ESE 2020
PRELIMINARY EXAMINATION

ELECTRONICS & COMMUNICATION ENGINEERING

ESE TOPICWISE OBJECTIVE
SOLVED PAPER-I

Detailed Solution  Topicwise Description
Fully Revised & Updated

UPSC Engineering Service Examination 2020
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IES Master Publication
New Delhi
Note: Direction of all **Assertion Reasoning (A–R)** type of questions covered in this booklet is as follows:

**DIRECTIONS:**

The following four items consist of two statements, one labelled as ‘**Assertion A**’ and the other labelled as ‘**Reason R**’. You are to examine these two statements carefully and select the answer to these two statements carefully and select the answer to these items using the codes given below:

(a) Both A and R are individually true and R is the correct explanation of A

(b) Both A and R are individually true but R is not the correct explanation of A

(c) A is true but R is false

(d) A is false but R is true.

Note: Direction of all **Statement-I** and **Statement-II** type of questions covered in this booklet is as follows:

**DIRECTION:**

Following items consists of two statements, one labelled as ‘Statement (I)’ and the other as ‘Statement (II)’. You are to examine these two statements carefully and select the answers to these items using the code given below:

(a) Both Statement : (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I).

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I).

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true.
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SYLLABUS
Basics of semiconductors; Diode/Transistor basics and characteristics; Diodes for different uses; Junction & Field Effect Transistors (BJTs, JFETs, MOSFETs); Transistor amplifiers of different types, oscillators and other circuits; Basics of Integrated Circuits (ICs); Bipolar, MOS and CMOS ICs; Basics of linear ICs, operational amplifiers and their applications-linear/non-linear, Optical sources/detectors; Basics of Opto electronics and its applications.

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1. Silicon devices can be employed for a higher temperature limit (190 °C to 200 °C) as compared to germanium devices (85 °C to 100 °C). With respect to this, which of the following are incorrect?
   1. Higher resistivity of silicon
   2. Higher gap energy of silicon
   3. Lower intrinsic concentration of silicon
   4. Use of silicon devices in high-power applications

   Select the correct answer using the code given below:
   (a) 1, 2 and 4
   (b) 1, 2 and 3
   (c) 1, 3 and 4
   (d) 2, 3 and 4

2. A sample of germanium is made p-type by addition of indium at the rate of one indium atom for every \(2.5 \times 10^8\) germanium atoms. Given, \(n_i = 2.5 \times 10^{19} / \text{m}^3\) at 300 K and the number of germanium atoms per \(\text{m}^3 = 4.4 \times 10^{28}\). What is the value of \(n_p\)?

   (a) \(3.55 \times 10^{18}/\text{m}^3\)
   (b) \(3.76 \times 10^{19}/\text{m}^3\)
   (c) \(7.87 \times 10^{19}/\text{m}^3\)
   (d) \(9.94 \times 10^{19}/\text{m}^3\)

3. The electrical conductivity of pure semiconductor is:
   (a) Proportional to temperature
   (b) Increases exponentially with temperature
   (c) Decreases exponentially with temperature
   (d) Not altered with temperature.

4. Which one of the following statements is correct?
   (a) For insulators the band-gap is narrow as compared to semiconductors
   (b) For insulators the band-gap is relatively wide whereas for semiconductors it is narrow
   (c) The band-gap is narrow in width for both the insulators and conductors
   (d) The band-gap is equally wide for both conductors and semiconductors.

5. In an extrinsic semiconductor the conductivity significantly depends upon:
   (a) Majority charge carriers generated due to doping
   (b) Minority charge carriers generated due to thermal agitation
   (c) Majority charge carriers generated due to thermal agitation
   (d) Minority charge carriers generated due to impurity doping.

6. A Ge sample at room temperature has intrinsic carrier concentration, \(n_i = 1.5 \times 10^{13} \text{ cm}^{-3}\) and is uniformly doped with acceptor of \(3 \times 10^{16} \text{ cm}^{-3}\) and donor of \(2.5 \times 10^{15} \text{ cm}^{-3}\). Then, the minority charge carrier concentration is:

   (a) \(0.918 \times 10^{10} \text{ cm}^{-3}\)
   (b) \(0.818 \times 10^{10} \text{ cm}^{-3}\)
   (c) \(0.918 \times 10^{12} \text{ cm}^{-3}\)
   (d) \(0.818 \times 10^{12} \text{ cm}^{-3}\)

7. Assume that the values of mobility of holes and that of electrons in an intrinsic semiconductor are equal and the values of conductivity and intrinsic electron density are \(2.32 / \Omega \text{m}\) and \(2.5 \times 10^{19} / \text{m}^3\) respectively. Then, the mobility of electron/hole is approximately:

   (a) \(0.3 \text{ m}^2/\text{Vs}\)
   (b) \(0.5 \text{ m}^2/\text{Vs}\)
   (c) \(0.7 \text{ m}^2/\text{Vs}\)
   (d) \(0.9 \text{ m}^2/\text{Vs}\)

8. A silicon sample A is doped with \(10^{18} \text{ atom/cm}^3\) of Boron and another silicon sample B of identical dimensions is doped with \(10^{18} \text{ atom/cm}^3\) of Phosphorous. If the ratio of electron to hole mobility is 3, then the ratio of conductivity of the sample A to that of B is:

   (a) \(\frac{3}{2}\)
   (b) \(\frac{2}{3}\)
9. The Hall-coefficient of a specimen of doped semiconductor is $3.06 \times 10^{-4} \text{ m}^3\text{C}^{-1}$ and the resistivity of the specimen is $6.93 \times 10^{-3} \Omega\text{m}$. The majority carrier mobility will be:
   (a) $0.014 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$
   (b) $0.024 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$
   (c) $0.034 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$
   (d) $0.044 \text{ m}^2\text{V}^{-1}\text{s}^{-1}$

10. Doped silicon has Hall-coefficient of $3.68 \times 10^{-4} \text{ m}^3\text{C}^{-1}$ and then its carrier concentration value is:
   (a) $2.0 \times 10^{22} \text{ m}^{-3}$
   (b) $2.0 \times 10^{-22} \text{ m}^{-3}$
   (c) $0.2 \times 10^{22} \text{ m}^{-3}$
   (d) $0.2 \times 10^{-22} \text{ m}^{-3}$

11. The position of the intrinsic Fermi level of an undoped semiconductor ($E_{Fi}$) is given by:
   (a) $E_C - E_V + \frac{kT}{2} \ln \frac{N_V}{N_C}$
   (b) $E_C + E_V - \frac{kT}{2} \ln \frac{N_V}{N_C}$
   (c) $E_C + E_V + \frac{kT}{2} \ln \frac{N_V}{N_C}$
   (d) $E_C - E_V - \frac{kT}{2} \ln \frac{N_V}{N_C}$

12. The radius of the first Bohr orbit of electrons in hydrogen atom is 0.529 Å. What is the radius of the second Bohr orbit in singly ionized helium atom ?
   (a) 1.058 Å
   (b) 0.264 Å
   (c) 10.58 Å
   (d) 0.0264 Å

13. For which one of the following materials, is the Hall coefficient closest to zero ?
   (a) Metal
   (b) Insulator
   (c) Intrinsic semiconductor
   (d) Alloy

14. At temperature of 298 Kelvin, Silicon is not suitable for most electronic applications, due to small amount of conductivity. This can be altered by
   (a) Gettering
   (b) Doping
   (c) Squeezing
   (d) Sintering

15. The energy gap in the energy band structure of a material is 9 eV at room temperature. The material is
   (a) Semiconductor
   (b) Conductor
   (c) Metal
   (d) Insulator

16. By doping Germanium with Gallium, the types of semiconductors formed are :
   1. N type
   2. P type
   3. Intrinsic
   4. Extrinsic
   Which of the above are correct ?
   (a) 1 and 4
   (b) 2 and 4
   (c) 1 and 3
   (d) 2 and 3

17. An n-type of silicon can be formed by adding impurity of :
   1. Phosphorous
   2. Arsenic
   3. Boron
   4. Aluminium
   Which of the above are correct ?
   (a) 1 and 2
   (b) 2 and 3
   (c) 3 and 4
   (d) 1 and 4

18. According to Einstein’s relationship for a semiconductor, the ratio of diffusion constant to the mobility of the charge carriers is
   (a) Variable and is twice the volt equivalent of the temperature
   (b) Constant and is equal to the volt equivalent of the temperature
   (c) Equal to two and is twice the volt equivalent of the temperature
   (d) Equal to one and is equal to the volt equivalent of the temperature

19. The number of holes in an N-type silicon with intrinsic value $1.5 \times 10^{10}/\text{cm}^3$ and doping concentration of $10^{17}/\text{cm}^3$, by using mass-action law is
   (a) $6.67 \times 10^{6}/\text{cc}$
   (b) $4.44 \times 10^{-25}/\text{cc}$
   (c) $1.5 \times 10^{-24}/\text{cc}$
   (d) $2.25 \times 10^{3}/\text{cc}$

20. Statement (I): Hall voltage is given by $V_H = \frac{R_H I_H}{t}$ where I is the current, H is the magnetic field strength, t is the thickness of probe and $R_H$ is the Hall constant.
    Statement (II): Hall effect does not sense the carrier concentration.
EXPLANATIONS

Sol–1: (b)
When silicon devices can be employed for higher temperature limit (190°C to 200°C) when compared to germanium devices (85°C to 100°C) implies that silicon devices can be used in high-power applications as they support flow of high amounts of currents. That is statement 4 is true therefore statements 1, 2, 3 are incorrect as per options.

Sol–2: (a)
Given that
1 indium atom is doped for every \(2.5 \times 10^8\) Ge atom
intrinsic carrier concentration \(n_i = 2.5 \times 10^{19}/m\)
number of germanium atoms = \(4.4 \times 10^{28}\)
1 \(\rightarrow\) \(2.5 \times 10^8\)
? \(\rightarrow\) \(4.4 \times 10^{28}\)
Concentration of p-type impurities
\[
\frac{n_p}{n_i} = \frac{2.5 \times 10^{19}}{2.5 \times 10^8} = 1.76 \times 10^{20} \text{ atom}
\]
We know
\[
(N_A)(n_p) = n_i^2
\]
\[
(1.76 \times 10^{20})(n_p) = (2.5 \times 10^{19})^2
\]
\[
n_p = \frac{(2.5)^2 \times 10^{38}}{1.76 \times 10^{20}} = 3.551 \times 10^{18}/m^3
\]

Sol–3. (b)
- In a pure semiconductor the no of holes and electrons are equal and is given by
  \[
n = p = n_i
\]
  where \(n\) = no of electrons
  \(p\) = no of holes
  \(n_i\) = intrinsic carrier concentration
- If the temperature of semiconductor increases, the concentration of charge carriers (electrons and holes) is also increased. Hence the conductivity of a semiconductor is increased accordingly.

- The relation between temperature and concentration of charge carriers in pure semiconductor is given as
  \[
n_i^2 = A_0 T^3 e^{-E_g/kT}
\]
  where \(T\) is the temperature in Kelvin scale.

Sol–4. (b)
- For insulators, the energy band-gap is greater than 6 eV, whereas for semiconductors, the energy band gap is approximately equal to 1 eV.
- Thus, for insulators, the band-gap is relatively wide, whereas for semiconductors, it is narrow.

Sol–5. (a)
In an extrinsic semiconductor,

<table>
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<th>n-type</th>
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<td>Major carrier concentration</td>
<td>(p_p = N_A)</td>
<td>(n_n = N_D)</td>
</tr>
<tr>
<td>Minority carrier concentration</td>
<td>(n_p = n_i^2/N_A)</td>
<td>(p_p = n_i^2/N_n)</td>
</tr>
</tbody>
</table>

Conductivity
\[
\sigma_e = q(p_n + n_n)\mu_n
\]
\[
\sigma_h = q(p_p + n_p)\mu_p
\]
\[
\sigma_p = n_p/n_i \mu_n
\]
\[
\sigma_n = qN_A\mu_p
\]
Thus, conductivity of an extrinsic semiconductor significantly depends upon majority charge carrier, generated due to impurity doping.

Sol–6. (b)
Given,
\[
N_A = 3 \times 10^{16} \text{ / cm}^3
\]
and \(N_D = 2.5 \times 10^{15} \text{ / cm}^3\)
Since, \(N_A > N_D\), semiconductor is of p-type.
Majority carrier (hole) concentration,
\[
p_p = N_A - N_D
\]
\[
= 2.75 \times 10^{16} \text{ / cm}^3
\]
Minority carrier (electron) concentration,
\[
n_p = \frac{n_i^2}{p_p} = \frac{(1.5 \times 10^{13})^2}{2.75 \times 10^{16}} \text{ / cm}^3
\]
\[
= 0.818 \times 10^{10} \text{ / cm}^3
\]
Sol–7. (a) 
Given, $\mu_n = \mu_p$
\[\sigma_i = 2.32 / \Omega m\]
\[n_i = 2.5 \times 10^{19} / \text{cm}^3\]
Conductivity, $\sigma_i = n_i q \mu_n + p_i q \mu_p$
\[= 2 n_i q \mu_n\]
\[
\Rightarrow \mu_n = \frac{2.32}{2 \times 2.5 \times 10^{19} \times 1.6 \times 10^{-19}} \text{m}^2 / \text{V} - \text{s}
\]
\[= 0.29 \text{ m}^2 / \text{V} - \text{s}\]
\[
\therefore \mu_n = \mu_p = 0.29 \text{ m}^2 / \text{V} - \text{s} = 0.3 \text{ m}^2 / \text{V} - \text{s}
\]

Sol–8. (c) 
Given,
\[p_A = 10^{18} / \text{cm}^3 \text{ and } n_B = 10^{18} / \text{cm}^3\]
\[\frac{\mu_n}{\mu_p} = 3\]
Conductivity of sample A, $\sigma_A = p_A q \mu_p$
Conductivity of sample B, $\sigma_B = n_B q \mu_n$
Thus,
\[\frac{\sigma_A}{\sigma_B} = \frac{p_A q \mu_p}{n_B q \mu_n}\]
\[
\therefore \frac{\sigma_A}{\sigma_B} = \frac{1}{3}
\]

Sol–9. (d) 
Given,
\[R_H = 3.06 \times 10^{-4} \text{ m}^3 \text{C}^{-1}\]
and $\rho = 6.93 \times 10^{-3} \Omega \text{m}$
Resistivity, $\rho = \frac{1}{\sigma} = \frac{R_H}{\mu}$
\[
\therefore \mu = \frac{R_H}{\rho} = \frac{3.06 \times 10^{-4}}{6.93 \times 10^{-3}} = 0.044 \text{ m}^2 / \text{V} - \text{s}
\]

Sol–10. (a) 
Given,
\[R_H = 3.68 \times 10^{-4} \text{ m}^3 \text{C}^{-1}\]
Hall Coefficient, $R_H = \frac{1}{\rho_v} = \frac{1}{n q}$
\[
\Rightarrow n = \frac{1}{R_H q}
\]
\[
= \frac{1}{3.68 \times 10^{-4} \times 1.6 \times 10^{-19}}
\]
\[
\therefore n = 1.7 \times 10^{22} / \text{m}^3 = 2 \times 10^{22} / \text{m}^3
\]

Sol–11. (c) 
Intrinsic electron concentration, $n_i$
\[= N_C \exp \left( \frac{E_C - E_{Fi}}{kT} \right)\]
Intrinsic hole concentration, $p_i$
\[= N_V \exp \left( \frac{E_{Fi} - E_V}{kT} \right)\]
For an intrinsic Semiconductor,
\[
\Rightarrow N_C \exp \left( \frac{-E_C - E_{Fi}}{-kT} \right) = N_V \exp \left( \frac{-E_{Fi} - E_V}{kT} \right)
\]
\[
\therefore E_{Fi} = \frac{E_C + E_V}{2} + \frac{kT}{2} \ln \left( \frac{N_V}{N_C} \right)
\]

Sol–12. (a) 
Radius of Bohr’s orbit of Hydrogen and Hydrogen like species is calculated as
\[r = \frac{n^2 h^2}{4 \pi^2 m e^2} \times \frac{1}{Z},\]
where $n = \text{principal quantum number of orbit}$ and $Z = \text{Atomic number}$
For Hydrogen,
\[r_H = \frac{h^2}{4 \pi^2 m e^2} \times \frac{1^2}{1} = 0.529 \text{Å} \ldots(i)\]
For Singly ionized Helium (He$^+$) :
\[n = 2 \text{ (for second Bohr orbit)}\]
and \[Z = 2\]
\[r_{He^+} = \frac{h^2}{4 \pi^2 m e^2} \times \frac{2^2}{2} = 0.529 \times 2 \text{Å}\]
\[
(\therefore \text{from Eq. (i), } \frac{h^2}{4 \pi^2 m e^2} = 0.529)\]
\[= 1.058 \text{Å}.\]

Sol–13. (a) 
Hall coefficient,
\[R_H = \frac{1}{n q}\]
For metals, ‘$n$’ is very large. Hence $R_H \approx 0$.

Sol–14. (b) 
Doping is the process of adding impurity to an intrinsic (Pure) semiconductor to increase its conductivity. Doping introduces