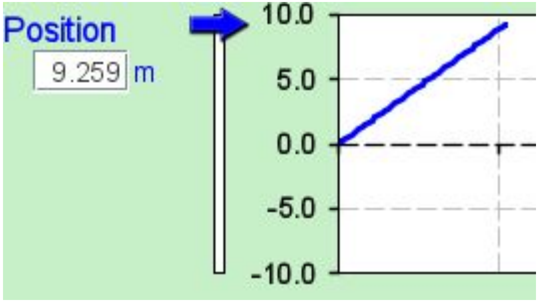
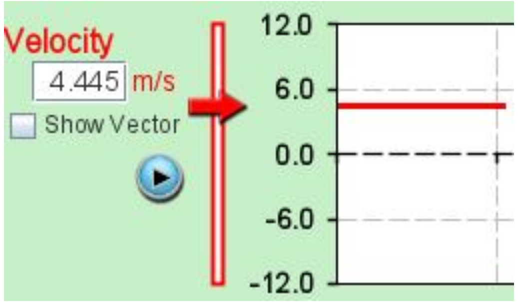
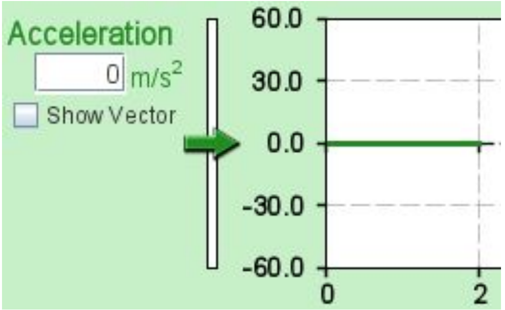
Constant Velocity





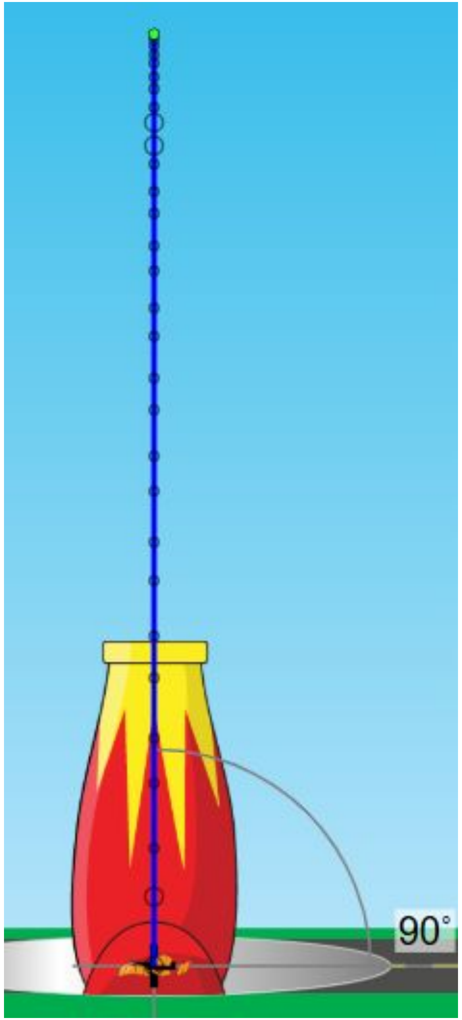


$$F_{net} = 0$$

$$W_{net} = 0 \qquad \Delta KE = 0$$

$$x = x_0 + v_{x0}t$$

Maximum height of an object thrown vertically upwards



- Final velocity = 0
- Use 1D Kinematics equations to solve for unknown variable

$$v_x = v_{x0} + a_x t$$

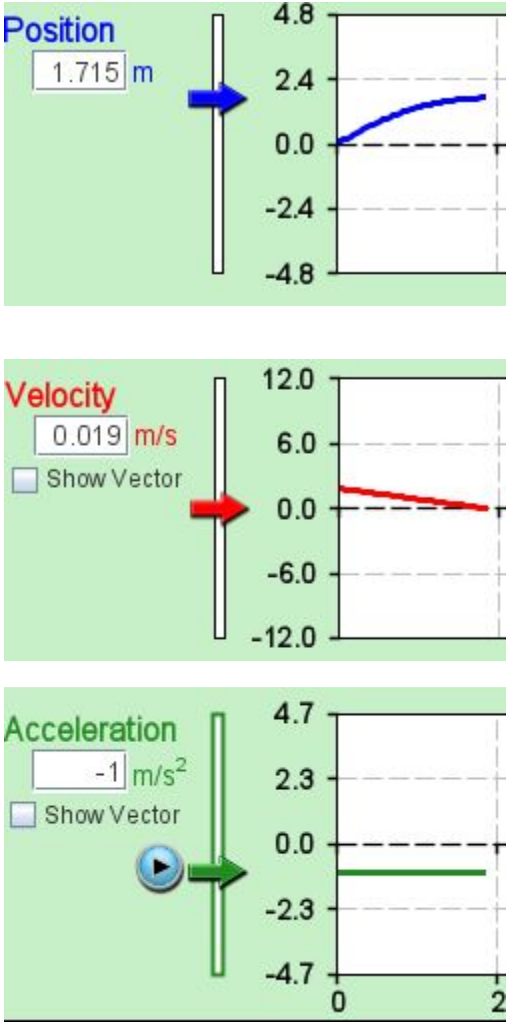
$$v_x^2 = v_{x0}^2 + 2a_x\left(x - x_0\right)$$

Object slowing down to a stop

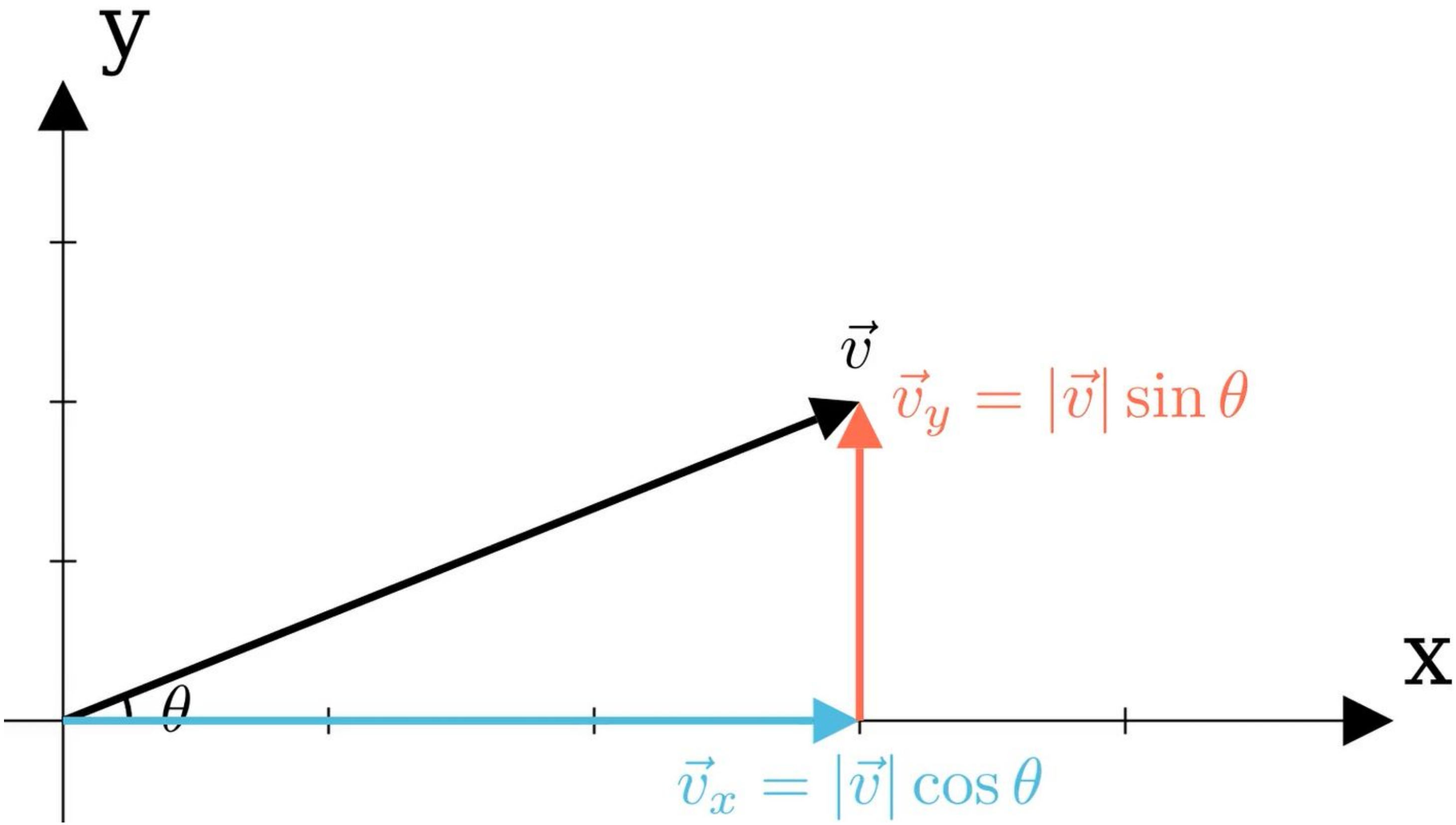
- Acceleration is negative
- Net work is negative
- Final velocity = 0

$$\Delta KE < 0$$

$$v_x = 0$$



Resolving a vector into x (horizontal) and y (vertical) components


y
x
$\vec{v}$
$\vec{v}_y = |\vec{v}| \sin\theta$
θ
$\vec{v}_x = |\vec{v}| \cos\theta$

Newton’s 1st Law

An object at rest stays at rest, and an object in motion stays in motion at constant velocity, unless acted upon by a net external force.

Static equilibrium means an object is **at rest** and **not moving** — and it will stay that way unless an external acts on it (net force = 0)

Dynamic equilibrium means an object is **moving at constant velocity** — but not accelerating (net force = 0)

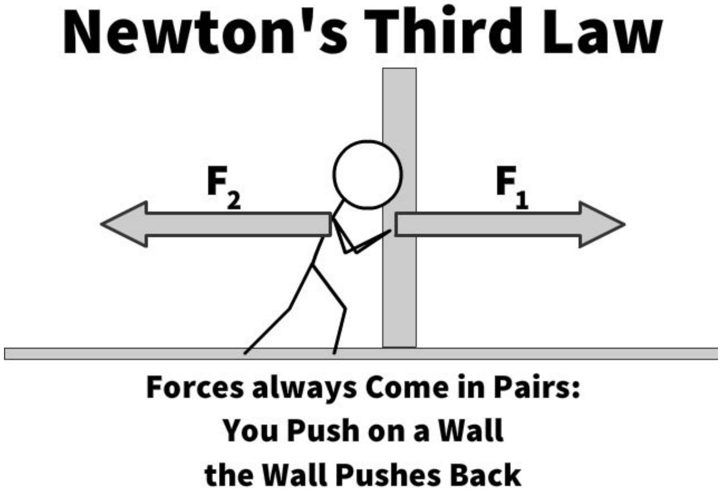
Newton’s 2nd Law

The net force acting on an object is equal to the object's mass times its acceleration.

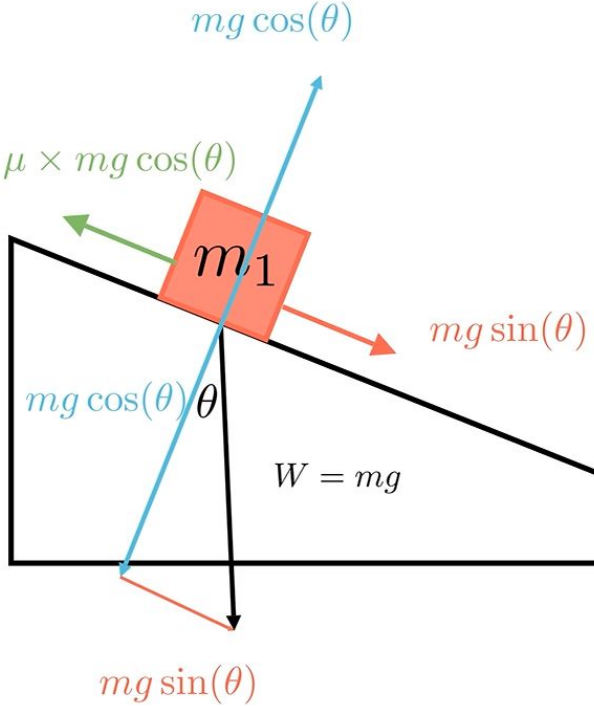
$$F = ma$$

Newton’s 3rd Law

For every action, there is an equal and opposite reaction.

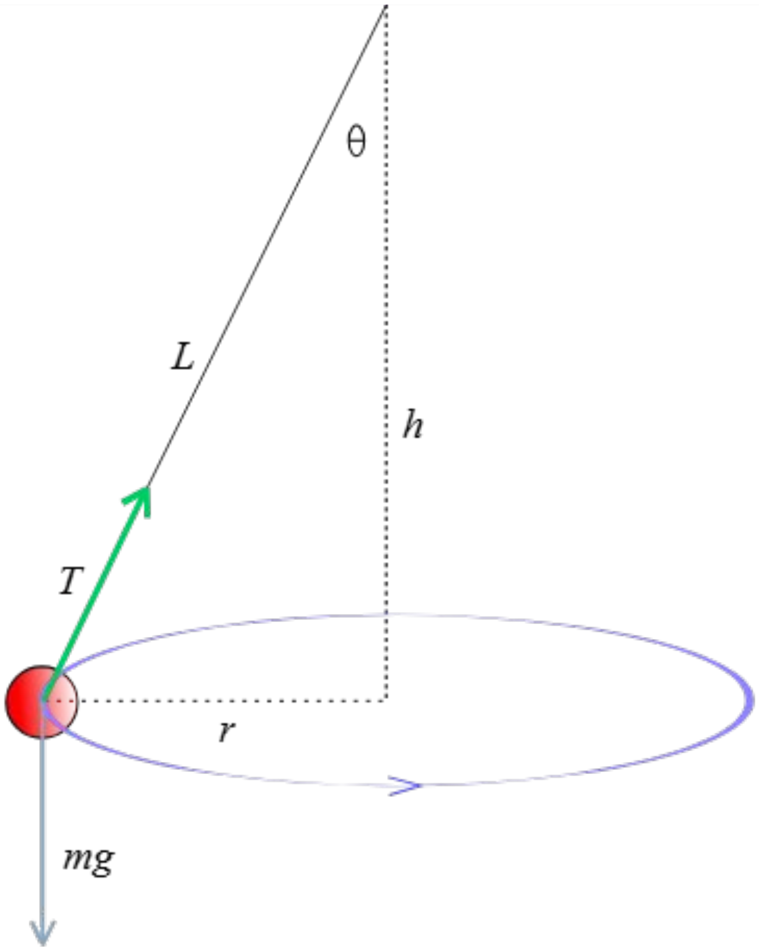


Forces acting on a block sliding down an inclined plane



$$F_{net} = mgsin(\theta) - \mu cos(\theta)$$

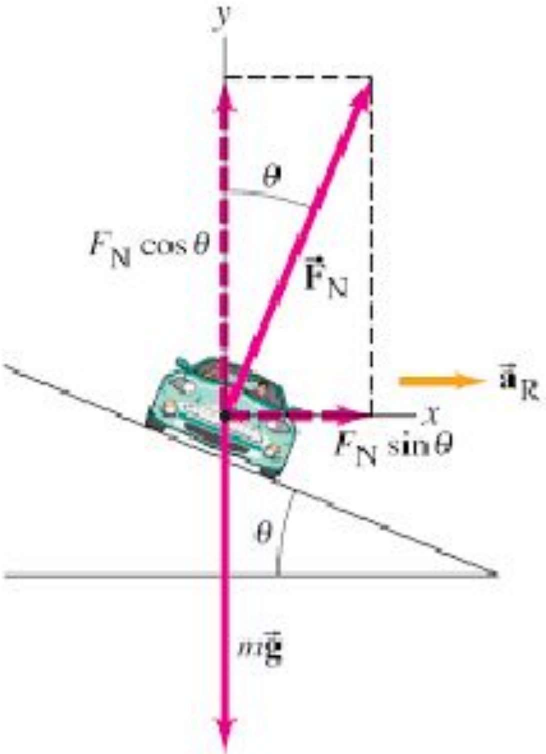
Conical Pendulum



$$T cos(\theta) = mg$$

$$T sin(\theta) = \frac{mv^2}{r}$$

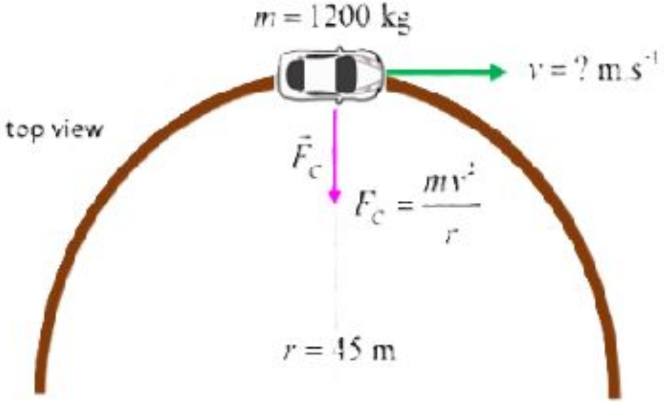
Banked Curves



$$F_N cos(\theta) = mg$$

$$F_N sin(\theta) = \frac{mv^2}{r}$$

Car
Turning



Friction provides centripetal force

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

$$\mu F_N = \mu mg = \frac{mv^2}{r}$$

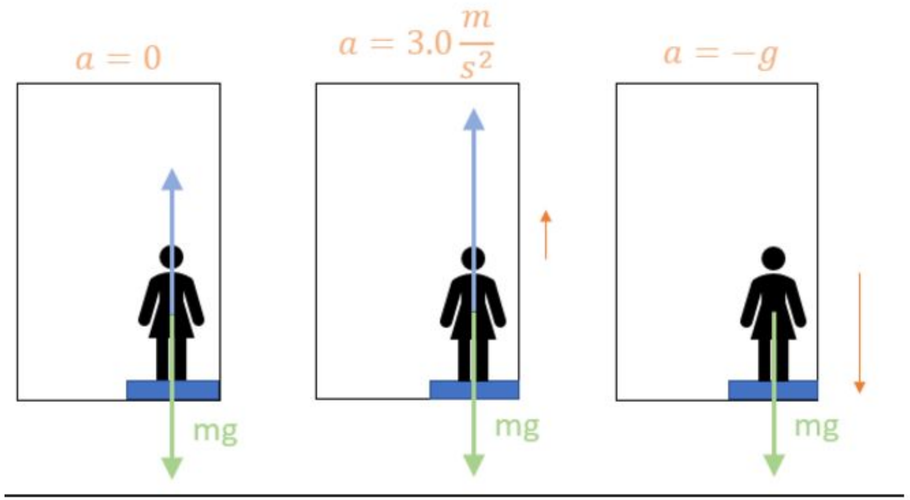
Elevator Dynamics Problems

"Apparent weight" = Normal Force

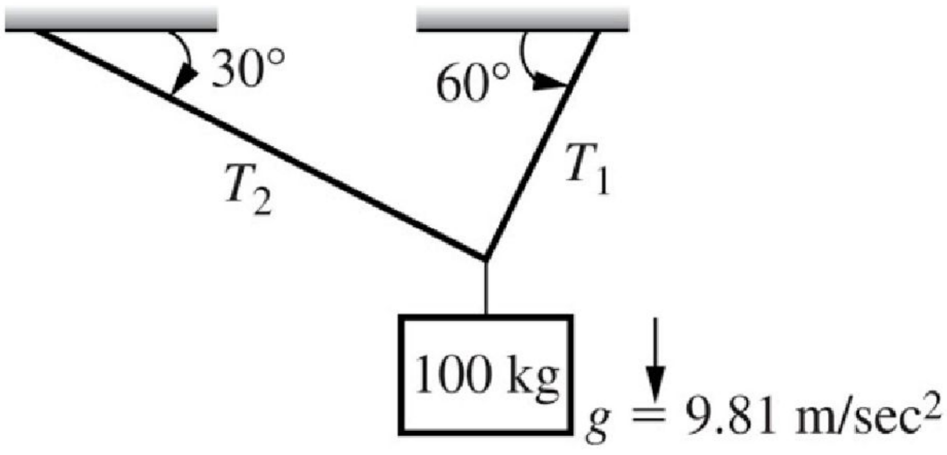
$$F_{net} = 0$$

$$F_N - F_g = ma$$

$$F_N - mg = ma$$



Block Suspended by Strings/Ropes/Wires



The box is in static equilibrium (it is not moving)

$$F_{net} = 0$$

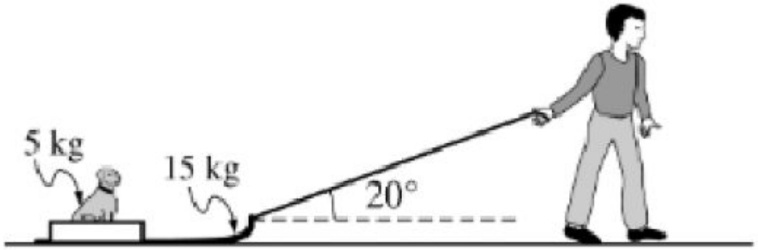
Horizontal components: left and right forces must be balanced

$$T_2 cos(30) = T_1 cos(60)$$

Vertical components: downward and upward forces must be balanced

$$T_2 sin(30) + T_1 sin(60) = 100g$$

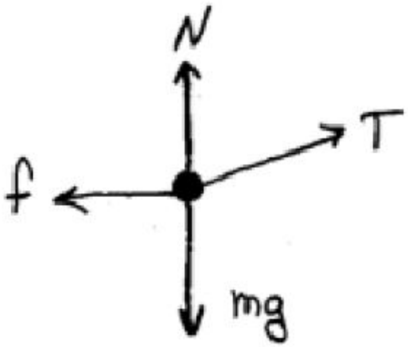
Block Suspended by Strings/Ropes/Wires



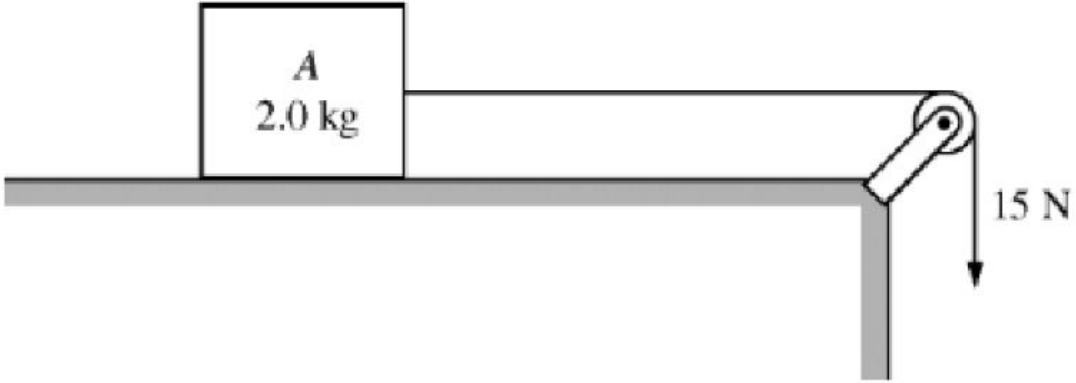
(a) On the dot below that represents the sled-dog system, draw and label a free-body diagram for the system as it is pulled along the surface.

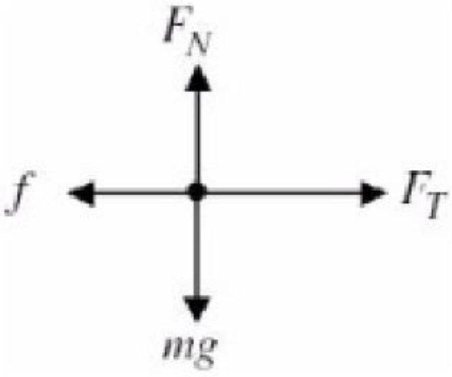
$$\sum F_y = 0$$

$$N + T\sin\theta - mg = 0$$



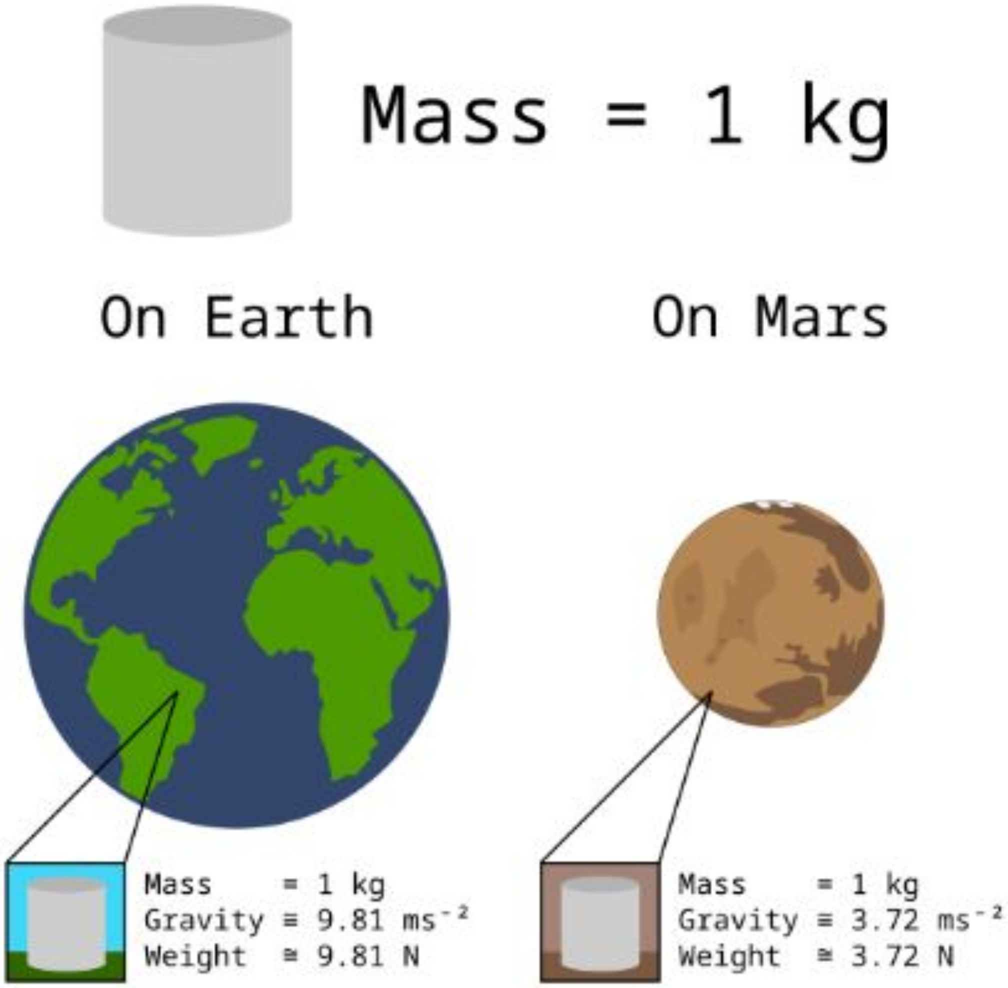
FBD and Net Force on a block lying on a flat table pulled by a string with friction present





$$F_T - f = ma$$

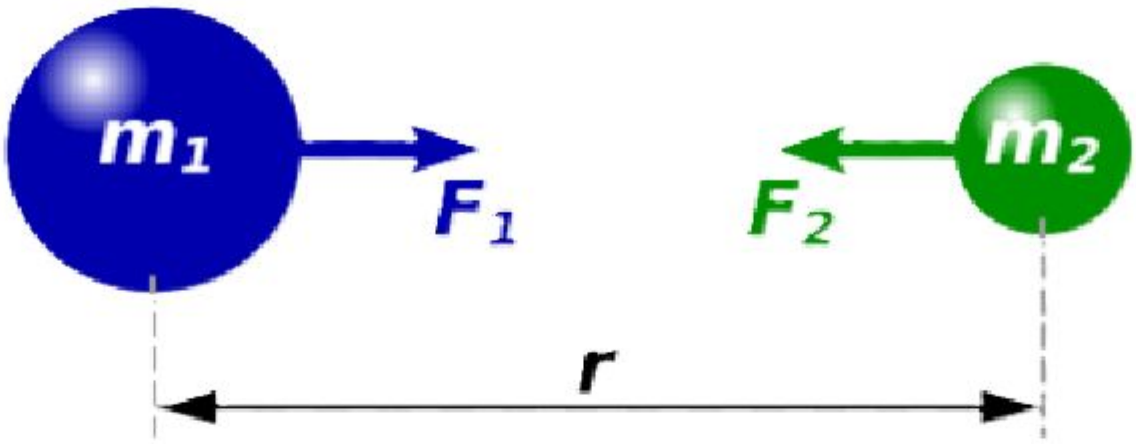
Weight vs Mass



Mass = 1 kg
On Earth
On Mars
Mass = 1 kg
Gravity ≡ 9.81 ms^{-2}
Weight ≅ 9.81 N
Mass = 1 kg
Gravity ≡ 3.72 ms^{-2}
Weight ≅ 3.72 N

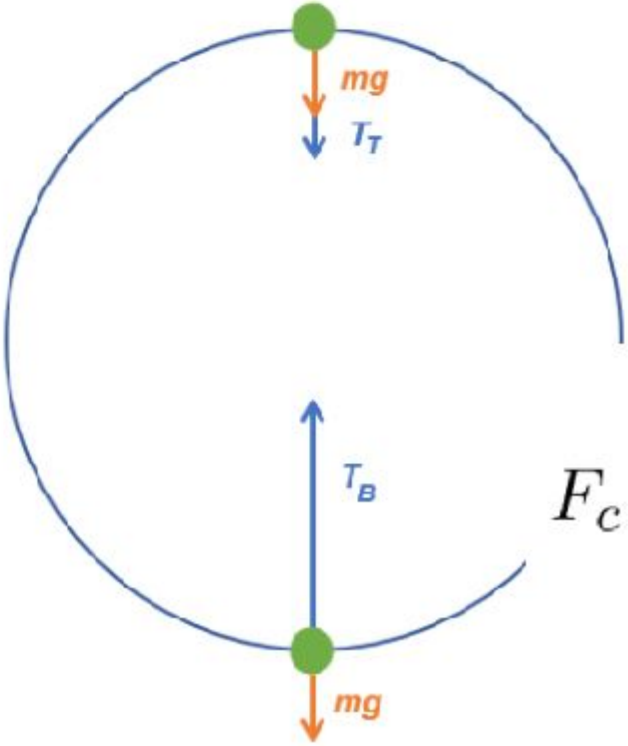
Newton's Universal Law of Gravitation

- The force of gravitational attraction between two bodies of matter is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them



$$F_1 = F_2 = G\,\frac{m_1 \times m_2}{r^2}$$

Vertical Circular Motion: A ball tied to a string



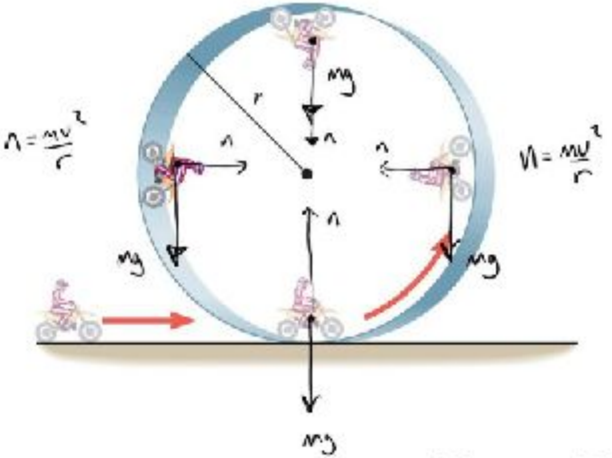
At the top:

$$F_c = F_{net} = F_T + F_g$$

At the bottom:

$$F_c = F_{net} = F_T - F_g$$

Vertical Circular Motion: An object making a loop



At the top:

$$F_c = F_{net} = F_N + F_g$$

At the bottom:

$$F_c = F_{net} = F_N - F_g$$

Orbital Velocity in terms of G, M and r

HSC Physics

Orbital Motion & Velocity

$$v_{\text{orbital}} = \sqrt{\frac{GM}{r}}$$

Derivation for Escape Velocity

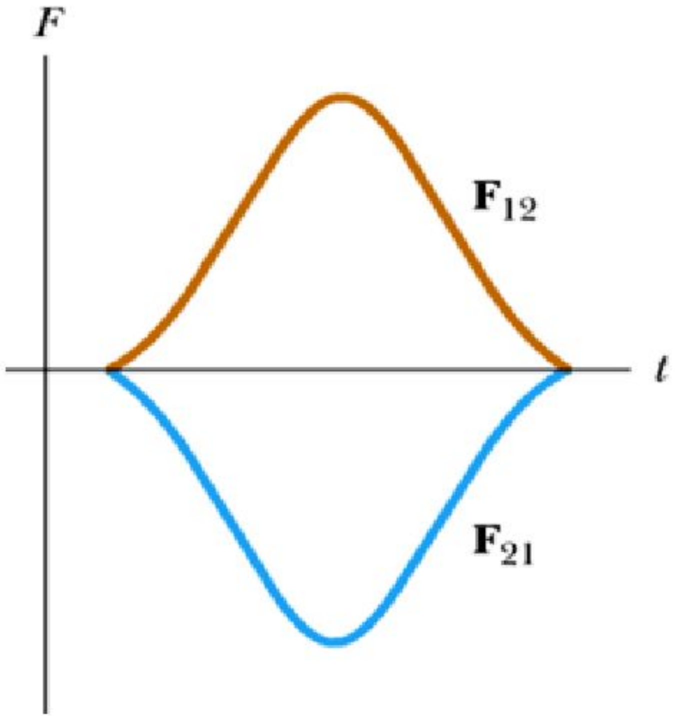
$$\frac{1}{2} m v_e^2 = \frac{GMm}{R}$$

$$v_e = \sqrt{\frac{2GM}{R}}$$

$$g = \frac{GM}{R^2}$$

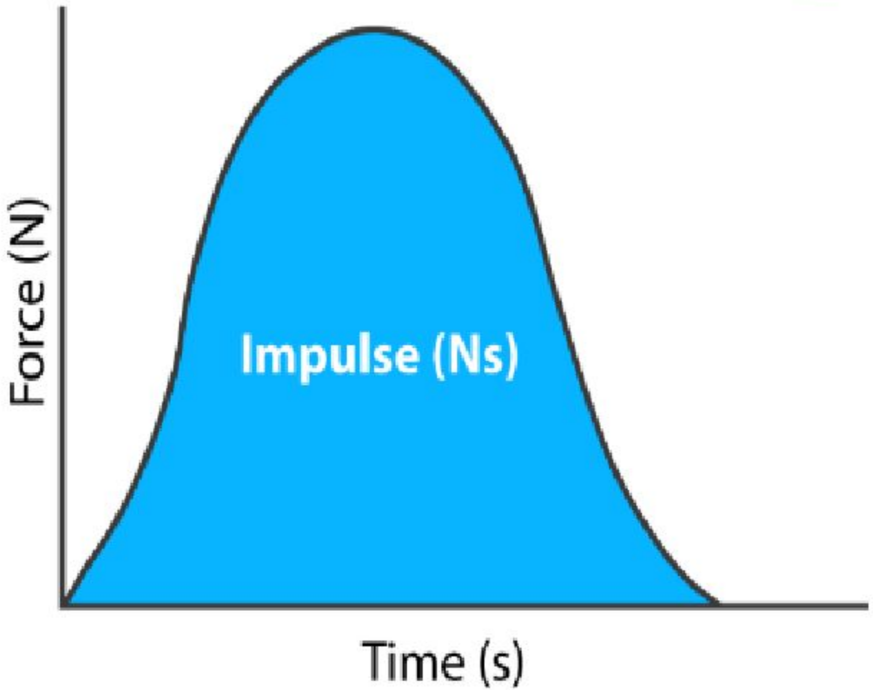
$$v_e = \sqrt{2gR}$$

Graph of Impulse during a Collision



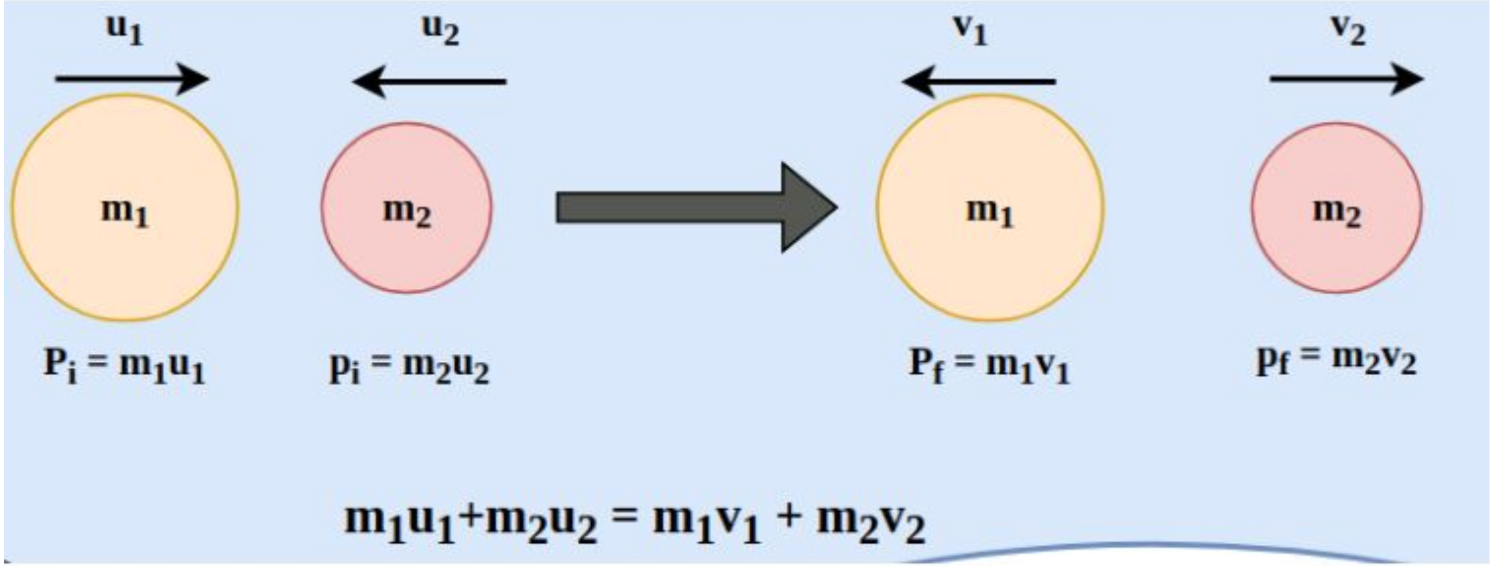
F
$\mathbf{F}_{12}$
t
$\mathbf{F}_{21}$

Area under a Force-Time Graph

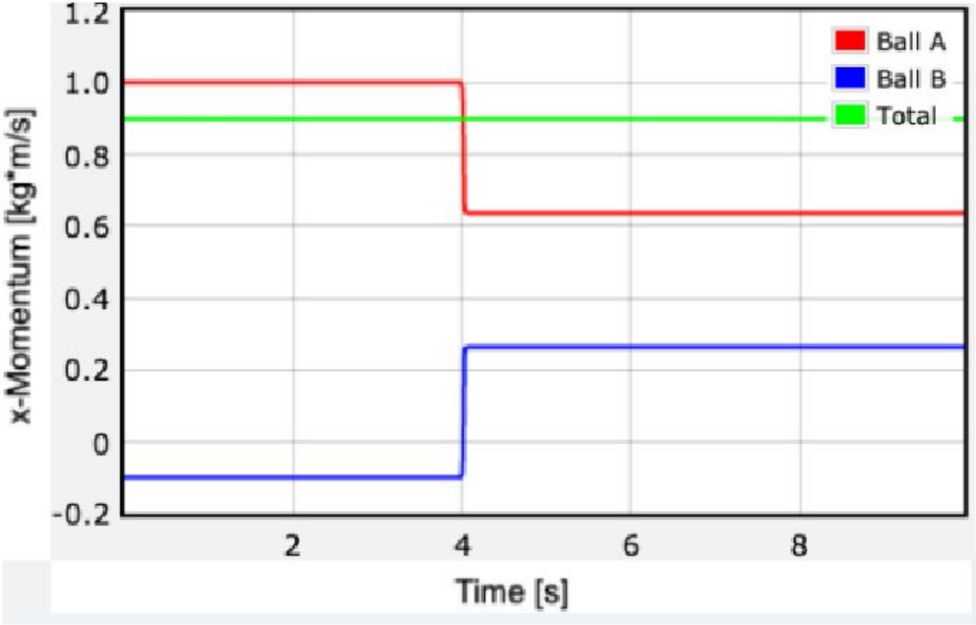

Force (N)
Impulse (Ns)
Time (s)

Principle of Conservation of Momentum

- In a closed system with no external forces, the total momentum before a collision or interaction is equal to the total momentum after.



Conservation of Momentum in Graph Form



Ball A
Ball B
Total
x-Momentum [kg*m/s]
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
2
4
6
8
Time [s]

Elastic Collisions

- Total kinetic energy of the system is conserved
- Momentum is conserved

$$p_i = p_f$$

$$\text{Total KE before} = \text{Total KE after}$$

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

Inelastic Collisions

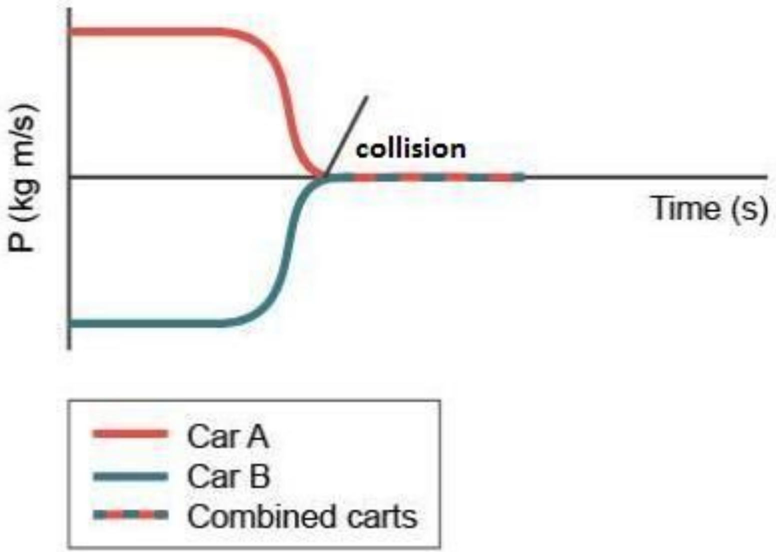
- Total kinetic energy of the system is **not** conserved
- Momentum is conserved

$$KE_i \neq KE_f$$

Perfectly Inelastic Collisions

- An inelastic collision where the two colliding bodies stick together after the collision

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$



Definition of Temperature

- A measure of the **average kinetic energy** of the particles in a substance
- A **scalar** quantity
- Temperature is related to thermal energy but they are not the same. Thermal energy depends on both temperature and the number of particles
- **SI Unit is Kelvin (K)**. Celsius (C) and Fahrenheit (F) are also used.

Specific Heat Capacity

- The **amount of heat energy** required to **raise the temperature of 1kg of a substance by 1 degree Celsius** (or 1 Kelvin)

$$Q = mc\Delta t$$

Latent Heat of Fusion

- The amount of heat energy required to change **1 kilogram of a substance** from **solid to liquid** at its **melting point**, **without changing its temperature**.

$$Q = mL_f$$

Latent Heat of Vaporisation

- The **amount of heat energy** required to **change 1 kilogram of a substance from liquid to gas** at its boiling point, without changing its temperature.

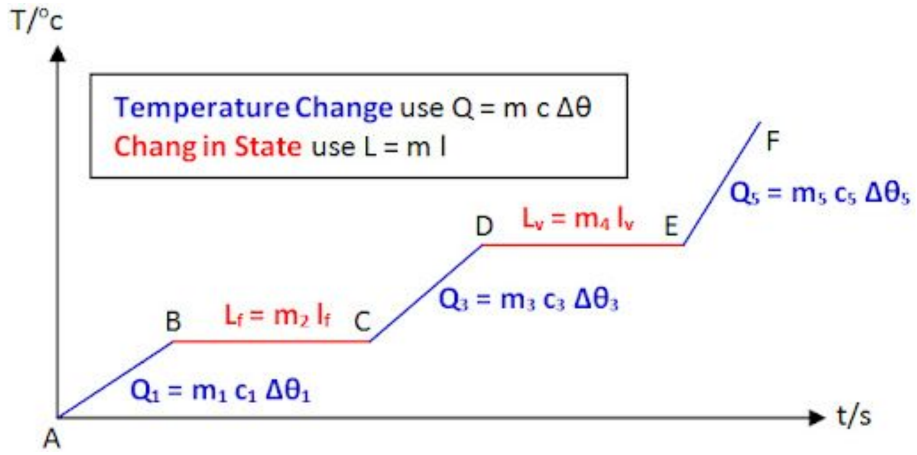
$$Q = mL_v$$

Heating Curve

- For temperature change, use $Q = mc\Delta t$
- For phase change, use $Q = mL_f$ for melting, and $Q = mL_v$ for evaporating

- To get from A to F (assuming for water):

$$mc_{ice}(0-\theta_{initial}) + mL_f + mc_{water}(100) + mL_v + mc_{steam}(\theta_{final}-100)$$

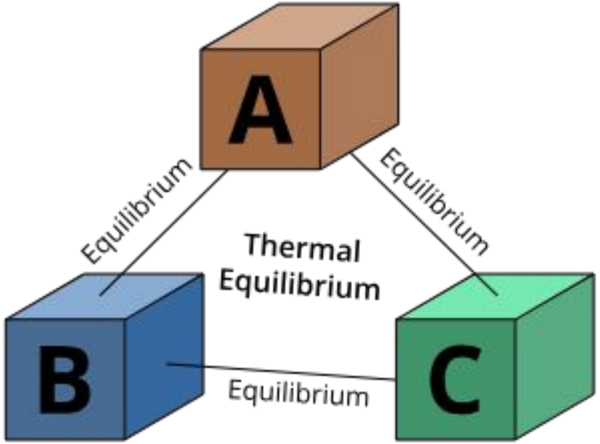


Thermal Equilibrium

- The state in which **two or more objects in contact** no longer exchange heat because they are at the **same temperature**.

Zeroth Law of Thermodynamics

- If two systems are each in thermal equilibrium with a third system, then they are all in thermal equilibrium with each other.



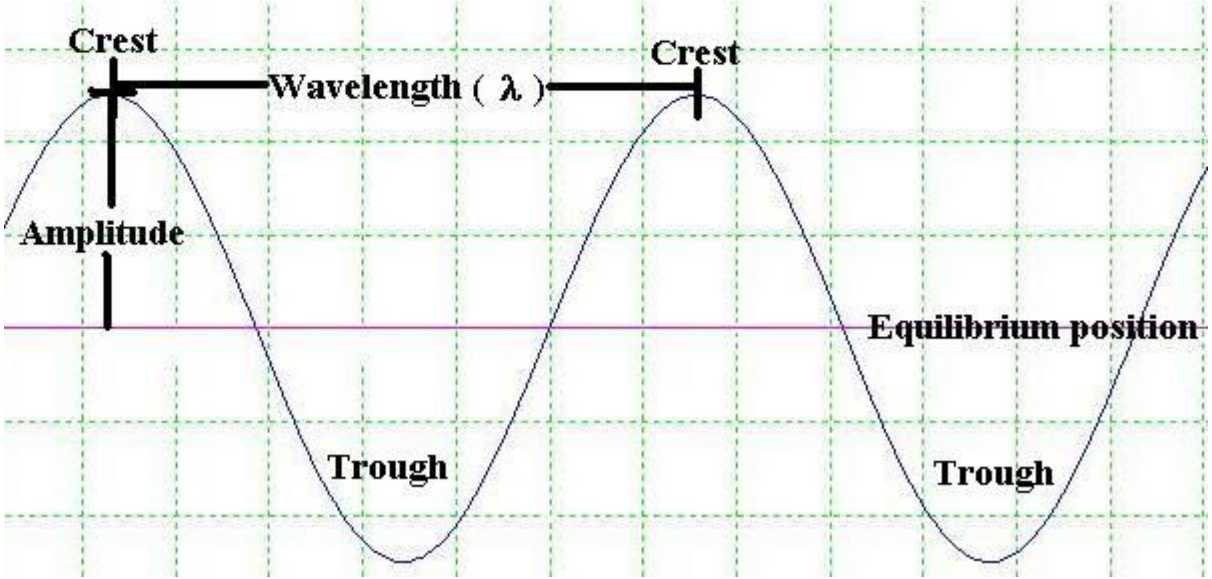
Zeroth law of Thermodynamics

Absolute Zero

- **Absolute zero** is the **lowest possible temperature**, where the **particles of a substance have minimum possible energy** — essentially **no thermal motion**.

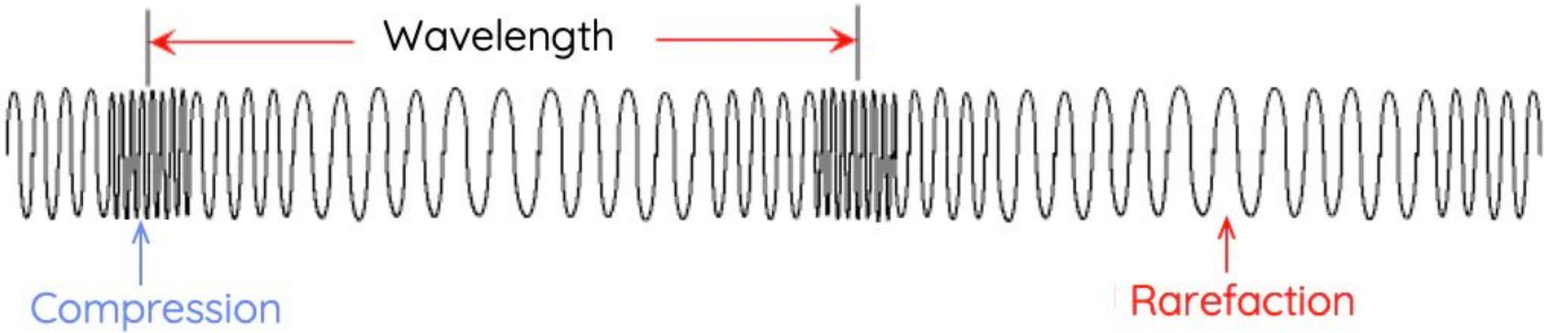
Transverse Wave

- A type of wave where the **particles of the medium move perpendicular** to the direction the wave is traveling.
- Examples: Electromagnetic waves, water waves



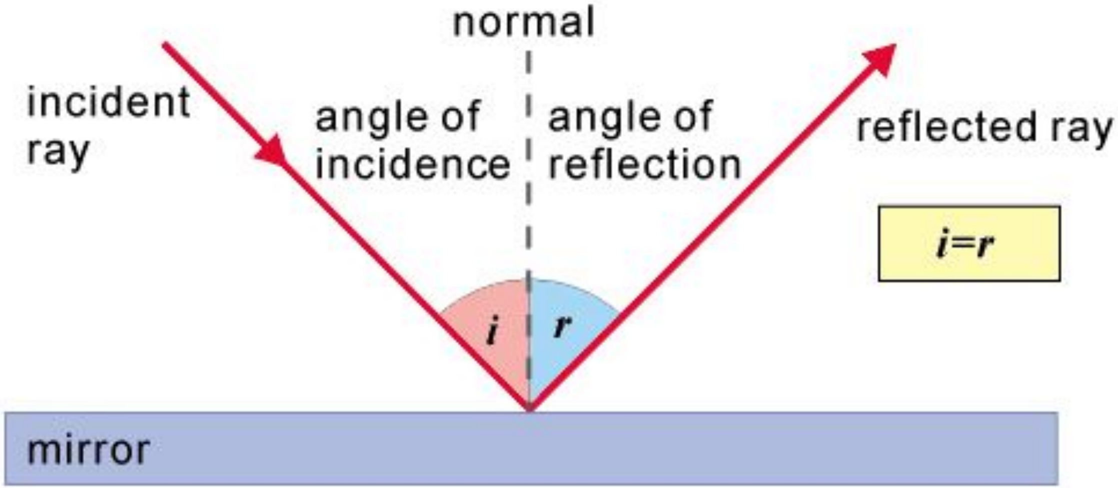
Longitudinal Wave

- A type of wave in which the **particles of the medium move parallel** to the direction the wave is travelling.
- Examples: sound waves in air, pressure waves



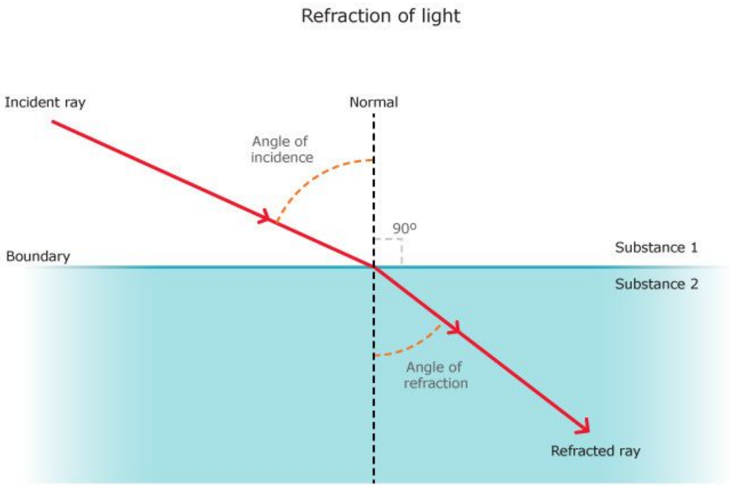
Reflection

- The change in direction of a wave when it bounces off a surface and returns to the medium it came from



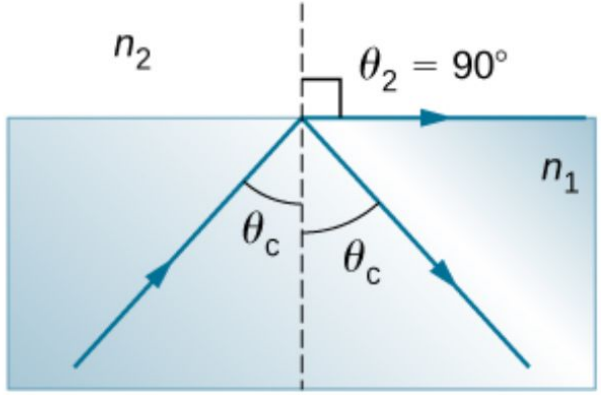
Refraction

- The bending of a wave as it **passes from one medium to another** and **changes speed**
- **Higher → Lower index**: wave speeds up, bends **away** from the normal.
- **Lower → Higher index**: wave slows down, bends **toward** the normal.



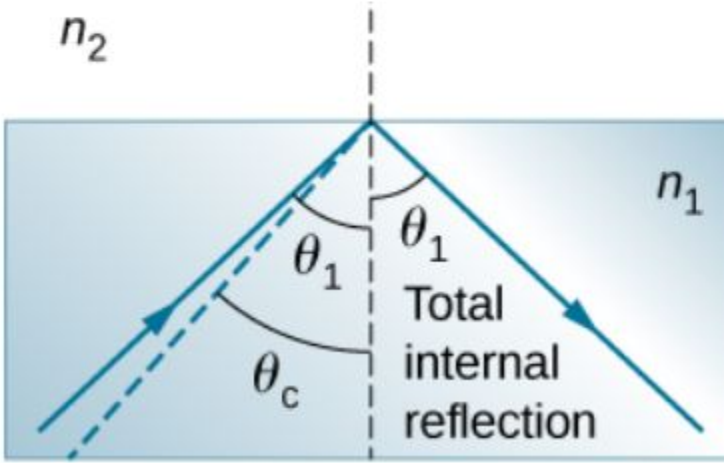
Critical Angle

- The **angle of incidence** in a denser medium at which the **refracted ray travels exactly along the boundary** between two media
- Happens (occurs) when light travels **from a medium with higher refractive index** to a **lower refractive index**
- Beyond this angle, **total internal reflection** happens — the light is **completely reflected** back into the denser medium.



Total Internal Reflection

- **Total Internal Reflection (TIR)** occurs when a wave (like light) traveling from a **denser medium to a less dense medium** hits the boundary at an angle **greater than the critical angle**, causing **all the wave to reflect back** into the denser medium



Medium

- The **substance or material** through which a wave travels.
- **Mechanical waves need a medium** (sound waves, water waves need a solid/liquid/gas to travel through)
- **Electromagnetic waves do not need a medium** and can travel through a vacuum (no substance/material)

Vacuum

- A **vacuum** is a space **completely devoid of matter** — it has **no particles**, meaning **no air, no gas, nothing**.
- **Outer space** is a near-perfect vacuum.
- **Light from the Sun** travels through the vacuum of space to reach Earth.
- **Vacuum chambers** are used in science labs to test equipment or observe phenomena without air resistance.

Period (T) and frequency (f)

Period

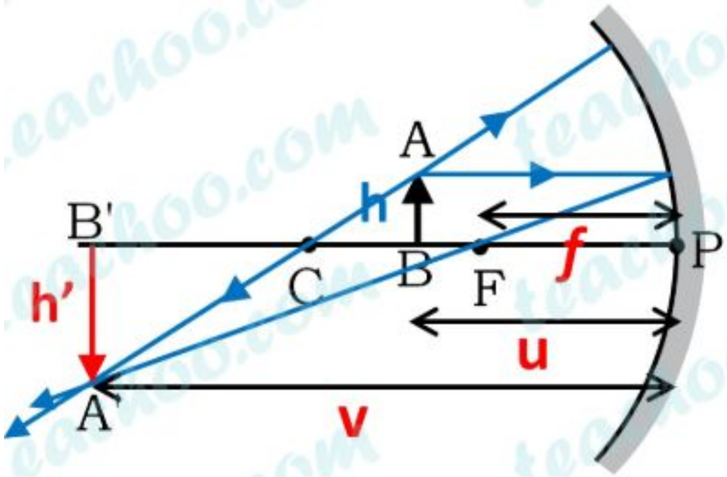
- The **time it takes for one full cycle** of a wave to pass a point
- Unit: seconds
- If a wave passes every 0.01 seconds, its period is 0.01 s

Frequency

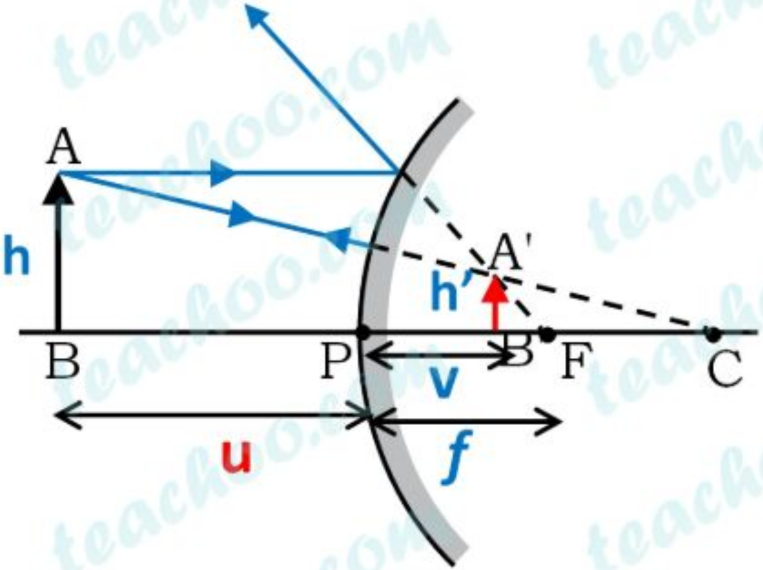
- The **number of cycles per second**
- Unit: The Hertz (Hz). 1 Hz = 1 cycle per second
- If 100 waves pass in 1 second, the frequency is 100 Hz

$$T = \frac{1}{f} \qquad\qquad f = \frac{1}{T}$$

The Mirror Equation



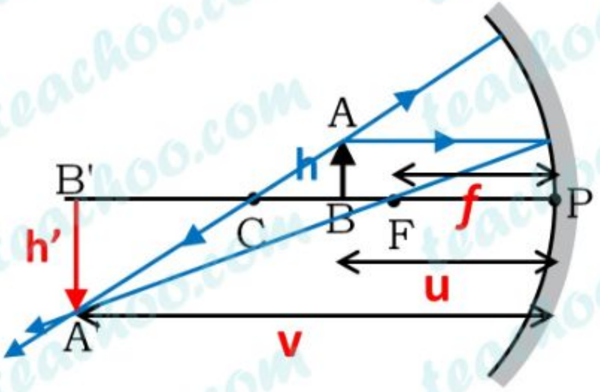
Concave Mirror



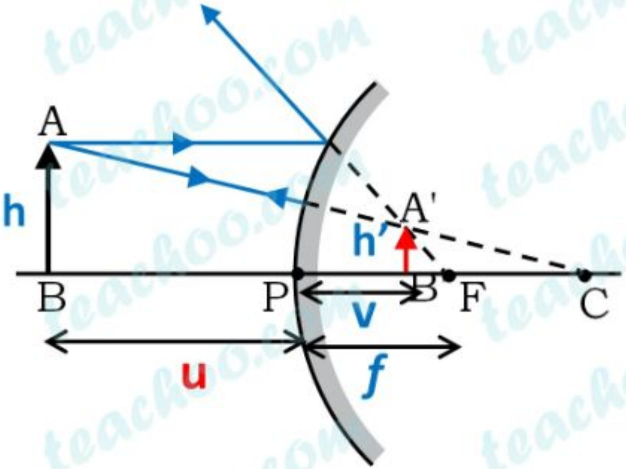
Convex Mirror

Mirror Formula: $$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$

Magnification



Concave Mirror



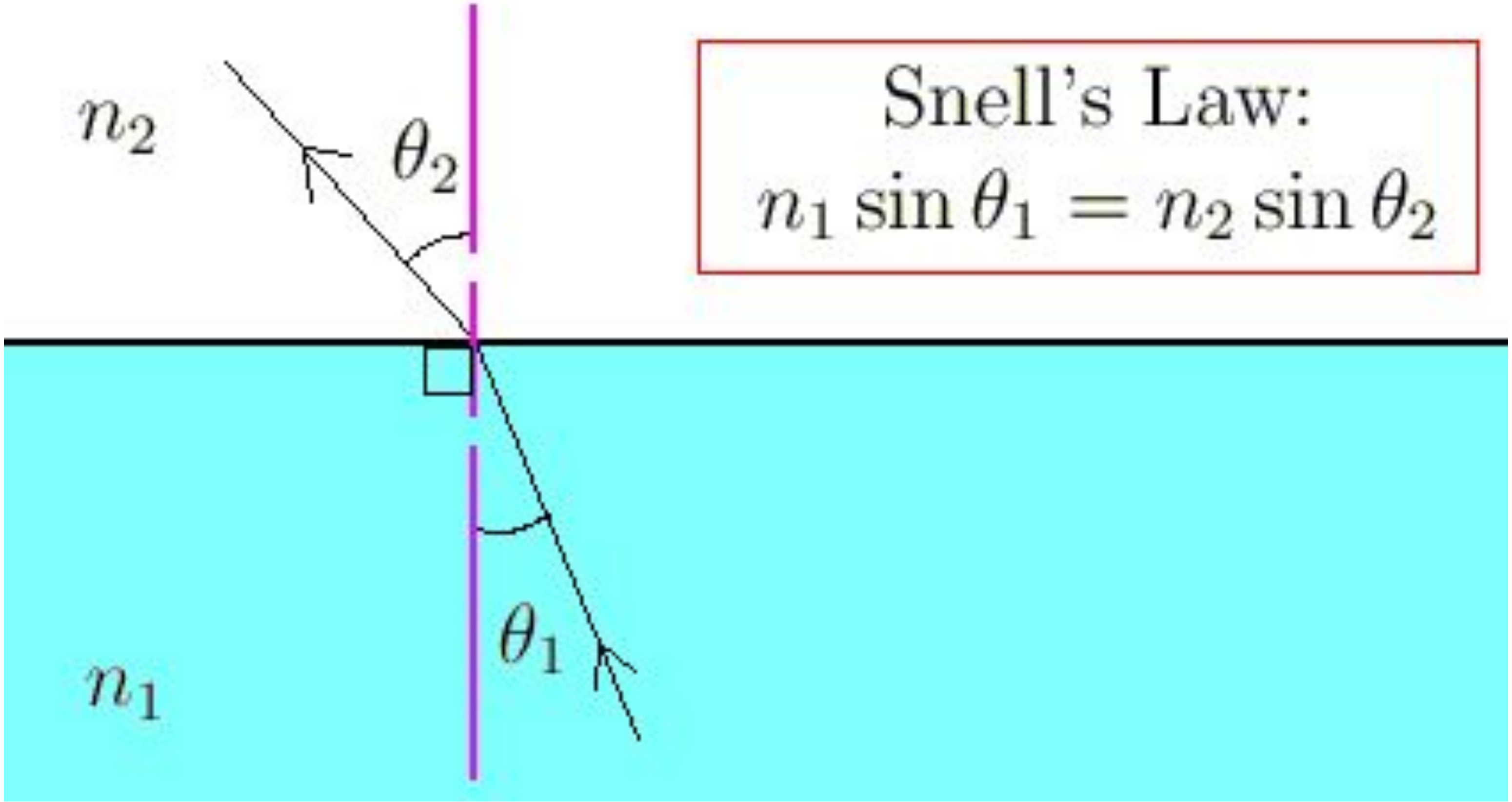
Convex Mirror

Magnification

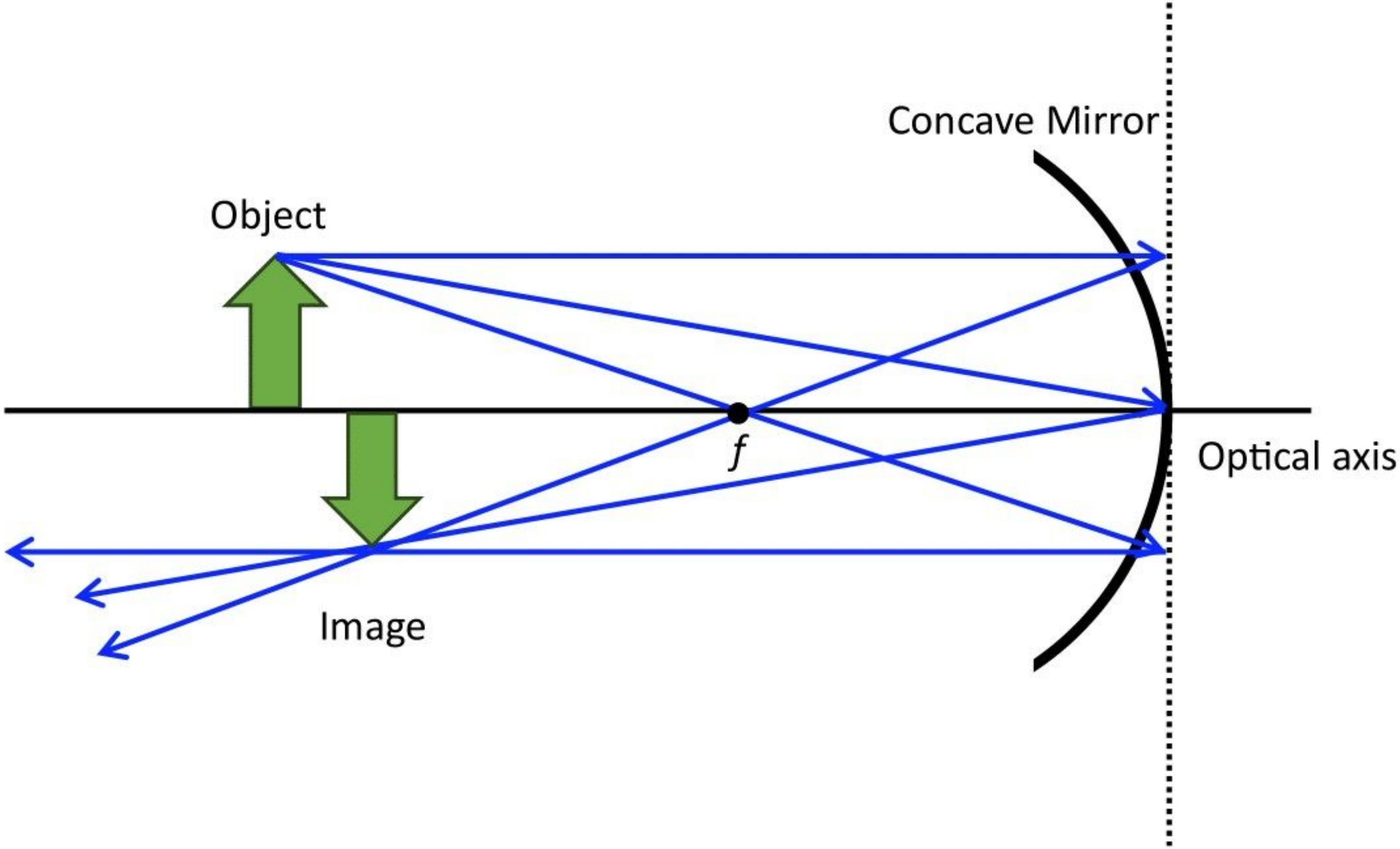
$$m = \frac{Height\ of\ image}{Height\ of\ Object}$$

$$m = \frac{-v}{u}$$

Snell’s Law

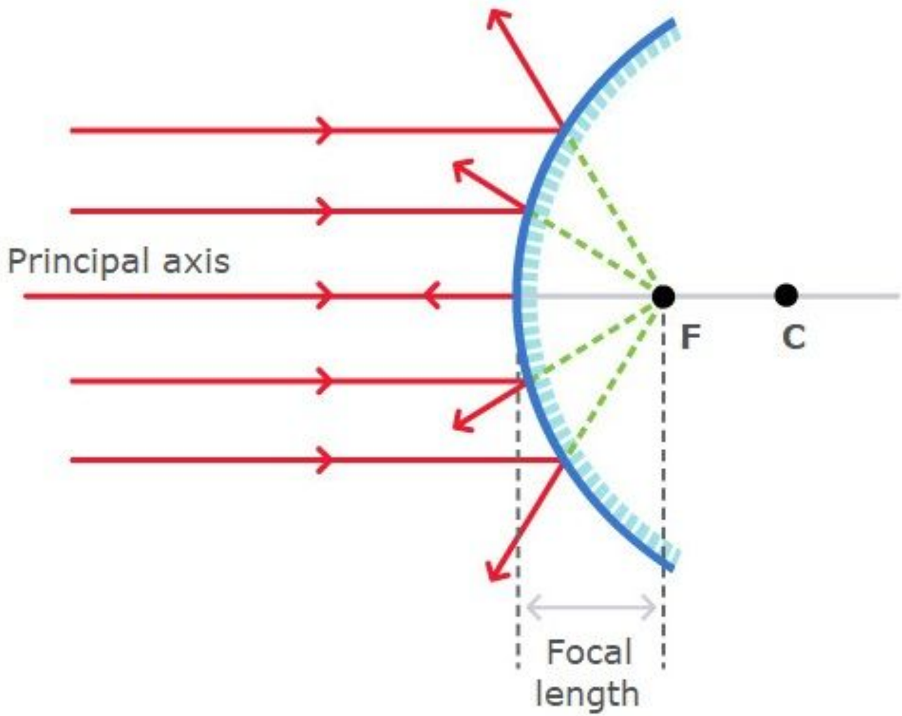

n_2
θ_2
Snell's Law:
$n_1 \sin\theta_1 = n_2 \sin\theta_2$
θ_1
n_1

Concave Mirror


Concave Mirror
Object
f
Optical axis
Image

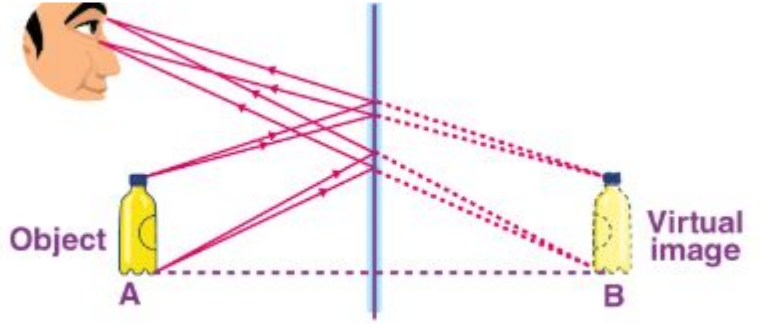
Convex Mirror

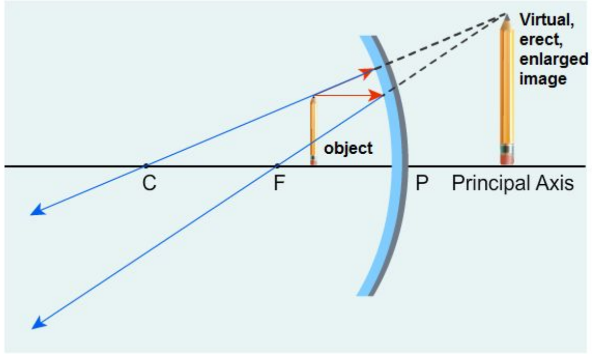
Reflection of light on convex mirror

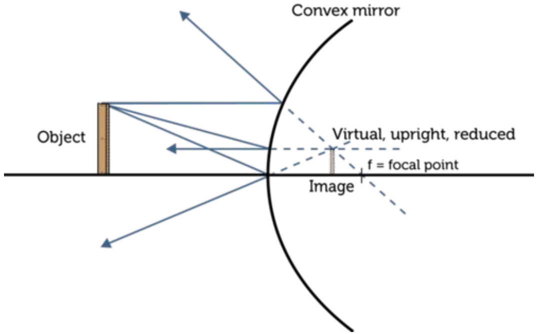


Virtual Image

- Formed by the “apparent” intersection of light rays
- Always formed behind the mirror
- **Plane and convex mirrors will always produce virtual images**
- In **concave mirrors, if the object is placed between the focus and the pole**, a virtual image will be formed

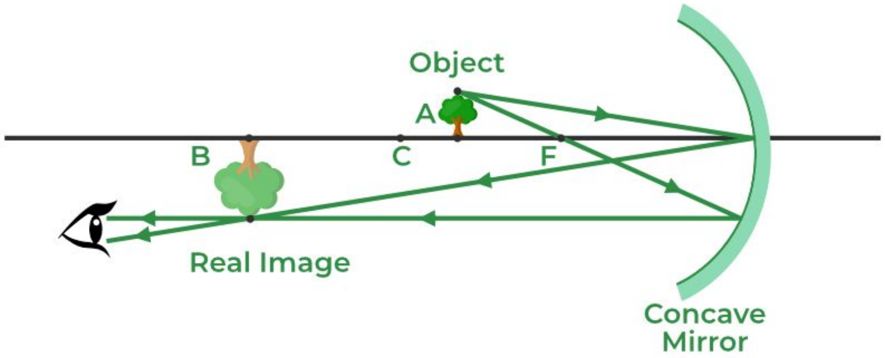






Real Image

- Formed by the “real” intersection of light rays.
- Always formed in front of the mirror
- If the object is placed outside of the focus, a real image will always be formed



The speed of light in a vacuum

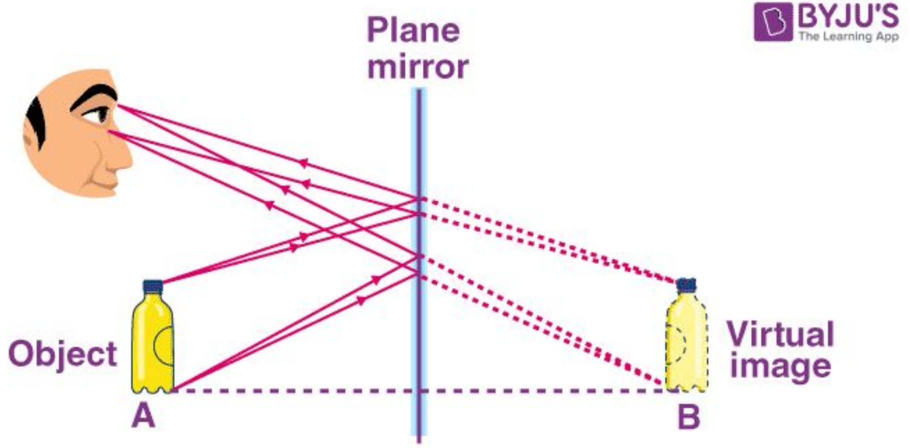
- Nothing can travel faster than the speed of light in a vacuum
- In a vacuum, all electromagnetic waves travel at this speed

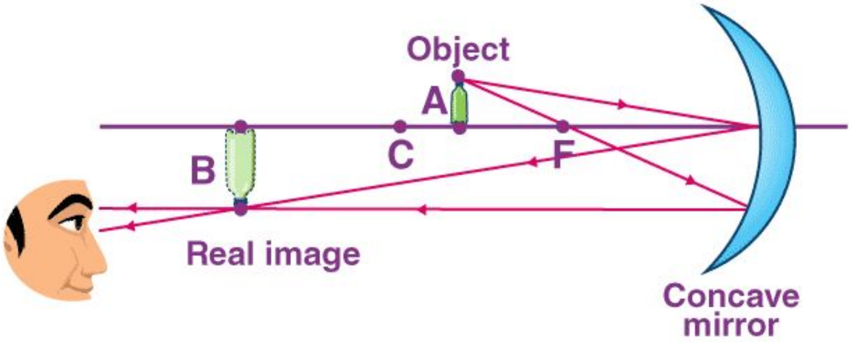
$$c = 299,792,458\,\mathrm{m/s}$$

Upright vs Inverted

Virtual vs Real Image

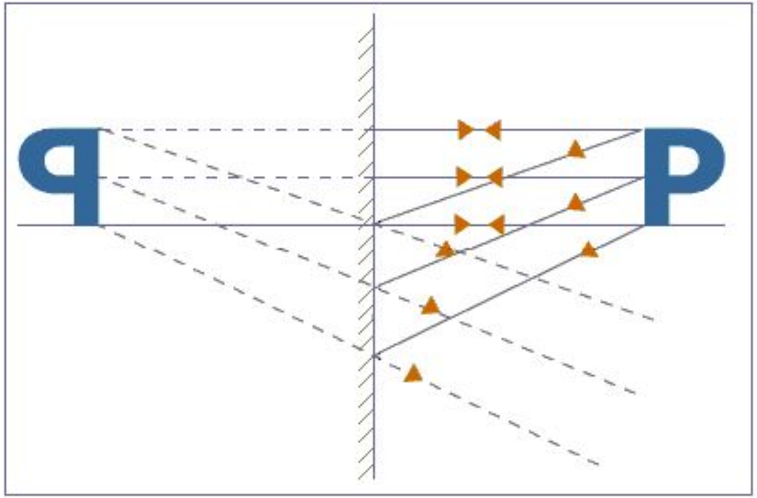
- **Virtual images** are formed by the **apparent** intersection of light rays
- **Real images** are formed by the **actual** intersection of light rays





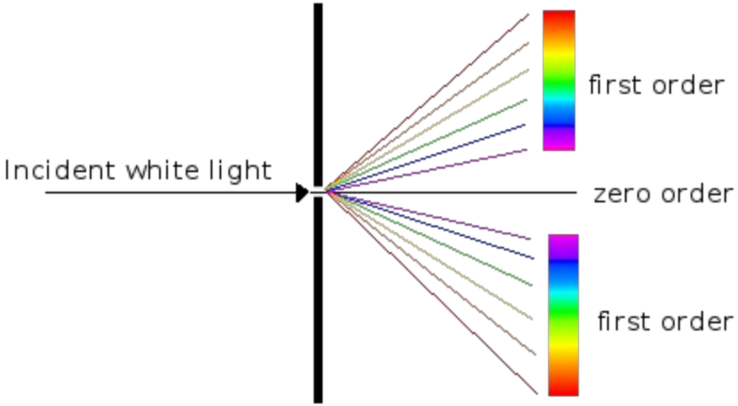
Lateral Inversion

- The phenomenon where the **left and right sides are reversed** in a **mirror image** — this happens with **plane mirrors**.



Diffraction

- When white light (which contains all visible wavelengths) bends around the edges of an obstacle or passes through a narrow slit or diffraction grating
- **Red light is diffracted the most and violet the least**



Refractive Index of Air

$$n_{air} \approx 1$$

Work

- Work is done when a force causes an object to move in the direction of the force
- **Maximum positive work** is done when the **force is exactly parallel** to the object's displacement (theta = 0)
- **No work is done** when the f**orce is exactly perpendicular** to the object's displacement (theta = 90)
- **Maximum negative work** is done when the force is exactly **anti-parallel** to the object's displacement (theta = 180)
- Unit: The Joule (J) or Newton metre (Nm)
- Scalar quantity

$$W = Fdcos(\theta)$$

Work-Energy Theorem

- The **net work** done on an object is equal to the **change in its kinetic energy**
- **Positive work** implies an **increase** in kinetic energy (speeding up)
- **No work** implies **no change** in kinetic energy (constant velocity)
- **Negative work** implies a **decrease** in kinetic energy (slowing down)

$$W = \Delta KE$$

Positive Work

- An increase in kinetic energy of the object the force is acting on

Negative Work

- A decrease in kinetic energy of the object the force is acting on

Net Work

- The total work done on an object by all forces acting on it

Power

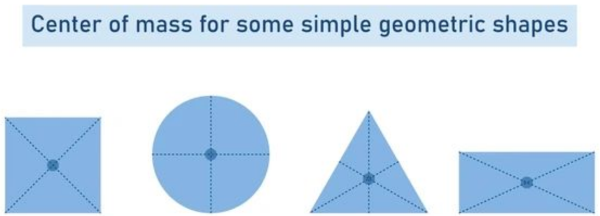
- Power is the rate of change of work
- Unit is the Watt (W)
- Watt can be considered as Joules/second
- Power is a scalar quantity since it has no direction

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

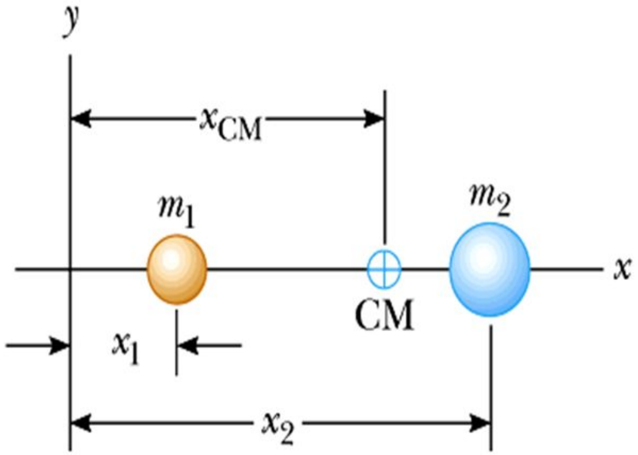
$$P = Fvcos(\theta)$$

Centre of Mass

- **Doesn't have to be inside** the object
- In **collisions**, the COM continues to move **at constant velocity** if no external force acts on it

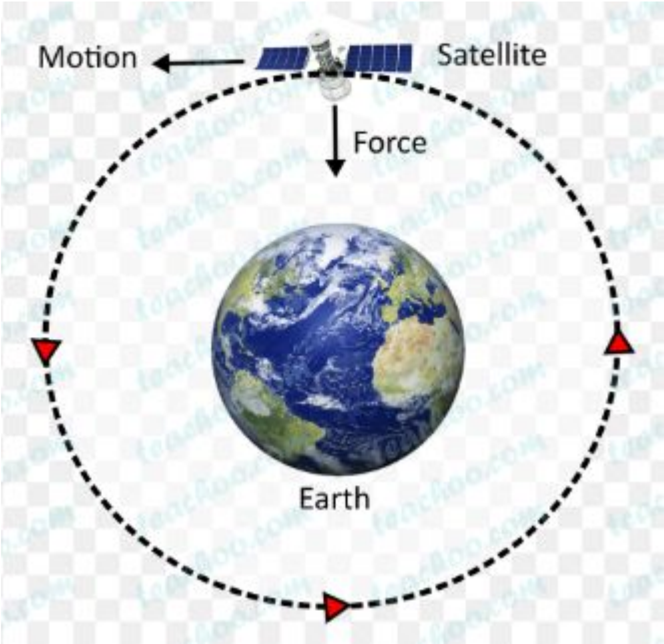


$$\vec{x}_{\mathrm{cm}} = \frac{\sum m_i \vec{x}_i}{\sum m_i}$$



Work done on an orbiting satellite

- Zero work is done since the direction of displacement and the force acting on the satellite are perpendicular to each other



Orbiting Satellites (travelling at constant speed)

- The force of gravity is providing centripetal force
- Constant speed, but velocity is always changing since its direction is changing
- Tangential acceleration is directed in the same direction as linear velocity at a specific point
- Centripetal (radial) acceleration is directed towards the centre of the circle

$$v = \sqrt{\frac{GM}{r}}$$

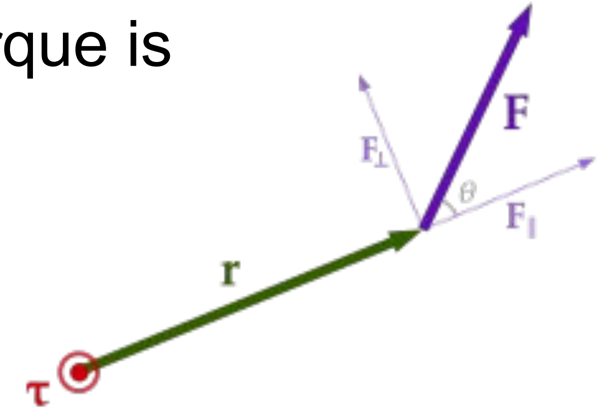
Escape Velocity

$$v_{escape} = \sqrt{\frac{2GM}{r}}$$

Torque

- Unit: Newton metre (Nm)
- Vector
- **Maximum torque** occurs when force is **perpendicular** to the lever arm
- **No torque** is done when force is **parallel** to the lever arm
- **Clockwise** torque is considered **negative**
- **Anti-clockwise** (counter-clockwise) torque is considered **positive**

$$\tau = rF_{\perp} = rF\sin\theta$$



Angular Momentum

- Vector quantity
- Angular momentum is conserved in a closed system with **no external torques**, just like linear momentum.
- Units: $\frac{kg\, m^2}{s}$

$$L = I\omega$$

Rotational Kinematics

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

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

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

Angular Work

- Unit is the Joule (J)
- **Angular displacement is expressed in radians**
- If torque and angular displacement are in the same direction, angular work is positive
- If they are in opposite direction, angular work is negative (energy is taken away)

$$W = \tau \Delta\theta$$

Rotational Kinetic Energy

- A scalar quantity
- A rigid system can have rotational kinetic energy even if its center of mass is at rest
- Unit is Joule (J)

$$K = \frac{1}{2} I \omega^2$$

Rolling Without Slipping

- Static friction is needed between the object and the surface to allow for rotation without slipping

6.5.B.1

While rolling without slipping, the translational motion of a system's center of mass is related to the rotational motion of the system itself with the equations:

$$\Delta x_{cm} = r\Delta\theta$$

$$v_{cm} = r\omega$$

$$a_{cm} = r\alpha$$

6.5.B.2

For ideal cases, rolling without slipping implies that the frictional force does not dissipate any energy from the rolling system.

Rolling While Slipping

6.5.C.1

When slipping, the motion of a system's center of mass and the system's rotational motion cannot be directly related.

6.5.C.2

When a rotating system is slipping relative to another surface, the point of application of the force of kinetic friction exerted on the system moves with respect to the surface, so the force of kinetic friction will dissipate energy from the system.

Total Kinetic Energy of a system that has translational and rotational motion

6.5.A.1

The total kinetic energy of a system is the sum of the system’s translational and rotational kinetic energies.

Relevant equation:.

$K_{\text{tot}} = K_{\text{trans}} + K_{\text{rot}}$

$$\frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

Rotational Inertia

- A measure of an object's resistance to changes in its **rotational motion** — basically, how hard it is to make it spin faster, slower, or stop.
- The closer the mass is concentrated to the axis of rotation, the smaller the rotational inertia becomes. In other words, a body becomes easier to rotate

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

Angular Impulse

- Change in angular momentum
- It is a vector quantity
- Positive angular impulse → positive angular acceleration → angular velocity increases
- Negative angular impulse → negative angular acceleration → angular velocity decreases
- Units: $N \cdot m \cdot s$ or $\frac{kg\,m^2}{s}$

$$\Delta L = \tau \Delta t = I \Delta \omega$$

Rotational Form of Impulse-Momentum Theorem

6.3.C.2.ii

The rotational form of the impulse–momentum theorem is a direct result of the rotational form of Newton's second law of motion for cases in which rotational inertia is constant:

$$\tau_{\text{net}} = \frac{\Delta L}{\Delta t} = I\frac{\Delta \omega}{\Delta t} = I\alpha$$

Translational Kinetic Energy

- The energy an object has due to its **motion in a straight line (translation)**
- **Unit is the Joule (J)**

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

Gravitational Potential Energy

- The energy stored in an object due to its position in a gravitational field — typically, how high it is above the ground
- Unit is the Joule (J)

$$U_g = mgh$$

Principle of Conservation of Energy

- Energy cannot be created or destroyed, it can only be transferred from one form to another

- The total energy of a closed system remains constant

$$E_i = E_f$$