5 Steps to a 5: AP Physics I

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1 How Things Move

1.1 Vocabulary

- Position - Where an object is, relative to another (usually the origin or some other zero-point)
- Speed - How fast an object is moving
- Acceleration - The rate of change of an object's speed
- Displacement - The change in an object's position from start to finish, excluding any other motion made
- Position-Time Graph - A graph where time is on the x-axis and position is on the y-axis. Slope is speed
- Velocity-Time Graph - A graph where time is on the x-axis and velocity is on the y-axis. Slope is acceleration
- Free fall - Described motion where the only force acting on an object is gravity and its x velocity is 0
- Projectile Motion - Described motion where the only force acting on an object is gravity and its x velocity is non-zero but constant

The five most important motion variables are:

- v_0 - Initial velocity
- v_f - Final velocity
- Δx - Displacement
- a - Acceleration
- t - Time

If you know three of the five, you can use your equations to find the last two

1.2 Graphical Analysis of Motion

- A common mistake is people confuse position-time and velocity-time graphs, DO NOT DO THIS
- A position-time graph gives an object's position on the vertical (y) axis
- The slope of a position-time graph is the object's speed
  - Steeper slope means the object is moving faster
  - If the slope is positive, the object is moving forward
  - If the slope is negative, the object is moving backward
- You may not know the exact slope of a position-time graph, just use your best guess
  - Questions that ask for this want to see that you get the basic idea, not the exact answer
- On a velocity-time graph, the object's speed is given on the vertical (y) axis
- The direction of motion on a velocity time graph is given by the sign of the vertical coordinate at any point in time
- The acceleration of an object is given by the slope of its velocity-time graph
- It is important to note that acceleration does not tell you if something is speeding up or slowing down
  - If something is moving backwards and has a negative acceleration, it is speeding up in the negative direction
  - Be careful not to make assumptions, only draw conclusion from information you know definitively
- The area between a velocity-time graph and the horizontal axis gives the displacement of an object, which only tells you how far an object ended up from its starting position, NOT where it ends up

1.3 Algebraic Analysis of Motion

Algebraic analysis is different from geometric analysis in that you are given a description of a problem. The most important things to extract from this description are:

- A positive direction
- What you know
- What you do not know
- What you WANT to know
- A start and end time

A good strategy is to make a table of known and unknown values with the same five variables from the previous section to better organize your problem solving. Caltulate the missing variables with the kinematic equations:

- $v_f = v_0 + a * t$
- $\Delta x = v_0 * t + \frac{1}{2} * a * t^2$
- $v_f^2 = v_0^2 + 2 * a * \Delta x$

1.4 Free Fall and Projectile Motion

- Remember that objects in free fall always have acceleration due to gravity, usually rounded to -10m/s^2 in the vertical direction, and no horizontal velocity or acceleration
- Objects in projectile motion have two velocities, a horizontal velocity that remains constant and a vertical velocity that changes due to gravity. This means you should have two tables of known and unknown variables for objects in projectile motion, one for each velocity
- The two velocities for projectile motion also use the same variable for time as they describe the same object, just in different directions. They must use the same variable for time
- The final velocity of an object in free fall or projectile motion is not 0, that is its velocity once it is at rest
- The true final velocity is the object's velocity the instant before it hits the ground

2 Forces and Newton's Laws

2.1 Vocabulary

- Force - A push or pull applied by one object and experienced by another
- Net Force - The sum of the force acting on an object. If the net force were applied instead of individual force, it would produce the same effect as the individual forces
- Weight - The force an object experiences due to gravity
- Friction - A force that acts on an object from a surface, acts parallel to the surface of an object
- Kinetic Friction - Friction that acts on an object in motion along a surface, acts opposite to the direction of motion
- Static Friction - Friction that acts on an object at rest
- Normal Force - The force of a surface on an object, acts perpendicular to the surface
- Coefficient of friction - A constant between two surface that tells how strong friction between them is
- - Newton's third Law - States the force of object A on object B is equal and opposite to the force of object B on object A
- - Newton's Second Law - States an object's acceleration is is the net force acting on it divided by its mass

2.2 Free Body Diagrams

- Objects cannot "have" force, the can only experience and apply it
- Free-body diagrams are used to show what forces act on an object in what direction
- Free-body diagrams should have:
  - A labeled arrow for each force, with its tail starting at the object and its head pointing in the direction of force
  - A list of all forces acting on the object, indicating the object applying the force and the object experiencing the force
  - The phrase "draw and label the forces that act on [object]" means "draw a free-body diagram"
  - The only forces that act on an object without contact are the gravitational and electrical force
  - When listing and determining forces, begin with the force of gravity acting on the object and call it "weight", then, think of everything else the object is touching and any force they may exert on the object

2.3 Determining Net Force

- To add forces, treat each direction separately, add forces that point in the same direction, and subtract forces that point in opposite directions
- When an object moves along a surface, it is not accelerating perpendicular to the surface and thus experiences no net force perpendicular to the surface
- Note that the normal force is not always equal to an object's weight as there may be other forces acting perpendicular to the surface
- The force of kinetic friction is defined as the coefficient of friction times the normal force:

$$F_f = \mu_k * F_n$$

- Make sure you use the coefficient of static friction for a stationary object and the coefficient of kinetic friction for a moving object

2.4 Newton's Third Law

- The equal and opposite force given by Newton's Third Law is called the "companion force"
- To find the companion force, reverse the objects acting on each other and reverse the direction of the original force

2.5 Forces at Angles

- If a net force has vertical and horizontal components, use the Pythagorean theorem to determine the value of the combined force
- Drawing a force at an angle on a free body diagram is the same as any other force, but you break the force into its components before doing analysis
- When an angle, θ if formed between the direction of the force and the horizontal:
  - The horizontal component of the force is: $\cos\theta * F$
  - The vertical component of the force is: $\sin\theta * F$
- Using $F = ma$, we see that the acceleration of an object with multiple forces acting on it is:

$$\frac{F_{net}}{m} = a$$

- ALWAYS remember that only the net force is equal to an object's mass times its acceleration, individual forces cause individual accelerations that cancel out

2.6 Inclinced Planes

- A similar process occurs for analysis of objects on an incline
- The normal force will be perpendicular to the incline
- Friction will act parallel to the incline
- Gravity will act at an angle, so it will be broken into components

2.7 Multiple Objects

- When two objects are connected over a pulley, it is easy to consider them one system and use $a = \frac{F_{net}}{m}$ to find the acceleration
- If you need to describe one object, then you can draw a free-body diagram for just that one
- Note that one rope has one force of tension

3 Collisions: Impulse and Momentum

3.1 Vocabulary

- Momentum - An object's mass times its velocity, a vector in the direction of an object's movement
- Impulse - Defined as the product of a net force and the time during which the net force acts, also equal to the change in an object's momentum
- System - Made up of a group of objects that can be treated as a single thing. Important to define the system in question at the beginning
- - Elastic Collision - A collision where kinetic energy is conserved

3.2 The Impulse-Momentum Theorem

- The theorem is: $\Delta\rho = F * \Delta t$
- A force-time graph usually indicates you will be finding impulse, which is the area under the graph and the horizontal axis, best estimated with triangles and rectangles
- Impulse on its own does not say much, to find an object's final momentum you still need its initial momentum, to find its velocity you need its mass
- In any system where the only forces are acting between objects in the system, momentum is conserved
- When defining your initial and final velocities in a momentum problem, denote the final velocities and momentums with an apostrophe. Then, apply the conservation of momentum equation:
  - Since momentum is conserved, the total change is 0, thus:
  $$0 = \Delta\rho_A + \Delta\rho_B$$
  - Then, split up the changes in momentum into the final and initial momentums:
  $$0 = (\rho'_A - \rho_A) + (\rho'_B - \rho_B)$$
  - You can then split this into the individual masses and velocities:
  $$0 = (m_A * v'_A - m_A * v_A) + (m_B * v'_B - m_B * v_B)$$
  - If the two objects stick together, then their final velocities are equal to each other, and can be treated as the same variable:
  $$v'_A = v'_B$$

3.3 When is the Momentum of a System not Conserved?

- The momentum of a system is not conserved if an object outside the system exerts a force on it
- Note that a change in the direction of momentum means conservation is not conserved. If a ball rebounds with the same velocity as it hit something, momentum was not conserved
- Momentum is only conserved when considering a single collision, if multiple collisions occur, momentum may or may not be conserved depending on what objects are within your system

3.4 Elastic/Inelastic Collisions

- In an elastic collision, the total kinetic energy of both objects is the same before and after (A good way to check is by comparing total kinetic energy before and after)
- Always try to start a problem with momentum, only move onto kinetic energy if you have to
- Remember that just because two object bounce off of each other, it does not mean the collision is elastic
- Also remember that kinetic energy is a scalar, so it does not have direction and kinetic energies in different directions do not cancel out

3.5 2D collisions

- When dealing with collisions in two dimensions, analyze the momentum in each direction separately
- If there is movement in one dimension after a collision but none in that dimension before the collision, then the total momentum in that dimension must equal 0 for it to be conserved

3.6 Motion of the Center of Mass

- The center of mass of a system obeys Newton's second law
- If an astronaut pulls on an asteroid, then the two will collide at the center of mass between the two, so it will not accelerate
- If a rocket is set to land 30m from its launch point splits up into two pieces in the air and one of its pieces lands 35 meters from the launch point, the other must land 25m from the launch point in order to maintain the center of mass' original path the same
- The center of mass of a system is given by

$$x_{cm} = \frac{m_1 * X_1 + m_2 * X_2 + ...}{M}$$

  Where M is the total mass of the system

4 Work and Energy

4.1 Vocabulary

- Kinetic energy - possess by any object in motion, a scalar value
- Translational KE - Exists when an object's center of mass is moving, defined as
$$\frac{1}{2} * m * v^2$$
- Rotational KE - Exists when an object rotates, defined as
$$\frac{1}{2} * I * \omega^2$$
- Gravitational Potential Energy - Energy stored in a gravitational field. Near a planet it is defined as
$$m * g * h$$
Far from a planet it is defined as
$$-G\frac{M_1 * M_2}{d}$$
- Elastic Potential Energy - Energy stored in a spring, defined as
$$\frac{1}{2} * k * x^2$$
- Internal Energy - Relates to the energy stored in a multi-object system
- Microscopic Internal Energy - Relates to the temperature of an object, caused by the vibrational energy of its particles
- Internal Energy of a two-object system - Another way of saying potential energy
- Mechanical Energy - Sum of potential and kinetic energies
- Work - done when a force acts on something that moves a distance parallel to that force
- Power - Energy used / work done per second

4.2 Energy

- Note the difference between object and systems, a single object alone cannot have potential energy as it is the result of the interaction between multiple objects
- Similarly, an object cannot store elastic potential energy, only the spring-object system can

4.3 Work

- Work is done on an object when a force is exerted on it and the object moves parallel to the force, work is calculated with:
$$W = F * \Delta x_{||}$$
- When an object moves in the direction of force, work is positive
- When an object moves opposite in the direction of force, work is negative
- For example, a string pulling on a box does positive work while the friction acting against the box's movement does negative work
- If a force acts at an angle to movement, split the force into components, one parallel to movement and the other perpendicular to movement
- To find net work done on an object, add up the work done by all forces on an object
- A conservative force converts potential energy to other types of mechanical energy, thus it does not change the total mechanical energy of a system
- The amount of work done by a conservative force is path independent, it only depends on the starting and end point (like displacement)
- A non-conservative force changes the mechanical energy of a system
- Friction is an example of a non-conservative force, work done by friction becomes microscopic internal energy and becomes heat, which cannot be recovered to convert back into kinetic energy

4.4 The Work-Energy Theorem

- Since the work done by non conservative forces changes the total mechanical energy of a system, it is the sum of the change in kinetic energy and change in potential energy, shown below

$$W_{NC} = \Delta KE + \Delta PE$$

- Note that there are only 3 ways to approach a mechanics proble: kinematics/Newton's Laws, momentum, and energy
- When there is a change in force, there is a change in acceleration, thus the kinematics equations would not work
- When there is no collision, there is likely no change in momentum and thus that approach would not work
- When a force changes as it is being applied, the definition of work equation would not work as it uses a constant force
- The work-energy theorem is the best approach when a force is changing as it is applied

4.5 Power

- Power is a measure of how much energy something can output or how much work it can do per unit time
- Power has units joules per second or watts and is defined as

$$P = \frac{W}{t}$$

5 Rotations

5.1 Vocabulary

- Centripetal Acceleration - The acceleration an object feels towards the center of a circle
- Torque - The force applied to an object that causes it to rotate
- Lever Arm - The closest distance from an object's center of rotation to the line on which the force rotating it acts

5.2 Circular Motion

- When an object moves at a constant speed in a circle, its acceleration in its directino of motion is 0 because it is not speeding up or slowing down
- The object is, however, constantly changing direction, so it is still accelerating
- The acceleration of an object moving at a constant speed in a circle points to the center of the circle and has magnitude defined as
$$a = \frac{v^2}{r}$$
Where v is its translational velocity and r is the radius of the circle
- A newton's law approach is typically the right thing to do as the force pointing to the center of the circle
- Remember that centripetal force is not a new force, it is simply the label we give to the force making an object rotate, which can be tension, friction, etc.
- Whatever the centripetal force is, we can calculate it using $F = ma$ by replacing centripetal acceleration with its definition from before:
$$F = m * \frac{v^2}{r}$$
- Sometimes questions will not provide enough information to be label to calculate the remaining variables completely, instead these questions may ask what remaining info is required, be mindful of what information you need!
- Sometimes, you can split up known values into their component units and cancel out what you don't have, which leaves the problem solvable

5.3 Torque

- The torque a force applies is defined as:
$$\tau = F * d_{\perp}$$
- The $\perp$ symbol means we want the perpendicular distance between the force line and the fulcrum or axis of rotation
- If a force is acting at an angle to an object, break it into components and use the component perpendicular to the object
- The distance, d is also called the lever arm of a force
- Another way to determine torque is to extend the force line until it is perpendicular to the lever arm, and using the lever arm's new length to calculate torque
- When an object is not rotating but still has torque applied to it, you can choose anywhere as the fulcrum to make calculations easier
- When you have a heavy extended object applying torque, pretend all of the object's mass is at the object's center of mass

5.4 Rotational Kinematics

- Rotational speed is how fast an object rotates, or how many radians / degrees it rotates through over time, shown with ω
- Rotational acceleration is how fast an object's rotational speed is changing, shown with α
- The variable, θ represents an objects rotational displacement
- The kinematic equations for translational motion also relate the variables for rotational motion:
  - $\omega_f = \omega_0 + \alpha * t$
  - $\Delta\theta = \omega_0 * t + \frac{1}{2} * \alpha * t^2$
  - $\omega_f^2 = \omega_0^2 + 2 * \alpha * \Delta\theta$

5.5 Rotational Inertia

- Rotational inertia is an object's ability to resist rotational motion
- The two things that affect an object's rotational inertia is its mass and its distance from the center of rotation
- For a single "point", the rotational inertia is defined as:

$$I = m * r^2$$

- For simple shapes, the rotational inertia formulae are given to you
- The rotational inertia of a system is given by the sum of the rotational inertia of individual objects

5.6 Newton's Second Law for Rotation

- Applying Newton's second law to rotational motion gives

$$\tau_{net} = I * \alpha$$

- Think of the many methods with which rotational speed can be determined (a camera, a protractor), you may need them for the test

5.7 Angular Momentum

- Similar to translational motion, the change in rotational momentum or rotational impulse of a rotating object is given by:

$$\Delta L = \tau * \Delta t$$

  Where ΔL is change in rotational momentum
- For a single rotating point, its momentum is given by

$$L = m * v * r$$

- For any object with known rotational inertia, its rotational momentum is given by:

$$L = I * \omega$$

- In a system where the only torques acting are from objects within that system, angular momentum is conserved
- There are more things than collisions that can conserve angular momentum, anytime during which a system experiences no net torque

5.8 Rotational Kinetic Energy

- An object's rotational kinetic energy is given by

$$\frac{1}{2} * I * \omega^2$$

6 Gravitation

6.1 Vocabulary

- Gravitational Field - Gives how much 1kg of mass weighs at a certain location relative to a planet. At Earth's surface, the field is 10N/kg
- Gravitational Force - The force felt by an object as a result of a gravitational field
- Newton's Gravitation Constant - A constant that applies to all objects, defined as

$$G = 6 * 10^{-11} \frac{N * m^2}{kg^2}$$

- Free-Fall Acceleration - Also called acceleration due to gravity, this is the acceleration an object feels as the result of a planet's gravity

6.2 Determining the Gravitational Field

- The gravitational force is the weakest of the fundamental forces
- The gravitational field is a vector quantity that points to the center of the planet
- The magnitude of a planet's gravitational field depends on the planet's mass and the distance you are from the planet's center, given by:

$$g = G\frac{M}{d^2}$$

- If given a planet's measurements in terms of Earth's, you can replace the new distance / mass in the above formula to find g

6.3 Determining Gravitational Force

- The weight of an object is the product of its mass and the gravitational field it experiences, $m * g$

6.4 Force of Two Planets on One Another - Order of Magnitude Estimates

- The gravitational force of one object on another is given by:

$$F = \frac{G * m_1 * m_2}{d^2}$$

- You will likely not be asked to calculate the exact force of gravity between two objects, but rather estimate it by plugging in powers of 10 into the above equation and adding/subtracting exponents for the correct order of magnitude

6.5 Gravitational Potential Energy

- Near the Earth's surface, the gravitational potential energy of an object is given by

$$PE = m * g * h$$

- In general, the gravitational potential energy between two objects is given by

$$PE = G\frac{M_1 * M_2}{d}$$

6.6 Gravitational and Inertial Mass

- Gravitational mass is how an objects responds to a gravitational field
- Inertial mass is how an object accelerates in response to a net force
- In every experiment ever conducted, an object's inertial and gravitational masses have been equal
- For the AP exam, anything that does not agree with the above should be rejected as ridiculous

6.7 Fundamental Forces: Gravity versus Electricity

- Gravity and electricity are the only two fundamental force studied in AP Physics 1
- ll other forces are a result of these two (friction results from the electrical repulsion between two forces)
- At a microscopic scale, the electrical forces between two objects take over and the gravitational forces between them are negligible
- The opposite happens are very large scales

7 Electricity: Coulomb's Law and Circuits

7.1 Vocabulary

- Charge - A scalar quantity that can either be positive or negative and refers to the excess electrical charge an object possesses as a result of electron imbalance
- Coulomb - Unit used to measure charge
- Current - Flow of charge over time
- Ampere - Unit for current, defined as one coulomb per second
- Resistance - A measure of how difficult it is for charge to flow through a circuit, measured in ohms
- Resistivity - The resistance of one cubic meter of a material
- Voltage - Electrical potential energy per coulomb of charge
- Series - Describes resistors connected in a single path
- Parallel - Describe resistors connected such that current divides and converges before and after flowing through the resistors

7.2 Electric Charge

- The two particles that carry charge are protons and electrons, which carry positive and negative charge, respectively
- The charge of one proton is $1.6 * 10^{-19}C$, the charge of one electron is $-1.6 * 10^{-19}C$
- Most objects are neutrally charged, that is, they have the same number of protons as electrons
- Some objects had more protons than electrons and are positively charged, others have more electrons than protons and are negatively charged
- The simple rule for electric charge is: like charges repel, opposite charges attract
- Only two types of charge exist, if an answer on the exam suggests a third type, reject the answer
- Coulomb's law is used to determine how strongly two charges attract or repel, or, how much force on exerts on another, shown below:
  $$F = k\frac{Q_1 * Q_2}{d^2}$$
  Where k is Coulomb's constant, defined as $9.0 * 10^9 \frac{N*m^2}{C^2}$, the Qs is the magnitude of each charge, and d is the distance between the two charges
- The law of conservation of charge states that the amount of charge in a system is always the same, similar to other conservation laws
- Charge can still be transferred between objects, but the total charge will not change

7.3 Circuits

- A circuit is any path that allows current to flow
- Current is defined as the flow of positive charge, and flows from the positive to negative terminals in a circuit
- Electricity can only flow when one side of a circuit has a higher potential energy than another
- Voltage is a measure of this potential difference per coulomb
- The resistance of a wire is given by:
  $$R = \frac{\rho * L}{A}$$
  Where ρ is its resistivity, L is its length, and A is its cross-sectional area
- In series circuits, all resistors carry the same current but different voltages, which all add up to the total voltage across the circuit
- In parallel circuits, resistors carry the same voltage but different currents, which all add up to the total current flowing in the circuit
- Consider making a V-I-R chart to determine the voltage, current, and resistance of each resistor in a circuit
- The total resistance of resistors connected in series is the sum of the individual resistances, shown below:
  $$R = R_1 + R_2 + ...$$

- The total resistance of resistors connected in parallel is the reciprocal of the sum of the reciprocals of the individual resistances, shown below:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + ...$$

- Ohm's law relates the voltage, current, and resistance that flows through circuit elements, shown below:

$$V = IR$$

- Ohm's law can only be used across a single row in a V-I-R chart
- Ohm's law and the rules for current and voltage for series and parallel circuits can be used to solve just about any simple circuit problem

7.4 Kirchoff's Laws: Conservation of Charge and Energy

- Kirchoff's junction law states that the current entering a wire junction equals the current leaving the junction
- The junction law conserves charge as none is created or destroyed, what enters leaves
- Kirchoff's loop law states that the sum of voltage changes around a circuit loop is zero
- The loop law conserves energy as potential energy is not creates or destroyed

7.5 Power in a Circuit

- Resistors convert electrical energy to some other form of energy, usually heat
- The power dissipated by a resistor is given by

$$P = I * V$$

  Rearranging the above with ohm's law also gives power as:

$$P = I^2 * R = \frac{V^2}{R}$$

- Most circuit components besides voltage sources can be thought of as resistors
- The brightness of a light bulb depends on how much power it can dissipate, higher-watt bulbs are brighter

7.6 Ammeters and Voltmeters

- Ammeters are devices used to measure current, voltmeters are devices used to measure voltage
- Remember that voltage is constant for all resistors in a parallel circuit, thus voltmeters are put in parallel to the resistor being measured
- Current is the same for all resistors in a series circuit, so ammeters are put in series with the resistor being measured

8 Waves and Simple Harmonic Motion

8.1 Vocabulary

- Period - The time one full cycle of simple harmonic motion takes to complete
- Frequency - The number of cycles passing a position in one second, measured in hertz, meaning "per second"
- Amplitude - The distance from the midpoint of a wave to its crest
- Wavelength - Measured from peak to peak or any successive identical points in a wave
- Spring Constant - Measure in newtons per meter, this relates to the stiffness of a spring
- Restoring Force - Any force that pushed an object to its equilibrium position
- Node - Stationary points on a standing wave
- Antinode - Positions in a standing wave with the largest amplitudes

8.2 Harmonic Motion

- Simple harmonic motion refers to back and forth oscillations whose position-time graphs looks like a sine wave
- Common examples of SHM are a mass on a spring or a pendulum
- The period of a mass on a spring in SHM is given by
$$2\pi\frac{\sqrt{m}}{\sqrt{k}}$$
Where m is the mass of the mass and k is the spring constant
- Frequency and period are inverse of one another, that is, they are each others reciprocals
- The amount of restoring force exerted b a spring is given by
$$F = kx$$
Where x is the displacement of the spring equilibrium position
- The potential energy of a spring is given by
$$PE = \frac{1}{2} * k * x^2$$
- To find the maximum kinetic energy from the potential energy of a spring, imagine the instant at which the spring is at its equilibrium point before it continues oscillating, here the potential energy is 0 because the spring's displacement is 0. Therefore, all the potential energy has been converted to kinetic energy. The below can then be used to find the maximum KE and thus maximum speed:
$$\frac{1}{2} * k * x^2 = \frac{1}{2} * m * v^2$$
- Pendulum's can be treated similar to springs, as they stil require an energy approach instead of a kinematics approach
- The period of a pendulum is given by:
$$2\pi\frac{\sqrt{L}}{\sqrt{g}}$$
Where L is the pendulum's length and g is the force of gravity

8.3 Waves

- The only waves AP Physics 1 covers is mechanical waves, such as sound, string, and ocean waves
- A transverse wave is one in which the motion of material is perpendicular to the motion of the wave, such as an ocean wave
- A longitudinal wave is one in which mateial moves parallel to the motion of the wave, such as a sound wave or a wave in a spring

8.4 Superposition and Interference

- When two waves collide, they interfere with each other
- Constructive interference occurs when waves collide such that their crests overlap, causing the combined crest to have a larger amplitude, the two crests then split up and continue moving in their original direction
- Destructive interference occurs when the crest of one wave overlaps with the trough of another, causing both of their amplitudes to drop during their interference

8.5 Standing Waves

- A standing wave is one that appears to stand in one place
- Some positions in the string vibrate with a large amplitude, these are antinodes
- Some positions in the string of a standing wave stay in one place, these are called nodes
- The wavelength of a standing wave is twice the node to node distance
- Placing your finger on the center point of a string with a standing wave forces it to have a node there, and half the wavelength, thus twice the frequency
- You can do this with any whole number of nodes, the process creates harmonics or whole number multiples of the string's original frequency
- For a string fixed on both ends or a pipe open at both ends, the smallest frequency for a standing wave is given by:

  $$f_1 = \frac{v}{2L}$$

  Where v is the speed of the waves in the string or pipe, generally the speed of sound in air, which is $340m/s$
- The pitch of a note depends on its frequency, its volume depends on its amplitude

8.6 Closed-End Pipe

- When a pipe is closed at one and but open at the other, the standing wave has a node at the closed end and an antinode at the open end, creating a wave whose smallest frequency is given by:

  $$f_1 = \frac{v}{4L}$$

8.7 Beats and the Doppler Effect

- Beats are rhythmic interference creates when two notes of different but close frequencies are played
- The interference caused by beats creates a "wa-wa" effect as the frequencies of the notes go in and out of sync
- The doppler effect is the change in a wave's frequency that you can observe whenever the source is moving towards or away from the observer
- When the sound source is moving closer to you, the waves become squished together as they are produced closer to you, this causes you to perceive a higher frequency
- The opposite happens when the sound source is moving away, the sound waves become spread apart and you perceive a lower frequency
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