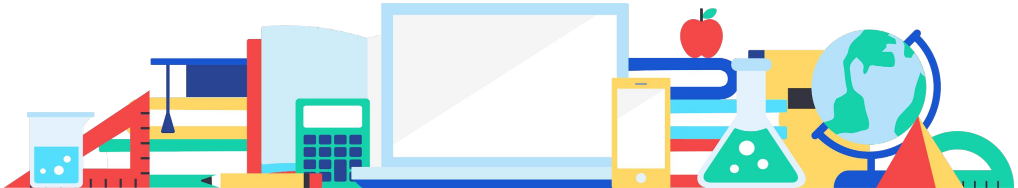
# Physics 1 Concepts & Vocab

Updated July 2020



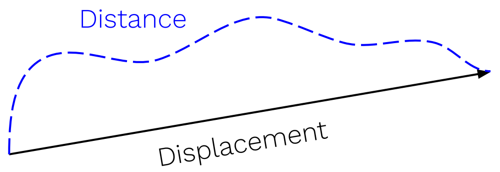
# Kinematics

# Kinematics: Displacement & Velocity

## Key Vocabulary

**Displacement** is the change in position of an object : displacement is a **vector**

The **distance traveled** (in meters m) by an object (which is a **scalar** quantity) does NOT necessarily equal the magnitude of the displacement




**Velocity** (in m/s) is the rate of change of position in time : velocity is a **vector**

**Average velocity** is defined as the change in position divided by the time of travel

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_0}{t_f - t_0}$$

On a position vs time graph, the average slope between two points represents the average velocity; the slope of the tangent line at a certain point in time represents the instantaneous velocity

# Kinematics: Acceleration

## Key Concept

**Acceleration** (in $m/s^2$) is the rate of change of velocity : acceleration is a **vector**

The **average acceleration** is

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$$

where $v_f$ is the final velocity, $v_0$ is the initial velocity, and **Δ**t is the time elapsed

If **acceleration is constant** the displacement (d), time interval (t), initial velocity ($v_0$), final velocity ($v_f$), and acceleration (a) are related by

$$v_f = v_0 + at \qquad d = \left(\frac{v_f + v_0}{2}\right) t$$

$$d = v_0 t + \frac{1}{2} a t^2 \qquad v_f^2 = v_0^2 + 2ad$$

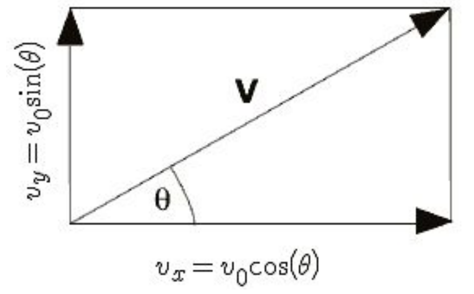
On a velocity vs time graph, the average slope between two points represents the average acceleration; the slope of the tangent line at a certain point in time represents the instantaneous acceleration. The area under the graph between two time points gives the net displacement

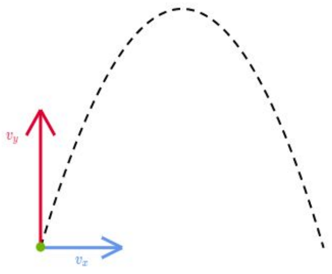
# Kinematics: Projectiles

## Problem Solving

A **projectile,** or an object undergoing **projectile motion,** is an object accelerating only due to the influence of **gravity**

- ➔ Component motions along horizontal and vertical axes are *independent* and can be analyzed separately - horizontal velocity is constant
- ➔ Projectiles near Earth's surface have a constant downward **acceleration due to gravity g** ≈ - 9.81 $m/s^2$
- ➔ For objects launched at an angle we decompose the initial velocity into x and y components, and apply the equations of motion with constant horizontal velocity, vertical acceleration minus g, and a common time t

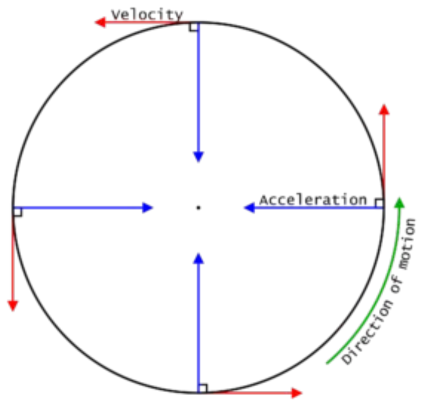


# Kinematics: Uniform Circular Motion

## Key Concept

- ➔ Velocity is a vector and to change its direction requires an acceleration
- ➔ Constant acceleration perpendicular to the velocity which changes only its direction results in **uniform circular motion**




This acceleration towards the center is called **centripetal acceleration** and its magnitude in terms of the velocity v and radius r is given by

$$a_c = \frac{v^2}{r}$$

# Dynamics & Energy

# Dynamics & Energy : Forces

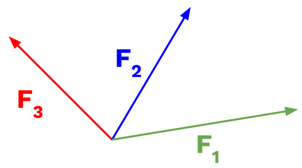
## Key Vocabulary

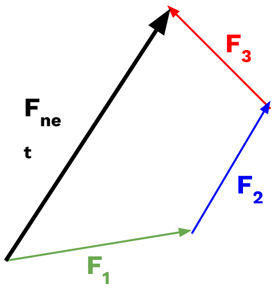
A **force** is a push or pull exerted on an object : Force is a **vector**

Types of force include weight, normal (contact) force, tension, or spring force

An **external force** is a force originating from outside an object ; **internal forces** within an object cannot cause a change in that object's overall motion

The **net force** on an object is the vector sum of all forces acting on the object




**Inertia** is the resistance of an object to change in its state of motion

- ➔ The inertia of an object is measured by its mass
- ➔ The more mass an object has, the harder it is to accelerate

# Dynamics & Energy: Newton's Laws of Motion

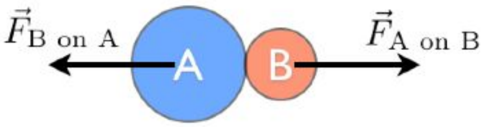
## Key Concepts

**Newton's First Law:** an object at rest will remain at rest and an object in uniform motion will remain in that state of motion unless acted upon by a net external force

**Newton's Second Law:** the net force (in Newtons N = kg m/s$^2$) on an object is equal to the mass m times the acceleration a in that direction

$$F_{net} = ma$$

**Newton's Third Law:** for every force, there is an equal but opposite force on the object causing the original force




$$\vec{F}_{\mathrm{B\ on\ A}} = -\vec{F}_{\mathrm{A\ on\ B}}$$

# Dynamics & Energy: Central Forces

## Key Concepts

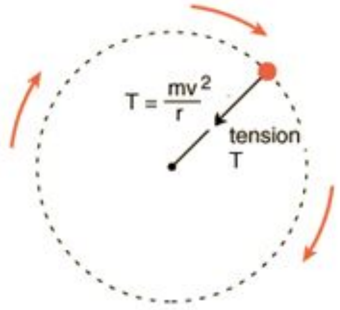
A mass moving in a circle has a constant **centripetal acceleration** of

$$a_c = \frac{v^2}{r}$$

which according to Newton's 2nd Law requires a force

$$F_c = \frac{mv^2}{r}$$

The component of force directed towards the center to maintain uniform circular motion is called the **centripetal force** (eg provided by tension in a string)




Note that **centrifugal force** is a fictitious or pseudo force perceived in the accelerated frame of reference of an object undergoing circular motion

# Dynamics & Energy: Friction

## Key Vocabulary

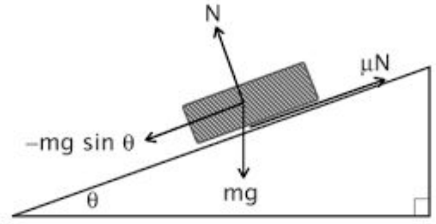
**Friction** is a contact force between two surfaces opposing motion

- ➔ **Static friction** holds an object in place before it begins to move
- ➔ **Kinetic friction** acts as drag on a moving object

Frictional force is proportional to the push of an object into the surface and therefore equivalently to the normal force of the surface on the object

The **coefficient of friction** relates the frictional and normal forces, and has kinetic and static versions

$$f_k = \mu_k N \qquad f_s \leq \mu_s N$$

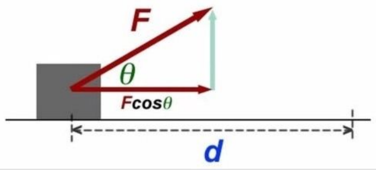


# Dynamics & Energy: Work & Power

## Key Concept

- **Work done** (in Joules J = Nm) by a constant force applied to an object is the product of displacement and the component of force in that direction

$$W = Fd\cos\theta$$




- If displacement is in the opposite direction to the force, work done is negative (energy is transferred from the object to the source of the force)
- **Power** (in Watts W = J/s) is the rate at which work W is performed

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

- If force F and velocity v are constant then the power is the product P = Fv

# Dynamics & Energy: Kinetic & Potential Energy

## Key Vocabulary

- The energy of motion (in Joules) is called **kinetic energy**

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

- Net work done by all external forces on an object results in a change in speed and therefore energy according to the **work-energy theorem**

$$W_{total} = \Delta KE$$

- **Potential energy** (also in Joules) is energy stored within a system - for example gravitational, elastic or electrical PE

$$PE_{gravity} = mgh \qquad PE_{elastic} = \frac{1}{2}kx^2$$

$$\Delta PE_{electrical} = q\Delta V$$

Note that unlike KE which is always positive, PE can be positive or negative

- Forces where the work done is independent of the path taken are **conservative forces** (eg gravity). Forces where work done is potentially path-dependent are **non-conservative** - for example **friction**

# Dynamics & Energy: Conservation of Energy

## Key Concept

- If only **conservative forces** are acting then **mechanical energy** (KE + PE) is **conserved** : so initial mechanical energy = final mechanical energy

$$KE_i + PE_i = KE_f + PE_f$$

- In the presence of non-conservative forces (eg friction) then work done by them must be included

$$KE_i + PE_i + W_{NC} = KE_f + PE_f$$

Note that the force of friction is in the opposite direction to motion and therefore the work done by it is negative, so the final mechanical energy is less than the initial mechanical energy in this case

# Impacts & Momentum

# Impacts & Momentum: Impact Forces & Momentum Changes

## Key Vocabulary

- In a collision between two objects, the forces of impact are equal and opposite. We refer to **impact forces** as being **internal forces** (as opposed to external forces like gravity or friction)

- **Linear momentum** $\vec{p} = m\vec{v}$

  and using Newton's 2nd Law $\vec{F} = \frac{m\Delta\vec{v}}{\Delta t} = \frac{\Delta\vec{p}}{\Delta t}$

- Rearranging we define the **impulse** which is equal to the change in momentum

  $$\vec{F}\Delta t = m\vec{v}_f - m\vec{v}_i$$

  where $v_f$ and $v_i$ are the initial and final velocities respectively

# Impacts & Momentum: Conservation of Momentum

## Key Concept

➔ An isolated system of two interacting objects will, according to Newton's 3rd Law, exert an **equal and opposite force** on each other and therefore (in the absence of friction) have an equal and opposite rate of change of momentum

$$\vec{F}_{12} = -\vec{F}_{21}$$

$$\frac{\Delta \vec{p}_1}{\Delta t} = -\frac{\Delta \vec{p}_2}{\Delta t} \qquad \frac{\Delta(\vec{p}_1 + \vec{p}_2)}{\Delta t} = 0$$

➔ The sum of the total momentum for the system is therefore a constant - the **law of conservation of linear momentum**

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$

➔ Since momentum is a vector it must also be separately conserved for the components in each direction

# Impacts & Momentum: Elastic and Inelastic Collisions

## Key Vocabulary

- **Momentum is always conserved** in a collision but if two objects stick together then **kinetic energy** is lost (to heat and friction)
- If kinetic energy is conserved as well as momentum the collision is **elastic**
- If kinetic energy is not conserved the collision is **inelastic**

For an **elastic collision** in addition to conservation of momentum, we have

$$\frac{1}{2}m_1v_{1i}^2+\frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2+\frac{1}{2}m_2v_{2f}^2$$

where $m_1$ and $m_2$ are the masses of the two objects and $v_{1i}$,$v_{2i}$,$v_{1f}$ and $v_{2f}$ are their initial and final velocities

## Impacts & Momentum: Center of Mass

### Key Vocabulary

- The **center of mass** is the point in a system about which all the mass is balanced
- It is found by taking the **weighted average** of all points of mass $m_i$ with position along each axis $x_i$ etc for example

$$x_{CM} = \frac{\sum m_i x_i}{\sum m_i}$$

- In free-body diagrams we apply our forces to the center of mass of each object

# Gravity

# Gravity: Newton's Law of Gravitation

## Key Concepts

- **Weight** (in Newtons) is the force $F_g$ exerted on a body (mass m) by gravity

$$F_g = mg$$

where g is acceleration due to gravity (near Earth's surface, 9.81 m/s$^2$)

- **Newton's Law of Universal Gravitation** gives the **gravitational force** between two masses as

$$F_g = \frac{GM_1M_2}{r^2}$$

where G the **universal gravitational constant** is 6.67 x 10$^{-11}$ Nm$^2$/kg$^2$

and therefore

$$g = \frac{GM_E}{{r_E}^2}$$

where $M_E$ and $r_E$ are the mass and radius of the Earth respectively

# Gravity: Gravitational Energy

## Key Concepts

- **Gravitational Potential Energy** due to the Earth's gravity is given by

$$PE = -\frac{GM_0M_E}{r}$$

(for any r at or above the Earth's surface) which allows us to calculate **escape velocity** by equating kinetic and potential energy according to

$$\frac{1}{2}M_0v_{esc}^2 = \frac{GM_0M_E}{r_E}$$

- For an object in a circular orbit we can set the centripetal force equal to the gravitational force giving **orbital velocity**

$$v_{orbit} = \sqrt{\frac{GM_E}{r}}$$

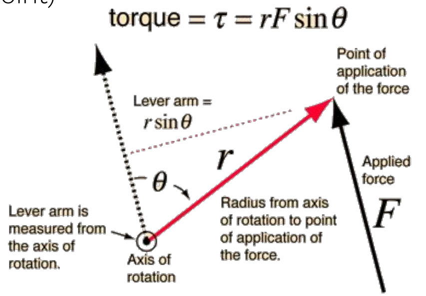
# Rotational & Oscillatory Motion

# Rotational and Oscillatory Motion: Moments & Torque

## Key Vocabulary

- A force directed through the center of mass of an object will produce linear acceleration, but a force not directed through the center of mass will also cause **rotation**
- The **moment** of a force is its tendency to cause a body to rotate
- The **torque** (in Nm) quantifies the twisting action of a force, given by the product of the force and the **perpendicular distance** of its application from axis (center of mass or pivot point)

$$\tau = Fr\sin\theta$$




- By convention clockwise/counterclockwise torque is negative/positive
- For **static equilibrium** both the **net force** and the **net torque** (taken about any axis) must be zero

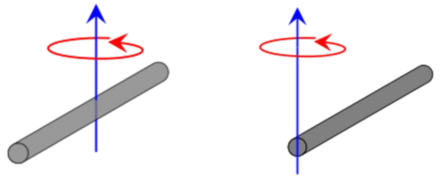
# Rotational and Oscillatory Motion: Moment of Inertia

## Key Concepts

- The **moment of inertia** I is the tendency of a body to resist changes in **angular motion**
- For a set of point masses $m_i$ and their distance $r_i$ from the rotational axis

$$I = \sum m_i r_i^2$$

- The moment of inertia therefore depends upon which **axis** the object is being rotated about - for example a solid rod has 4 times bigger a moment of inertia (harder to rotate) about one end than about its center



$$I_{center} = \frac{1}{12} mL^2 \qquad I_{end} = \frac{1}{3} mL^2$$

# Rotational and Oscillatory Motion: Angular Kinematics

## Key Concepts

- In **rotational motion** position is denoted by **angle** $\vartheta$ (in radians) and **angular velocity** $\omega$ and **angular acceleration** $\alpha$ are denoted by

$$\omega = \frac{\Delta\theta}{\Delta t} \qquad \alpha = \frac{\Delta\omega}{\Delta t}$$

- The following relationships for **angular displacement**, **acceleration** (cf F=ma) and **momentum** L take the same form as their linear equivalents

$$\Delta\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \qquad \tau = I\alpha$$

$$L = I\omega \qquad \tau = \frac{\Delta L}{\Delta t}$$

- Similarly for **rotational kinetic energy** and **work done**

$$KE = \frac{1}{2}I\omega^2 \qquad W = \tau\theta$$

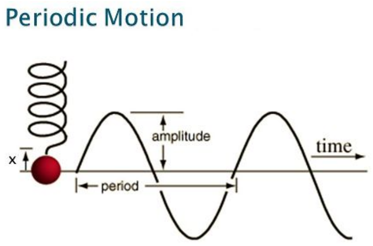
- For an isolated system **angular momentum is conserved** - eg when a spinning skater pulls their legs/arms inward, lowering their moment of inertia I and therefore correspondingly increasing their rotational speed $\omega$

# Rotational and Oscillatory Motion: Simple Harmonic Motion

## Key Concepts

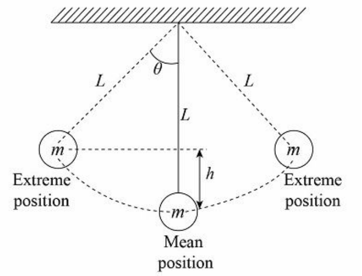
- A periodic motion in which acceleration is proportional and opposite to displacement is called **simple harmonic motion** (SHM)
- For example for a **mass on a spring** oscillates sinusoidally with **period** T given by

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad F = -kx$$




- A **simple pendulum** also approximates SHM with period independent of amplitude and mass

$$T = 2\pi\sqrt{\frac{L}{g}}$$




- **Conservation of energy** (KE + spring/gravitational PE) lets us find the velocity vs displacement (since at maximum amplitude KE is zero)

# Electricity

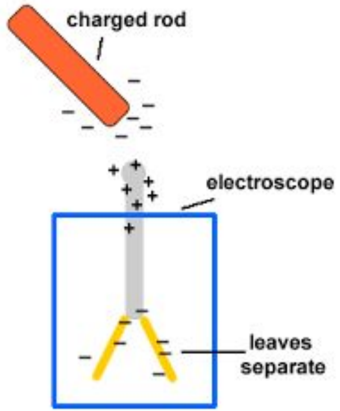
# Electricity: Electric Charges

## Key Vocabulary

- ➔ Solid objects become **charged** by the transfer of negative charges called **electrons**
- ➔ Charge in **insulators** like rubber or plastic remains localized and static
- ➔ Metals and other **conductors** allow charge to flow freely through them
- ➔ **Like charges repel** and **unlike charges attract**

In an **electroscope**, the gold leaves are vertical when uncharged, but diverge due to repulsion when the electroscope is charged by contact or by induction as in the diagram

The units of charge are Coulombs (C)



# Electricity: Coulomb's Law and Current

## Key Concepts

The electrostatic force (in N) between two point charges $q_1$ and $q_2$ (in C) separated by a distance r is given by **Coulomb's Law**

$$F = \frac{kq_1q_2}{r^2}$$

where the Coulomb or **electrostatic constant** $k \approx 9 \times 10^9$ $Nm^2/C^2$ and a negative sign indicates attraction. For a distribution of point charges, the net force is given by a vector sum of the electrostatic forces (**superposition**)

If two points with different concentrations of charge are connected by a conductor, **potential difference** will cause negative charges to flow, analogous to water in a pipe connecting different pressures. (Note : By convention current is defined to be the flow of positive charge in the opposite direction)

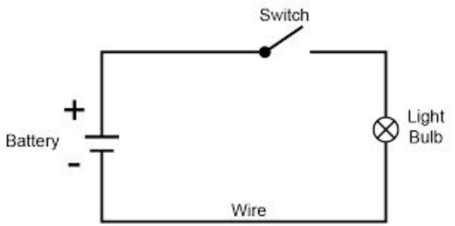
The **rate of charge** passing a given point is called **current** (in Amperes)

$$I = \frac{\Delta Q}{\Delta t}$$

# Electricity: Circuits & Resistance

## Key Concepts

➔ A **battery** supplies a **potential difference** (in Volts) to cause a flow of charge. Connecting the terminals of the battery creates a **circuit**




➔ Electrons will flow from the negative to positive terminal. The electrical PE they gain allows them to do work eg. lighting the bulb

➔ The interaction of the flowing electrons with the bulb filament creates electrical **resistance** (in Ohms $\Omega$) converting electrical PE to heat energy

➔ **Ohm's Law** relates current, potential difference (voltage) and resistance R

$$R = \frac{V}{I} \qquad\qquad V = IR$$

➔ For a material of **resistivity** $\varrho$ with length L and cross section A

$$R = \frac{\rho L}{A}$$

# Electricity: Electric Power & Energy

## Key Concept

- Since the voltage V (potential difference) is the energy supplied to each unit of charge moving between two points, the **power** P (work/time) is

$$P = \frac{qV}{t} = \left(\frac{q}{t}\right) V = IV$$

and thus the **energy** (in Joules)

$$E = PT = IVt$$

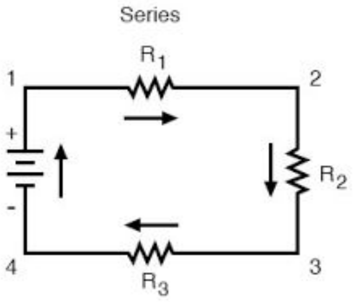
- **Electrical energy** can produce light or heat, or turn a motor

# Electricity: Series and Parallel Circuits

## Problem Solving

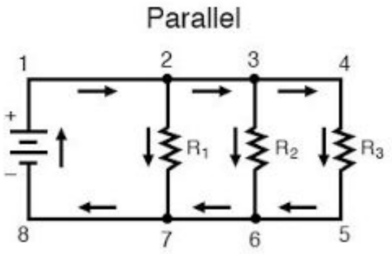
- ➔ Circuits can be analyzed using **Kirchhoff's rules**
  - ◆ **Junction rule** - current leaving junction equals current entering
  - ◆ **Loop rule** - total voltage drops/gains round a closed loop are zero
- ➔ **Series circuits**

$$I = I_1 = I_2 = I_3$$
$$V = V_1 + V_2 + V_3$$
$$R = R_1 + R_2 + R_3$$




- ➔ **Parallel circuits**

$$V = V_1 = V_2 = V_3$$
$$I = I_1 + I_2 + I_3$$
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

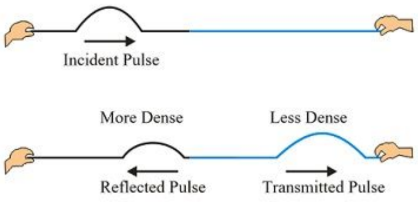


# Waves

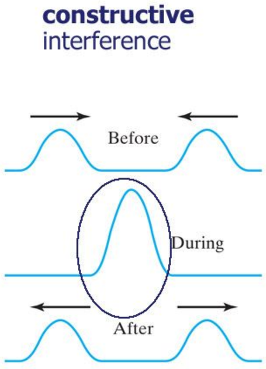
# Waves: Pulses

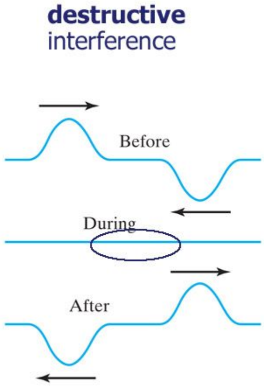
## Key Concepts

- ➔ A **pulse** is a single vibratory disturbance eg travelling along a string/rope.
- ➔ At a fixed end point a pulse will reflect and invert. At a boundary between two media reflection behaviour depends upon their relative properties




- ➔ Amplitudes of pulses add (**superposition**) resulting in **constructive** or **destructive interference**



# Waves:
# Wave Motion & Types of Wave

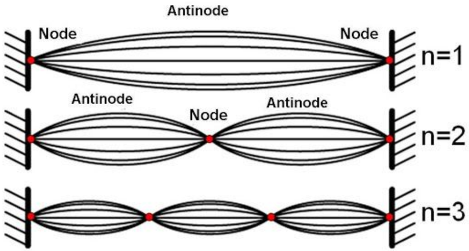
## Key Vocabulary

- **Waves** are **periodic** vibratory disturbances
  - **Mechanical waves** are vibration of a physical medium
  - **Electromagnetic waves** involve EM fields and require no medium
- The time to complete one wave cycle is the **period** T and the **frequency** f (number of wave cycles per second, in Hertz) is 1/T
- The distance between two points in the wave in the same phase is the **wavelength** $\lambda$. The speed of the wave $v = f\lambda$
- The **amplitude** of the wave is the maximum displacement (height of the peaks and troughs)
  - Amplitude determines the intensity or volume while frequency corresponds to pitch
- If the vibrations are perpendicular to the direction of wave travel the wave is **transverse** (eg waves on water, light)
- If the vibrations are in the same direction as wave travel the wave is **longitudinal** (eg compression waves in a spring, sound)

# Waves:
# Standing Waves & Resonance

## Key Vocabulary

- ➔ **Standing waves** occur when reflected and incoming waves interfere such that apparent horizontal motion stops, with segmented pattern of **nodes** and **antinodes** as in the diagram shown for a taut string




- ➔ For the fundamental mode (n=1) the length of the string is one half wavelength, and for the second mode the wavelength equals l etc
- ➔ **Resonance** is the buildup of wave energy due to constructive interference of standing waves at an object's natural vibrating frequency, for example soldiers marching on a bridge, a tuning fork vibrating an identical tuning fork, or an opera singer shattering a glass

# Waves:
# Sound & The Doppler Effect

## Key Vocabulary

- **Sound** is a **longitudinal** wave consisting of alternating compression and spacing of a medium (eg air) as pressure differences move through it
- Transmission of sound is medium dependent - for example sound travels more slowly in gases (where molecules are moving randomly) than solids
- When two different frequency sound waves interfere, this causes **beats** with a frequency equal to the difference in frequency of the two sources
- Interference of sound from two point sources depends on the **path-length difference** and will be constructive/destructive if the difference in distance is an integer/half-integer number of wavelengths
- **Diffraction** occurs when sound passes around a corner or through a narrow opening, with the corner/opening behaving like a point source of circular waves
- The **Doppler Effect** occurs when a wave emitter is in motion relative to an observer. There is an apparent increase/decrease in **frequency** (pitch) when the source moves toward/away from the observer

# Additional Resources

## Physics 1

## Additional Resources

- ➔ https://apstudents.collegeboard.org/courses/ap-physics-1-algebra-based
- ➔ https://www.khanacademy.org/science/ap-physics-1
- ➔ https://www.edx.org/course/ap-physics-1
- ➔ https://en.wikipedia.org/wiki/AP_Physics_1
- ➔ https://www.princetonreview.com/college-advice/ap-physics-1-exam
- ➔ https://fiveable.me/ap-physics/study-guides-for-every-ap-physics-1-unit/