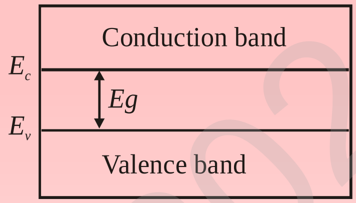
CHAPTER 14

SEMICONDUCTOR ELECTRONICS

- Semiconductors have a unique property that their conductivity increases with rise in temperature.

E_v is the top most energy of the valence band and E_c is the bottom most energy of the conduction band then $E_g = E_c - E_v$ represents forbidden energy gap.



In semiconductor $E_g = 1eV$. At room temperature it is about 1–2% filled.

At 0 Kelvin temperature semiconductor is a perfect insulator.

$E_g(\text{for } Ge) = 0.71\text{eV}$, $E_g(\text{for } Si) = 1.12\text{eV}$.

In insulators $E_g = 6\text{eV}$, for example Diamond has $E_g = 6.3\text{eV}$.

❖ **Semiconductors are of two types**

(a) Intrinsic: No impurity from 3rd or 5th group of the periodic table has been added. So that the density of electrons in conduction band is equal to the density of hole in valence band *i.e.*, $n_e = n_h$.

(b) Extrinsic: These are of two types

(i) *p*-type: Here majority carriers are holes $\therefore n_h > n_e$. Third group impurity (B, Al, Ga, In) is added here.

(ii) *n*-type: Here majority carriers are electrons $\therefore n_h < n_e$. Fifth group impurity (P, As, Bi, Sb) is added here.

At equilibrium $n_e n_h = n_i^2$.

Example 1: **Pure Si at 300 K has equal concentration of free electrons (n_e) and holes (n_h) as 2.8 × 10^{16} m^{-3}. Doping by trivalent impurity increases hole concentration to 5.0 × 10^{22} m^{-3}. Calculate n_e in doped silicon.**

Solution: Here $n_i = 2.5\times10^{16}\,\text{m}^{-3}, n_h = 5.0\times10^{22}\,\text{m}^{-3}$.

Using, $n_e = \dfrac{n_i^2}{n_h} = \dfrac{(2.8\times10^{16})^2}{5.0\times10^{22}} = 1.57\times10^{10}\,\text{m}^{-3}$.

Example 3: **A semiconductor is known to have an electron concentration of $8\times10^{13}\,\text{cm}^{-3}$ and a hole concentration of $5\times10^{12}\,\text{cm}^{-3}$ (a) is the semiconductor n-type or p-type? (b) what is the resistivity of the sample, if the electron mobility is 23,000 $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ and hole mobility is $100\,\text{cm}^2\text{V}^{-1}\text{s}^{-1}$? Take charge on electron, $e=1.6\times10^{-19}\,\text{C}$**

Solution: Here, $n_e = 8\times10^{13}\,\text{m}^{-3} = 18\times10^{19}\,\text{m}^{-3}$

$$n_h = 5\times10^{12}\,\text{cm}^{-3} = 5\times10^{18}\,\text{m}^{-2}$$

$$\mu_c = 23{,}000\,\text{cm}^3\text{V}^{-1}\text{s}^{-1} = 2.3\,\text{m}^2\text{V}^{-1}\text{s}^{-1}$$

$$\mu_h = 100\,\text{cm}^2\,\text{V}^{-1}\,\text{s}^{-1} = 0.01\,\text{m}^2\text{V}^{-1}\text{s}^{-1}$$

(a) Since the semiconductor has greater electron concentration, it is n-type semiconductor.

(b) Now, $\dfrac{1}{\rho} = e(n_e\mu_e + n_h\mu_h) \;= 1.6\times10^{-19}(8\times10^{19}\times2.3 + 5\times10^{18}\times0.01)$

$$= 1.6\times10^{-19}(1.84\times10^{20} + 5\times10^{16}) \approx 29.45\ \text{mho m}^{-1}$$

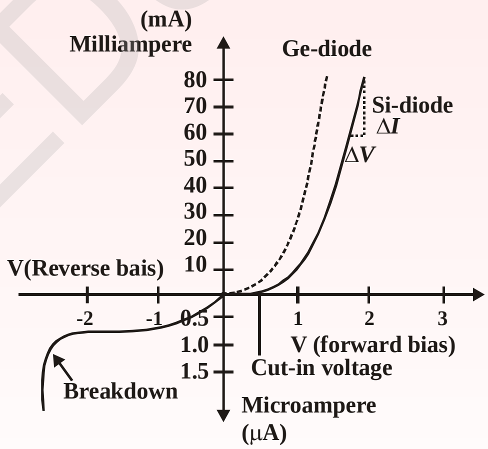
or $\quad \rho = \dfrac{1}{29.45} = 3.396\times10^{-2}\,\Omega\text{m}$

P-N Junction Diode

- When p and n type semiconductors of same material either both Si or both Ge are joined to form a homo junction, called p-n junction.
- During forward biasing potential barrier reduces hence decreases the width of depletion layer. During reversed biasing potential barrier increases hence increases the width of depletion layer

$$I = I_s[e^{V/V_T} - 1]$$

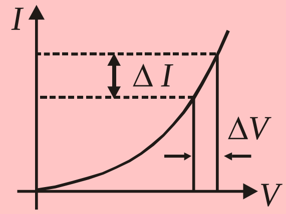
where $I_s \to$ reverse saturation current
$V \to$ applied potential
$V_T \to$ thermal voltage.



$V_T = \dfrac{kT}{e} = 0.026\text{V}$ at 300K.

$k \to$ Boltzmann's constant
T is the temperature of an electron and e is the charge

❖ **Dynamic or incremental resistance**



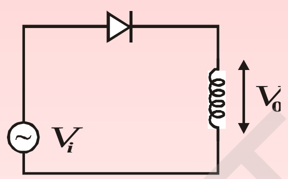
$$r = \frac{\Delta V}{\Delta I} = \frac{dV}{dI}$$

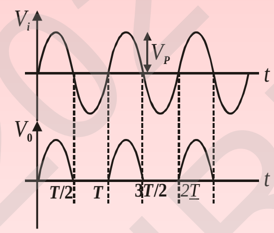
$$\frac{dI}{dV} = \frac{I_s}{V_T} e^{V/V_t} = \frac{I}{V_T}$$

Rectifier

➢ It is a circuit, which converts AC to unidirectional pulsating output. (AC to DC).

(i) Half wave rectifier:





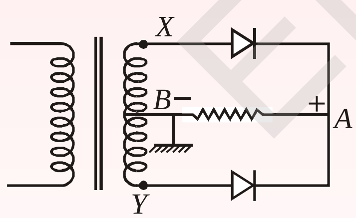
$$V_0(\text{DC}) = \frac{V_P}{\pi}, V_0(\text{rms}) = \frac{V_P}{2}$$

$$\text{Ripple factor } = \frac{V_{AC}}{V_{DC}} = \sqrt{\left(\frac{V_{\mathbf{rms}}}{V_{DC}}\right)^2 - 1} = 1.21$$

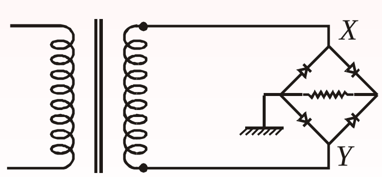
$$\text{Rectification of efficiency } (\eta) = \frac{P_{DC}}{P_{\mathbf{rms}}} \times 100 = 40.6\%$$

$f(\text{output}) = f(\text{input})$. (f is frequency)

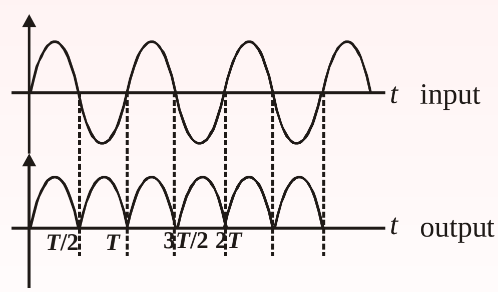
(ii) Full wave rectifier:



or



Bridge Rectifier



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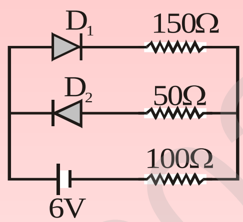
$$V_0(DC) = \frac{2V_p}{\pi}, V_0(\text{rms}) = \frac{V_p}{\sqrt{2}}.$$

Ripple factor = 0.48

Rectification efficiency $\eta = \frac{P_{DC}}{P_{\text{rms}}} \times 100 = 81.2\%$

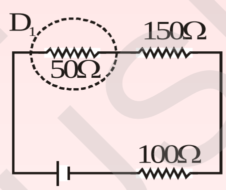
f (output) = $2f_{\text{input}}$.

Example 4: **The circuit shown in the figure contains two diodes each with a forward resistance of 50 ohm and with infinite reverse resistance. If the battery voltage is 6V, find the current through the 100-ohm resistance.**

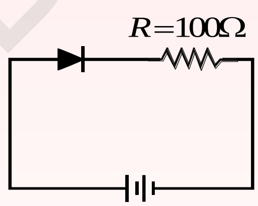


Solution: As per given circuit, diode D_1 is forward biased and offer a resistance of 50 ohm. Diode D_2 is reverse biased as a its corresponding resistance in infinite, no current flows through it. Thus, the equivalent circuit is as shown in the figure. As all the three resistances are series, the current through them is

$$I = \frac{6}{50+150+100} = \frac{6}{300} = 0.02\text{A}$$



Example 5: **Figure shows a junction diode connected to an external resistance of 100Ω and a source of emf 3.0 V. Assuming that the barrier potential developed in the junction diode is 0.7 V obtain the current in the circuit.**



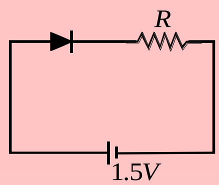
Solution: Here emf of source $E = 3.0V$

Barrier potential developed in the diode, $V_d = 0.7V$

Therefore, potential drop across external resistance, $V = E - V_d = 3.0 - 0.7 = 2.3V$

Hence, current in the circuit $I = \frac{V}{R} = \frac{2.3}{100} = 2.3 \times 10^{-2}\,A = 23\,mA$

Example 6: **A diode used in the circuit shown in the figure has a constant voltage drop of 0.5V at all currents and a maximum power rating of 100 MW. What should be the value of the resistance R connected in series with diode for obtaining maximum current?**



Solution: Here, emf of source $E = 1.5V$

Voltage drops across diode, $V_d = 0.1V$

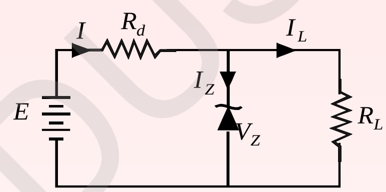
Maximum power rating of diode, $P = 100mW = 0.1W$

Therefore, maximum current through the diode, $I = \frac{P}{V_d} = \frac{0.1}{0.5} = 0.2A$

Potential drop across resistance R, $V = E - V_d = 1.5 - 0.5 = 1.0V$

$$R = \frac{V}{I} = \frac{1.0}{0.2} = 5\Omega$$

Example 7: **In the circuit shown in the figure, a Zener diode of voltage $V_Z (= 6V)$ is used to maintain a constant voltage across a load resistance $R_L (= 1000\Omega)$ by using a series resistance $R (= 100\Omega)$. If the emf of source (E) is 9V, calculate the value of current through series resistance, Zener diode and load resistance. What is the power being dissipated in Zener diode?**



Solution: Here, $E = 9V$; $V_Z = 6V$; $R_L = 1000\Omega$ and $R_d = 100\Omega$

Potential drop across series resistor $V = E - V_Z = 9 - 6 = 3V$

Therefore, current through series resistance R, $I = \frac{V}{R} = \frac{3}{100} = 0.03A$

Current through load resistance R_L, $I_L = \frac{V_Z}{R_L} = \frac{6}{1000} = 0.006\,A$

Therefore, current through Zener diode, $I_Z = I - I_L = 0.03 - 0.006 = 0.024A$

Power dissipated in Zener diode, $P_Z = V_Z I_Z = 6 \times 0.024 = 0.144$ W.

Example 8: **A junction diode of negligible forward resistance is used as a half-wave rectifier. A sinusoidal voltage supply having peak value 50V is fed to the junction diode and output is obtained across the load resistance R_L. Calculate (a) the rms voltage across R_L and (b) reading of a dc voltmeter connected across R_L.**

Solution: (a) Here, $E_o = 50V$; $E_{rms} = \frac{50}{\sqrt{2}}V$

A half wave rectifier gives output corresponding to alternate half cycles of the ac input. Since junction diode is of negligible forward resistance, the rms value of voltage across R_L during half cycle of conduction is $50/\sqrt{2}V$. Therefore, rms value of voltage for a complete cycle (including the non-conducting half cycle) is

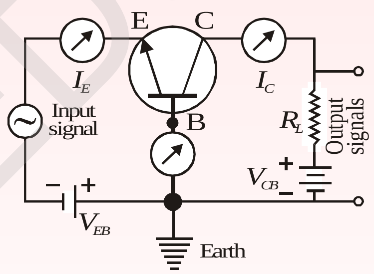
$$V_{rms} = \sqrt{\frac{(50/\sqrt{2})^2 + (0)^2}{2}} = \sqrt{\frac{1250+0}{2}} = \sqrt{625} = 25$$

(b) The dc voltmeter connected across R_L would read the average value of voltage across R_L during complete cycle. Therefore, reading of dc voltmeter connected across R_L

$$V_{dc} = \frac{2E_o/\pi + 0}{2} = \frac{E_o}{\pi} = \frac{50}{\pi} = 15.92V$$

Common Base Amplifier

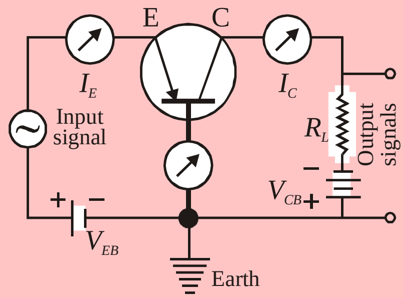
- Input signals are fed into emitter-base circuit. Output signals are taken from collector-base circuit. High load resistance (R_L) is connected between collector and base. Input circuit is forward biased while the output circuit is reverse biased. Hence input circuit may be considered as a low resistance circuit and the output circuit may be considered as a high resistance circuit. So, the introduction of a high resistance R_L in the output circuit is not going to affect the characteristics of the transistor. This property, however, enables us to amplify.



Common base amplifier (*npn*)

The connections for a *pnp* common base amplifier are exactly as above except that the polarities of the batteries are reversed and the transistor used in a *pnp* transistor in place of *npn* transistor.

Due to the imposition of signal, voltage of emitter base circuit undergoes a variation which in turn results in collector current, I_C. Since R_L is very high, variation in I_C produces a large variation in voltage across it, thus amplifying the input signal.



Common base amplifier (*pnp*)

❖ The *ac* Voltage Gain (A_V):

Let δI_E = incremental change in I_E $\quad$ δI_C = incremental change in I_C

E_i = input voltage $\quad$ R_i = input resistance

R_L = load resistance $\quad$ E_0 = output voltage

$\therefore$ $E_i = R_i \times \delta I_E$ …(i)

$E_0 = R_L \times \delta I_C$ …(ii)

$$\therefore \text{ voltage gain } = \frac{E_0}{E_i} = \frac{R_L \delta I_C}{R_i \delta I_E} = \alpha_{ac} \times \frac{R_L}{R_i}\left[\because \frac{\delta I_C}{\delta I_E} = \alpha\right]$$

$\boxed{\text{Voltage gain} = \alpha_{ac} \times \text{Resistance gain}}$.

❖ The *ac* Gain (α_{ac}):

As written above, ratio of change in collector current (δI_C) and change in emitter current. (δI_E) at constant collector voltage (V_C) is called current gain.

Current gain $= \dfrac{\delta I_C}{\delta I_E}$, at constant V_C.

Note: *dc* current gain α was simply (I_C/I_E) i.e. without δ_S.

Power Gain:

Power output = $E_0 \times \delta I_C$

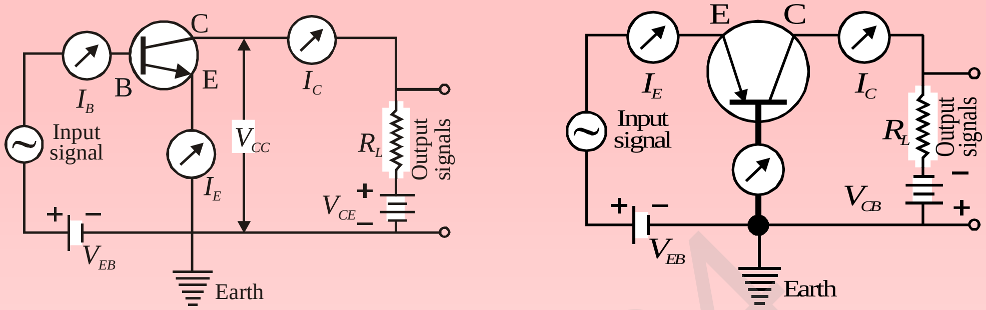
Power input = $E_i \times \delta I_E$

$$\therefore \text{ Power gain } = \frac{E_0 \times \delta I_C}{E_i \times \delta I_E} = \frac{(R_L \times \delta I_C) \times \delta I_C}{(R_i \times \delta I_E) \times \delta I_E} = \left(\frac{\delta I_C}{\delta I_E}\right)^2 \times \frac{R_L}{R_i}.$$

$\boxed{\text{Power gain} = \alpha_{ac}^2 \times \text{Resistance gain}}$.

Common Emitter Amplifier

➢ Common emitter amplifier is used as a voltage amplifier. The connections for a *pnp* common emitter amplifier are exactly the same except the polarities of the batteries are reversed.



Common emitter amplifier (*npn*)
(a)

Common base amplifier (*pnp*)
(b)

Take special notices that the phase difference between input and output signals is 180°.

The input signal (to be amplified) is connected in the emitter base circuit and output signal is taken from the collector-emitter circuit. Imposition of signal results in the variation of base current I_B and hence a variation in I_C. This produces a large variation in the voltage across R_L thus causing amplification.

❖ **Current Gains β and β_{ac}:**

Current gain is also called common-emitter amplification factor. It can be either *dc* gain (β) or *ac* gain (β_{ac})

❖ **The *dc* Gain (β):**

It is defined as the ratio of the collector current (I_C) and the base current (I_B)

$$\therefore \quad \beta = \frac{I_C}{I_B} = \frac{I_C}{I_E - I_C} = \frac{I_C / I_E}{1 - I_C / I_E} = \frac{\alpha}{1-\alpha} \quad [\because \alpha = I_C / I_E]$$

While α is always less than 1 (generally 0.98 or less), then value of β is always higher than 1.

If $\quad \alpha = 0.9, \beta = \frac{0.9}{1-0.9} = \frac{0.9}{0.1} = 9$

If $\quad \alpha = 0.95, \beta = \frac{0.95}{1-0.95} = 19$

If $\quad \alpha = 0.98, \beta = \frac{0.98}{1-0.98} = 49$

Hence, slight variation in α cause large variation in β.

- **The *ac* Gain (β_{ac}):**

It is defined as the ratio of the change in the collector current (δI_C) and the change in the base current (δI_B) at constant collector voltage

$$\therefore \quad \boxed{\beta_{ac} = \frac{\delta I_C}{\delta I_B}, \text{ at constant } V_C}$$

Its value lies between 15 and 50 generally for a transistor.

- **Voltage Gain:**

Voltage input = $\delta I_B \times R_i$ *Voltage* output = $\delta I_C \times R_L$

$$\therefore \quad \text{Voltage Gain } = \frac{\delta I_C \times R_L}{\delta I_B \times R_i}$$

$$\boxed{\text{Voltage gain} = \beta_{ac} \times \text{Resistance gain}}.$$

- **Power gain:**

Power output = $E_0 \times \delta I_C$

Power input = $E_i \times \delta I_B$

$$\therefore \quad \text{Power gain } = \frac{E_0 \times \delta I_C}{E_i \times \delta I_B} = \frac{(R_L \times \delta I_C) \times \delta I_C}{(R_i \times \delta I_B) \times \delta I_B} = \left(\frac{\delta I}{\delta I_B}\right)^2 \times \frac{R_L}{R_i}$$

$$\boxed{\text{Power gain} = \beta_{ac}^2 \times \text{Resistance gain}}.$$

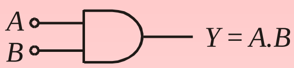
- **Amplifier is a circuit which gives power gain**

SL	Property	CB amplifier	CE amplifier	CC amplifier
1.	Input Impedance	Low	Medium	High
2.	Output impedance	High	High	Low
3.	Current gain (A_i)	$A_i = \alpha < 1$	$A_i = \beta > 1$	$A_i = (\beta + 1) > 1$
4.	Voltage gain (A_v)	$A_v = \alpha \frac{R_L}{R_i} > 1$ $= A_i \frac{R_L}{r_e} > 1$	$A_v = \beta \frac{R_L}{R_i} > 1$ $= A_i \frac{R_L}{r_b} > 1$	$A_v = (\beta + 1) \frac{R_L}{R_i} < 1$ $= A_i \frac{R_L}{r_b} < 1$
5.	Power gain (A_p)	$A_p = A_v A_i$ $= \frac{\alpha^2 R_L}{r_e} > 1$	$A_p = \beta^2 \frac{R_L}{r_b} > 1$	$A_p = (\beta + 1)^2 \frac{R_L}{r_b} > 1$

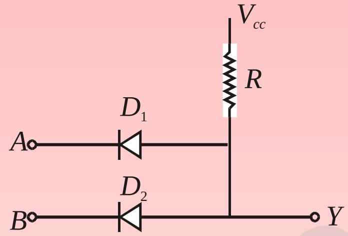
Logic Gates

➤ Logic is of two type positive logic and negative logic.
In positive logic high state (+ 5V) is assigned '1' and low state (0V) is assigned '0'. In negative logic low state is assigned '1' and high state is assigned 0.

(a) AND gate:



(Symbol)

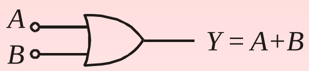


(Circuit)

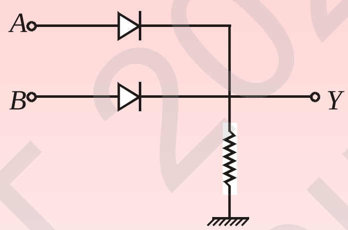
A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

(Truth table)

(b) OR gate:



(Symbol)

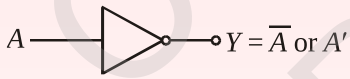


(Circuit)

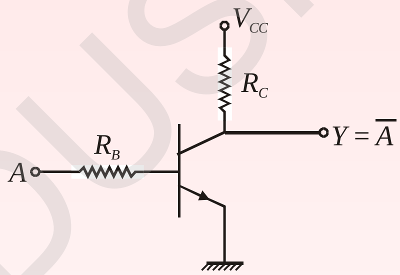
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

(Truth table)

(c) NOT gate or Invertor:



(Symbol)

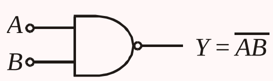


(Circuit)

A	Y
0	1
1	0

(Truth table)

(d) NAND gate:

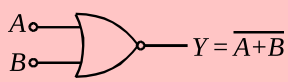


(Symbol)

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

(Truth table)

e) NOR gate:

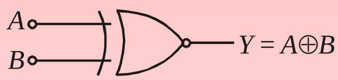


(Symbol)

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

(Truth table)

(f) XOR (exclusive OR):

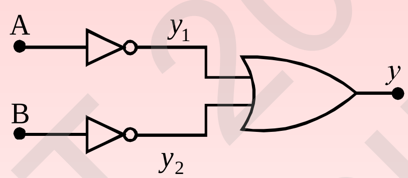


(Symbol)

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

(Truth table)

Example 12: **Express by a truth table, the output y for all possible inputs A and B for the combination of gates shown in figure. Hence, show that it behaves as a NAND gate.**



Solution: Here, outputs y_1 and y_2 of two NOT gates form the two inputs of the OR gate. Let us consider in turn the possibilities for A, B of 0, 0 then 0, 1 then 1, 0 and finally 1, 1. Because of the Not gates, the column y, contains ones, wherever $A=0$ and zeroes, where $A=1$. Similarly, y_2 is opposite to B. The output y of OR gate is 1, if y_1 or y_2 is 1 or both are 1. Hence, the truth table for the given combination of gates is as shown in figure.

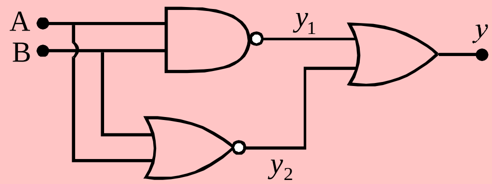
A	B	y_1	y_2	y
0	0	1	1	1
1	0	0	1	1
0	1	1	0	1
1	1	0	0	0

$\equiv$

A	B	y
0	0	1
1	0	1
0	1	1
1	1	0

From the completed table showing the relationship between output y and the inputs A and B, it follows that it is the truth table for a single NAND gate. Hence, the combination of gates shown in figure behaves as NAND gate.

Example 13: **Produce the truth table for the combination of gates shown in figure.**



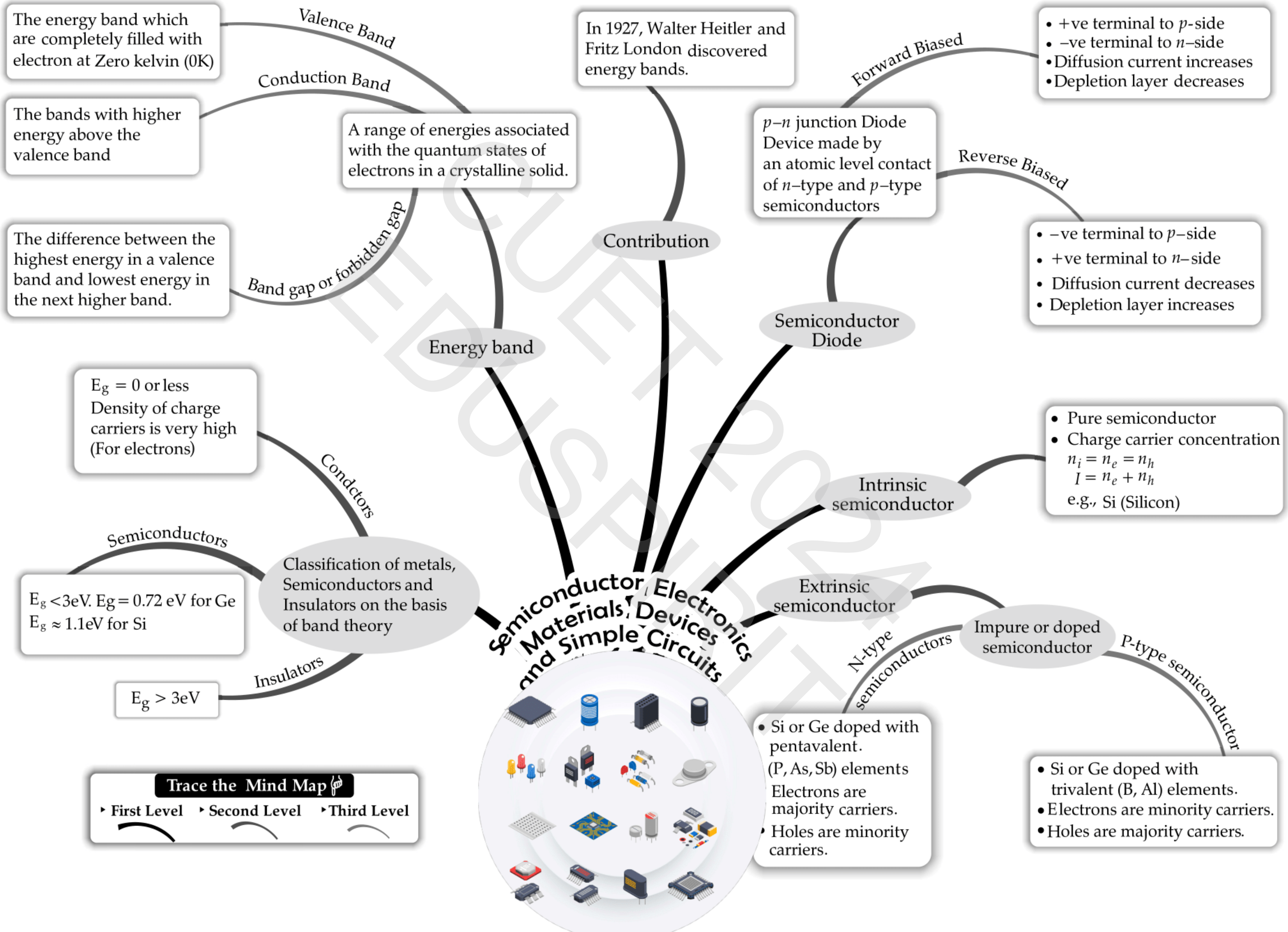
Solution: Here, the outputs y_1 and y_2 of AND and NOR gates respectively form the two inputs of another NOR gate. Because of NAND gate, the column y_1 contains 1, when both A and B are1 and the column y_2 contains 1, when both A and B are zero. Hence, the truth table for the given combination of gates is as shown in figure.

A	B	y_1	y_2	y
0	0	1	1	1
1	0	1	0	1
0	1	1	0	1
1	1	0	0	0

≡

A	B	y
0	0	1
1	0	1
0	1	1
1	1	0

From the completed table showing the relationship between output y and the inputs A and B.

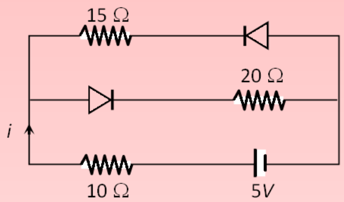

Semiconductor Electronics Materials, Devices and Simple Circuits
Energy band
A range of energies associated with the quantum states of electrons in a crystalline solid.
Valence Band
The energy band which are completely filled with electron at Zero kelvin (0K)
Conduction Band
The bands with higher energy above the valence band
Band gap or forbidden gap
The difference between the highest energy in a valence band and lowest energy in the next higher band.
Contribution
In 1927, Walter Heitler and Fritz London discovered energy bands.
Semiconductor Diode
p–n junction Diode Device made by an atomic level contact of n–type and p–type semiconductors
Forward Biased
• +ve terminal to p-side
• –ve terminal to n–side
• Diffusion current increases
• Depletion layer decreases
Reverse Biased
• –ve terminal to p–side
• +ve terminal to n–side
• Diffusion current decreases
• Depletion layer increases
Intrinsic semiconductor
• Pure semiconductor
• Charge carrier concentration
$n_i = n_e = n_h$
$I = n_e + n_h$
e.g., Si (Silicon)
Extrinsic semiconductor
Impure or doped semiconductor
N-type semiconductors
• Si or Ge doped with pentavalent.
(P, As, Sb) elements
Electrons are majority carriers.
• Holes are minority carriers.
P-type semiconductor
• Si or Ge doped with trivalent (B, Al) elements.
• Electrons are minority carriers.
• Holes are majority carriers.
Classification of metals, Semiconductors and Insulators on the basis of band theory
Condctors
E_g = 0 or less
Density of charge carriers is very high (For electrons)
Semiconductors
E_g <3eV. Eg = 0.72 eV for Ge
E_g ≈ 1.1eV for Si
Insulators
E_g > 3eV
Trace the Mind Map
First Level
Second Level
Third Level

PRACTICE QUESTIONS

1.In a common-emitter amplifier, the load resistance of the output circuit is 1200 times the resistance of the input circuit. If $\alpha = 0.98$, then voltage gain is

a) 4.8×10^3 b) 2.4×10^2 c) 1.5×10^2 d) 4.8

2. Current in the circuit will be

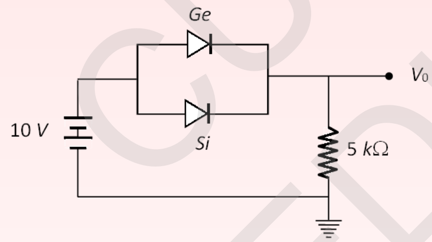


a) $\frac{5}{10}$ A b) $\frac{5}{55}$ A c) $\frac{5}{15}$ A d) $\frac{5}{20}$ A

3. What would be the behaviour of a germanium sample after adding traces of gallium as an impurity?

a) A conductor
b) A P-type semiconductor
c) An N-type semiconductor
d) An insulator

4. If the connection of the Ge diode is reversed in the given circuit, which initially had Ge and Si diodes conducting at 0.3 V and 0.7 V, respectively, how will this reversal affect the value of V_0 in the figure?



a) 0.2 V b) 0.4 V c) 0.6 V d) 0.8 V

5. The grid voltage of any triode valve is changed from -2 volt to -3 volt and the mutual conductance is 5×10^{-4} mho. The change in plate circuit current will be

a) 0.8 mA b) 0.6 mA c) 0.5 mA d) 1 mA

6. Approximately, what is the minimum potential difference between the base and emitter needed to turn on a silicon transistor?

a) 1 V b) 3 V c) 5 V d) 4.2 V

7. When testing a functioning transistor with labelled legs A, B, and C using a multimeter, there is no conduction observed between legs A and B. However, connecting the common (negative) terminal of the multimeter to leg C and the other (positive) terminal to either leg A or leg B shows some resistance on the multimeter. Based on this information, what can be deduced about the behaviour or characteristics of the transistor?

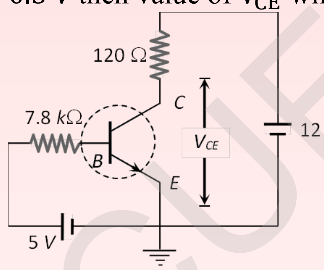
a) It is an n-p-n transistor with C as base
b) It is an p-n-p transistor with C as collector
c) It is an p-n-p transistor with C as emitter
d) It is an n-p-n transistor with C as collector

8. A gate has the following truth table

A	1	1	0	0
B	1	0	1	0
C	1	0	0	0

The gate is
a) NOR b) OR c) NAND d) AND

9. For the transistor circuit shown below, if $\beta = 100$, voltage drop between emitter and base is 0.5 V then value of V_{CE} will be



a) 2.4 V b) 5 V c) 4.8 V d) 0 V

10. With a semiconductor material having a band gap of 2.5 eV, what is the wavelength of the signal that can be detected by the p-n photodiode fabricated from this material?

a) 6000 Å b) 4000 nm c) 6000 nm d) 4000 Å

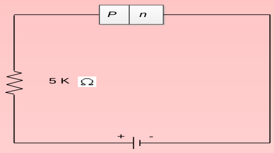
11. Given a Zener diode with a contact potential of 2 V when unbiased, it experiences Zener breakdown when the electric field at the depletion region of its p-n junction reaches 10^5 V/m. If the width of the depletion region is 3 μm, what magnitude of reverse bias voltage should be applied to the Zener diode to trigger the Zener breakdown?

a) 4 V b) 6 V c) 1 V d) 5 V

12. The current gain α of a transistor is 0.5. The transistor is connected to common base configuration. What would be the change in collector current when base current changes by 2.5 mA?

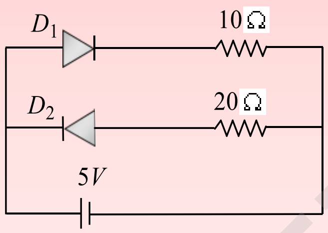
a) 1.2 mA b) 12 mA c) 24 mA d) 2.5 mA

13. A p-n junction in series with a resistance of 3 kΩ is connected across a 30 V DC source. If the forward bias resistance of the junction is 60 Ω, the forward bias current is



a) 9.8 mA b) 1 mA c) 2 mA d) 9.9 mA

14. In the given circuit, there are two ideal diodes connected to a battery. Determine the current provided by the battery.



a) 0.75 A b) Zero c) 0.25 A d) 0.5 A

15. In a triode valve the amplification factor is 10 and mutual conductance is 2×10^{-3} mho. The plate resistance is

a) $2 \times 10^{3}\ \Omega$ b) $5 \times 10^{3}\ \Omega$ c) $2 \times 10^{4}\ \Omega$ d) $2 \times 10^{5}\ \Omega$

16. Why does the resistance of a metal and a semiconductor vary differently with temperature?

a) Crystal structure
b) Variation of the number of charges carries with temperature
c) Type of bonding
d) Variation of scattering mechanism with temperature

17. The resonance frequency of the tank circuit of an oscillator when $L = \frac{20}{\pi^2}$ mH and $C = 0.5\mu$ F are connected in parallel is

a) 5 kHz b) 50 kHz c) 0.5 kHz d) 5 MHz

18. The device that can act as a complete electronic circuit is

a) Zener diode b) Junction diode c) Integrated circuit d) Junction transistor

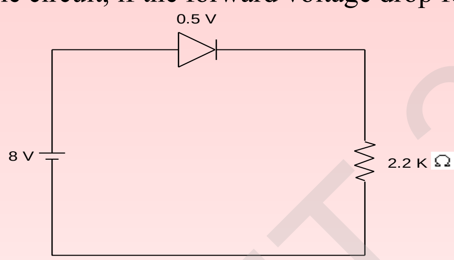
19. What is the difference in energy between the Fermi level and the conduction band in a silicon crystal with a forbidden gap width of 2.2 eV when it is converted into an N-type semiconductor?

a) Greater than 1.1 eV b) Equal to 1.1 eV c) Lesser than 1.1 eV d) Equal to 1.1 eV

20. An amplifier has a voltage gain $A_V = 100$. The voltage gain in dB is

a) 10 dB b) 40 dB c) 3 dB d) 20 dB

21. In the circuit, if the forward voltage drop for the diode is 0.2 V, the current will be



a) 3.25 mA b) 2 mA c) 2.5 mA d) 3 mA

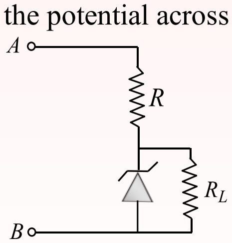
22. For a silicon diode with a 2μm wide depletion layer and a knee potential of 0.8 V, what is the magnitude of the electric field present within the depletion layer?

a) $0.4\ Vm^{-1}$ b) $4 \times 10^4\ Vm^{-1}$ c) $4 \times 10^5\ Vm^{-1}$ d) Zero

23. In a body-centre packing of sodium atoms, where the distance between two nearest atoms is measured to be 7.4 Å, what is the lattice parameter of the sodium crystal structure?

a) 4.8 Å b) 4.3 Å c) 3.9 Å d) 3.3 Å

24. If the voltage between the terminals A and B is 10 V and Zener-breakdown voltage is 4 V, then the potential across R is



a) 6 V b) 8 V c) 9 V d) 17 V

25. The value of current in a triode valve is given by $I_p = 0.002\left(V_p + 10V_g\right)^{3/2}$ mA . When plate potential and grid potential are 100 V and -2V respectively, then the value of mutual conductance will be

a) 600 mho   b) 90 mho   c) 6 mho   d) 9×10^{-5} mho

26. For a transistor amplifier in common emitter configuration for load impedance of 1.5 kΩ ($h_{fe} = 50$ and $h_{oe} = 25\ \mu\ AV^{-1}$), the current gain is

a) -5.2 b) -15.7 c) -24.8 d) -48.19

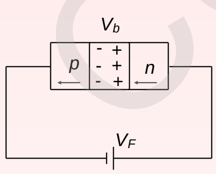
27. The length of germanium rod is 0.89 cm and its area of cross-section is 1.2 mm^2. If for germanium $n_i = 2.5 \times 10^{19}\ m^{-3}$, $\mu_h = 0.19\ m^2V^{-1}s^{-1}$, $\mu_e = 0.39\ m^2V^{-1}s^{-1}$

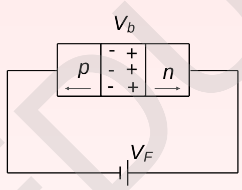
a) 2.5 kΩ   b) 3.0 kΩ   c) 5.0 kΩ   d) 10.0 kΩ

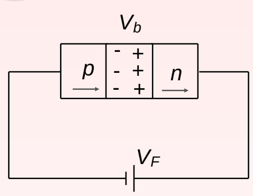
28. Two diodes, one made of silicon (Si) and the other made of germanium (Ge), have identical physical dimensions. In comparison, the band gap of silicon is larger than that of germanium. Both diodes are subjected to an identical reverse bias. What are the consequences of applying this reverse bias to the diodes?

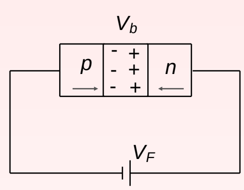
a) The reverse current in Ge is larger than that in Si
b) The reverse current in Si is larger than that in Ge
c) The reverse current is identical in the two diodes
d) The relative magnitude of the reverse currents cannot be determined from the given data only

29. Which of the following figures correctly represents the direction of carrier flow in a p-n junction when it is forward biased?

a) 

b) 

c) 

d) 

30. At what condition, a pure semiconductor behaves like a conductor?

a) Room temperature   b) Low temperature   c) High temperature   d) Both (b) and (c)

31. In NPN transistor, 1.5×10^{10} electrons enter in emitter region in 10^{-7}s. If 4% electrons are lost in base region then collector current and current amplification factor (β) respectively are

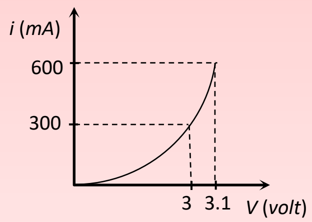
a) 1.57 mA, 49   b) 1.92 mA, 70   c) 2.3 mA, 24   d) 2.25 mA, 100

32. At what condition, a pure semiconductor behaves like a conductor?
   a) Room temperature
   b) Low temperature
   c) High temperature
   d) Both (b) and (c)

33. In NPN transistor, 1.5×10^{10} electrons enter in emitter region in 10^{-7}s. If 4% electrons are lost in base region then collector current and current amplification factor (β) respectively are
   a) 1.57 mA, 49
   b) 1.92 mA, 70
   c) 2.3 mA, 24
   d) 2.25 mA, 100

34. If the reverse bias across a junction diode is increased from 7 V to 13 V, causing the current to rise from 30 μA to 60 μA, what is the resistance of the junction diode?
   a) $2 \times 10^5 \Omega$
   b) $2.5 \times 10^5 \Omega$
   c) $3 \times 10^5 \Omega$
   d) $4 \times 10^5 \Omega$

35. The i-V characteristic of a P-N junction diode is shown below. The approximate dynamic resistance of the P-N junction when a forward bias of 3 volt is applied\



   a) 1 Ω
   b) 0.33 Ω
   c) 0.5 Ω
   d) 5 Ω

36. What will be the input of A and B for the Boolean expression $\overline{(A + B)} + \overline{(A \cdot B)} = 1$
   a) 0, 0
   b) 0, 1
   c) 1, 0
   d) 1, 1

37. What causes the rapid rise in current in a Zener diode?
   a) Due to rupture of bonds
   b) Resistance of depletion layer becomes less
   c) Due to high doping
   d) None of the above

38. At room temperature, the Fermi level of an intrinsic semiconductor is fixed at the midpoint of the band gap. What is the likelihood of occupation of the highest electron state in the valence band?
   a) Zero
   b) Between zero half
   c) Half
   d) One

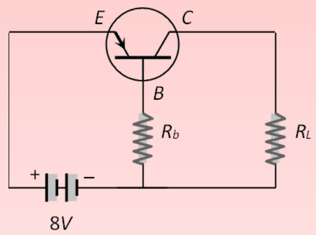
39. In a hexagonal close-packed crystal structure containing N atoms, how many electronic states are present in a single band?

a) N b) 2 N c) 4 N d) 6 N

39. The peak voltage in the output of a half-wave diode rectifier fed with a sinusoidal signal without filter is 20 V. The dc compound of the output voltage is

a) $10/\sqrt{2}$ V b) $10/\pi$ V c) 10 V d) $20/\pi$ V

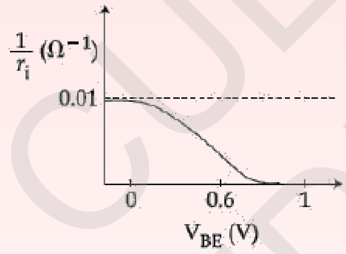
40. In a transistor circuit shown here the base current is 32 μA. The value of the resistor R_b is



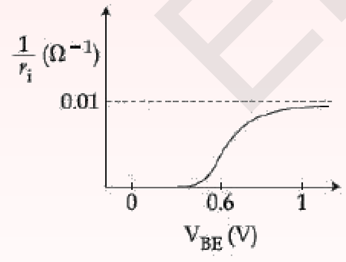
a) 125 kΩ b) 250 kΩ c) 350 kΩ d) None of these

41. In an input characteristics measurement for a common-emitter transistor configuration, provide a graph that accurately depicts the variation of the reciprocal of input resistance.

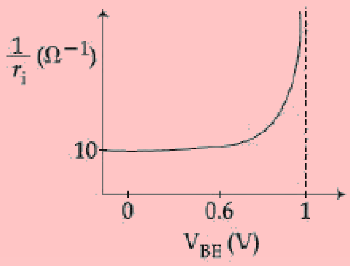
a)



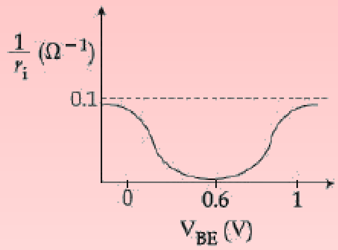
b)



c)



d)



--------------------------------ANSWER KEY------------------------------------

1)	a	2)	b	3)	b	4)	b
5)	c	6)	a	7)	a	8)	d
9)	c	10)	d	11)	b	12)	d
13)	a	14)	d	15)	b	16)	b
17)	a	18)	c	19)	c	20)	d
21)	a	22)	c	23)	b	24)	a
25)	d	26)	d	27)	b	28)	c
29)	d	30)	a	31)	c	32)	a
33)	b	34)	a	35)	a	36)	c
37)	c	38)	a	39)	a	40)	d
41)	b						

HINTS AND SOLUTIONS

1. (a)

Given, $\beta = \frac{\alpha}{1-\alpha} = \frac{0.8}{1-0.8} = 4$

$\therefore$ Voltage gain

$= \beta \frac{R_2}{R_1} = 4 \times 1200 = 4.8 \times 10^3$

2. (b)

The diode in lower branch is forward biased and diode in upper branch is reverse biased

$$\therefore i = \frac{5}{25+20} = \frac{5}{55} A$$

3. (b)

Gallium is trivalent impurity

When it is added to the germanium, extra hole is created in lattice by each gallium atom. Hole is assumed to have a positive charge on it, hence germanium will behave like a p-type semiconductor.

4. (b)

Consider the case when Ge and Si diodes are connected as show in the given figure.

Equivalent voltage drops across the combination Ge and Si diode = 0.15 V

$\Rightarrow$ Current $i = \frac{10-0.3}{5\text{ k}\Omega} = 1.94$ mA

$\therefore$ Out put voltage $V_0 = Ri = 5\text{ k}\Omega \times 1.94\text{ mA} = 9.7$ V

Now consider the case when diode connection is reversed. In this case voltage drop across the diode's combination = 0.7 V

$\Rightarrow$ Current $i = \frac{10-0.7}{5\text{ k}\Omega} = 1.86$ mA

$\therefore V_0 = iR$

$= 1.86\text{ mA} \times 5\text{ k}\Omega = 9.3$ V

Hence charge in the value of $V_0 = 9.7 - 9.3 = 0.4$ V

5. c)

By using $g_m = \frac{\Delta i_p}{\Delta v_g} \Rightarrow 5 \times 10^{-4} = \frac{\Delta i_p}{-2-(-3)}$

$\Rightarrow \Delta i_p = 5 \times 10^{-4} A = 0.5\, mA$

6. (a)

The minimum potential difference between the base and emitter required to turn on a silicon transistor is typically around 0.6 to 0.7 volts.

7. (a)

Since no conduction is found when multimeter is connected across A and B it means either both A and B are n-type or p-type. So, it means C is base. When C is connected to common terminal and conduction is seen when the other terminal is connected to A and B, so it means transistor is in p-n with C as base.

8. (d)

The Boolean expression for 'AND' gate is $C + A.B$

$\Rightarrow 1.1 = 1, 1.0 = 0, 0.1 = 0, 0.0 = 0$

9. (c)

$$i_b = \frac{5-0.5}{7.8} = 0.57\, mA \Rightarrow I_c = \beta\, I_b$$
$$= 100 \times 0.6\, mA$$

By using $V_{CE} = V_{CC} - I_c R_L = 12 - 60 \times 10^{-3} \times 120 = 4.8V$

10. (d)

$$E = \frac{hc}{\lambda} \Rightarrow \lambda = \frac{12400}{E(ev)} = \frac{12400}{2.5}$$
$$= 4960\text{Å}$$

This is the maximum wavelength i.e., the signals having wavelength greater than this value are not detected by photodiode.

11. (b)

Reverse biased potential for the Zener breakdown

$V_r = Ed = 10^6 \times 2 \times 3 \times 10^{-6} =$ 6 volt

12. (d)

The ratio of collector current (I_c) to emitter current (I_e) is known as current gain (α) of a transistor. Therefore,

$\alpha = \frac{\Delta I_c}{\Delta I_e}$ …(i)

Also, emitter current is equal to sum of change of base current and collector current. Therefore,

$\Delta I_e = \Delta I_b + \Delta I_c$ …(ii)

From Eqs. (i) and (ii), we get

$$\alpha = \frac{I_c}{\Delta I_b + \Delta I_c}$$

Given, $\alpha = 0.5, \Delta I_b = 2.5$ Ma

$0.5 = \frac{I_c}{2.5+\Delta I_c}$

⇒ $0.5\,(2.5 + I_c) = I_c$

⇒ $1.25 + 0.5\,I_c = I_c$

⇒ $1.25 = 0.5\,I_c$

⇒ $I_c = 2.5$ mA

13. (a)

Total resistance = 60 + 3000 = 3050 Ω

∴ Forward current $i = \frac{30}{3060} = \frac{1}{102} = 9.8$ mA

14. (d)

Here D_1 is in forward bias and D_2 is in reverse bias so

$$I = \frac{V}{R} = \frac{5}{10} = \frac{1}{2} Amp$$

15. (b)

$$\mu = r_p \times g_m \Rightarrow r_p = \frac{10}{2 \times 10^{-3}}$$
$$= 5 \times 10^3 \Omega$$

16. (b)

The difference in the variation of resistance with temperature in metal and semiconductor is caused due to difference in the variation of the number of charge carriers with temperature.

17. (a)

$$v = \frac{1}{2\pi\sqrt{LC}}$$
$$= \frac{1}{2\pi}\frac{1}{\sqrt{\frac{20}{\pi^2} \times 10^{-3} \times 0.5 \times 10^{-6}}}$$
$$= 5\ kH_Z$$

18. ***(c)***

19. ***(c)***

20. (d)

Voltage gain, $A_V = 100$

In dB, voltage gain

$A = 10 \log_{10} 100$ dB

$= (10 \times 2)\ \log_{10} 10$ dB

$= \because \log_{10} 10 = 1$

21. (a)

When diode is forward biased, then there is a small voltage drop across it

$$i = \frac{V - V'}{R}$$

Given, $V = 8$ volt, $V' = 0.2$ volt,

$R = 2.4\text{ k}\,\Omega = 2.4 \times 10^3 \Omega$

$= \frac{8-0.2}{2.4\times10^3} = \frac{7.8\times10^3}{2.4} = 3.25 \times 10^{-3}$ A

$i = 3.25$ mA.

22. (c)

$E = -\frac{dV}{dr} = \frac{0.8}{2\times10^{-6}} = 4 \times 10^5\ \text{Vm}^{-1}$

23. (b)

Atomic radius for bcc structure is $r = \frac{a\sqrt{3}}{4}$

or $a = \frac{4r}{\sqrt{3}} = \frac{4(7.4/2)}{\sqrt{3}} = \frac{4\times3.7}{1.732} = 8.5$Å

24. (a)

The potential across R is $= 10\ V - 4\ V = 6\ V$

25. d)

$I_p = 0.002(V_p + 10V_g)^{1/2} \times 10^{-3}$ ...(i)

Differentiating it w.r.t. V_g, keeping V_p constant, we have

$$\frac{\Delta I_p}{\Delta V_g} = 0.002 \times \frac{1}{2}(V_p + 10\ V_g)^{1/2} \times 10 \times 10^{-3}$$

or $g_m = 0.002 \times \frac{1}{2}[73 + 10 \times (-2)]^{1/2} \times 10^{-2}$

$= 9 \times 10^{-5}$ mho

26. (d)

For a transistor amplifier in common emitter configuration, current gain

$$A_i = \frac{h_{fe}}{1 + h_{oe}R_L}$$

where h_{fe} and h_{oe} are hybrid parameters of a transistor.

$$\therefore\ A_i = \frac{50}{1 + 25 \times 10^{-6} \times 1.5 \times 10^3}$$

$= -48.19$

27. (b)

$$R = \frac{\rho l}{A} = \frac{L}{n_i e(\mu_e + \mu_h)A}$$

$$= \frac{0.89 \times 10^{-2}}{2.5 \times 10^{19} \times 1.6 \times 10^{-19}(0.39 + 0.19) \times 1.2 \times 10^{-6}}$$

$= 3196\ \Omega$

28. (c)

The reverse current is identical in two diodes if the identical reverse bias is applied across the diodes

29. (d)

Positive charge (*ie*, holes) should move in the direction of current and negative charge (*ie*, electrons) should move opposite to the direction of current.

30. (a)

At room temperature some covalent bonds break and semiconductor behaves slightly as a conductor

31. (c)

$$I_e = 1.5 \times 10^{10} \times 1.6 \times 10^{-19} \times \frac{1}{10^{-6}}$$

$= 2.4\ mA$ $\left[\because I = \frac{Q}{t}\right]$

Since 4% electrons are absorbed by base, hence 96% electrons reach the collector, *i.e.*, $\alpha = 0.98$

$\Rightarrow I_c = \omega I_e = 0.96 \times 2.4$

$= 2.304\ mA$

$\approx 1.57\ mA$

Also, current amplification factor

$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{0.02} = 24$

32. (a)

$$R_e = \frac{\Delta V}{\Delta I} = \frac{(13 - 7)}{(60 - 30) \times 10^{-6}}$$

$= 2 \times 10^5\ \Omega.$

33. (b)

The current at $3V$ is $300\ mA$ and at $3.1\ V$ it is $600\ mA$. The dynamic resistance in this region

$$R = \frac{\Delta V}{\Delta i} = \frac{(3.1 - 3)}{(600 - 300) \times 10^{-3}}$$

$= \frac{1}{3} = 0.33\Omega$

34. (a)

The given Boolean expression can be written as

$Y = (\overline{A + B}).(\overline{A.B}) = (\bar{A}.\bar{B}).(\bar{A} + \bar{B})$

$= (\bar{A}\ \bar{A}).\bar{B} + (\bar{B}.\bar{B})$

$= \bar{A}.\bar{B} + \bar{A}\ \bar{B} = \bar{A}\ \bar{B}$

A	***B***	***Y***
0	0	1
1	0	0
0	1	0
1	1	0

35. **(a)**
The Zener potential, denoted as V_Z, is the reverse bias voltage that triggers a sudden change in a diode's characteristics. When the reverse bias voltage is increased, the minority carriers in the diode gain velocity and kinetic energy, leading to the generation of reverse saturation current. Collisions of these minority carriers with the atomic structure cause an ionization process, resulting in a significant increase in current known as the avalanche current in the avalanche breakdown region. By increasing the doping levels in both the p-type and n-type materials, the magnitude of the Zener potential can be reduced.
When V_Z decreases to a very low level, a strong electric field forms in the junction region, which can break the atomic bonds, generating charge carriers. This phenomenon is referred to as Zener breakdown.

36. **(c)**
The probability of occupation of the highest electron state in valence band at room temperature becomes half according to Fermi distribution.

37. **(c)**
Given, ne/nh=8/5
Ie/Ih=8/4
As we know, I=neAvd

⇒ Ie/Ih=ne×(vd)e×Ae/nh×(vd)h×Ae

⇒ 8/4=8/5×(vd)e/(vd)h

⇒ (vd)e/(vd)h=5/8×8/4=5/4

38. **(a)**
THEORY

39. **(a)**
In a hexagonal close-packed crystal structure containing N atoms, the number of electronic states in a single band is directly related to the number of atoms in the crystal. In a perfect crystal, each atom contributes one electronic state to the band structure. In a hexagonal close-packed structure, each atom has a total of three nearest neighbours. Considering the close-packed arrangement, each atom can be shared among three-unit cells, which means there are 3N/3 = N electronic states per atom in a single band. Therefore, in a hexagonal close-packed crystal structure with N atoms, there are N electronic states present in a single band.

40. **(d)**
In half wave rectifier $V_{dc} = \frac{V_0}{\pi} = \frac{20}{\pi}$

41. **(b)**

$$V_b - i_b R_b \Rightarrow R_b = \frac{8}{32 \times 10^{-6}}$$
$$= 250\ k\Omega$$