium vapor and they are all filled in normal conditions.

Also, there are $1\times 6.02\times 10^{23} = 6.02\times 10^{23}$. 3s energy states in one mole. The 3s energy states is partially filled in normal conditions.

Answer.2

A single atom has discrete energy levels. Let us now take N atoms and assume that it is possible to vary the inter-atomic distance. When the inter-atomic distance *(distance between the two atoms)* is large, the energy levels of total N atoms coincide with those of a single atom. Let us now reduce the inter-atomic distance. This causes an atom to exert an electric force on its neighbors. The closely packed atoms have energy levels overlapped and hence closely spaced energy levels are formed so that the system now obeys Pauli Exclusion Principle. These closely spaced energy levels are discrete and called as energy bands. We don't have continuous energy variation in a band.

Answer.3

An insulator has a large energy band gap between the conduction band and valence band. There will be no carriers in the conduction band at 0 K as well as at 300 K.

A semiconductor has a moderate energy band gap and there will be no carriers in the conduction band at 0 K. There will be carriers in conduction band at room temperature.

A conductor has overlapped conduction and valence band (energy band gap do not exist). The conduction band is partially filled with carriers at 0 K and it will be fully filled at room temperature. Therefore, the material is a conductor in which the conduction band is partially filled at 0 K.

Answer.4

Thermal collisions continue to generate some number of electron-hole pairs due to the jumping of electrons from valence band to conduction band while other electron-hole pairs disappear due to the recombination process. *Recombination is the process where an electron moves from the conduction band to the valence band so that a mobile electron-hole pair disappears*. The electron in the conduction band will lose its energy when it collides with atoms and hence it comes back to the valence band filling an empty place, thus recombination takes place. Therefore, recombination is the main reason for the conduction electrons not go on increasing with time as thermal collisions continuously generates electron-hole pair.

Answer.5

Thermal collision means that the electrons have already acquired sufficient energy due to the room temperature (300 K) and it moves freely thus colliding with lattice atoms and transferring its energy to other electrons in the atom.

At room temperature, some of the electrons occupying the highest energy level in the valence band will acquire enough energy (greater than 1.1 eV) and hence they jump to the conduction band from the valence band before any collisions take place. Also some excited electrons (energy less than 1.1 eV) occupying lower energy levels in the valence band collides with other excited electrons occupying the highest energy level in the valence band. Due to this collision, there is the exchange of 0.026 eV which makes these electrons to jump from higher energy level of valence band to the conduction band. The thermal collision as well as already applied room temperature are the reason for this movement of electrons.

Answer.6

The carriers are absent in the conduction band of an intrinsic semiconductor at 0 K. Therefore, the conductivity is zero and hence resistivity is infinity. Thus the resistance is infinite (much large) of an intrinsic semiconductor at 0 K.

Answer.7

We have valence electrons in the outer orbit of a semiconductor. We have conduction electrons in the conduction band of semiconductor at 300 K. When an electron jumps from the valence band to the conduction band, a hole is created in the valence band at the place from where that electron jumped. There is no such concept of 'valence holes' and 'conduction holes'. A place void of electron is a hole.

Answer.8

When a p-type impurity is added in a pure semiconductor, a large number of holes are created. Thus, each impurity atom is deficient of one electron and they accept the electrons which are loosely bound to other neighboring atoms. So, each impurity atom acquires negative charges. The number of negatively charged impurity atoms and the number of holes are equal in p-type semiconductor. Thus, it is electrically neutral. But when holes diffuse from the p-side to the n-side in a p-n junction or in other words we say that when an electron diffuses from the n-side to the p-side in a p-n junction, it leaves a vacant place in the n-side region and thus the n-side gets positively charged. Also, the p-side gets negatively charged due to the diffusion of electrons from the n-side.

Answer.9

The electric field is directed from n-side to p-side across the p-n junction. When temperature is increased, more covalent bonds break up and hole-electron pairs are generated across the junction. The electric field attracts the electrons towards n-side while it repels the holes towards p-side. Thus the direction of the current due to this movement of holes and electrons is same as the direction of drift current flowing from the n-side to the p-side. Hence the current flowing due to the increase in temperature adds up to the drift current flowing initially in the reverse biased p-n junction diode. Therefore, the total drift current is increased.

Answer.10

Vacuum diode consists of two electrodes- a cathode and an anode. The cathode emits free electrons while the anode collects the free electrons. Thus the current only flows from the anode to the cathode. A large current flows in forward biased p-n junction diode while a small current flows in reverse-biased p-n junction diode. Therefore, vacuum diode is close to an ideal diode which passes current only in one direction.

Answer.11

The output/collector current of the amplifier circuit is given by $I_L = I_C = \beta \times I_B$, where I_B is the base current and $\beta = \frac{\alpha}{1-\alpha}$. α is the fraction of emitter current received at the collector. This means that $I_C = \alpha \times I_E$ and value of α is about 0.95 to 0.99. Let us put $\alpha = 0.99$ in equation of β and therefore $\beta = \frac{0.99}{0.01} = 99$. The power gain at the output is directly proportional to β^2. Putting β=99 then power gain is proportional to $99^2 = 9801$. Hence the output power is several times greater than the input power. The power gain or extra power is coming from the relationship between α and β parameters.

Objective I

Answer.1

Assuming the Semiconductor is at room temperature (300°K), there are equal numbers of free electrons and holes present in the semiconductor. Hence both electrons and holes participate in the electrical conduction in a semiconductor. Therefore, the correct answer is option C.

Answer.2

If the temperature is increased, there will be more breaking of the Covalent bonds and more charge carriers are generated. This leads to total increase in moving charge carriers and thus their average drift speed will now be decrease due to *increase in probability of collision with the lattice atoms* of semiconductor. Hence number of charge carrier n will increase but the average drift speed v will decrease. Therefore, the correct answer is option B.

Answer.3

Intrinsic semiconductor is pure semiconductor which belongs to the group fourth A of the periodic table. At room temperature (300°K), some covalent bonds break and equal number of electrons and holes (the place from where the electron vacated its place) are generated. Hence $n_p=n_e$. So, the correct answer is option B.

Answer.4

Extrinsic semiconductor made up by adding trivalent impurities are called p-type semiconductor. In p-type semiconductor, the number of holes is greater than number of electrons ($n_p > n_e$).

Extrinsic semiconductor made up by adding pentavalent impurities are called n-type semiconductor. In n-type semiconductor, the number of electrons is greater than number of holes ($n_p < n_e$).

However, the question does not mention which type of extrinsic semiconductor is considered. Option B is true for intrinsic semiconductor. Hence we can say that the number of electrons and holes are not equal for an extrinsic semiconductor. Therefore, the correct answer is option D.

Answer.5

When a p-type impurity is added in a pure semiconductor, a large number of holes are created in a p-type semiconductor. Thus, each impurity atom is deficient of one electron and they accept the electrons which are loosely bound to other neighboring atoms. So, each impurity atom acquires negative charges. The number of negatively charged impurity atoms and the number of holes are equal in p-type semiconductor. Thus, it is electrically neutral. Therefore, the correct answer is option C.

Answer.6

When impurity (trivalent or pentavalent) is added into an intrinsic semiconductor, extrinsic semiconductor (p-type or n-type respectively) is obtained. This has increased holes or electrons respectively in conduction band (intrinsic carriers plus the carriers due to impurity). Hence the conductivity of the extrinsic semiconductor increases. Therefore, the correct answer is option A

Answer.7

Let us consider there will be current ($I \neq 0$) flowing through the two ends of a P-N junction joined by a wire. This should generate heat at *metal ohmic contacts* (the metal used to connect p-n junction and the wire). This heat must be supplied by the p-n junction since there is no other external excitation applied. The p-n junction, therefore, would have to cool off. Clearly, under thermal equilibrium the simultaneous heating of metal ohmic contacts and cooling of the p-n junction is impossible and we conclude that $I=0$. Therefore, the correct answer is option A.

Answer.8

An open-circuited p-n junction has drift current flowing from the n-side to the p-side. The option A is true.

An open-circuited p-n junction has diffusion current flowing from the p-side to the n-side. The option B is false.

The drift current flowing from the n-side to the p-side if the junction is forward-biased, is true but the drift current flowing from the p-side to the n-side if the junction is reverse-biased, is false. Hence, the option C overall is false.

The drift current flowing from the p-side to the n-side if the junction is forward biased is false but the drift current flowing from the n-side to the p-side if the junction is reverse-biased, is true. Hence the option D overall is false.

Therefore, the correct answer is Option A.

Answer.9

An open-circuited p-n junction has drift current flowing from the n-side to the p-side. The option A is false.

An open-circuited p-n junction has diffusion current flowing from the p-side to the n-side. The option B is true.

The diffusion current flowing from the n-side to the p-side if the junction is forward-biased, is false but the diffusion current (approx zero) flowing from the p-side to the n-side if the junction is reverse-biased, is true. Hence, the option C overall is false.

The diffusion current flowing from the p-side to the n-side if the junction is forward biased, is true but the diffusion current flowing from the n-side to the p-side if the junction is reverse-biased, is false. Hence the option D overall is false.

Therefore, the correct answer is Option B.

Answer.10

In an unbiased p-n junction, the drift current is equal to diffusion current to keep the net current equal to zero. Hence Option C is false.

The junction/barrier potential is reduced by the forward biased applied voltage and hence more holes diffuse on the n-side and more electrons diffuse on the p-side. The diffusion current is large when compared to the drift current and hence the net current is in the direction of diffusion current. Hence option A is true.

The junction/barrier potential is increased by the reverse biased applied voltage. This blocks the diffusion of holes and electrons. The drift current (in microamperes) is large when compared to the diffusion current and hence the net current is in the direction of drift current. Hence option B is false.

Therefore, the correct answer is option A.

Answer.11

Circuit 1: The first p-n junction is forward biased since the p-side is at greater potential than the n-side. Also, the second p-n junction is reverse biased since its p-side is at lower potential than its n-side. Therefore, the potential across the first (forward biased) and the second (reverse biased) p-n junction is not equal.

Circuit 2: The first p-n junction is forward biased since the p-side is at greater potential than the n-side. Also, the second p-n junction is forward biased since its n side is at lower potential than its p side. Therefore, the potential across the first and the second p-n junction (both forward biased) is same.

Circuit 3: The first p-n junction is reverse biased since the n-side is at greater potential than the p-side. Also, the second p-n junction is reverse biased since its p-side is at lower potential than its n-side. Therefore, the potential across the first and the second p-n junction (both reverse biased) is same.

Therefore, the correct answer is option B.

Answer.12

The p side of the p-n junction diode is at higher potential than the n side and hence the diode is forward biased in figure (a). Assuming ideal diode case, the diode is treated as short circuit. The figure (a) network thus becomes a series source free RC circuit. The voltage equation in source free series RC circuit is given by

$$v(t) = v(0)e^{\frac{-t}{RC}}$$

At t=0, $v(t) = v(0) = V \;\cdots\cdots (given)$

At t=RC, $v(t = RC) = v(0)e^{\frac{-RC}{RC}} = Ve^{-1}$

Since, the charge is given by $Q = CV$.

At t=RC, the charge is $Q = Cv(t = RC) = CV/e$

The diode in the figure (b) is reverse biased since its p side is at low potential than its n side. Assuming ideal diode case, the diode is treated as open circuit in figure (b). Thus the charge on the capacitor at all times is $Q = CV$

Therefore, the correct answer is option B.

Answer.13

Diffusion is a natural phenomenon which occurs when there is concentration difference between the two regions. The covalent bond is formed between the trivalent (or pentavalent) and semiconductor atom in p-type (or n-type). Thus there are many vacant places (holes) and electrons in the p-side and n-side respectively. Thus there are less or no electrons in p-side while there are many electrons in n-side. Clearly, there is concentration difference of electrons across the junction and diffusion will take place. This forces the covalent bond to be broken on the n-side so that the electrons freed from this bond, jumps to the vacant places in the p-side. Also when the electron jumps from the n-side to the p-side, a vacant place (hole) is created in n-side which represents that a hole has been moved from the p-side to the n-side.

Therefore, the correct answer is option C.

Answer.14

The emitter has the greatest concentration of impurity so that the large number of carriers traverses the path to the collector via base and hence contributes to desire current. Some carriers (holes or electrons) while traversing this path get recombine with carriers (electrons or holes) present in base and thus current will decrease. If the base has impurity concentration greater than the collector, more carriers get recombine in the base and less carriers will go to the collector thus contributing current less than desired. Hence, the base should have impurity concentration less than the impurity concentration in the collector so that there will be much less recombination in base and it contributes to desire current. Therefore, the base has least impurity concentration to keep recombination much less. The collector is moderately impure. So the correct answer is option C.

Answer.15

To make transistor work as an amplifier, the emitter-base junction must be forward biased while the collector-base junction is reverse-biased.

Therefore, the correct answer is option D.

Objective II

Answer.1

A.) Simply, when the temperature decreases the motion of electrons decreases and at 0K their motion tends to cease due. Thus, no conduction or free electrons are possible a 0K.

Therefore, option A is correct.

B.) At any temperature above 0K, in semiconductors the bonds are continuously breaking and producing electron-hole pairs. Thus, there will always be some conducting electrons present for conduction.

Therefore, option B is incorrect.

C.) As the temperature increases the heat energy tends to break the covalent bonds between the atoms which leads to the creation of free electrons. Thus, more temperature means more breaking of covalent bonds and more free electrons.

Therefore, option C is correct.

D.) The energy band gap of a conductors is very less than that of a semiconductor.

Therefore, option D is correct.

Answer.2

For A.) and B.)

Diffusion of the electrons and holes from n and p side to p and n side, respectively, due to higher a concentration of holes on the p-side and lower at n-side and vice-versa for electrons results in systematic motion of charges take place.

Therefore, option A is incorrect and B is correct.

C.) Since, there are same number of electrons transferred as the number of holes transferred. Thus, the net charge transferred is zero.

Therefore, the option C is correct.

D.) As the During equilibrium there is no flow of charges at junction therefore the electric field there remains constant.

Therefore, the option D is correct.

Answer.3

For A.) and B.)

The formation of the new holes and conduction electrons happens continuously and throughout the materials because the heat of room temperature affects all region of the material equally. Therefore, option A is correct and B is incorrect.

For C.) and D.)

In the depletion region the electrons-hole pairs produced move away from each other due to the force of electric field. Thus, holes and conduction electrons do not recombine continuously throughout the material and option D.) is correct and C.) is wrong.

Answer.4

To make p-type semiconductor we dope Silicon with trivalent atoms, i.e., B.) Boron and D.) Aluminum, since trivalent atoms will create holes.

Answer.5

For A

Increasing the temperature increases the breaking of the covalent bonds and generation of more electron-hole pairs. Thus, increasing the conductivity.

For B and C

Since doping will increase the no. of charge carriers, therefore the conductivity will increase.

For D

Irradiating UV light on germanium will provide energy enough to break the covalent bond and thus create an electron-hole pair. Thus increasing the electrical conductivity.

Answer.6

For A.), B.) and C.)

In case of intrinsic semiconductor, it will always be the case that the electrons will flow to the positive terminal and holes to the negative terminal polarity because the holes and electrons are uniformly distributed. And similar would be the case for both types of semiconductor.

For D.)

In p-n junction, when the p-side is connected in forward bias, the depletion region decreases and the charge carriers are able to diffuse and a diffusion current is produced. But when the polarity is reversed, the depletion region increases, which decreases the diffusion current. Therefore, the current in p-n junction only flows in forward biasing and reduces to zero in reverse biasing.

Answer.7

A donor will form four bonds with neighboring atoms of the semiconductors and the fifth electron of the donor atom will be responsible for conduction. Thus, the concentration of electrons tends to increase. Then some of these electrons recombine with holes which lead to the decrease in the concentration of the holes. Therefore, B and C are correct.

Answer.8

So, if we consider p-n-p transistor, the emitter will have holes as the majority charge carriers and they will move to the base due to forward biasing of collector-base junction. Very few holes will combine with the electrons of the base (since it is n-type) due to the thin size and light doping of the base. Because of reverse biasing at collector-base junction, majority of the holes will move to the collector side and constitute I_c which will be slightly less than I_e since no. of holes reaching the collector is less than that at emitter. Also, at the base some holes from the emitter can escape from the base terminal but due very thin size of the base a very little holes can only pass through terminal and constitute I_b and thus I_b is much smaller than I_e.

Thus, from explanation it can be seen that option A and C are correct.

Answer.9

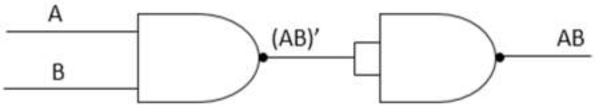
The normal operation of a transistor is applied for amplifying signals in the circuit. Configuration A and D of biasing will allow the current to amplify according to the input current.

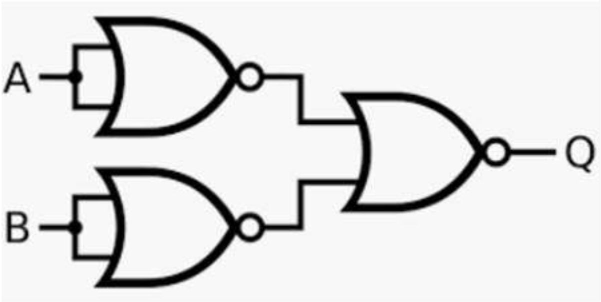
Therefore, option A and D are correct and B and C are incorrect as they are contrary to D and A respectively.

Answer.10

NOR and NAND gates are the universal or the basic gates. Using these gates any other gate can be created. Following figure shows AND gate using NAND and NOR gate respectively.

AND gate using two NAND gate.





AND gate using three NOR gates

Exercises

Answer.1

Electronic configuration of Sodium atom is → $1s^2 2s^2 2p^6 3s^1$

Each 3s orbit will have two state and one of each would be occupied,

∴ in N atoms of sodium there will be 2N states possible states and N states will be empty.

Given:

mass of the sodium in 1 m^3 = 1013 kgm^{-3}

∴ the total number of atoms

$$= \frac{mass \times avogadro's\ number}{atomic\ mass} = \frac{1013 \times 10^3 \times 6.022 \times 10^{23}}{23} = 265.22 \times 10^{26}\ atoms$$

Therefore, total number of states

$$= 2 \times N \ = 265.22 \times 10^{26} \times 2 = 5.30 \times 10^{28}\ states$$

And total unoccupied states are $= 2.65 \times 10^{28}\ states$

Answer.2

Given: Number of conduction electrons $= 6 \times 10^{19}\ \ m^{-3}$

Since in pure semiconductor the number of holes = number of conduction electron

∴ number of holes $= 6 \times 10^{19}\ m^{-3}$

∴ number of holes in
$1cm \times 1cm \times 1mm\ or\ 10^{-7}\ m^{3} = 6 \times 10^{19} \times 10^{-7} = 6 \times 10^{12}\ holes$

∴ answer is $6 \times 10^{12}\ holes$

Answer.3

Given:

Bandgap energy of antimonite$= 0.23eV$

Now for temperature, we solve following equation,

$kT = 0.23eV$

Where,

k = Boltzmann constant $=\ 8.62 \times 10^{-5}eVK^{-1}\ and\ T =\ temperature$

$$T = \frac{0.23eV}{k} = \frac{0.23eV}{8.62 \times 10^{-5}eVK^{-1}} = 2668.21\ K \cong 2670\ K$$

∴ at temperature 2670 K, kT is equal to 0.23eV

Answer.4

Given:

Band gap for silicon $= 1.1\ eV$ and kT at room temperature$= 0.026eV$

a) Ratio of band gap to $kT = \frac{1.1eV}{0.026eV} \cong 43$

b) One-tenth of the ratio in part a) $= 4.3$

Now,

$$\frac{band\ gap}{kT} = 4.3 \Rightarrow \frac{1.1}{8.62 \times 10^{-5} \times T} = 4.3 \Rightarrow T = \frac{1.1}{8.62 \times 10^{-5} \times 4.3}$$

$= 2967.67K \cong 3000K$

∴ Temperature = 3000 K

Answer.5

Given:

Indirectly in the problem we are given the acceptor level $= 2 \times\ k \times T$.

This is because the electron was at the top of the edge of valance band and reaches acceptor level on receiving the energy given.

∴ energy of the acceptor level must $= 2 \times\ k \times T$

$= 2 \times 8.62 \times 300 \times 10^{-5}$

$=\ 5.172 \times 10^{-2}eV == \ 51.72meV$

∴Answer is 51.72meV

Answer.6

For the electron to move from the conduction band to valance band it will have to loose energy same as the energy band gap of ZnO, i.e., 3.2eV.

The energy lost is in the form of electromagnetic radiation, for which the energy is given as following,

$E = (hc)/\lambda$

where,

$h = planck's\ constant\ = 4.14 \times 10^{-15} eV\ s$,

$c =\ speed\ of\ light = 3 \times 10^{8}$

λ is the wavelength

$$\therefore E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} \Rightarrow \lambda = \frac{(4.14 \times 10^{-15} eVs \times 3 \times 10^{8} ms^{-1})}{3.2eV} = 3.8812 \times 10^{-7} m$$

$$\therefore \lambda = 388.12nm \cong 390nm$$

Answer.7

Minimum energy will produce maximum wavelength and ∴ we consider the energy lost by the electrons is only due to it moving from the conduction to valence band, which is the energy band gap

The energy lost is in the form of electromagnetic radiation, for which the energy is given as following,

$E = (hc)/\lambda$

where,

$h = planck's\ constant\ = 4.14 \times 10^{-15} eV\ s$,

$c =\ speed\ of\ light = 3 \times 10^{8}$

λ is the wavelength

$$\therefore E = \frac{hc}{\lambda} \Rightarrow E = \frac{(4.14 \times 10^{-15} eVs \times 3 \times 10^{8} ms^{-1})}{820 \times 10^{-9}} = 1.514eV$$

∴ Energy band gap = 1.514eV

Answer.8

Only if the electron gains energy to move to the conduction band it will lead to the creation of electron-hole pairs.

$\therefore$ *the energy required to produce the e − h pair = energy band gap*
$= 0.65eV$

The energy of electromagnetic wave,

$$E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{hc}{E} = \frac{(4.14 \times 10^{-15} eVs \times 3 \times 10^{8} ms^{-1})}{0.65eV} = 1.9 \times 10^{-6} m$$

$\therefore$ maximum wavelength of electromagnetic radiation which can create e-h pair in germanium is $1.9 \times 10^{-6} m$

Answer.9

The conduction if take place if the energy provided to the electron is more equal or more than the band gap.

Given:

Maximum wavelength at which the conduction starts $= 620nm$

$\therefore$ this wavelength provides minimum energy to the electron to move to conduction band,

Energy of this radiation=Energy band gap

$$E = \frac{(4.14 \times 10^{-15} eVs \times 3 \times 10^{8} ms^{-1})}{620 \times 10^{-9}} = 2.003eV$$

$\therefore$ energy band gap = 2.003eV ≅ 2eV

Answer.10

Given: energy band gap,

For silicon, $\Delta E_1 = 1.1eV$

For diamond, $\Delta E_2 = 6.0eV$

Also, we know that concentration of conduction electron(n) is proportional to $e^{-\Delta E/2kT}$

$\therefore n = ke^{-\frac{\Delta E}{2kT}}$

For silicon, $n_1 = ke^{-\frac{\Delta E_1}{2kT}} = ke^{-\frac{1.1}{2\times8.62\times10^{-5}\times300}} = k \times 5.84 \times 10^{-10}$

For diamond, $n_2 = ke^{-\frac{\Delta E_2}{2kT}} = e^{-\frac{6.0}{2\times8.62\times10^{-5}\times300}} = k \times 4.18 \times 10^{-51}$

We want, $\frac{n_2}{n_1} = \frac{k\times4.18\times10^{-51}}{k\times5.84\times10^{-10}} = 7.157 \times 10^{-42}$

Since, ΔE_2 is very large, due to which the value of n_2 is in the negative power of 51, thus almost zero conduction electrons will be there in the diamond. Due to this diamond is an insulator.

Answer.11

Given:

At temperature 4K, E_1= 0.74 eV

At temperature 300K, E_2=0.67eV

The conductivity is proportional to $T^{3/2}\ e^{-\Delta E/2kT}$,

Let conductivity at 4K be =σ_1

and at 300k be = σ_2

$\therefore \frac{\sigma 1}{\sigma 2} = \left(\frac{4}{300}\right)^{\frac{3}{2}} \times (e^{-\frac{\Delta E_1}{2kT}})/(e^{-\frac{\Delta E_2}{2kT}}) = 0.0015 \times e^{\frac{\frac{\Delta E_2}{300}-\frac{\Delta E_1}{4}}{2\times8.62\times10^{-5}}}$

$= 0.0015 \times e^{\frac{\frac{0.67}{300}-\frac{0.74}{4}}{2\times8.62\times10^{-5}}} = 0.0015 \times 4.5 \times 10^{-461} \Rightarrow$

$\sigma_2 = 0.148 \times 10^{463} \times \sigma_1 \cong\ 10^{463}\sigma_1$

$\therefore$ conductivity increases by the factor of 10^{463}

Answer.12

Given:

Since, the number conduction electron and holes are the same,

∴ Number of charge carriers initially$= 7 \times 10^{15} + 7 \times 10^{15} = 14 \times 10^{15}$

On adding the impurity to the pure silicon the conductivity becomes 100 times the initial , therefore the total charge carriers should become
$= 14 \times 10^{15} \times 100 = 14 \times 10^{17}$

(∵ σ is directly proportional to concentration of charge carriers)

Let x be the holes after adding the impurity and $(14 \times 10^{17} - x)$ will be the electrons

Now, the product of the total conduction electrons and holes remains nearly constant,

∴ $(7 \times 10^{15}) \times (7 \times 10^{15}) = x \times (14 \times 10^{17} - x)$

$\Rightarrow 49 \times 10^{30} = 14 \times 10^{17} \times x - x^2$

$\Rightarrow x^2 - 14 \times 10^{17} x + 49 \times 10^{30} = 0$

Solving for x by discriminant method,

We get

$x = 13.982 \times 10^{17}\ or\ 1.8 \times 10^{15}$

Rejecting the second value on the basis of the fact that the initial number of holes must be smaller than the number of holes after doping.

∴ the number of holes or boron atoms added

$= 1398.2 \times 10^{15} - 7 \times 10^{15} = 13.912 \times 10^{17}$

Ratio of number of silicon atom to boron atom

$$= \frac{5 \times 10^{28}}{13.912 \times 10^{17}} = 3.59 \times 10^{10}$$

∴ boron must be added in proportion of 1 boron atom in 3.59×10^{10} silicon atoms.

Answer.13

Given:

Initially,

Concentration of conduction electron= 6×10^{19}

Concentration of holes= 6×10^{19}

After doping,

Concentration of conduction electron= 2×10^{23}

Concentration of holes= n_h

We know,

Product of concentration of conduction electron and that of holes remains constant,

$\therefore (6 \times 10^{19}) \times (6 \times 10^{19}) = (2 \times 10^{23}) \times n_h$

$$\Rightarrow n_h = \frac{36 \times 10^{38}}{2 \times 10^{23}} = 18 \times 10^{15} \, per \; cubic \; metre$$

$\therefore$ number of holes after doping= $18 \times 10^{15} \, per \; cubic \; metre$

Answer.14

Let T_1=300K and T_2=temperature at which the conductivity will be double of its value at T_1.

And let the conductivities at temperatures T_1 and T_2 be σ_1 and σ_2 respectively.

We are given,

Band gap, ΔE= 0.650 eV

$$\sigma = \sigma_0 e^{\frac{-\Delta E}{2kT}}$$

$2\sigma_1 = \sigma_2$

- $2\sigma_0 e^{\frac{-\Delta E}{2kT_1}} = \sigma_0 e^{\frac{-\Delta E}{2kT_2}}$
- $2e^{\frac{-0.650}{2\times 8.62\times 10^{-5}\times 300}} = e^{\frac{-0.650}{2\times 8.62\times 10^{-5}\times T_2}}$
- $e^{-\frac{0.650}{2\times 8.63\times 10^{-5}\times T_2}} = 6.9656 \times 10^{-6}$

Taking natural log both sides,

$$\frac{-0.650}{2\times 8.68\times 10^{-5}\times T_2} = -11.874525$$

On solving, we get T_2=317.512K.

Answer.15

Originally the band gap was 1eV. After doping, the band gap will become =(1eV-1meV)

= (1-0.001) eV

=0.999 eV

It is given that the transition is almost forbidden at 1/50 of 0.999eV. Let the upper limit for temperature be T_1 over which the transition becomes a forbidden transition.

- kT_1=0.999/50
- T_1=231.78K≈231.8K

Let the lower limit for temperature be T_2 for which the transitions are most feasible or for which the upper levels have maximum population.

- kT_2=2(0.999)

- T_2=23.2K

Therefore, the required temperature range=(23.2K-231.8K)

Answer.16

Width of depletion region, d= 400 nm= 4×10^{-7} m

Electric Field, E= 5×10^{5} Vm^{-1}

(a) Let the height of potential barrier be V Volts.

We know that, $\text{Electric field} = \frac{\text{Potential}}{\text{Width of the Potential}}$

- E=V/d
- V=Ed
- V=$5\times10^{5}\times4\times10^{-7}$
- V=0.2 Volts

(b) The minimum kinetic energy required for diffusion of an electron from n-side to p-side

$K.E_{min}$= Potential barrier × Charge on an electron

= 0.2 V × 1.6 × 10^{-19} C

= 0.2 eV

Answer.17

Potential barrier across unbiased p-n junction = 0.2 Volts

Minimum kinetic energy required for diffusion of a hole from p-side to the n-side,

K.E.

$_{min}$ = (Potential barrier - biasing voltage) × Charge on hole

(a) Biasing Voltage=0V

$K.E._{min}$ = (0.2-0) × e

= 0.2eV

(b) Biasing Voltage for forward biased=+0.1V

$K.E._{min}$ = (0.2-0.1) × e

= 0.1eV

(c) Biasing Voltage for reverse biased=-0.1

$K.E._{min}$ = (0.2+0.1) × e

= 0.3eV

Answer.18

Potential barrier, d = 250 meV

Initially the kinetic energy of the hole = 300 meV

(a) When the hole approaches the junction from p-side, junction will act like forward biasing.

Therefore, the kinetic energy of the hole will decrease.

Final kinetic energy of the hole = (300-250) meV

= 50 meV

(b) When the hole approaches the junction from n-side, junction will act like reverse biasing.

Therefore, the kinetic energy of the hole in this case will increase.

Final kinetic energy of the hole = (300+250) meV

= 550 meV

Answer.19

It is given that drift current is 25 μA and biasing current is 75 μA at 200 mV forward biasing.

A. We know that when the diode is unbiased,

Diffusion current = drift current = 25μA

B. When the diode is reverse biased, diffusion current = 0

C. When the diode is forward biased at 200mV,

Diffusion current - Drift current = Forward biasing current

Diffusion current – 25 μA = 75 μA

Diffusion current = (75+25) μA

Diffusion current =100 μA

Answer.20

Drift current, I_d = 20μA

$$I_d = (N_e + N_h) \times e$$

Where, N_e= Number of electrons crossing a cross section per second

N_h= Number of holes crossing a cross section per second

e= magnitude of charge on an electron/hole = 1.6×10^{-19} C

Without any biasing applied on the junction, $N_e = N_h = N$

$I_d = 2N \times e$

$$N = \frac{I_d}{2e}$$

$$N = \frac{20 \times 10^{-6}}{2 \times 1.6 \times 10^{-19}}$$

$N = 6.25 \times 10^{13}$

Answer.21

The current voltage characteristic of ideal p-n junction diode is

$$i = i_0\left(e^{\frac{eV}{kT}} - 1\right)$$

(a) For large value of voltages, 1 can be neglected. So, the relation becomes

$$i = i_0 e^{\frac{eV}{kT}}$$

We need to find the value of V_0 for which $e^{ev/kT} = 100$

It is given that $T = 300K$, $i_0 = 10\mu A$ and $i = 100$

Taking natural log to both sides,

$$\ln 100 = \frac{1.6 \times 10^{-19} \times V_0}{8.62 \times 10^{-5} \times 300}$$

$$\frac{2.303}{e} \times \log_{10} 100 \times 8.62 \times 10^{-5} \times 300 = V_0$$

$V_0 = 0.12V$

(b) Dynamic Resistance of the diode, R= Rate of change of voltage with respect to current

- $R = \frac{dV}{di}$

We know, $i = i_0\left(e^{\frac{eV}{kT}} - 1\right)$

Differentiating both sides with respect to V,

- $di = \frac{i_0 e}{kT} e^{\frac{eV}{kT}} dV$
- $\frac{di}{dv} = \frac{i_0 e}{kT} e^{\frac{eV}{kT}}$
- $R = \frac{dV}{di} = \frac{kT}{i_0 e} e^{-\frac{eV}{kT}}$

(c) Given, R = 0.2Ω

- $R = \frac{dV}{di} = \frac{kT}{i_0 e} e^{-\frac{eV}{kT}}$
- $\ln R = \ln\frac{kT}{i_0 e} - \frac{eV}{kT}$
- $\frac{eV}{kT} = 2.303 \log_{10}\frac{kT}{i_0 eR}$
- $V = \frac{kT}{e} 2.303 \log_{10}\frac{kT}{i_0 eR}$

$k=8.62\times10^{-5}$

T=300K

i_0=10μA

R=0.2Ω

$e=1.6\times10^{-19}$ C

On substituting the values, we will get V=0.25 V

Answer.22

Given, i_0 =20 μA =20×10^{-6} A And temperature, T=300K

a) Forward biasing voltage, V=300mVAccording to the current diode equation,

- $i = i_0(e^{eV/KT} - 1)$
- $i = 20 \times 10^{-6} \times (e^{\frac{0.3e}{8.62\times10^{-5}\times300}} - 1)$
- $i = 2.18A = 2A$

b) Now the current has doubled, i.e. i = 4 A

According to the current diode equation,

- $i = i_0\ (e^{eV/kT} - 1)$
- $4 = 20 \times 10^{-6}\left(e^{eV/8.62\times300\times10^{-5}} - 1\right)$
- $e^{\frac{eV\times10^3}{8.62\times3}} - 1 = \frac{4\times10^6}{20}$
- $e^{\frac{eV\times10^3}{8.62\times3}} = 200001$

Taking log both sides,

- $\frac{eV\times10^3}{8.62\times3} = 12.2060$
- $V = 12.206 \times 8.63 \times 3 \times 10^{-3}$
- V= 318mV

Answer.23

From the given circuit diagram, we can see that the diode is reverse biased.

- Drift current = Diffusion current = 20 μA

∴ Current through the circuit =20 μA

Voltage drop across the 20Ω resistor = 20μA×20Ω

= 4×10^{-4} V

Voltage through the circuit= (Voltage from the source)–(Voltage drop across the 20Ω resistor)

=5-0.0004

=4.9996 V ≈5V

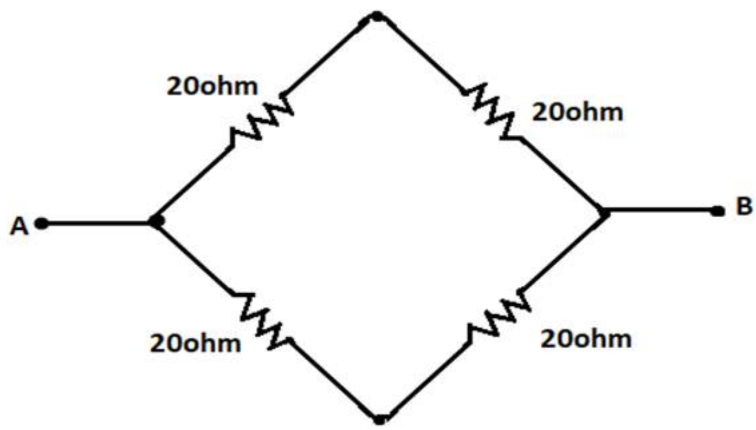
Answer.24

The given figure can also be made as:

which looks like a Wheatstone bridge. Hence, current through the middle arm = 0A

∴ Current through the diode = 0A.

Equivalent circuit diagram becomes:



∴ Net resistance $R = \frac{1}{\frac{1}{20+20}+\frac{1}{20+20}}$

- $R = \frac{\frac{1}{2}}{40}$
- R = 20ohm

Answer.25

(a) In fig1, both diodes D_1 and D_2 are forward biased. So, resistance due to diodes=0.Net resistance = 2ΩNet current = 2V/2Ω = 1A

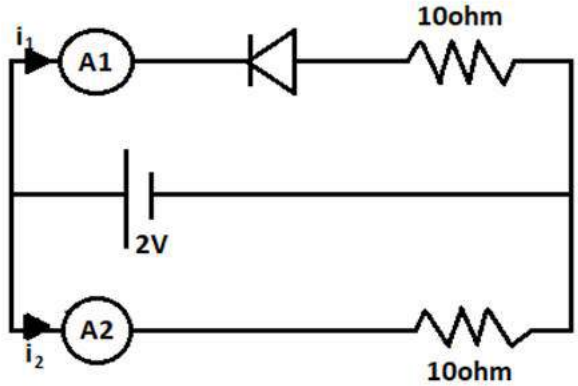
(b) In fig2, diode D_1 is forward biased and D_2 is reverse biased. So, no current will flow through this circuit because D_2 will offer infinite resistance.Net current = 0A

(c) In fig3, diode D_1 and D_2, both are forward biased, So, resistance due to diodes=0.Net resistance = 2ΩNet current = 2V/2Ω = 2A

(d) Diode D_1 is forward biased and D_2 is reverse biased. So current will flow through D_1 but not through D_2.Net resistance = 2ΩNet current = 2V/2Ω = 2A

Answer.26

Diode is in reverse bias.



Current i_1=0A as the diode is in reverse bias.

Current i_2 = 2V/10Ω = 0.2A

∴ Reading in A_1=0A and reading in A_2=0.2A

Answer.27

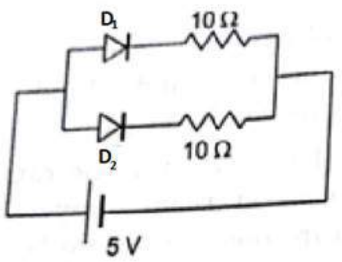


fig1

In fig1, both diodes D_1 and D_2 have forward biasing. Net diode resistance=0.Net resistance =(10×10)/(10+10) =5Ω∴ Current = 5V/Net resistance =5V/5Ω =1A

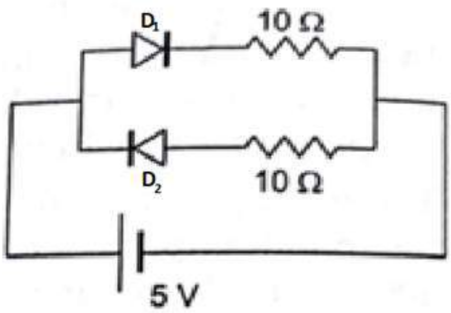
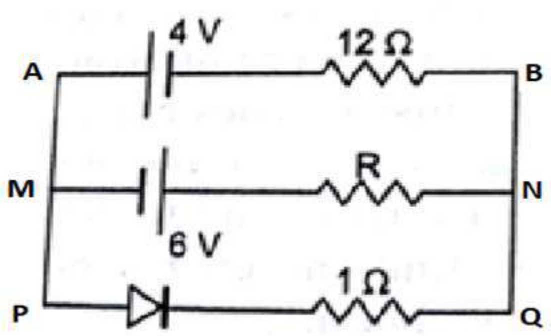


fig2

In fig2, diode D_1 has forward biasing and diode D_2 has reverse biasing. Hence, current will flow only through diode D_1.Net resistance =10+0 =10Ω∴ Current =5V/10Ω

Answer.28



Net potential difference across arm PQ is negative.

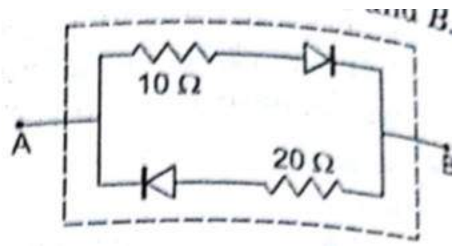
• The diode is reverse biased.

• No current flows through arm PQ

Net resistance = (R + 12) Ω

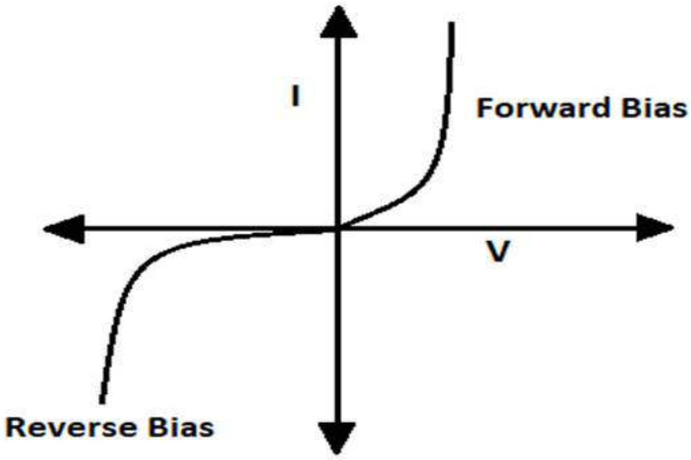
(a) R=12ΩNet resistance =12+12 =24ΩCurrent= (4V+6V)/24Ω = 0.42A

(b) R=48ΩNet resistance=48+12 = 60ΩCurrent= (4V+6V)/60Ω = 0.16A



Answer.29

In the first figure it is clear that the only one diode is present between A and B. The I-V characteristics will be:



In the second figure, the diode in the upper arm in series with the 10Ω resistor has p-side connected to A and n-side connected to B.Whereas, the other diode has exactly opposite polarities. When a potential difference is applied across terminals A and B, one of the diodes will become reverse biased and there will be no flow of current through that arm. ∴ I-V characteristics between terminals AB will be same as the previous figure.

Answer.30

Case 1: Potential at terminal A > Potential at terminal BThe diode will be forward biased and it can be replaced by short circuit.

Net resistance = $\frac{1}{\frac{1}{10}+\frac{1}{10}}$ = 10/2 = 5Ω

Case 2: Potential at terminal A < Potential at terminal BThe diode will be reverse biased and it can be replaced by open circuit.

Net resistance=10Ω

Answer.31

Current gain, β=Rate of change of collector current with respect to base current at constant output voltage

- $\beta = \frac{(3.5-1)\text{mA}}{(80-30)\mu\text{A}} = \frac{2.5\times\times10^{-3}}{50\times10^{-6}}$
- $\beta=0.05\times10^{3}$
- β=50

Answer.32

The current gain β=50

Input current in a common emitter mode is the base current. Change in base current or input current = $\delta I_b=50\mu A$

Output voltage, $V_0 = \beta\times R_G = 50\times20.5 = 200V$

(a) Voltage Gain, $V_G = V_0/V_1$

Input voltage, $V_1 = \delta l_b + R_i$

Input resistance, R_i = 0.5kΩ = 500Ω

$V_G = 200/(50\times10^{-6}+500)$

$V_G = 8000V$

(b) Change in input voltage, $\delta V_1 = \delta I_b \times R_i$

$= 50\times10^{-6}\times5\times10^2$

$=25\times10^{-3}$ V

=25 mV

(c) Resistance Gain, R_G= Load Resistance/Input resistance

$= R_L/R_i$

Power gain $=\beta^2\times R_G$

$=\beta^2\times R_{L/}R_i$

$=2500\times2/0.5=2500\times20.5=2500\times205=10^4$

Answer.33

$$X = A\overline{BC} + B\overline{CA} + C\overline{AB}$$

(a) A=1, B=0, C=1

$$X = 1\overline{(0 \times 1)} + 0\overline{(1 \times 1)} + 1\overline{(1 \times 1)}$$

X = 1×1+ 0×0 + 1×0

X=1

(b) A=B=C=1

$$X = 1\overline{(1 \times 1)} + 1\overline{(1 \times 1)} + 1\overline{(1 \times 1)}$$

X = 1×0 + 1×0 + 1×0

X=0

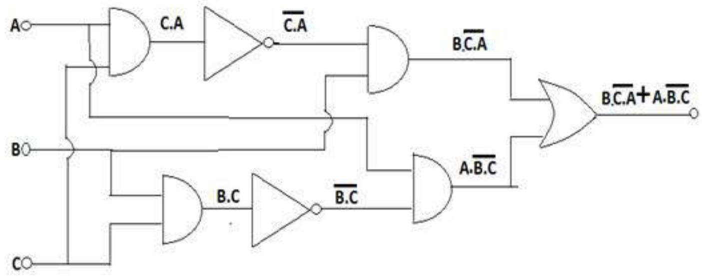
(c) A=B=C=0

$$X = 0\overline{(0 \times 0)} + 0\overline{(0 \times 0)} + 0\overline{(0 \times 0)}$$

X = 0×1 + 0×1 + 0×1

X=0

Answer.24



Answer.25

We will show this using a truth table.

A	**B**	**AB**	$\overline{AB}$	$AB+\overline{AB}$
0	0	0	1	1
0	1	0	1	1
1	0	0	1	1
1	1	1	0	1

Also, we can let AB=X

As we know,

$X+\overline{X}$ is always 1,

$AB+\overline{AB}$ will also always be 1