

Concepts

- [PHYSICSBOWL COMPREHENSIVE REVISION NOTES](#)

PHYSICSBOWL COMPREHENSIVE REVISION NOTES

PHYSICSBOWL COMPREHENSIVE REVISION NOTES

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:

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2} at^2$$

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

$$x - x_0 = \frac{1}{2}(v_0 + v)t$$

Free Fall

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

$$g = 9.8 \text{ m/s}^2 \approx 10 \text{ m/s}^2$$

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:

$$\text{Time of flight: } t = (2v_0 \sin\theta)/g$$

$$\text{Maximum height: } H = (v_0^2 \sin^2\theta)/2g$$

$$\text{Range: } R = (v_0^2 \sin(2\theta))/g$$

The range is maximum at $\theta = 45^\circ$.

1.2 Example Questions

Example 1 (From typical PhysicsBowl): A car accelerates from rest at 3.0 m/s^2 for 4.0 seconds.

What is the car's final velocity?

Solution: Using $v = v_0 + at$

$$v_0 = 0 \text{ (starts from rest)}$$

$$a = 3.0 \text{ m/s}^2$$

$$t = 4.0 \text{ s}$$

$$v = 0 + (3.0)(4.0) = 12 \text{ m/s}$$

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

Solution: At maximum height, $v = 0$

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

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

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

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

$$\text{Solution: For constant velocity: } x = vt \quad 100 = v(5) \quad v = 20 \text{ m/s}$$

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

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

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.

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

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

Important notes:

Force is measured in Newtons (N): $1 \text{ N} = 1 \text{ kg}\cdot\text{m}/\text{s}^2$

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: $F = ma$ $20 = 5a$ $a = 4 \text{ m/s}^2$

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: $f_s(\text{max}) = \mu_s N = \mu_s mg = 0.4 \times 10 \times 10 = 40 \text{ N}$

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: $2T \sin(30^\circ) = mg = 2 \times 10 = 20 \text{ N}$ $T \sin(30^\circ) = 10$ $T(0.5) = 10$ $T = 20 \text{ N}$ in each rope

Example 4: A 1000 kg elevator accelerates upward at 2 m/s^2 . What is the tension in the supporting cable?

Solution: $T - mg = ma$ $T = m(g + a) = 1000(10 + 2) = 12,000 \text{ N}$

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 = $3 + 5 = 8 \text{ kg}$ $F = ma$ $16 = 8a$ $a = 2 \text{ m/s}^2$

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: $N = mg = 2 \times 10 = 20 \text{ N}$ Kinetic friction: $f_k = \mu_k N = 0.3 \times 20 = 6 \text{ N}$ Net force: $F_{\text{net}} = 8 - 6 = 2 \text{ N}$ $a = F_{\text{net}}/m = 2/2 = 1 \text{ m/s}^2$

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) = $1 \text{ N} \cdot \text{m}$

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: $W = -f_k d = -\mu_k N d$

3.2 Kinetic Energy

$$KE = \frac{1}{2} mv^2$$

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

3.3 Gravitational Potential Energy

$$PE_g = mgh$$

(Choose reference point where $h = 0$)

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

3.4 Power

Average Power: $P_{avg} = W/t = Fv_{avg}$

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: $W = mg\Delta y = 2 \times 10 \times 5 = 100 \text{ J}$

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

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

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 $mgh = \frac{1}{2}mv^2$ $mg(L \sin 30^\circ) = \frac{1}{2}mv^2$ $v^2 = 2gL \sin 30^\circ = 2(10)(10)(0.5) = 100$ $v = 10 \text{ m/s}$

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

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

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

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

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

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

4. LINEAR MOMENTUM AND COLLISIONS

4.1 Linear Momentum

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

Vector quantity

Unit: $\text{kg}\cdot\text{m/s}$

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

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

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: $m_1 v_1 + m_2 v_2 = (m_1 + m_2) v'$
 $5(4) + 3(0) = 8v'$
 $20 = 8v'$
 $v' = 2.5 \text{ m/s}$

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 = $\Delta p = m(v_f - v_i) = 2(-4 - 6) = -20 \text{ N}\cdot\text{s}$ (Magnitude = 20 N·s)

Example 3 (2016 Physics Bowl 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 = $\dot{m} \times v_{rel} = 100 \text{ kg/s} \times 500 \text{ m/s} = 50,000 \text{ N}$

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: $p_{total} = m_1 v_1 + m_2 v_2 = 2(6) + 4(-3) = 12 - 12 = 0$ (They could be at rest together or moving in opposite directions with equal momentum)

5. ROTATIONAL MOTION

5.1 Angular Quantities

Linear Angular Relationship

$$x = r\theta$$

$$v = r\omega$$

$$a = r\alpha$$

Radians:

$$\text{Full circle} = 2\pi \text{ rad} = 360^\circ$$

$$1 \text{ rad} = 57.3^\circ$$

5.2 Rotational Kinematics

$$\omega = \omega_0 + \alpha t$$

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$$

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

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: $\tau_{\text{net}} = I\alpha$

5.5 Angular Momentum

$L = I\omega = mvr$

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

5.6 Rotational Kinetic Energy

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

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

5.7 Example Questions

Example 1: A disk with moment of inertia $0.5 \text{ kg}\cdot\text{m}^2$ rotates at 4 rad/s . What is its angular momentum?

Solution: $L = I\omega = 0.5 \times 4 = 2 \text{ kg}\cdot\text{m}^2/\text{s}$

Example 2: A solid sphere ($I = \frac{2}{5}MR^2$) rolls without slipping. What fraction of its kinetic energy is rotational?

Solution: $KE_{\text{total}} = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2}Mv^2 + \frac{1}{2}(\frac{2}{5}MR^2)(v^2/R^2) = \frac{1}{2}Mv^2 + \frac{1}{5}Mv^2 = \frac{7}{10}Mv^2$
Rotational fraction = $(\frac{1}{5})/(\frac{7}{10}) = \frac{2}{7} \approx 28.6\%$

Example 3: A torque of $10 \text{ N}\cdot\text{m}$ is applied to a disk ($I = 2 \text{ kg}\cdot\text{m}^2$). What is the angular acceleration?

Solution: $\tau = I\alpha$
 $10 = 2\alpha$
 $\alpha = 5 \text{ rad/s}^2$

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

Solution: $L_1 = L_2$
 $I_1\omega_1 = I_2\omega_2$
 $5(2) = 2\omega_2$
 $\omega_2 = 5 \text{ rad/s}$

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: $I = \frac{1}{2}MR^2 = \frac{1}{2}(4)(0.25) = 0.5 \text{ kg}\cdot\text{m}^2$
Using $a = g \sin\theta / (1 + I/MR^2) = g \sin\theta / (1 + 0.5/4) = g \sin\theta / 1.125$
If $\theta = 30^\circ$: $a = 10(0.5)/1.125 = 4.44 \text{ m/s}^2$

6. GRAVITATION

6.1 Newton's Law of Universal Gravitation

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

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

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: $g = 9.8 \text{ m/s}^2$

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

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: $g' = g/4 = 10/4 = 2.5 \text{ m/s}^2$ Weight = $mg' = 10 \times 2.5 = 25 \text{ N}$
(Earth surface weight = 100 N)

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

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

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

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

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

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

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

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

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

7.5 Example Questions

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

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

Example 2: A pendulum has length 1 m on Earth. What is its period on the Moon ($g_{\text{moon}} \approx 1.6 \text{ m/s}^2$)?

Solution: $T_{\text{moon}} = 2\pi\sqrt{L/g_{\text{moon}}} = 2\pi\sqrt{1/1.6} = 2\pi \times 0.79 = 4.95 \text{ s}$ (Earth period = $2\pi\sqrt{1/10} \approx 2 \text{ s}$)

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: $E = \frac{1}{2}mv_{\text{max}}^2 = \frac{1}{2}(0.5)(4) = 1 \text{ J}$ Also $E = \frac{1}{2}kA^2 = 1 \Rightarrow \frac{1}{2}k(0.01) = 1 \Rightarrow k = 200 \text{ N/m}$

Example 4: What is the acceleration of a mass at maximum displacement in SHM?

Solution: At maximum displacement ($x = \pm A$): $a = -\omega^2x = \pm\omega^2A$ (maximum magnitude) At equilibrium ($x = 0$): $a = 0$

8. FLUID MECHANICS

8.1 Density and Pressure

Density: $\rho = m/V$

Unit: kg/m^3

Water: 1000 kg/m^3

Pressure: $P = F/A$

Unit: Pascal (Pa) = N/m^2

For fluids: $P = \rho gh$ (hydrostatic pressure)

8.2 Buoyancy (Archimedes' Principle)

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

Key points:

Buoyant force equals weight of displaced fluid

Object floats when $F_B = mg$

Fraction submerged = $\rho_{\text{object}}/\rho_{\text{fluid}}$

8.3 Fluid Dynamics

Continuity Equation: $A_1 v_1 = A_2 v_2$

(Conservation of mass for fluid flow)

Bernoulli's Equation: $P + \frac{1}{2}\rho v^2 + \rho gh = \text{"constant"}$

For horizontal flow: $P + \frac{1}{2}\rho v^2 = \text{"constant"}$

8.4 Example Questions

Example 1: A 100 cm^3 object with density 0.8 g/cm^3 is placed in water. What volume is submerged?

Solution: Fraction submerged = $\rho_{\text{object}}/\rho_{\text{fluid}} = 0.8/1.0 = 0.8$ Volume submerged = $0.8 \times 100 = 80 \text{ cm}^3$

Example 2: What pressure exists at a depth of 10 m in water?

Solution: $P = \rho gh = 1000 \times 10 \times 10 = 100,000 \text{ Pa} = 1 \text{ atm}$ (Plus atmospheric pressure: $\sim 101,300 \text{ Pa}$)

Example 3: Water flows through a pipe with diameter 0.1 m at 2 m/s. What is the flow rate?

Solution: $A = \pi r^2 = \pi(0.05)^2 = 0.00785 \text{ m}^2$ $Q = Av = 0.00785 \times 2 = 0.0157 \text{ m}^3/\text{s}$

Example 4 (2023 PhysicsBowl style): A balloon is filled with helium (density 0.18 kg/m^3) in air (density 1.2 kg/m^3). The balloon envelope mass is 0.5 g and volume 0.01 m^3 . What is the maximum load it can lift?

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

9. ELECTRIC FIELDS AND CAPACITANCE

9.1 Electric Charge

$$q = ne$$

$$e = 1.602 \times 10^{-19} \text{ C (proton), } -e \text{ (electron)}$$

Conservation of charge

Like charges repel, opposites attract

9.2 Coulomb's Law

$$F = k (q_1 q_2) / r^2$$

Where $k = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2 \approx 9 \times 10^9$

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: $C = (\epsilon_0 A) / d$

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

9.6 Example Questions

Example 1: Two charges, $+2 \mu\text{C}$ and $-3 \mu\text{C}$, are 0.1 m apart. Find the force on each.

Solution: $F = k |q_1 q_2| / r^2 = (9 \times 10^9)(2 \times 10^{-6})(3 \times 10^{-6}) / (0.1)^2 = (9 \times 10^9)(6 \times 10^{-12}) / 0.01 = 5.4 \times 10^{-3} / 0.01 = 0.54 \text{ N}$ (attractive)

Example 2: What is the electric field 0.2 m from a $+5 \mu\text{C}$ charge?

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

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

Example 4: A $10 \mu\text{F}$ capacitor is charged to 50 V . What charge is stored?

Solution: $Q = CV = 10 \times 10^{-6} \times 50 = 5 \times 10^{-4} \text{ C} = 500 \mu\text{C}$

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: $F = kq(2q)/r^2 = 2kq^2/r^2$ $0.2 = 2(9 \times 10^9)q^2/(0.05)^2$ $q^2 = 0.2(0.05)^2/(2 \times 9 \times 10^9) = 0.2 \times 0.0025/(1.8 \times 10^{10})$ $q^2 = 2.78 \times 10^{-14}$ $q = 5.27 \times 10^{-7} \text{ C} = 0.527 \mu\text{C}$

Example 6: An electron ($q = -1.6 \times 10^{-19} \text{ C}$, $m = 9.1 \times 10^{-31} \text{ kg}$) is accelerated through 1000 V . What is its final speed?

Solution: $\text{KE gained} = qV = 1.6 \times 10^{-19} \times 1000 = 1.6 \times 10^{-16} \text{ J}$ $\frac{1}{2}mv^2 = 1.6 \times 10^{-16}$ $v^2 = 2(1.6 \times 10^{-16})/(9.1 \times 10^{-31}) = 3.52 \times 10^{14}$ $v = 1.88 \times 10^7 \text{ m/s}$

10. CIRCUITS

10.1 Current and Resistance

Ohm's Law: $V=IR$

Current: $I=q/t$

Unit: Ampere (A) = C/s

Resistance: $R=\rho L/A$

ρ = resistivity

Depends on temperature: $R = R_0[1 + \alpha(T - T_0)]$

10.2 Power in Circuits

$P=IV=I^2R=V^2/R$

Energy: $E=Pt$

Unit: Joule (J)

Also: $\text{kWh} = 3.6 \times 10^6 \text{ J}$

10.3 Series and Parallel

Series:

$R_{\text{total}} = R_1 + R_2 + R_3 + \dots$

I is same through each component

V divides across components

Parallel:

$1/R_{\text{total}} = 1/R_1 + 1/R_2 + 1/R_3 + \dots$

V is same across each branch

I divides through branches

10.4 Circuit Analysis

Kirchhoff's Laws:

Junction rule: $\Sigma I_{\text{in}} = \Sigma I_{\text{out}}$

Loop rule: $\Sigma V = 0$ around any closed loop

EMF (ϵ): Voltage source, work per unit charge

Internal Resistance: For real battery: $V_{\text{terminal}} = \epsilon - Ir_{\text{internal}}$

10.5 Example Questions

Example 1: Three resistors, 2Ω , 3Ω , and 6Ω , 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 10Ω resistors in parallel are connected in series with a 5Ω resistor. If connected to a 20 V battery, find the current from the battery.

Solution: $R_{parallel} = (10 \times 10)/(10 + 10) = 5 \Omega$ $R_{total} = 5 + 5 = 10 \Omega$ $I = V/R_{total} = 20/10 = 2 \text{ A}$

Example 5: A battery with EMF 12 V and internal resistance 1Ω is connected to a 5Ω external resistor. Find terminal voltage.

Solution: $I = \epsilon/(r + R) = 12/(1 + 5) = 2 \text{ A}$ $V_{terminal} = \epsilon - Ir = 12 - 2(1) = 10 \text{ V}$

Example 6 (2018 PhysicsBowl style): How much energy is dissipated in a 100Ω resistor in 10 seconds if the current is 0.5 A ?

Solution: $P = I^2R = (0.5)^2(100) = 0.25 \times 100 = 25 \text{ W}$ $E = Pt = 25 \times 10 = 250 \text{ J}$

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 $\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$

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: $\epsilon = -(d\Phi_B)/dt$

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: $F = qvB = (1.6 \times 10^{-19})(10^6)(0.1) = 1.6 \times 10^{-14} \text{ N}$

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: $F = ILB = 2 \times 0.5 \times 0.3 = 0.3 \text{ N}$

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

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

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: $B = \mu_0 NI / (2r) = (4\pi \times 10^{-7} \times 100 \times 2) / (2 \times 0.1) = (8\pi \times 10^{-5}) / (0.2) = 1.26 \times 10^{-3} \text{ T}$

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: $\epsilon = -\Delta\Phi/\Delta t = -(0.05 - 0.01)/0.2 = -0.04/0.2 = -0.2 \text{ V}$ (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 $\lambda \approx$ obstacle size)

Interference:

Constructive: Path difference = $m\lambda$

Destructive: Path difference = $(m + \frac{1}{2})\lambda$

12.4 Sound

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

At 20°C: $v \approx 343 \text{ m/s}$

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

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

Where $I_0 = 10^{-12} \text{ W/m}^2$

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: $v = f\lambda = 500 \times 0.68 = 340 \text{ m/s}$

Example 2: What is the wavelength of a 1000 Hz sound wave in air?

Solution: $\lambda = v/f = 343/1000 = 0.343 \text{ m}$

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/ $\lambda = 0.5/0.25 = 2$ 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: $c = 3 \times 10^8$ m/s

Electromagnetic Spectrum: Radio \rightarrow Microwave \rightarrow IR \rightarrow Visible \rightarrow UV \rightarrow X-ray \rightarrow 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: $n_1 \sin\theta_1 = n_2 \sin\theta_2$ $1 \times \sin 30^\circ = 1.5 \times \sin\theta_2$ $0.5 = 1.5 \sin\theta_2$ $\sin\theta_2 = 0.333$ $\theta_2 = 19.5^\circ$

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: $\sin\theta_c = n_2/n_1 = 1/2.42 = 0.413$ $\theta_c = 24.4^\circ$

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

image height.

Solution: $1/f = 1/d_o + 1/d_i$ $1/20 = 1/30 + 1/d_i$ $1/d_i = 1/20 - 1/30 = 3/60 - 2/60 = 1/60$ $d_i = 60 \text{ cm}$
 $m = -d_i/d_o = -60/30 = -2$ $h_i = m \times h_o = -2 \times 5 = -10 \text{ cm}$ (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: $\Delta y = \lambda L/d = (500 \times 10^{-9} \times 2)/(0.1 \times 10^{-3}) = 10^{-6}/10^{-4} = 0.01 \text{ m} = 1 \text{ cm}$

14. THERMODYNAMICS

14.1 Temperature and Heat

Temperature Scales: $K = ^\circ\text{C} + 273.15$ $^\circ\text{F} = 9/5^\circ\text{C} + 32$

Heat Transfer: $Q = mc\Delta T$

c = specific heat capacity (J/kg·K)

For water: $c = 4186 \text{ J/kg}\cdot\text{K}$

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: $PV = nRT$

$PV = NkT$

$R = 8.314 \text{ J}/(\text{mol}\cdot\text{K})$

$k = 1.38 \times 10^{-23} \text{ J/K}$

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: $V = \text{constant}$, $W = 0$

Isobaric: $P = \text{constant}$

Isothermal: $T = \text{constant}$, $\Delta U = 0$, $Q = W$

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): $e_{\text{max}} = 1 - T_C/T_H$

(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: $Q = mc\Delta T = 1 \times 4186 \times (80 - 20) = 4186 \times 60 = 251,160 \text{ J}$

Example 2: How much heat is needed to melt 1 kg of ice at 0°C?

Solution: $Q = mL_f = 1 \times 334,000 = 334 \text{ kJ}$

Example 3: A gas occupies 0.02 m^3 at 100 kPa and 300 K. How many moles of gas are present?

Solution: $PV = nRT$ $n = PV/RT = (100,000 \times 0.02)/(8.314 \times 300) = 2000/2494 = 0.80 \text{ mol}$

Example 4: An ideal heat engine operates between 500 K and 300 K. What is its maximum efficiency?

Solution: $e_{\text{max}} = 1 - T_C/T_H = 1 - 300/500 = 1 - 0.6 = 0.4$ 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: $U = \frac{3}{2} nRT$ $\Delta U = \frac{3}{2} nR\Delta T = \frac{3}{2} \times 2 \times 8.314 \times 200 = 3 \times 8.314 \times 200 = 4988 \text{ J}$

15. MODERN PHYSICS

15.1 Quantum Theory

Photon Energy: $E = hf = hc/\lambda$

Where $h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$ (Planck's constant)

Photoelectric Effect: $K_{\text{max}} = hf - \phi$

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 (${}^2\text{He}^4$)

Mass: 4 amu

Charge: +2e

Beta Decay:

Electron emission

Neutron \rightarrow 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: $E = hc/\lambda = (6.626 \times 10^{-34} \times 3 \times 10^8)/(500 \times 10^{-9}) = (1.988 \times 10^{-25})/(5 \times 10^{-7}) = 3.98 \times 10^{-19} \text{ J} = 2.48 \text{ eV}$

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: $K_{\text{max}} = hf - \phi = 4.0 - 2.0 = 2.0 \text{ eV}$ Since $eV_{\text{stop}} = K_{\text{max}}$: $V_{\text{stop}} = 2.0 \text{ V}$

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 ($m = 9.1 \times 10^{-31} \text{ kg}$) moving at 10^6 m/s ?

Solution: $\lambda = h/mv = 6.626 \times 10^{-34}/(9.1 \times 10^{-31} \times 10^6) = 6.626 \times 10^{-34}/9.1 \times 10^{-25} = 7.28 \times 10^{-10} \text{ m} = 0.728 \text{ nm}$

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: $t = t_0/\sqrt{1 - v^2/c^2} = 1/\sqrt{1 - 0.64} = 1/\sqrt{0.36} = 1/0.6 = 1.67 \text{ years}$

Example 6: The binding energy of a deuterium nucleus (${}^2\text{H}$) is 2.2 MeV. What is its mass defect?

Solution: $E = mc^2$ $m = E/c^2 = (2.2 \times 10^6 \times 1.6 \times 10^{-19})/(9 \times 10^{16}) = 3.52 \times 10^{-29}/9 \times 10^{-16} = 3.9 \times 10^{-30} \text{ kg}$

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

$$F = kq_1q_2/r^2$$

$$E = F/q = kQ/r^2$$

$$V = kQ/r$$

$$C = Q/V$$

$$V = IR$$

$$P = IV = I^2R = V^2/R$$

$$F = qvB$$

$$B = \mu_0 I/(2\pi r)$$

$$\epsilon = -d\Phi/dt$$

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

$$E = hf = hc/\lambda$$

$$E = mc^2$$

$$\lambda = h/p$$

$$t = t_o/\sqrt{1 - v^2/c^2}$$

$$N = N_o e^{(-\lambda t)}$$

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: $g = 10 \text{ m/s}^2$, $c = 3 \times 10^8 \text{ m/s}$, 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 | $3.00 \times 10^8 \text{ m/s}$ |
| Planck's constant | h | $6.626 \times 10^{-34} \text{ J}\cdot\text{s}$ |
| Boltzmann constant | k | $1.38 \times 10^{-23} \text{ J/K}$ |
| Gas constant | R | $8.314 \text{ J}/(\text{mol}\cdot\text{K})$ |
| Coulomb's constant | k | $8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$ |
| Permeability of free space | μ_0 | $4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$ |
| Elementary charge | e | $1.602 \times 10^{-19} \text{ C}$ |
| Electron mass | m_e | $9.11 \times 10^{-31} \text{ kg}$ |
| Proton mass | m_p | $1.673 \times 10^{-27} \text{ kg}$ |
| Specific heat of water | c | $4186 \text{ J}/(\text{kg}\cdot\text{K})$ |
| Latent heat of fusion (ice) | L_f | $3.34 \times 10^5 \text{ J/kg}$ |
| Latent heat of vaporization | L_v | $2.26 \times 10^6 \text{ J/kg}$ |

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 $+2 \mu\text{C}$ and $-2 \mu\text{C}$ are 0.1 m apart. What is the force between them? (Answer: 3.6 N, attractive)

A 100Ω 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: $8 \times 10^{-14} \text{ N}$)

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 $\lambda = 0.25$ 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

$$v = at = 4 \times 6 = 24 \text{ m/s}$$

$$a = F/m = 20/5 = 4 \text{ m/s}^2$$

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

$$m_1v_1 + m_2v_2 = (m_1+m_2)v' \rightarrow 3 \times 4 + 6 \times (-2) = 9v' \rightarrow 12-12 = 9v' \rightarrow v' = 0$$

For rolling without slipping: $PE = KE_{\text{trans}} + KE_{\text{rot}}$. $KE_{\text{rot}}/I = \omega^2 R^2/v^2 = (v^2/R^2)(I/MR^2) = v^2(I/MR^2)$. For solid cylinder: $I/MR^2 = 1/2$. So $KE_{\text{rot}} = 1/2(Mv^2) = 1/2 KE_{\text{trans}}$. Thus $KE_{\text{trans}} : KE_{\text{rot}} = 2:1$, so translational $KE = 2/3$ of total.

Set 2

$$F = k|q_1q_2|/r^2 = (9 \times 10^9)(2 \times 10^{-6})(2 \times 10^{-6})/(0.1)^2 = 3.6 \text{ N}$$

$$P = I^2R = (2)^2(100) = 400 \text{ W}$$

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

$$Q = CV = (20 \times 10^{-6})(100) = 2 \times 10^{-3} \text{ C}$$

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

Set 3

$$\lambda' = \lambda/n = 600/1.5 = 400 \text{ nm}$$

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

Path difference = 0.5 m = $2\lambda = 2(0.25)$, so constructive interference

$$f' = f \times v/(v-v_s) = 400 \times 340/(340-30) = 400 \times 340/310 = 438.7 \text{ Hz} \approx 435 \text{ Hz (or } \sim 439 \text{ Hz)}$$

Set 4

$$Q = m[c_{\text{ice}}\Delta T + L_f + c_{\text{water}}\Delta T + L_v] = 1[2100(20) + 334000 + 4186(100) + 2260000] = 42000 + 334000 + 418600 + 2260000 \approx 3,061,600 \text{ J} \approx 3.06 \text{ MJ}$$

$V/T = \text{constant}$ (Charles's Law), so $V_2/V_1 = T_2/T_1 = 600/300 = 2 \rightarrow$ volume doubles

$$E = hc/\lambda \rightarrow \lambda = hc/E = (6.626 \times 10^{-34} \times 3 \times 10^8)/(6 \times 1.6 \times 10^{-19}) = 2.07 \times 10^{-7} \text{ m} = 207 \text{ nm}$$

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

