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NCERT SOLUTIONS

Class 12 Physics

Chapter 14-Semiconductor Electronics: Materials, Devices and Simple Circuits

Detailed Step-by-Step Exercise Solutions

Q1 **In an n-type silicon, which of the following statements is true:**

(a) Electrons are the majority carriers, and trivalent atoms are the dopants.

(b) Electrons are minority carriers, and pentavalent atoms are the dopants.

(c) Holes are minority carriers, and pentavalent atoms are the dopants.

(d) Holes are the majority carriers, and trivalent atoms are the dopants.

Solution

Concept: n-type Semiconductors

Doping a pure semiconductor (like Silicon) with impurity atoms alters its conductivity.

- **Silicon (Si)** belongs to Group 14 of the periodic table and has **4 valence electrons**.
- **Pentavalent atoms** (Group 15, e.g., Phosphorus, Arsenic, Antimony) have **5 valence electrons**.
- When a pentavalent atom replaces a Si atom in the crystal lattice, four of its electrons form covalent bonds with neighbouring Si atoms. The fifth electron is loosely bound and becomes a **free electron** for conduction.

- This type of doping creates an **n-type** semiconductor where **electrons** are the **majority carriers** and **holes** are the **minority carriers**.
- **Trivalent atoms** (Group 13, e.g., Boron, Aluminium, Gallium) create p-type semiconductors, not n-type.

Evaluation of Statements:

(a) False. Trivalent atoms create p-type, not n-type. Dopants are incorrect.

(b) False. In n-type, electrons are majority carriers, not minority.

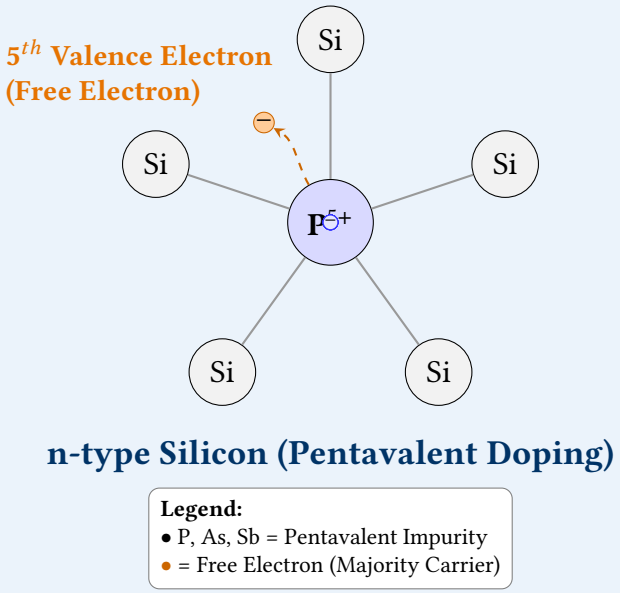
(c) True. Holes are indeed minority carriers in n-type silicon, and pentavalent atoms are the correct dopants.

(d) False. This describes p-type semiconductors.

Final Answer:

Option **(c)** is correct.

Visual Representation: n-type Silicon Doping



The diagram shows the creation of a free electron in an n-type semiconductor due to a pentavalent dopant.

Expert's Solution — Dr. Kavya Sharma, Ph.D. Solid State Physics, IISc Bangalore

Quick Mnemonic to Remember n-type vs p-type:

- **n-type** → **N**egative charge carriers (electrons) are majority. Doped with Pe**N**tavalent atoms

(P, As, Sb).

- **p-type** → **P**ositive charge carriers (holes) are majority. Doped with Tri**v**alent atoms (B, Al, Ga) — which create a **v**acancy (hole).

> **Did You Know?**
>
> The term "pentavalent" comes from *penta-* (five) + *-valent* (valence). Similarly, "trivalent" comes from *tri-* (three). In an n-type semiconductor, the extra electron from the pentavalent atom creates a **donor energy level** just below the conduction band, making it very easy for the electron to jump into the conduction band and conduct electricity.

Q2 Which of the statements given in Exercise 14.1 is true for p-type semiconductors?

Solution

Recalling the Statements from Exercise 14.1:

(a) Electrons are majority carriers and trivalent atoms are the dopants.

(b) Electrons are minority carriers and pentavalent atoms are the dopants.

(c) Holes are minority carriers and pentavalent atoms are the dopants.

(d) Holes are majority carriers and trivalent atoms are the dopants.

Concept: p-type Semiconductors

Doping pure Silicon (Group 14, 4 valence electrons) with trivalent impurity atoms creates a p-type semiconductor.

- **Trivalent atoms** (Group 13, e.g., Boron, Aluminium, Gallium) have **3 valence electrons**.
- When a trivalent atom replaces a Si atom in the crystal lattice, its three electrons form covalent bonds with three neighbouring Si atoms. One bond remains incomplete, creating a **vacancy** or **hole**.
- This hole behaves as a positive charge carrier. Neighbouring electrons can jump into this hole, creating a new hole elsewhere.
- In a p-type semiconductor, **holes** are the **majority carriers** and **electrons** are the **minority carriers**.
- **Pentavalent atoms** (Group 15) create n-type semiconductors, not p-type.

Evaluation of Statements for p-type:

(a) **False.** In p-type, holes (not electrons) are majority carriers. However, "trivalent atoms are the dopants" is correct.

(b) **False.** This describes n-type semiconductors. Pentavalent atoms are not used for p-type.

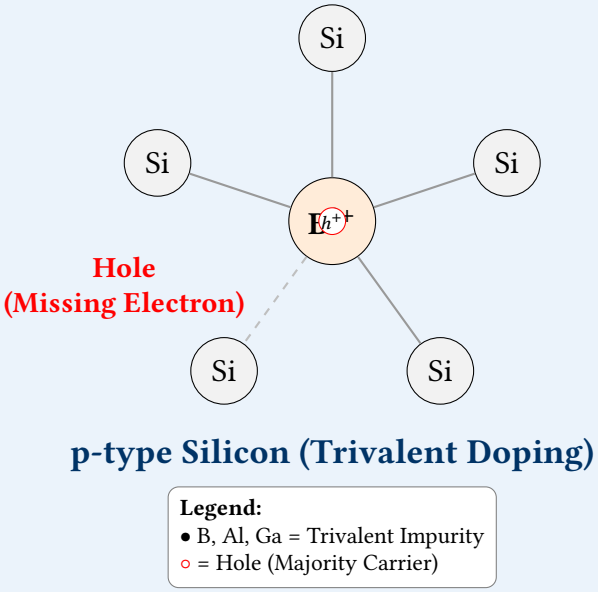
(c) **False.** This also describes n-type semiconductors.

(d) **True.** Holes are indeed majority carriers in p-type semiconductors, and trivalent atoms are the correct dopants.

Final Answer:

Option **(d)** is correct.

Visual Representation: p-type Silicon Doping



The diagram shows the creation of a hole in a p-type semiconductor due to a trivalent dopant atom.

Expert's Solution — Dr. Kiran, Ph.D. Physics, NIT Calicut

Comparing n-type and p-type Semiconductors:

Property	n-type	p-type
Dopant Type	Pentavalent (Group 15)	Trivalent (Group 13)
Example Dopants	P, As, Sb	B, Al, Ga
Majority Carriers	Electrons (e^-)	Holes (h^+)
Minority Carriers	Holes (h^+)	Electrons (e^-)
Donor/Acceptor	Donor level	Acceptor level

Did You Know?

A simple way to remember:
n-type = **n**egative charge (electrons)
p-type = **p**ositive charge (holes)
The type is named after the polarity of the majority charge carriers, not the dopant!

Q3 **Carbon, silicon and germanium have four valence electrons each. These are characterised by valence and conduction bands separated by energy band gap respectively equal to $(E_g)_C$, $(E_g)_{Si}$ and $(E_g)_{Ge}$. Which of the following statements is true?**

(a) $(E_g)_{Si} < (E_g)_{Ge} < (E_g)_C$

(b) $(E_g)_C < (E_g)_{Ge} > (E_g)_{Si}$

(c) $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$

(d) $(E_g)_C = (E_g)_{Si} = (E_g)_{Ge}$

Solution

Concept: Energy Band Gap in Group 14 Elements

Carbon (C), Silicon (Si), and Germanium (Ge) are all Group 14 elements with four valence electrons. However, their electrical conductivity differs significantly due to their **energy band gap** (E_g) — the energy difference between the top of the valence band and the bottom of the conduction band.

- **Band Gap Trend in Group 14:** As we move **down** the group (from C to Si to Ge), the atomic size increases. The valence electrons are farther from the nucleus and are less tightly bound. This results in:

- Weaker binding of electrons.
- Greater overlap of electron wavefunctions.
- Wider energy bands.
- **Smaller energy band gap** (E_g).

- Thus, the band gap decreases down the group.

Actual Band Gap Values (at 300 K):

- Carbon (Diamond): $(E_g)_C \approx 5.5$ eV **(Insulator)**
- Silicon: $(E_g)_{Si} \approx 1.1$ eV **(Semiconductor)**
- Germanium: $(E_g)_{Ge} \approx 0.7$ eV **(Semiconductor)**

Evaluation of Options:

(a) False. The ordering is incorrect. Ge has the smallest gap, not Si.

(b) False. This statement is inconsistent (C ¡ Ge but Ge ¿ Si? The order is not clear and does not match the decreasing trend).

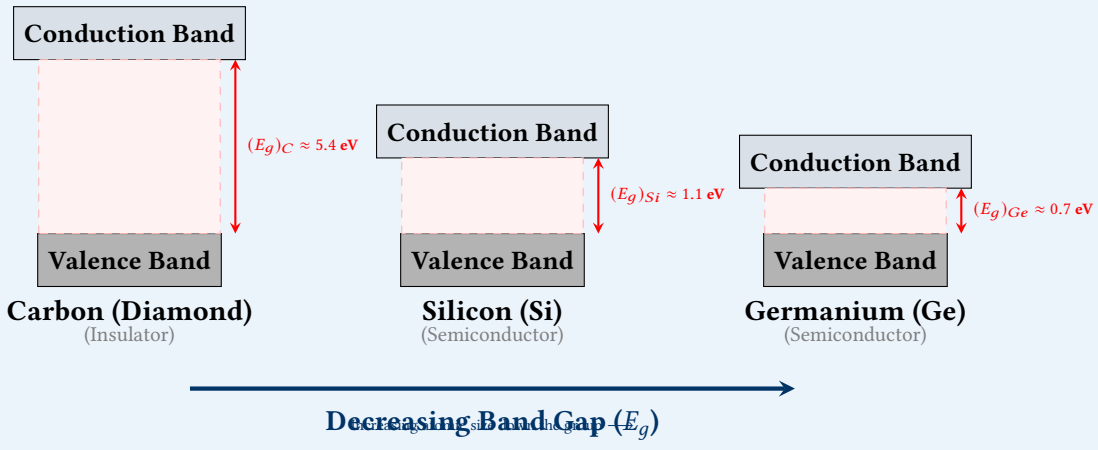
(c) True. $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$ is the correct decreasing order down the group.

(d) False. The band gaps are not equal; they vary significantly.

Final Answer:

Option **(c)** is correct: $(E_g)_C > (E_g)_{Si} > (E_g)_{Ge}$

Visual Representation: Energy Band Diagrams



The energy band gap decreases as we move down Group 14 of the periodic table.

Expert's Solution — Praveen Singh, M.Tech CSE, IIT Ropar

Why Band Gap Decreases Down the Group:

- Carbon has the **smallest atomic radius** among the three. Its valence electrons are held most tightly, resulting in a **large band gap**.
- As we go down to Si and Ge, the atomic size increases. The outermost electrons are farther from the nucleus and experience a weaker Coulomb attraction.
- This weak binding leads to **greater orbital overlap** between adjacent atoms in the crystal lattice, forming broader energy bands. A direct consequence is a **narrower forbidden energy gap**.
- This trend is the reason Carbon (Diamond) is an excellent insulator, while Si and Ge are semiconductors.

Did You Know?

The band gap of a semiconductor is temperature-dependent. As temperature increases, the band gap typically **decreases** slightly due to thermal expansion of the lattice and electron-phonon interactions. For Silicon, E_g at 0 K is about 1.17 eV and at 300 K it drops to about 1.11 eV.

Q4 **In an unbiased p-n junction, holes diffuse from the p-region to n-region because**

(a) free electrons in the n-region attract them.

(b) they move across the junction by the potential difference.

(c) hole concentration in p-region is more as compared to n-region.

(d) All the above.

Solution

Concept: Unbiased p-n Junction and Diffusion

An **unbiased p-n junction** is one where no external voltage is applied. The behaviour of charge carriers at the junction is governed by two key processes:

- **Diffusion:** The movement of charge carriers from a region of **higher concentration** to a region of **lower concentration**.

- **Drift:** The movement of charge carriers due to an electric field (potential difference).

Why Holes Diffuse from p-region to n-region:

- In the **p-region**, holes are the **majority carriers** and are present in very large numbers (high concentration).
- In the **n-region**, holes are the **minority carriers** and are present in extremely small numbers (low concentration).
- This **concentration gradient** across the junction is the primary driving force.
- Holes naturally **diffuse** from the region of their high concentration (p-side) to the region of their low concentration (n-side). This process requires no external energy.

Evaluation of Options:

(a) **False.** Diffusion is not caused by attraction from electrons. It is driven by the concentration gradient. Additionally, in an unbiased junction, the diffusion of holes and electrons leads to the creation of a depletion region and a built-in potential barrier that *opposes* further diffusion, not attraction.

(b) **False.** In an unbiased junction, there is no external potential difference. The internal potential barrier that forms actually **opposes** the diffusion of majority carriers. Holes diffuse despite this barrier, not because of it. They move initially due to the concentration gradient.

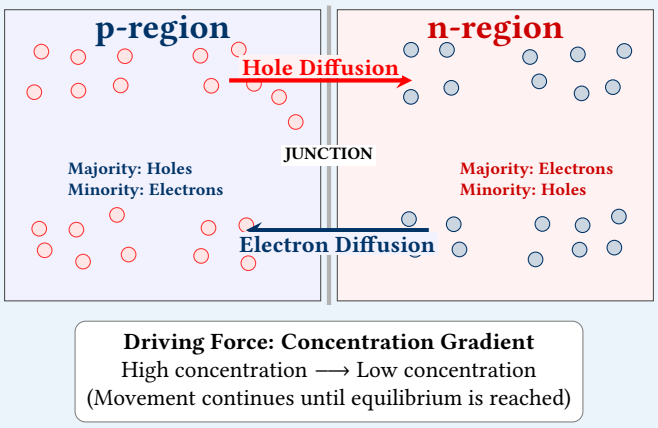
(c) **True.** This is the fundamental reason for diffusion. Particles move from a region of higher concentration to a region of lower concentration.

(d) **False.** Since (a) and (b) are incorrect, "All the above" is false.

Final Answer:

Option **(c)** is correct.

Visual Representation: Diffusion in an Unbiased p-n Junction



The diagram illustrates how majority carriers (holes from p-side, electrons from n-side) diffuse across the junction due to the large difference in their concentrations.

Expert's Solution — Tilak Pandey, B.Tech CSE, IIIT Bangalore

Understanding Diffusion vs Drift: In an unbiased p-n junction:

1. **Initial Stage:** Majority carriers (holes in p, electrons in n) diffuse across the junction solely due to the large **concentration gradient**. This is a natural process, like a drop of ink spreading in water.
2. **Formation of Depletion Region:** As holes leave the p-side, they uncover negatively charged acceptor ions. As electrons leave the n-side, they uncover positively charged donor ions. This creates an electric field pointing from n to p.
3. **Equilibrium:** The internal electric field opposes further diffusion. An equilibrium is reached where the **diffusion current** is balanced by the **drift current** (minority carriers swept across by the field). The net current becomes zero.

The initial push for diffusion is purely entropic (driven by the concentration gradient), making option (c) the only correct, fundamental answer.

Did You Know?

The process is entirely analogous to diffusion in gases. If you have a box with high pressure on one side and low pressure on the other, gas molecules will naturally flow from high to low pressure. Similarly, holes "flow" from a region of high hole concentration (p-side) to low hole concentration (n-side). No external "attraction" is needed!

Q5 **When a forward bias is applied to a p-n junction, it**

(a) raises the potential barrier.

(b) reduces the majority carrier current to zero.

(c) lowers the potential barrier.

(d) None of the above.

Solution

Concept: Forward Bias in a p-n Junction

In a p-n junction, a **forward bias** is applied by connecting the **positive terminal** of the external battery to the **p-side** and the **negative terminal** to the **n-side**.

Effect of Forward Bias:

- The external voltage creates an electric field that **opposes** the internal built-in electric field of the depletion region.
- This reduces the effective electric field across the junction.
- Consequently, the **potential barrier** at the junction is **lowered** (reduced in height).
- With the barrier reduced, more majority carriers (holes from p-side, electrons from n-side) can now overcome the barrier and diffuse across the junction.
- This results in a significant **increase** in the current flowing through the junction.

Evaluation of Options:

(a) False. Forward bias does not raise the potential barrier; it lowers it. Reverse bias raises the barrier.

(b) False. Forward bias does not reduce the majority carrier current to zero; it significantly **increases** it. The majority carrier diffusion current becomes dominant.

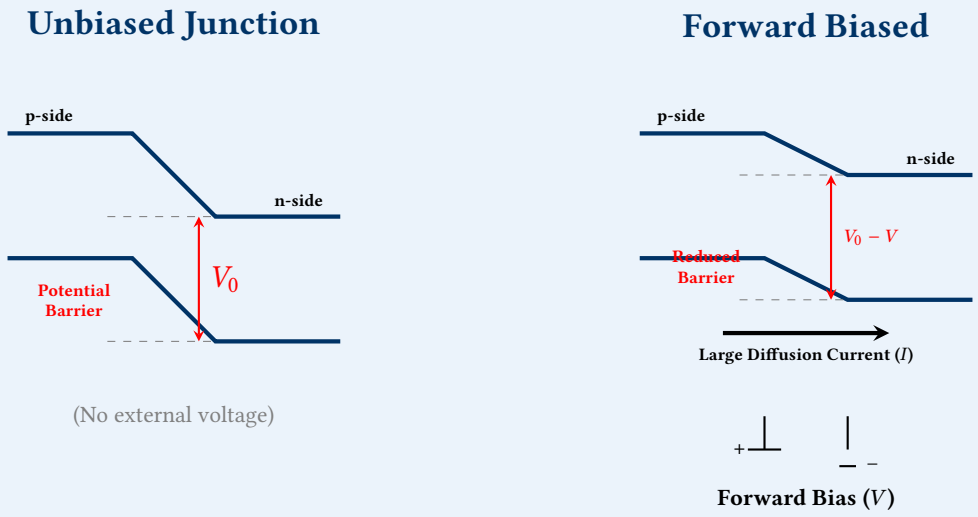
(c) True. The primary effect of forward bias is to reduce (lower) the potential barrier across the depletion region.

(d) False. Option (c) is a correct statement.

Final Answer:

Option **(c)** is correct.

Visual Representation: Effect of Forward Bias on Potential Barrier



The diagrams compare the potential energy barrier in an unbiased junction (high barrier) and a forward-biased junction (lowered barrier), showing why large current flows.

Expert's Solution — Arjun Patel, B.Tech Electrical Engineering, IIT Gandhinagar

Key Differences Between Forward and Reverse Bias:

Feature	Forward Bias	Reverse Bias
Battery Connection	+ to p, − to n	− to p, + to n
Potential Barrier	**Decreases** $(V_0 - V)$	**Increases** $(V_0 + V)$
Depletion Width	**Narrows**	**Widens**
Current	**High** (mA range)	**Very Low** (μA range)
Current due to	Majority carriers	Minority carriers

Did You Know?

Quick Tip: Remember the simple mnemonic:
Forward = **F**acilitates flow (barrier **F**alls)
Reverse = **R**estricts flow (barrier **R**ises)
In forward bias, the external voltage helps majority carriers overcome the barrier, like pushing a ball over a smaller hill.

Q6 **For transistor action, which of the following statements are correct:**

(a) Base, emitter and collector regions should have similar size and doping concentrations.

(b) The base region must be very thin and lightly doped.

(c) The emitter junction is forward biased and collector junction is reverse biased.

(d) Both the emitter junction as well as the collector junction are forward biased.

Solution

Concept: Transistor Structure and Biasing for Amplification

A Bipolar Junction Transistor (BJT) is a three-terminal semiconductor device with regions called Emitter (E), Base (B), and Collector (C). For a transistor to function as an amplifier (active mode), it must satisfy specific structural design rules and biasing conditions.

Part I: Structural Requirements of a BJT

- **Emitter:** It is **heavily doped** and moderate in size. Its job is to inject a large number of charge carriers into the base.
- **Base:** It is **very thin** and **lightly doped**. This is the most critical design aspect. A thin, lightly doped base ensures that most injected carriers diffuse through it and reach the collector, rather than recombining in the base.
- **Collector:** It is **moderately doped** and physically the **largest** region. Its job is to collect carriers coming from the emitter via the base. It is made large to dissipate the heat generated due to the high power at the reverse-biased collector junction.

Thus, the three regions are intentionally **not** similar in size or doping.

Part II: Biasing Requirements (Active Mode) For transistor action (amplification), the biasing must be:

- **Emitter-Base (EB) Junction: Forward Biased**. This reduces the potential barrier, allowing a large number of majority carriers from the emitter to be injected into the base.
- **Collector-Base (CB) Junction: Reverse Biased**. The high reverse bias creates a strong electric field in the CB depletion region that sweeps the injected carriers into the collector circuit, producing the output current.

Evaluation of Statements:

(a) Incorrect. The emitter, base, and collector have distinctly **different** sizes and doping concentrations. They are not similar.

(b) Correct. The base region must indeed be **very thin** and **lightly doped** to minimize carrier recombination, which is essential for achieving high current gain.

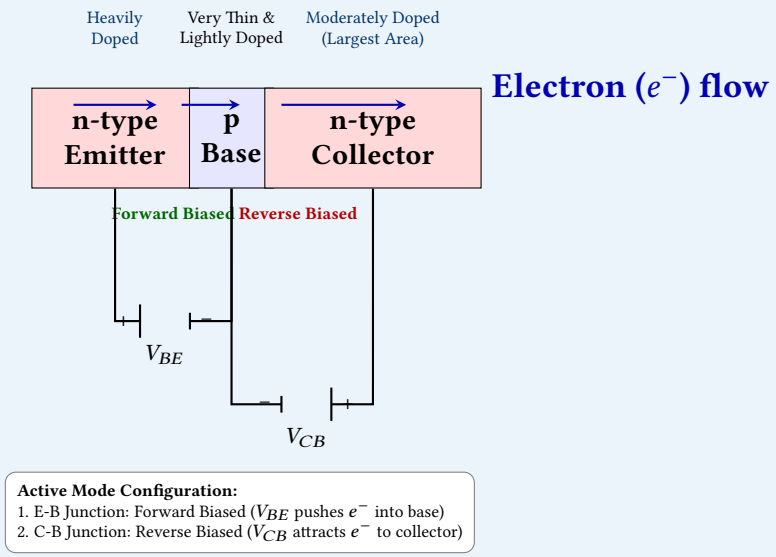
(c) Correct. In the active region, the EB junction is **forward biased** and the CB junction is **reverse biased**.

(d) Incorrect. If both junctions are forward biased, the transistor operates in the **saturation mode** (acts as a closed switch), not in the active mode required for amplification.

Final Answer:

Statements **(b)** and **(c)** are correct.

Visual Representation: npn Transistor in Active Mode



The diagram shows an npn BJT in active mode with correct structural proportions and biasing polarities.

Expert's Solution — Priya Sharma, B.Tech Electrical Engineering, NIT Trichy

Summary of Transistor Operating Modes: The biasing of the two junctions determines the operating region of a BJT:

Mode	Emitter-Base Junction	Collector-Base Junction	Application
Active (Amplifier)	Forward Biased	Reverse Biased	Amplification
Cut-off	Reverse Biased	Reverse Biased	Switch (OFF)
Saturation	Forward Biased	Forward Biased	Switch (ON)

Why the Base Must Be Thin and Lightly Doped: The current gain of a transistor in common-emitter configuration is given by $\beta = I_C/I_B$. The base current I_B arises from recombination of minority carriers in the base region. To maximize β, we must minimize this recombination. A thin base gives carriers less distance to travel (less chance to recombine), and light doping reduces the number of majority carriers available for recombination. Thus, most injected carriers ($\approx$ 95%–99%) successfully reach the collector.

Did You Know?

Quick Mnemonic: To remember the biasing for Active mode:
"E-Front, C-Back"
Emitter junction is **F**orward biased (F→Front).
Collector junction is Re**v**erse biased (the opposite).
Also, the **C**ollector is the **C**oolest—it's physically the **largest** to dissipate the most heat!

Q7 **For a transistor amplifier, the voltage gain**

(a) remains constant for all frequencies.

(b) is high at high and low frequencies and constant in the middle frequency range.

(c) is low at high and low frequencies and constant at mid frequencies.

(d) None of the above.

Solution

Concept: Frequency Response of a Transistor Amplifier

The voltage gain of a transistor amplifier is **not constant** over the entire range of input signal frequencies. The variation of gain with frequency is known as the **frequency response** of the amplifier.

Three Regions of Frequency Response: A typical RC-coupled transistor amplifier exhibits the following behaviour across the frequency spectrum:

1. **Low-Frequency Region:**
   - At low frequencies, the reactance of the **coupling capacitors** ($X_C = 1/2\pi fC$) becomes significant.
   - This high reactance causes a large voltage drop across the coupling capacitors, reducing the signal available for amplification.
   - Additionally, the **emitter bypass capacitor** becomes less effective at low frequencies, introducing negative feedback.
   - **Result: Voltage gain is low and falls with decreasing frequency.**
2. **Mid-Frequency Region:**

- In this range, the coupling capacitors behave almost like short circuits (very low reactance).
- The bypass capacitor effectively shorts the emitter resistor, removing negative feedback.
- The junction capacitances of the transistor are small enough to be treated as open circuits.
- **Result: Voltage gain is maximum, constant, and independent of frequency.**

3. **High-Frequency Region:**

- At high frequencies, the internal **junction capacitances** (base-emitter and base-collector) and **wiring stray capacitances** provide low-reactance paths.
- These shunt capacitances divert the signal current away from the load, reducing the effective gain.
- The current gain factor (β or h_{fe}) of the transistor itself decreases at high frequencies.
- **Result: Voltage gain falls with increasing frequency.**

Evaluation of Options:

(a) **False.** The voltage gain does not remain constant; it varies with frequency.

(b) **False.** The gain is **low** (not high) at high and low frequencies. It is constant and maximum in the middle frequency range.

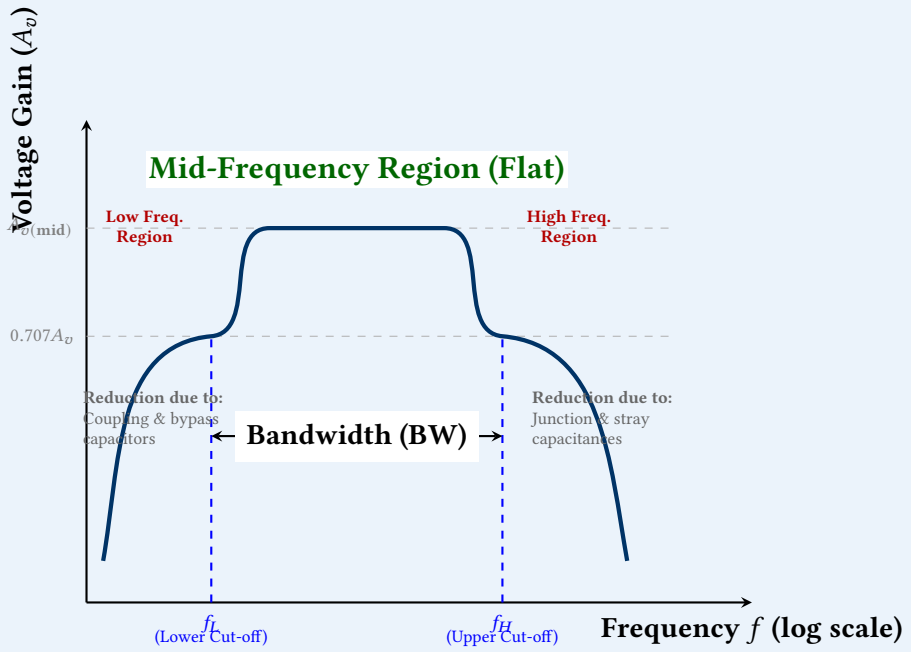
(c) **True.** This correctly describes the frequency response: gain is low at low and high frequencies, and remains constant (and maximum) at mid frequencies.

(d) **False.** Option (c) is a correct statement.

Final Answer:

Option **(c)** is correct.

Visual Representation: Frequency Response Curve of an Amplifier



The frequency response curve of a typical RC-coupled amplifier showing low, mid, and high-frequency regions.

Expert's Solution — Rahul Verma, B.Tech Electronics & Communication, NIT Surathkal

Understanding the Cut-off Frequencies and Bandwidth:

- **Lower Cut-off Frequency (f_L):** The frequency at which the gain falls to $1/\sqrt{2}$ (or 0.707) of the mid-band gain. Below this frequency, coupling and bypass capacitors degrade performance.
- **Upper Cut-off Frequency (f_H):** The frequency at which the gain again falls to 0.707 of the mid-band value. Above this frequency, internal transistor capacitances shunt the signal.
- **Bandwidth (BW):** The range of frequencies over which the gain is nearly constant. $BW = f_H - f_L$.

Why Gain Falls at Extremes – A Quick Summary:

Frequency Range	Dominant Cause of Gain Fall	Reactive Component
Low f	Series impedance drop	Coupling Capacitor (C_C)
High f	Shunt current diversion	Junction Capacitance (C_μ, C_π)

Did You Know?

Quick Tip: Visualise the frequency response as a **trapezoid** rather than a rectangle. The top flat region is where your amplifier works best. In audio amplifiers, the mid-band is designed to cover the human hearing range (20 Hz to 20 kHz). Capacitors act as **open circuits** at very low frequencies (blocking signal) and as **short circuits** at very high frequencies (shunting signal), which is why they are the culprits for gain reduction at both extremes!

Q8 In half-wave rectification, what is the output frequency if the input frequency is 50 Hz? What is the output frequency of a full-wave rectifier for the same input frequency?

Solution

Given Data:

- Input AC frequency, $f_{in} = 50$ Hz

Part I: Half-Wave Rectifier
Working Principle:

- A half-wave rectifier allows current to pass only during one half-cycle (say, the positive half) of the input AC signal.
- During the negative half-cycle, the diode is reverse biased and no current flows.
- Thus, the output consists of pulses corresponding to only one half of each input cycle.

Frequency of Output Ripple:

- The output waveform completes **one pulse per input cycle**.
- The time period of the output ripple is the same as the time period of the input AC.
- Therefore, the frequency of the output ripple is **equal to the input frequency**.

$$f_{\text{out (half-wave)}} = f_{in} = 50 \text{ Hz}$$

Part II: Full-Wave Rectifier
Working Principle:

- A full-wave rectifier (using a centre-tap transformer or bridge rectifier) inverts the negative half-cycle and makes it positive.

- Thus, current flows through the load during **both half-cycles** of the input AC.
- The output consists of **two pulses per input cycle**.

Frequency of Output Ripple:

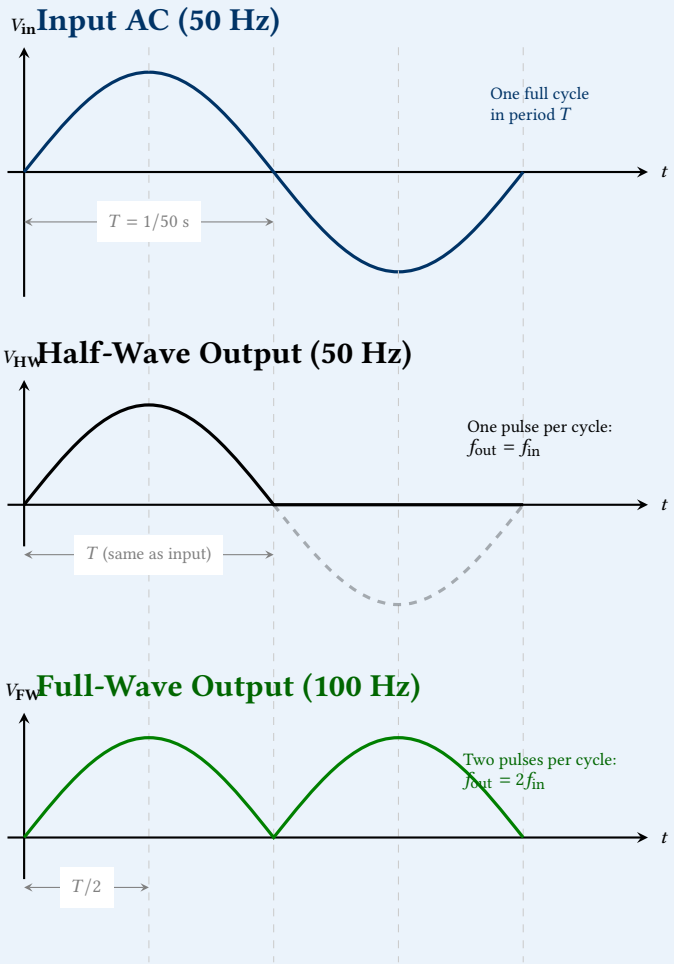
- For every one cycle of the input AC, the output completes **two cycles** (pulses).
- The time period of the output ripple is **half** the time period of the input AC.
- Therefore, the frequency of the output ripple is **double** the input frequency.

$$f_{\text{out (full-wave)}} = 2 \times f_{\text{in}} = 2 \times 50 = 100 \text{ Hz}$$

Final Answer:

Half-wave rectifier output frequency: $f_{\text{out}} = 50$ Hz
Full-wave rectifier output frequency: $f_{\text{out}} = 100$ Hz

Visual Representation: Input and Output Waveforms



Comparison of input AC waveform with half-wave and full-wave rectified outputs showing the relationship between input and output frequencies.

Expert's Solution — Ananya Gupta, B.Tech Electrical Engineering, NIT Kurukshetra

Understanding Ripple Frequency: The **ripple frequency** is the frequency of the fluctuating DC output of a rectifier. It is a crucial parameter for designing filter circuits:

Rectifier Type	Ripple Frequency	Relationship
Half-Wave	$f_{out} = f_{in}$	Same as line frequency
Full-Wave (Centre-tap/Bridge)	$f_{out} = 2f_{in}$	Double the line frequency

Practical Significance:

- A higher ripple frequency (100 Hz vs 50 Hz for 50 Hz mains) makes filtering **easier** in full-wave rectifiers. The filter capacitor does not need to hold charge as long between peaks.
- This is one of the key advantages of full-wave rectification over half-wave rectification, along with higher efficiency and lower ripple factor.

Did You Know?

In countries with a 60 Hz power supply (like the USA), the ripple frequencies are 60 Hz (half-wave) and 120 Hz (full-wave). The humming sound you sometimes hear from poorly filtered audio equipment is at these ripple frequencies—50/100 Hz in India, or 60/120 Hz in the US! The smoother DC from a full-wave rectifier is why it's preferred in almost all electronic power supplies.

Q9 **For a CE-transistor amplifier, the audio signal voltage across the collector resistance of 2 kΩ is 2 V. Suppose the current amplification factor of the transistor is 100, find the input signal voltage and base current, if the base resistance is 1 kΩ.**

Solution

Given Data:

- Collector resistance, $R_C = 2\ \text{k}\Omega = 2 \times 10^3\ \Omega$
- Output signal voltage (across R_C), $V_o = 2\ \text{V}$
- Current amplification factor, $\beta = 100$
- Base resistance, $R_B = 1\ \text{k}\Omega = 1 \times 10^3\ \Omega$

Step 1: Calculate Collector Current (I_C) The output voltage V_o is developed across the collector resistance R_C due to the collector current I_C. Using Ohm's law:

$$V_o = I_C \cdot R_C$$

$$I_C = \frac{V_o}{R_C} = \frac{2}{2 \times 10^3} = 1 \times 10^{-3} \text{ A} = 1 \text{ mA}$$

Step 2: Calculate Base Current (I_B) The current amplification factor β (also known as h_{FE}) for a common-emitter (CE) transistor is defined as the ratio of collector current to base current:

$$\beta = \frac{I_C}{I_B}$$

Rearranging to find I_B:

$$I_B = \frac{I_C}{\beta} = \frac{1 \times 10^{-3}}{100} = 1 \times 10^{-5} \text{ A} = 10 \ \mu\text{A}$$

Step 3: Calculate Input Signal Voltage (V_i) The input signal voltage V_i is applied across the base resistance R_B. Using Ohm's law:

$$V_i = I_B \cdot R_B$$

$$V_i = (1 \times 10^{-5}) \times (1 \times 10^3) = 1 \times 10^{-2} \text{ V} = 10 \text{ mV}$$

Step 4: Verify Voltage Gain (A_v) The voltage gain of the CE amplifier can be verified:

$$A_v = \frac{V_o}{V_i} = \frac{2}{10 \times 10^{-3}} = 200$$

Alternatively, using the theoretical formula for voltage gain:

$$A_v = \beta \cdot \frac{R_C}{R_B} = 100 \times \frac{2 \text{ k}\Omega}{1 \text{ k}\Omega} = 100 \times 2 = 200$$

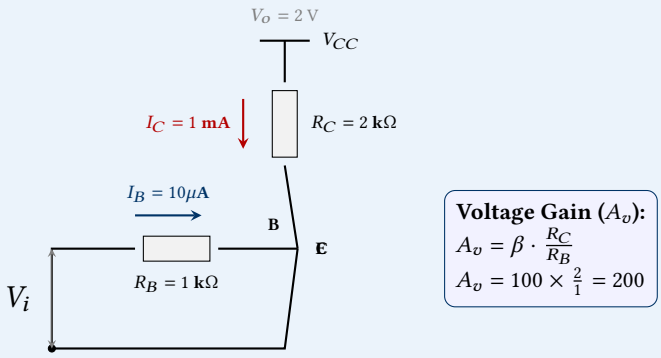
Both results match, confirming the calculations.

Final Answer:

Input signal voltage: $V_i = 10 \text{ mV} = 0.01 \text{ V}$

Base current: $I_B = 10 \ \mu\text{A} = 1 \times 10^{-5} \text{ A}$

Visual Representation: CE Amplifier Circuit



Simplified circuit diagram of a CE amplifier showing the relationship between input and output parameters.

Expert's Solution — Vikram Singh, B.Tech Electronics Engineering, NIT Jalandhar

Key Relationships in a CE Amplifier:

- **Current Gain:** $\beta = I_C/I_B$. A small base current controls a large collector current.
- **Voltage Gain:** $A_v = V_o/V_i = \beta \cdot (R_C/R_B)$. The voltage gain is proportional to β and the ratio of collector to base resistance.
- **Power Gain:** $A_p = A_v \times \beta = \beta^2 \cdot (R_C/R_B)$. The transistor amplifies power significantly.

Verification of Results: Working backwards to verify:

$$V_i = I_B \cdot R_B = 10\ \mu\text{A} \times 1\ \text{k}\Omega = 10\ \text{mV}$$
$$I_C = \beta \cdot I_B = 100 \times 10\ \mu\text{A} = 1\ \text{mA}$$
$$V_o = I_C \cdot R_C = 1\ \text{mA} \times 2\ \text{k}\Omega = 2\ \text{V}$$

All values are perfectly consistent.

Did You Know?

Quick Tip: In CE amplifier numericals, remember this flow:
$V_i \rightarrow I_B$ (via R_B) $\rightarrow I_C = \beta I_B \rightarrow V_o = I_C R_C$.
The beauty is that a tiny 10 mV input becomes a 2 V output—that's a **200x amplification**! The transistor is essentially a **current-operated** device where a small base current "controls" a much larger collector current.

Q10 Two amplifiers are connected one after the other in series (cascaded). The first amplifier has a voltage gain of 10 and the second has a voltage gain of 20. If the input signal is 0.01 volt, calculate the output ac signal.

Solution

Given Data:

- Voltage gain of first amplifier, $A_{v1} = 10$
- Voltage gain of second amplifier, $A_{v2} = 20$

- Input signal voltage, $V_i = 0.01$ V

Concept: Cascaded Amplifiers When two or more amplifiers are connected in series (cascaded), the output of the first amplifier serves as the input to the second amplifier.

- The **total voltage gain** (A_v) of cascaded amplifiers is the **product** of the individual voltage gains.
- This is because the voltage gets multiplied at each stage of amplification.

Step 1: Calculate Total Voltage Gain

$$A_v = A_{v1} \times A_{v2}$$

$$A_v = 10 \times 20 = 200$$

Step 2: Calculate Output Signal Voltage The total voltage gain is defined as the ratio of output voltage to input voltage:

$$A_v = \frac{V_o}{V_i}$$

Rearranging to find V_o:

$$V_o = A_v \times V_i$$

$$V_o = 200 \times 0.01 = 2.0 \text{ V}$$

Alternative Step-by-Step Method: We can also calculate the output step-by-step through each amplifier:

$$V_{o1} = A_{v1} \times V_i = 10 \times 0.01 = 0.1 \text{ V}$$

This V_{o1} becomes the input to the second amplifier:

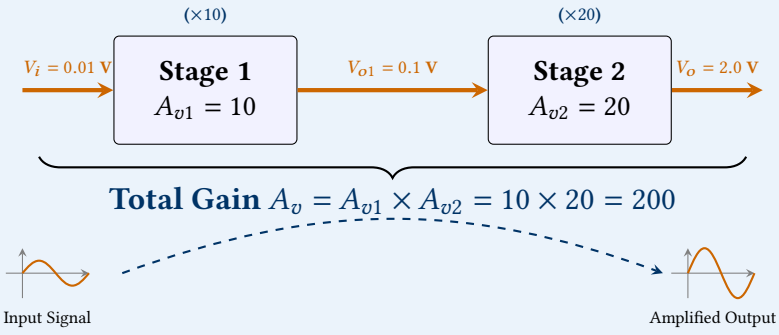
$$V_{o2} = A_{v2} \times V_{o1} = 20 \times 0.1 = 2.0 \text{ V}$$

Both methods yield the same final output.

Final Answer:

$$\boxed{V_o = 2.0 \text{ V}}$$

Visual Representation: Cascaded Amplifier Chain



Block diagram of cascaded amplifiers showing the multiplication of voltage gains at each stage.

Expert's Solution — Neha Patil, B.Tech Electronics & Communication, NIT Goa

Understanding Cascaded Amplifiers:

- The **overall voltage gain** of cascaded systems is the **product** of individual gains:

$$A_{v(\text{total})} = A_{v1} \times A_{v2} \times A_{v3} \times \dots$$

- This multiplicative nature is why cascading is used when high gain is needed. Instead of a single amplifier with gain 200, two stable amplifiers with gains 10 and 20 can be used.
- **Decibel (dB) Representation:** Gains are often expressed in decibels, where the product becomes a **sum**:

$$A_v(\text{dB}) = 20 \log_{10}(A_v) = 20 \log_{10}(200) \approx 46 \text{ dB}$$

Practical Considerations: In real circuits, the overall gain might be slightly less than the product due to **loading effects**—the input impedance of the next stage loads the output of the previous stage, reducing the effective gain. Proper **impedance matching** (or buffering) between stages ensures the theoretical gain is achieved.

Did You Know?

Quick Tip: Cascading amplifiers is like a **relay race**—each runner (amplifier) takes the baton (signal) from the previous one and advances it further. The final lead (output) is the product of all individual efforts (gains). Also, note that the output signal (2 V) is in phase with the input signal in a CE amplifier, meaning both are sinusoidal AC signals with the same frequency, just different amplitudes!

Q11 A p-n photodiode is fabricated from a semiconductor with band gap of 2.8 eV. Can it detect a wavelength of 6000 nm?

Solution

Given Data:

- Energy band gap of the semiconductor, $E_g = 2.8$ eV
- Wavelength of incident light, $\lambda = 6000 \text{ nm} = 6000 \times 10^{-9} \text{ m} = 6 \times 10^{-6} \text{ m}$

Concept: Working Principle of a Photodiode A photodiode operates on the principle of **photoelectric absorption**. When light of sufficient energy is incident on the photodiode, electron-hole pairs are generated in the depletion region, producing a photocurrent.

- For the photon to create an electron-hole pair, its energy must be **greater than or equal to** the band gap energy of the semiconductor:

$$E_{\text{photon}} \geq E_g$$

- The energy of a photon is related to its wavelength by:

$$E = h\nu = \frac{hc}{\lambda}$$

Step 1: Calculate the Energy of the Incident Photon Using the formula $E = \frac{hc}{\lambda}$:

$$E = \frac{hc}{\lambda}$$

where:

- Planck's constant, $h = 6.626 \times 10^{-34}$ J s
- Speed of light, $c = 3 \times 10^8$ m s^{-1}
- $\lambda = 6 \times 10^{-6}$ m

$$E = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{6 \times 10^{-6}}$$

$$E = \frac{1.9878 \times 10^{-25}}{6 \times 10^{-6}} = 3.313 \times 10^{-20} \text{ J}$$

Step 2: Convert Energy from Joules to Electron-Volts We know that 1 eV $= 1.6 \times 10^{-19}$ J.

$$E = \frac{3.313 \times 10^{-20}}{1.6 \times 10^{-19}} \text{ eV}$$

$$E = \frac{3.313}{16} \approx 0.207 \text{ eV}$$

Step 3: Compare Photon Energy with Band Gap Energy

$$E_{\text{photon}} = 0.207 \text{ eV}$$

$$E_g = 2.8 \text{ eV}$$

Since E_{photon} (0.207 eV) $\ll E_g$ (2.8 eV), the energy of the incident photon is **much less** than the band gap energy.

Conclusion: The photon does not have sufficient energy to excite an electron from the valence band to the conduction band. Therefore, no electron-hole pair will be generated, and **the photodiode cannot detect this wavelength**.

Alternative Method: Calculate the Threshold Wavelength We can also find the maximum

wavelength (λ_{max}) that the photodiode can detect. This corresponds to a photon energy exactly equal to the band gap:

$$\lambda_{max} = \frac{hc}{E_g}$$

First, convert E_g to Joules:

$$E_g = 2.8 \text{ eV} = 2.8 \times 1.6 \times 10^{-19} = 4.48 \times 10^{-19} \text{ J}$$

$$\lambda_{max} = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{4.48 \times 10^{-19}}$$

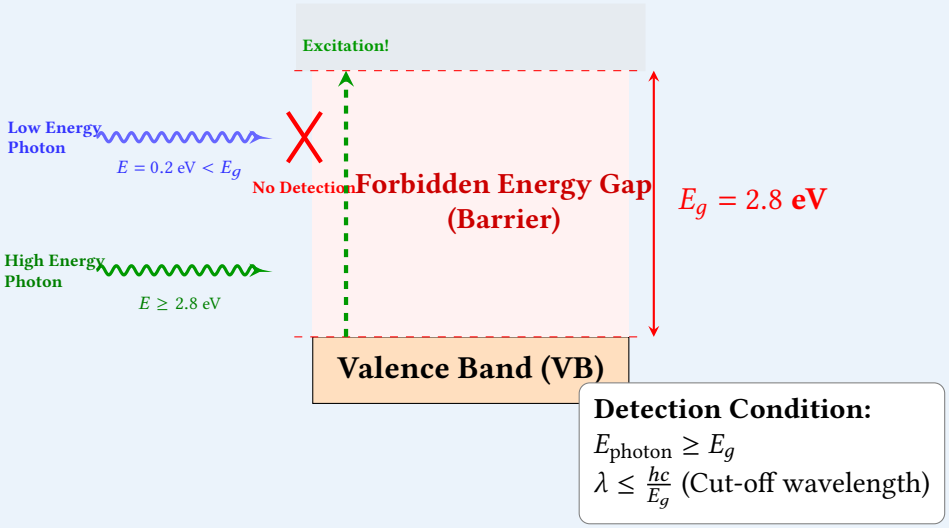
$$\lambda_{max} = \frac{1.9878 \times 10^{-25}}{4.48 \times 10^{-19}} \approx 4.44 \times 10^{-7} \text{ m} \approx 444 \text{ nm}$$

The given wavelength $\lambda = 6000$ nm is much larger than $\lambda_{max} = 444$ nm. Hence, it **cannot be detected**.

Final Answer:

No, the photodiode cannot detect the wavelength of 6000 nm.

Visual Representation: Energy Band Diagram and Photon Absorption



Energy band diagram illustrating why a photon of 6000 nm cannot be detected by a photodiode with $E_g = 2.8$ eV.

Expert's Solution — Karthik Menon, B.Tech Engineering Physics, NIT Calicut

Understanding the Cut-off Wavelength: Every photodiode has a **cut-off wavelength** (λ_c), also known as the long-wavelength limit, given by:

$$\lambda_c = \frac{hc}{E_g} \approx \frac{1240}{E_g(\text{eV})} \text{ nm}$$

This is a very handy formula for quick calculations!

Semiconductor	E_g (eV)	λ_c (nm)	Spectral Range
Silicon (Si)	1.1	≈ 1130	Visible to Near-IR
Germanium (Ge)	0.7	≈ 1770	Near-IR
InGaAs	0.75	≈ 1650	IR (fiber optics)
GaN (this problem)	2.8	≈ 443	UV to Blue

Converting to Practical Units: The wavelength 6000 nm = 6 μm falls in the **infrared (IR) region** of the electromagnetic spectrum. A semiconductor with $E_g = 2.8$ eV can only detect wavelengths ≤ 444 nm, which falls in the **visible (violet/blue) and ultraviolet** region. Hence, this photodiode is suitable for UV detection, not IR.

Did You Know?

Quick Tip: Remember the simple conversion:

$$\text{Photon energy (eV)} \approx \frac{1240}{\text{Wavelength (nm)}}$$

For $\lambda = 6000$ nm: $E \approx \frac{1240}{6000} \approx 0.207$ eV, which is far less than 2.8 eV. This quick mental check instantly tells you that detection is impossible! No elaborate calculation is needed in an MCQ situation.