AP Physics 1

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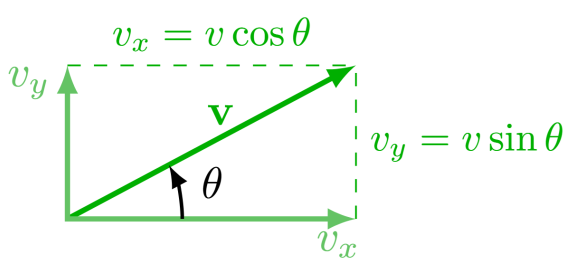
Unit 1 - Kinematics

Kinematics is the study of motion without considering the forces that cause it. It focuses on describing motion using quantities like displacement, velocity, and acceleration.

1.1 Scalars and Vectors

- Scalar: A quantity with magnitude only (e.g., speed, distance, mass, volume, temperature, energy).
- Vector: A quantity with both magnitude and direction (e.g., velocity $\vec{v}$, displacement $\Delta\vec{x}$, acceleration $\vec{a}$).
- Component Vectors: If a vector is at an angle use trigonometric functions to get the x and y components. Remember to use the correct angle and appropriate Trig function.



1.2 Distance, and Speed

- Distance: Distance is how far something moves and it includes the path travelled.
- Speed: $\frac{distance}{time}$

1.3 Displacement, Velocity, and Acceleration

Quantity	Equation
Displacement: The straight-line distance from where the object started to where it ended. The change in position of an object.	$\Delta\vec{x} = \vec{x}_f - \vec{x}_i$

Quantity	Equation
Average Velocity: The rate of change of displacement over a time interval.	$\vec{v}_{\text{avg}} = \frac{\Delta\vec{x}}{\Delta t}$
Instantaneous Velocity: The velocity of an object at a specific moment in time.	$\vec{v} = \frac{d\vec{x}}{dt}$
Average Acceleration: The rate of change of velocity over a time interval.	$\vec{a}_{\text{avg}} = \frac{\Delta\vec{v}}{\Delta t}$
Instantaneous Acceleration: The acceleration of an object at a specific moment in time.	$\vec{a} = \frac{d\vec{v}}{dt}$

1.4 Equations of Motion (UAM - Uniformly Accelerated Motion)

These equations apply when acceleration is constant.

Description	Equation
Relates final velocity to initial velocity, acceleration, and time.	$v_f = v_i + at$
Relates displacement to initial velocity, acceleration, and time.	$\Delta x = v_i t + \frac{1}{2}at^2$
Relates final velocity to initial velocity, acceleration, and displacement.	$v_f^2 = v_i^2 + 2a\Delta x$
Relates displacement to average velocity and time.	$\Delta x = \frac{1}{2}(v_i + v_f)t$

1.5 Graphical Analysis of Motion

Graph	Slope Represents	Area Represents	Key Observations
Position vs. Time	Velocity	-	Steeper slope = higher velocity, Zero slope = object at rest.
Velocity vs. Time	Acceleration	Displacement	Steeper slope = higher acceleration, Zero slope = constant velocity.
Acceleration vs. Time	-	Change in velocity	Area under the curve = Δv.

1.6 Free Fall

- Acceleration due to gravity (g): $g = 9.81\,\mathrm{m/s^2}$ (downward direction is negative).
- In free fall, the only force acting on the object is gravity (ignoring air resistance).
- Equations of motion apply with $a = -g$.

1.7 Projectile Motion

Projectile motion is the motion of an object launched into the air, subject only to gravity.

Key Points:

- The horizontal and vertical motions are independent.

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

Equations:

Quantity	Equation
Horizontal displacement	$\Delta x = v_{x0}t$
Vertical displacement	$\Delta y = v_{y0}t - \frac{1}{2}gt^2$
Time of flight	$t = \frac{2v_{y0}}{g}$ (for symmetric projectile motion)

1.8 Relative Motion

- The motion of an object as observed from a different frame of reference
- Relative velocity: $\vec{v}_{\mathrm{A\ relative\ to\ B}} = \vec{v}_{\mathrm{A}} - \vec{v}_{\mathrm{B}}$

Problem-solving tips

- Be careful to not add vectors that represent different types of quantities. This seems obvious when talking about scalar quantities like temperature and volume. For example, you can't add [25\degree\text{C}] to [2,\text{L}.] Similarly, you can't add a displacement vector of [25,\text{m}] to a velocity vector of [-2,\text{m/s}.] The result would be meaningless. As always in science, paying careful attention to units can help avoid mistakes.
    - Remember to clearly define your coordinate system before doing any calculations with vectors. It's easy to forget that you're working with vectors, especially since positive vector values "look like" scalars with no sign. But direction and sign are very important with vectors, even if the direction is an implied "[+]."
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    - **Confusion about choosing the "correct" coordinate system.** All coordinate systems are equally valid, so we can choose any system. The choice will affect the numbers in the calculation, but as long as we use the coordinate system consistently, the physical meaning of the answer won't change.

Unit 2 - Force and translational dynamics

Dynamics is the study of forces and how they affect the motion of objects. It builds on the concepts of kinematics by introducing the causes of motion.

2.1 Newton's Laws of Motion

Laws

- First Law (Inertia): An object at rest stays at rest, and an object in motion stays in motion unless acted upon by a net external force. $\sum \vec{F} = 0 \Rightarrow \vec{a} = 0$
- Second Law: The acceleration of an object is directly proportional to the net force and inversely proportional to its mass. $\sum \vec{F} = m\vec{a}$

- Third Law (Action-Reaction) ($\vec{F}_{12} = -\vec{F}_{21}$): For every action, there is an equal and opposite reaction. Forces always occur in pairs e.g., when you push a wall, the wall pushes back on you with an equal force. Third law can be counterintuitive, remember that two interacting objects exert equal and opposite forces on each other, even if they have very different masses or velocities.

Applications

- Atwood's Machine: A system of two masses connected by a string over a pulley.
- Pulleys: Used to change the direction of a force.
- Elevators: Analyze forces when an elevator accelerates upward or downward.

2.2 Types of Forces

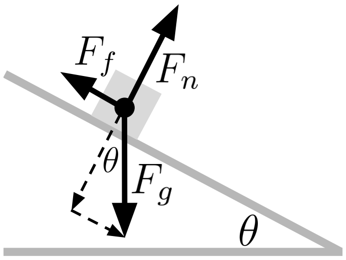
- Gravitational Force ($\vec{F}_g = m\vec{g}$): The force exerted by Earth (or any massive object) on another object.
- Normal Force ($\vec{F}_N$): The force exerted by a surface to support an object. It acts perpendicular to the surface.
- Frictional Force: The force that opposes motion between two surfaces in contact and depends on the normal force and the coefficient of friction.
  - Static friction ($F_{f,\text{static}} \leq \mu_s F_N$): Prevents an object from moving when a force is applied.
  - Kinetic friction ($F_{f,\text{kinetic}} = \mu_k F_N$): Acts on an object in motion.
- Tension ($\vec{T}$): The force exerted by a string, rope, or cable, acts along the direction of the string
- Applied Force ($\vec{F}_{\text{applied}}$): A force applied to an object by an external agent (e.g., pushing or pulling).
- Spring Force:
- Centripetal Force ($F_c = \frac{mv^2}{r} = mr\omega^2$): The net force directed toward the center of a circular path that causes circular motion.
  - Centripetal Acceleration ($a_c = \frac{v^2}{r} = r\omega^2$): The acceleration directed toward the center of the circle.

2.3 Free Body Diagrams

- A diagram showing all the forces acting on an object.
- Steps to Draw:
  1. Identify the object of interest.
  2. Draw all forces acting on the object as vectors.
  3. Label each force (e.g., $\vec{F}_g$, $\vec{F}_N$, $\vec{F}_f$).
  4. Break forces into components if necessary (e.g., on an incline).

2.4 Inclined Planes

Forces on an object on an inclined plane can be broken into components parallel and perpendicular to the surface.



- Parallel to Incline: The component of gravity acting down the incline. $F_{g,\parallel} = mg\sin\theta$
- Perpendicular to Incline: The component of gravity acting perpendicular to the incline. $F_{g,\perp} = mg\cos\theta$

Circular Orbits

2.7 Translational Equilibrium

- An object is in translational equilibrium when the net force acting on it is zero.
- **Condition:** $\sum \vec{F} = 0$
- **Implications:** The object is either at rest or moving with constant velocity.

Problem-solving tips

Newtons Laws

- In any physical problem it's essential to clearly define your system. The system of interest can vary significantly. It may be a single ball, a bucket of balls, the entire Earth, or anything else. Define a system that's convenient for your problem, and remain consistent with that choice throughout the analysis.
- We will almost always deal with "objects" that are in fact systems of smaller objects. But the value in defining a system is that we no longer need to worry about each individual interaction between the smaller objects in the system. All of the internal force pairs are contained within the system. So, be sure to only label *external* forces on the system's free-body diagram.
- When locating the center of mass for a system, start by looking for any lines of symmetry. If you identify one or more lines of symmetry for the system, you know the center of mass must lie somewhere along that line.
- A system remaining at rest is not accelerating. A system moving with constant velocity is also not accelerating. A system in either of these states of motion must be experiencing zero net force. (You may also see such scenarios described as being in **translational equilibrium**.)
- A system's acceleration points in the same direction as the net force acting on the system. However, the system's acceleration and velocity may not point in the same direction.
- A system may have zero [\Sigma \vec{F}] and [\vec{a}] in one dimension, but nonzero [\Sigma \vec{F}] and [\vec{a}] in another dimension. The system only accelerates in the direction of the net force.
- There may be cases when a system experiences forces directed at various angles. In those cases, trigonometry may be needed to resolve the force vectors into perpendicular components so [\Sigma \vec{F}_x] and [\Sigma \vec{F}_y] can be determined.

Inclines

- For an incline that makes an angle θ with the horizontal, $\boxed{F_{g,\parallel}=mg\sin\theta}$ and $\boxed{F_{g,\perp}=mg\cos\theta}$. Though you can re-derive this result using diagrams and trigonometry, it's helpful to remember offhand. Considering the limiting cases of 0° and 90° can help you confirm which is which.
- An object on an incline does not accelerate perpendicular to the incline's surface (unless the surface is breaking or stretching). So, the forces perpendicular to the surface must be balanced.
- For an object at rest or sliding down an incline, the force of friction $\vec{F}_f$ points up the incline, parallel to the surface. (If the object was sliding up the incline, $\vec{F}_f$ would point down the incline, parallel to the surface.)
- The analysis above was for an object undergoing **translational motion** only. The entire block was moving together in the same way (i.e., no part of the block was moving differently than any other part of the block). Therefore, we could treat the block as a point object located at the block's center of mass. However, if we were analyzing something that could *rotate* while moving down the incline (e.g., a disk or a ball), we'd need to consider additional factors when analyzing its motion.

Circular Motion

- The term "centripetal force" is sometimes used to refer to the net force in the radial direction, $\Sigma\vec{F}_\text{rad}$, acting on an object following a circular path.
- Similarly, centripetal acceleration refers to the acceleration *in the radial direction* of an object following a circular path. Centripetal acceleration can be related to the net force in the radial dimension by applying Newton's second law to the radial dimension, $a_c=\dfrac{\left|\Sigma\vec{F}_\text{rad}\right|}{m}$. The magnitude of centripetal acceleration is also $a_c=\dfrac{v^2}{r}$. These expressions for a_c often need to be equated when analyzing circular motion scenarios.
- The analysis above also applies to objects that only traverse *part* of a circular path. For example, if a car rounds a circular curve, it's in circular motion while making the turn. This is true even if the car does not complete a full circle.
- An object in circular motion will move at constant speed if it experiences zero tangential force. However, if the object experiences a nonzero tangential force, it will change speed as well as direction.

Unit 3 - Work, energy, and, power

Work, energy, and power are fundamental concepts in physics that describe how forces transfer energy to objects and how that energy is used or transformed.

3.1 Work

Work is done when a force causes a displacement of an object.

Concept	Description	Equation/Key Points
Work	The product of force and displacement in the direction of the force.	$W = F \cdot d \cdot \cos\theta$

Concept	Description	Equation/Key Points
Units	Work is measured in joules (J).	$1\,\mathrm{J} = 1\,\mathrm{N} \cdot \mathrm{m}$
Positive Work	Work is positive when force and displacement are in the same direction.	$\theta < 90^\circ$
Negative Work	Work is negative when force and displacement are in opposite directions.	$\theta > 90^\circ$
Zero Work	Work is zero when force and displacement are perpendicular.	$\theta = 90^\circ$

3.2 Kinetic Energy

Kinetic energy is the energy of motion.

Concept	Description	Equation/Key Points
Kinetic Energy	The energy an object possesses due to its motion.	$KE = \frac{1}{2}mv^2$
Work-Energy Theorem	The net work done on an object equals its change in kinetic energy.	$W_{\text{net}} = \Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$

3.3 Potential Energy

Potential energy is the energy stored due to an object's position or configuration.

Concept	Description	Equation/Key Points
Gravitational Potential Energy	Energy due to an object's height above a reference point.	$PE_g = mgh$
Elastic Potential Energy	Energy stored in a compressed or stretched spring.	$PE_{\text{elastic}} = \frac{1}{2}kx^2$
Conservation of Energy	Total mechanical energy (KE + PE) remains constant in the absence of non-conservative forces.	$KE_i + PE_i = KE_f + PE_f$

3.4 Power

Power is the rate at which work is done or energy is transferred.

Concept	Description	Equation/Key Points
Power	The rate of doing work.	$P = \frac{W}{t}$
Units	Power is measured in watts (W).	$1\,\mathrm{W} = 1\,\mathrm{J/s}$
Instantaneous Power	Power at a specific moment in time.	$P = F \cdot v$

3.5 Conservation of Energy

Energy cannot be created or destroyed, only transformed from one form to another.

Concept	Description	Equation/Key Points
Mechanical Energy	The sum of kinetic and potential energy.	$E_{\text{mech}} = KE + PE$
Non-Conservative Forces	Forces like friction that cause energy to be lost as heat.	$W_{\text{non-conservative}} = \Delta E_{\text{mech}}$

3.6 Work Done by Variable Forces

When the force is not constant, work is calculated using integration.

Concept	Description	Equation/Key Points
Work by Variable Force	Work is the area under the force vs. displacement graph.	$W = \int_{x_i}^{x_f} F(x)\, dx$
Spring Force	The force exerted by a spring is proportional to its displacement.	$F = -kx$

3.7 Applications of Work, Energy, and Power

Application	Description	Equation/Key Points
Pulleys and Inclines	Systems involving pulleys or inclined planes can be analyzed using work and energy.	$W = F \cdot d$
Efficiency	The ratio of useful work output to total work input.	$\text{Efficiency} = \frac{W_{\text{useful}}}{W_{\text{input}}} \times 100\%$

Unit 4 - Linear momentum

Linear momentum is a measure of an object's motion and is central to understanding collisions, explosions, and other interactions.

4.1 Momentum and Impulse

Momentum is a vector quantity that depends on an object's mass and velocity.

Concept	Description	Equation/Key Points
Momentum	The product of an object's mass and velocity.	$\vec{p} = m\vec{v}$

Concept	Description	Equation/Key Points
Impulse	The change in momentum caused by a force acting over a time interval.	$\vec{J} = \Delta\vec{p} = \vec{F} \cdot \Delta t$
Impulse-Momentum Theorem	The impulse equals the change in momentum.	$\vec{J} = \vec{p}_f - \vec{p}_i$

4.2 Conservation of Momentum

The total momentum of a system remains constant if no external forces act on it.

Concept	Description	Equation/Key Points
Conservation of Momentum	The total momentum before an interaction equals the total momentum after.	$\vec{p}_{\text{total, initial}} = \vec{p}_{\text{total, final}}$
Isolated System	A system with no external forces acting on it.	$\sum \vec{F}_{\text{external}} = 0$

4.3 Collisions

Collisions are interactions where objects exert forces on each other for a short time.

Type of Collision	Description	Equation/Key Points
Elastic Collision	Kinetic energy and momentum are conserved.	$KE_{\text{initial}} = KE_{\text{final}}$ $\vec{p}_{\text{initial}} = \vec{p}_{\text{final}}$
Inelastic Collision	Momentum is conserved, but kinetic energy is not.	$\vec{p}_{\text{initial}} = \vec{p}_{\text{final}}$
Perfectly Inelastic Collision	Objects stick together after the collision.	$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}_f$

4.4 Center of Mass

The center of mass is the point where the mass of a system is concentrated.

Concept	Description	Equation/Key Points
Center of Mass (COM)	The average position of all the mass in a system.	$\vec{r}_{\text{COM}} = \frac{\sum m_i\vec{r}_i}{\sum m_i}$
Motion of COM	The COM moves as if all the mass were concentrated at that point.	$\vec{v}_{\text{COM}} = \frac{\sum m_i\vec{v}_i}{\sum m_i}$

4.5 Recoil and Propulsion

Recoil and propulsion are applications of momentum conservation.

Concept	Description	Equation/Key Points
Recoil	The backward motion of an object after ejecting part of its mass.	$m_1\vec{v}_1 + m_2\vec{v}_2 = 0$
Rocket Propulsion	Rockets gain momentum by expelling exhaust gases.	$\Delta\vec{p}_{\text{rocket}} = -\Delta\vec{p}_{\text{exhaust}}$

4.6 Applications of Momentum

Application	Description	Equation/Key Points
Car Crashes	Seatbelts and airbags increase the time of impact, reducing the force on passengers.	$\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$
Sports	Momentum is key in analyzing collisions in sports like football or hockey.	$\vec{p} = m\vec{v}$

Unit 5 - Torque and rotational dynamics

Rotational dynamics deals with the motion of objects that rotate about an axis, introducing concepts like torque, angular momentum, and rotational inertia.

5.1 Torque

Torque is the rotational equivalent of force and causes objects to rotate.

Concept	Description	Equation/Key Points
Torque	The product of force and the lever arm (distance from the pivot point).	$\tau = rF\sin\theta$
Units	Torque is measured in newton-meters (N·m).	$1\,\mathrm{N}\cdot\mathrm{m}$
Direction	Torque is a vector quantity with direction determined by the right-hand rule.	Clockwise: negative Counterclockwise: positive
Lever Arm	The perpendicular distance from the pivot point to the line of action of the force.	$r_\perp = r\sin\theta$

5.2 Rotational Inertia (Moment of Inertia)

Rotational inertia is the resistance of an object to changes in its rotational motion.

Concept	Description	Equation/Key Points
Moment of Inertia	Depends on the mass distribution relative to the axis of rotation.	$I = \sum m_i r_i^2$
Common Shapes	- Point mass: $I = mr^2$ - Solid sphere: $I = \frac{2}{5}mr^2$ - Rod (center): $I = \frac{1}{12}mL^2$	

5.3 Rotational Kinematics

Rotational kinematics describes the motion of rotating objects without considering the forces involved.

Concept	Description	Equation/Key Points
Angular Displacement	The angle through which an object rotates.	$\Delta\theta = \theta_f - \theta_i$
Angular Velocity	The rate of change of angular displacement.	$\omega = \frac{\Delta\theta}{\Delta t}$
Angular Acceleration	The rate of change of angular velocity.	$\alpha = \frac{\Delta\omega}{\Delta t}$
Equations of Motion	- $\omega_f = \omega_i + \alpha t$ - $\Delta\theta = \omega_i t + \frac{1}{2}\alpha t^2$ - $\omega_f^2 = \omega_i^2 + 2\alpha\Delta\theta$	

5.4 Rotational Dynamics

Rotational dynamics relates torque to angular acceleration.

Concept	Description	Equation/Key Points
Newton's Second Law for Rotation	The net torque equals the moment of inertia times angular acceleration.	$\sum \tau = I\alpha$
Rotational Kinetic Energy	The energy due to rotational motion.	$KE_{\text{rot}} = \frac{1}{2}I\omega^2$

5.5 Angular Momentum

Angular momentum is the rotational equivalent of linear momentum.

Concept	Description	Equation/Key Points
Angular Momentum	The product of moment of inertia and angular velocity.	$\vec{L} = I\vec{\omega}$
Conservation of Angular Momentum	The total angular momentum of a system remains constant if no external torque acts on it.	$\vec{L}_{\text{initial}} = \vec{L}_{\text{final}}$

5.6 Rolling Motion

Rolling motion combines translational and rotational motion.

Concept	Description	Equation/Key Points
Condition for Rolling Without Slipping	The point of contact with the ground has zero instantaneous velocity.	$v = r\omega$
Total Kinetic Energy	The sum of translational and rotational kinetic energy.	$KE_{\text{total}} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

5.7 Applications of Rotational Dynamics

Application	Description	Equation/Key Points
Pulleys	Rotational motion is used to analyze systems with pulleys.	$\tau = rF$
Gyroscopes	Devices that use angular momentum to maintain orientation.	$\vec{L} = I\vec{\omega}$
Spinning Tops	Stability is due to conservation of angular momentum.	$\vec{L}_{\text{initial}} = \vec{L}_{\text{final}}$

Unit 6 - Energy and momentum of rotating systems

This unit explores the interplay between energy, momentum, and rotational motion, focusing on systems where rotation plays a key role.

6.1 Rotational Kinetic Energy

Rotational kinetic energy is the energy associated with an object's rotation.

Concept	Description	Equation/Key Points
Rotational Kinetic Energy	The energy due to rotational motion.	$KE_{\text{rot}} = \frac{1}{2}I\omega^2$
Total Kinetic Energy	The sum of translational and rotational kinetic energy.	$KE_{\text{total}} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

6.2 Angular Momentum

Angular momentum is a conserved quantity in rotational systems.

Concept	Description	Equation/Key Points
Angular Momentum	The product of moment of inertia and angular velocity.	$\vec{L} = I\vec{\omega}$

Concept	Description	Equation/Key Points
Conservation of Angular Momentum	The total angular momentum of a system remains constant if no external torque acts on it.	$\vec{L}_{\text{initial}} = \vec{L}_{\text{final}}$

6.3 Rolling Motion and Energy

Rolling motion combines translational and rotational motion, and energy is shared between the two.

Concept	Description	Equation/Key Points
Condition for Rolling Without Slipping	The point of contact with the ground has zero instantaneous velocity.	$v = r\omega$
Energy Distribution	Energy is divided between translational and rotational kinetic energy.	$KE_{\text{total}} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

6.4 Torque and Angular Acceleration

Torque causes angular acceleration in rotating systems.

Concept	Description	Equation/Key Points
Newton's Second Law for Rotation	The net torque equals the moment of inertia times angular acceleration.	$\sum \tau = I\alpha$
Work and Power in Rotation	Work done by torque and power in rotational systems.	$W = \tau\Delta\theta$ $P = \tau\omega$

6.5 Gyroscopic Motion

Gyroscopes exhibit unique behavior due to conservation of angular momentum.

Concept	Description	Equation/Key Points
Gyroscopic Precession	The axis of rotation of a gyroscope moves in a circular path when a torque is applied.	$\Omega = \frac{\tau}{L}$
Stability	Gyroscopes maintain orientation due to conservation of angular momentum.	$\vec{L} = I\vec{\omega}$

6.6 Applications of Rotational Energy and Momentum

Application	Description	Equation/Key Points
Flywheels	Store rotational energy for use in mechanical systems.	$KE_{\text{rot}} = \frac{1}{2} I\omega^2$
Figure Skaters	Skaters change their moment of inertia to control spin rate.	$I_1\omega_1 = I_2\omega_2$
Planetary Orbits	Angular momentum plays a key role in the motion of planets and satellites.	$\vec{L} = m\vec{r} \times \vec{v}$

Unit 7 - Oscillations

Oscillations are repetitive motions around an equilibrium position. This unit covers simple harmonic motion, pendulums, and damped/driven oscillations.

7.1 Simple Harmonic Motion (SHM)

Simple harmonic motion is a type of periodic motion where the restoring force is directly proportional to the displacement.

Concept	Description	Equation/Key Points
Displacement	The position of the object relative to equilibrium.	$x(t) = A\cos(\omega t + \phi)$
Amplitude	The maximum displacement from equilibrium.	A
Angular Frequency	The rate of oscillation in radians per second.	$\omega = \sqrt{\frac{k}{m}}$
Period	The time for one complete oscillation.	$T = \frac{2\pi}{\omega}$
Frequency	The number of oscillations per unit time.	$f = \frac{1}{T}$
Phase Constant	Determines the initial position of the oscillator.	ϕ

7.2 Energy in Simple Harmonic Motion

Energy in SHM is conserved and oscillates between kinetic and potential forms.

Concept	Description	Equation/Key Points
Potential Energy	Energy stored due to displacement from equilibrium.	$PE = \frac{1}{2} kx^2$
Kinetic Energy	Energy due to motion.	$KE = \frac{1}{2} mv^2$
Total Mechanical Energy	The sum of kinetic and potential energy.	$E_{\text{total}} = \frac{1}{2} kA^2$

7.3 Pendulums

Pendulums exhibit simple harmonic motion for small angles.

Concept	Description	Equation/Key Points
Simple Pendulum	A mass swinging on a string.	$T = 2\pi\sqrt{\frac{L}{g}}$
Physical Pendulum	A rigid body swinging about a pivot.	$T = 2\pi\sqrt{\frac{I}{mgh}}$
Torsional Pendulum	A disk suspended by a wire that twists.	$T = 2\pi\sqrt{\frac{I}{\kappa}}$

7.4 Damped Oscillations

Damped oscillations occur when a resistive force (e.g., friction) reduces the amplitude over time.

Concept	Description	Equation/Key Points
Damping Force	A force that opposes motion and reduces amplitude.	$F_d = -bv$
Underdamped	Oscillations gradually decrease in amplitude.	$x(t) = Ae^{-\frac{b}{2m}t}\cos(\omega_d t + \phi)$
Overdamped	The system returns to equilibrium without oscillating.	$x(t) = C_1e^{-\gamma_1 t} + C_2e^{-\gamma_2 t}$
Critically Damped	The system returns to equilibrium as quickly as possible without oscillating.	$x(t) = (C_1 + C_2t)e^{-\gamma t}$

7.5 Driven Oscillations and Resonance

Driven oscillations occur when an external force is applied to the system.

Concept	Description	Equation/Key Points
Driving Force	An external force that sustains oscillations.	$F(t) = F_0\cos(\omega_d t)$
Resonance	Maximum amplitude occurs when the driving frequency matches the natural frequency.	$\omega_d = \omega_0$
Amplitude at Resonance	The amplitude is maximized at resonance.	$A_{\max} = \frac{F_0}{b\omega_0}$

7.6 Applications of Oscillations

Application	Description	Equation/Key Points
Clocks	Pendulums are used to regulate timekeeping.	$T = 2\pi\sqrt{\frac{L}{g}}$
Musical Instruments	Strings and air columns oscillate to produce sound.	$f_n = \frac{n}{2L}\sqrt{\frac{T}{\mu}}$
Seismometers	Measure ground motion during earthquakes.	$x(t) = A\cos(\omega t + \phi)$

Unit 8 - Fluids

Fluids are substances that flow, including liquids and gases. This unit covers fluid statics, dynamics, and the principles governing fluid behavior.

8.1 Fluid Statics

Fluid statics deals with fluids at rest and the forces exerted by them.

Concept	Description	Equation/Key Points
Density	Mass per unit volume of a substance.	$\rho = \frac{m}{V}$
Pressure	Force exerted per unit area.	$P = \frac{F}{A}$
Hydrostatic Pressure	Pressure due to the weight of a fluid column.	$P = P_0 + \rho g h$
Pascal's Principle	Pressure applied to a confined fluid is transmitted equally in all directions.	$\Delta P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$
Buoyant Force	The upward force exerted by a fluid on an immersed object.	$F_b = \rho_{\text{fluid}} V_{\text{displaced}} g$

8.2 Fluid Dynamics

Fluid dynamics deals with fluids in motion and the forces acting on them.

Concept	Description	Equation/Key Points
Continuity Equation	The product of cross-sectional area and flow speed is constant for an incompressible fluid.	$A_1 v_1 = A_2 v_2$
Bernoulli's Equation	Relates pressure, speed, and height in a fluid.	$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$
Viscosity	A measure of a fluid's resistance to flow.	$\eta = \frac{F \cdot d}{A \cdot v}$
Laminar Flow	Smooth, orderly flow of fluid layers.	-
Turbulent Flow	Chaotic, irregular flow of fluid.	-

8.3 Applications of Fluid Principles

Application	Description	Equation/Key Points
Hydraulic Systems	Use Pascal's Principle to amplify force.	$\frac{F_1}{A_1} = \frac{F_2}{A_2}$
Aerodynamics	Study of air flow around objects, such as airplane wings.	Bernoulli's Equation

Application	Description	Equation/Key Points
Blood Flow	Blood circulation in the human body follows fluid dynamics principles.	Continuity Equation

8.4 Archimedes' Principle

Archimedes' Principle explains buoyancy and floating objects.

Concept	Description	Equation/Key Points
Buoyant Force	The upward force on an object immersed in a fluid.	$F_b = \rho_{\text{fluid}} V_{\text{displaced}} g$
Floating Objects	An object floats when the buoyant force equals its weight.	$F_b = mg$
Density Comparison	An object floats if its density is less than the fluid's density.	$\rho_{\text{object}} < \rho_{\text{fluid}}$

8.5 Surface Tension and Capillary Action

Surface tension and capillary action are phenomena caused by cohesive forces in liquids.

Concept	Description	Equation/Key Points
Surface Tension	The energy required to increase the surface area of a liquid.	$\gamma = \frac{F}{L}$
Capillary Action	The ability of a liquid to flow in narrow spaces without external forces.	$h = \frac{2\gamma \cos\theta}{\rho g r}$

8.6 Practice Problems

1. **Problem 1**: A block of wood with a volume of 0.01 m³ is fully submerged in water. Calculate the buoyant force acting on the block. (Density of water = 1000 kg/m³, $g = 9.8\,\text{m/s}^2$)
   - **Solution**: $F_b = \rho_{\text{fluid}} V_{\text{displaced}} g = 1000 \cdot 0.01 \cdot 9.8 = 98\,\text{N}$.
2. **Problem 2**: Water flows through a pipe with a cross-sectional area of 0.02 m² at a speed of 3 m/s. If the pipe narrows to 0.01 m², what is the new speed of the water?
   - **Solution**: $A_1 v_1 = A_2 v_2$
     $0.02 \cdot 3 = 0.01 \cdot v_2$
     $v_2 = 6\,\text{m/s}$.
3. **Problem 3**: A fluid with a density of 800 kg/m³ flows through a horizontal pipe. At one point, the pressure is 120 kPa and the speed is 2 m/s. If the pipe narrows and the speed increases to 4 m/s, what is the new pressure? (Use Bernoulli's Equation)

- **Solution**: $P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$
  $120,000 + \frac{1}{2} \cdot 800 \cdot 2^2 = P_2 + \frac{1}{2} \cdot 800 \cdot 4^2$
  $120,000 + 1600 = P_2 + 6400$
  $P_2 = 115,200\,\text{Pa}.$

Appendix

Resources

- College Board Course Guide
- Khan Academy
- Textbook
- Flipping Physics