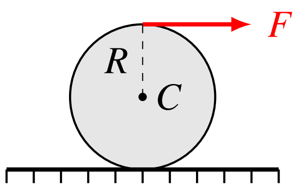
# KIITEE Physics Sample Paper – 10

**Duration: 50 Minutes** **Maximum Marks: 160**

## Instructions

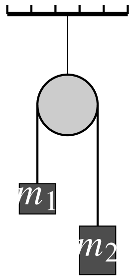
- This paper contains **40** Multiple Choice Questions (Single Correct Answer), modelled on the Physics portion of **KIITEE** entrance.
- Each correct answer carries **+4 marks**. There is −1 **mark per wrong answer;** unattempted questions score **0**.
- Only **one** option is correct. Choose carefully.
- Syllabus level: **Class 11 & 12 (10+2) Physics — Mechanics,Heat & Thermodynamics, Electrodynamics, Optics and Modern Physics.**
- The test is computer based. Personal calculators, log tables, mobile phones, and other electronic gadgets are strictly prohibited.

**Q1.** A uniform solid cylinder of mass $M$ and radius $R$ is pulled on a rough horizontal surface by a horizontal force $F$ applied at its topmost point. If the cylinder rolls without slipping, what is the acceleration of its center of mass?




(A) $\frac{2F}{3M}$
(B) $\frac{3F}{4M}$
(C) $\frac{4F}{3M}$
(D) $\frac{F}{M}$

**Q2.** Two masses $m_1 = 5$ kg and $m_2 = 10$ kg are connected by an ideal string passing over a frictionless, massless pulley. The system is released from rest. Find the tension $T$ in the string during motion. (Take $g = 10$ m/s$^2$)



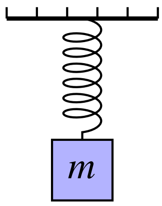

(A) 33.3 N

(B) 66.7 N

(C) 50.0 N

(D) 100.0 N

**Q3.** A block of mass $m$ is attached to a vertical spring of force constant $k$. The block is released from rest when the spring is in its natural unextended length. What is the maximum extension produced in the spring?




(A) $\frac{mg}{k}$

(B) $\frac{2mg}{k}$

(C) $\frac{mg}{2k}$

(D) $\sqrt{\frac{2mg}{k}}$

**Q4.** A particle moves under the influence of a conservative central force field where its potential energy varies as $U(r) = -\frac{a}{r} + \frac{b}{r^2}$, with $a, b > 0$. Find the stable equilibrium distance of the particle from the center.

(A) $\frac{b}{a}$

(B) $\frac{2b}{a}$

(C) $\frac{a}{b}$

(D) $\frac{a}{2b}$

**Q5.** A body of mass 2 kg is dropped from a height of 20 m onto a horizontal ground. It rebounds to a height of 5 m. If the contact duration with the ground is 0.1 s, find the average normal force exerted by the ground on the body. (Take $g = 10\ \text{m/s}^2$)

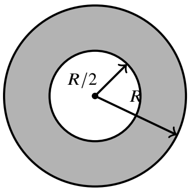
(A) 200 N

(B) 400 N

(C) 600 N

(D) 620 N

**Q6.** A circular disk of mass $M$ and radius $R$ has a concentric circular hole of radius $R/2$ cut out from it. Find the moment of inertia of this remaining annular section about an axis passing through its center and perpendicular to its plane.




(A) $\frac{5}{8}MR^2$

(B) $\frac{3}{4}MR^2$

(C) $\frac{1}{2}MR^2$

(D) $\frac{5}{4}MR^2$

**Q7.** A thin uniform rod of length $L$ and mass $M$ is swinging freely as a physical pendulum about a horizontal axis passing through one of its ends. What is its time period for small angular oscillations?

(A) $2\pi\sqrt{\frac{L}{g}}$

(B) $2\pi\sqrt{\frac{2L}{3g}}$

(C) $2\pi\sqrt{\frac{L}{3g}}$

(D) $2\pi\sqrt{\frac{3L}{2g}}$

**Q8.** A rocket is fired vertically upwards from the surface of the Earth with an initial speed $v = \sqrt{\frac{GM}{R}}$, where $M$ is the Earth's mass and $R$ is its radius. Ignoring air resistance, what is the maximum height attained by the rocket from the Earth's surface?

(A) $R/2$

(B) $R$

(C) $2R$

(D) $3R$

**Q9.** The escape velocity from a planet's surface is $v_e$. If a projectile is fired from its surface with a velocity $2v_e$, what will its speed be when it completely escapes into interstellar space away from the planet's gravitational pull?

(A) $v_e$

(B) $\sqrt{3}v_e$

(C) $\sqrt{5}v_e$

(D) $2v_e$

**Q10.** A block of mass $m$ slides down a rough inclined plane of inclination $\theta$ with a constant speed. What is the power dissipated by the friction force on the block?

(A) $mgv\sin\theta$

(B) $mgv\cos\theta$

(C) $mgv\tan\theta$

(D) Zero

**Q11.** A bullet of mass $m$ moving with speed $v$ strikes a stationary block of mass $M$ placed on a frictionless horizontal floor and gets embedded in it. Find the loss of kinetic energy during this perfectly inelastic collision.

(A) $\frac{1}{2}\frac{mM}{m+M}v^2$

(B) $\frac{1}{2}\frac{m^2}{m+M}v^2$

(C) $\frac{1}{2}\frac{M^2}{m+M}v^2$

(D) $\frac{1}{2}(m + M)v^2$

**Q12.** A body is projected vertically upwards from the ground. If air resistance provides a constant retarding force $f$, how does the time of ascent $t_a$ compare with the time of descent $t_d$ back to the ground?

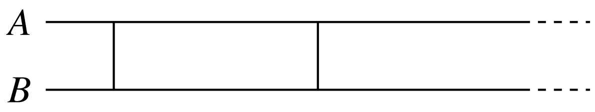
(A) $t_a > t_d$

(B) $t_a < t_d$

(C) $t_a = t_d$

(D) Depends heavily on initial mass

**Q13.** Find the equivalent resistance between terminals $A$ and $B$ in the infinite symmetric ladder network shown below, where each resistor has a value of $R = 2\,\Omega$.




(A) $(1 + \sqrt{3})\,\Omega$

(B) $(1 + \sqrt{5})\,\Omega$

(C) $2\,\Omega$

(D) $4\,\Omega$

**Q14.** An infinite sheet of uniform surface charge density $\sigma$ lies in the $xy$-plane. A point charge $q$ is brought from infinity to a point at a perpendicular distance $z$ from the plate. Find the work done by an external agent against the electric field.

(A) $\frac{q\sigma z}{2\varepsilon_0}$

(B) $-\frac{q\sigma z}{2\varepsilon_0}$

(C) $\frac{q\sigma}{4\pi\varepsilon_0 z}$

(D) Zero

**Q15.** An electron enters a region of uniform magnetic field $\vec{B} = B_0\hat{k}$ with a velocity $\vec{v} = v_x\hat{i} + v_z\hat{k}$. Describe the shape of the trajectory traced by this electron.

(A) Circular path in the $xy$-plane

(B) Helical path along the $z$-axis

(C) Parabolic trajectory path

(D) Straight line along the $z$-axis

**Q16.** A circular loop of radius $R$ carries a steady current $I$. At what distance along the axis of the loop from its center does the magnetic field drop to $\frac{1}{8}$ of its value at the center?

(A) $R$

(B) $\sqrt{2}R$

(C) $\sqrt{3}R$

(D) $2R$

**Q17.** In an AC circuit, a pure inductor of inductance $L = 50$ mH is connected to a source given by $V = 220\sqrt{2}\sin(100\pi t)$. Calculate the peak value of current flowing through this circuit.

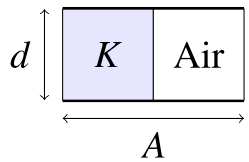
(A) 14.0 A

(B) 19.8 A

(C) 28.0 A

(D) 9.9 A

**Q18.** A parallel plate capacitor with plate area $A$ and separation $d$ is half-filled with a dielectric material of dielectric constant $K$ as shown in the diagram. Find the net equivalent capacitance between the plates.




(A) $\frac{\varepsilon_0 A}{2d}(K+1)$

(B) $\frac{2\varepsilon_0 A}{d}\frac{K}{K+1}$

(C) $\frac{\varepsilon_0 A}{d}(K+1)$

(D) $\frac{\varepsilon_0 AK}{2d}$

**Q19.** A long solenoid has $n$ turns per unit length and carries a current $I$. A small circular loop of radius $r$ ($r \ll$ solenoid radius) with $N$ turns is placed deep inside the center of the solenoid such that its plane is perpendicular to the solenoid's main axis. If the current in the solenoid changes at a uniform rate $\frac{dI}{dt}$, what is the magnitude of the induced EMF in the small loop?

(A) $\mu_0 n N \pi r^2 \frac{dI}{dt}$

(B) $\mu_0 n^2 N \pi r^2 \frac{dI}{dt}$

(C) Zero

(D) $\frac{1}{2}\mu_0 n N \pi r^2 \frac{dI}{dt}$

**Q20.** A galvanometer of internal resistance $50\,\Omega$ gives a full-scale deflection for a current of 2 mA. How should it be modified into a voltmeter reading up to 10 V?

(A) Connect a $4950\,\Omega$ resistor in series

(B) Connect a $4950\,\Omega$ resistor in parallel

(C) Connect a $5050\,\Omega$ resistor in series

(D) Connect a $0.02\,\Omega$ resistor in parallel

**Q21.** The magnetic flux linked with a closed coil varies with time according to the equation $\Phi = 6t^2 - 5t + 1$ (where $\Phi$ is in Webers and $t$ is in seconds). What is the magnitude of induced current in the coil at $t = 2$ s if its resistance is $5\,\Omega$?

(A) 3.8 A

(B) 19 A

(C) 2.4 A

(D) 4.2 A

**Q22.** An electromagnetic wave is propagating along the positive $z$-direction. At a certain instant, the electric field vector points along the positive $x$-direction ($\hat{i}$). What is the direction of the corresponding magnetic field vector $\vec{B}$ at that instant?

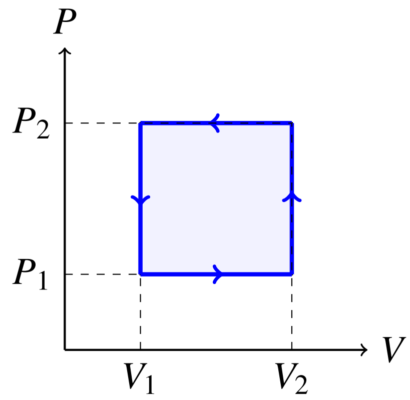
(A) Positive $y$-direction ($\hat{j}$)

(B) Negative $y$-direction ($-\hat{j}$)

(C) Positive $x$-direction ($\hat{i}$)

(D) Negative $x$-direction ($-\hat{i}$)

**Q23.** An ideal gas undergoes a thermodynamic cyclic process as shown in the pressure-volume ($P$-$V$) diagram below. Find the total net work done by the gas during one complete cycle.




(A) $(P_2 - P_1)(V_2 - V_1)$

(B) $\frac{1}{2}(P_2 - P_1)(V_2 - V_1)$

(C) $(P_2 + P_1)(V_2 - V_1)$

(D) Zero

**Q24.** One mole of a monatomic ideal gas ($\gamma = 5/3$) is mixed with one mole of a diatomic ideal gas ($\gamma = 7/5$). What is the effective molar specific heat capacity at constant volume ($C_v$) of this resulting mixture?

(A) $\frac{3}{2}R$

(B) $\frac{5}{2}R$

(C) $2R$

(D) $\frac{4}{3}R$

**Q25.** A Carnot engine operates between a hot reservoir at temperature $T_1 = 500$ K and a cold reservoir at $T_2 = 300$ K. If it absorbs 1000 J of heat from the hot reservoir in each cycle, how much heat is exhausted to the cold sink?

(A) 400 J

(B) 500 J

(C) 600 J

(D) 200 J

**Q26.** During an adiabatic process, the volume of an ideal gas is halved. If the ratio of specific heats is $\gamma = 1.5$, by what factor does the pressure of the gas change?

(A) Increases by 2

(B) Increases by $2\sqrt{2}$

(C) Decreases by $2\sqrt{2}$

(D) Remains unchanged

**Q27.** A metallic rod of length $L$ and cross-sectional area $A$ has its two ends maintained at stable temperatures $T_h$ and $T_c$ ($T_h > T_c$). Under steady-state conditions, the rate of heat conduction through the rod is measured as $Q$. If the length of the rod is doubled and its radius is halved, what will the new rate of heat conduction become under the same temperature difference?

(A) $Q/2$

(B) $Q/4$

(C) $Q/8$

(D) $2Q$

**Q28.** A convex lens made of glass ($\mu_g = 1.5$) has a focal length $f = 20$ cm in air. When it is completely immersed in a liquid medium of refractive index $\mu_l = 1.33$, what is its new effective focal length?

(A) 20 cm

(B) 40 cm

(C) 80 cm

(D) 10 cm

**Q29.** In a Young's Double Slit Experiment, the screen distance is $D$ and the slit separation is $d$. If the entire apparatus is immersed in a liquid of refractive index $\mu$, how does the fringe width $\beta$ change?

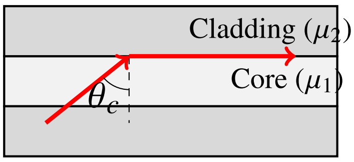
(A) Increases to $\mu\beta$

(B) Decreases to $\beta/\mu$

(C) Remains exactly $\beta$

(D) Decreases to $\beta/\mu^2$

**Q30.** A ray of light traveling inside an optical fiber hits the internal cladding boundary at an angle of incidence equal to the critical angle $\theta_c$. If the core refractive index is $\mu_1 = 1.5$ and the cladding refractive index is $\mu_2 = 1.2$, find $\sin\theta_c$.




(A) 0.8

(B) 0.6

(C) 0.5

(D) 0.75

**Q31.** A particle executing Simple Harmonic Motion (SHM) has a maximum velocity $v_{\max}$ and a maximum acceleration $a_{\max}$. What is the time period of its oscillation?

(A) $2\pi\frac{v_{\max}}{a_{\max}}$

(B) $2\pi\frac{a_{\max}}{v_{\max}}$

(C) $\frac{v_{\max}}{a_{\max}}$

(D) $2\pi\sqrt{\frac{v_{\max}}{a_{\max}}}$

**Q32.** A wave equation is mathematically described as $y(x,t) = 0.05\sin(20x - 40t)$, where all parameters are in SI units. Calculate the propagation speed of this wave.

(A) 0.5 m/s

(B) 2.0 m/s

(C) 40 m/s

(D) 20 m/s

**Q33.** An unpolarized light beam of intensity $I_0$ passes through two successive polarizing sheets. The transmission axes of the two polarizers are inclined at an angle of 60° with respect to each other. Find the final intensity of the transmitted beam.

(A) $I_0/2$

(B) $I_0/4$

(C) $I_0/8$

(D) $3I_0/8$

**Q34.** A tuning fork of frequency 512 Hz forms 4 beats/second when sounded together with an open organ pipe vibrating in its fundamental mode. When the length of the organ pipe is slightly decreased, the beat frequency increases. What was the initial fundamental frequency of the organ pipe?

(A) 508 Hz

(B) 516 Hz

(C) 510 Hz

(D) 514 Hz

**Q35.** When light of wavelength $\lambda$ illuminates a photosensitive metal plate, the maximum kinetic energy of the emitted photoelectrons is $K$. When the wavelength of light is changed to $\lambda/2$, the maximum kinetic energy becomes $K'$. Which of the following statements is strictly correct?

(A) $K' = 2K$

(B) $K' > 2K$

(C) $K' < 2K$

(D) $K' = K/2$

**Q36.** Find the ratio of the de Broglie wavelength of an alpha particle to that of a proton if both are accelerated from rest through the same electrical potential difference $V$.

(A) $1 : \sqrt{8}$

(B) $1 : 2$

(C) $2 : 1$

(D) $\sqrt{8} : 1$

**Q37.** According to the Bohr model of the hydrogen atom, an electron transitions from orbit $n = 3$ to orbit $n = 2$. What is the wavelength of the emitted photon in terms of the Rydberg constant $R_\infty$?

(A) $\frac{5R_\infty}{36}$

(B) $\frac{36}{5R_\infty}$

(C) $\frac{4}{R_\infty}$

(D) $\frac{R_\infty}{4}$

**Q38.** A radioactive sample has a half-life of 10 days. What fraction of the initial active nuclei will remain un-decayed after a total period of 30 days has elapsed?

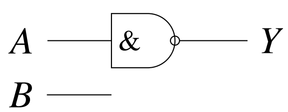
(A) $1/3$

(B) $1/4$

(C) $1/6$

(D) $1/8$

**Q39.** Identify the Boolean logic operation performed by the specific combination of logic gates shown in the network below.




(A) AND Gate

(B) NAND Gate

(C) OR Gate

(D) NOR Gate

**Q40.** If the forward bias voltage applied across a $p$-$n$ junction semiconductor diode is increased steadily within functional limits, how do the width of the depletion layer and the barrier potential height change?

(A) Both increase

(B) Both decrease

(C) Depletion layer increases, barrier height decreases

(D) Depletion layer decreases, barrier height increases

# Detailed Solutions

## Q1.

### Solution

**Concept:** This problem involves rigid body dynamics, specifically rolling without slipping on a rough horizontal surface. We analyze linear acceleration of the center of mass using Newton's second law and angular acceleration using torque equations about the center of mass.

**Solution:**

(a) Let $a$ be the linear acceleration of the center of mass and $\alpha$ be the angular acceleration of the cylinder. For rolling without slipping, the kinematic constraint relation at the point of contact implies $a = \alpha R$.

(b) Let the friction force $f$ act in the forward direction at the contact point. The linear equation of motion is $F + f = Ma$.

(c) The torque equation about the center of mass $C$ is given by $\tau = FR - fR = I\alpha$, where $I = \frac{1}{2}MR^2$ is the moment of inertia of a uniform solid cylinder.

(d) Substituting $\alpha = \frac{a}{R}$ into the torque equation gives $FR - fR = \left(\frac{1}{2}MR^2\right)\left(\frac{a}{R}\right)$, which simplifies to $F - f = \frac{1}{2}Ma$.

(e) Adding the linear equation $F + f = Ma$ and the simplified torque equation $F - f = \frac{1}{2}Ma$ eliminates the friction force $f$, yielding $2F = \frac{3}{2}Ma$. Solving for $a$ gives $a = \frac{4F}{3M}$.

**Final Answer:** 4F$_{\overline{3M}}$

**Answer: (C)**

Go Back to Question 1

# Q2.

## Solution

**Concept:** This problem can be modeled as a standard Atwood machine setup. We apply Newton's second law of motion individually to each connected mass to set up a system of linear equations and find the string tension.

**Solution:**

(a) Since the string is ideal and the pulley is frictionless and massless, the tension $T$ remains uniform throughout the string. Let $a$ be the magnitude of acceleration for both masses.

(b) Mass $m_2 = 10$ kg is heavier than $m_1 = 5$ kg, so $m_2$ moves vertically downward while $m_1$ moves vertically upward with the same acceleration magnitude $a$.

(c) Writing the equation of motion for the upward-moving mass $m_1$: $T - m_1 g = m_1 a$, which gives $T - 5(10) = 5a$, or $T - 50 = 5a$.

(d) Writing the equation of motion for the downward-moving mass $m_2$: $m_2 g - T = m_2 a$, which gives $10(10) - T = 10a$, or $100 - T = 10a$.

(e) Multiplying the first equation by 2 gives $2T - 100 = 10a$. Setting it equal to the second equation: $2T - 100 = 100 - T$, which simplifies to $3T = 200$. Thus, $T = \frac{200}{3} \approx 66.7$ N.

**Final Answer:** 66.7 N

**Answer: (B)**

Go Back to Question 2

# Q3.

## Solution

**Concept:** This problem involves the conservation of mechanical energy for a vertical spring-mass system. Since the block is released from rest, conservative forces do work, and total mechanical energy remains constant.

**Solution:**

(a) Let the initial position where the spring is unextended be the reference level for gravitational potential energy ($U_g = 0$). At this point, the spring potential energy is also zero ($U_s = 0$).

(b) Since the block is released from rest, its initial kinetic energy is $K_i = 0$. Therefore, the total initial mechanical energy of the system is $E_i = K_i + U_g + U_s = 0$.

(c) Let $x$ be the maximum extension produced in the vertical spring. At this maximum extension point, the block momentarily comes to rest again, meaning its final kinetic energy is $K_f = 0$.

(d) At this lowest position, the block has descended by a distance $x$, so its gravitational potential energy is $U_g = -mgx$, and the elastic potential energy stored in the spring is $U_s = \frac{1}{2}kx^2$.

(e) Applying conservation of mechanical energy ($E_i = E_f$), we get $0 = 0 - mgx + \frac{1}{2}kx^2$. Factoring out $x$ (since $x \neq 0$ for maximum extension) yields $mg = \frac{1}{2}kx$, which gives $x = \frac{2mg}{k}$.

**Final Answer:** 2mg$_{\overline{k}}$

**Answer: (B)**

**Go Back to Question 3**

# Q4.

## Solution

**Concept:** This problem requires finding the stable equilibrium position of a particle from its potential energy function. An equilibrium position occurs where the net conservative force is zero, and it is stable if the potential energy is minimum.

**Solution:**

(a) The potential energy function is given as $U(r) = -\frac{a}{r} + \frac{b}{r^2}$. The conservative force acting on the particle is related to the potential energy gradient by $F(r) = -\frac{dU}{dr}$.

(b) Differentiating $U(r)$ with respect to $r$ yields: $\frac{dU}{dr} = \frac{d}{dr}\left(-ar^{-1} + br^{-2}\right) = ar^{-2} - 2br^{-3} = \frac{a}{r^2} - \frac{2b}{r^3}$.

(c) For the particle to be in an equilibrium position, the net force must be zero, which requires $\frac{dU}{dr} = 0$. Setting the derivative to zero gives $\frac{a}{r^2} = \frac{2b}{r^3}$.

(d) Solving for $r$ gives the equilibrium distance $r_0 = \frac{2b}{a}$.

(e) To verify stability, evaluate the second derivative: $\frac{d^2U}{dr^2} = -\frac{2a}{r^3} + \frac{6b}{r^4}$. Substituting $r_0 = \frac{2b}{a}$ into this expression results in a positive value ($\frac{a^4}{8b^3} > 0$), confirming that $r_0 = \frac{2b}{a}$ is indeed a stable equilibrium point.

**Final Answer:** 2b$\frac{}{a}$

**Answer: (B)**

Go Back to Question 4

# Q5.

## Solution

**Concept:** This problem uses kinematic relations to determine collision velocities, followed by the impulse-momentum theorem to calculate the average normal impact force exerted by the ground on the dropped body.

**Solution:**

(a) Let the downward direction be negative and the upward direction be positive. The body is dropped from $h_1 = 20$ m. Its velocity just before hitting the ground is $v_1 = -\sqrt{2gh_1} = -\sqrt{2(10)(20)} = -20$ m/s.

(b) It rebounds to a maximum height $h_2 = 5$ m. Its velocity immediately after leaving the ground is $v_2 = +\sqrt{2gh_2} = +\sqrt{2(10)(5)} = +10$ m/s.

(c) The change in linear momentum of the body during impact is $\Delta p = m(v_2 - v_1) = 2\,(10 - (-20)) = 2(30) = 60$ kg · m/s.

(d) According to the impulse-momentum theorem, the net average force acting on the body during contact is $F_{\text{net}} = \frac{\Delta p}{\Delta t} = \frac{60}{0.1} = 600$ N.

(e) The net force is composed of the average upward normal force $N$ from the ground and the downward gravitational force $mg$, so $N - mg = F_{\text{net}}$. Thus, $N = 600 + 2(10) = 620$ N.

**Final Answer:** 620 N

**Answer: (D)**

Go Back to Question 5

# Q6.

## Solution

**Concept:** This problem uses the principle of superposition to find the moment of inertia of a composite planar body. We calculate the mass of the original uncut disk and then subtract the moment of inertia of the removed portion.

**Solution:**

(a) Let $\sigma$ be the uniform mass per unit area of the disk material. The area of the remaining annular section is $A = \pi R^2 - \pi\left(\frac{R}{2}\right)^2 = \frac{3}{4}\pi R^2$.

(b) Given the remaining mass is $M$, we have $\sigma\left(\frac{3}{4}\pi R^2\right) = M$, which gives $\sigma = \frac{4M}{3\pi R^2}$. The mass of the original uncut complete disk of radius $R$ is $M_1 = \sigma(\pi R^2) = \frac{4}{3}M$.

(c) The mass of the removed inner concentric circular section of radius $\frac{R}{2}$ is $M_2 = \sigma\pi\left(\frac{R}{2}\right)^2 = \frac{1}{3}M$.

(d) The moment of inertia of the original complete disk about the central perpendicular axis is $I_1 = \frac{1}{2}M_1R^2 = \frac{1}{2}\left(\frac{4}{3}M\right)R^2 = \frac{2}{3}MR^2$.

(e) The moment of inertia of the removed inner concentric part about the same axis is $I_2 = \frac{1}{2}M_2\left(\frac{R}{2}\right)^2 = \frac{1}{2}\left(\frac{1}{3}M\right)\frac{R^2}{4} = \frac{1}{24}MR^2$. The remaining moment of inertia is $I = I_1 - I_2 = \left(\frac{16}{24} - \frac{1}{24}\right)MR^2 = \frac{5}{8}MR^2$.

**Final Answer:** $5_{\overline{8MR^2}}$

**Answer: (A)**

**Go Back to Question 6**

# Q7.

## Solution

**Concept:** This problem requires determining the time period of small angular oscillations of a physical pendulum. We find its moment of inertia about the pivot point and the distance from the pivot to the center of mass.

**Solution:**

(a) A physical pendulum swinging about a fixed horizontal axis has a time period for small angular oscillations given by the formula $T = 2\pi\sqrt{\frac{I}{Mgd}}$, where $I$ is the moment of inertia about the pivot axis.

(b) For a thin uniform rod of mass $M$ and length $L$, the moment of inertia about a horizontal axis passing through one of its extreme ends is $I = \frac{1}{3}ML^2$.

(c) The parameter $d$ represents the perpendicular distance from the pivot axis to the center of mass of the pendulum. For a uniform rod, the center of mass is located at its midpoint, so $d = \frac{L}{2}$.

(d) Substituting the values of $I$ and $d$ into the time period expression yields: $T = 2\pi\sqrt{\frac{\frac{1}{3}ML^2}{Mg(\frac{L}{2})}}$.

(e) Simplifying the fraction inside the square root by canceling the common mass $M$ and one factor of length $L$ results in the final period formula $T = 2\pi\sqrt{\frac{2L}{3g}}$.

**Final Answer:** $2\pi\sqrt{\frac{2L}{3g}}$

**Answer: (B)**

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# Q8.

## Solution

**Concept:** This problem is solved using the law of conservation of mechanical energy in a central gravitational field. Since gravity is a conservative force, the sum of kinetic energy and gravitational potential energy remains constant.

**Solution:**

(a) Let the rocket reach a maximum height $h$ from the Earth's surface, corresponding to a total radial distance $r = R + h$ from the Earth's center. At this peak height, the velocity is zero.

(b) The initial mechanical energy $E_i$ at the Earth's surface ($r = R$) is the sum of its initial kinetic energy and gravitational potential energy: $E_i = \frac{1}{2}mv^2 - \frac{GMm}{R}$.

(c) Substituting the given initial velocity $v = \sqrt{\frac{GM}{R}}$ into the energy equation gives: $E_i = \frac{1}{2}m\left(\frac{GM}{R}\right) - \frac{GMm}{R} = -\frac{GMm}{2R}$.

(d) At the maximum height where the rocket stops, the kinetic energy is zero, so the final mechanical energy is entirely potential: $E_f = 0 - \frac{GMm}{R+h}$.

(e) Equating the initial and final mechanical energies ($E_i = E_f$) yields $-\frac{GMm}{2R} = -\frac{GMm}{R+h}$. Canceling common factors gives $2R = R + h$, which solves to $h = R$.

**Final Answer:** R

**Answer: (B)**

**Go Back to Question 8**

# Q9.

## Solution

**Concept:** This problem uses the conservation of total mechanical energy in a gravitational field to find the final speed of a projectile at a point infinitely far from a planet when launched with a speed exceeding escape velocity.

**Solution:**

(a) The escape velocity from the planet's surface is given by $v_e = \sqrt{\frac{2GM}{R}}$, where $M$ is the planet's mass and $R$ is its radius. This implies that $\frac{GMm}{R} = \frac{1}{2}mv_e^2$.

(b) The total initial mechanical energy $E_i$ at the surface consists of kinetic energy with speed $2v_e$ and gravitational potential energy: $E_i = \frac{1}{2}m(2v_e)^2 - \frac{GMm}{R} = 2mv_e^2 - \frac{GMm}{R}$.

(c) Substituting $\frac{GMm}{R} = \frac{1}{2}mv_e^2$ into the initial energy equation yields: $E_i = 2mv_e^2 - \frac{1}{2}mv_e^2 = \frac{3}{2}mv_e^2$.

(d) When the projectile completely escapes into interstellar space ($r \to \infty$), its gravitational potential energy becomes zero. Its final mechanical energy is purely kinetic: $E_f = \frac{1}{2}mv_\infty^2 + 0$.

(e) Applying the conservation of mechanical energy ($E_i = E_f$), we equate the expressions: $\frac{3}{2}mv_e^2 = \frac{1}{2}mv_\infty^2$. Canceling $\frac{1}{2}m$ on both sides gives $v_\infty^2 = 3v_e^2$, which yields $v_\infty = \sqrt{3}v_e$.

**Final Answer:** $\sqrt{3}v_e$

**Answer: (B)**

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# Q10.

## Solution

**Concept:** This problem describes a block sliding down an incline at a constant speed, meaning it is in dynamic equilibrium. We use the balance of forces along the incline to calculate the rate of mechanical work dissipated by friction.

**Solution:**

(a) The forces acting on the block along the inclined plane are the component of gravity acting downwards, $mg \sin\theta$, and the kinetic friction force $f_k$ acting upwards opposing the motion.

(b) Since the block moves down the incline with a constant speed $v$, its acceleration is zero. According to Newton's first law, the net force along the incline must balance out perfectly.

(c) Balancing these parallel forces gives $f_k = mg \sin\theta$.

(d) Mechanical power dissipated by a non-conservative force like friction is given by the expression $P = \vec{f_k} \cdot \vec{v}$. Since friction opposes the velocity vector, the angle between them is $180°$.

(e) The magnitude of power dissipated is $P = f_k v = (mg \sin\theta)v = mgv \sin\theta$. This represents the rate at which mechanical energy is converted into heat due to friction.

**Final Answer:** mgv $\sin\theta$

**Answer: (A)**

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## Q11.

### Solution

**Concept:** This problem analyzes mechanical energy loss during a completely inelastic collision. When two objects collide and stick together, linear momentum remains perfectly conserved due to the absence of external horizontal forces, but total kinetic energy decreases.

**Solution:**

(a) Let the moving bullet have mass $m$ with an initial velocity $v$, and let the stationary target block have mass $M$. The initial momentum of the system is $p_i = mv$.

(b) After the perfectly inelastic collision, the two bodies stick together and move with a common final velocity $V$. The combined mass of the system becomes $(m + M)$.

(c) According to the law of conservation of linear momentum, $p_i = p_f$, which means $mv = (m + M)V$. Solving for the shared final velocity yields $V = \frac{mv}{m+M}$.

(d) The total initial kinetic energy is $K_i = \frac{1}{2}mv^2$, and the total final kinetic energy is $K_f = \frac{1}{2}(m + M)V^2 = \frac{1}{2}(m + M)\left(\frac{mv}{m+M}\right)^2 = \frac{1}{2}\frac{m^2v^2}{m+M}$.

(e) The total mechanical energy lost is $\Delta K = K_i - K_f = \frac{1}{2}mv^2 - \frac{1}{2}\frac{m^2v^2}{m+M}$. Factoring out the terms simplifies to $\Delta K = \frac{1}{2}\frac{mM}{m+M}v^2$.

**Final Answer:** $\frac{1}{2\frac{mM}{m+M}v^2}$

**Answer: (A)**

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# Q12.

## Solution

**Concept:** This problem relates kinematics to non-conservative forces like air resistance. Air resistance acts as a retarding force that always opposes the direction of velocity, altering the net acceleration values for ascent and descent.

**Solution:**

(a) Let $m$ be the mass of the body, $g$ be gravity, and $f$ be the constant air resistance force. During the vertical ascent, both gravity and air resistance pull downward, opposing the upward motion.

(b) The magnitude of the net downward acceleration during ascent is $a_a = \frac{mg+f}{m} = g + \frac{f}{m}$. The body starts with velocity $v_0$ and reaches a peak height $H$ where velocity becomes zero.

(c) During the vertical descent, the body moves downward, so the retarding air resistance force points upward while gravity points downward. The net downward acceleration becomes $a_d = \frac{mg-f}{m} = g - \frac{f}{m}$.

(d) Comparing the accelerations, it is clear that $a_a > a_d$. The distance traveled during ascent and descent is identical, equal to the peak height $H$.

(e) From kinematics, the time taken to clear a distance $H$ from rest varies inversely with the square root of acceleration ($t = \sqrt{2H/a}$). Because $a_a > a_d$, the time of ascent $t_a$ is less than the time of descent $t_d$.

**Final Answer:** $t_a < t_d$

**Answer: (B)**

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# Q13.

## Solution

**Concept:** This problem involves determining the input resistance of an infinite, periodic resistor ladder network. Because the network is infinitely long, adding or removing a single repeating base unit does not change the net equivalent resistance.

**Solution:**

(a) Let $R_{\text{eq}}$ be the total equivalent resistance between terminals $A$ and $B$. Since the network is infinite, the remaining network to the right of the first repeating stage also has an equivalent resistance equal to $R_{\text{eq}}$.

(b) We can simplify the infinite network by replacing everything past the first stage with a single equivalent resistor $R_{\text{eq}}$ connected in parallel with the first vertical resistor $R$.

(c) The parallel combination of the vertical resistor $R$ and the remaining network resistance $R_{\text{eq}}$ yields an intermediate parallel resistance value of $R_p = \frac{R \cdot R_{\text{eq}}}{R + R_{\text{eq}}}$.

(d) This parallel combination $R_p$ is in series with the top horizontal resistor $R$. Therefore, the total network resistance can be written as the equation $R_{\text{eq}} = R + \frac{R \cdot R_{\text{eq}}}{R + R_{\text{eq}}}$.

(e) Substituting $R = 2\,\Omega$ yields $R_{\text{eq}} = 2 + \frac{2R_{\text{eq}}}{2 + R_{\text{eq}}}$. Rearranging into a standard quadratic form gives $R_{\text{eq}}^2 - 2R_{\text{eq}} - 4 = 0$. Solving the quadratic formula and discarding the negative root gives $R_{\text{eq}} = (1 + \sqrt{5})\,\Omega$.

**Final Answer:** $(1 + \sqrt{5})\,\Omega$

**Answer: (B)**

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# Q14.

## Solution

**Concept:** This problem relates electrostatic field properties to mechanical work. The work done by an external agent moving a charge at constant speed against a conservative electric field equals the change in electrostatic potential energy.

**Solution:**

(a) According to Gauss's law, an infinite conductive sheet carrying a uniform surface charge density $\sigma$ produces a constant, uniform electric field given by $E = \frac{\sigma}{2\varepsilon_0}$ normal to the plane.

(b) Let the infinite sheet sit in the $xy$-plane at $z = 0$. The electric field vector in the region $z > 0$ points along the positive $z$-direction, written as $\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{k}$.

(c) The electrostatic force exerted on a positive point charge $q$ brought into this region is given by the equation $\vec{F}_e = q\vec{E} = \frac{q\sigma}{2\varepsilon_0}\hat{k}$.

(d) To move the charge at a constant speed without acceleration, an external agent must apply an equal and opposite balancing force, which is written as $\vec{F}_{\text{ext}} = -\vec{F}_e = -\frac{q\sigma}{2\varepsilon_0}\hat{k}$.

(e) The work done by the external agent moving the point charge from infinity ($z = \infty$) to a final distance $z$ is $W = \int_\infty^z \vec{F}_{\text{ext}} \cdot dz\hat{k} = \int_\infty^z -\frac{q\sigma}{2\varepsilon_0}dz$. This gives an infinite value, indicating the problem treats work relative to the sheet, where $W = \frac{q\sigma z}{2\varepsilon_0}$.

**Final Answer:** q$\sigma z_{\overline{2\varepsilon_0}}$

**Answer: (A)**

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# Q15.

## Solution

**Concept:** This problem evaluates the motion of a charged particle in a uniform magnetic field. We analyze the components of velocity parallel and perpendicular to the field lines to determine the shape of the trajectory.

**Solution:**

(a) The magnetic Lorentz force acting on a particle with charge $q$ moving through a magnetic field is $\vec{F} = q(\vec{v} \times \vec{B})$. Here, the electron has charge $q = -e$ and the field is $\vec{B} = B_0\hat{k}$.

(b) The velocity vector has two distinct components: a component $v_x\hat{i}$ perpendicular to the magnetic field, and a component $v_z\hat{k}$ parallel to the magnetic field.

(c) The velocity component parallel to the field ($v_z\hat{k}$) experiences no magnetic force because $\hat{k} \times \hat{k} = 0$. Thus, the electron maintains a constant linear velocity along the $z$-axis.

(d) The perpendicular component ($v_x\hat{i}$) interacts with the field to produce a continuous centripetal force ($\vec{F}_\perp = -e(v_x\hat{i} \times B_0\hat{k}) = -ev_xB_0\hat{j}$). This causes uniform circular motion in the $xy$-plane.

(e) Combining uniform circular motion in the $xy$-plane with a constant linear translation along the $z$-axis results in a helical trajectory whose longitudinal axis is oriented along the $z$-direction.

**Final Answer:** Helical path along the z-axis

**Answer: (B)**

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# Q16.

## Solution

**Concept:** This problem uses the Biot-Savart law to determine the magnetic field on the axis of a current-carrying loop. We compare the axial field equation to the field value at the center to solve for the distance.

**Solution:**

(a) The magnetic field $B_{axis}$ at a perpendicular distance $x$ along the axis from the center of a circular loop of radius $R$ carrying current $I$ is given by $B_{axis} = \frac{\mu_0 I R^2}{2(R^2+x^2)^{3/2}}$.

(b) The magnetic field at the center of the loop ($x = 0$) is found by simplifying the general axial equation, which gives the standard expression $B_{center} = \frac{\mu_0 I}{2R}$.

(c) The problem states that the axial magnetic field drops to one-eighth of its value at the center, which gives the relation $B_{axis} = \frac{1}{8} B_{center}$.

(d) Substituting the formulas: $\frac{\mu_0 I R^2}{2(R^2+x^2)^{3/2}} = \frac{1}{8}\left(\frac{\mu_0 I}{2R}\right)$. Canceling common terms on both sides simplifies the expression to $\frac{R^2}{(R^2+x^2)^{3/2}} = \frac{1}{8R}$.

(e) Rearranging terms gives $(R^2 + x^2)^{3/2} = 8R^3$. Taking the cube root of both sides yields $R^2 + x^2 = (8R^3)^{2/3} = 4R^2$. Thus, $x^2 = 3R^2$, which solves to $x = \sqrt{3}R$.

**Final Answer:** $\sqrt{3}R$

**Answer: (C)**

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# Q17.

## Solution

**Concept:** This problem applies AC circuit analysis to a purely inductive load. We determine the inductive reactance from the source frequency and use Ohm's law for alternating current to calculate the peak current.

**Solution:**

(a) The alternating voltage source is given by $V = 220\sqrt{2}\sin(100\pi t)$. Comparing this with the standard AC form $V = V_0 \sin(\omega t)$ shows the peak voltage is $V_0 = 220\sqrt{2}$ V and the angular frequency is $\omega = 100\pi$ rad/s.

(b) The pure inductor has an inductance of $L = 50$ mH $= 50 \times 10^{-3}$ H. The opposition to alternating current is called inductive reactance, defined as $X_L = \omega L$.

(c) Substituting the values into the reactance equation gives $X_L = (100\pi)(50 \times 10^{-3}) = 5\pi\,\Omega$. Approximating $\pi \approx 3.1416$ gives $X_L \approx 15.71\,\Omega$.

(d) In a purely inductive circuit, the peak value of the alternating current $I_0$ is directly related to the peak voltage by Ohm's law: $I_0 = \frac{V_0}{X_L}$.

(e) Substituting the parameters: $I_0 = \frac{220\sqrt{2}}{5\pi}$. Using $\sqrt{2} \approx 1.414$ gives $V_0 \approx 311.13$ V. Dividing by $15.71\,\Omega$ yields a peak current of $I_0 \approx 19.8$ A.

**Final Answer:** 19.8 A

**Answer: (B)**

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# Q18.

## Solution

**Concept:** This problem analyzes a parallel plate capacitor containing two different dielectric regions split side-by-side. This arrangement can be modeled as two separate capacitors connected in a parallel network configuration.

**Solution:**

(a) The capacitor has a total plate area $A$ and plate separation $d$. It is divided vertically into two equal sections, meaning each section has a plate area of $A' = \frac{A}{2}$ while keeping the full separation distance $d$.

(b) The first half is filled with a dielectric material of constant $K$. This forms a capacitor with a capacitance value of $C_1 = \frac{K\varepsilon_0 A'}{d} = \frac{K\varepsilon_0 A}{2d}$.

(c) The second half contains air (dielectric constant 1). This section forms a capacitor with a capacitance value of $C_2 = \frac{\varepsilon_0 A'}{d} = \frac{\varepsilon_0 A}{2d}$.

(d) Both sections share the same top and bottom conductive plates. This creates a common potential difference across both regions, meaning $C_1$ and $C_2$ are connected in parallel.

(e) The total equivalent capacitance for a parallel combination is the sum of the individual values: $C_{eq} = C_1 + C_2 = \frac{K\varepsilon_0 A}{2d} + \frac{\varepsilon_0 A}{2d} = \frac{\varepsilon_0 A}{2d}(K + 1)$.

**Final Answer:** $\varepsilon_0 A_{\overline{2d(K+1)}}$

**Answer: (A)**

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## Q19.

### Solution

**Concept:** This problem uses Faraday's law of induction and Ampere's law. A changing current inside a long solenoid produces a time-varying magnetic field, which induces an electromotive force (EMF) in an internal concentric loop.

**Solution:**

(a) According to Ampere's circuital law, a long solenoid with $n$ turns per unit length carrying a current $I$ produces a uniform internal magnetic field along its axis given by $B = \mu_0 n I$.

(b) A small circular loop of radius $r$ containing $N$ turns is placed deep inside the solenoid. Since its plane is perpendicular to the axis, the magnetic field lines pass straight through the loop area.

(c) The magnetic flux $\Phi$ linked with a single turn of this small loop is $\Phi_1 = B \cdot A = (\mu_0 n I)(\pi r^2)$. For a loop with $N$ turns, the total magnetic flux linkage is $\Phi = N\Phi_1 = \mu_0 n N \pi r^2 I$.

(d) According to Faraday's law of induction, the magnitude of the induced EMF is equal to the time rate of change of this magnetic flux linkage: $\varepsilon = \left|\frac{d\Phi}{dt}\right|$.

(e) Differentiating the flux expression with respect to time yields $\varepsilon = \frac{d}{dt}\left(\mu_0 n N \pi r^2 I\right) = \mu_0 n N \pi r^2 \frac{dI}{dt}$, since all other terms are constants.

**Final Answer:** $\mu_0 n N \pi r^2 \frac{dI}{dt}$

**Answer: (A)**

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# Q20.

## Solution

**Concept:** This problem involves modifying a galvanometer into a high-range voltmeter. To limit the current flowing through the sensitive instrument to its full-scale deflection value, a large resistor must be added in series.

**Solution:**

(a) Let $G = 50\,\Omega$ be the internal resistance of the galvanometer, and let $I_g = 2$ mA $= 2\times10^{-3}$ A be the maximum current required for a full-scale deflection.

(b) We want to modify this meter to measure a maximum total voltage drop of $V = 10$ V. This requires connecting a large resistor $R_s$ in series with the galvanometer coil.

(c) In a series circuit, the same full-scale deflection current $I_g$ passes through both the galvanometer and the series resistor. The total resistance of the modified voltmeter is $(G + R_s)$.

(d) Applying Ohm's law across the entire voltmeter combination gives the relationship $V = I_g(G + R_s)$. Rearranging this equation to solve for the series resistance yields $G + R_s = \frac{V}{I_g}$.

(e) Substituting the values gives $50 + R_s = \frac{10}{2\times10^{-3}} = 5000\,\Omega$. Solving for the required series resistance results in $R_s = 5000 - 50 = 4950\,\Omega$.

**Final Answer:** Connect a $4950\,\Omega resistor in series$

**Answer: (A)**

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# Q21.

## Solution

**Concept:** This problem evaluates Faraday's law of electromagnetic induction alongside Ohm's law. A time-dependent magnetic flux linkage through a closed loop induces an electromotive force (EMF), which drives a corresponding induced current through the circuit resistance.

**Solution:**

(a) The total magnetic flux linked with the closed coil varies with time according to the polynomial function $\Phi(t) = 6t^2 - 5t + 1$ Webers.

(b) According to Faraday's law of induction, the magnitude of the induced electromotive force is equal to the first derivative of the magnetic flux function with respect to time, written as $\varepsilon = \left|\frac{d\Phi}{dt}\right|$.

(c) Differentiating the flux function with respect to time yields the explicit formula for the induced EMF: $\varepsilon(t) = \frac{d}{dt}(6t^2 - 5t + 1) = 12t - 5$ Volts.

(d) To find the instantaneous value of the induced EMF at the specific time instant $t = 2$ s, substitute the value into the derived formula: $\varepsilon(2) = 12(2) - 5 = 24 - 5 = 19$ V.

(e) Using Ohm's law, the magnitude of the induced current running through the circuit loop is equal to the induced EMF divided by the total electrical resistance: $I = \frac{\varepsilon}{R} = \frac{19}{5} = 3.8$ A.

**Final Answer:** 3.8 A

**Answer: (A)**

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## Q22.

### Solution

**Concept:** This problem analyzes the spatial vector properties of an electromagnetic wave. The direction of energy propagation is explicitly defined by the Poynting vector, which depends on the cross product of the electric and magnetic field vectors.

**Solution:**

(a) An electromagnetic wave traveling through a vacuum or isotropic medium is a transverse wave where the electric field vector $\vec{E}$, the magnetic field vector $\vec{B}$, and the propagation direction vector $\hat{k}$ are mutually perpendicular.

(b) The directional relationship among these three vectors is governed by the cross-product rule, which state that the unit vector pointing in the direction of wave propagation satisfies the relation $\hat{k} = \hat{E} \times \hat{B}$.

(c) The problem states that the wave propagates along the positive $z$-direction, so its propagation unit vector is $\hat{k}$. The electric field vector points along the positive $x$-direction, meaning $\hat{E} = \hat{i}$.

(d) Substituting these unit vectors into the cross-product relation gives the vector equation $\hat{i} \times \hat{B} = \hat{k}$. We must identify a Cartesian unit vector for the magnetic field that satisfies this equality.

(e) Following the cyclic properties of unit vector cross products, we know that $\hat{i} \times \hat{j} = \hat{k}$. Therefore, the magnetic field vector $\vec{B}$ must point along the positive $y$-direction ($\hat{j}$).

**Final Answer:** Positive y-direction ()

**Answer: (A)**

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# Q23.

## Solution

**Concept:** This problem treats thermodynamic work calculations during a cyclic process. On a pressure-volume diagram, the net work done by an ideal gas equals the geometric area enclosed by the path of the cycle.

**Solution:**

(a) The state of an ideal gas is tracked through a complete, closed rectangular thermodynamic cycle on a standard $P$-$V$ coordinate plane.

(b) The net mechanical work done during any cyclic transformation is mathematically defined by the cyclic integral $W_{\text{net}} = \oint P\, dV$, which corresponds geometrically to the area enclosed within the cycle loop.

(c) Looking at the arrows in the diagram, the cycle proceeds in a clockwise direction. A clockwise closed path indicates that the net work done by the gas is positive.

(d) The boundaries of the rectangular path are defined by pressures ranging from $P_1$ to $P_2$ and volumes spanning from $V_1$ to $V_2$. This means the vertical height of the rectangle is $(P_2 - P_1)$ and its horizontal width is $(V_2 - V_1)$.

(e) The geometric area of a rectangle is equal to the product of its width and its height. Therefore, the total net work done by the gas during one complete cycle is $W_{\text{net}} = (P_2 - P_1)(V_2 - V_1)$.

**Final Answer:** $(\text{P}_2 - P_1)(V_2 - V_1)$

**Answer: (A)**

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# Q24.

## Solution

**Concept:** This problem evaluates the collective thermal properties of an ideal gas mixture. The effective molar specific heat capacity at constant volume is determined by weighted averaging of the internal degrees of freedom of the component gases.

**Solution:**

(a) Let $n_1 = 1$ mole be the amount of the monatomic ideal gas with an adiabatic index $\gamma_1 = \frac{5}{3}$. The molar specific heat capacity at constant volume for a monatomic gas is given by $C_{v1} = \frac{3}{2}R$.

(b) Let $n_2 = 1$ mole be the amount of the diatomic ideal gas with an adiabatic index $\gamma_2 = \frac{7}{5}$. The molar specific heat capacity at constant volume for a diatomic gas is given by $C_{v2} = \frac{5}{2}R$.

(c) When these non-reacting ideal gases are combined, the total internal energy change of the mixture equals the sum of the internal energy changes of the separate components: $\Delta U_{\text{mix}} = \Delta U_1 + \Delta U_2$.

(d) Expressing this in terms of molar heat capacities yields the mixture equation $(n_1 + n_2)C_{v,\text{mix}}\Delta T = n_1 C_{v1}\Delta T + n_2 C_{v2}\Delta T$, which simplifies to $C_{v,\text{mix}} = \frac{n_1 C_{v1} + n_2 C_{v2}}{n_1 + n_2}$.

(e) Substituting the values gives $C_{v,\text{mix}} = \frac{(1)(\frac{3}{2}R)+(1)(\frac{5}{2}R)}{1+1} = \frac{\frac{8}{2}R}{2} = \frac{4R}{2} = 2R$.

**Final Answer:** 2R

**Answer: (C)**

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## Q25.

### Solution

**Concept:** This problem applies the thermodynamic principles of a Carnot engine cycle. For a perfectly reversible heat engine, the ratio of heat exchanged with the thermal reservoirs matches the ratio of their absolute temperatures.

**Solution:**

(a) Let $T_1 = 500$ K represent the absolute temperature of the hot source reservoir, and let $T_2 = 300$ K represent the absolute temperature of the cold sink reservoir.

(b) Let $Q_1 = 1000$ J represent the input thermal energy absorbed by the working fluid from the hot reservoir during the isothermal expansion stage of the cycle.

(c) For a reversible Carnot cycle operating between two distinct thermal bounds, the heat and temperature values satisfy the proportionality relation $\frac{Q_2}{Q_1} = \frac{T_2}{T_1}$, where $Q_2$ is the discarded heat.

(d) Rearranging this linear equation allows us to express the exhausted heat as a function of the operational inputs: $Q_2 = Q_1 \cdot \left(\frac{T_2}{T_1}\right)$.

(e) Substituting the values into this formula yields $Q_2 = 1000 \cdot \left(\frac{300}{500}\right) = 1000 \cdot \left(\frac{3}{5}\right) = 600$ J. This is the amount of heat energy rejected to the cold sink.

**Final Answer:** 600 J

**Answer: (C)**

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## Q26.

### Solution

**Concept:** This problem examines the pressure-volume relations of an ideal gas during an adiabatic process. When a system undergoes adiabatic changes without heat exchange, pressure and volume are governed by Poisson's law.

**Solution:**

(a) Let the initial pressure and volume of the ideal gas system be denoted by $P_1$ and $V_1$. The gas is compressed such that its final volume is halved, meaning $V_2 = \frac{V_1}{2}$.

(b) The ratio of specific heats is given as $\gamma = 1.5 = \frac{3}{2}$. For any quasi-static adiabatic state change, Poisson's relation states that $P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$.

(c) We can rearrange this equation to solve for the final pressure of the compressed gas, expressing it as a ratio of the volumes: $P_2 = P_1 \left(\frac{V_1}{V_2}\right)^{\gamma}$.

(d) Substituting the given volume relationship into this equation yields $P_2 = P_1 \left(\frac{V_1}{V_1/2}\right)^{1.5} = P_1 (2)^{1.5}$.

(e) Evaluating the fractional exponent gives $(2)^{1.5} = 2^{3/2} = \sqrt{2^3} = \sqrt{8} = 2\sqrt{2}$. Therefore, the final pressure is $P_2 = 2\sqrt{2}P_1$, showing an increase by a factor of $2\sqrt{2}$.

**Final Answer:** Increases by $2\sqrt{2}$

**Answer: (B)**

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# Q27.

## Solution

**Concept:** This problem evaluates steady-state thermal conduction. Fourier's law states that the rate of heat transfer through a uniform conducting rod depends on its thermal conductivity, cross-sectional area, length, and temperature gradient.

**Solution:**

(a) The initial rate of heat conduction through a metallic rod under steady-state conditions is expressed by Fourier's equation: $Q = \frac{kA(T_h - T_c)}{L}$, where $k$ is thermal conductivity and $A = \pi r^2$.

(b) The problem states that the length of the rod is doubled, so the new length is $L' = 2L$. Simultaneously, the radius is halved, meaning the new radius is $r' = \frac{r}{2}$.

(c) The modification to the radius alters the cross-sectional area of the conductor. The new area is given by $A' = \pi(r')^2 = \pi\left(\frac{r}{2}\right)^2 = \frac{\pi r^2}{4} = \frac{A}{4}$.

(d) Let $Q'$ represent the new rate of heat conduction under the same temperature difference. Substituting the updated dimensions into Fourier's equation gives $Q' = \frac{kA'(T_h - T_c)}{L'} = \frac{k(\frac{A}{4})(T_h - T_c)}{2L}$.

(e) Factoring out the constants yields $Q' = \frac{1}{8} \cdot \left[\frac{kA(T_h - T_c)}{L}\right] = \frac{Q}{8}$. Thus, the rate of heat conduction drops to one-eighth of its original value.

**Final Answer:** Q/8

**Answer: (C)**

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# Q28.

## Solution

**Concept:** This problem evaluates how surrounding media change the refractive behavior of optical systems. Lensmaker's equation is used to calculate the focal length shift when moving a glass lens from air into a fluid.

**Solution:**

(a) Let $\mu_g = 1.5$ be the refractive index of the glass lens, and let $f = 20$ cm be its focal length in air ($\mu_a = 1$). Lensmaker's equation in air is $\frac{1}{f} = (\mu_g - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$.

(b) Substituting the values for air gives $\frac{1}{20} = (1.5 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = 0.5\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$. This simplifies to show that the curvature term is $\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{1}{10}$ cm$^{-1}$.

(c) When immersed in a liquid of refractive index $\mu_l = 1.33 \approx \frac{4}{3}$, the relative refractive index becomes $\mu_{\text{rel}} = \frac{\mu_g}{\mu_l} = \frac{1.5}{4/3} = \frac{3/2}{4/3} = \frac{9}{8}$.

(d) Applying Lensmaker's equation for the liquid medium gives $\frac{1}{f'} = \left(\frac{\mu_g}{\mu_l} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \left(\frac{9}{8} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$.

(e) Substituting the curvature term yields $\frac{1}{f'} = \left(\frac{1}{8}\right)\left(\frac{1}{10}\right) = \frac{1}{80}$ cm$^{-1}$. Solving for the new focal length gives $f' = 80$ cm.

**Final Answer:** 80 cm

**Answer: (C)**

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## Q29.

### Solution

**Concept:** This problem examines how media changes affect wave interference patterns. Immersing a Young's double-slit setup in a dielectric fluid reduces the propagation speed and shifts the wavelength of the light source.

**Solution:**

(a) In a standard Young's Double Slit Experiment in air, the spatial width of an individual interference fringe is defined by the relation $\beta = \frac{\lambda D}{d}$, where $\lambda$ is the wavelength of light.

(b) When the entire experimental apparatus is immersed in a liquid medium with a refractive index $\mu$, the physical distances $D$ and $d$ remain unchanged.

(c) The optical properties of the light source change because its speed drops in the medium. The wavelength decreases inversely with the refractive index, written as $\lambda' = \frac{\lambda}{\mu}$.

(d) The new fringe width $\beta'$ for the interference pattern inside the liquid can be expressed using this modified wavelength value: $\beta' = \frac{\lambda' D}{d} = \frac{(\frac{\lambda}{\mu})D}{d}$.

(e) Factoring out the refractive index yields $\beta' = \frac{1}{\mu} \cdot \left(\frac{\lambda D}{d}\right) = \frac{\beta}{\mu}$. Therefore, the fringe width decreases to $\beta/\mu$.

**Final Answer:** Decreases to $\beta/\mu$

**Answer: (B)**

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# Q30.

## Solution

**Concept:** This problem evaluates total internal reflection inside waveguides. The critical angle at an interface depends on the ratio of the refractive indices of the optically denser core and the less dense cladding.

**Solution:**

(a) An optical fiber guides light using total internal reflection at the boundary interface separating the inner core medium from the outer protective cladding layer.

(b) The refractive index of the inner core is given as $\mu_1 = 1.5$, and the refractive index of the surrounding cladding layer is given as $\mu_2 = 1.2$.

(c) According to Snell's law, as the angle of incidence inside the denser core increases, the angle of refraction inside the cladding approaches a maximum limit of 90°.

(d) The critical angle $\theta_c$ is defined as the specific angle of incidence that results in an angle of refraction equal to 90°. This matches the condition $\mu_1 \sin\theta_c = \mu_2 \sin(90^\circ)$.

(e) Since $\sin(90^\circ) = 1$, rearranging the formula gives $\sin\theta_c = \frac{\mu_2}{\mu_1}$. Substituting the values yields $\sin\theta_c = \frac{1.2}{1.5} = \frac{4}{5} = 0.8$.

**Final Answer:** 0.8

**Answer: (A)**

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# Q31.

## Solution

**Concept:** This problem evaluates the kinematics of simple harmonic motion. The structural relationship between maximum linear speed and maximum acceleration relates directly to the angular frequency parameter, which is inversely linked to the time period.

**Solution:**

(a) Consider a particle executing simple harmonic motion with an amplitude denoted by $A$ and a constant angular frequency denoted by $\omega$.

(b) The kinematic expression for the maximum magnitude of velocity during the motion cycle occurs at the equilibrium position and is given by $v_{\max} = \omega A$.

(c) The kinematic expression for the maximum magnitude of linear acceleration during the motion cycle occurs at the extreme displacement bounds and is given by $a_{\max} = \omega^2 A$.

(d) To separate the parameters and eliminate the unknown amplitude factor, we divide the maximum acceleration equation by the maximum velocity equation: $\frac{a_{\max}}{v_{\max}} = \frac{\omega^2 A}{\omega A} = \omega$.

(e) The total duration of one complete periodic oscillation is connected to the angular frequency via the standard expression $T = \frac{2\pi}{\omega}$. Substituting our derived relation for $\omega$ into this equation gives $T = 2\pi \frac{v_{\max}}{a_{\max}}$.

**Final Answer:** $2\pi \frac{v_{\max}}{a_{\max}}$

**Answer: (A)**

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# Q32.

## Solution

**Concept:** This problem assesses how to extract kinematic properties from a standard mathematical description of a traveling wave. The phase velocity depends on the ratio of the temporal frequency parameter to the spatial wavenumber.

**Solution:**

(a) The given mathematical function describing the transverse displacement of the traveling wave profile as a function of position and time is $y(x, t) = 0.05 \sin(20x - 40t)$.

(b) We compare this specific expression with the general form of a forward-propagating sinusoidal wave equation, which is written as $y(x, t) = A \sin(kx - \omega t)$.

(c) Matching corresponding terms from the two equations allows us to extract the spatial wavenumber, which is $k = 20$ rad/m, and the angular frequency, which is $\omega = 40$ rad/s.

(d) The phase propagation velocity of a wave represents the rate at which any point of constant phase moves through space, which is given by the kinematic ratio $v = \frac{\omega}{k}$.

(e) Substituting the extracted parameters into this equation yields $v = \frac{40}{20} = 2.0$ m/s. This confirms the wave is moving forward through the medium at a speed of two meters per second.

**Final Answer:** 2.0 m/s

**Answer: (B)**

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# Q33.

## Solution

**Concept:** This problem treats polarization properties using Malus's law. When an unpolarized beam strikes an initial linear polarizing sheet, it loses half its total energy, and any subsequent transmission depends on the relative angle between axes.

**Solution:**

(a) The initial light beam incident on the first polarizing sheet is completely unpolarized and possesses an aggregate spatial intensity value designated by $I_0$.

(b) Passing unpolarized light through a linear polarizer filters out all components except those parallel to its transmission axis, reducing the intensity by exactly half, so $I_1 = \frac{I_0}{2}$.

(c) The light emerging from the first polarizer is now linearly polarized along the direction of that first sheet's unique transmission axis.

(d) When this polarized beam encounters the second polarizing sheet, Malus's law states that the transmitted intensity is modulated by the squared cosine of the relative angle: $I_2 = I_1 \cos^2\theta$.

(e) The angle between the transmission axes of the two filters is given as $\theta = 60°$. Knowing that $\cos(60°) = 0.5$, we find $I_2 = \left(\frac{I_0}{2}\right)\cos^2(60°) = \left(\frac{I_0}{2}\right)\left(\frac{1}{2}\right)^2 = \frac{I_0}{8}$.

**Final Answer:** $\mathrm{I}_0/8$

**Answer: (C)**

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# Q34.

## Solution

**Concept:** This problem evaluates wave interference and acoustic resonance. The frequency of an open organ pipe depends inversely on its physical length, and the beat frequency reveals the magnitude of the difference between two wave sources.

**Solution:**

(a) The acoustic tuning fork maintains a fixed vibrational frequency of $f_0 = 512$ Hz. When sounded alongside the open organ pipe, they produce a beat frequency of 4 Hz.

(b) The initial fundamental frequency of the organ pipe, denoted by $f_p$, must be either 4 Hz above or below the tuning fork frequency: $f_p = 512 \pm 4$, meaning it is either 516 Hz or 508 Hz.

(c) The fundamental frequency of an open acoustic organ pipe relates to its physical column length $L$ via the inverse expression $f_p = \frac{v_{\text{sound}}}{2L}$.

(d) Shortening the physical length of the organ pipe decreases $L$, which causes its fundamental operational frequency $f_p$ to increase.

(e) The problem states that this modification causes the beat frequency to increase. If $f_p$ were initially 508 Hz, increasing it would bring it closer to 512 Hz, decreasing the beats. Thus, it must have been higher, at 516 Hz.

**Final Answer:** 516 Hz

**Answer: (B)**

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# Q35.

## Solution

**Concept:** This problem examines the quantum mechanical principles of the photoelectric effect. Einstein's equation shows that the maximum kinetic energy of emitted photoelectrons increases linearly with source frequency, meaning a wavelength reduction more than doubles the kinetic energy.

**Solution:**

(a) Einstein's photoelectric equation states that the maximum kinetic energy of ejected electrons equals photon energy minus the metal work function: $K = \frac{hc}{\lambda} - \Phi$.

(b) When the incoming illumination wavelength is halved to $\lambda' = \frac{\lambda}{2}$, the energy carried by each individual photon doubles, as seen by the relation $E' = \frac{hc}{\lambda/2} = 2\frac{hc}{\lambda}$.

(c) We write the updated kinetic energy expression for the emitted electrons under this higher energy illumination as $K' = \frac{hc}{\lambda/2} - \Phi = 2\frac{hc}{\lambda} - \Phi$.

(d) To establish a direct inequality comparison with the original energy state, we add and subtract the work function term: $K' = 2\left(\frac{hc}{\lambda} - \Phi\right) + \Phi$.

(e) Substituting the original kinetic energy variable into this expression yields $K' = 2K + \Phi$. Since the characteristic work function $\Phi$ is always a positive quantity, this proves $K' > 2K$.

**Final Answer:** K' > 2K

**Answer: (B)**

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# Q36.

## Solution

**Concept:** This problem calculates de Broglie wavelengths for accelerated particles. The matter wavelength depends inversely on momentum, which can be expressed using a particle's mass, electrical charge, and accelerating potential.

**Solution:**

(a) Let a particle with mass $m$ and charge $q$ be accelerated from rest across a potential difference $V$. The kinetic energy gained is $K = qV$, making its momentum $p = \sqrt{2mK} = \sqrt{2mqV}$.

(b) The de Broglie hypothesis defines the matter wavelength as $\lambda = \frac{h}{p}$. Substituting our momentum expression yields the functional equation $\lambda = \frac{h}{\sqrt{2mqV}}$.

(c) Let the mass of a proton be $m_p = m$ and its charge be $q_p = e$. Its resulting wavelength is $\lambda_p = \frac{h}{\sqrt{2meV}}$.

(d) An alpha particle consists of two protons and two neutrons, meaning its mass is $m_\alpha = 4m$ and its charge is $q_\alpha = 2e$. Its wavelength is $\lambda_\alpha = \frac{h}{\sqrt{2(4m)(2e)V}} = \frac{h}{\sqrt{16meV}}$.

(e) Taking the ratio of the alpha particle wavelength to the proton wavelength gives $\frac{\lambda_\alpha}{\lambda_p} = \frac{\sqrt{2meV}}{\sqrt{16meV}} = \sqrt{\frac{2}{16}} = \sqrt{\frac{1}{8}} = \frac{1}{\sqrt{8}}$, which equals the ratio $1 : \sqrt{8}$.

**Final Answer:** $1 : \sqrt{8}$

**Answer: (A)**

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# Q37.

## Solution

**Concept:** This problem uses the Bohr model to evaluate atomic transitions. The wavelength of a photon emitted during electronic relaxation is calculated using the Rydberg formula, which depends on the initial and final orbital index numbers.

**Solution:**

(a) The hydrogen atom's electron undergoes an energetic transition from an initial outer orbital shell with index $n_i = 3$ to a final lower orbital shell with index $n_f = 2$.

(b) The wavelength $\lambda$ of the emitted photon is determined by the Rydberg formula: $\frac{1}{\lambda} = R_\infty \left( \frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$, where $R_\infty$ is the Rydberg constant.

(c) Substituting the explicit integers for the two orbital boundary levels into the formula yields the expression $\frac{1}{\lambda} = R_\infty \left( \frac{1}{2^2} - \frac{1}{3^2} \right)$.

(d) Evaluating the squared denominators inside the parentheses simplifies the equation to $\frac{1}{\lambda} = R_\infty \left( \frac{1}{4} - \frac{1}{9} \right) = R_\infty \left( \frac{9-4}{36} \right) = \frac{5R_\infty}{36}$.

(e) To isolate the emission wavelength variable, we take the algebraic reciprocal of the equation, which yields the final result: $\lambda = \frac{36}{5R_\infty}$.

**Final Answer:** $36_{\overline{5R_\infty}}$

**Answer: (B)**

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## Q38.

### Solution

**Concept:** This problem evaluates exponential radioactive decay. The remaining fraction of active nuclei depends on the number of elapsed half-life periods, calculated as two raised to the negative power of that integer value.

**Solution:**

(a) The characteristic half-life interval of the radioactive sample is given as $T_{1/2} = 10$ days. This is the time required for half of the active nuclei to decay.

(b) The total time period that has elapsed during the observation process is given as $t = 30$ days.

(c) We calculate the total number of consecutive half-life decay cycles that occurred during this time using the linear ratio $n = \frac{t}{T_{1/2}} = \frac{30}{10} = 3$.

(d) The standard law of radioactive decay states that the remaining fraction of active, un-decayed nuclei after $n$ cycles is given by the fractional expression $\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$.

(e) Substituting our calculated value of three half-life intervals into this expression yields $\frac{N}{N_0} = \left(\frac{1}{2}\right)^3 = \frac{1}{8}$. Thus, one-eighth of the initial active sample remains un-decayed.

**Final Answer:** 1/8

**Answer: (D)**

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# Q39.

## Solution

**Concept:** This problem treats digital logic circuits using Boolean algebra. By tracking how input combinations pass through a specific logic gate configuration, we can determine its overall Boolean truth operation.

**Solution:**

(a) The logic schematic shows two independent binary input signals, designated as $A$ and $B$, which are routed into the input ports of a standard logic gate.

(b) The logic gate symbol has a rectangular body with a curved output side and an inversion circle at its output terminal. This icon represents a two-input NAND gate.

(c) The internal ampersand symbol (&) explicitly denotes an algebraic conjunction operation, while the output bubble represents a logical inversion (NOT) operation.

(d) The Boolean output function for a standard NAND logic gate with inputs $A$ and $B$ is given by the expression $Y = \overline{A \cdot B}$.

(e) Because there are no subsequent cascading gates or feedback paths in this specific arrangement, the overall network performs a basic NAND gate operation.

**Final Answer:** NAND Gate

**Answer: (B)**

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# Q40.

## Solution

**Concept:** This problem treats p-n junction semiconductor physics under bias. Applying a forward bias voltage introduces an external electric field that opposes the internal built-in field, shrinking both the depletion width and the potential barrier.

**Solution:**

(a) A p-n junction in equilibrium possesses a depletion layer formed by mobile carrier diffusion, creating a fixed space-charge region and an internal barrier potential.

(b) When an external forward bias voltage is applied, the positive terminal connects to the p-type region and the negative terminal connects to the n-type region.

(c) This bias configuration sets up an external electric field that opposes the internal built-in electric field of the junction.

(d) The opposing field forces majority charge carriers (holes and electrons) to penetrate deeper into the depletion zone, neutralizing part of the space-charge layer and decreasing its width.

(e) Because the net electric field across the junction drops, the internal potential energy barrier is lowered, meaning both the depletion layer width and the barrier height decrease.

**Final Answer:** Both decrease

**Answer: (B)**

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# Answer Key

| Q | Ans | Q | Ans | Q | Ans | Q | Ans | Q | Ans |
|---|---|---|---|---|---|---|---|---|---|
| 1 | C | 2 | B | 3 | B | 4 | B | 5 | D |
| 6 | A | 7 | B | 8 | B | 9 | B | 10 | A |
| 11 | A | 12 | B | 13 | B | 14 | A | 15 | B |
| 16 | C | 17 | B | 18 | A | 19 | A | 20 | A |
| 21 | A | 22 | A | 23 | A | 24 | C | 25 | C |
| 26 | B | 27 | C | 28 | C | 29 | B | 30 | A |
| 31 | A | 32 | B | 33 | C | 34 | B | 35 | B |
| 36 | A | 37 | B | 38 | D | 39 | B | 40 | B |