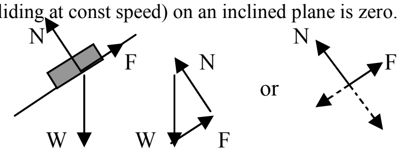
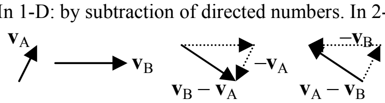
Physics unit 3 summary sheets

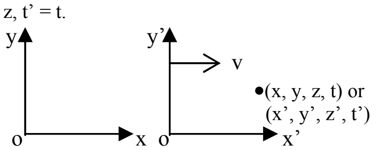
According to Newton, space (length), time and mass are **absolute**, i.e. they remain the same irrespective of the observers.
Newton's first law: Objects have **inertia**, i.e. a stationary object remains stationary, or a moving object keeps on moving at the same speed in the same direction, if there is no net force acting on it.
Newton's second law: Acceleration of an object is directly proportional to and in the same direction as the net force on it, and inversely proportional to its mass. $\mathbf{a} = \mathbf{F}_{net}/m$. **Newton's third law**: When object A exerts a force on object B, B exerts a force of the same magnitude in the opposite direction on A .
Net force is determined by vector addition. In one dimension: by addition of directed numbers. In two dimensions: by placing vectors head to tail or by resolving each vector into two perpendicular components. E.g. net force on an object at rest (or sliding at const speed) on an inclined plane is zero.



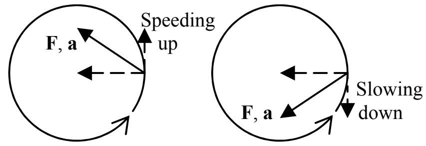
Inertial frame of reference: A frame of reference in which Newton's first law is valid. Frames of reference that are stationary or moving at constant velocity are inertial frames. Accelerating frames are **non-inertial**.
Relative motion: When object A moves at velocity $\mathbf{v}_A$ and object B moves at velocity $\mathbf{v}_B$ as determined by the same observer (usually but not necessarily taken as stationary), then velocity of B relative to A is $\mathbf{v}_B - \mathbf{v}_A$ and velocity of A relative to B is $\mathbf{v}_A - \mathbf{v}_B$.
In 1-D: by subtraction of directed numbers. In 2-D:



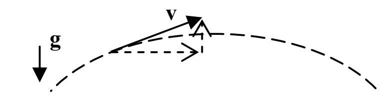
Galilean transformation converts coordinates (x, y, z, t) in one inertial frame to coordinates (x', y', z', t') in another inertial frame moving at velocity v (along the x-axis) relative to the former. x' = x – vt, y' = y, z' = z, t' = t.



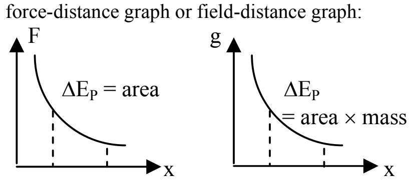
Uniform (constant speed v) **circular motion**:
$f = \frac{1}{T}$, $v = \frac{2\pi r}{T} or 2\pi rf$, direction of motion is given by velocity vector that is tangential to the circular path; magnitude of acceleration is $a = \frac{v^2}{r}$ or $a = \frac{4\pi^2 r}{T^2}$ or $a = 4\pi^2 rf^2$, and direction of acceleration is always towards the centre of circle, ∴**centripetal acceleration**. Both velocity and acceleration in uniform circular motion are not constant because their directions are changing continuously. They are always perpendicular to each other. A net force towards the centre of the circle (**centripetal force**) is required to keep an object in uniform circular motion, F = ma.
Non-uniform circular motion: Besides the centripetal force, a tangential force is also required to speed up or to slow down the object. Hence the net force and the acceleration are no longer towards the centre of the circular motion.



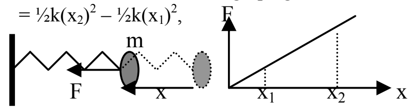
Projectile motion: Two-dimensional motion under a constant force (force of gravity or weight).



Horizontal component of velocity vector remains constant throughout motion. **Vertical component** of velocity vector is affected by gravity and has constant acceleration g downwards. Let V be the speed of projection at angle θ to the horizontal.
For hori.. comp: a = 0, v = u = Vcosθ, s =ut
For vert. comp: the five equations for rectilinear motions under constant acceleration are applicable, $v = u + at$, $s = \frac{1}{2}(u + v)t$, $s = ut + \frac{1}{2}at^2$, $s = vt - \frac{1}{2}at^2$, $v^2 = u^2 + 2as$, where u = Vsinθ is the initial velocity, v final vel, a = –g acceleration, s displacement from the initial position at time t. Up is chosen as +ve.
Impulse = **change in momentum**, **I** = Δ**p**,
FΔt = m**v** – m**u**. **Conservation of momentum**: In collisions between objects, total momentum before = total momentum during = total momentum after collision, $m_1\mathbf{u}_1 + m_2\mathbf{u}_2 = m_1\mathbf{v}_1 + m_2\mathbf{v}_2$.
When one object gains momentum, the other loses momentum by the same amount, the total remains constant. $\Delta\mathbf{p}_2 = -\Delta\mathbf{p}_1$, i.e. $\mathbf{I}_2 = -\mathbf{I}_1$.
Work is done by a system on another system during energy transfer in which the former exerts a force on the latter. W = Fs = ΔE.
Change in kinetic energy of an object results from work done by net force. $W = \Delta E_K$ i.e.
$F_{net}s = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$.
When an object moves in a gravitational field, e.g. in projectile motion, kinetic energy changes to **gravitational potential energy** and vice versa. The total energy remains constant during its flight.
$E_{K1} + E_{P1} = E_{K2} + E_{P2}$.
At earth's surface, $E_P = mgh$, $\Delta E_P = mgh_2 - mgh_1$. If an object moves a long distance away from (or towards) the earth, gravitational field cannot be considered constant, ΔE_P is given by area under force-distance graph or field-distance graph:

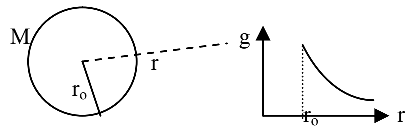


Hooke's law: F = kx. When an object interacts with a spring that obeys Hooke's law, kinetic energy is changed to **elastic potential energy** and vice versa. The total energy remains constant during the interaction. $E_{K1} + E_{P1} = E_{K2} + E_{P2}$ where $E_P = \frac{1}{2}kx^2$.
Area under force-distance graph gives ΔE_P
$= \frac{1}{2}k(x_2)^2 - \frac{1}{2}k(x_1)^2$,

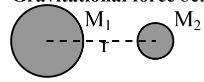


Elastic collision between objects: the total kinetic energy of objects before and after collision remains the same. During collision some kinetic energy is changed to elastic potential energy and all elastic potential energy is changed back to kinetic energy at the end of collision. For **inelastic collision**, total kinetic energy after collision is less than total before, because some kinetic energy is changed to other forms of energy as well, such as sound and heat.

Universal gravitational field: $g = GM/r^2$



Gravitational force between any two objects:

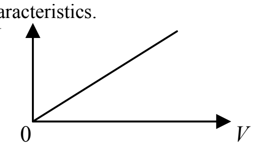


$F = GM_1M_2/r^2$

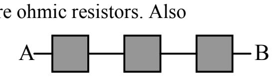
Planetary and satellite motions: Planets around the sun move in its gravitational field; ∴a = g , they are in free fall (also true for satellites around the earth),
i.e. $\frac{v^2}{r} = \frac{GM}{r^2}$ or $\frac{4\pi^2 r}{T^2} = \frac{GM}{r^2}$, hence
$v^2 r = GM$ (constant) or $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$ (const).
$\therefore v_a^2 r_a = v_b^2 r_b$ or $\frac{r_a^3}{T_a^2} = \frac{r_b^3}{T_b^2}$.

Electric current through a component is measured with an **ammeter** connected in series with it**.**
$I = \frac{Q}{t}$, $Q = It$. **Electric potential** V (v) at a point is the amount of electric potential energy E (J) possessed by each unit of charge at that point.
$V = \frac{E}{Q}$, $E = VQ$. **Electric potential difference**, also denoted as V and measured in v, is the difference in potential between two points. When current flows from high to low potential, electric potential energy of the charges changes to other forms of energy. Amount of energy change is also given by $E = VQ$ where V is the potential difference measured with a **voltmeter** connected to the two points.
$E = VQ = VIt$, $E = Pt$, **power** $P = VI$.
Resistance R of a conductor is a measure of the ability of the conductor to resist the flow of electric current and is defined as the ratio of V to I.
$R = \frac{V}{I}$.
Ohm's law states that for some conductors the resistance stays constant when potential difference and current vary. Conductors that obey Ohm's law are called **ohmic conductors** (**resistors**) and have the following I-V characteristics.

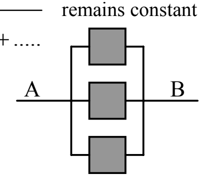
A straight line through the origin.



Components connected in series
$I = I_1 = I_2 = I_3 = ...$
$V_{AB} = V_1 + V_2 + V_3 + ...$
$R_T = R_1 + R_2 + R_3 + ...$ remains constant if components are ohmic resistors. Also
$R_T = \frac{V_{AB}}{I}$.



Components connected in parallel
$V_{AB} = V_1 = V_2 = V_3 = ...$
$I = I_A = I_1 + I_2 + I_3 + ... = I_B$
$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...}$ remains constant for ohmic resistors.
Also $R_T = \frac{V_{AB}}{I}$.



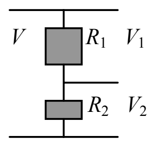
Power in series and parallel circuits: Total power consumption in parallel or series connection is the sum of the individual power of the components.

Voltage dividers A series connection of two or more resistors forms a voltage divider. The supply voltage to the series connection is divided into voltages in the same ratio as the resistances of the components.

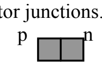
$\frac{V_1}{V_2} = \frac{R_1}{R_2}$,

$V_1 = \frac{R_1}{R_1 + R_2} \times V$,

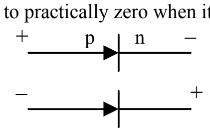
$V_2 = \frac{R_2}{R_1 + R_2} \times V$.



pn semiconductor junction A pn semiconductor junction is formed when a p-type and a n-type semiconductors are in contact. Many electronic devices are made of pn semiconductor junctions.



Non-ohmic conductors:
diodes, thermistors and photonic transducers such as LDR, photodiodes and LED.
A **diode** is an electronic device that can be used to control current and voltage. It is a pn junction. It conducts when it is forward biased and the current drops to practically zero when it is reverse biased.



Forward bias, $R \to 0$.
Reverse bias, $R \to \infty$.

A **thermistor** is a semiconductor device whose electrical resistance varies with temperature.
Transducers are devices that change other forms of energy into electrical energy (input transducers) and vice versa (output transducers), e.g. thermistor is an input transducer; loudspeaker is an output transducer. **Photonic transducers** changes light (which carries encoded information) into electrical energy and vice versa. The following devices are photonic transducers. A **light dependent resistor** (LDR) is a semiconductor device whose resistance changes with the intensity of light it is exposed to.
A **photodiode** is a diode whose conduction changes with illuminating light intensity when it is reverse biased and is said to be in *photoconductive mode*. When light intensity increases (i.e. number of photons hitting the pn junction increases), number of electrons freed from the valence bonds increases and thus reverse biased current (called **photocurrent**) through the pn junction increases.
A **light emitting diode** (LED) emits light when forward biased. When forward biased, electrons move from n region to fill holes in p region. When an electron fills a hole, a photon is emitted. When forward biased current increases, number of holes filled by electrons increases, thus number of photons emitted increases and light intensity increases.

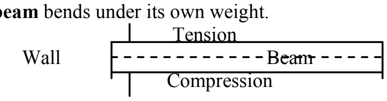
Using npn transistors as voltage amplifier:
To make full use of the linear operation of a npn transistor the input signal must be 'centred' at the mid-point of the linear section by biasing the base-emitter voltage. The output signal will then be centred at the mid-point of the full output range ($0 – V_{cc}$ approx). V_{cc} is the supply voltage to the transistor. Manufacturer usually specifies the ratio of dc collector current to dc base current,
i.e. $G_I = \frac{I_c}{I_b}$, **current gain**. Amplification factor of the device, i.e. **voltage gain**, defined as the ratio
$G_v = \frac{\Delta v_o}{\Delta v_i}$, is the gradient of the linear graph.
Amplifier is **saturated** when it is in its maximum conducting condition. At **cut-off** current is essentially zero. Linear amplification is achieved when time-varying input signal voltages are between cut-off and **saturation**. Because output signal is restricted by cut-off and saturation voltages, input signal must be correctly centred and have its peak-to-peak voltage within certain range, or **clipping** will occur and give rise to a distorted output signal.

Coupling capacitors: Signals coming from input transducers usually contain both dc and ac components. When these signals are fed into a biased npn transistor amplifier they upset the biasing of the transistor and cause it to operate away from the mid-point of the linear section. A capacitor (coupling) is used to filter out dc component from signal and allow only ac component to pass through.
Output signal of amplifier also contains both dc and ac components. Dc component is removed with a second coupling capacitor before signal is fed to output transducer or a second biased transistor amplifier for further amplification.
Transmission of information using cables:
Analogue electrical signals in metal conductor can be changed to **intensity modulated light** signals (to be sent through an optical fibre) by means of an electrical-optical converter, e.g. a **laser diode**. A laser diode works like a LED with a much faster response. At the other end of the optical fibre, intensity modulated light signals are changed back to electrical signals by an optical-electrical converter, e.g. a photodiode.

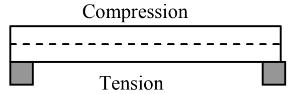
If structure is irregular, determine the **centre of mass** by referring to an x-y frame of reference with 0 chosen at a point that simplifies the calculations.

$$x_{CofM} = \frac{m_A x_A + m_B x_B + m_C x_C}{m_A + m_B + m_C}.$$

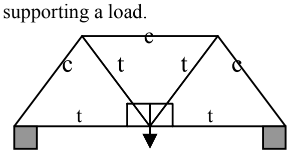
Structure is in **compression** (*tension*) when **pushed** (*pulled*) at the two ends. Compression and tension can co-exist within a structure, e.g. a **cantilevered beam** bends under its own weight.



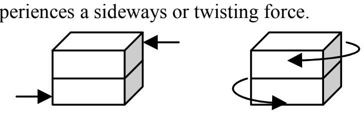
A beam supported at its two ends, i.e. a **simply supported beam**, bends under its own weight.



A **truss**, a network of beams joined together in rigid triangles, supporting a load.

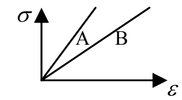


Shear refers to the sliding of a layer over another layer in a structure. It may occur when a structure experiences a sideways or twisting force.



Tension in a beam of non uniform cross-section is the same along the entire length, which is equal to the pulling force *F*, but **stress** σ which is defined as
$\sigma = \frac{F}{A}$, where *A* is the cross-sectional area, is different at different positions. Since $\sigma \propto \frac{1}{A}$, therefore stress is higher at the narrower section where fracture is most likely to occur. When a material is loaded (either in tension or compression) its length changes. The fractional or percentage change in length is called **strain**. It is defined as
$\varepsilon = \frac{\Delta l}{l}$, where l is the length of the material and Δl is the change in length.
Linear relationship exists between stress and strain for all materials under 'small' tensile or compressive stress, i.e. $\sigma = Y\varepsilon$, *Y* is a constant called **Young's modulus**. It is a measure of **stiffness** of the material and its unit is Nm^{-2} (or Pa).
Different materials have different *Y* values. The gradient of σ-ε graph is the value of *Y*.

A is stiffer than B shown by the gradients of the lines.



In Hooke's Law $F = kx$, $k = \frac{YA}{l}$.

Elastic material has the same σ-ε graph when stress is applied (**loading**) or removed (**unloading**). The material deforms and returns to its original shape. This is true only when applied stress is below certain limiting stress called **elastic limit** of the material. When stress is below the elastic limit, material shows **elastic behaviour**, i.e. it returns to its original shape. Above the elastic limit, material changes its shape permanently, **plastic behaviour**. Permanent change in shape is called **plastic deformation**. When loading continues, eventually it reaches the point of breaking. The maximum stress a material can withstand before breaking is called the **tensile** (or **compressive**) **strength** of the material.
Strain energy is the amount of potential energy stored in the loaded material. It is estimated from area under t force-extension (compression) graph. Alternatively, strain energy (J) =
volume of material (m^3) × area under σ-ε graph.
Some materials fracture at the linear section or just past the elastic limit, e.g. glass, ceramics. They are classified as **brittle**. If a material fractures after it is well past the elastic limit and has undergone plastic deformation, it is called **ductile** material, e.g. aluminium, steel.
Tough material is ductile and absorbs large amount of strain energy before it fractures, e.g. polyethylene. Total area under the stress-strain graph gives good indication of toughness when comparing materials.
Composite materials are made from two or more component materials that can be separated mechanically, e.g. clay with added straw.
Concrete is weak under tension (but strong in compression) because of the existence of small cracks. These cracks propagate easily when the material is stretched. Concrete can be strengthened by placing steel rods or mesh in it when it is poured. It is called **reinforced concrete** and is considered as a composite material. Another way to strengthen concrete is to keep it in compression all the time so that cracks cannot propagate. This is done by keeping the steel rods in tension while the concrete is poured, and allowed to dry before the tension is released. The contraction of the rods after releasing the tension compresses the concrete. The rods have a very rugged surface texture to prevent slipping after the tension is released. This strengthened concrete is called **pre-stressed concrete**. Concrete can also be strengthened by compression after it is set. This requires the steel rods to be smooth to slip through the dry concrete when stretched and anchored at the ends of the concrete. This strengthened concrete is called **post-stressed concrete**.
To ensure safety a structure is built to withstand a load that is many times what it actually carries. The number of times is called the **factor of safety**. In general industrial practice it is between 3 and 10. It is defined as:
Factor of safety (for brittle materials) = $\frac{tensile(compressive)strength}{average.stress}$, factor of safety (for ductile materials) = $\frac{elastic.\lim it}{average.stress}$.
Structure in a state of balance is said to be in **equilibrium** and the line of force of gravity passes through the base of structure. If structure is also at rest, it is in **static equilibrium**.
Torque $\tau = r \times F$ has turning effect on a structure. It is defined as product of force F on structure and perpendicular distance r of the line of force of F from a chosen convenient point. The two conditions for a structure to remain in static equilibrium are:
$\mathbf{F_{net} = 0}$, $\mathbf{\tau_{net} = 0}$. In 2-D situations, first equation is split into x and y components: $\mathbf{F_{x,net} = 0}$, $\mathbf{F_{y,net} = 0}$.