Linear Mechanics

Motion along straight line:

quantity types

Scalar quantity: magnitude only
- distance: length of path followed by object
- speed: $\frac{d\,\text{distance}}{dt}$

vector quantity: magnitude and direction
- displacement: distance moved in certain direction
- velocity: $\frac{d\,\text{displacement}}{dt}$
- acceleration: $\frac{d\,\text{velocity}}{dt}$

graphical analysis

$$\frac{d}{dt}\text{displacement}(k) = \text{velocity}(k)$$
$$\frac{d}{dt}\text{velocity}(k) = \text{acceleration}(k)$$
$$\int_0^k \text{acceleration}(x)\,dx = \text{velocity}(k)$$
$$\int_0^k \text{velocity}(x)\,dx = \text{displacement}(k)$$

Equations of Motions		
	$a=\frac{v-u}{t}$	s – displacement [m]
	$v^2=u^2+2as$	u – initial velocity [m/s]
	$s=ut+\frac{1}{2}at^2$	v – final velocity [m/s]
	$s=\frac{1}{2}(u+v)\times t$	a – acceleration [m/s^2]
		t – time [s]

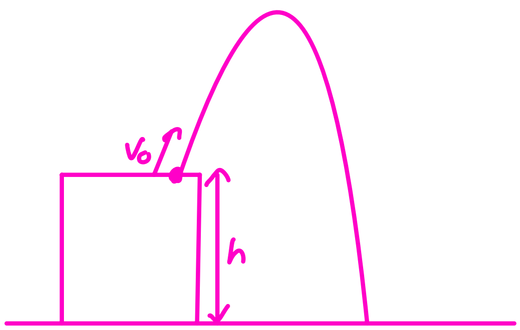
equations of motion

$$a = \frac{v-u}{t}$$
$$v^2 = u^2 + 2as$$
$$s = ut + \frac{1}{2}at^2$$
$$s = \frac{1}{2}t(u+v)$$

s = displacement
u = initial velocity
v = final velocity
a = acceleration = constant
t = time

free fall (no air resistance)
- ejected vertically upwards
- only experience weight
- upward velocity slows
- reach highest point
- acceleration when falling back down

$$\frac{d}{dt}f(t) = g \longrightarrow f(t) = \frac{1}{2}gt^2 + v_0t + h$$



free fall (air resistance)

- object experience viscous drag (air resistance)
- opposite to velocity

air resistance (non turbulent) $= \underbrace{\tfrac{1}{2}}\ \underbrace{\rho}_{\text{density}} v^2 \underbrace{C_d}_{\text{drag coeff (given)}} \underbrace{A}_{\text{(cross section) area}}$

- proportional to velocity ^{2}
- object experience weight (downwards acceleration) and air resistance (upward acceleration)
- air resistance increase until same as weight
- object has zero net acceleration
- terminal velocity reached

Projectile motion:

projectile motion (no air resistance)

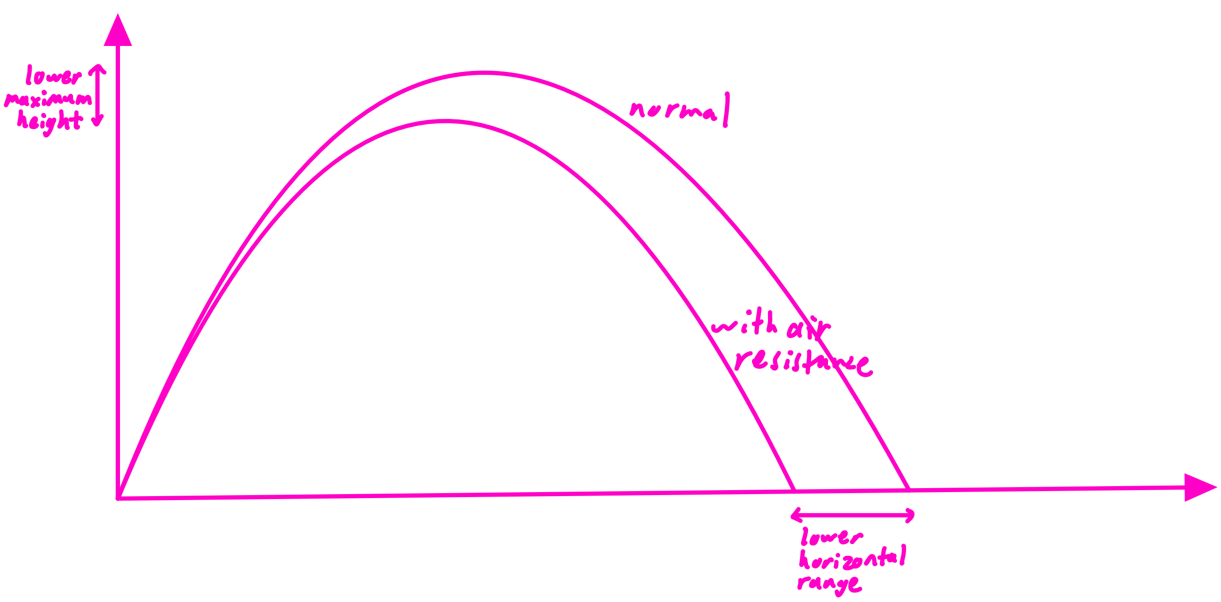
- projectile launched on surface of Earth follows curved path in vertical plane
- resolve needed vectors into horizontal/vertical components
- apply equations and laws in each direction

horizontal acceleration $= 0$
vertical acceleration $= -g$

- path always parabola
- symmetrical about highest point
- direction of velocity = tangent of trajectory

projectile motion (air resistance)

- trajectory no longer symmetrical
- lower maximum height
- lower horizontal range



air resistance has both horizontal and vertical components (use equation in both directions)

Laws of motion:

forces

dynamics: study of motion
- forces cause change in motion
- force is a push or a pull
- measured in Newtons ($N = kgms^{-2}$)

mass
- measure of a body's resistance to velocity change
- amount of matter in object

weight
- force acting on mass due to gravity

$W = mg$

g = gravitational field strength (9.81 on Earth)

Newton's First Law

A body forever moves at constant (possibly zero) speed in a straight line unless a force acts on it.
- no net force acting on object ⇒ keep moving

Equilibrium
- 2 or more forces act on object
- vector sum is zero, no net force
- no net force for both motion and rotation

Newton's Third Law

If object A exert a force on object B, then object B exert a force of the same type and magnitude but of opposite direction on A.
- forces must be same type
- forces must act on different objects
- do not cancel out

Free body diagrams
- representation of all forces acting on object

1. draw sketch of diagram (if not given)
2. isolate body of interest
3. draw all forces acting on body of interest, not forces exerted by body of interest
4. label all forces properly
   - in words unless defined (or define yourself first)
   - magnitude and direction represented by length and direction of arrows
   - note from where each force originate
   - check again all forces act on body of interest

weight: downwards from centre

normal: perpendicular to surface

friction: opposite of net force sum (but less magnitude)

Momentum:

linear momentum

momentum = mass · velocity

$\underset{\text{momentum}}{p} = mv$

- vector quantity
- measured in Ns ($kg\,m\,s^{-1}$)

total momentum $= \sum_{i=1}^{n}$ individual momentum

Newton's Second Law

Rate of change of momentum, proportional to acceleration, is also proportional to the force acting on the body, taking place in the direction of the force

$\underset{\text{force}}{F} = \underset{\text{mass}}{m}\,\underset{\text{acceleration}}{a}$

- momentum measures resistance of object to being made to stop
- object with greater momentum cause more impact when stopped
- more force needed if force applied over shorter time

Impulse

impulse $= \int_0^x$ force dt

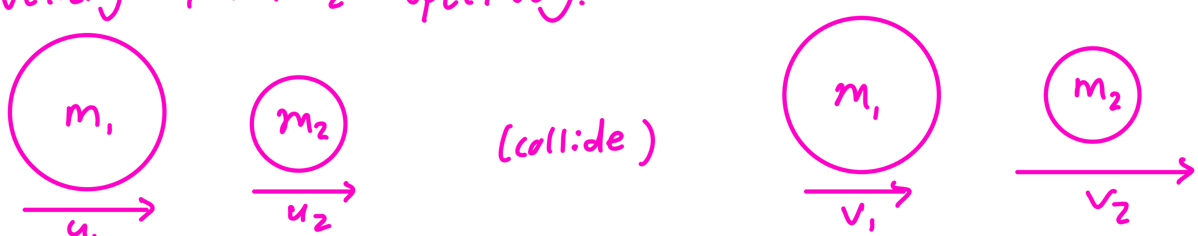
- change in momentum
- total force experienced, not instantaneous

Collisions:

- large force act on particle for short time
- abrupt change in motion of at least 1 particle
- clear distinction before or after collision
- conserve momentum and energy

conservation laws (elastic collision)

Moving object A with mass m_1 and velocity u_1 collide with object B with mass m_2 and velocity u_2 moving in the same direction, after which they move off with velocity v_1 and v_2 respectively.



conservation of momentum: $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

conservation of relative speed: $u_1 - u_2 = v_2 - v_1$

elastic collision

- total momentum conserved
- total kinetic energy conserved
- kinetic energy transferred between objects

inelastic collision

- total momentum conserved
- total kinetic energy not conserved
- kinetic energy converted to sound and internal energy (elastic potential energy)
- objects deformed after collision

completely inelastic collision

- total momentum conserved
- total kinetic energy not conserved
- kinetic energy converted to sound and internal energy (elastic potential energy)
- particles stick together after collision
- same final velocity

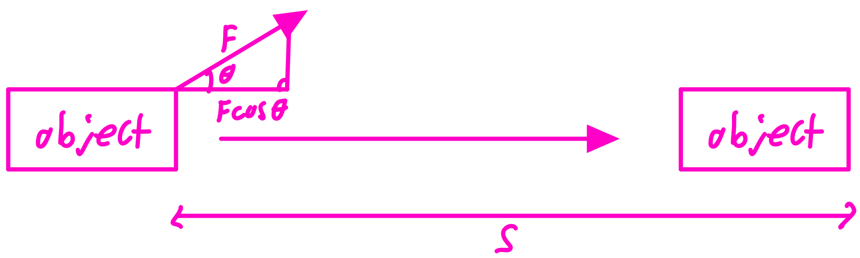
solving collision problems

1. draw sketch of particles before and after collision
2. select direction to be positive
3. indicate velocity (possibly negative) and mass of objects
4. solve for unknowns using conservation laws

work, energy, power:

work

- product of force and displacement in direction of force
- object move through certain displacement (possibly negative) while force is applied
- consider only component of force along direction of displacement



$$W = Fs\cos\theta$$

- measured in Joules (J)

$J = Nm = kg\,m^2 s^{-2}$

chemical potential energy

- potential energy in structual arrangement of atoms or molecules
- fuels such as coal, oil, wood
- food
- batterys, electric cells
- explosives

nuclear energy

- energy released from atomic nucleus
- radioactive decay

- nuclear reactions (fusion, fission)
- nuclear weapons
- nuclear reactors

radiant energy (light and heat energy)
- energy of electromagnetic waves
- radio waves
- microwaves, infrared (heat energy)
- visible light (light energy)
- ionising radiation (ultraviolet, x rays, γ rays)

electrical energy
- energy provided by electricity
- electrical current
- power stations

kinetic energy
- energy in moving objects
- work done change speed of object

kinetic energy $= E_k = \frac{1}{2}mv^2$

work done $= W = \Delta E_k = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$

potential energy
- energy stored in object
- released by changing position or shape

gravitational potential energy
- energy of object due to mass in gravitational field
- only relative gravitational potential energy matter, not absolute
- zero gravitational potential energy can be set at any height

gravitational potential energy $= E_p = mgh$

elastic potential energy
- energy stored in elastic object during deformation (x)
- extension is difference between deformed and original length (k)
- spring constant given

elastic potential energy $= E_p = \frac{1}{2}kx^2$

conservation of energy
- energy cannot be created or destroyed (except $E=mc^2$)
- energy can be converted to other forms of energy (not matter)
- total energy of isolated system (without $E=mc^2$) remain constant

efficiency
- not all input energy converted to output energy (except antimatter heater)
- other forms of energy produced not used by machine is wasted
- friction, air resistance waste energy by conversion to heat and sound

$$\text{effeciency} = \frac{\text{useful energy output}}{\text{energy input}} = \frac{\text{work done}}{\text{energy input}}$$

power

- rate of work done
- rate of energy transfer

$$\text{power} = \frac{\text{work done}}{\text{time}} = \frac{\text{energy converted}}{\text{time}}$$

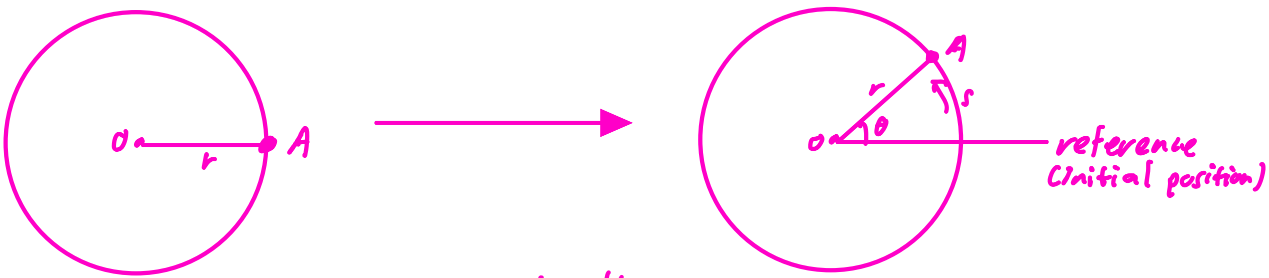
instanteous power = force · velocity

Circular Mechanics

Circular motion:

angular displacement

- angle object move through in time interval



angular displacement $= \frac{\text{arc length}}{\text{radius}}$

- measured in radians (rad)

angular velocity

- rate of change of angular displacement

angular velocity $= \omega = \frac{\theta}{t} = \frac{d}{dt}\theta$

- vector quantity
- direction is clockwise/anti-clockwise

period

- time taken to complete 1 revolution (T)

frequency

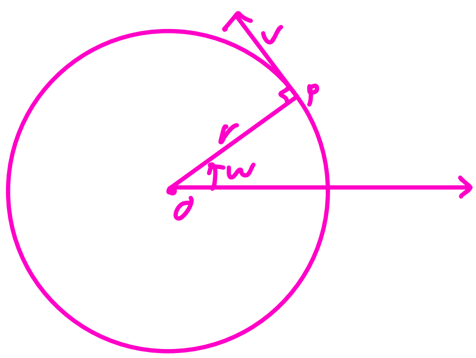
- number of complete revolutions per unit time

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

- measured in Hertz (Hz)

$Hz = s^{-1}$

$\omega = 2\pi f$



tangential velocity (linear speed)

- direction tangential to circle

tangential velocity $= v = r\omega = \frac{2\pi r}{T}$

centripetal acceleration and force

- object at constant speed
- direction changing
- velocity changing
- results in acceleration

Centripetal acceleration $= a = r\omega^2 = \frac{v^2}{r}$

Centripetal force $= F = ma = mv\omega = mr\omega^2 = \frac{mv^2}{r}$

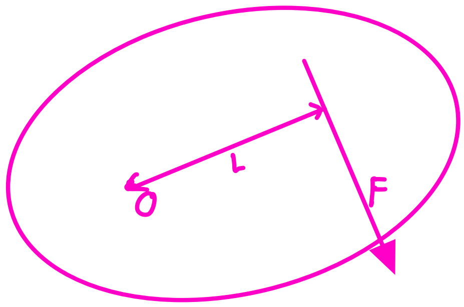
- act at right angles to motion
- change direction not speed of velocity
- centripetal force does no work as it is perpendicular to motion
- centripetal force is not a new force, can be tension in a string or gravitational attraction
- when centripetal force is removed, object follows a tangential path

torque (moment)

- turning effect of force
- product of force and distance to line of action
- vector quantity
- direction is clockwise / anti-clockwise

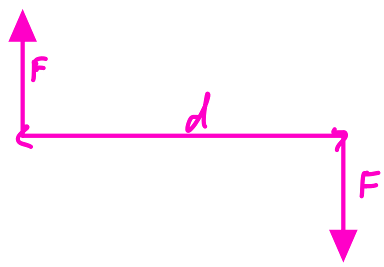
torque $= \tau = FL$

- measured in $Nm = kg\,m^2 s^{-2}$



couple

- pair of equal but opposite parallel forces without lines of action coinciding
- net force is zero, translational equilibrium
- torque is product of distance between forces and one of their magnitude
- producing turning effect on object
- not in rotational equilibrium
- overall not in equilibrium



total (clockwise) torque $= Fd$

equilibrium

- net force is zero
- in translational equilibrium
- net torque at all points is zero
- in rotational equilibrium
- no part of object is moving

Fluid Mechanics

pressure

- force has different effect over different area
- pressure is normal force acting per unit area

$$\text{pressure} = p = \frac{F}{A}$$

- measured in $Pa = Nm^{-2} = kg\,m^{-1}s^{-2}$

pressure in fluids

- fluids have weight
- more fluid above deeper column
- higher force exerted as weight
- higher pressure

$$\text{pressure in liquid} = \underbrace{\rho}_{\text{density}} g \underbrace{h}_{\text{depth}}$$

- equal pressure in all directions
- fluid have same horizontal height in any container for pressure balance

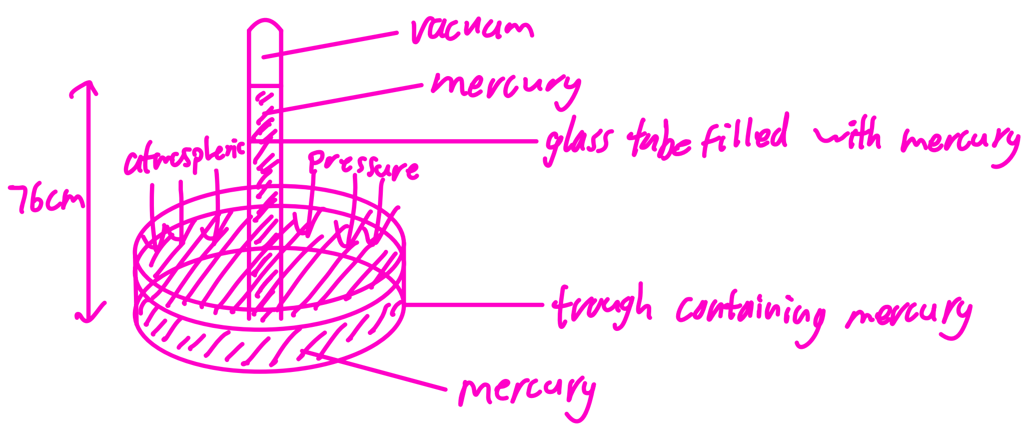
atmospheric pressure

- atmosphere is thick layer of air surrounding the Earth
- exerts atmospheric pressure
- at standard atmospheric pressure (1.01325×10^5 Pa) at sea level
- equal to 10.3m of water or 76cm of mercury

mercury barometer

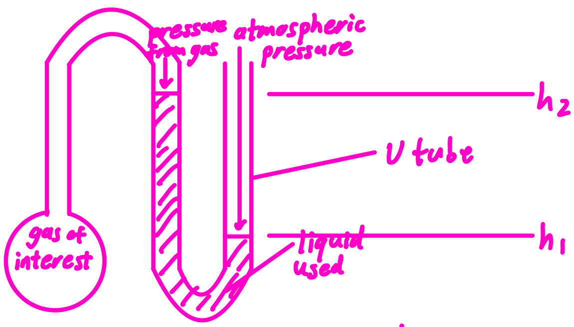
- use height of mercury to measure atmospheric pressure
- clean, dry, thick-walled glass tube 1m long
- sealed at one end and filled with mercury
- turned upside down on trough of mercury
- mercury level drop to 76cm
- atmospheric pressure acting on surface of mercury in trough hold up mercury column
- atmospheric pressure measured in mm Hg
- space above mercury column is vacuum

$$760\,\text{mm Hg} = 10^5\,\text{Pa}$$



manometer

- U tube filled with liquid
- measure difference between atmospheric pressure and pressure in gas of interest
- one arm connected to gas supply
- pressure in gas of interest act on fluid in that arm
- other arm exposed to atmospheric pressure
- atmospheric pressure act on liquid surface in the other arm
- higher surface has lower pressure

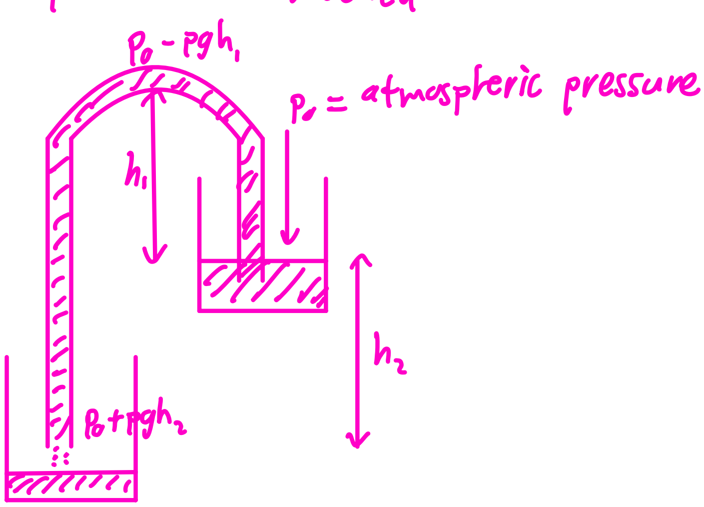


pressure of gas
$= \text{atmospheric pressure} + \rho g (h_1 - h_2)$

- oil usually used as liquid
- water evaporates
- mercury is poisonous
- oil more sensitive (less dense)
- oil need longer tube

siphon

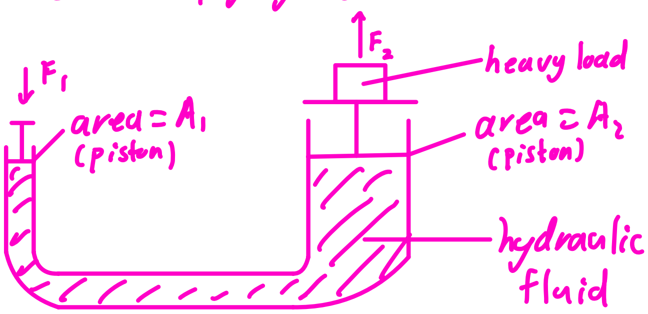
- upside down U tube
- provide drainage from upper level to lower level for fluids
- use pressure difference between 2 ends at the start
- filled with fluid and ends sealed
- placed into tanks and seal opened
- at lower end, pressure inside tube $\approx P_0 + \rho g h_2$
- pressure in lower tank $\approx P_0$
- fluid flow into lower tank
- vacuum created inside tube
- fluid in upper tank forced into tube by atmospheric pressure
- pressure as labelled



Hydraulic systems

Pascal's law: pressured to an enclosed fluid is transmitted to all parts of the fluid and walls of the container.

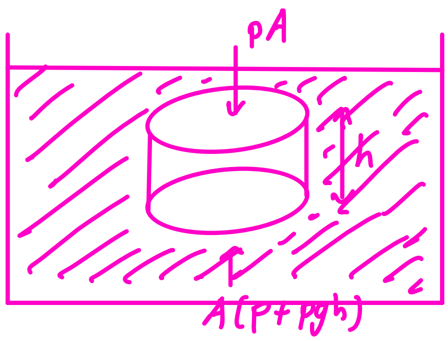
- force exerted on piston
- pressure produced in fluid
- transmitted to large piston
- large piston pushed up by same force
- large piston is pushed up by less distance
- force multiplying device



$$F_2 = pA_2 = \frac{A_2}{A_1}F_1$$

upthrust

- vertical upward force exerted on object by fluid when object is submerged
- difference in forces from pressure on upper and lower parts of object



- pressure from above = pA
- pressure from below = $A(p+\rho gh)$

upthrust = net upward force = $\rho ghA = \rho \overset{\text{volume}}{V} g$ = weight of displaced fluid

- upthrust = weight of displaced fluid
- floating objects displace their own weight of fluid

Fluid and flow

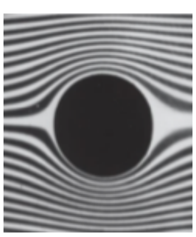
Fluid: substance with no fixed shape

ideal fluid: incompressible fluid

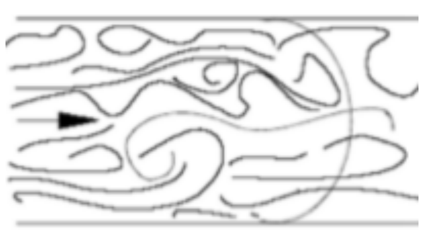
flow line: path of particle in flowing fluid

laminar flow: layers of fluid slide smoothly past each other, do not cross and mix

turbulent flow: viscousity destroy layer, irregular and chaotic flow



laminar flow



turbulent flow

equation of continuity

- fluids flow faster in narrow tubes
- flow speed inversely proportional to cross section of tube

volume flow rate $= Av$

mass flow rate $= \rho A v$

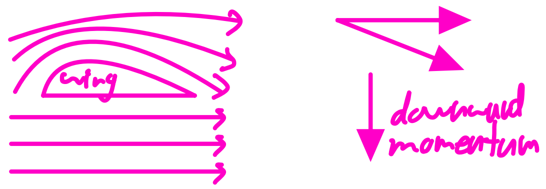
Bernoulli's Principle

- pressure low when flow speed is high

pressure $= P = \text{constant} - \frac{1}{2}\rho v^2 - \rho g h$ (ρ = density)

lift force (aircrafts)

- top surface has larger surface area than bottom surface
- air above wing flow faster than air below wing
- pressure below wing higher
- net upward force on plane
- wing give air net downward momentum
- reaction force provide lift

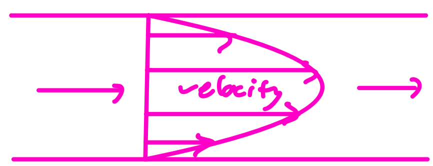


Spinning ball

- ball has initial spin
- air near surface of ball pulled due to viscousity
- air move faster in direction of spin
- lower pressure in direction of spin
- net force towards direction of spin
- ball move toward direction of spin

drag force

- fluid have internal friction (viscousity)
- between layers of fluid and tube walls
- fluid tend to stick to surroundings
- fluid at edge of pipe almost at rest
- fastest flow along axis of pipe
- viscousity constant η (given)



sphere in laminar fluid flow:

drag force $= F = 6\pi r \eta v$

object moving through turbulent fluid (air resistance):

drag force $= F = \frac{1}{2}\underset{\text{density}}{\rho}\,\underset{\text{drag coefficient}}{C_d}\,\underset{\text{cross section area}}{A}\,\underset{\text{velocity}}{v^2}$

Oscillation

Oscillation:

- back and forth movement
- repeat at definite intervals

examples of oscillation

- sounds transmitted by oscillating air moleculer
- light (in waves) is also oscillation
- atoms and molecules constantly oscillate due to heat
- oscillation of quartz crystals in watches keep time
- can occur in machines and buildings, causing collapse

motion during oscillation

- resting at origin without oscillation
- displacement with respect to origin
- body pulled to one extremum
- start oscillation
- force required to hold object at extremum
- body accelerates upon release
- move towards origin due to restoring force
- body reaches origin
- no more restoring force
- body has momentum
- body move past origin
- restoring force in opposite direction
- body slow down and stop
- reach other extremum
- restoring force move body towards origin
- cycle repeats indefinitely without friction

important terms

equilibrium point: point where no net force act on body, origin
displacement: distance from origin in certain direction
amplitude: maximum displacement from origin
period: time required for 1 complete oscillation (T)
frequency: number of complete oscillations per unit time (f)
angular frequency: $2\pi \cdot$ frequency (ω)
phase difference: angle in terms of π added to align start time in equations (ϕ)

Simple harmonic motion:

trajectory

- acceleration always towards origin
- acceleration proportional to displacement from origin
- acceleration in opposite direction to displacement
- special kind of oscillation

$$a = -\underbrace{\omega}_{\text{angular frequency}}{}^2 \underbrace{x}_{\text{displacement}}$$

- for numerical calculations, ignore negative sign
- displacement vary in sine wave

$$x = \underbrace{x_0}_{\text{amplitude}} \sin(\omega t + \phi)$$

- timing start at origin

$$\left.\begin{aligned} \text{velocity} &= v = x_0 \omega \cos(\omega t + \phi) \\ \text{acceleration} &= a = -x_0 \omega^2 \sin(\omega t + \phi) \end{aligned}\right\} \text{differentiation}$$

projection

- projection of uniform circular motion sideways result in simple harmonic motion
- consider sine value of angle

energy conversion

- sum of kinetic and gravitational potential energy constant
- conservation of energy
- continuous interchange of kinetic and gravitational potential energy
- at extremum (highest point), only gravitational potential energy
- at origin, only kinetic energy (fastest speed)
- exchange and conversion of energy in between

kinetic energy $= \frac{1}{2} m \omega^2 (x_0^2 - x^2)$

gravitational potential energy $= \frac{1}{2} m \omega^2 x^2$

period $= T = 2\pi \sqrt{\frac{L}{g}}$ (pendulum) $= 2\pi \sqrt{\frac{m}{k}}$ (spring)

damping:

- decrease of amplitude
- eventual rest position at origin
- caused by friction and air resistance
- energy converted to heat and dissipated

light damping

- weak resistive force
- gradually decreasing amplitude in oscillation
- pendulum swinging in air

critical damping

- object returns to origin in shortest possible time
- no oscillation occur
- pointer of scientific instruments for fastest available reading
- car suspension system for less bumpy journey

heavy damping

- very large resistive force
- object return to origin
- no oscillations
- slower than critical damping
- auto-closing door

forced oscillation:

- periodic force supply energy to system
- energy lost as heat due to friction

- maximum energy input (largest amplitude) when forcing frequency = natural frequency
- resonance caused, maximum energy transfer
- amplitude diverge without damping
- energy continously added into system without dissipative forces
- energy lost through damping
- finite maximum amplitude of resonance
- greater damping, less maximum amplitude, less distinct peak in amplitude

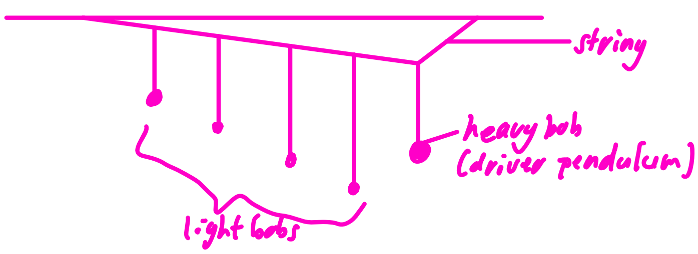
examples of resonance

shattering of glass
- sound wave of natural frequency disturb glass
- resonance occurs
- enough energy transferred to glass to break it

tuning a guitar
- piece of paper folded into v shape balanced on string
- correct note sounded
- sound waves pass over guitar string
- frequency match
- string resonate and vibrate
- paper fall off

Barton's pendulum

natural frequency of pendulum = $f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$
- driver pendulum has length matching another pendulum
- large amplitude oscillation for affected pendulum



sound production
- column of air in musical instrument
- air blown across opening in a tube
- air vibrate and resonate
- resonance of air column produce loud sound
- air made to resonate in vocal cords when speaking
- cause loud sound

microwave oven
- water molecules in food vibrate due to microwave
- microwave match natural frequency of water
- resonance occurs
- water molecules vibrate
- heat produced heat up food

radio receiver
- radio waves incident on receiving aerial
- electrons in aerial oscillate
- aerial correct length for frequency of incoming radio waves
- resonance occur
- maximise amplitude of vibrating electrons, thus detected
- signal received

collapse of bridge

- each bridge has own natural frequency
- damping usually dissipate oscillations
- wind cause bridge to resonate
- large amplitude of oscillations caused collapse of bridge
- dangerous to march across suspension bridge
- frequency of steps near natural frequency
- build up of dangerous oscillation

vibration in vehicles

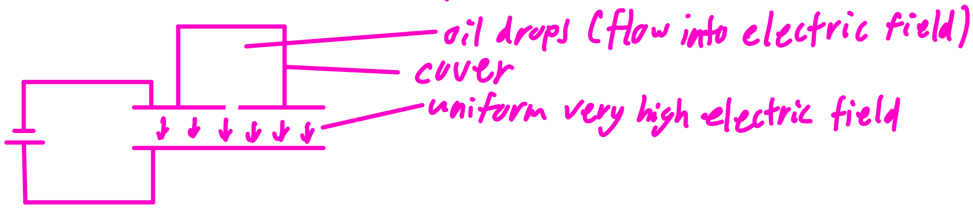
- vibration can occur in moving vehicles
- natural frequency of vehicle must not be produced in use
- resonance may cause excessive stress

Electricity

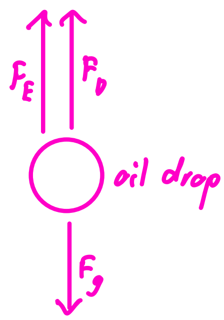
Quantisation of charge:

Millikan's Oil Drop Experiment

- oil drop sprayed into a chamber
- a few drops enter the very high electric field
- drop can be made to flow by adjusting electric field
- mass and charge of drop can be determined



- at terminal velocity of oil drop falling (very slowly), acceleration = 0



F_D = drag force = $6\pi r \eta v$

F_E = force applied by electric field = qE (q: charge, E: electric field strength)

F_g = gravitational acceleration = $\frac{4}{3}\pi r^3 \rho g$ (ρ: density)

$$q = \frac{\frac{4}{3}\pi r^3 \rho g - 6\pi r \eta v}{E}$$

- q always integer multiple of e^- charge $= 1.6 \times 10^{-19}$ C
- all charges are quantised

Electric fields:

Coulomb's Law

- electrostatic force between 2 particles proportional to product of their charges and inversely proportional to the square of the distance

electrostatic force $= F = \frac{q_1 q_2}{4\pi r^2 \varepsilon_0}$ (q_1: charge 1, q_2: charge 2, r: distance)

ε_0 = permittivity of vacuum (constant) $= 8.85 \times 10^{-12}\ CV^{-1}m^{-1} = 8.85 \times 10^{-12}\ C^2 m^{-3} s^2 kg^{-1}$

- can be positive or negative depending on charges
- opposite charges attract, force negative
- same charges repel, force positive
- all charges taken to be point charges with no mass (neglect all effects of gravity)

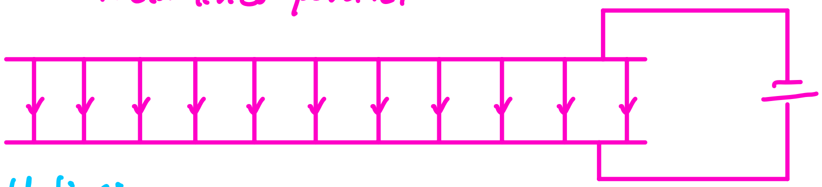
Electric field strength

- electrostatic force per unit charge for positive point charge placed in field

electric field strength $= E = \frac{F}{q}$

- can be positive or negative depending on the charge
- E same direction as F for positive charges
- measured in $NC^{-1} = kgms^{-2}C^{-1}$
- only depend on source charge, not test charge

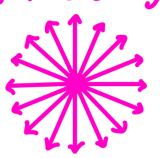
uniform electric field
- between 2 parallel plates equally long
- plates oppositely charged
- all field lines parallel



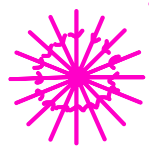
field lines
- electric field represented by field lines
- field lines are arrows
- point in direction of force experienced by positive test charge
- density represent strength of electric field
- close together field lines indicate strong field
- far apart field lines indicate weak field

field lines for isolated charges:

positive charge



negative charge



Gauss' law
- electric flux out of closed surface is ratio of charge to permittivity

electric flux $= \phi = \frac{q}{\underset{\text{permittivity}}{\varepsilon}}$

- independent of shape of surface

motion of charged particle in uniform electric field
- particle accelerate towards either plane (depending on charge)
- parabolic path produced unless initial momentum parallel to field lines

acceleration $= \frac{qE}{m}$

Electric potential:

- work done per unit charge by external force moving positive test charge from infinity to source charge at constant speed
- measured in volts ($V = JC^{-1} = kg\,m^2 s^{-2} C^{-1}$)
- scalar
- field lines point to regions with lower electric potential
- moving in the direction of field lines lose potential

electric potential $= V = \frac{q}{4\pi r \varepsilon_0}$

- positive charge cause positive electric potential
- negative charge cause negative electric potential
- if no charge, then no electric potential

electric potential in uniform electric field

electric field strength $= E = \frac{V}{d} = \frac{\text{electric potential difference}}{\text{distance}}$

electric potential energy

- ability to do work due to position in electric field

electric potential energy $= U = \frac{q_1 q_2}{4\pi r \varepsilon_0}$

Capacitors:

- device with 2 conductors isolated from each other
- store electrical charges thus electrical energy

Capacitance

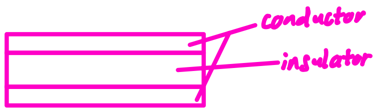
- measure of capacitor's ability to store charge

capacitance $= C = \frac{q}{V} = \frac{\text{charge on positive side}}{\text{potential difference}}$

- measured in farad ($F = CV^{-1} = C^2 m^{-2} s^2 kg^{-1}$)
- charges on each side equal in magnitude and opposite in sign
- net charge of capacitor neutral

charging of capacitors

- 2 parallel plates of conductors
- separated by insulator
- charged by connecting to battery
- e^- flow until potential difference in battery and capacitor equal



Capacitance $= C = \frac{\overset{\text{permittivity of insulator}}{\varepsilon}\overset{\text{area of each plate}}{A}}{\underset{\text{distance between plates}}{d}}$

- transmittivity given
- e^- transfer from positive plate to negative plate
- e^- removed from positive plate
- e^- added to negative plate
- work done to move e^-
- electric potential energy stored in electrical field between plates

connected capacitors

total capacitance for capacitors connected in series:

$$C = \left(\frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n}\right)^{-1}$$

total capacitance for capacitors connected in parallel:

$$C = C_1 + C_2 + \dots + C_n$$

charged capacitor connected to uncharged capacitor:

- charges transferred until equal potential difference
- total charged conserved
- total energy not conserved

charged capacitors connected + to + or - to -

- final charge = sum of initial charges

charged capacitors connected + to -

- final charge = difference between initial charges

Electromagnetism

Current, potential difference, resistance:

basic laws

- junction is a point in electrical network at which ≥3 conductors are joined
- loop is any closed conducting path

Current Law:

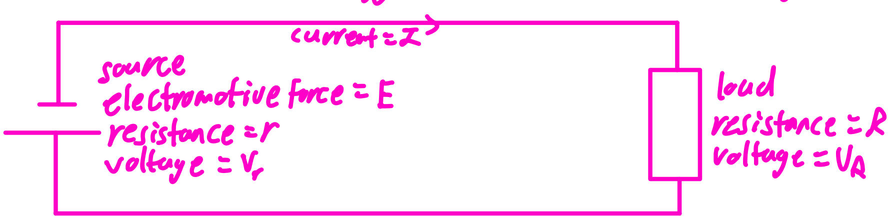
- sum of all currents towards any junction is zero
- no charge accumulate at a junction
- total charge entering = total charge leaving

Voltage Law:

- sum of electromotive forces in any loop = sum of electricity used
- total energy delivered to components in loop = sum of electricity used
- total electrical energy supplied = sum of electromotive forces

internal resistance

- in ideal circuit, source and wires have no resistance
- potential difference across battery = electromotive force of battery
- in real circuit, there is always resistance
- internal resistance exist in source of electromotive force
- potential difference across battery > electromotive force produced
- not all electrical energy available to load
- some electrical energy lost as heat within battery



power generated by source = IE

power lost with source = $I^2 r = IV_r$

power supplied to load = $I^2 R = IV_R$

voltage = V = current · resistance

$V_r = E - Ir$

- full voltage cannot be achieved unless no current is drawn

Maximum Power Theorem

electromotive force source deliver greatest power when resistance of the load is equal to internal resistance of the source

magnetic forces:

magnetic field

- region in which a magnet or a moving charge experience magnetic forces
- direction of field at any point given by direction pointed by north end of compass
- strength indicated by magnetic flux density (B)
- measured in Teslas ($T = kg\,C^{-1}s^{-1}$)

field lines

- point from north end to south end
- direction of magnetic flux density is direction of tangent to field lines
- magnitude of magnetic flux density given by number of field lines per area
- moving charge or current conductor set up a magnetic field

magnetic flux density

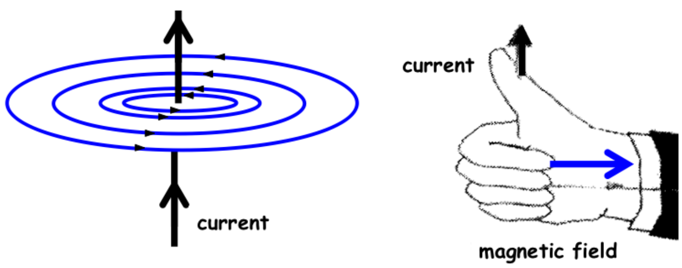
- vector quantity
- direction tangent to field lines
- measures strength of magnetic field
- force per unit length acting on wire carrying unit current at right angle to magnetic field

magnetic flux density $= B = \frac{F}{IL}$ (F: magnetic force; I: current in wire; L: length of wire)

- if wire is at angle θ to field, divide by $\sin\theta$

magnetic field of long straight wire

- right hand corkscrew rule for direction

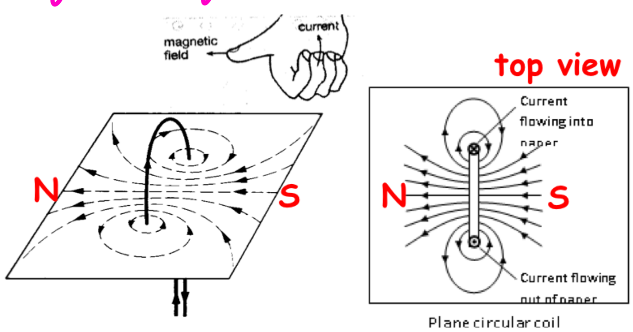


magnetic flux density at distance $r = B = \frac{\mu_0 I}{2\pi r}$

μ_0 = permeability of free space $= 4\pi \times 10^{-7}\ Hm^{-1} = kgmc^{-2}$

magnetic field of flat circular coil

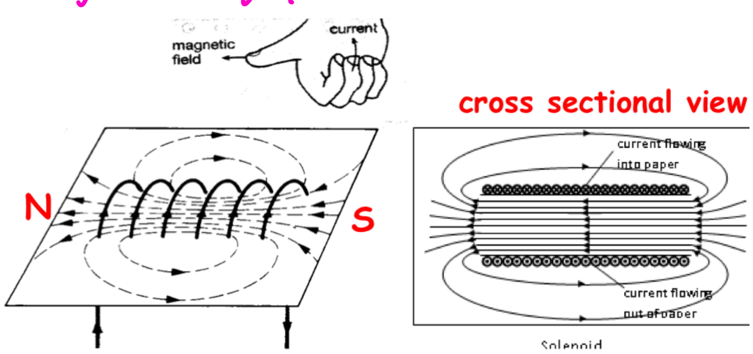
- right hand grip rule for direction



magnetic flux density at centre of coil with N turns and radius $r = B = \frac{\mu_0 N I}{2r}$

magnetic field of long standard electromagnet without core

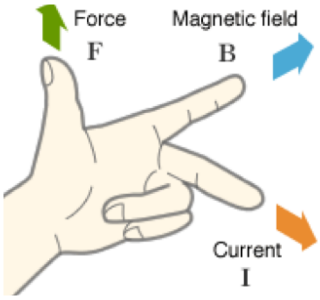
- right hand grip rule for direction

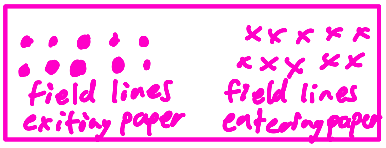


magnetic flux density along axis of hollow cylinder with n turns per length = $B = \mu_0 n I$
if core is added, add the 2 magnetic flux density

Fleming's Left Hand Rule

- direction of force acting on current carrying conductor
- any 2 of force, magnetic field, current at right angles



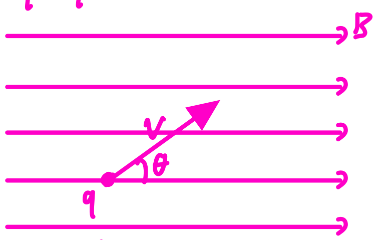


motion of moving charge

- moving charge q enters a magnetic field of flux density B at velocity v and angle θ

force on charge = $F = Bqv\sin\theta$

- perpendicular to velocity



- conditions met for circular motion

mass of charge = m
flux density of magnetic field = B
charge = q

radius of orbit = $r = \dfrac{mv}{qB}$

- radius depend on specific charge (charge per mass)
- separate different atomic nuclei

force between 2 long parallel current carrying conductors

- interaction of their own magnetic fields
- attract if same direction of current
- repel if opposite direction of current

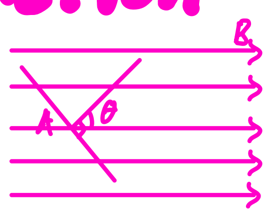
force (per length) = $\dfrac{F}{L} = \dfrac{\mu_0 \overbrace{I_1 I_2}^{\text{product of currents}}}{2\pi \underbrace{d}_{\text{distance}}}$

Electromagnetic induction

magnetic flux

- through plane surface

magnetic flux = $\phi = B\underbrace{A}_{\text{area of surface}}\cos\theta$ angle between field and normal of surface



- measured in weber ($Wb = kg\,m^2 s^{-1} C^{-1}$)

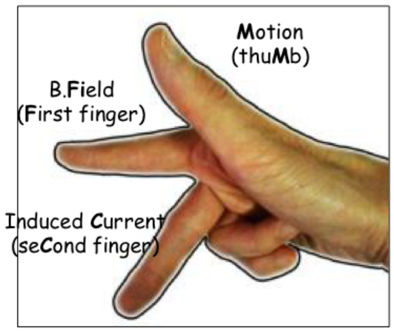
- magnetic flux linkage through coil with N turns = N · magnetic flux of coil if it is a plane

induced current

- magnet move toward wire coil
- increase in magnetic flux linkage
- current induced to oppose increase in magnetic flux linkage
- current induced in coil
- magnet move away from coil
- decrease in magnetic flux linkage
- current induced to oppose decrease in magnetic flux linkage
- current induced in opposite direction
- changing magnetic flux induce current in a circuit
- direction of induced current oppose change in magnetic flux
- faster rate of change of magnetic flux, larger magnitude of induced current
- induced current (electromotive force) directly proportional to rate of change of magnetic flux

$$\text{electromotive force} = -\frac{\overset{\text{number of coil}}{N}\ \overset{\text{change in magnetic flux}}{\Phi}}{\underset{\text{change in time}}{t}}$$

- direction of induced current from Right Hand Rule

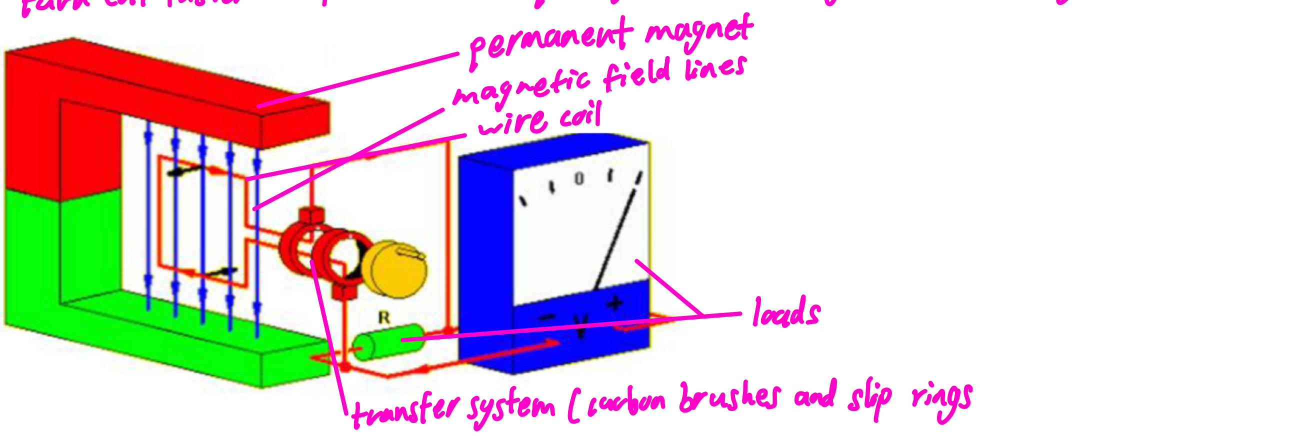


Right-hand rule
(to find direction of induced current)

alternating current generator

- mechanical force cause coil to rotate
- rotating coil cut magnetic field lines
- current (electromotive force) induced in coil
- current transferred to carbon brushes
- carbon brushes transfer current to slip rings
- slip rings provide load with electricity
- maximum current when coil parallel to magnetic field
- no current when coil perpendicular to magnetic field
- voltage output vary like sine wave with time
- alternating current produced

stronger magnet: amplitude increase, denser magnetic field lines
insert soft iron core inside coil: amplitude increase, core strengthen magnetic field
use coil with more turns: amplitude increase, more wires to cut magnetic field lines
turn coil faster: amplitude and frequency increase, magnetic flux change faster



Thermodynamics

Heat transfer:

changes in temperature

amount of heat transfer $= Q = \underbrace{m}_{\text{mass}}\underbrace{c}_{\text{specific heat capacity}}\underbrace{\theta}_{\text{change in temperature}}$

- specific heat capacity (given) measured in $Jkg^{-1}K^{-1} = ms^{-2}K^{-1}$
- temperature change in K = temperature change in °C

changes in state

amount of heat transfer $= Q = m\underbrace{L}_{\text{specific latent heat}}$

- specific latent heat (given) measured in $Jkg^{-1} = ms^{-2}$

specific latent heat of fusion: solid $\longleftrightarrow$ liquid

specific latent heat of vaporisation: liquid $\longleftrightarrow$ gas

Thermal equilibrium

- 2 objects of different temperature brought into contact
- heat flow from hotter to cooler object
- end temperature same
- heat lost by hot object = heat gained by cold object

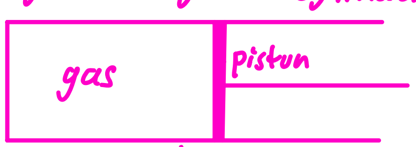
Internal energy:

cause of internal energy

- matter made of many molecules
- molecules in constant motion
- have kinetic energy
- attraction and repulsion between molecules
- have potential energy
- internal energy depend on state of system
- sum of kinetic and potential energy of molecules within system
- do not include energy of the whole system
- temperature measure average kinetic energy of molecules in an object
- no attraction between molecules of ideal gas
- potential energy is zero
- internal energy = sum of kinetic energy

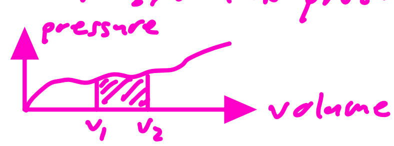
work done on and work done by a system of gas

- system of gas in cylinder with frictionless movable piston



- gas expand
- force applied by gas on piston to move piston against external pressure
- piston moved by small distance x

suppose gas moved piston, causing its volume to change from V_1 to V_2, and its pressure to change from P_1 to P_2



work done by gas $= \int_{V_1}^{V_2} p(v)\,dv$, where $p(V_1) = P_1$, $p(V_2) = P_2$

gas expand: work done by gas

gas contract: work done on gas

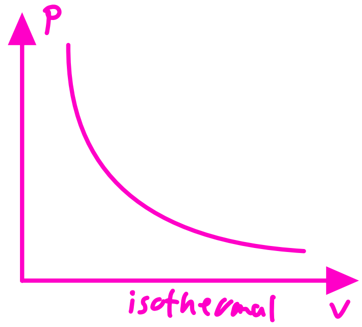
work done by gas = − work done on gas

First law of Thermodynamics

- system of gas with pressure p, volume V, temperature T
- 3 variables completely describe state of gas
- internal energy dependent only on state, pressure, volume, temperature

increase in internal energy = heat supplied to system + work done on system

- heat can be supplied or removed by doing work
- expansion decrease temperature
- contraction increase temperature
- applicable also to solids and liquids

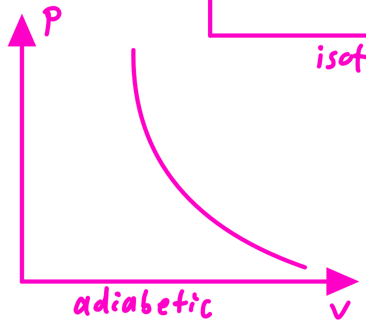


isothermal process

- change in pressure and volume with temperature constant

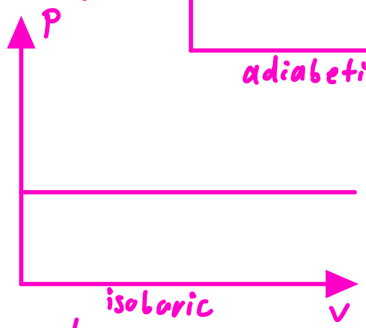
pressure $\propto$ volume^{-1}

- no change in internal energy for ideal gas



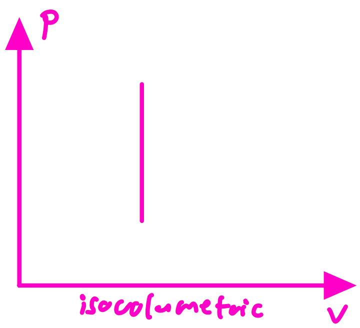
adiabetic process

- changes without heat supplied or taken
- cylinder insulated
- changes occur much faster than heat transfer
- expansion and contraction affect internal energy
- steeper curve than isothermal process



isobaric process

- changes at constant pressure
- curve is horizontal



isovolumetric (isochoric) process

- changes occur with volume constant
- no work done
- energy transfer change internal energy only
- graph is vertical line

Ideal gas law:

Ideal gas equation

- constant temperature, $p \propto \frac{1}{V}$
- constant pressure, $V \propto T$
- constant volume, $p \propto T$

$$pV = nRT$$

- amount of gas (n) measured in moles
- R = molar gas constant $= 8.314\ \mathrm{J\,K\,mol^{-1}} = 8.314\ \mathrm{kg\,m\,s^{-2}\,K\,mol^{-1}}$

mean translational kinetic energy of a ideal gas molecule

- mean translational kinetic energy = quadratic mean of all individual kinetic energy

mean translational kinetic energy $= C_{rms} = \sqrt{\frac{3RTn}{m}}$

total internal energy of ideal gas

- sum of all kinetic energy

total internal energy $= U = \frac{3}{2}nRT = \frac{3}{2}\underbrace{N}_{\text{number of molecules}}\underbrace{k}_{\text{Boltzmann constant}}T \quad \left(k = \frac{R}{\underbrace{N_A}_{\text{Avogadro's constant}}}\right)$

- affected by temperature only