AP Physics 1 Notes

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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).
- **Vector:** A quantity with both magnitude and direction (e.g., velocity, displacement, acceleration, force).
- **Component Vectors:** If a vector is at an angle use trignometric fucntions to get the x and y components. e.g. $\sin(\theta) = \frac{O}{H} \quad \Rightarrow \quad A_x = A\sin(\theta)$. Remember to use the corret angle and appropriate Trig function.

1.2 Distance, and Speed

- **Distance:** Distance is how far something moves and it includes the path travelled.
- **Speed:** Distance/Time

1.3 Displacement, Velocity, and Acceleration

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

	Description	Equation
Velocity as a function of time	Relates final velocity to initial velocity, acceleration, and time.	$v_f = v_i + at$
Displacement as a function of time	Relates displacement to initial velocity, acceleration, and time.	$\Delta x = v_i t + \frac{1}{2}at^2$

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

These equations apply when acceleration is constant.

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):** $g = 9.81$ 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:** $\vec{v}_{\text{A relative to B}} = \vec{v}_{\text{A}} - \vec{v}_{\text{B}}$

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

Law	Description	Equation/Key Points
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)	For every action, there is an equal and opposite reaction.	$\vec{F}_{12} = -\vec{F}_{21}$

2.2 Types of Forces

Force	Description	Equation/Key Points
Gravitational Force	The force exerted by Earth (or any massive object) on another object.	$\vec{F}_g = m\vec{g}$
Normal Force	The force exerted by a surface to support an object. It acts perpendicular to the surface.	$\vec{F}_N$ is perpendicular to the surface.
Frictional Force	The force that opposes motion between two surfaces in contact.	- Static friction: $F_{f,\text{static}} \leq \mu_s F_N$ - Kinetic friction: $F_{f,\text{kinetic}} = \mu_k F_N$
Tension	The force exerted by a string, rope, or cable.	$\vec{T}$ acts along the direction of the string.
Applied Force	A force applied to an object by an external agent (e.g., pushing or pulling).	$\vec{F}_{\text{applied}}$

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.

Force Component	Description	Equation
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.	$F_{g,\perp} = mg \cos\theta$

2.5 Friction

Friction opposes motion and depends on the normal force and the coefficient of friction.

Type of Friction	Description	Equation
Static Friction	Prevents an object from moving when a force is applied.	$F_{f,\text{static}} \leq \mu_s F_N$
Kinetic Friction	Acts on an object in motion.	$F_{f,\text{kinetic}} = \mu_k F_N$

2.6 Centripetal Force

The net force directed toward the center of a circular path that causes circular motion.

Concept	Description	Equation
Centripetal Force	Required for circular motion.	$F_c = \frac{mv^2}{r} = mr\omega^2$
Centripetal Acceleration	The acceleration directed toward the center of the circle.	$a_c = \frac{v^2}{r} = r\omega^2$

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.

2.8 Action-Reaction Pairs

- Forces always occur in pairs. For every action, there is an equal and opposite reaction.
- **Example:** When you push a wall, the wall pushes back on you with an equal force.

2.9 Applications of Newton's Laws

- **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.

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.	$W = F \cdot d \cdot \cos\theta$
Units	Work is measured in joules (J).	$1\,\text{J} = 1\,\text{N}\cdot\text{m}$
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.	$PE_{\text{elastic}} = \frac{1}{2}kx^2$

Concept	Description	Equation/Key Points
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 W $= 1$ 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.	Efficiency $= \frac{W_{\text{useful}}}{W_{\text{input}}} \times 100\%$

3.8 Practice Problems

1. **Problem 1**: A 5 kg box is lifted vertically by a force of 60 N over a distance of 10 m. Calculate the work done.
   - **Solution**: $W = F \cdot d = 60 \cdot 10 = 600$ J.
2. **Problem 2**: A spring with a spring constant of 200 N/m is compressed by 0.1 m. Calculate the elastic potential energy stored in the spring.
   - **Solution**: $PE_{\text{elastic}} = \frac{1}{2}kx^2 = \frac{1}{2} \cdot 200 \cdot (0.1)^2 = 1$ J.
3. **Problem 3**: A car engine delivers 100 kW of power. How much work is done in 10 seconds?
   - **Solution**: $W = P \cdot t = 100,000 \cdot 10 = 1,000,000$ J.

Let me know when you're ready for **Unit 4: Linear Momentum**!

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

4.7 Practice Problems

1. **Problem 1**: A 2 kg object moving at 3 m/s collides with a 3 kg object at rest. If they stick together, what is their final velocity?
   - **Solution**: $m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$ $2 \cdot 3 + 3 \cdot 0 = (2+3) v_f$ $6 = 5 v_f$ $v_f = 1.2$ m/s.
2. **Problem 2**: A 0.5 kg ball is thrown against a wall with a velocity of 10 m/s. It bounces back with a velocity of 8 m/s. Calculate the impulse.
   - **Solution**: $\vec{J} = \Delta \vec{p} = m(\vec{v}_f - \vec{v}_i)$ $\vec{J} = 0.5(8 - (-10)) = 0.5 \cdot 18 = 9$ kg · m/s.
3. **Problem 3**: A 1000 kg car moving at 20 m/s collides with a 1500 kg car moving at 10 m/s in the opposite direction. If they stick together, what is their final velocity?
   - **Solution**: $m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$ $1000 \cdot 20 + 1500 \cdot (-10) = (1000 + 1500) v_f$ $20,000 - 15,000 = 2500 v_f$ $v_f = 2$ m/s.

Let me know when you're ready for **Unit 5: Torque and Rotational Dynamics**!

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 N · 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.	$\vec{L}_{\text{initial}} = \vec{L}_{\text{final}}$

5.8 Practice Problems

1. **Problem 1**: A force of 10 N is applied perpendicular to a wrench at a distance of 0.5 m from the pivot point. Calculate the torque.
   - **Solution**: $\tau = rF \sin\theta = 0.5 \cdot 10 \cdot \sin 90^\circ = 5\,\text{N} \cdot \text{m}$.
2. **Problem 2**: A solid sphere of mass 2 kg and radius 0.1 m rolls without slipping. Calculate its moment of inertia.
   - **Solution**: $I = \frac{2}{5}mr^2 = \frac{2}{5} \cdot 2 \cdot (0.1)^2 = 0.008\,\text{kg} \cdot \text{m}^2$.
3. **Problem 3**: A disk with a moment of inertia of 0.1 kg·m² accelerates from rest to an angular velocity of 10 rad/s in 5 seconds. Calculate the torque applied.
   - **Solution**: $\alpha = \frac{\Delta\omega}{\Delta t} = \frac{10}{5} = 2\,\text{rad/s}^2$ $\tau = I\alpha = 0.1 \cdot 2 = 0.2\,\text{N} \cdot \text{m}$.

Let me know when you're ready for **Unit 6: Energy and Momentum of Rotating Systems**!

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.	$\vec{L} = I\vec{\omega}$
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.	$\vec{L} = m\vec{r} \times \vec{v}$

6.7 Practice Problems

1. **Problem 1**: A solid cylinder of mass 5 kg and radius 0.2 m rolls without slipping at a velocity of 4 m/s. Calculate its total kinetic energy.
   - **Solution**: $I = \frac{1}{2}mr^2 = \frac{1}{2} \cdot 5 \cdot (0.2)^2 = 0.1\,\text{kg}\cdot\text{m}^2$ $\omega = \frac{v}{r} = \frac{4}{0.2} = 20\,\text{rad/s}$ $KE_{\text{total}} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2} \cdot 5 \cdot 4^2 + \frac{1}{2} \cdot 0.1 \cdot 20^2 = 40 + 20 = 60\,\text{J}$.
2. **Problem 2**: A figure skater with an initial angular velocity of 2 rad/s and moment of inertia of 5 kg·m² pulls in their arms, reducing their moment of inertia to 2 kg·m². What is their new angular velocity?
   - **Solution**: $I_1\omega_1 = I_2\omega_2$ $5 \cdot 2 = 2 \cdot \omega_2$ $\omega_2 = 5\,\text{rad/s}$.

3. **Problem 3**: A torque of 10 N·m is applied to a wheel with a moment of inertia of 2 kg·m² for 5 seconds. Calculate the final angular velocity if the wheel starts from rest.
   - **Solution**: $\tau = I\alpha$ $\alpha = \frac{\tau}{I} = \frac{10}{2} = 5$ rad/s^2 $\omega_f = \omega_i + \alpha t = 0 + 5 \cdot 5 = 25$ rad/s.

Let me know when you're ready for **Unit 7: Oscillations**!