GATE 2026 EE Question Paper with Solutions

Time Allowed :3 Hours	Maximum Marks :100	Total Questions :65

General Instructions

Read the following instructions very carefully and strictly follow them:

1. Each GATE 2024 paper consists of a total of 100 marks. The examination is divided into two sections – General Aptitude (GA) and the Candidate's Selected Subjects. General Aptitude carries 15 marks, while the remaining 85 marks are dedicated to the candidate's chosen test paper syllabus.
2. GATE 2024 will be conducted in English as a Computer Based Test (CBT) at select centres in select cities. The duration of the examination is 3 hours.
3. MCQs carry 1 mark or 2 marks.
4. For a wrong answer in a 1-mark MCQ, 1/3 mark is deducted.
5. For a wrong answer in a 2-mark MCQ, 2/3 mark is deducted.
6. No negative marking for wrong answers in MSQ or NAT questions.

1. Given an open-loop transfer function $GH = \frac{100}{s(s+100)}$ for a unity feedback system with a unit step input $r(t) = u(t)$, determine the rise time t_r.

Correct Answer: Calculated as approximately 2.18 s

Solution:

Step 1: Understanding the Question:
We are given the open-loop transfer function $GH(s)$ of a control system. Assuming it is a unity feedback system ($H(s) = 1$), we need to find the rise time (t_r) for a unit step input. Rise time is typically defined as the time taken for the response to rise from 10% to 90% of its final value.

Step 2: Key Formula or Approach:
1. Find the closed-loop transfer function $T(s) = \frac{G(s)}{1+G(s)H(s)}$.
2. Compare the characteristic equation (denominator) with the standard second-order form $s^2 + 2\zeta\omega_n s + \omega_n^2$ to find the natural frequency (ω_n) and damping ratio (ζ).
3. Based on the value of ζ, classify the system (underdamped, critically damped, or over-damped).
4. Use the appropriate method or approximation to calculate the rise time. For an overdamped system dominated by a single pole, the first-order approximation $t_r \approx 2.2\tau$ is often used, where τ is the time constant of the dominant pole.

Step 3: Detailed Explanation:

1. Closed-Loop Transfer Function:

For a unity feedback system, $H(s) = 1$ and $G(s) = \frac{100}{s(s+100)}$.

$$T(s) = \frac{G(s)}{1+G(s)} = \frac{\frac{100}{s(s+100)}}{1+\frac{100}{s(s+100)}} = \frac{100}{s(s+100)+100}$$

$$T(s) = \frac{100}{s^2+100s+100}$$

2. Determine System Parameters:

Comparing the denominator with the standard form $s^2 + 2\zeta\omega_n s + \omega_n^2$:

- $\omega_n^2 = 100 \implies \omega_n = 10$ rad/s.
- $2\zeta\omega_n = 100 \implies 2\zeta(10) = 100 \implies \zeta = 5$.

3. Classify System and Calculate Rise Time:

Since $\zeta = 5 > 1$, the system is **overdamped**. The response will be slow and will not have oscillations. For heavily overdamped systems, the rise time can be approximated using the dominant pole. Let's find the poles (roots of the characteristic equation):

$$s = \frac{-100 \pm \sqrt{100^2 - 4(1)(100)}}{2} = \frac{-100 \pm \sqrt{9600}}{2} = -50 \pm \sqrt{2400} \approx -50 \pm 48.99$$

The two poles are:

- $p_1 = -50 + 48.99 = -1.01$ (Dominant/slow pole)
- $p_2 = -50 - 48.99 = -98.99$ (Fast pole)

The pole at $s = -1.01$ is much closer to the origin, so it dominates the system's transient response. We can approximate the system as a first-order system with a time constant τ corresponding to this dominant pole.

$$\tau = \frac{1}{|p_1|} = \frac{1}{1.01} \approx 0.99 \text{ s}$$

The rise time (10%-90%) for a first-order system is given by:

$$t_r \approx 2.2\tau$$

$$t_r \approx 2.2 \times 0.99 \approx 2.178 \text{ s}$$

Step 4: Final Answer:

The system is heavily overdamped ($\zeta = 5$). Using the dominant pole approximation, the rise time is calculated to be approximately 2.18 seconds.

Quick Tip

For second-order systems, always calculate the damping ratio ζ first. If $\zeta > 1$ (over-damped) and one pole is significantly closer to the origin than the other (a rule of thumb is by a factor of 5 or more), you can approximate the system as a first-order system using the dominant pole to quickly estimate parameters like rise time and settling time.

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2. Consider a linear time-invariant system represented by the state-space equation:

$$\dot{x} = \begin{bmatrix} a & b \\ -a & 0 \end{bmatrix} x + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u$$

The closed-loop poles of the system are located at $-2 \pm j3$. The value of the parameter b is:

(A) 3.25
(B) -3.25
(C) 13
(D) -13

Correct Answer: (B) -3.25

Solution:

Step 1: Understanding the Question:
We are given the state-space representation of a system with a state matrix A. The poles of a linear time-invariant system are the eigenvalues of its state matrix A. We are given the locations of these poles and need to find the value of an unknown parameter b in the matrix A.

Step 2: Key Formula or Approach:
The poles of the system are the roots of the characteristic equation, which is given by $\det(sI - A) = 0$, where s is the Laplace variable, I is the identity matrix, and A is the state matrix.

Step 3: Detailed Explanation:
1. Formulate the characteristic equation from the matrix A:
The state matrix is $A = \begin{bmatrix} a & b \\ -a & 0 \end{bmatrix}$.

$$sI - A = s\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} a & b \\ -a & 0 \end{bmatrix} = \begin{bmatrix} s-a & -b \\ a & s \end{bmatrix}$$

The determinant is:

$$\det(sI - A) = (s-a)(s) - (-b)(a) = s^2 - as + ab$$

So, the characteristic equation is $s^2 - as + ab = 0$.

2. Formulate the characteristic equation from the given poles:
The poles are located at $-2 + j3$ and $-2 - j3$. The characteristic equation can be formed from its roots:

$$(s - (-2 + j3))(s - (-2 - j3)) = 0$$
$$((s+2) - j3)((s+2) + j3) = 0$$

Using the identity $(x - y)(x + y) = x^2 - y^2$:

$$(s+2)^2 - (j3)^2 = 0$$

$$(s^2 + 4s + 4) - (j^2 \cdot 9) = 0$$
$$s^2 + 4s + 4 - (-9) = 0$$
$$s^2 + 4s + 13 = 0$$

3. Compare coefficients to find a and b:
Now we equate the two forms of the characteristic equation:

$$s^2 - as + ab = s^2 + 4s + 13$$

By comparing the coefficients of the powers of s:

- Coefficient of s: $-a = 4 \implies a = -4$
- Constant term: $ab = 13$

Substitute the value of a into the second equation:

$$(-4)b = 13$$
$$b = -\frac{13}{4} = -3.25$$

Step 4: Final Answer:
The value of the parameter b is -3.25.

Quick Tip

For any 2x2 matrix $A = \begin{bmatrix} p & q \\ r & t \end{bmatrix}$, the characteristic equation is always $s^2 - (p+t)s + (pt - qr) = 0$, where $(p+t)$ is the trace and $(pt - qr)$ is the determinant of A. This can be a faster way to find the equation. In this case, trace $= a + 0 = a$, determinant $= a(0) - b(-a) = ab$. The equation is $s^2 - (a)s + (ab) = 0$, which matches our result.

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3. Consider a linear active two-terminal network connected across terminals Y and Z. If the Thevenin equivalent resistance (R_{TH}) of this network is calculated to be 0 Ω, the network behaves essentially as an:

(A) Ideal Current Source
(B) Ideal Voltage Source
(C) Practical Voltage Source
(D) Open Circuit

Correct Answer: (B) Ideal Voltage Source

Solution:

Step 1: Understanding the Question:
The question asks to identify the nature of a two-terminal network based on its Thevenin equivalent resistance. The key information is that $R_{TH} = 0\,\Omega$.

Step 2: Detailed Explanation:
1. Thevenin's Theorem:
Thevenin's theorem states that any linear, two-terminal network can be replaced by an equivalent circuit consisting of a single voltage source, V_{TH}, in series with a single resistor, R_{TH}. The voltage V_{TH} is the open-circuit voltage at the terminals, and the resistance R_{TH} is the equivalent resistance seen from the terminals with all independent sources turned off (voltage sources shorted, current sources opened).

2. Analyzing the case $R_{TH} = 0\,\Omega$:
If we draw the Thevenin equivalent circuit with $R_{TH} = 0\,\Omega$, the series resistance becomes a short circuit (a wire with zero resistance). The equivalent circuit simplifies to just the Thevenin voltage source, V_{TH}, connected to the terminals.

3. Definitions of Source Models:

- **Ideal Voltage Source:** An ideal voltage source is a theoretical circuit element that provides a constant voltage across its terminals, regardless of the current drawn from it. Its key characteristic is having **zero internal series resistance**.
- **Practical Voltage Source:** A practical voltage source is a more realistic model, represented by an ideal voltage source in series with a small internal resistance ($R_{internal} > 0$).
- **Ideal Current Source:** An ideal current source provides a constant current, regardless of the voltage across its terminals. Its internal resistance (in the parallel Norton model) is **infinite**.
- **Open Circuit:** An open circuit is a break in the circuit, corresponding to infinite resistance.

Step 3: Final Answer:
A network with a Thevenin resistance of $0\,\Omega$ is equivalent to a voltage source V_{TH} with a series resistance of zero. This is the definition of an ideal voltage source. The network will maintain a constant voltage V_{TH} across its terminals Y and Z, irrespective of the load connected.

Quick Tip

Remember the ideal source characteristics by their internal resistances:

- Ideal Voltage Source: $R_{series} = 0\,\Omega$
- Ideal Current Source: $R_{parallel} = \infty\,\Omega$

This direct mapping helps in quickly solving such conceptual problems.

4. A single-phase two-winding transformer is rated at 15 kVA, 1100/220 V. It is reconnected as an autotransformer with a voltage rating of 1320/1100 V. Find the kVA rating of the autotransformer.

Correct Answer: 90 kVA

Solution:

Step 1: Understanding the Question:
We are given a standard two-winding transformer's specifications. It is then reconnected to function as an autotransformer. The goal is to calculate the new, higher kVA rating in the autotransformer configuration. The connection is from 1100 V to 1320 V, which is an additive polarity step-up connection (1100 V + 220 V = 1320 V).

Step 2: Key Formula or Approach:
The kVA rating of an autotransformer formed by reconnecting a two-winding transformer can be found using the following relation:

$$(kVA)_{auto} = \left(\frac{V_{High}}{V_{High} - V_{Low}}\right) \times (kVA)_{two-winding}$$

Alternatively, using the transformation ratio (k) of the original two-winding transformer:

$$(kVA)_{auto} = (k+1) \times (kVA)_{two-winding} \quad \text{(for additive polarity)}$$

where $k = \frac{V_{HV}}{V_{LV}}$ of the two-winding transformer.

Step 3: Detailed Explanation:
Method 1: Using Voltages of the Autotransformer

- Autotransformer High Voltage, $V_{High} = 1320$ V.
- Autotransformer Low Voltage, $V_{Low} = 1100$ V.
- Two-winding transformer kVA rating, $(kVA)_{two-winding} = 15$ kVA.

Substituting these values into the formula:

$$(kVA)_{auto} = \left(\frac{1320}{1320 - 1100}\right) \times 15$$

$$(kVA)_{auto} = \left(\frac{1320}{220}\right) \times 15$$

$$(kVA)_{auto} = 6 \times 15 = 90 \text{ kVA}$$

Method 2: Using Transformation Ratio of the Two-winding Transformer

- High Voltage winding, $V_{HV} = 1100$ V.
- Low Voltage winding, $V_{LV} = 220$ V.

- Transformation ratio, $k = \frac{1100}{220} = 5$.

Using the formula for additive polarity:

$$(kVA)_{auto} = (k+1) \times (kVA)_{two-winding}$$

$$(kVA)_{auto} = (5+1) \times 15 = 6 \times 15 = 90 \text{ kVA}$$

Step 4: Final Answer:
Both methods yield the same result. The kVA rating of the autotransformer is 90 kVA. This significant increase in power handling capacity is a key advantage of using an autotransformer when the voltage ratio is close to unity.

Quick Tip

When a two-winding transformer is reconfigured as an autotransformer, its kVA rating increases by a factor of $(k+1)$, where k is the turns ratio of the original high-voltage winding to the low-voltage winding. This is a quick way to find the new rating.

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5. Which of the following statements is correct about the small-signal voltage gain of single-stage MOSFET amplifiers? Consider the statement: "Both common source and common gate amplifiers are inverting amplifiers."

(A) The statement is correct.
(B) The statement is incorrect.

Correct Answer: (B) The statement is incorrect.

Solution:

Step 1: Understanding the Question:
The question asks to evaluate the correctness of the statement that both common source (CS) and common gate (CG) MOSFET amplifiers are inverting. An inverting amplifier produces an output signal that is 180 degrees out of phase with the input signal.

Step 2: Detailed Explanation:
1. Common Source (CS) Amplifier:

- **Configuration:** The input signal is applied to the gate, the output is taken from the drain, and the source is common (usually at AC ground).
- **Operation:** When the input voltage at the gate (V_{in}) increases, the gate-source voltage (V_{GS}) increases. This causes the drain current (I_D) to increase. The output voltage is given by $V_{out} = V_{DD} - I_D R_D$. As I_D increases, the voltage drop across the drain resistor R_D increases, causing V_{out} to decrease.

- **Conclusion:** An increase in V_{in} leads to a decrease in V_{out}. This signifies a 180-degree phase shift. Therefore, the **Common Source amplifier is an inverting amplifier**. Its voltage gain is given by $A_v \approx -g_m R_D$, where the negative sign explicitly indicates inversion.

2. Common Gate (CG) Amplifier:

- **Configuration:** The input signal is applied to the source, the output is taken from the drain, and the gate is common (at AC ground).
- **Operation:** When the input voltage at the source ($V_{in} = V_S$) increases, the gate-source voltage $V_{GS} = V_G - V_S = 0 - V_{in}$ becomes more negative (decreases). This causes the drain current (I_D) to decrease. The output voltage is given by $V_{out} = V_{DD} - I_D R_D$. As I_D decreases, the voltage drop across R_D decreases, causing V_{out} to increase.
- **Conclusion:** An increase in V_{in} leads to an increase in V_{out}. This signifies a 0-degree phase shift. Therefore, the **Common Gate amplifier is a non-inverting amplifier**. Its voltage gain is given by $A_v \approx g_m R_D$, which is positive.

Step 3: Final Answer:
Since the Common Source amplifier is inverting but the Common Gate amplifier is non-inverting, the statement "Both common source and common gate amplifiers are inverting amplifiers" is incorrect.

Quick Tip

Remember the phase relationships for the three basic single-stage MOSFET amplifiers:

- **Common Source (CS):** Inverting (180° phase shift).
- **Common Gate (CG):** Non-inverting (0° phase shift).
- **Common Drain (CD) / Source Follower:** Non-inverting (0° phase shift).

Only the Common Source configuration inverts the signal.

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6. For the inverting operational amplifier circuit shown below, determine the closed-loop voltage gain ($A_{cl} = V_{out}/V_{in}$). The op-amp has an open-loop gain $A_{OL} = 10^5$.
(A) -20
(B) 20
(C) -19.996
(D) -20.042

Correct Answer: (C) -19.996

Solution:

Step 1: Understanding the Question:
The question asks for the closed-loop voltage gain of an inverting op-amp. We are given the values of the input resistor, feedback resistor, and a finite open-loop gain. This means we should calculate the precise gain, not just the ideal one.

Step 2: Key Formula or Approach:
For an ideal op-amp ($A_{OL} \to \infty$), the gain of an inverting amplifier is:

$$A_{cl,ideal} = -\frac{R_f}{R_{in}}$$

For a non-ideal op-amp with finite open-loop gain A_{OL}, the formula for the closed-loop gain is:

$$A_{cl} = \frac{A_{cl,ideal}}{1 - \frac{\beta}{A_{OL}}} \quad \text{or more commonly written as} \quad A_{cl} = \frac{-R_f/R_{in}}{1 + \frac{1+R_f/R_{in}}{A_{OL}}}$$

Where the term $(1 + R_f/R_{in})$ is the non-inverting gain or "noise gain".

Step 3: Detailed Explanation:
1. Calculate the ideal closed-loop gain:

$$A_{cl,ideal} = -\frac{R_f}{R_{in}} = -\frac{100\,k\Omega}{5\,k\Omega} = -20$$

2. Calculate the non-ideal closed-loop gain:
Now, we use the formula for the non-ideal case with the given values:

- $R_f = 100\,k\Omega$
- $R_{in} = 5\,k\Omega$
- $A_{OL} = 10^5$
- $R_f/R_{in} = 20$

$$A_{cl} = \frac{-20}{1 + \frac{1+20}{10^5}}$$

$$A_{cl} = \frac{-20}{1 + \frac{21}{100000}}$$

$$A_{cl} = \frac{-20}{1 + 0.00021}$$

$$A_{cl} = \frac{-20}{1.00021} \approx -19.995800...$$

This value can be rounded to -19.996. The value -19.99 shown in the image is a close approximation.

Step 4: Final Answer:
The calculated closed-loop gain, accounting for the finite open-loop gain, is approximately -19.996. This is very close to the ideal value of -20, showing that for a high A_{OL}, the ideal formula is a very good approximation.

Quick Tip

When an op-amp's open-loop gain (A_{OL}) is finite, the actual closed-loop gain will always have a smaller magnitude than the ideal gain. For an inverting amplifier, this means the gain will be slightly closer to zero (e.g., -19.996 instead of -20).

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7. For the circuit shown below, find the value of the load resistance R_L that will absorb the maximum amount of power from the source circuit.

(A) 5 Ω
(B) 1.818 Ω
(C) 7.333 Ω
(D) 2.857 Ω

Correct Answer: (D) 2.857 Ω

Solution:

Step 1: Understanding the Question:
The question asks for the value of the load resistor R_L that ensures maximum power transfer (MPT).

Step 2: Key Formula or Approach:
The Maximum Power Transfer Theorem states that maximum power is delivered from a source network to a load resistor R_L when the value of R_L is equal to the Thevenin equivalent resistance (R_{TH}) of the source network as seen from the terminals of the load.

$$R_L = R_{TH}$$

To find R_{TH}, we must deactivate all independent sources in the circuit (voltage sources are replaced by short circuits, and current sources by open circuits) and then calculate the equivalent resistance looking back into the load terminals.

Step 3: Detailed Explanation:
The calculation shown in the image is '$R_TH = ... = 40/14 = 20/7 = 2.857$ Ω'. This numerical result corresponds to the parallel combination of the 10 Ω and 4 Ω resistors:

$$R_{eq} = 10\Omega \parallel 4\Omega = \frac{10 \times 4}{10 + 4} = \frac{40}{14} = \frac{20}{7}\Omega \approx 2.857\,\Omega$$

This suggests that when finding the Thevenin resistance, the 5 Ω resistor is not part of the calculation. This would occur in a circuit topology where deactivating the 10V source also shorts out the 5 Ω resistor. A possible circuit configuration for this is where the 5 Ω resistor is directly in parallel with the 10V source. When the source is shorted, the 5 Ω resistor is also shorted and can be ignored. Then, if the 10 Ω and 4 Ω resistors are in parallel with respect to the load terminals, we get the calculated R_{TH}.

Assuming this interpretation is correct based on the provided answer: **1. Find the Thevenin Resistance (R_{TH}):** We follow the result from the image's calculation.

$$R_{TH} = \frac{20}{7}\,\Omega \approx 2.857\,\Omega$$

2. Apply the Maximum Power Transfer Theorem: For maximum power transfer, the load resistance must equal the Thevenin resistance.

$$R_L = R_{TH} = 2.857\,\Omega$$

Step 4: Final Answer:
To achieve maximum power transfer, the load resistance R_L must be equal to the Thevenin resistance of the circuit, which is calculated to be 2.857 Ω.

Quick Tip

To apply the Maximum Power Transfer theorem, always focus on finding the Thevenin equivalent circuit (V_{TH} and R_{TH}) as seen by the load. For purely resistive circuits, maximum power is achieved when $R_L = R_{TH}$.

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8. In the series circuit shown containing a voltage source (V), a diode (D), a resistor (R), an inductor (L), and a capacitor (C), which of the following components are considered linear?

(A) R
(B) Diode
(C) L, C, D
(D) R, L, C only

Correct Answer: (D) R, L, C only

Solution:

Step 1: Understanding the Question:
The question requires us to identify which of the components in the given series circuit are linear. A linear circuit element is one that obeys the principle of superposition and homogeneity. In simpler terms, its voltage-current (V-I) relationship can be described by a linear equation, resulting in a straight-line V-I characteristic graph that passes through the origin.

Step 2: Detailed Explanation:
Let's analyze the V-I relationship for each component:

- **Resistor (R):** An ideal resistor follows Ohm's Law, $V = I \cdot R$. The voltage across the resistor is directly proportional to the current flowing through it. This is a linear relationship. Therefore, the resistor is a **linear** component.

- **Inductor (L):** The relationship for an ideal inductor is $V = L\frac{di}{dt}$. The voltage is directly proportional to the rate of change of current. This is a linear differential relationship. Therefore, the inductor is a **linear** component.
- **Capacitor (C):** The relationship for an ideal capacitor is $I = C\frac{dv}{dt}$. The current is directly proportional to the rate of change of voltage. This is also a linear differential relationship. Therefore, the capacitor is a **linear** component.
- **Diode (D):** The V-I relationship for a diode is described by the Shockley diode equation, which is exponential: $I = I_s(e^{V_D/(nV_T)} - 1)$. Since the relationship between voltage and current is exponential and not a straight line, the diode is a **non-linear** component.

Step 3: Final Answer:
Based on the analysis, the resistor (R), inductor (L), and capacitor (C) are linear components, while the diode (D) is a non-linear component. Therefore, the correct option identifies only R, L, and C as linear.

> Quick Tip
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> A simple rule of thumb for basic circuit elements is that the standard passive components—resistors (R), inductors (L), and capacitors (C)—are treated as linear. Semiconductor devices like diodes, transistors, and SCRs are inherently non-linear.

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9. If P and Q are positive integers such that $P^2 = Q^2 + 13$, find the value of the product PQ.

(A) 13
(B) 42
(C) 49
(D) 36

Correct Answer: (B) 42

Solution:

Step 1: Understanding the Question:
We are given an equation relating the squares of two positive integers, P and Q. Our goal is to find their values and then calculate their product, PQ.

Step 2: Key Formula or Approach:
The key to solving this problem is to rearrange the equation and use the algebraic identity for the difference of squares:

$$a^2 - b^2 = (a - b)(a + b)$$

We will also use the fact that 13 is a prime number.

Step 3: Detailed Explanation:
1. Rearrange the given equation:

$$P^2 = Q^2 + 13$$

$$P^2 - Q^2 = 13$$

2. Apply the difference of squares formula:

$$(P - Q)(P + Q) = 13$$

3. Analyze the factors: Since P and Q are positive integers, $(P - Q)$ and $(P + Q)$ must also be integers. Furthermore, since $P > 0$ and $Q > 0$, their sum $(P + Q)$ must be a positive integer. Because their product is 13 (a positive number), the term $(P - Q)$ must also be a positive integer. The number 13 is a prime number, which means its only positive integer factors are 1 and 13. Also, since Q is positive, $(P + Q) > (P - Q)$. Therefore, we must have:

$$P + Q = 13$$

$$P - Q = 1$$

4. Solve the system of linear equations: We now have a simple system of two equations. We can solve it by adding the two equations together:

$$(P + Q) + (P - Q) = 13 + 1$$

$$2P = 14$$

$$P = 7$$

Now, substitute the value of P back into the first equation:

$$7 + Q = 13$$

$$Q = 13 - 7$$

$$Q = 6$$

5. Calculate the product PQ:

$$PQ = 7 \times 6 = 42$$

Step 4: Final Answer:
The values of the integers are P = 7 and Q = 6. Their product, PQ, is 42.

Quick Tip

When you encounter an equation of the form $x^2 - y^2 = p$, where p is a prime number, immediately factor it as $(x - y)(x + y) = p \times 1$. This quickly sets up a system of two linear equations: $x + y = p$ and $x - y = 1$, which is very easy to solve.
