

Physics Formulas

5 Linear Motion Equations

	Equation	Variables found in equation	Variables not in equation
Equation 1	$\Delta \vec{d} = \left(\frac{\vec{v}_f + \vec{v}_i}{2} \right) \Delta t$	$\Delta \vec{d}, \Delta t, \vec{v}_f, \vec{v}_i$	$\vec{a}_{av}$
Equation 2	$\vec{v}_f = \vec{v}_i + \vec{a}_{av} \Delta t$	$\vec{a}_{av}, \Delta t, \vec{v}_f, \vec{v}_i$	$\Delta \vec{d}$
Equation 3	$\Delta \vec{d} = \vec{v}_i \Delta t + \frac{1}{2} \vec{a}_{av} \Delta t^2$	$\Delta \vec{d}, \vec{a}_{av}, \Delta t, \vec{v}_i$	$\vec{v}_f$
Equation 4	$v_f^2 = v_i^2 + 2a_{av}\Delta d$	$\Delta d, a_{av}, v_f, v_i$	Δt
Equation 5	$\Delta \vec{d} = \vec{v}_f \Delta t - \frac{1}{2} \vec{a}_{av} \Delta t^2$	$\Delta \vec{d}, \vec{a}_{av}, \Delta t, \vec{v}_f$	$\vec{v}_i$

Gravity – an attractive force that is felt by all forms of matter

$$\mathbf{F} = \frac{\mathbf{G M m}}{r^2}$$

G is the gravitational constant ($6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2$)

Rotational Equilibrium

Rotational motion depends on both the magnitude and direction of the force as well as the distance the force is from the axis of rotation

$$\text{torque} = \tau = rF \sin \theta$$

Circular Motion

When an object is travelling in circular motion, the velocity vector is always tangent to the circular path

Despite being in uniform circular motion and the speed of the object remains constant, acceleration exists and is directed towards the center of the circle

→ this acceleration is called **centripetal acceleration**

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

Therefore, the equation for centripetal force is:

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

Work

$$W = Fd \cos \theta$$

Power

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

The unit of power is in watts (joule/sec)

Kinetic Energy -

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

Potential Energy

$$E_p = mgh$$

Total Mechanical Energy

$$E_{\text{mechanical}} = mgy_1 + \frac{1}{2}mv_1^2 = mgy_2 + \frac{1}{2}mv_2^2$$

Pulleys – allows for heavy weight to be lifted using a much smaller force
→ the same amount of work is done, but pulleys allow for the pull to occur over a longer distance

Load – the weight of the object being lifted (mg)

Load Distance – the distance that it rises at

Effort – The force exerted on the rope when lifting the load

Effort Distance – the distance at which effort is exerted

$$\begin{aligned}\text{Efficiency} &= \frac{W_{\text{out}}}{W_{\text{in}}} \\ &= \frac{\text{Load} \times \text{Load distance}}{\text{Effort} \times \text{Effort distance}}\end{aligned}$$

Momentum

$$P = mv$$

Impulse

$$J = Ft = mv - mv_0 = \Delta p$$

Center of Mass

$$\begin{aligned}X &= \frac{m_1x_1 + m_2x_2 + m_3x_3 + \dots}{m_1 + m_2 + m_3 + \dots} \\ Y &= \frac{m_1y_1 + m_2y_2 + m_3y_3 + \dots}{m_1 + m_2 + m_3 + \dots} \\ Z &= \frac{m_1z_1 + m_2z_2 + m_3z_3 + \dots}{m_1 + m_2 + m_3 + \dots}\end{aligned}$$

Thermal Expansion

$$\Delta L = \alpha L_0 \Delta T$$

ΔL = Change in Length, L_0 = original length,
 ΔT = change in temperature, α = coefficient of linear expansion

Volume Expansion – liquids expand when heated, but the volume expands in their case

$$\Delta V = \beta V_0 \Delta T$$

Specific Heat

The heat (Q) gained or lost by an object and the change in temperature of that object is related by the equation:

$$Q = mc\Delta T = mc(T_f - T_i)$$

Pressure

$$P = F/A$$

For when pressure is constant, work can be given by:

$$W = P\Delta V = P(V_f - V_i)$$

For when neither pressure nor volume is held constant, the total area under the graph gives the work done:

$$W = A_I + A_{II}$$

$$A_I = \frac{1}{2} \Delta V \Delta P$$

$$A_{II} = P_2 V$$

First Law – internal energy (U or E) is the measure of all the energy, potential and kinetic, possessed by the molecules in the system

→ internal energy of a system increased by doing work on it or by adding heat to it

$$\Delta U = Q - W$$

Q = heat energy transferred to the system

W = work done by the system

Special Cases of the First Law

Process	First Law Becomes
Adiabatic ($Q = 0$)	$\Delta U = -W$
Constant Volume ($W = 0$)	$\Delta U = Q$
Closed Cycle ($U = 0$)	$Q = W$

Second Law of Thermodynamics

Entropy

Isothermal Processes – when the temperature remains constant throughout, the change of entropy in a system can be calculated by:

$$\Delta S = Q/T$$

Where Q = heat energy, T = temperature (kelvins), S = entropy

Density and Pressure

Density (ρ) is a scalar quantity that is defined as mass (m) per unit volume (V)

$$\rho = m/V$$

The units of density are kg/m^3

$$\begin{aligned} W &= mg \\ m &= \rho V \\ W &= \rho Vg \end{aligned}$$

Absolute Pressure (P) – the pressure in a fluid due to gravity on an object (somewhere below the surface)

$$P = P_0 + \rho gh$$

Where P_0 = pressure at the surface, ρ = density,
 g = gravitational acceleration, h = depth below the surface

Typically, P_0 is simply atmospheric pressure ($P_0 = P_{\text{atm}} = 1.013 \times 10^5 \text{ Pa}$)

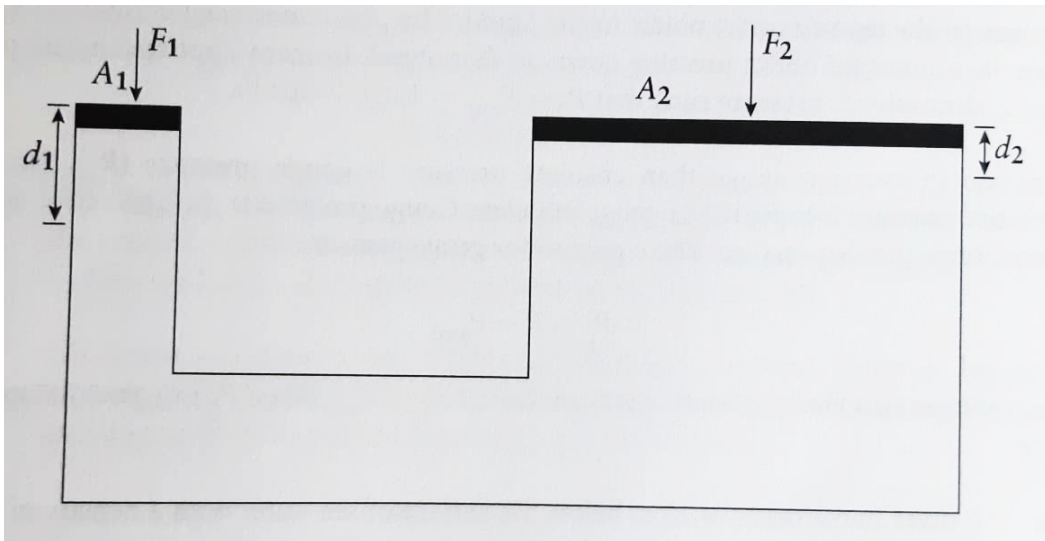
Gauge Pressure (P_g) – the difference between absolute and atmospheric pressure

$$P_g = P - P_{\text{atm}}$$

Note that if $P_0 = P_{\text{atm}}$, then $P_g = \rho gh$

Hydrostatics

Pascal's Principle



Using the figure above, the external force F_1 needs to balance the other external force F_2 in order to maintain an equilibrium state

$$\Delta P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$$

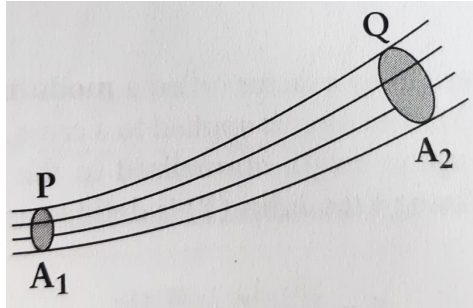
$$F_2 = F_1 \frac{A_2}{A_1}$$

Archimedes' Principle

This principle discusses the buoyancy of objects when placed in a fluid and explains why ships float
 → the buoyant force is given by:

$$F_B = \rho_{\text{fluid}} g V_{\text{submerged}}$$

Hydrodynamics



$$v_1 A_1 = v_2 A_2 = \text{constant}$$

Bernoulli's Equation – Energy is also conserved as the fluid flows

$$P_1 + \frac{\rho v_1^2}{2} + \rho g y_1 = P_2 + \frac{\rho v_2^2}{2} + \rho g y_2 = \text{a constant}$$

Elastic Properties of Solids

Young's Modulus – the elasticity of a solid is characterized by a factor called a **modulus**

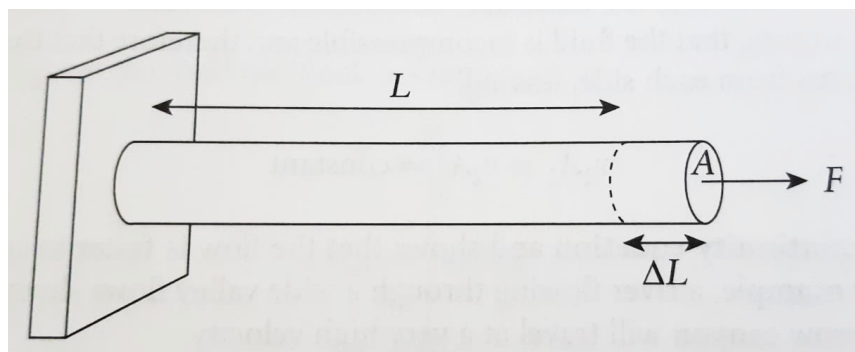
When subject to a force F , a material will change its length by ΔL

Stress – F/A (force applied to a cross-sectional area)

Strain – $\Delta L/L$ (length change over starting length of material)

Young's Modulus (Y) – stress over strain defined by:

$$Y = \frac{(F/A)}{(\Delta L/L)} = \frac{\text{stress}}{\text{strain}}$$



Yield Strength – the point at which a material will not return to its original dimensions once the force is removed

→ if more stress is applied, ultimate strength is reached

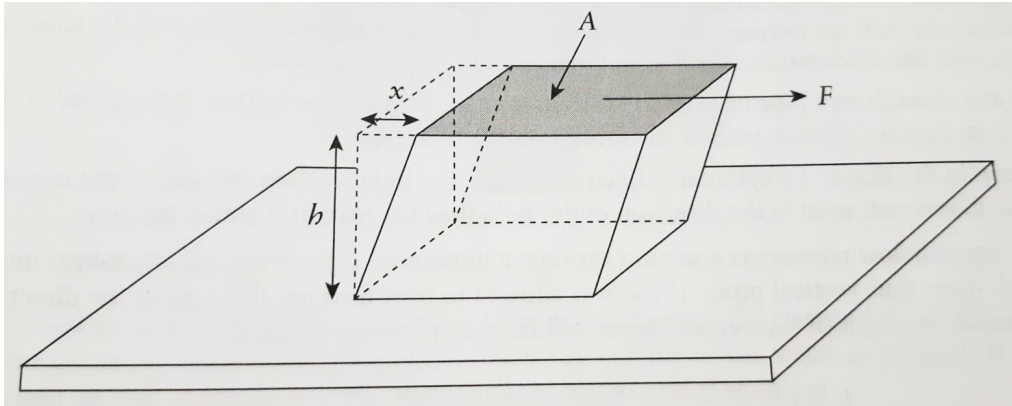
→ beyond that, rupture may occur

Shear Modulus – another form of deforming stress (also F/A)

Stress – F/A (force applied to an area)

Strain – x/h (movement in the direction of force/ height)

$$S = \frac{(F/A)}{(x/h)}$$



Bulk Modulus (B) – change in pressure acting on the surfaces of a solid or fluid

$$B = \frac{\Delta P}{\Delta V / V}$$

where ΔP = pressure, ΔV = change in volume, V = initial volume

Coulomb's Law

The electrostatic force F between 2 charges is given by:

$$F = k \frac{q_1 q_2}{r^2}$$

where k = coulomb's constant ($9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2\cdot\text{e0}$)

q = charge (coulombs), r = distance (meters)

Electric Field

The electric charge sets up a surrounding **electric field** (can be detected by other electric charges)

$$\mathbf{E} = k \frac{q}{r^2}$$

Electric Potential

Electric Potential is the amount of work needed to move an electric charge in an electric field
 → the amount of work needed to move a positive test charge from infinity to that point is defined as:

$$V = \frac{W}{q_0}$$

The SI units for electric potential can be measured in **volts (V)**, where 1 volt = 1 joule/coulomb
 → electric potential can also be defined as:

$$V = k \frac{q}{r}$$

Since electric potential is a scalar quantity (V), where positive charge is positive, negative charge is negative

→ total electric potential can be defined as the scalar sum of:

$$V_{\text{total}} = V_{q1} + V_{q2} + V_{q3} + \dots (\text{scalar sum})$$

Potential Difference – the difference between potential can also be defined as the term “**voltage**”
 → the difference can be defined as:

$$V_b - V_a = \frac{W_{ab}}{q_0}$$

Electric Potential Energy (U) – defined by the amount of work needed to move the charge from infinity to that point through an electric field (created by a separate source charge)

$$U = k \frac{qQ}{r}$$

Force on a Moving Charge:

$$F = qvB \sin \theta$$

whereas q = charge of moving particle, v = velocity of particle,
 B = magnitude of the magnetic field vector

Current

→ this flow is called an **electric current (I)**

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

Force on a Current-Carrying Wire

Since moving charge is subject to magnetic forces and electric current is a flow of charge, magnetic forces can also act on a current-carrying wire

→ follows the same right-hand rule

$$F = ILB \sin \theta$$

Long, Straight Current-Carrying Wire

$$B = \frac{\mu_0 I}{2\pi r}$$

Circular Loop of Current-Carrying Wire

$$B = \frac{\mu_0 I}{2r}$$

Direct Current

Current and Circuit Voltage – the flow of charge (also referred as electric current)

→ the magnitude of current (I) is given by:

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

Electromotive Force (emf)

$$V - IR_{\text{int}} = \varepsilon.$$

Resistance (R) – the opposition to the flow of an electric current that occurs within a conductor

$$V = IR$$

The Resistance found within the Conductor

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

Whereas, ρ = resistivity of the material, L = length, A = cross-sectional area

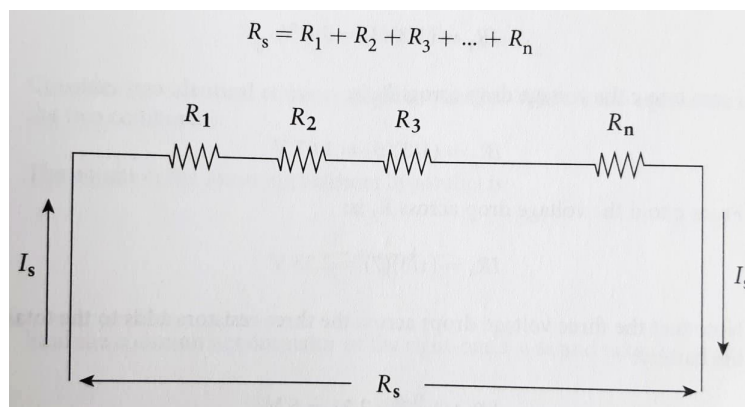
Power Dissipated by a Resistor – power is defined as the change in energy over time
→ the rate at which energy conversion occurs is equal to the power dissipated by the resistor and is given by:

$$P = IV$$

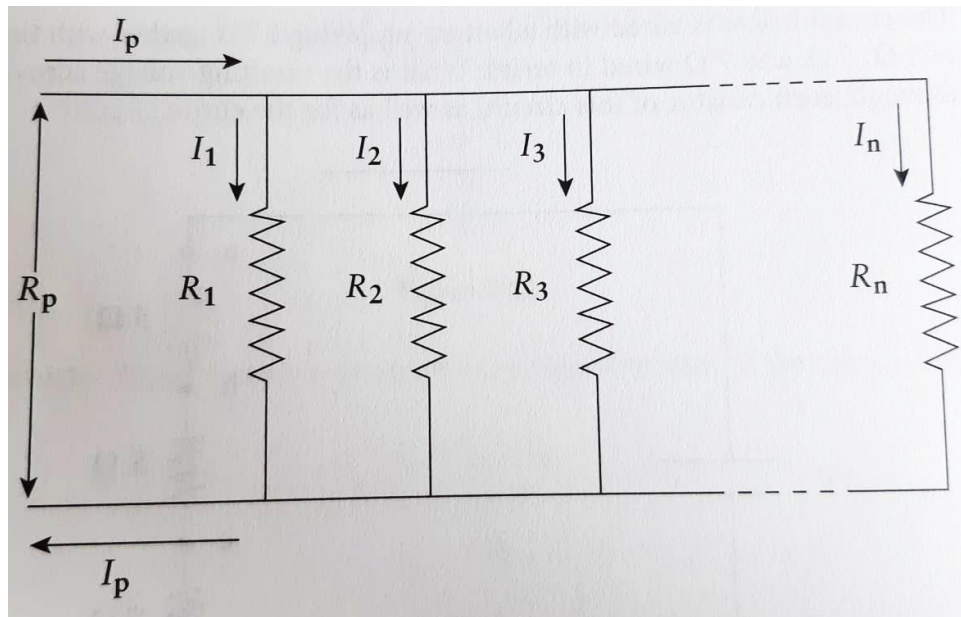
The current, I can be substituted and rewritten as:

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

Resistors in Series



Resistors in Parallel



$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

$$V_p = V_1 = V_2 = V_3 = \dots = V_n$$

Capacitors and Dielectrics

Capacitors – a 2 plate system that is capable of storing charge when there is a potential difference between the plates

→ the charge Q collects on the plates, with $+Q$ on the positive plate and $-Q$ on the negative plate

$$C = \frac{Q}{V}$$

The SI unit of capacitance is the **farad (1 C/V)**

The Capacitance of a capacitor also Depends on the Geometry of the 2 Conducting Surfaces

$$C = \epsilon_0 \frac{A}{d}$$

Whereas, ϵ_0 = permittivity of free space (8.85×10^{-12} F/m),
 A = area of overlap between the plates, d = distance between the 2 plates

The electric field between the plates of the parallel plate capacitor is given by:

$$E = \frac{V}{d}$$

Dielectrics – insulating material that increases the ability of a capacitor to store charge
 → examples include glass, plastic and certain metal oxides

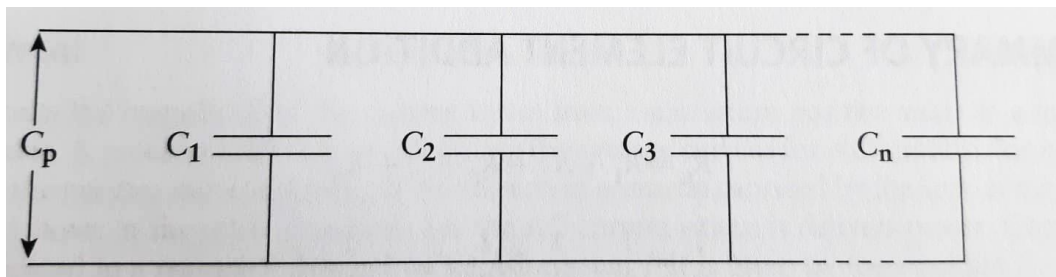
$$C' = kC$$

Whereas, C' = new capacitance with dielectric,
 C = initial capacitance, k = dielectric constant

Capacitors in Parallel

When Capacitors are added in parallel, they are combining to form a single larger capacitor with increased overlapping area

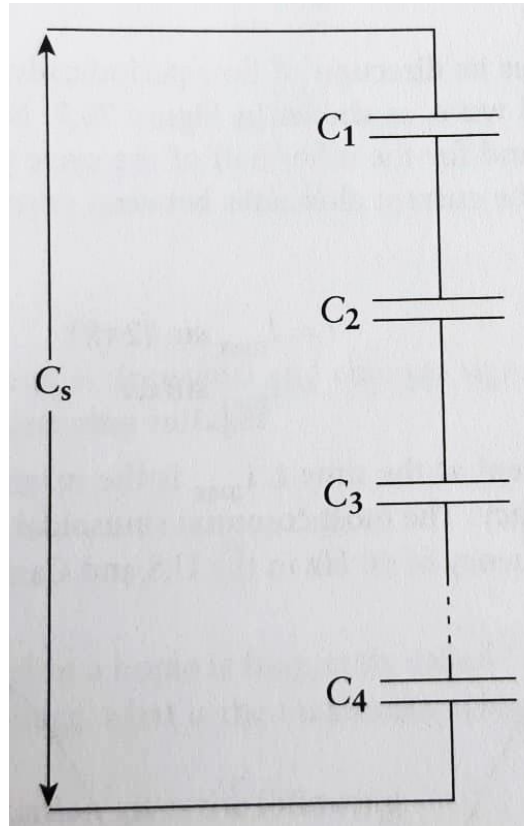
$$C_p = C_1 + C_2 + C_3 + \dots + C_n$$



Capacitors in Series

When wired in series, the addition of capacitors will only decrease the total capacitance of the circuit

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots + \frac{1}{C_n}$$



Alternating Current

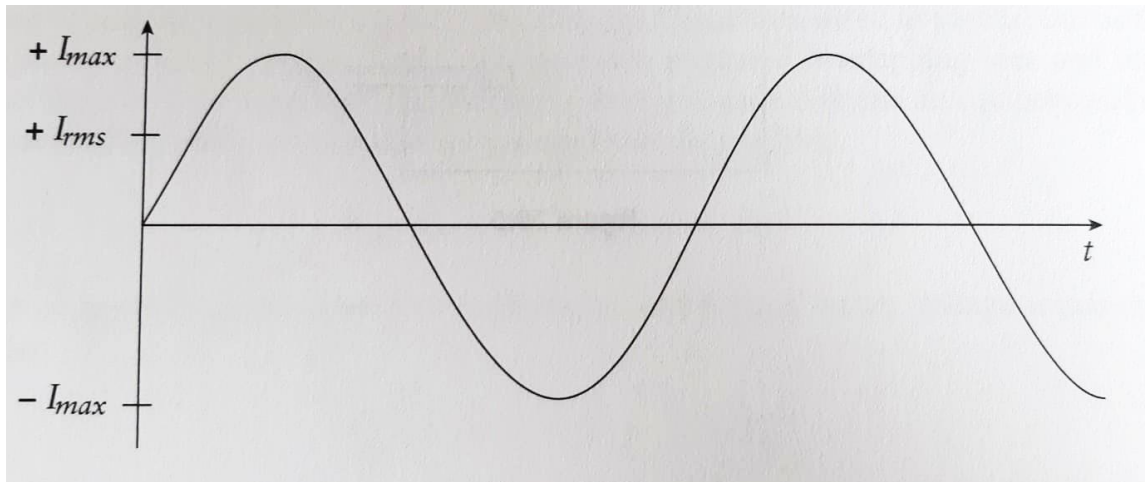
When the direction of flow changes periodically

→ the most common form of AC is when it oscillates in a sinusoidal wave

$$i = I_{\max} \sin (2\pi ft)$$

whereas, i = instantaneous current,

$I_{\max}$ = maximum current, f = frequency, t = time



Since current is never constant with AC, rms current must be calculated instead

$$I_{\text{rms}} = \frac{I_{\text{max}}}{\sqrt{2}}$$

RMS Voltage

$$V_{\text{rms}} = \frac{V_{\text{max}}}{\sqrt{2}}$$

Uniform Circular Motion – when a particle is moving around in a circular path

- the time to complete one revolution is the **period (T)**
- the number of cycles the particle completes is the **frequency (f)**
- the number of radians per second is **angular frequency** (multiply frequency by 2pi)

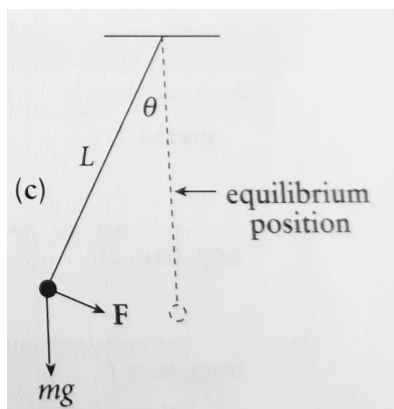
$$\omega = 2\pi f = 2\pi/T$$

Simple Harmonic Motion

$$\mathbf{F} = -k\mathbf{x}$$

$$\mathbf{a} = -\omega^2\mathbf{x}$$

Simple Harmonic Motion of a Pendulum



The position of a pendulum can be plotted against time on a graph where:

$$x = A \sin(\omega t)$$

whereas, x = particle displacement,

A = maximum amplitude of the particle, ω = angular frequency, t = time

These Scenarios can also be Considered Using the Concept of Energy

	Mass-spring	Simple pendulum
force constant k	spring constant k	mg/L
period T	$2\pi\sqrt{\frac{m}{k}}$	$2\pi\sqrt{\frac{L}{g}}$
ang. freq. ω	$\sqrt{\frac{k}{m}}$	$\sqrt{\frac{g}{L}}$
frequency f	$\frac{1}{T}$ or $\frac{\omega}{2\pi}$	$\frac{1}{T}$ or $\frac{\omega}{2\pi}$
kinetic energy K	$\frac{1}{2}mv^2$	$\frac{1}{2}mv^2$
$K_{\max}$ occurs at	$x = 0$	$\theta = 0$ (vertical position)
potential energy U	$\frac{1}{2}kx^2$	mgh
$U_{\max}$ occurs at	$x = \pm A$	max value of θ
max acceleration at	$x = \pm A$	max value of θ

Describing Waves – the displacement (y) of a particle at point (x) is given mathematically by:

$$y = A \sin (kx - \omega t)$$

A = amplitude (maximum displacement),
k = wave number, ω = angular frequency, t = time

Speed of the Wave

$$v = f\lambda$$

Where v = velocity of the wave, f = frequency, wavelength

Other Equations include:

$$k = \frac{2\pi}{\lambda}$$
$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$v = f\lambda = \frac{\omega}{k} = \frac{\lambda}{T}$$

$$\lambda = \frac{2L}{n} \quad (n=1,2,3,\dots)$$

$$f = \frac{nv}{2L} \quad (n=1,2,3,\dots)$$

For string that have pipes

$$\lambda = \frac{4L}{n} \quad (n = 1, 3, 5, \dots \text{odd integers only})$$

$$f = \frac{nv}{4L} \quad (n = 1, 3, 5, \dots \text{odd integers only})$$

Intensity – defined as the power transported per unit area by a sound wave
→ has SI units of W/m^2

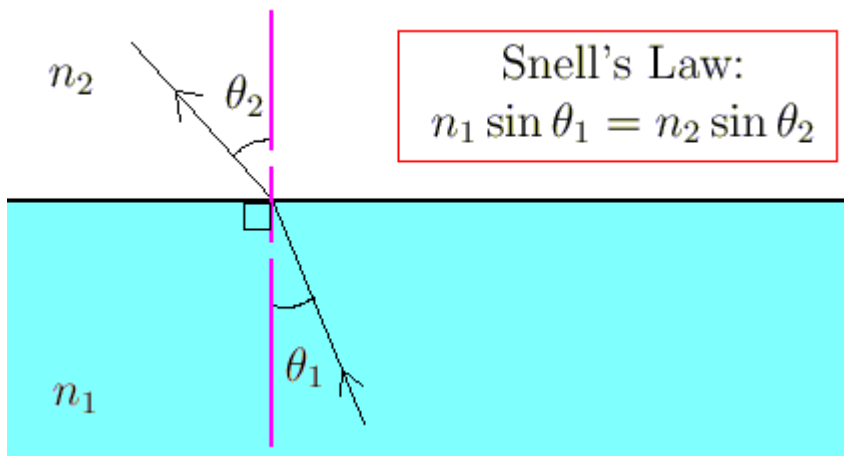
Power = IA
whereas, I = intensity of the wave, A = surface area

The intensity of sound is often expressed as a ratio known as the decibel

$$(dB) = 10 \log_{10} \left[\frac{I}{I_0} \right]$$

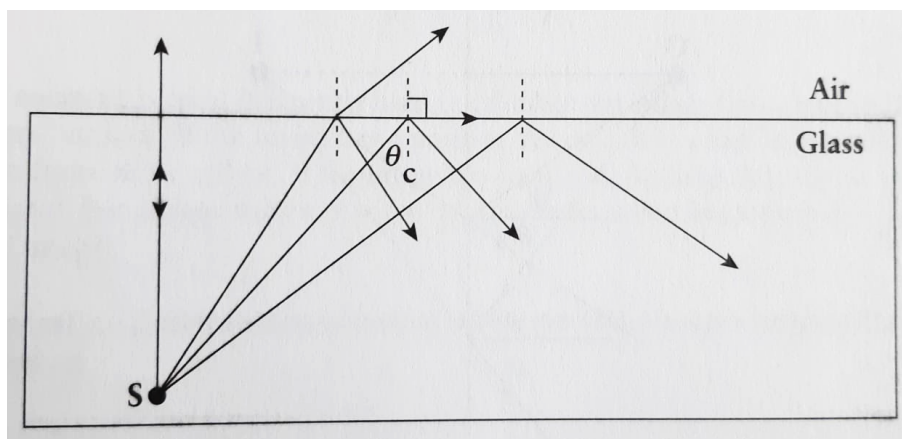
whereas, $I_0 = 10^{-12} \text{ W/m}^2$ (lowest reference intensity)

Snell's Law



Total Internal Reflection

$$\sin c = n_2/n_1$$

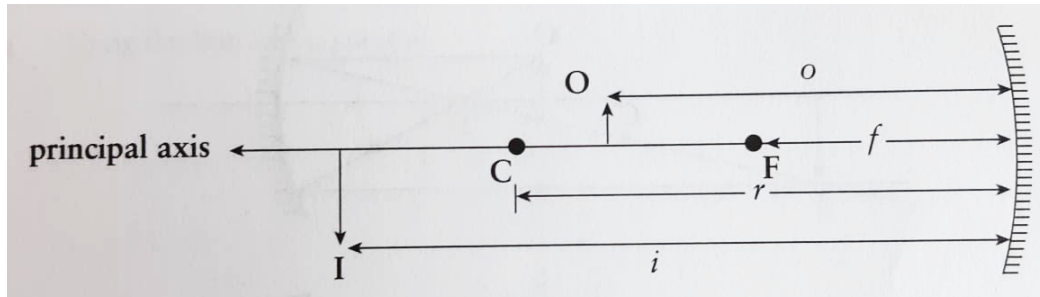


Concave Mirrors – converging mirrors where the focal point and center of curvature are in front of the mirror

→ defined as positive

Convex Mirrors – diverging mirrors where the focal point and the center of curvature are behind the mirror

→ defined as negative



Magnification (m) – the ratio of the image's height to the object's height

$$M = -i/o$$

Magnification of the System is Given by:

$$M = m_1 \times m_2 \times m_3 \times \dots$$

Blackbody – an ideal radiator and ideal absorber

→ however, for every black body, there is one wavelength at which a maximum amount of energy is emitted (peak wavelength)

$$\lambda_{\text{peak}} T = 2.90 \times 10^{-3} \text{ m} \cdot \text{K}$$

Stefan-Boltzmann Law – relates to the total energy being emitted (energy per unit area per unit time)

$$E_T = \sigma T^4$$

Photoelectric Effect

$$E = hf$$

whereas, h = Planck's constant ($6.63 \times 10^{-34} \text{ J*s}$)

Kinetic Energy of the Emitted Electron

$$K = hf - W$$

W = work function = hf_0

The Bohr Model of the Hydrogen Atom

Energy Levels – the energy required to remove a hydrogen atom from their orbit (n) can be calculated by the **principal quantum number**

$$E_n = \frac{-13.6}{n^2}$$

Principal quantum number	Energy level
n	E_n
1	$\frac{-13.6}{1} \text{ eV} = -13.6 \text{ eV}$
2	$\frac{-13.6}{4} \text{ eV} = -3.40 \text{ eV}$
3	$\frac{-13.6}{9} \text{ eV} = -1.51 \text{ eV}$
4	$\frac{-13.6}{16} \text{ eV} = -0.85 \text{ eV}$
∞	$\frac{-13.6}{\infty} \text{ eV} = 0 \text{ eV}$