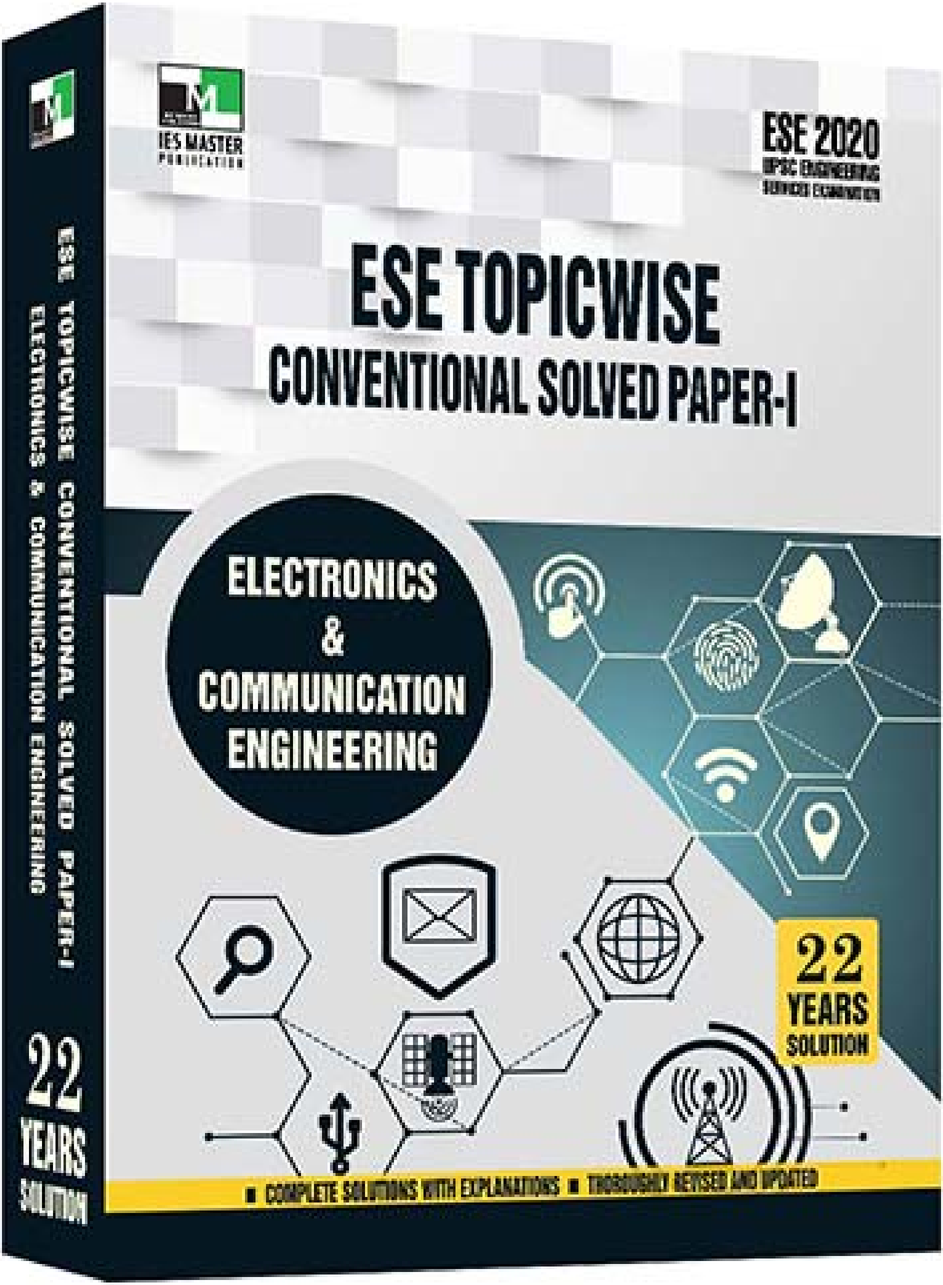
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PREFACE

Engineering Services Exam (ESE) is one of most coveted exams written by engineering students aspiring for reputed posts in the various departments of the Government of India. ESE is conducted by the Union Public Services Commission (UPSC), and therefore the standards to clear this exam too are very high. To clear the ESE, a candidate needs to clear three stages - ESE Prelims, ESE Mains and Personality Test.

It is not mere hard work that helps a student succeed in an examination like ESE that witnesses lakhs of aspirants competing neck to neck to move one step closer to their dream job. It is hard work along with smart work that allows an ESE aspirant to fulfil his dream.

After detailed interaction with students preparing for ESE, IES Master has come up with this book which is a one-stop solution for engineering students aspiring to crack this most prestigious engineering exam. The book includes previous years' solved conventional questions segregated subject-wise along with detailed explanation. This book will also help ESE aspirants get an idea about the pattern and weightage of questions asked in ESE.

IES Master feels immense pride in bringing out this book with utmost care to build upon the exam preparedness of a student up to the UPSC standards. The credit for flawless preparation of this book goes to the entire team of IES Master Publication. Teachers, students, and professional engineers are welcome to share their suggestions to make this book more valuable.

IES Master Publication
New Delhi

CONTENTS

UNIT 1

BASIC ELECTRONICS ENGINEERING

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.

CONTENTS

Chapter 1

Basics of Semiconductor

Q–1: Show that a semiconductor has minimum conductivity at a given temperature when n = $n_i\sqrt{{}_n/{}_e}$ & p = $n_i\sqrt{{}_e/{}_n}$ ***[8 Marks ESE–1998]***

Sol. The conductivity of a semiconductor is given as

$$\sigma = n\mu_n q + p\mu_p q = (n\mu_n + p\mu_p).q \quad \text{...(i)}$$

We know that at a given temperature, the product of concentration of electron and concentration of hole is equal to the square of intrinsic concentration at that temperature (Mass action law) i.e.

$$n.p. = n_i^2 \text{ or } n = \left(\frac{n_i^2}{p}\right) \quad \text{...(ii)}$$

Putting this value in equation (i), we get

$$\sigma = p\mu_p.q + \frac{n_i^2}{p}.\mu_n q$$

For maximum conductivity, $\frac{d\sigma}{dp} = 0$

or $$\frac{d}{dp}\left[p\mu_p q + \frac{n_i^2}{p}\mu_n q\right] = 0$$

or $$\mu_p q + q\mu_n.n_i^2\left(-\frac{1}{p^2}\right) = 0$$

or $$\mu_p = \mu_n\frac{n_i^2}{p^2}$$

or $$p^2 = \left(\frac{\mu_n}{\mu_p}\right)n_i^2$$

or $$p = n_i\sqrt{\frac{\mu_n}{\mu_p}}$$

as $$n = n_i^2/p$$

$$n = n_i\sqrt{\frac{\mu_p}{\mu_n}}$$

Q–2: Discuss "Hall Effect" in materials. ***[10 Marks ESE–2000]***

Or

Describe the Hall effect in a semiconductor bar. Derive the expression for the Hall voltage.

[15 Marks ESE–2009]

Or

Define Hall coefficient R_H. Obtain an expression for R_H in terms of Hall Voltage V_H.

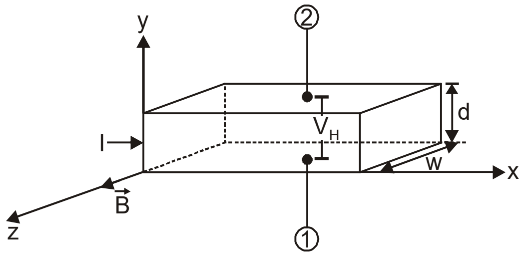
[20 Marks ESE–2000]

Or

When a current is passed through a semiconductor and a magnetic field is applied at right angles to the direction of the current flow, it is observed that an electric field is induced in a direction mutually perpendicular to the magnetic field and the flow of current. Name this phenomenon and calculate the voltage developed. [15 Marks ESE–2005]

Sol. **Hall effect :** If a specimen, carrying current I is placed in a transverse magnetic field $\vec{B}$, then an electric field $\vec{E}$ is induced in the direction perpendicular to both $\vec{I}$ and $\vec{B}$. It is applicable in case of metals and semiconductors. It can be used to determine whether specimen of semiconductor is of n-type or p-type.

The induced voltage V_H is given as



$$V_H = E.d. = B.v.d. = \frac{BI}{\rho w} \quad \text{...(i)}$$

where,
B = Magnetic field
I = Current
ρ = Charge density
w = Width of the specimen

and Hall coefficient R_H is given as

$$R_H = \frac{1}{\rho} = \frac{V_H.w}{BI} \quad \text{...(ii)}$$

The sign of the Hall voltage (V_H) determines whether positive or negative charge carriers are carrying the current.

In metals, the Hall voltages are generally negative, indicating that the electric current is composed of moving negative charges or electrons. The Hall voltage is positive, homever, for a few metals such as beryllium, zinc, and cadmium, indicating that these metals conduct electric currents by the movements of positively charged carriers called holes.

In semiconductors, in which the current consists of a movement of positive holes in one direction and electrons in the opposite direction, the sign of the Hall voltage shows which type of charge carrier predominates.

The Hall effect can also be used to measure the density of current carriers, their mobility, as well as to detect the presence of a current on a magnetic field.

Derivation for Hall voltage:

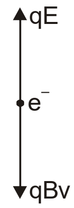
At equilibrium, the electric and magnetic forces applied on electron will balance each other.

$$\Sigma F = 0$$

$$qE = qBv_d$$

or $$E = B \cdot v_d \quad \ldots(i)$$

Now hall voltage is $$V_H = E.d = (B.v_d)d \quad \ldots(ii)$$



Now drift velocity is given as $$v_d = \frac{E}{B} = \frac{J}{\rho}$$

where, J = Current density

ρ = Charge density

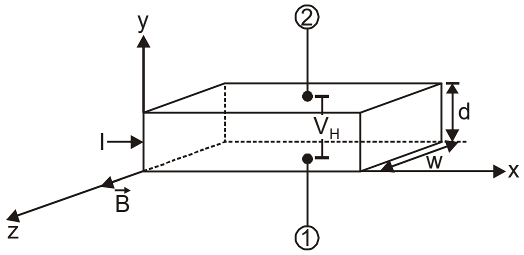
From equation (ii) $$V_H = B.V_d.d = \frac{B.J.d}{\rho} = \frac{B.d}{\rho}\left(\frac{I}{A}\right)$$

$$= \frac{B.d.I}{\rho.w.d} = \frac{B.I}{\rho.w} \text{ or } V_H = \frac{B.I.}{\rho w}$$

This is the required expression for Hall voltage.

Q–3: ***Explain how this phenomenon can be used to determine whether a semiconductor is 'n' type or 'p' type.*** ***[10 Marks ESE–2000]***

Sol. **Case-I :** If the given specimen is of n-type semiconductor then the current is carried by electrons. These electrons will accumulate on face-(1) and hence face-(1) will become negatively charged with respect to face-(2). Hence Hall voltage will be (+)ve.



Case-II : If the given specimen is of p-type semiconductor, then event will be carried by holes. Hence in this case face-(1) will become positively charged with respect to face-(2). Hence Hall voltage V_H will be (–)ve.

Hence V_H = +ve, for n-type semiconductor

= –ve, for p-type semiconductor

Q–4: ***In intrinsic silicon, the Fermi level lies near the middle of the bandgap. How does the Fermi level move when it is doped with (i) phosphorus, and (ii) boron atoms? Can the Fermi level be pushed up into the conduction band? If yes, explain how, If not, explain, why.*** ***[15 Marks ESE–2001]***

Sol.

(i) **When intrinsic silicon is doped with phosphorous :** Phosphorous is a donor type impurity when it is added to the crystal, then first N_D states in the conduction band will be filled by free electrons of phosphorous. Hence it will be more difficult for electron from valance band to cross the band gap by thermal agitation. Hence the number of electron-hole pair thermally generated for that temperature will be reduced and since fermi layer is a measure of probability of occupancy of allowed energy states, it is clear that fermi-level (E_F) must move closer to conduction band, to indicate that many of the energy states in the band are filled by donor electrons and fewer holes exist in valance band.

(ii) **When intrisic silicon is doped with boron :** Boron is a p-type material. The same type of explanation as above can be given to prove that E_F moves closer to valance band for p-type material.

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