UNIT-IX SEMICONDUCTOR DEVICES

FORMULA AT A GLANCE

No. of electrons in conduction band (or holes in valance band) at T temperature

$$n_e = Ce^{-E_g/2kT}$$

No. of total charge carriers (at T temperature)

$$n_i = Ce^{-E_g/kT}$$

In Intrinsic semiconductors

$$n_e = n_h = n_i$$

No. of charge carriers (electrons and holes)

$$n_i = Ce^{\frac{-E_g}{kT}}$$

Rate of Recombination

$$Rn_i^2$$

For extrinsic as well as intrinsic semiconductor

$$Rn_en_h = Rn_i^2$$

$$\Rightarrow n_en_h = n_i^2$$

Emitter Current

$$I_E = I_C + I_B$$

Input resistance, $r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}}$

Output resistance, $r_0 = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$

Current amplification factor (β) or current gain

$$\beta = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CB}}$$

The voltage gain

$$A_V = \left(\frac{v_0}{v_i}\right) = \left(\frac{i_C r_C}{i_B r_i}\right)$$

GATES

Type	Output
OR	$Y = A + B$
AND	$Y = A \times B$
NOT	$Y = \overline{A}$
NOR	$Y = \overline{A + B}$
NAND	$Y = \overline{A \times B}$

SYNOPSIS

Energy bands in solid. Due to interaction between closed packed atoms in solids, the splitting of energy levels takes place and it gives rise to formation of energy bands. The energy band formed by a series of levels containing valence electrons called **valence band** and the lowest unfilled energy band formed just above the valence band is called **covalent band**.

- In some solids, there is an energy gap between the valence and conduction bands.
- This energy gap is called **forbidden energy gap**.
- The behavior of conductors, semiconductors and insulators can be explained on the basis of energy bands.

Conductors. The conduction and valence bands partly overlap each other in case of conductors. In other words, there is no forbidden energy gap in conductors.

Semiconductors. The conduction and valence bands are separated by the small width (~1 eV) of forbidden energy gap. The valence band is completely filled, while the conduction band is empty. The electrons cross from valence band to conduction band even when a small amount of energy is supplied.

Insulators. The width of forbidden energy gap between the valence and conduction bands is quite large (~ 10eV). Ordinarily, electrons cannot jump from valence to conduction band even on applying a strong electric field.

Intrinsic semiconductors. A semiconductor free from all types of impurities is called intrinsic semiconductor. At 0 a semiconductor is an insulator i,e. it possesses zero conductivity. When temperature is increased, a few covalent bonds break up and release the electrons. These electrons move to conduction band living behind equal number of holes in and balance band. The conductivity of an intrinsic semiconductor is due to both electrons and holes.

Doping. The process of adding impurity atoms (pentavalent or trivalent) to a pure semiconductor, so as to increase its conductivity a controlled manner is called doping. The impurity atoms added are very small (~1 in 10^6 semiconductor atoms) The pentavalent impurity atoms are called **donor atoms**, While the trivalent impurity atoms are called **acceptor atoms**.

Extrinsic semiconductors. A semiconductor doped with a suitable impurity, so as to possess conductivity much higher than the semiconductor in pure from is called an extrinsic semiconductor.

- **n-type semiconductor**. When a pentavalent impurity, such as arsenic or antimony or phosphorus is added to pure semiconductor the number of free electrons become more than the holes in the semiconductor and such an extrinsic semiconductor is called n- type semiconductor. In other words, in a n-type semiconductor, electrons are majority carried and holes are minority carriers.
- **p-type semiconductors.** When a trivalent impurity, such as indium or gallium or boron is added to a pure semiconductor, semiconductor becomes deficient in electrons i e, number

of holes become more than the number of electrons. Such a semiconductor is called p-type semiconductor. It has holes as majority carriers and electrons as minority carriers.

Electrical conductivity of a semiconductor. The conductivity of a semiconductor is determined by the mobility (u) of both electrons and holes and their concentration.

p-n junction. The device obtained by growing a p-type semiconductor over a n-type semiconductor or vice- versa is called a p-n junction. It conducts in one direction only. It is also called a junction diode.

Depletion layer. It is a thin layer formed between p and n- section and devoid of holes and electrons. Its width is about 10^{-6}m. A potential difference of about 0.7 V is produced across the junction, which give rise to a very high electric field (~ 10^6 V m^{-1})

Forward biasing. The p-n junction is said to be forward biased, when the positive terminal of the external battery in the circuit is connected to p-section and the negative terminal to n-section of the junction diode. The flow of majority carriers across the junction from both the sections of the junction diode is responsible for the forward current.

Reverse biasing. The p-n junction is said to be reverse biased, when the positive terminal of the external battery in the circuit is connected to n-section and the negative terminal to p-section of the junction diode. The flow of minority carriers across the junction from both the sections of the junction diode is responsible for the reverse current.

Junction diode as rectifier. Because of its unidirectional conductional conduction property, the p-n junction is used to convert an a.c. voltage into d.c voltage. It is then, said to be acting as a rectifier.

- **Half wave rectifier**. A rectifier, which rectifies only one half of each a.c. input supply cycle, is called a half wave rectifier. A half wave rectifier gives discontinuous and pulsating d.c.output. As alternative half cycles of the a.c.input supply go waste, its efficiency is very low.
- **Full wave rectifier**. A rectifier which rectifies both halves of each a.c.input cycle is called a full wave rectifier. The output of a full wave rectifier is continuous but pulsating in nature. However, it can be made smooth by using a filter circuit.

Zener diode. It is a specially designed junction diode, which can operate in the reverse breakdown voltage region continuously without being damaged.

Photo diode. It is a junction diode made from light (or photo) sensitive semiconductor.

Light Emitting Diode (LED). It is a junction diode, which when forward biased, release energy at the junction due to the recombination of electrons and holes. In case of silicon and germanium diodes, the energy released is in infra-red region and in the junction diode made of gallium arsenide or indium phosphide, the energy is released in visible region.

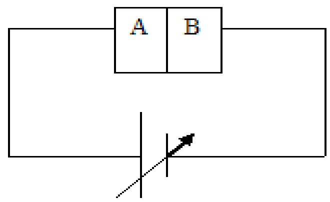
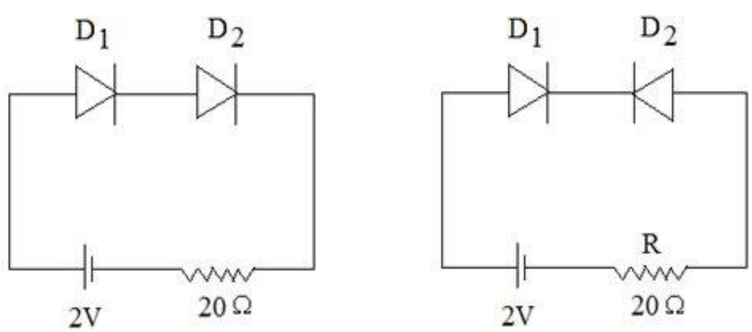
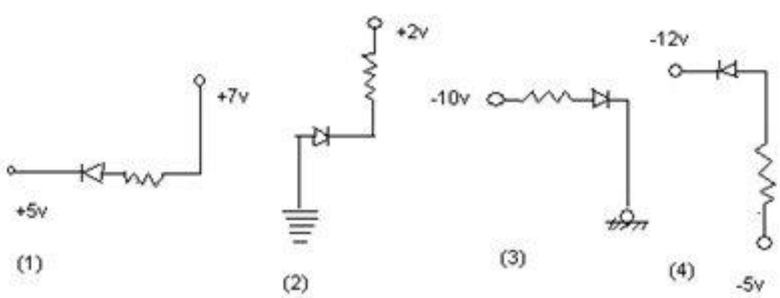
Solar cell. It is a junction diode, in which one of the p or n-section is made very thin (so that the light energy falling on the diode is not greatly absorbed before reaching the junction) can be used to convert light energy into electric energy.

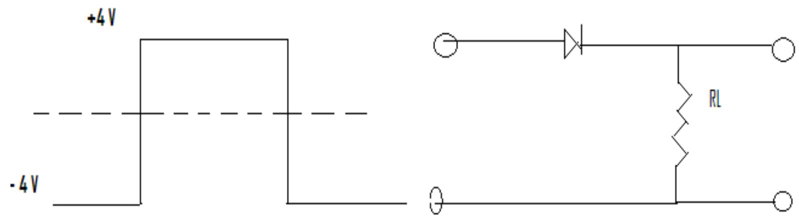
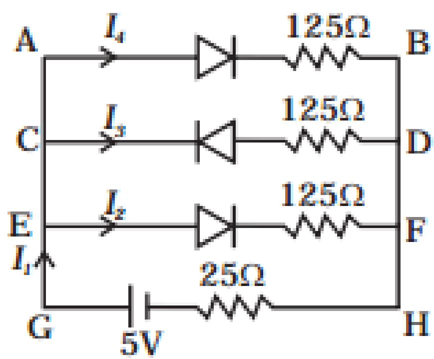
Sl.no:	Question Details	Marks
	MULTIPLE CHOICE QUESTIONS	
1.	When n–type of semiconductor is heated a) number of electrons increases while that of holes decreases b) number of electrons and holes remains same c) number of holes increases while that of electrons is same d) number of electrons and holes increases equally	**1**
2.	Majority current carriers in N – types are a) holes b) positive ions c) electrons d) negative ions	**1**
3.	An N-type Ge is obtained on doping the Ge-crystal with a) phosphorus b) gold c) aluminum d) boron	**1**
4.	The depletion layer in the p-n junction region is caused by a) Drift of holes b) Drift of electrons c) Diffusion of carriers d) Migration of impurity ions	**1**
5.	In a photoelectric cell, the photoelectric current depends on the a) wavelength of light b) potential difference applied c) intensity of light d) frequency of light	**1**
6.	A piece of copper and another of germanium are cooled from room temperature to 80 K. The resistance of a) each of them increases fast b) copper increases fast and that of germanium increases gradually c) each of them decreases fast d) copper decreases fast and that of germanium decreases gradually	**1**

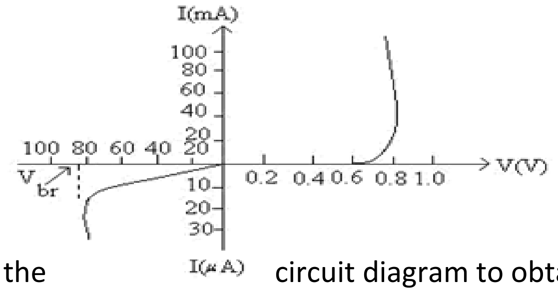
7.	In case of diamond, the forbidden gap is about a) 1.2 eV b) 0.8 eV c) 6.0 eV d) 8.2 eV	1
8.	Which of the following statement is not true? a) The majority carriers in n-type semiconductors are holes b) The resistance of intrinsic semiconductors decreases with increase of Temperature c) A p-n junction can act as a semiconductor diode d) Doping pure Si with trivalent impurities provide p-type semiconductors	**1**
9.	In a middle of the depletion layer of a reverse biased p-n junction, the a) electric field is maximum b) potential is zero c) potential is maximum d) electric field is zero	**1**
10.	When we apply reverse bias to a junction diode it a) lowers the potential barrier b) raises the potential barrier c) increases the minority carrier current d) increases the majority carrier current	**1**
11.	A half wave rectifier is being used to rectify an alternating voltage of frequency 50 Hz. The number of pulses of rectified current obtained in one second is a) 50 Hz b) 200 Hz c) 100 Hz d) 25 Hz	**1**
12.	To provide the abundance of holes the impurity added should be a) tetravalent b) pentavalent c) trivalent d) monovalent	**1**
13.	A p-n junction has a thickness of the order of a) 1 cm b) 1 mm c) 10^{-6} cm d) 10^{-12} cm	**1**

14.	P-N junction can be used as a) a rectifier b) an oscillator c) a modulator d) an amplifier	**1**
	FILL IN THE BLANKS	
1.	Mobility of hole is ________ than that of electron.	1
2.	The forward voltage beyond which the current through the junction starts to increase rapidly with linear variation is known as ________ voltage.	1
3.	When a pure semi-conductor of Ge or Si is doped with a controlled amount of trivalent atoms is called ________ semiconductor.	1
4.	The ratio of small change in voltage (ΔV) applied across the p-n junction to a small change in current is known as ________.	1
5.	________ is defined as the ratio of the change in output voltage to the change in input voltage.	1
6.	A doped semiconductor or a semiconductor with suitable impurity atoms added to it is called ________ semiconductor.	1
7.	When positive terminal of external battery is connected to p-side and negative to n-side of p-n junction, the p-n junction is said to be ________.	1
8.	A pure semiconductor which is free from every impurity is called ________ semiconductor	1
9.	When a pure semiconductor of Ge or Si is doped with a controlled amount of pentavalent atoms is called ________ semiconductor.	1
10.	When a p-type crystal is brought into close contact with n-type crystal, the resulting arrangement is called ________.	1
	In the following questions, two statements are given-one labelled as Assertion (A) and the other labelled as Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below. (a) Both A and R are true and R is the correct explanation of A (b) Both A and R are true but R is NOT the correct explanation of A (c) A is true but R is false (d) A is false and R is also false	
1	Assertion (A): The number of electrons in a P-type silicon semiconductor is less than the number of electrons in intrinsic silicon semiconductor at room temperature. Reason (R): It is due to law of mass action.	
2	Assertion (A): The resistivity of a semiconductor increases with temperature.	

	Reason (R): The atoms of a semiconductor vibrate with larger amplitude at higher temperature there by increasing it's resistivity.	
3	Assertion (A): As the temperature of a semiconductor increases, its resistance decreases. Reason (R): The energy gap between conduction band and valence band is small	
4	Assertion (A): Silicon is preferred over Germanium for making semiconductor devices. Reason (R): The energy gap of Germanium is more than the energy gap of Silicon.	
5	Assertion (A): Semiconductors do not obey Ohm's law. Reason (R): V-I characteristic of semiconductors is linear	
	VERY SHORT ANSWER QUESTIONS	
1.	Name the type of biasing of a p-n junction diode so that the junction offers very high resistance	1
2.	What is the most common use of photodiode?	1
3.	Carbon and silicon both have four valence electrons each, then how are they distinguished?	1
4.	How does the energy gap in an intrinsic semiconductor change, when doped with a trivalent impurity?	1
5.	At what temperature would an intrinsic semiconductor behave like a perfect insulator?	1
6.	Which semiconductor has more mobility: p-type or n-type? Explain	1
7.	A p-n photodiode is fabricated from a semiconductor with band gap of 2.8 eV. Can it detect a wavelength of 600 nm?	1
9.	Name two factors on which electrical conductivity of a pure semiconductor at a given temperature depends.	1
10.	What is doping?	1
11.	Give the ratio of number of holes and the no. of conduction electrons in an intrinsic semiconductor.	**1**
12.	What type of impurity is added to obtain n-type semiconductor?	**1**
14.	How does the thickness of the depletion layer in a p-n junction vary with increase in reverse bias?	**1**
15.	Name the type of biasing of a p-n junction offers very high resistance.	**1**
16.	How does the conductance of a semiconducting material change with the rise of temperature?	**1**
17.	What is the ratio of number of holes and the number of conduction electrons in an intrinsic semiconductor?	**1**
19.	How does the energy gap in an intrinsic semiconductor vary when doped with a pentavalent impurity?	**1**

20.	What is donor energy level?	**1**
	2 MARKER QUESTIONS	
21.	Doping germanium crystal with indium and arsenic respectively makes two semiconductor materials B and A shown in the figure. The two are joined end-to-end and connected to a battery as shown. Will the junction be forward biased or reverse biased? 	**2**
22.	Draw the typical V – I characteristics of a silicon diode. Describe briefly the following terms : (i) ‘‘minority carrier injection’’ in forward bias (ii) ‘‘breakdown voltage’’ in reverse bias	
23.	Determine the currents through resistance R of the circuits (i) and (ii) when similar diodes D_1 and D_2 are connected as shown in the figure. 	**2**
24.	In the following diagrams, indicate which of the diodes are forward biased and which are reverse biased. 	**2**
25.	Name the two factors on which electrical conductivity of a pure semiconductor at a given temperature depends.	**2**
26.	State with reason why a photodiode is usually operated at a reverse bias?	**2**

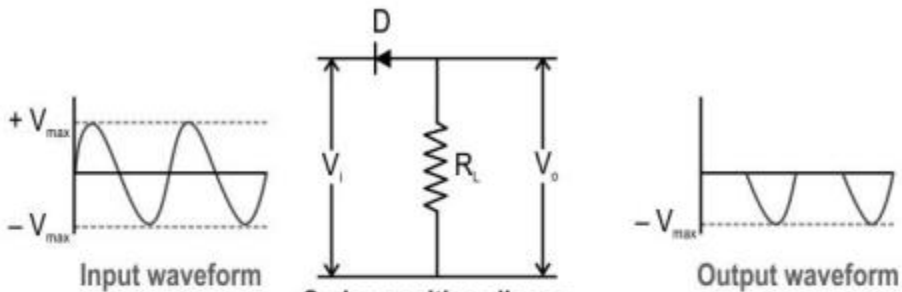
27.	Why is the frequency of the output of a full wave rectifier twice that of the input frequency?	**2**
28.	If in the p-n junction diode a square input signal is 8 V then find out the output signal across R_L 	**2**
29.	Derive an expression for the conductivity of charge carriers in a p-type semiconductor.	**2**
30.	If each diode in figure has a forward bias resistance of 25Ω and infinite resistance in reverse bias, what will be the values of the current I 1, I 2, I 3 and I 4? 	
	3 MARKER QUESTIONS	
33.	What are energy bands? How are these formed? Distinguish between a conductor, an insulator and a semiconductor on the basis of energy band diagram.	**3**
34.	The current in the forward bias is known to be more (mA) than the current in the reverse bias(μA).What is the reason to operate the photo diodes in reverse bias?	**3**
37.	A semiconductor has equal electron and hole concentration of 6 x 10^8 m^{-3}.On doping with certain impurity, the electron concentration increases to 9 x10^{12} m^{-3}. (i) Identify the new semiconductor obtained after doping. (ii)Calculate the new hole concentration.	**3**

38.	The figure below shows the V-1 characteristic of a semiconductor diode.  Identify the semiconductor diode used. Draw the circuit diagram to obtain the given characteristics of this device. (iii)Briefly explain how this diode can be used as a voltage regulator.	**3**
	5 MARKER QUESTIONS	
	CASE STUDY	
	Band theory of solid: Consider that the Si or Ge crystal contains N atoms. Electrons of each atom will have discrete energies in different orbits. The electron energy will be same if all the atoms are isolated, i.e., separated from each other by a large distance. However, in a crystal, the atoms are close to each other (2 Å to 3 Å) and therefore the electrons interact with each other and also with the neighbouring atomic cores. The overlap (or interaction) will be more felt by the electrons in the outermost orbit while the inner orbit or core electron energies may remain unaffected. Therefore, for understanding electron energies in Si or Ge crystal, we need to consider the changes in the energies of the electrons in the outermost orbit only. For Si, the outermost orbit is the third orbit (n = 3), while for Ge it is the fourth orbit (n = 4). The number of electrons in the outermost orbit is 4 (2s and 2p electrons). Hence, the total number of outer electrons in the crystal is 4N. The maximum possible number of outer electrons in the orbit is 8 (2s + 6p electrons). So, out of the 4N electrons, 2N electrons are in the 2N s-states (orbital quantum number l = 0) and 2N electrons are in the available 6N p-states. Obviously, some p-electron states are empty. This is the case of well separated or isolated atoms. Q. 1.1 The energy of electrons of atoms of a substance will be same if: (A) atoms are isolated. (B) atoms are closely spaced. (C) atoms are excited. (D) atoms are charged. Q.1.2 In a crystal, the distance between two atoms is: (A) 200 Å to 300 Å (B) 2 Å to 3 micron (C) 2 Å to 3 Å (D) 2 mm to 3 mm Q.1.3. The overlap (or interaction) will be more felt by the electrons when they are: (A) in the outermost orbit. (B) in the innermost orbit. (C) free. (D) in any orbit. Q. 1.4. For Silicon and Germanium the outermost orbits are respectively:	

(A)n = 3 and n = 5
(B) n = 4 and n = 3
(C) n = 5 and n = 4
(D)n = 3 and n = 4

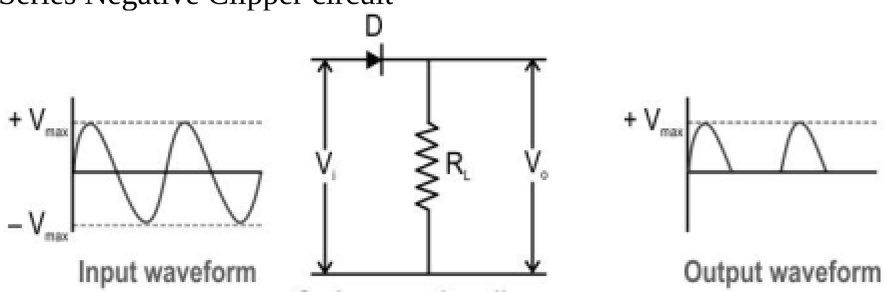
Q. 1.5. The maximum possible electrons in an orbit is:
(A) 8 (2s + 6p electrons)
(B) 8 (6s + 2p electrons)
(C) 8 (4s + 4p electrons
(D)8 (1s + 7p electrons)

Case study: Clipper circuits A half wave rectifier circuit is also known as a clipper. A clipper circuit removes either the positive half or negative half or a part of the input positive or negative cycles of the input AC signal. In a typical half wave rectifier circuit, as shown in the circuit diagram, only the positive half cycles are completely removed. This circuit is also known as the Series Positive Clipper



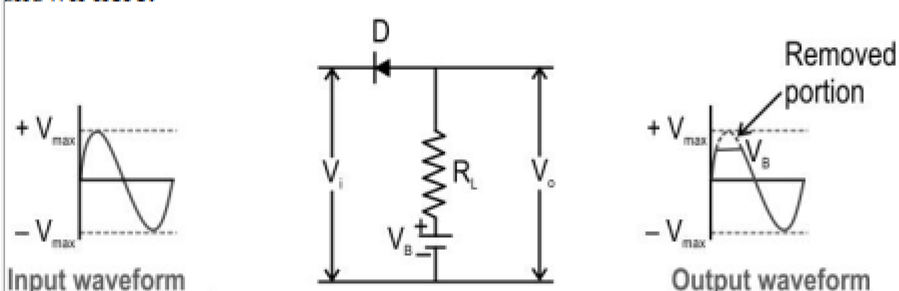
Series positive clipper

Similarly, just by reversing the diode, only the negative half cycles are removed. This is Series Negative Clipper circuit



Series negative clipper

Now a Series Positive Clipper circuit can be modified by including a battery as shown here.



Series positive clipper with positive bias

	During the positive input half cycle, the diode is reverse biased by the input supply voltage Vi. But since the positive terminal of the battery is connected to p-side and the negative terminal of the battery is connected to n-side of the diode, the diode is forward biased by the battery voltage VB. That means the diode is reverse biased by the input supply voltage (Vi) and forward biased by the battery voltage (VB). Initially, the input supply voltage Vi < VB , so VB dominates over the Vi . Hence, the diode is forward biased by the VB and allows electric current through it. As a result, the signal appears at the output. As soon as Vi becomes greater than VB, the diode is reverse biased. So no current flows through the diode. As a result, input signal does not appear at the output. Instead a constant voltage = VB appears across the output. So the clipping takes place during the positive half cycle, at the time the input Vi is greater than the VB. Now consider the negative input half cycle. The diode is forward biased by both VB and Vi. That means, during the negative half cycle, it doesn't matter whether the Vi is greater or less than the VB, the diode remains forward biased. So the complete negative half cycle appears at the output. Thus, the series positive clipper with positive bias clips a small portion of the positive half cycles in the output. Answer the following questions: (a) Draw the circuit diagram to represent the series clipper circuit with a negative bias. (b) Which part of the input ac cycle will get clipped in the case of series clipper circuit with a negative bias? Represent the clipped output waveform through this circuit. (c) Explain the output waveform during the positive input cycle in the series clipper circuit with a negative bias. OR © Explain the output waveform during the negative input cycle in the series clipper circuit with a negative bias	

ANSWER KEY - MCQ

1	2	3	4	5	6
(d)	(c)	(a)	(c)	(c)	(d)
7	**8**	**9**	**10**	**11**	**12**
(c)	(a)	(d)	(b)	(a)	(c)
13	**14**	**15**			
(c)	(a)				

ANSWER KEY – FILL IN THE BLANKS

1	2	3	4	5
Smaller	Knee	p-type	Dynamic resistance	A.C. Voltage gain
6	**7**	**8**	**9**	**10**
Extrinsic	Forward biased	Intrinsic	n-type	p-n junction

ANSWER KEY – ASSERTION AND REASON

1	2	3	4	5
A	D	A	B	C