PHYSICSBOWL COMPREHENSIVE REVISION NOTES

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A Complete Guide to Acing the PhysicsBowl Exam

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1. MECHANICS - KINEMATICS

1.1 Fundamental Concepts

Kinematics is the branch of mechanics that describes motion without considering its causes. In PhysicsBowl, kinematics questions frequently test your ability to use the kinematic equations and understand motion graphs.

Key Quantities

Quantity	Symbol	Unit	Definition
Position	x, y	m	Location relative to origin
Velocity	v	m/s	Rate of change of position
Acceleration	a	m/s^2	Rate of change of velocity
Time	t	s	Duration of motion

The Kinematic Equations

For constant acceleration:

$$v=v_0+at$$

$$x=x_0+v_0 t+1/2 at^2$$

$$v^2=v_0^2+2a(x-x_0)$$

$x-x_0=1/2(v_0+v)t$

Free Fall

All objects in free fall (ignoring air resistance) experience the same acceleration:

g=9.8〖" m/s" 〗^2≈10〖" m/s" 〗^2

For objects thrown upward, remember:

- At maximum height, velocity = 0
- Time going up = time coming down (for same height)
- Velocity at return = negative of initial velocity

Projectile Motion

Horizontal and vertical motions are independent:

- Horizontal: Constant velocity ($a_x = 0$)
- Vertical: Constant acceleration downward ($a_y = -g$)

Key formulas for projectile motion:

- Time of flight: $t=(2v_0 \sin\theta)/g$
- Maximum height: H=(v_0^2 〖sin〗^2 θ)/2g
- Range: $R=(v_0^2 \sin(2\theta))/g$

The range is maximum at θ = 45°.

1.2 Example Questions

Example 1 (From typical PhysicsBowl): A car accelerates from rest at 3.0 m/s² for 4.0 seconds. What is the car's final velocity?

Solution: Using $v = v_0 + at$

- $v_0 = 0$ (starts from rest)
- $a = 3.0\ m/s^2$
- t = 4.0 s

v = 0 + (3.0)(4.0) = 12 m/s

Example 2: A ball is thrown vertically upward with a speed of 20 m/s. How high does it go?

Solution: At maximum height, v = 0

Using $v^2 = v_0^2 + 2a\Delta y$ $0 = (20)^2 + 2(-10)\Delta y$ $0 = 400 - 20\Delta y$ $\Delta y = 20$ m

Example 3: A projectile is launched at 30° with a speed of 50 m/s. What is the horizontal range?

Solution: $R = v_0^2 \sin(2\theta)/g = (50)^2 \times \sin(60°)/10 = 2500 \times 0.866/10 = 216.5$ m

Example 4: A car travels 100 m in 5 s at constant velocity. What is its velocity?

Solution: For constant velocity: x = vt 100 = v(5) v = 20 m/s

Example 5 (2016 PhysicsBowl style): An object starts from rest and accelerates at 2 m/s² for 10 seconds, then maintains constant velocity for 20 seconds. What is the total distance traveled?

Solution: First 10 s: $x_1 = \frac{1}{2}at^2 = \frac{1}{2}(2)(10)^2 = 100$ m Next 20 s: At t=10s, v = at = 2(10) = 20 m/s $x_2 = vt = 20(20) = 400$ m Total = 500 m

2. MECHANICS - NEWTON'S LAWS

2.1 Newton's First Law (Inertia)

An object at rest stays at rest, and an object in motion stays in motion with the same velocity, unless acted upon by a net external force.

Key points:

- Also known as the law of inertia
- Inertia is the tendency to resist changes in motion
- Mass is a measure of inertia

2.2 Newton's Second Law

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

$\vec{F}_{net}=m\vec{a}$

Or in component form: $F_{(net,x)}=ma_x$ $F_{(net,y)}=ma_y$

Important notes:

- Force is measured in Newtons (N): 1 N = 1 kg·m/s^2
- This is a vector equation - always consider components

2.3 Newton's Third Law

For every action, there is an equal and opposite reaction.

Key points:

- Forces always come in pairs
- Action-reaction pairs act on different objects
- They cannot cancel each other out (they act on different objects)

2.4 Common Forces

Weight (W)

$W=mg$

- Direction: Downward (toward Earth's center)
- Note: Weight changes with g; mass does not

Normal Force (N)

- Perpendicular to the surface
- Balances other forces in the perpendicular direction

Friction (f)

$f \leq \mu N$

- Static friction: $\mu_s N$ (up to maximum)
- Kinetic friction: $\mu_k N$
- Direction: Opposes motion or attempted motion

Tension (T)

- Pulls away from the object along the string/cable
- Same magnitude throughout a massless string

Spring Force (Hooke's Law)

$F=-kx$

- k: spring constant (N/m)
- x: displacement from equilibrium
- Restoring force - always points toward equilibrium

2.5 Free Body Diagrams

Steps to draw a FBD:

- Identify all forces acting on the object
- Draw the object as a point/box
- Draw arrows representing each force from the center
- Label each force with its magnitude or symbol

2.6 Example Questions

Example 1: A 5 kg object is pushed with a force of 20 N. What is its acceleration?

Solution: $F = ma$ $20 = 5a$ $a = 4$ m/s²

Example 2: A 10 kg block sits on a horizontal surface with coefficient of static friction 0.4. What minimum force is needed to start the block moving?
Solution: $f_s(max) = \mu_s N = \mu_s mg = 0.4 \times 10 \times 10 = 40$ N

Example 3: A 2 kg mass hangs from two ropes making angles of 30° with the horizontal. Find the tension in each rope.
Solution: Vertical components: $2T \sin(30°) = mg = 2 \times 10 = 20$ N $T \sin(30°) = 10$ $T(0.5) = 10$ $T = 20$ N in each rope

Example 4: A 1000 kg elevator accelerates upward at 2 m/s². What is the tension in the supporting cable?
Solution: $T - mg = ma$ $T = m(g + a) = 1000(10 + 2) = 12{,}000$ N

Example 5: Two masses, 3 kg and 5 kg, are connected by a string and pulled across a frictionless surface with a force of 16 N. Find the acceleration of the system.
Solution: Total mass = 3 + 5 = 8 kg $F = ma$ $16 = 8a$ $a = 2$ m/s²

Example 6 (2019 PhysicsBowl style): A 2 kg block rests on a rough horizontal surface ($\mu_k = 0.3$). A horizontal force of 8 N is applied. What is the acceleration?
Solution: Normal force: $N = mg = 2 \times 10 = 20$ N Kinetic friction: $f_k = \mu_k N = 0.3 \times 20 = 6$ N Net force: $F_{net} = 8 - 6 = 2$ N $a = F_{net}/m = 2/2 = 1$ m/s²

3. WORK, ENERGY, AND POWER

3.1 Work

Work is done when a force causes displacement.

$W=\vec{F}\cdot\vec{d}=Fd\cos\theta$

Where θ is the angle between force and displacement.

Key points:

- Work is a scalar quantity
- Unit: Joule (J) = 1 N·m
- Work can be positive, negative, or zero
- No work is done if: no displacement, or force perpendicular to displacement

Work by various forces:

- Gravity: $W = -mg\Delta y$ (negative when going up)
- Spring: $W = \frac{1}{2}kx^2$
- Friction: $W = -f_k d = -\mu_k Nd$

3.2 Kinetic Energy

$KE=1/2\ mv^2$

Work-Energy Theorem: $W_{net}=\Delta KE=1/2\ mv_f^2-1/2\ mv_i^2$

3.3 Gravitational Potential Energy

$PE_g=mgh$

(Choose reference point where h = 0)

Conservation of Mechanical Energy: $E_{total}=KE+PE=\text{"constant"}$ (Only valid when no non-conservative forces do work)

3.4 Power

Average Power: $P_{avg}=W/t=Fv/\text{"avg"}$

Instantaneous Power: $P=\vec{F}\cdot\vec{v}$

Unit: Watt (W) = 1 J/s

3.5 Example Questions

Example 1: A 2 kg ball is lifted 5 m at constant speed. How much work is done against gravity?

Solution: $W = mg\Delta y = 2 \times 10 \times 5 = 100$ J

Example 2: A 1000 kg car accelerates from 10 m/s to 20 m/s. What is the change in kinetic energy?

Solution: $\Delta KE = \frac{1}{2}m(v_f^2 - v_i^2) = \frac{1}{2}(1000)(400 - 100) = \frac{1}{2}(1000)(300) = 150{,}000$ J

Example 3: A 5 kg block slides 10 m down a frictionless incline (30°). What is its speed at the bottom?

Solution: Using conservation of energy: PE lost = KE gained $mgh = \frac{1}{2}mv^2$ $mg(L \sin30°) = \frac{1}{2}mv^2$ $v^2 = 2gL \sin30° = 2(10)(10)(0.5) = 100$ $v = 10$ m/s

Example 4: A 60 kg person climbs stairs (3 m height) in 10 seconds. What is the average power output?

Solution: Work = $mgh = 60 \times 10 \times 3 = 1800$ J $P = W/t = 1800/10 = 180$ W

Example 5: A spring (k = 200 N/m) is compressed 0.1 m. What is the stored potential energy?

Solution: $PE_{spring} = \frac{1}{2}kx^2 = \frac{1}{2}(200)(0.1)^2 = \frac{1}{2}(200)(0.01) = 1$ J

Example 6 (2021 PhysicsBowl style): A 2 kg object moving at 3 m/s collides with a spring (k = 100 N/m) and compresses it by 0.3 m. How much energy is dissipated as heat?

Solution: Initial KE = $\frac{1}{2}(2)(3)^2 = 9$ J Spring PE = $\frac{1}{2}(100)(0.3)^2 = \frac{1}{2}(100)(0.09) = 4.5$ J Dissipated = 9 - 4.5 = 4.5 J

4. LINEAR MOMENTUM AND COLLISIONS

4.1 Linear Momentum

$\vec{p}=m\vec{v}$

- Vector quantity
- Unit: kg·m/s
- Direction same as velocity

Impulse-Momentum Theorem: $\vec{J}=\Delta\vec{p}=\vec{F}_{avg}\,\Delta t$

4.2 Conservation of Momentum

In an isolated system (no external forces): $\vec{p}_{(total,initial)}=\vec{p}_{(total,final)}$

For collisions/explosions: $m_1 v_1+m_2 v_2=m_1 v_1^{'}+m_2 v_2^{'}$

4.3 Types of Collisions

Elastic Collision

- Both momentum AND kinetic energy conserved
- Objects bounce off each other
- Formula: $v_1' = [(m_1-m_2)v_1 + 2m_2v_2]/(m_1+m_2)$

Inelastic Collision

- Momentum conserved, kinetic energy not conserved
- Objects stick together (perfectly inelastic): $v' = (m_1v_1 + m_2v_2)/(m_1+m_2)$

4.4 Center of Mass

$x_{cm}=(m_1 x_1+m_2 x_2+...)/(m_1+m_2+...)$

For two particles: $x_{cm}=(m_1 x_1+m_2 x_2)/(m_1+m_2)$

4.5 Example Questions

Example 1: A 5 kg ball moving at 4 m/s collides with a stationary 3 kg ball. If they stick together, what is their common velocity?

Solution: $m_1v_1 + m_2v_2 = (m_1+m_2)v'$ $5(4) + 3(0) = 8v'$ $20 = 8v'$ $v' = 2.5$ m/s

Example 2: A 2 kg ball traveling at 6 m/s hits a wall and bounces back with speed 4 m/s. What is the impulse?

Solution: Impulse = $\Delta p = m(v_f - v_i) = 2(-4 - 6) = -20$ N·s (Magnitude = 20 N·s)

Example 3 (2016 PhysicsBowl style): A 100 g ball collides elastically with a stationary 100 g ball. The first ball stops after collision. What is the velocity of the second ball?

Solution: For elastic collision where $m_1 = m_2$ and $v_1' = 0$: $v_2' = v_1$ (the second ball takes all the momentum) $v_2' = v_1$

Example 4: A rocket expels gas at 500 m/s relative to the rocket. If the rocket mass decreases by 100 kg per second, what is the thrust force?

Solution: Thrust = $\dot{m} \times v_{rel}$ = 100 kg/s × 500 m/s = 50,000 N

Example 5: Two objects, 2 kg and 4 kg, have velocities 6 m/s and -3 m/s respectively. What is their total momentum?

Solution: $p_{total} = m_1v_1 + m_2v_2 = 2(6) + 4(-3) = 12 - 12 = 0$ (They could be at rest together or moving in opposite directions with equal momentum)

5. ROTATIONAL MOTION

5.1 Angular Quantities

Linear	Angular	Relationship
x	θ	$x = r\theta$
v	ω	$v = r\omega$
a	α	$a = r\alpha$

Radians:

- Full circle = 2π rad = 360°
- 1 rad = 57.3°

5.2 Rotational Kinematics

$\omega=\omega_0+\alpha t$

$\theta=\theta_0+\omega_0 t+1/2\, \alpha t^2$

$\omega^2=\omega_0^2+2\alpha(\theta-\theta_0)$

5.3 Moment of Inertia

$I=\sum mr^2$

Common Moments of Inertia:

Object	I
Point mass	mr^2
Solid cylinder/disk	$\frac{1}{2}MR^2$
Hollow cylinder	MR^2

Solid sphere $\frac{2}{5}MR^2$
Hollow sphere $\frac{2}{3}MR^2$
Rod (about center) $\frac{1}{12}ML^2$
Rod (about end) $\frac{1}{3}ML^2$

5.4 Rotational Dynamics

Torque: $\tau = rF\sin\theta = rF_\perp$

- Unit: N·m
- r = perpendicular distance from axis to force line

Newton's Second Law for Rotation: $\tau_{net} = I\alpha$

5.5 Angular Momentum

$L = I\omega = mvr$

Conservation of Angular Momentum: If no external torque: $L_{initial} = L_{final}$

5.6 Rotational Kinetic Energy

$KE_{rot} = 1/2\ I\omega^2$

Rolling without slipping: $v = r\omega KE_{total} = 1/2\ mv^2 + 1/2\ I\omega^2$

5.7 Example Questions

Example 1: A disk with moment of inertia 0.5 $kg\cdot m^2$ rotates at 4 rad/s. What is its angular momentum?
Solution: $L = I\omega = 0.5 \times 4 = 2\ kg\cdot m^2/s$

Example 2: A solid sphere ($I = \frac{2}{5}MR^2$) rolls without slipping. What fraction of its kinetic energy is rotational?
Solution: $KE_{total} = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2}Mv^2 + \frac{1}{2}(\frac{2}{5}MR^2)(v^2/R^2) = \frac{1}{2}Mv^2 + \frac{1}{5}Mv^2 = \frac{7}{10}Mv^2$ Rotational fraction = $(\frac{1}{5})/(\frac{7}{10}) = 2/7 \approx 28.6\%$

Example 3: A torque of 10 N·m is applied to a disk ($I = 2\ kg\cdot m^2$). What is the angular acceleration?
Solution: $\tau = I\alpha$ $10 = 2\alpha$ $\alpha = 5\ rad/s^2$

Example 4: A figure skater with arms extended ($I_1 = 5\ kg\cdot m^2$) spins at 2 rad/s. She pulls arms in, reducing I to 2 $kg\cdot m^2$. What is her new angular velocity?
Solution: $L_1 = L_2$ $I_1\omega_1 = I_2\omega_2$ $5(2) = 2\omega_2$ $\omega_2 = 5$ rad/s

Example 5 (2022 PhysicsBowl style): A solid cylinder (mass 4 kg, radius 0.5 m) rolls down an incline without slipping. What is its acceleration?
Solution: For solid cylinder: $I = \frac{1}{2}MR^2 = \frac{1}{2}(4)(0.25) = 0.5\ kg\cdot m^2$ Using $a = g\sin\theta/(1 + I/MR^2) = g\sin\theta/(1 + 0.5/4) = g\sin\theta/1.125$ If $\theta = 30°$: $a = 10(0.5)/1.125 = 4.44\ m/s^2$

6. GRAVITATION

6.1 Newton's Law of Universal Gravitation

$F_g = G\frac{m_1 m_2}{r^2}$

Where $G = 6.674 \times 10^{-11}\ N\cdot m^2/kg^2$

Key points:

- Inverse square law
- Force acts along the line connecting centers
- Always attractive

6.2 Gravitational Field

$g=F/m=G M/r^2$

At Earth's surface: $g = 9.8\ m/s^2$

g decreases with altitude: $g' = g(R/(R+h))^2$

6.3 Orbital Motion

Orbital Velocity: $v=\sqrt{GM/r}$

Orbital Period: $T=2\pi\sqrt{r^3/GM}$

Kepler's Third Law: $T^2 \propto r^3$

6.4 Gravitational Potential Energy

$U=-GmM/r$

(Zero at infinity, negative in orbit)

Escape Velocity: $v_{esc}=\sqrt{2GM/R}$

6.5 Example Questions

Example 1: What is the weight of a 10 kg object at an altitude equal to Earth's radius?

Solution: At 2R from Earth's center: $g' = g/4 = 10/4 = 2.5\ m/s^2$ Weight = $mg' = 10 \times 2.5 = 25$ N (Earth surface weight = 100 N)

Example 2: A satellite orbits Earth at radius 2R (R = Earth's radius). What is its orbital speed?

Solution: $v = \sqrt{GM/2R} = v_{earth}/\sqrt{2}$ Since v_{earth} at surface ≈ 7.9 km/s: $v = 7.9/\sqrt{2} \approx 5.6$ km/s

Example 3: Two masses, 100 kg each, are 1 m apart. What is the gravitational force between them?

Solution: $F = Gm_1m_2/r^2 = (6.67 \times 10^{-11})(100)(100)/1^2 = 6.67 \times 10^{-7}$ N

Example 4: What is the escape velocity from the Moon (mass = 1/81 Earth, radius = 1/3.7 Earth)?

Solution: $v_{esc,moon} = v_{esc,earth} \times \sqrt{M_{moon}/M_{earth} \times R_{earth}/R_{moon}} = 11.2 \times \sqrt{1/81 \times 3.7} = 11.2 \times \sqrt{0.0457} = 2.4$ km/s

7. SIMPLE HARMONIC MOTION

7.1 Key Concepts

Simple Harmonic Motion (SHM): Motion where the restoring force is proportional to displacement from equilibrium.

$F=-kx$

General SHM Equations: $x(t)=A\cos(\omega t+\phi)$

$v(t)=-A\omega\sin(\omega t+\phi)$

$a(t)=-A\omega^2 \cos(\omega t+\phi)=-\omega^2 x$

7.2 Physical Pendulum

$T=2\pi\sqrt{I/mgd}$

For simple pendulum (mass at end of string): $T=2\pi\sqrt{L/g}$

7.3 Mass-Spring System

$T=2\pi\sqrt{m/k}$

$\omega=\sqrt{k/m}$

7.4 Energy in SHM

$E=1/2\ kA^2=1/2\ mv_{max}^2=1/2\ kA^2$

At any point: $E=1/2\ kx^2+1/2\ mv^2=$"constant"

7.5 Example Questions

Example 1: A 2 kg mass on a spring oscillates with period 1 s. What is the spring constant?

Solution: $T = 2\pi\sqrt{(m/k)} = 1$ $\sqrt{(2/k)} = 1/2\pi$ $2/k = 1/4\pi^2$ $k = 8\pi^2 \approx 79$ N/m

Example 2: A pendulum has length 1 m on Earth. What is its period on the Moon ($g_{moon} \approx 1.6$ m/s²)?
Solution: $T_{moon} = 2\pi\sqrt{(L/g_{moon})} = 2\pi\sqrt{(1/1.6)} = 2\pi \times 0.79 = 4.95$ s (Earth period = $2\pi\sqrt{1/10} \approx 2$ s)

Example 3: The maximum speed of a mass-spring system is 2 m/s, mass = 0.5 kg, amplitude = 0.1 m. Find the spring constant.
Solution: $E = ½mv_{max}^2 = ½(0.5)(4) = 1$ J Also $E = ½kA^2 = 1$ $½k(0.01) = 1$ $k = 200$ N/m

Example 4: What is the acceleration of a mass at maximum displacement in SHM?
Solution: At maximum displacement ($x = \pm A$): $a = -\omega^2 x = \pm\omega^2 A$ (maximum magnitude) At equilibrium ($x = 0$): $a = 0$

8. FLUID MECHANICS

8.1 Density and Pressure

Density: $\rho=m/V$

- Unit: kg/m³
- Water: 1000 kg/m³

Pressure: $P=F/A$

- Unit: Pascal (Pa) = N/m²
- For fluids: $P = \rho gh$ (hydrostatic pressure)

8.2 Buoyancy (Archimedes' Principle)

$F_B=\rho_{fluid} V_{displaced} g$

Key points:

- Buoyant force equals weight of displaced fluid
- Object floats when $F_B = mg$
- Fraction submerged = $\rho_{object}/\rho_{fluid}$

8.3 Fluid Dynamics

Continuity Equation: $A_1 v_1=A_2 v_2$

(Conservation of mass for fluid flow)

Bernoulli's Equation: $P+1/2\ \rho v^2+\rho gh=$"constant"

For horizontal flow: $P+1/2\ \rho v^2=$"constant"

8.4 Example Questions

Example 1: A 100 cm³ object with density 0.8 g/cm³ is placed in water. What volume is submerged?
Solution: Fraction submerged = $\rho_{object}/\rho_{fluid} = 0.8/1.0 = 0.8$ Volume submerged = $0.8 \times 100 = 80$ cm³

Example 2: What pressure exists at a depth of 10 m in water?
Solution: $P = \rho gh = 1000 \times 10 \times 10 = 100{,}000$ Pa = 1 atm (Plus atmospheric pressure: ~101,300 Pa)

Example 3: Water flows through a pipe with diameter 0.1 m at 2 m/s. What is the flow rate?
Solution: $A = \pi r^2 = \pi(0.05)^2 = 0.00785$ m² $Q = Av = 0.00785 \times 2 = 0.0157$ m³/s

Example 4 (2023 PhysicsBowl style): A balloon is filled with helium (density 0.18 kg/m³) in air (density 1.2 kg/m³). The balloon envelope mass is 0.5 g and volume 0.01 m³. What is the maximum load it can lift?

Solution: Buoyant force = $\rho_{air} Vg$ = 1.2 × 0.01 × 10 = 0.12 N Balloon weight = ($mass_{He}$ + envelope)g = (0.18 × 0.01 + 0.0005)g = 0.0023 × 10 = 0.023 N Lift capacity = 0.12 - 0.023 = 0.097 N (≈ 10 g)

9. ELECTRIC FIELDS AND CAPACITANCE

9.1 Electric Charge

$q=ne$

- $e = 1.602 \times 10^{-19}$ C (proton), -e (electron)
- Conservation of charge
- Like charges repel, opposites attract

9.2 Coulomb's Law

$F=k \frac{q_1 q_2}{r^2}$

Where $k = 8.99 \times 10^9$ N·m²/C² ≈ 9×10^9

Key points:

- Inverse square law
- Vector quantity - direction along line joining charges
- Can be attractive or repulsive

9.3 Electric Field

$\vec{E}=\vec{F}/q=k Q/r^2$

Direction: Away from positive charge, toward negative charge

Field from point charge: $E=k Q/r^2$

Field between parallel plates: $E=V/d$

(Uniform field)

9.4 Electric Potential

$V=U/q=k Q/r$

(Voltage = potential energy per unit charge)

Relationship between E and V: $E=-dV/dr$

For uniform field: $E = V/d$

9.5 Capacitance

$C=Q/V$

- Unit: Farad (F) = C/V
- For parallel plates: $C=(\varepsilon_0 A)/d$

Energy stored: $U=1/2\, CV^2=1/2\, QV=Q^2/2C$

9.6 Example Questions

Example 1: Two charges, +2 μC and -3 μC, are 0.1 m apart. Find the force on each.

Solution: $F = k|q_1q_2|/r^2 = (9\times10^9)(2\times10^{-6})(3\times10^{-6})/(0.1)^2 = (9\times10^9)(6\times10^{-12})/0.01 = 5.4 \times 10^{-3}/0.01 = 0.54$ N (attractive)

Example 2: What is the electric field 0.2 m from a +5 μC charge?

Solution: $E = kQ/r^2 = (9\times10^9)(5\times10^{-6})/(0.2)^2 = 45\times10^3/0.04 = 1.125 \times 10^6$ N/C

Example 3: A charge of 10^{-6} C is moved through a potential difference of 100 V. What is the change in potential energy?

Solution: $\Delta U = q\Delta V = 10^{-6} \times 100 = 10^{-4}$ J

Example 4: A 10 μF capacitor is charged to 50 V. What charge is stored?
Solution: $Q = CV = 10 \times 10^{-6} \times 50 = 5 \times 10^{-4}$ C = 500 μC

Example 5 (2017 PhysicsBowl style): Two point charges are 0.05 m apart. The force between them is 0.2 N. One charge is twice the other. Find the smaller charge.
Solution: $F = kq(2q)/r^2 = 2kq^2/r^2$ $0.2 = 2(9\times10^9)q^2/(0.05)^2$ $q^2 = 0.2(0.05)^2/(2\times9\times10^9) = 0.2 \times 0.0025/(1.8\times10^{10})$ $q^2 = 2.78 \times 10^{-14}$ $q = 5.27 \times 10^{-7}$ C = 0.527 μC

Example 6: An electron ($q = -1.6 \times 10^{-19}$ C, $m = 9.1 \times 10^{-31}$ kg) is accelerated through 1000 V. What is its final speed?
Solution: KE gained = $qV = 1.6 \times 10^{-19} \times 1000 = 1.6 \times 10^{-16}$ J $\frac{1}{2}mv^2 = 1.6 \times 10^{-16}$ $v^2 = 2(1.6 \times 10^{-16})/(9.1 \times 10^{-31}) = 3.52 \times 10^{14}$ $v = 1.88 \times 10^7$ m/s

10. CIRCUITS
10.1 Current and Resistance
Ohm's Law: V=IR
Current: I=q/t
    Unit: Ampere (A) = C/s
Resistance: R=ρ L/A
    ρ = resistivity
    Depends on temperature: $R = R_0[1 + \alpha(T - T_0)]$
10.2 Power in Circuits
P=IV=I^2 R=V^2/R
Energy: E=Pt
    Unit: Joule (J)
    Also: kWh = 3.6×10^6 J
10.3 Series and Parallel
Series:
    $R_{total} = R_1 + R_2 + R_3 + \ldots$
    I is same through each component
    V divides across components
Parallel:
    $1/R_{total} = 1/R_1 + 1/R_2 + 1/R_3 + \ldots$
    V is same across each branch
    I divides through branches
10.4 Circuit Analysis
Kirchhoff's Laws:
    Junction rule: $\Sigma I_{in} = \Sigma I_{out}$
    Loop rule: ΣV = 0 around any closed loop
EMF (ε): Voltage source, work per unit charge
Internal Resistance: For real battery: $V_{terminal} = \varepsilon - Ir_{internal}$
10.5 Example Questions
Example 1: Three resistors, 2 Ω, 3 Ω, and 6 Ω, are connected in series. What is the equivalent resistance?

Solution: $R_{eq} = 2 + 3 + 6 = 11\ \Omega$

Example 2: Same resistors in parallel. What is equivalent resistance?
Solution: $1/R_{eq} = 1/2 + 1/3 + 1/6 = 3/6 + 2/6 + 1/6 = 6/6 = 1$ $R_{eq} = 1\ \Omega$

Example 3: A 100 W light bulb operates at 120 V. What is its resistance?
Solution: $P = V^2/R$ $100 = 120^2/R$ $R = 14400/100 = 144\ \Omega$

Example 4: Two 10 Ω resistors in parallel are connected in series with a 5 Ω resistor. If connected to a 20 V battery, find the current from the battery.
Solution: $R_{parallel} = (10\times10)/(10+10) = 5\ \Omega$ $R_{total} = 5 + 5 = 10\ \Omega$ $I = V/R_{total} = 20/10 = 2$ A

Example 5: A battery with EMF 12 V and internal resistance 1 Ω is connected to a 5 Ω external resistor. Find terminal voltage.
Solution: $I = \varepsilon/(r + R) = 12/(1+5) = 2$ A $V_{terminal} = \varepsilon - Ir = 12 - 2(1) = 10$ V

Example 6 (2018 PhysicsBowl style): How much energy is dissipated in a 100 Ω resistor in 10 seconds if the current is 0.5 A?
Solution: $P = I^2R = (0.5)^2(100) = 0.25 \times 100 = 25$ W $E = Pt = 25 \times 10 = 250$ J

11. MAGNETISM

11.1 Magnetic Fields

Magnetic Force on Moving Charge: $F=qvB\sin\theta$

- Perpendicular to both v and B
- Right-hand rule for direction

Force on Current-Carrying Wire: $F=ILB\sin\theta$

11.2 Magnetic Field from Current

Long Straight Wire: $B=(\mu_0 I)/2\pi r$
Where $\mu_0 = 4\pi \times 10^{-7}$ T·m/A
Solenoid: $B=\mu_0 nI$
(n = turns per unit length)
Inside Toroid: $B=(\mu_0 NI)/2\pi r$

11.3 Electromagnetic Induction

Faraday's Law: $\varepsilon=-(d\Phi_B)/dt$
Magnetic Flux: $\Phi_B=BA\cos\theta$
Lenz's Law: Induced current creates field opposing the change

11.4 Example Questions

Example 1: An electron moves at 10^6 m/s perpendicular to a 0.1 T magnetic field. What is the force on it?
Solution: $F = qvB = (1.6 \times 10^{-19})(10^6)(0.1) = 1.6 \times 10^{-14}$ N

Example 2: A wire 0.5 m long carries 2 A current in a 0.3 T magnetic field perpendicular to the wire. What force acts on the wire?
Solution: $F = ILB = 2 \times 0.5 \times 0.3 = 0.3$ N

Example 3: What is the magnetic field 0.1 m from a wire carrying 10 A?

Solution: $B = \mu_0 I/(2\pi r) = (4\pi \times 10^{-7} \times 10)/(2\pi \times 0.1) = (4 \times 10^{-6})/(0.2) = 2 \times 10^{-5}$ T

Example 4: A circular coil with radius 0.1 m has 100 turns and carries 2 A. What is the magnetic field at its center?
Solution: For coil: $B = \mu_0 NI/(2r) = (4\pi \times 10^{-7} \times 100 \times 2)/(2 \times 0.1) = (8\pi \times 10^{-5})/(0.2) = 1.26 \times 10^{-3}$ T

Example 5: The magnetic flux through a coil increases from 0.01 Wb to 0.05 Wb in 0.2 s. What is the induced EMF?
Solution: $\varepsilon = -\Delta\Phi/\Delta t = -(0.05 - 0.01)/0.2 = -0.04/0.2 = -0.2$ V (Magnitude = 0.2 V)

12. WAVES AND SOUND

12.1 Wave Properties

Wave Equation: $v=f\lambda$

- v = wave speed (m/s)
- f = frequency (Hz)
- λ = wavelength (m)

Period and Frequency: $f=1/T$

12.2 Types of Waves

- Transverse: Displacement perpendicular to propagation direction
- Longitudinal: Displacement parallel to propagation direction

12.3 Wave Behavior

Reflection:

- Fixed end: Inverted reflection
- Free end: Upright reflection

Refraction: $n_1 v_1=n_2 v_2 \quad \sin\theta_1/\sin\theta_2 =v_1/v_2 =n_2/n_1$

Diffraction: Bending around obstacles (greatest when λ ≈ obstacle size)

Interference:

- Constructive: Path difference = mλ
- Destructive: Path difference = (m + ½)λ

12.4 Sound

Speed of Sound: $v=331\sqrt{1+T/273}$ m/s

At 20°C: v ≈ 343 m/s

Intensity: $I=P/A=P/(4\pi r^2)$

Sound Level (decibels): $\beta=10\log I/I_0$

Where $I_0 = 10^{-12}$ W/m²

Doppler Effect: $f'=f (v\pm v_o)/(v\mp v_s)$

- Observer moving toward source: + in numerator
- Source moving toward observer: - in denominator

12.5 Example Questions

Example 1: A wave has frequency 500 Hz and wavelength 0.68 m. What is its speed?
Solution: v = fλ = 500 × 0.68 = 340 m/s

Example 2: What is the wavelength of a 1000 Hz sound wave in air?
Solution: λ = v/f = 343/1000 = 0.343 m

Example 3: A car horn (f = 400 Hz) is approaching you at 30 m/s. What frequency do you hear? (Speed of sound = 340 m/s)
Solution: $f' = f \times v/(v - v_s) = 400 \times 340/(340 - 30) = 400 \times 340/310 = 438$ Hz

Example 4: Two sources emit waves with path difference 0.5 m. What is the phase difference if wavelength is 0.25 m?
Solution: Path difference/λ = 0.5/0.25 = 2 wavelengths = In-phase (constructive)

Example 5: The intensity of a sound is doubled. What is the change in decibel level?
Solution: $\beta_2 - \beta_1 = 10\log(I_2/I_1) = 10\log(2) = 10 \times 0.301 = +3$ dB

13. OPTICS

13.1 Light as a Wave

Speed of Light: $c=3\times10^8 m/s$
Electromagnetic Spectrum: Radio → Microwave → IR → Visible → UV → X-ray → Gamma (increasing frequency, decreasing wavelength)

13.2 Reflection

Law of Reflection: $\theta_i=\theta_r$
Plane Mirror:

- Image distance = Object distance
- Laterally inverted
- Virtual (behind mirror)

13.3 Refraction

Snell's Law: $n_1 \sin\theta_1=n_2 \sin\theta_2$
Refractive Index: $n=c/v$
Critical Angle: $\sin\theta_c=n_2/n_1$ (for $n_1 > n_2$)
Total internal reflection when $\theta > \theta_c$

13.4 Lenses

Thin Lens Equation: $1/f=1/d_o +1/d_i$
Magnification: $m=-d_i/d_o =h_i/h_o$
Lens Power: $P=1/f$(in meters)
Unit: Diopter (D)

13.5 Example Questions

Example 1: Light goes from air (n=1) into glass (n=1.5) at 30° to the normal. What is the refracted angle?
Solution: $n_1 \sin\theta_1 = n_2 \sin\theta_2$ $1 \times \sin30° = 1.5 \times \sin\theta_2$ $0.5 = 1.5 \sin\theta_2$ $\sin\theta_2 = 0.333$ $\theta_2 = 19.5°$

Example 2: A convex lens has focal length 20 cm. An object is placed 60 cm from the lens. Where is the image formed?
Solution: $1/f = 1/d_o + 1/d_i$ $1/20 = 1/60 + 1/d_i$ $1/d_i = 1/20 - 1/60 = 3/60 - 1/60 = 2/60$ $d_i = 30$ cm (real, inverted)

Example 3: What is the critical angle for light going from diamond (n=2.42) to air?
Solution: $\sin\theta_c = n_2/n_1 = 1/2.42 = 0.413$ $\theta_c = 24.4°$

Example 4: A 5 cm tall object is placed 30 cm from a concave mirror with focal length 20 cm. Find

image height.
Solution: $1/f = 1/d_o + 1/d_i$ $1/20 = 1/30 + 1/d_i$ $1/d_i = 1/20 - 1/30 = 3/60 - 2/60 = 1/60$ $d_i = 60$ cm $m = -d_i/d_o = -60/30 = -2$ $h_i = m \times h_o = -2 \times 5 = -10$ cm (inverted, 10 cm tall)

Example 5 (2021 PhysicsBowl style): Two slits are 0.1 mm apart. Light of wavelength 500 nm produces an interference pattern on a screen 2 m away. What is the spacing between adjacent bright fringes?
Solution: For double slit: $\Delta y = \lambda L/d = (500 \times 10^{-9} \times 2)/(0.1 \times 10^{-3}) = 10^{-6}/10^{-4} = 0.01$ m = 1 cm

14. THERMODYNAMICS

14.1 Temperature and Heat

Temperature Scales: $K = °C + 273.15$ $°F = 9/5\,°C + 32$

Heat Transfer: $Q = mc\Delta T$

- c = specific heat capacity (J/kg·K)
- For water: c = 4186 J/kg·K

Phase Changes: $Q = mL$

- L = latent heat
- L_f (fusion/ice) = 334 kJ/kg
- L_v (vaporization) = 2260 kJ/kg

14.2 Kinetic Theory

Ideal Gas Law: $PV = nRT$

$PV = NkT$

- R = 8.314 J/(mol·K)
- $k = 1.38 \times 10^{-23}$ J/K

Gas Pressure: $P = 2/3\ N/V \langle KE \rangle$

$\langle KE \rangle = 3/2\ kT$

14.3 Thermodynamic Processes

First Law: $\Delta U = Q - W$

- Q = heat added to system
- W = work done BY system

Processes:

- Isochoric: V = constant, W = 0
- Isobaric: P = constant
- Isothermal: T = constant, $\Delta U = 0$, Q = W
- Adiabatic: Q = 0, $\Delta U = -W$

14.4 Heat Engines

Efficiency: $e = W/Q_H = (Q_H - Q_C)/Q_H = 1 - Q_C/Q_H$

Carnot Efficiency (maximum possible): $e_{max} = 1 - T_C/T_H$

(Temperatures in Kelvin)

14.5 Example Questions

Example 1: How much heat is needed to raise 1 kg of water from 20°C to 80°C?
Solution: $Q = mc\Delta T = 1 \times 4186 \times (80 - 20) = 4186 \times 60 = 251{,}160$ J

Example 2: How much heat is needed to melt 1 kg of ice at 0°C?
Solution: $Q = mL_f = 1 \times 334{,}000 = 334$ kJ

Example 3: A gas occupies 0.02 m^3 at 100 kPa and 300 K. How many moles of gas are present?
Solution: $PV = nRT$ $n = PV/RT = (100{,}000 \times 0.02)/(8.314 \times 300) = 2000/2494 = 0.80$ mol

Example 4: An ideal heat engine operates between 500 K and 300 K. What is its maximum efficiency?
Solution: $e_{max} = 1 - T_C/T_H = 1 - 300/500 = 1 - 0.6 = 0.4$ or 40%

Example 5 (2019 PhysicsBowl style): A monatomic ideal gas (3 degrees of freedom) is heated at constant volume from 200 K to 400 K. What is the change in internal energy for 2 moles?
Solution: For monatomic: $U = \frac{3}{2} nRT$ $\Delta U = \frac{3}{2} nR\Delta T = \frac{3}{2} \times 2 \times 8.314 \times 200 = 3 \times 8.314 \times 200 = 4988$ J

15. MODERN PHYSICS

15.1 Quantum Theory

Photon Energy: $E=hf=hc/\lambda$
Where $h = 6.626 \times 10^{-34}$ J·s (Planck's constant)
Photoelectric Effect: $K_{max}=hf-\phi$
- f = threshold frequency
- φ = work function

15.2 Atomic Physics

Bohr Model: $E_n=-13.6\text{ eV}/n^2$
Photon Emission/Absorption: $hf=E_i-E_f$

15.3 Nuclear Physics

Mass-Energy Equivalence: $E=mc^2$
Radioactive Decay: $N=N_0 e^{-\lambda t}$
Half-life: $t_{1/2}=\ln 2/\lambda=0.693/\lambda$
Alpha Decay:
- Helium nucleus ($^2He^4$)
- Mass: 4 amu
- Charge: +2e

Beta Decay:
- Electron emission
- Neutron → proton + electron + antineutrino

Gamma Decay:
- High-energy photon emission
- No change in mass/charge

15.4 Relativity

Time Dilation: $t=t_0/\sqrt{1-v^2/c^2}$
Length Contraction: $L=L_0 \sqrt{1-v^2/c^2}$
Mass Increase: $m=m_0/\sqrt{1-v^2/c^2}$
Energy-Momentum: $E^2=(pc)^2+(m_0 c^2)^2$

15.5 Example Questions

Example 1: What is the energy of a photon with wavelength 500 nm?
Solution: $E = hc/\lambda = (6.626 \times 10^{-34} \times 3 \times 10^8)/(500 \times 10^{-9}) = (1.988 \times 10^{-25})/(5 \times 10^{-7}) = 3.98 \times 10^{-19}$ J = 2.48 eV

Example 2: Light with work function 2.0 eV hits a metal. What is the stopping potential if photon energy is 4.0 eV?
Solution: $K_{max} = hf - \varphi = 4.0 - 2.0 = 2.0$ eV Since $eV_{stop} = K_{max}$: $V_{stop} = 2.0$ V

Example 3: A radioactive sample has half-life 10 days. What fraction remains after 30 days?
Solution: After 3 half-lives: $(1/2)^3 = 1/8 = 12.5\%$

Example 4: What is the de Broglie wavelength of an electron ($m = 9.1 \times 10^{-31}$ kg) moving at 10^6 m/s?
Solution: $\lambda = h/mv = 6.626 \times 10^{-34}/(9.1 \times 10^{-31} \times 10^6) = 6.626 \times 10^{-34}/9.1 \times 10^{-25} = 7.28 \times 10^{-10}$ m = 0.728 nm

Example 5 (2022 PhysicsBowl style): A spaceship travels at 0.8c. How much time passes on Earth when 1 year passes on the spaceship?
Solution: $t = t_0/\sqrt{(1 - v^2/c^2)} = 1/\sqrt{(1 - 0.64)} = 1/\sqrt{0.36} = 1/0.6 = 1.67$ years

Example 6: The binding energy of a deuterium nucleus (^2H) is 2.2 MeV. What is its mass defect?
Solution: $E = mc^2$ $m = E/c^2 = (2.2 \times 10^6 \times 1.6 \times 10^{-19})/(9 \times 10^{16}) = 3.52 \times 10^{-29}/9 \times 10^{-16} = 3.9 \times 10^{-30}$ kg

APPENDIX A: KEY FORMULAS SUMMARY

Mechanics

- $v = v_0 + at$
- $x = v_0t + \frac{1}{2}at^2$
- $v^2 = v_0^2 + 2ax$
- $F = ma$
- $W = Fd \cos \theta$
- $KE = \frac{1}{2}mv^2$
- $PE = mgh$
- $p = mv$
- $\tau = rF \sin \theta$
- $L = I\omega$

Electricity & Magnetism

- $F = kq_1q_2/r^2$
- $E = F/q = kQ/r^2$
- $V = kQ/r$
- $C = Q/V$
- $V = IR$
- $P = IV = I^2R = V^2/R$
- $F = qvB$
- $B = \mu_0I/(2\pi r)$
- $\varepsilon = -d\Phi/dt$

Waves & Optics

- $v = f\lambda$
- $n = c/v$
- $n_1 \sin \theta_1 = n_2 \sin \theta_2$

$1/f = 1/d_o + 1/d_i$
$m = -d_i/d_o$

Thermodynamics

$Q = mc\Delta T$
$PV = nRT$
$\Delta U = Q - W$
$e = 1 - T_C/T_H$

Modern Physics

$E = hf = hc/\lambda$
$E = mc^2$
$\lambda = h/p$
$t = t_0/\sqrt{1 - v^2/c^2}$
$N = N_0 e^{-\lambda t}$

APPENDIX B: PHYSICSBOWL PROBLEM-SOLVING STRATEGIES

Time Management

- Know the easy topics: Mechanics and electricity typically comprise ~50% of questions
- Don't get stuck: If a question takes >30 seconds, skip and come back
- Use process of elimination: Eliminate obviously wrong answers first
- Guess intelligently: There's no penalty for wrong answers, so never leave blank

Problem-Solving Tips

- Write down given information: List all known values and what you're solving for
- Use units as a guide: Check that your answer has correct dimensions
- Look for shortcuts: Many PhysicsBowl questions have elegant solutions
- Estimate when possible: Multiple choice lets you eliminate by approximation
- Remember common values: $g = 10$ m/s², $c = 3 \times 10^8$ m/s, etc.

Common Mistakes to Avoid

- Confusing mass and weight
- Forgetting to convert units (cm to m, minutes to seconds)
- Using degrees instead of radians in wave/rotation problems
- Confusing frequency and angular frequency ($\omega = 2\pi f$)
- Forgetting signs in kinematics and electrostatics

APPENDIX C: FREQUENTLY TESTED CONCEPTS BY TOPIC

High Frequency (appear in >70% of exams)

- Newton's laws ($F = ma$)
- Kinematic equations
- Work-energy theorem
- Conservation of energy/momentum
- Coulomb's law
- Ohm's law and power in circuits
- Wave equation ($v = f\lambda$)
- Snell's law

Medium Frequency (appear in 40-70% of exams)

- Rotational motion (torque, angular momentum)
- Simple harmonic motion

- Capacitance and energy storage
- Magnetic force on moving charges
- Doppler effect
- Lens/mirror equations
- Ideal gas law

Lower Frequency (appear in <40% of exams)

- Special relativity
- Quantum mechanics (photoelectric effect)
- Nuclear physics
- Buoyancy
- Bernoulli's equation

APPENDIX D: IMPORTANT CONSTANTS

Constant	Symbol	Value
Gravitational acceleration	g	9.8 m/s^2 (≈10 for estimates)
Speed of light	c	3.00×10^8 m/s
Planck's constant	h	6.626×10^{-34} J·s
Boltzmann constant	k	1.38×10^{-23} J/K
Gas constant	R	8.314 J/(mol·K)
Coulomb's constant	k	8.99×10^9 $N·m^2/C^2$
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T·m/A
Elementary charge	e	1.602×10^{-19} C
Electron mass	m_e	9.11×10^{-31} kg
Proton mass	m_p	1.673×10^{-27} kg
Specific heat of water	c	4186 J/(kg·K)
Latent heat of fusion (ice)	L_f	3.34×10^5 J/kg
Latent heat of vaporization	L_v	2.26×10^6 J/kg

PRACTICE PROBLEMS SET

Set 1: Mechanics

- A car accelerates from rest at 4 m/s^2 for 6 seconds. What is its final velocity? (Answer: 24 m/s)
- A 5 kg block is pulled across a frictionless surface with a force of 20 N. What is its acceleration? (Answer: 4 m/s^2)
- A 2 kg ball is thrown upward with 40 J of kinetic energy. What is its maximum height? (Answer: 2 m)
- Two objects, 3 kg and 6 kg, collide and stick together. If their initial velocities are 4 m/s and -2 m/s respectively, what is their final velocity? (Answer: 0 m/s)
- A solid cylinder (mass M, radius R) rolls without slipping down an incline. What fraction of its gravitational potential energy goes into translational kinetic energy? (Answer: 2/3)

Set 2: Electricity & Magnetism

- Two charges of +2 μC and -2 μC are 0.1 m apart. What is the force between them? (Answer: 3.6 N, attractive)
- A 100 Ω resistor draws 2 A of current. What power is dissipated? (Answer: 400 W)
- An electron enters a 0.5 T magnetic field perpendicularly with speed 10^6 m/s. What force acts on it? (Answer: 8×10^{-14} N)

A 20 μF capacitor is charged to 100 V. How much charge is stored? (Answer: 2×10^{-3} C)

What is the magnetic field 0.2 m from a wire carrying 5 A current? (Answer: 5×10^{-6} T)

Set 3: Waves & Optics

Light with wavelength 600 nm enters glass (n = 1.5). What is its new wavelength? (Answer: 400 nm)

A convex lens has focal length 15 cm. An object is placed 30 cm from the lens. Where is the image formed? (Answer: 30 cm, real and inverted)

Two sound sources have a path difference of 0.5 m. What type of interference occurs at that point if λ = 0.25 m? (Answer: Constructive)

A car moving at 30 m/s sounds its horn (f = 400 Hz). What frequency does a stationary observer hear as the car approaches? (Speed of sound = 340 m/s) (Answer: ~435 Hz)

Set 4: Thermodynamics & Modern Physics

How much heat is needed to convert 1 kg of ice at -20°C to steam at 100°C? (Answer: ~3.06 MJ)

An ideal gas is heated at constant pressure from 300 K to 600 K. What happens to its volume? (Answer: It doubles)

What is the wavelength of a photon with energy 6 eV? (Answer: ~207 nm)

A sample has half-life of 5 years. What fraction remains after 15 years? (Answer: 1/8)

ANSWERS TO PRACTICE PROBLEMS

Set 1

v = at = 4 × 6 = 24 m/s

a = F/m = 20/5 = 4 m/s²

KE = PE → 40 = mgh = 5 × 10 × h → h = 0.8 m (actually 4 m with g=10, but correct is 40/50 = 0.8 m, or 4 m with g=10... let's use g=10: 40 = 5×10×h → h = 0.8 m = 0.8... wait: KE = 40 J, PE = mgh = 5×10×h = 50h, so h = 40/50 = 0.8 m. With g=10, 40 = 5×10×h, h = 0.8 m = 0.8... hmm, let me recalculate with g=9.8: 40 = 5×9.8×h = 49h, h = 0.816 m)

$m_1v_1 + m_2v_2 = (m_1+m_2)v'$ → 3×4 + 6×(-2) = 9v' → 12-12 = 9v' → v' = 0

For rolling without slipping: PE = KE_trans + KE_rot. KE_rot/I = $\omega^2R^2/v^2 = (v^2/R^2)(I/MR^2)$ = $v^2(I/MR^2)$. For solid cylinder: I/MR^2 = ½. So KE_rot = ½(Mv^2) = ½KE_trans. Thus KE_trans : KE_rot = 2:1, so translational KE = $^2/_3$ of total.

Set 2

$F = k|q_1q_2|/r^2 = (9\times10^9)(2\times10^{-6})(2\times10^{-6})/(0.1)^2 = 3.6$ N

$P = I^2R = (2)^2(100) = 400$ W

$F = qvB = (1.6\times10^{-19})(10^6)(0.5) = 8\times10^{-14}$ N

$Q = CV = (20\times10^{-6})(100) = 2\times10^{-3}$ C

$B = \mu_0 I/(2\pi r) = (4\pi\times10^{-7})(5)/(2\pi\times0.2) = 5\times10^{-6}$ T

Set 3

λ' = λ/n = 600/1.5 = 400 nm

$1/f = 1/d_o + 1/d_i \rightarrow 1/15 = 1/30 + 1/d_i \rightarrow 1/d_i = 1/15-1/30 = 1/30 \rightarrow d_i = 30$ cm

Path difference = 0.5 m = 2λ = 2(0.25), so constructive interference

$f' = f \times v/(v-v_s)$ = 400 × 340/(340-30) = 400 × 340/310 = 438.7 Hz ≈ 435 Hz (or ~439 Hz)

Set 4

Q = m[c_iceΔT + L_f + c_waterΔT + L_v] = 1[2100(20) + 334000 + 4186(100) + 2260000] = 42000 + 334000 + 418600 + 2260000 ≈ 3,061,600 J ≈ 3.06 MJ

V/T = constant (Charles's Law), so $V_2/V_1 = T_2/T_1$ = 600/300 = 2 → volume doubles

$E = hc/\lambda \rightarrow \lambda = hc/E = (6.626\times10^{-34} \times 3\times10^8)/(6\times1.6\times10^{-19}) = 2.07\times10^{-7}$ m = 207 nm

After 3 half-lives: $(1/2)^3 = 1/8$

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