- radian - angle subtended at the centre of a circle by an arc of a circle whose length is equal to the radius

- if θ small: $\sin\theta \approx \tan\theta \approx \theta$

- angular displacement - angle moved through relative to specific axis
  - $\Delta\theta$ measured in radians

- angular velocity - rate of change of angular displacement
  - ω $[\omega] = rad\ s^{-1}$ $\omega = \frac{\Delta\theta}{\Delta t}$ $\omega = \frac{2\pi}{T} = 2\pi f$ $v = r\omega$

- rotational frequency - number of rotations per unit time $f = \frac{n}{t} = \frac{1}{T}$

- centripetal acceleration - α $[\alpha] = rad\ s^{-2}$ $\alpha = r\omega^2$ $\alpha = \frac{v^2}{r}$

- centripetal force - not actual force - allways resultant force which accelerates the object towards centre giving circular motion

$$F_c = mr\omega^2 = m\frac{v^2}{r}$$

- centrifugal force - pseudo force introduced to account for effects of inertia in an accelerated (non-inertial) reference frame

- gravitational field - region of space where a massive object experiences an attractive force

- gravitational field lines - lines indicating direction + strength of gravitational force acting on a test mass in field
  - assume the test mass doesnt affect field itself

- newtons law of gravitation
  ↳ any two point masses attract eachother with a force whose magnitude is directly proportional to the product of their masses and inversly proportional to the square of their separation

  $F \propto m_1 m_2$ $F \propto \frac{1}{r^2}$ $F_g = \frac{G m_1 m_2}{r^2}$

  ↳ assuming: masses are point like + separation is much greater than radius

- G - gravitational constant $G = 6.67 \times 10^{-11}\ N m^2 kg^{-2}$

- gravitational field strength - g
  ↳ gravitational force per unit mass at a point in the field
  ↳ in a radial field: $g = \frac{F_g}{m_{test}}$ $g = \frac{Gm}{r^2}$ assuming $m_{test} \ll m$

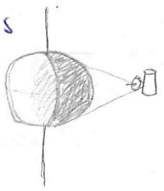
- gravitational potential energy - E_p
  - ↳ work done in bringing a mass from ∞ to r (point in the field) by gravity
  - ↳ -ve since work is done by force
  - ↳ for radial field where $m_1 << m_2$ $E_p = -\frac{Gm_1m_2}{r}$

- gravitational potential - $\varnothing$ $[\varnothing] = J\,kg^{-1} = m^2s^{-2}$
  - ↳ at a point is the work done per unit mass in bringing the mass from ∞ to the point $\varnothing = \frac{E_p}{m}$ $W = m_1 \Delta \varnothing$
  - ↳ allways -ve at ∞ $\varnothing = 0$ for radial field: $\varnothing = -\frac{Gm_2}{r}$

- equipotential lines
  - ↳ potential doesnt change along them so no work done
  - ↳ perpendicular to field lines if $\vec{s} \cdot \vec{F_g} = 0$ $W = 0$ since $\Delta\varnothing = 0$

- satelite - object orbiting anaother object in space
  - ↳ natural: stars, planets, moons ↳ artificial: ISS, weather satelites

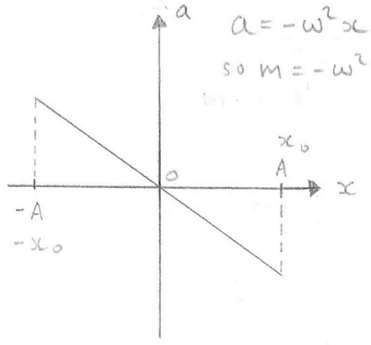
- geostationary orbits - 3.6×10^7 m above equator
  - ↳ can transmit to whole $\frac{1}{2}$ of earth - bad reception at poles
  - ↳ have same ω as earth so appear stationary
  - ↳ rotate west → east with earth



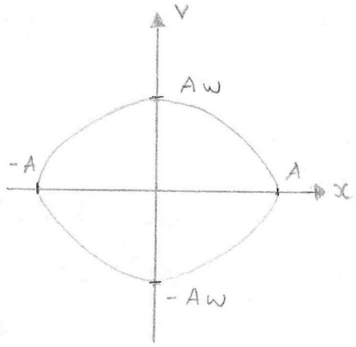
- oscillation - repeated movement of system between 2 states (positions) either side of an equilibrium

- amplitude - A - maximum displacement from equilibrium
- frequency - f - number of oscillations per unit time
- period - T - time required for 1 complete oscillation
- phase difference - $\varnothing$ - horizontal distance/time which a particular point on a wave leads/lags to anaother one

- Simple Harmonic Motion - SHM $a \propto -x$
  - ↳ oscilation in which a is dirrectly proportional and in opposite direction to displacement
  - ↳ isochronous - period is independant of amplitude
  - ↳ conditions:
    - oscilating body
    - equilibrium position
    - restoring force

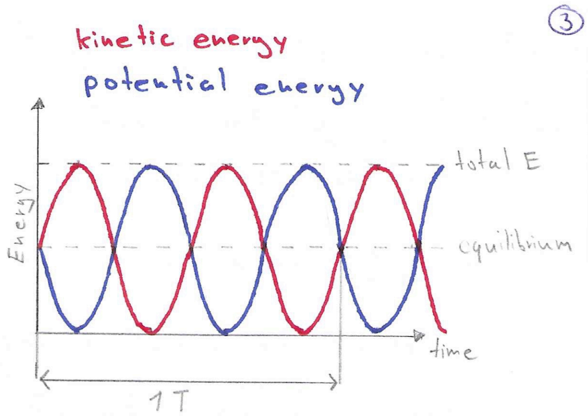


acceleration / displacement



velocity / displacement

$v = x_0 w \cos(wt)$ }
$x = x_0 \sin(wt)$ } polar equation of elipse



since kE going down then back up is +ve in both direction

$T = \frac{1}{f} = \frac{2\pi}{\omega}$ $\omega = 2\pi f$

SHM: $x = x_0 \sin(\omega t + \phi)$

$V = \omega x_0 \cos(\omega t + \phi)$

$a = -\omega^2 x_0 \sin(\omega t + \phi)$

$= -\omega^2 x$

$V = \pm\omega\sqrt{x_0^2 + x^2}$

$E_{total} = \frac{1}{2} m(v^2 - w^2 x^2)$

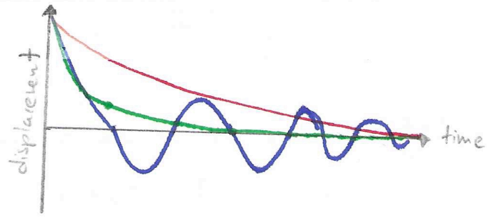
- Damping - reduction in E of oscillation (or Amplitude) due to a force allways acting opposite to direction of motion (opposes restoring force)
  - exponential decrease in amplitude
  - doesnt change period or frequency

$$\frac{d^2x}{dt^2} + 2\gamma\frac{dx}{dt} + \omega_0^2 x = 0$$

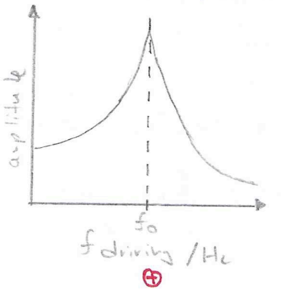
γ - damping factor

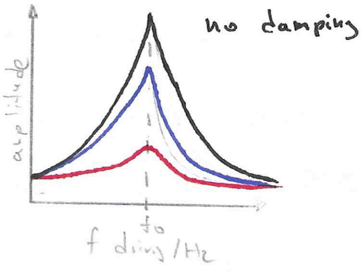
gives 3 solution corresponding to each damping scenario

- Light damping - gradual decrease in A ●
  - oscillations continue for long
- Critical damping - oscillations stop imediately ●
- Over damping - amplitude decreases rapidly ●
  - oscillations still occour for short time
  - eg spring in viscous oil

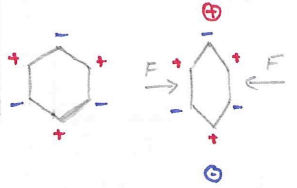


- resonance - when driving frequency = natural frequency resulting in large amplitude $f_{driving} = f_0$





- piezo electric transducer
  - ↳ converts mechanical E ⟷ electrical E
  - ↳ thickness should be $\frac{\lambda}{2}$
  - ↳ diameter should be $\approx 10\lambda$ to give nice planar wave (not point source)
  - ↳ resonance at $f_{ac} = f_0$



(charge separation)

- acoustic impedance - Z
  - ↳ property of material - how much it opposes acoustic flow

$Z = \rho c$

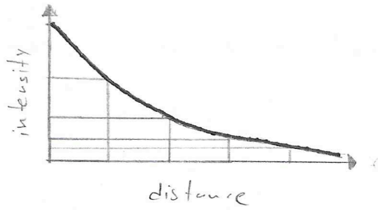
$[Z] = kg m^{-2} s^{-1}$

ρ - density

c - acoustic velocity

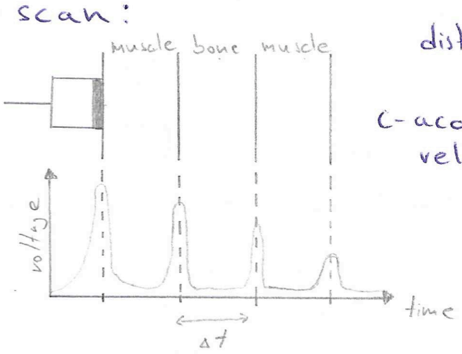
- on boundary some ultrasound is reflected and some transmitted (and refracted)

- intensity reflection coefficient - α $\alpha = \frac{I_R}{I_0} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$ (when $\theta_i = 0$)
- coupling gel (medium)
  - ↳ used for impedance matching to ↓α
- signal attenuated by absorption μ - attenuation coefficient
  $[\mu] = dbm^{-1}$ $I = I_0 e^{-\mu x}$
- half value thickness - $x_{\frac{1}{2}}$
  - ↳ distance a wave travelles for transmitted intensity to halve $x_{\frac{1}{2}} = \frac{\ln(2)}{\mu}$



- resolution - ability to destinguish 2 separate structures if f↑, λ↓ resolution↑ but penetration↓

A scan:



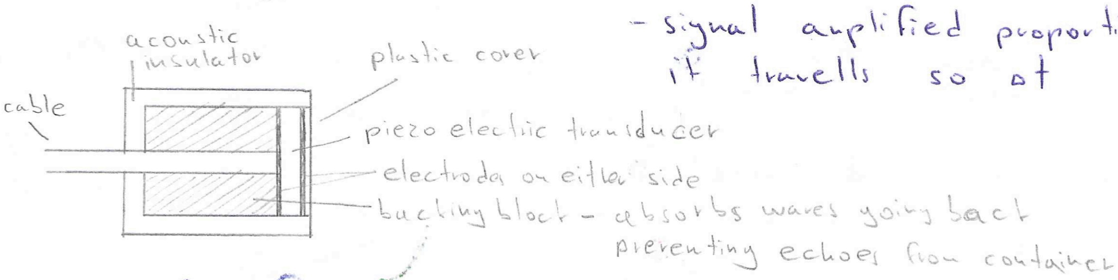
distance = $\frac{C \Delta t}{2}$

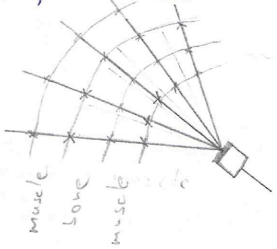
C - acoustic velocity

B scan:

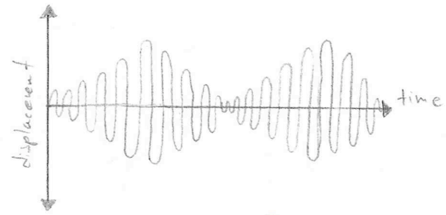
↳ series of A scans at different angles plotted on a diagram

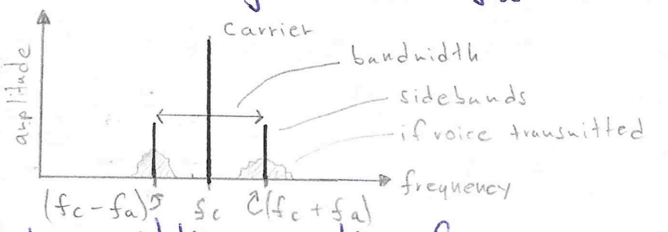
- Δt gives info about distance (thickness) and density of tissue
- amplitude (V) gives info about density
- signal amplified proportionally to distance it travells so Δt



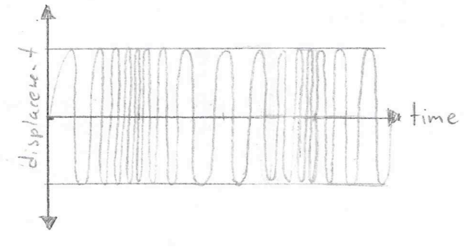


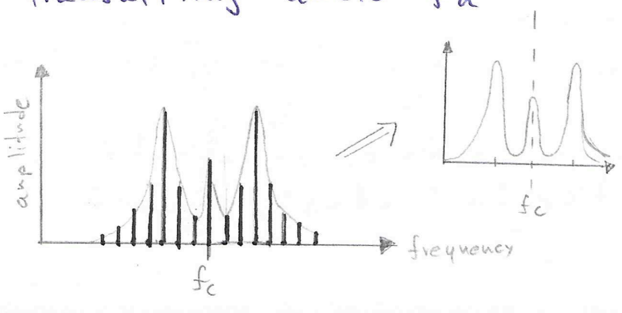
- AM - amplitude of carrier wave is made to vary synchronously with displacement of transmitted signal.
- FM - frequency of carrier wave is made to vary synchronously with displacement of transmitted signal
- frequency of carrier wave must be at least 2 × frequency of signal
- AM - carrier frequency fc transmitting audio fa





- FM - carrier frequency fc transmitting audio fa





- AM: advantages
  - ↳ cheaper + simpler electronics
  - ↳ larger transmission range ∴ covers greater area
  - ↳ small bandwidth ∴ more stations per Δf

  disadvantages
  - ↳ more interference
  - ↳ lower bandwidth ∴ lower quality of signal

- FM advantages
  - ↳ less electrical interference
  - ↳ greater bandwidth ∴ better quality
  - ↳ lower transmission range ∴ stations at same f in one area don't interfere
  - ↳ higher frequency f_c ∴ greater Δf

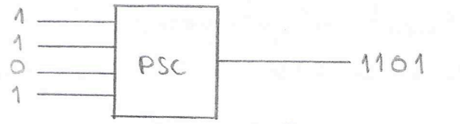
  disadvantages
  - ↳ lower range + more expensive electronics
  - ↳ higher bandwidth ∴ less stations per Δf

- attenuation - gradual reduction in signal power
- noise - random unwanted signal added to transmitted signal distorting it
- repeater amplifier - reciers signal and transmits it together with the noise at a higher power
  - signal to noise ratio stays constant
- regenerator amplifier - reciers digital signal, eliminates noise and transmits it at a higher power
- advantages of digital signal:
  - ↳ repeater amplifiers can be used ∴ higher range
  - ↳ digital circuits cheaper to build and more reliable
  - ↳ extra information can be transmitted and used by reciever to check and correct errors in recieved signal
  - ↳ higher rate of transfer of information than analogue
- Binary numbers - each digit is one bit
  - ↳ MSB - most significant bit - on the left
  - ↳ LSB - least significant bit - on the right
  - ↳ telephones use 8 bit $2^8 = 256$ binary numbers
  - ↳ information transmitted right → left (⟵)

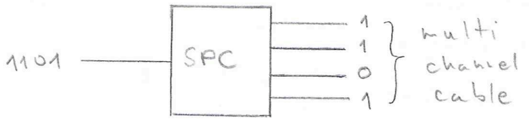
8 4 2 1 $4+2=6$
$6V = 0110$
MSB ↲ ↳ LSB
8 4 2 1
$13V = 1101$ $8+4+1=13$

- ADC - samples analogue signal at regulor intervals given by sampling f and sends voltages out as binary data
  - rounds down to most significant bit
- DAC - converts binary data into analogue voltage levels
  - distorts signal since reproduction isnt accurate (creates steps)
- niquist rule - highest frequency which can be reproduced is halve the sampling f
  - to reproduce signal f_a $f_{sampling} \geq 2 f_a$
  - telephone sampled at 8kHz ∴ can reproduce 3.4 kHz

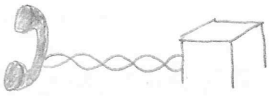
- parallel to serial converter - takes all simultaniously recieved bits and sends them out as a sequence down a single line



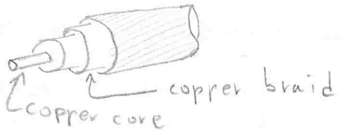
- serial to parallel converter - takes whole sequence of bits and sends them out simultaniously via a multi channel cable



- power falls off logarithmically
- attenuation $= 10 \log \left(\frac{P_{in}}{P_{out}} \right)$ in dB   gain $= 10 \log \left(\frac{P_{out}}{P_{in}} \right)$
- signal to noise $= 10 \log \left(\frac{P_{signal}}{P_{noise}} \right)$ in dB   attenuation per unit length $= \frac{10}{L} \log \left(\frac{P_{in}}{P_{out}} \right)$ in dBm^{-1}
- comunication channel - medium or pathway used to convey information between 2 points.
- Wire pairs
  ↳ signal sent as pd across 2 wires. second wire acts as current return path
  ↳ used in early land telephones
  ↳ ✗ - repeaters needed - high attenuation
  - crosstalk - security wire tapping - wires pick up noise = interference
  - low bandwidth



- Coaxial cable
  ↳ signal sent as pd in central copper wire
  ↳ copper braid - grounded ∴ shielding
  - acts as current return path

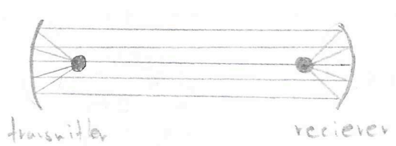


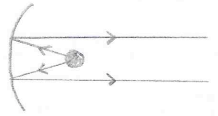
✓ - better security - less prone to interference + cross talk
- higher bandwidth <100 MHz - less repeater amplifiers needed

✗ - more expensive cable

- Radio
  ↳ different carier frequencies allow radios to share air space → frequency multiplexing
  ↳ long range comunication using AM long waves reflected off iono sphere
  ↳ short wave space waves can pass to space
  ↳ bad reception in valleys - SW dont reflect from ground
  ↳ for line of sight transmission there must be no obsticles in path
  ↳ point to point transmission with special antennas
  ↳ UHF and VHF used in phones + waltie talkies can have very short antennas

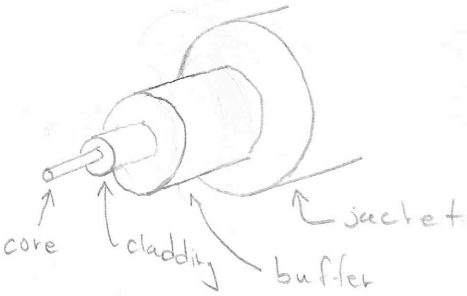
- Microwave link
  - ↳ short distance point to point
  - ↳ parabolic reflector focuses E of the wave into a point or parallel wave. ↓λ = less spreading out





- ↳ Satellites
  - uplink signal: earth ⟶ satelite downlink: satelite → earth
  - uplink and downlink have different frequencies to prevent downlink from $\boxed{\text{swamping}}$ uplink (results in +ve feed back)
  - 6/4 GHz, 14/11 GHz, 30/20 GHz band-width ≈ 0.5 GHz
- ↳ satelite orbits
  - ↳ polar
    - N → S ⊥ to rotation of earth
    - scans whole surface
    - weather satelites
    - ✓ - low orbit ∴ cheap to launch
    - ✗ - more relative to surface
    - ✓ smaller time delay
  - ↳ geostationary
    - W → E at equitorial orbit
    - 36000 km above surface
    - ✓ - one satelite covers almost ½ earth
    - stationary to surface so satelite dish can be set permanently
    - ✗ - high orbit ∴ expensive to launch
    - large time delay
    - bad reception at poles

- Optic fibres
  - ↳ undersea cables for long distance communication (telephone + internet)
  - ↳ digital pulses of visible or IR light created by lasers
  - ✓ - high bandwidth ≈ GHz
    - constant and relatively low noise
    - rejeverated every 80 - 200 km
  - ✗ - difficult to connect one-another
    - expensive technology
    - difficult to repair



- electric field - region of space where a charged body experiences a force

- coulombs law - electrical force between 2 charged particles is directly proportional to product of their charges and inversly proportional to square of their separation
  - for point charges so radius << separation

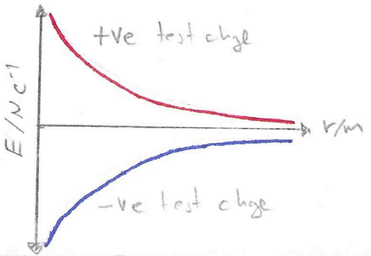
$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$$ -ve = attraction +ve = repulsion

- ε_0 - permitivity of free space $\varepsilon_0 \approx 8.85 \times 10^{-12}\ C^2 N^{-1} m^{-2}$

- electric field strength - force experienced by charged particle in an electric field per unit charge $E = \frac{F_e}{Q}$.

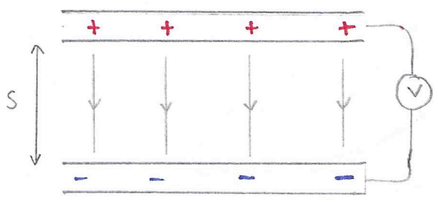
radial:

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

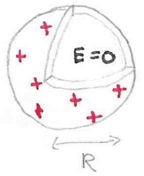


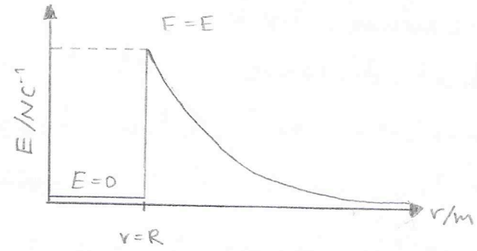
uniform:

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



- electric field of a hollow spherical conductor
  ↳ inside field cancels out
  $E_{inside} = 0$





- electric potential – V
  ↳ work done per unit charge in bringing it from ∞ to the point in an electric field

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

- electric potential energy – E_p
  radial field: $E_p = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r}$ uniform field: $E_p = Eqs$ $E_p = q\int E\,ds$
  $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ $V = V$

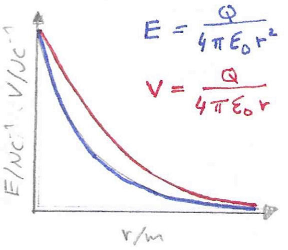
- equipotential lines – lines connecting points of equal potentials (V)
  – perpendicular to field lines

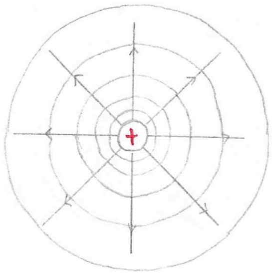
- potential gradient – rate of change of electric potential with respect to distance in a direction (displacement) within the fied

$\nabla V = -E$ $\left(\frac{\Delta V}{\Delta r} = -E\right)$

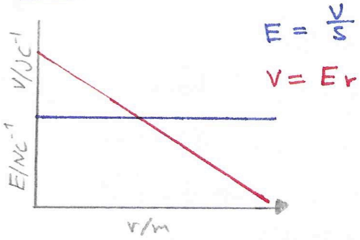
$\nabla V = \frac{dV}{dr}$

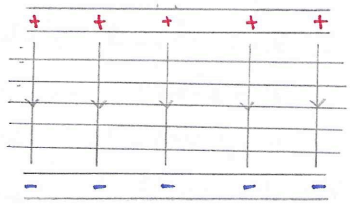
- radial field:





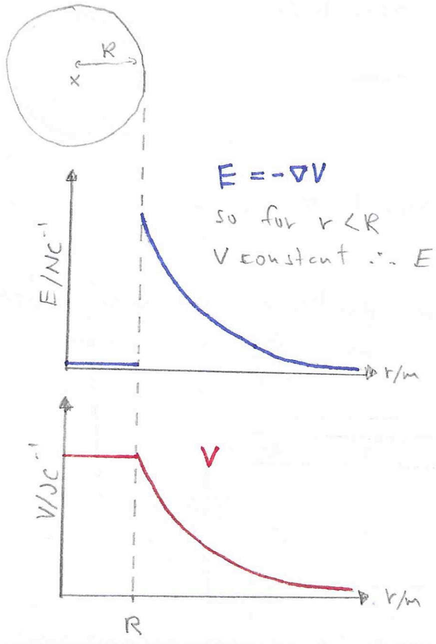
- uniform field:

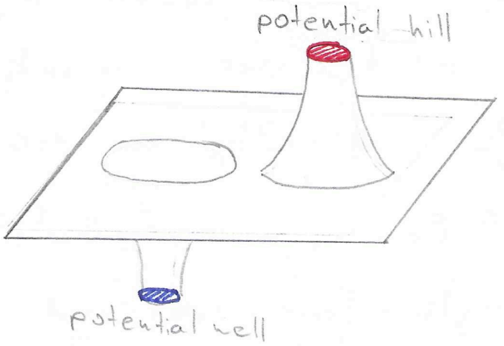




- potential well – region surrounding a local minimum
  – E in potential well is unable to do work

- potential hill – region surrounding a local maximum
  – E in potential hill able to do work





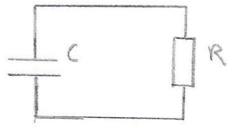
- Capacitance - charge stored per unit potential difference across it
- Farad - capacitance when pd across capacitor plates is 1V and they store a charge of 1C
- capacitor - allways neutral ∴ no net charge
  - doesnt store charge only displaces it to store E
- factors affecting capacitance
  - ↳ area - $C \propto A$
  - ↳ separation - $C \propto \frac{1}{s}$
  - ↳ permitivity of dielectric - $C \propto \varepsilon$

$C = \frac{\varepsilon A}{s}$ $C = \frac{Q}{V}$

parallel: $C_T = \sum_{i=1}^{n} C_i$

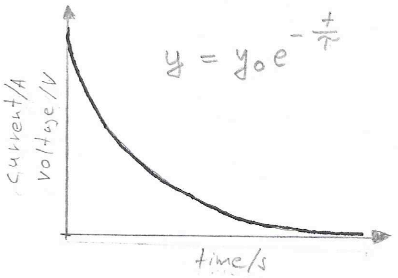
Series: $C_T = \frac{1}{\sum_{i=1}^{n} \frac{1}{C_i}}$

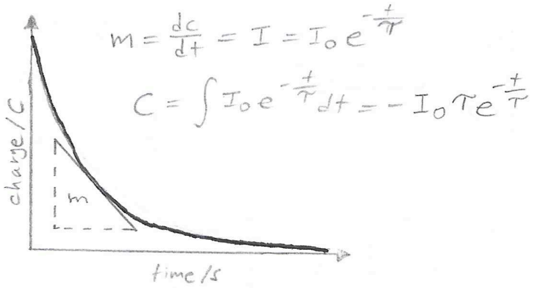
- discharging - time for discharge depends on C and R
  - never actually fully charged or discharged



$\tau = RC$ $V = V_0 e^{-\frac{t}{\tau}}$ $I = I_0 e^{-\frac{t}{\tau}}$ $E = \frac{1}{2} QV = \frac{1}{2} CV^2$

$[\tau] = s$

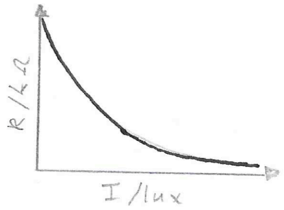


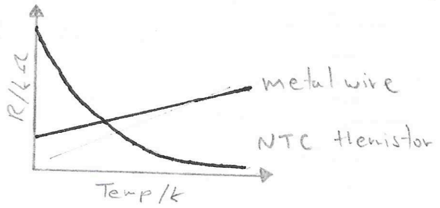


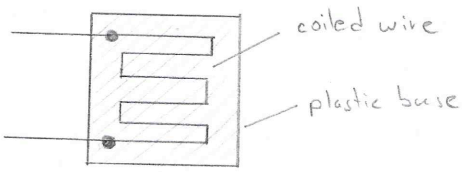
uses:
- ↳ timing - charged / discharged periodically
- ↳ smoothening after rectificatin
- ↳ tuning of radio - variable C in RC oscilator
- ↳ storing E - camera flash
- ↳ coupling

- electrical sensyng system:
  Sensing device → Processor → Output device

- piezoelectric transducer — direct effect: pressure → pd or reverse
- LDR - semiconductor - γ absorbed by valence e^- excited into conductive band and R↓
  - dark ≈ 1MΩ light ≈ 100Ω
- NTC thermistor - semiconductor so same principle as LDR
  - resistance decreases exponentially with ↑T





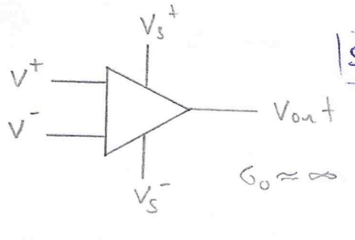


- strain gauge - strain = $\frac{x}{L_0}$ as strain ↑ L↑ and A↓ $R = \frac{\rho L}{A}$ so R↑
  - stretching R↑, compressing R↓

$\Delta R \propto \Delta L$

- Operational amplifier
  - ↳ IC containing many transistors arranged to give circuit with very high gain
  - ↳ V^+ - non-inverting input V^- - inverting input
    Pout > Pin so separate supply needed

saturation!



- ideal OP amp (5)
  - ↳ G_0 - open loop gain is ∞
  - ↳ input impedance = ∞ output impedance = 0
  - ↳ bandwidth = ∞ all f signals amplified equally
  - ↳ slew rate = ∞ $\frac{dV_{out}}{dt} = \infty$
  - ↳ 0 noise contribution

realistically :

$G_0 \approx 10^5$

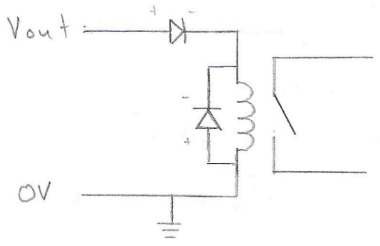
$R_{in} \approx 10^6 - 10^{12}\ \Omega$

$R_{out} \approx 75\Omega$

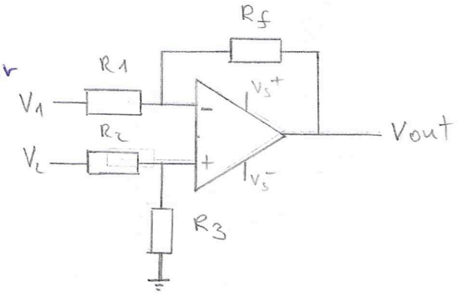
$I_{out} \approx 25mA$

$V_{out} \approx \pm 15V$

- use relay to switch higher V or higher A in an external circuit



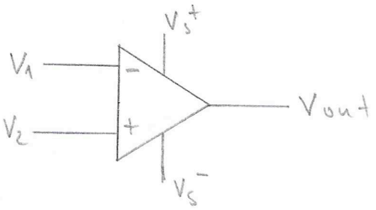
- differential amplifier



$V_{out} = \frac{R_f}{R_1}(V_2 - V_1)$

$G = \frac{R_f}{R_1}$

- comparator amplifier
  - ↳ saturates
  - ↳ 2 types - inverting
    - non-inverting



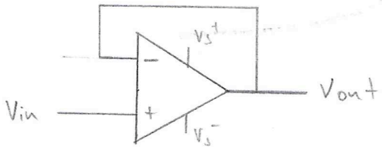
if $V_+ > V_-$ then $V_+ - V_- = +ve$

so $V_{out} = V_s^+$

if $V_+ < V_-$ then $V_+ - V_- = -ve$

so $V_{out} = V_s^-$

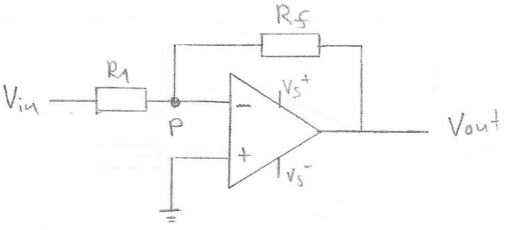
- buffer amplifier
  - ↳ entire output fed back to inverting input
  - ↳ used for protection + impedance matching eg) piezo microphone



$G = 1$

$V_{out} = V_{in}$

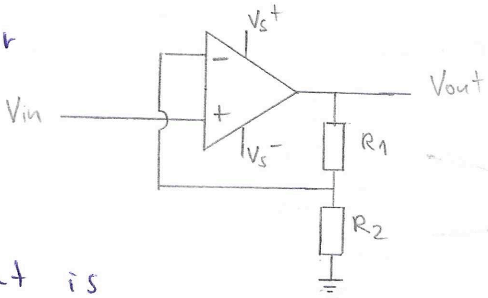
- Inverting amplifier
  - ↳ P - virtual earth at almost 0V
  - ↳ no current flows through opamp



$V_{out} = -\frac{R_f}{R_1} V_{in}$

$G = -\frac{R_f}{R_1}$

- non-inverting amplifier



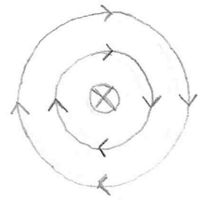
$V_{out} = \left(1 + \frac{R_1}{R_2}\right) V_{in}$

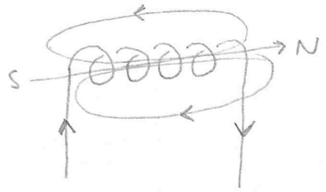
$G = 1 + \frac{R_1}{R_2}$

- feedback
  - ↳ fraction of output is added (fed back) to the input
  - ↳ advantages: reduced gain, increased bandwidth, increased output stability
- magnetic field N → S
- test pole - north

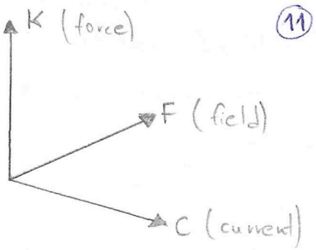
⊗ - into paper ⊙ - out of paper

- right hand grip rule:





- flemings left hand grip rule:

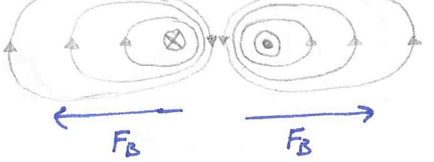


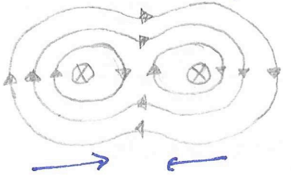
- magnetic flux density - B
  ↳ at a point in space is the force experienced per unit length by a long straight conductor carrying a unit current placed at 90° to the field at that point.

  $F = BIL \sin\theta$; $[B] = T = N m^{-1} A^{-1}$

- Tesla
  ↳ Magnetic flux density of a field when a wire carrying 1 A placed at 90° to the field experiences a force of 1 N per metre of its length.

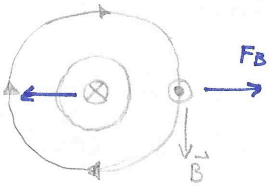
- B measured with: calibrated hall probe or current balance



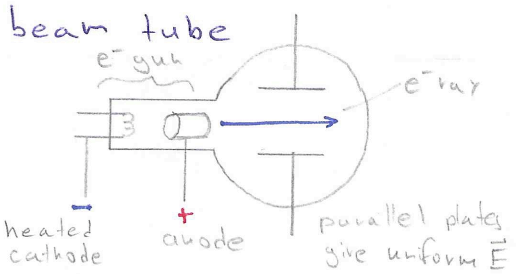


motor effect:

second force due to newtons 3rd law of motion



- e^- beam tube

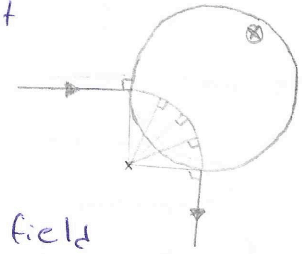


- F_B allways 90° to $\vec{v}$ so gives centripetal force resulting in circular motion

$F = BIL$ $I = \frac{Q}{t}$ $L = s = vt$

$F = B\frac{Q}{t}vt$

$= BQv$



- if $\vec{v} \cdot \vec{B} \neq 0$ so not perpendicular
  split $\vec{v}$ into components parallel and perpendicular to field and use the one perpendicular to $\vec{B}$ (other one is along equipotential)

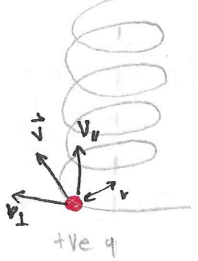
- circular motion:

$F_B = BQV$ $F_c = m\frac{v^2}{r}$

$F_B = F_c$

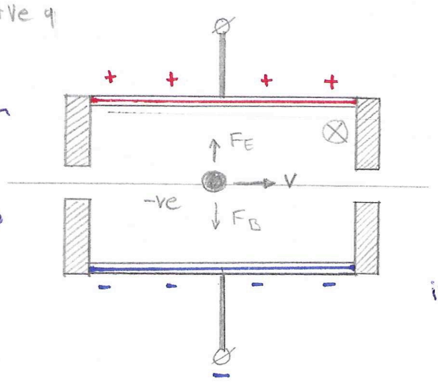
$BQV = m\frac{v^2}{r}$

$r = \frac{mv}{BQ}$



- charge to mass ratio = $\frac{q}{m}$
- specific charge = $\frac{e}{m_e}$

- Veloci selector
  ↳ evacuated chamber with uniform electric field $\vec{E}$ and magnetic field $\vec{B}$ at right angles $\vec{E} \cdot \vec{B} = 0$
  ↳ slit at each end. only particles with given speed can pass



$F_E = Eq$ $F_B = Bqv$

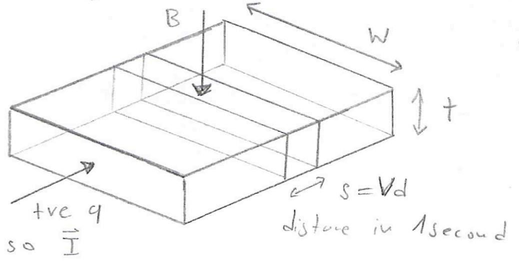
$F_E = F_B$

$Eq = Bqv$

$v = \frac{E}{B}$

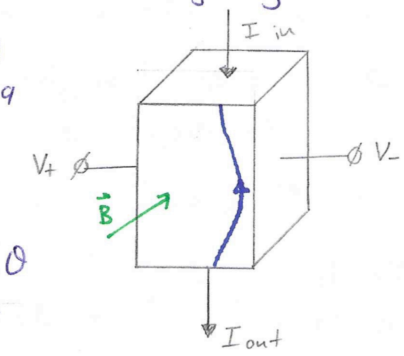
invariant of q or m

- Hall probe
  - ↳ small semiconductor strip through which I is passed
  - ↳ semiconductor since - e^- travel faster / lower n than metals so greater hall effect per given I
  - ↳ magnetic force causes flow of e^- to shift to one side giving V_H



$$V_H = \frac{BIq}{nt} \sin\theta$$

$$F_E = qE \quad F_B = Bq V_d \quad I = nAV_d q$$
$$= q\frac{V_H}{W} \quad = \frac{BI}{nwt} \quad = nWtV_d q$$
$$F_E = F_B \quad V_d = \frac{I}{nwtq}$$
$$q\frac{V_H}{W} = \frac{BI}{nw\cancel{t}} \Rightarrow V_H = \frac{BIq}{nt}\sin\theta$$

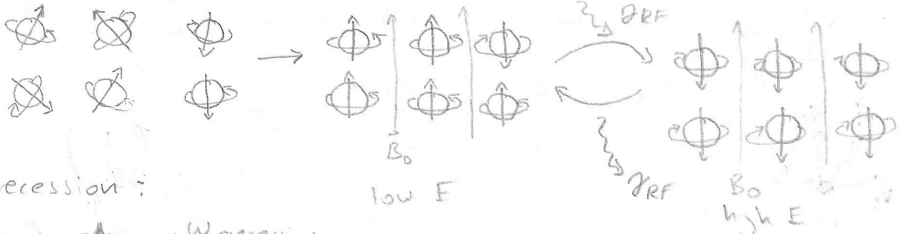


- MRI
  - ↳ nuclei have spin ∴ magnetic moment
  - ↳ in body nuclei of H in H_2O but alligned randomly so individual $\vec{B}$ cancel out $\Sigma\vec{B} = 0$
  - ↳ large $B_0 \approx 1T$ so that $f_{larmour}$ in RF range

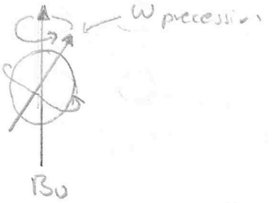
$n^0 + p^+ =$ odd - halve integer spin
n^0 and $p^+ =$ odd - integer spin

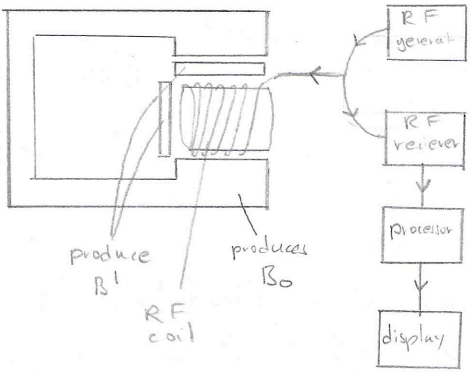
$$f = \frac{\gamma B_0}{2\pi} \approx 42.6 \, MHz$$
for p^+ in $B_0 = 1T$

1.) strong uniform magnetic field $\vec{B}_0$ allignes nuclei
2.) nuclei precess about $\vec{B}_0$ with larmour frequency
3.) RF pulse at larmour f applied, resonates with nuclei
4.) nuclei absorb this E and flip into excited anti-parallel state
5.) nuclei de-excited by emitting RF pulse in form of RF photon
6.) RF pulse detected processed and displayed
7.) calibrated weak non-uniform magnetic field superimposed on $\vec{B}_0$
8.) adjusts $f_{larmour}$ of nuclei so only those in one region resonate
9.) allows for excitation of region to be varied and only one region excited at a time ∴ determines location of nuclei

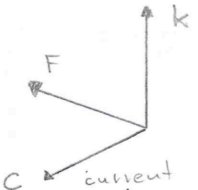


precession :



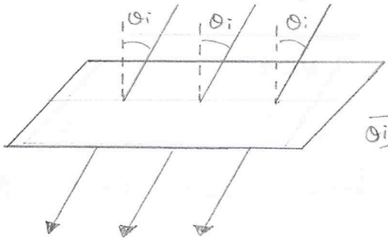


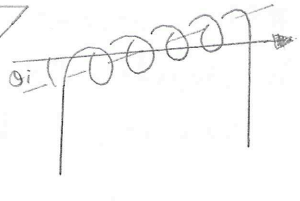
- flemings right hand rule



- or use right hand rule to see where charge accumulates

- magnetic flux – ϕ
  - ↳ product of magnetic flux density and area perpendicular to the field





$\phi = BA\cos\theta$ $[\phi] =$ Webber (Wb)

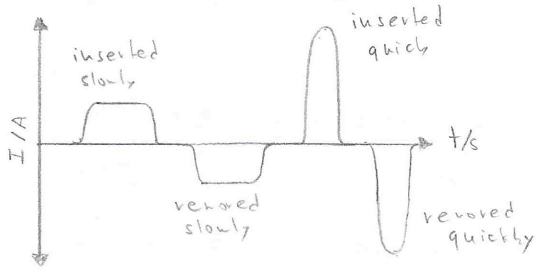
- magnetic flux linkage – ϕN
  - ↳ measure of magnetic flux of coil $\phi N = BAN\cos\theta$

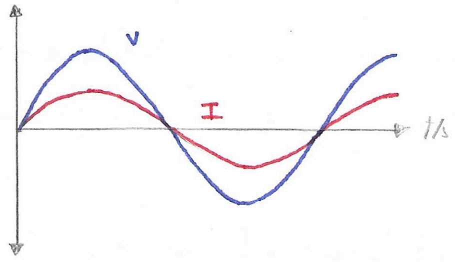
- Webber
  - ↳ amount of magnetic flux with density 1T passing through an area of $1m^2$ perpendicular to the field

- Faradays law of EM induction
  - ↳ magnitude of induced emf is equal to the rate of change of magnetic flux linkage through a circuit

$$\mathcal{E} = -N\frac{d\phi}{dt} \approx -N\frac{\Delta\phi}{\Delta t}$$

- General Lenzes Law
  - ↳ induced current is established in a direction so as to produce effects which oppose the change causing it



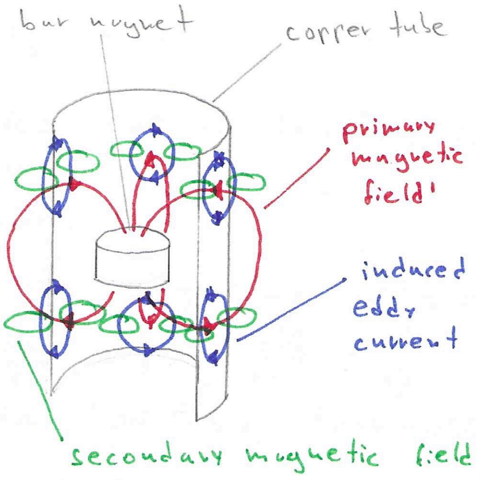


for R > 1

- induced I depends on induced $\mathcal{E}$ and R of the circuit

- as magnet falls through coil while it is fully inside $\mathcal{E} = 0$

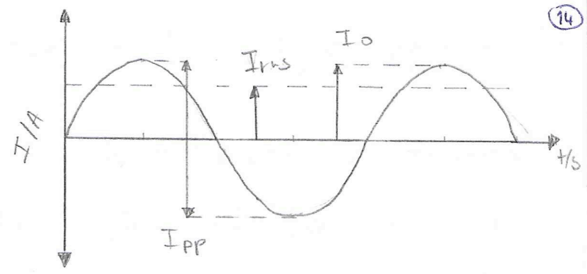
- Eddy currents
  1.) as magnet falls there is $\frac{d}{dt}$ of magnetic flux linkage in the copper tube
  2.) eddy current induced in the conductor
  3.) eddy current = flow of e^- so produces a secondary magnetic field
  4.) 2° magnetic field opposes motion of magnet by Lenzes law so force acts against gravity and $a < g$



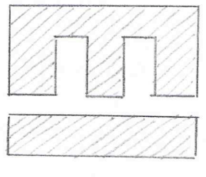
- ω - angular frequency $\omega = 2\pi f$
- I_0 - peak current
- I - momentary current
- I_{pp} - peak to peak current $I_{pp} = 2I_0$

$V = V_0 \sin(\omega t)$

$I = I_0 \sin(\omega t)$



- RMS current I_{RMS}
  - ↳ steady DC which delivers the same average power to a resistive load as the AC $I_{RMS} = \frac{I_0}{\sqrt{2}}$
  - ↳ AC both +,- so avg would be 0 therefore square it then average $I \to I^2 \to \frac{I^2}{2}$ and square root to $\frac{I}{\sqrt{2}}$
- Transformer - device which changes peak value of alternating voltage using principle of EM induction
  1. I in 1° coil magnetizes soft iron core producing a changing magnetic flux
  2. magnetic flux in core changes magnitude + direction continuously
  3. magnetic flux is linking with the 2° coil
  4. by faradays law of EM induction ε is induced in 2° coil
- Eddy currents
  - ↳ Alternating field in core is different at different points so ε induced in each point is different
  - ↳ current flows between regions. P lost to heating effect
- Loss in transformer
  - ↳ resistive losses - resistance of wires $P = I^2R$ - use low R wires
  - ↳ flux losses - magnetic flux from 1° doesnt completly link with 2°
    - 2° coil is wound on top of 1° ∴ good coupling
  - ↳ hysterisis losses - constantly magnetised / demagnetised 100 times s^{-1} and resists it
    - use soft iron core
  - ↳ eddy currents - laminated core used



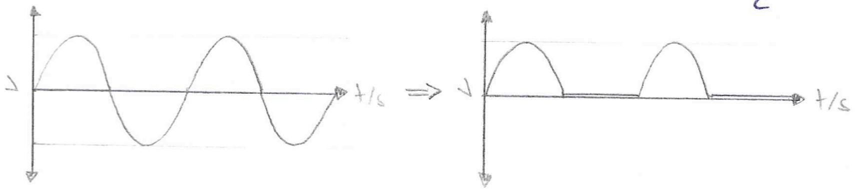
$\frac{V_2}{V_1} = \frac{N_2}{N_1}$ $\eta = \frac{P_{out}}{P_{in}} = \frac{V_2 I_2}{V_1 I_1}$ $\eta = 1$ $\frac{V_2}{V_1} = \frac{I_1}{I_2}$

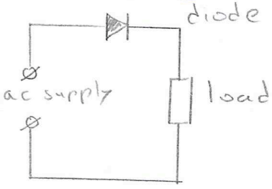
- Notional grid - network of power lines transmitting electrical energy
  - ↳ AC - required by transformers used to step up/down voltage as required
    - easily converted to DC
  - ↳ High voltage - reduces losses to heating in power lines at a constant P I↓ so $P_{lost} = I^2R$

- diode - semi conductor - allows I to only flow in 1 direction

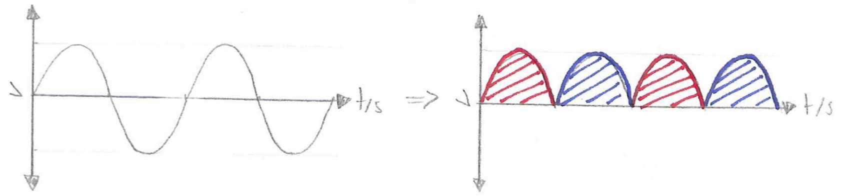
- Rectification - process which makes AC flow in only 1 direction

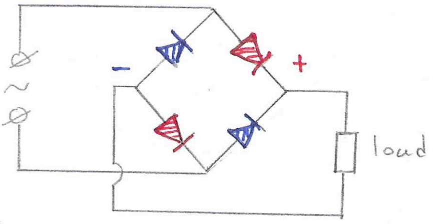
↳ Halve way rectification - only $\frac{1}{2}$ P_{RMS} available



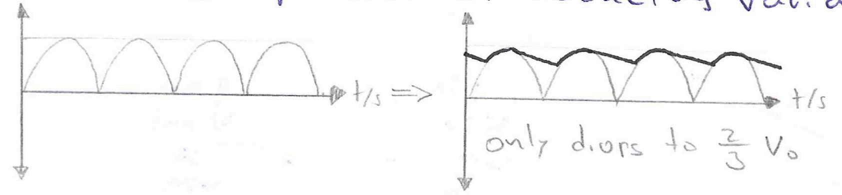


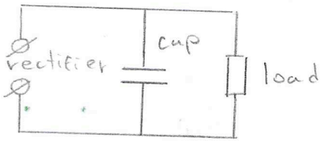
↳ Full wave rectification - all of P_{RMS} available





- Smoothening - process of reducing variation in rectified voltage





↳ to reduce ripple : - ↑ C of capacitor

- ↑ R of load so smaller I slower discharge of C

$V_{ripple} \propto RC$

- Thermocouple  ✓ - self powered, wide range, responsive, cheap

✗ - non-linear, low voltage (amplifier), low sensitivity

- RTD  ✓ - most stable, most accurate, most linear

✗ - expensive, self heating, current source required

- Thermistor  ✓ - high output V, only 2 wires, measured in ohms

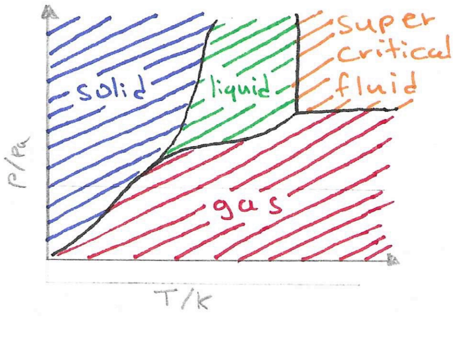
✗ - non-linear, limited range, fragile, self heating

- thermodynamic temperature - k $T_{(k)} = \theta_c + 273.15$

- 0k - absolute zero - temp at which particles have 0 E_k

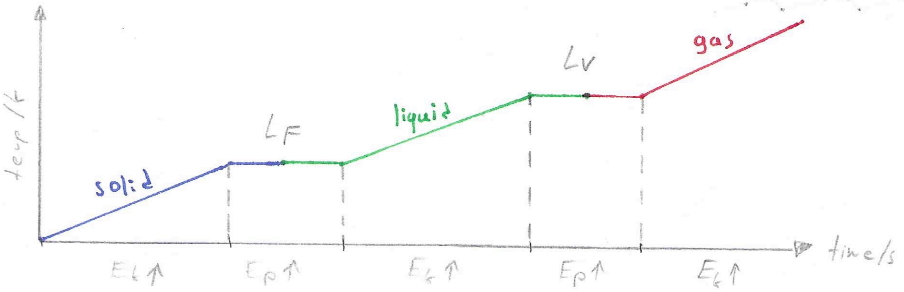
- triple point of H_2O - 273.16k 6.12 Pa

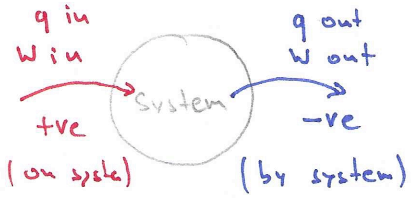
↳ point at which pure H_2O exists in a thermodynamic equilibrium with ice, water, vapour



- Thermal equilibrium
  - ↳ two systems at the same temperature and there is no net flow of thermal energy between them
- Thermal capacity - C
  - ↳ amount of thermal energy required to raise temp of body by 1K
- Specific thermal capacity - c
  - ↳ amount of thermal energy required to raise temp of body of mass 1kg by 1k (unit mass)
- Specific latent heat - L
  - ↳ amount of thermal energy required to change state of unit mass of pure substance without a ΔT

L_F - fusion L_V - vaporisation





- Thermal energy - Q
  - ↳ component of systems internal E due to its temp, random distribution of translational E_k of particles.
- Heat - net flow of thermal energy
- Internal energy - U
  - ↳ sum of random distribution of translational kinetic and potential energies
- 1st law of thermodynamics
  - ↳ formal statement of conservation of E $\Delta U = q + W$
- pressure
  - ↳ normal force excerted per unit area by gas on walls of container
- Volume
  - ↳ measure of space occupied by gas

- Brownian motion
  - ↳ random motion of massive particles due to collisions with smaller lighter particles

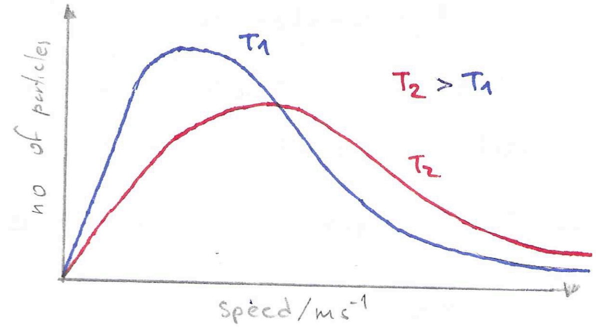
- Amount of substance - mol - n
  - ↳ amount of substance which contains same number of particles as there are atoms in 0.012 kg of C-12 isotope
- molar mass - M
  - ↳ mass of 1 mole of substance $n = \frac{N}{N_A} = \frac{m}{M}$
- avogadro constant - N_A $N_A = 6.02 \times 10^{23}$
- avogadros law $\frac{V}{n} = k$
  - ↳ same vol of different gases at same temp and pressure will contain equal no of particles
- Ideal gas law - only for ideal gases

$pV = nRT$ $R = 8.31 \ Jmol^{-1}k^{-1}$ molar gas constant

$pV = NkT$ $k = 1.38 \times 10^{-23} \ Jk^{-1}$ Boltzman constant

- ↳ assumed ideal at ↓P and ↑T

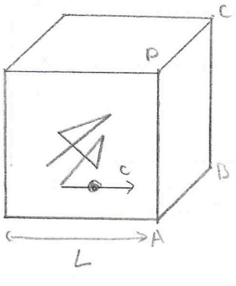
- Maxwell Boltzmann distribution
  - ↳ A under curve = no of particles ∴ A stays constant



- root mean square speed - C_{rms}
- mean square speed - $\langle c^2 \rangle$

$$C_{rms} = \sqrt{\frac{\sum^{N} (c_i)^2}{N}} \quad \langle c^2 \rangle = (C_{rms})^2 = \frac{\sum_i^N (c_i)^2}{N}$$

- assumptions
  - ↳ particles moving with random + continuous motion
  - ↳ particles have negligable vol compared to gas (container)
  - ↳ all collisions perfectly elastic
  - ↳ duration of collisions << time between collisions
  - ↳ no potential energy of particles - no forces between them
- mean translational kinetic energy of a particle or ideal gas is proportional to the thermodynamic temperature



$V = L^3$

$t = 2\frac{L}{c}$ $\Delta p = -2mc$

$F = \frac{\Delta p}{\Delta t}$

$= \frac{-2mc}{2\frac{L}{c}}$

$= -\frac{mc^2}{L}$

$P = \frac{F}{A} = \frac{mc^2}{V}$

$\langle c^2 \rangle = C_x^2 + C_y^2 + C_z^2$

$c^2 = \frac{1}{3}\langle c^2 \rangle$

$P = \frac{1}{3} \frac{Nm\langle c^2 \rangle}{V}$

$= \frac{1}{3} \rho \langle c^2 \rangle$

$PV = \frac{1}{3} Nm \langle c^2 \rangle$

$\langle E_k \rangle = \frac{3}{2} nRT$ - for gas

$\langle E_k \rangle = \frac{3}{2} kT$ - for particle

$\langle E_k \rangle \propto T$ $C_{rms} \propto \sqrt{T}$

- photon - discrete quantized packet of EM radiation energy

- proof of wave nature - diffraction + interference
 proof of particulate nature - photoelectric effect

- electron volt
 ↳ amount of E transferred to single e^- accelerated through pd of 1V

- treshold frequency - f_0
 ↳ minimum frequency of photons required to release e^- from metal surface

- work function energy - ϕ
 ↳ minim E required to for an e^- to escape metal surface ($E_k = 0$)

$\phi_{metal} \approx 10^{-19}$ $\lambda = \frac{c}{f}$ $E_\gamma = hf = \frac{hc}{\lambda}$ $E_\gamma = \phi + E_k$

$hf = hf_0 + \frac{1}{2} m_e V^2$

- observations
 ↳ Treshold f - photoelectric effect only occours if f above certain value
 ↳ Time of emission - e^- emitted instantaneously or never if $f < f_0$
 ↳ Intensity - greater intensity greater no of e^- emitted per time if $f > f_0$
 ↳ Max E_k of photoelectrons - only depends on f of light

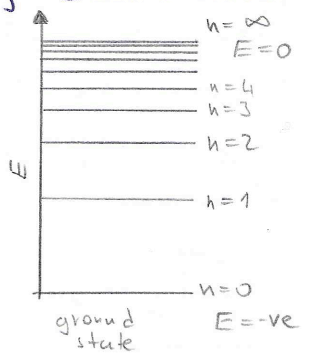
- photoelectric current - I_p
 ↳ rate of emission of e^- $I_p \propto I$ $I_p \propto \frac{1}{f}$ at constant P

- max E_k of photoelectrons
 ↳ independent of intensity

- ionisation energy
 ↳ amount of E required to remove a valence e^- of isolated gaseous atom to form isolated gaseous ion

- causes of ionisation - nuclear radiation, heating, passing electric curret

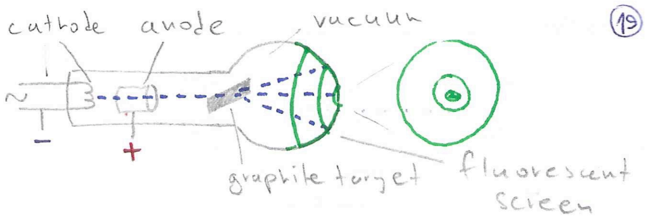
- excitation
 ↳ promotion of e^- to higher E levels within atom
 ↳ incoming e^- collides with valence e^- transfering E_k to excite the valance e^-
 ↳ incoming γ absorbed by e^- and its E excites e^- occours only if $E_\gamma = \Delta E$



- line spectra - only in vapours/gases at low P
 - γ re-emitted in all directions

- absorption spectra - white light passed through cool gas

- De Broglie wavelength $\lambda = \frac{h}{p}$
  ↳ longer wavelength less particle like

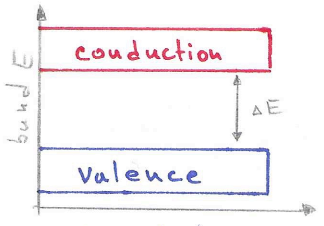


- graphite target acts as diffraction grating in 2 planes ∴ circular pattern

- if anode-cathode voltage ↑ speed of e^- ↑ so $\lambda \downarrow$ ∴ less diffraction

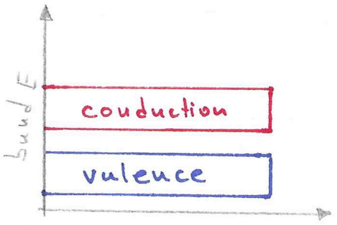
  $\lambda = 2d\sin\theta$ d - lattice spacing

- bands created from line spectra since bonding in solids affects ΔE and spreads out spectral line into band



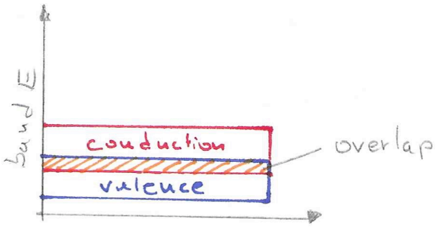
insulator

valance band full
large ΔE



semi-conductor

valence band full
small ΔE



conductor

conduction band already partially filled

- resistance of metals
  ↳ as T ↑ rate of collision of e^- with ions in lattice ↑ so resistance slightly increases $V_d \downarrow$ $I = NAV_dq$ $I\downarrow$ $R = \frac{V}{I}$ $R\uparrow$

- resistance of semi conductors
  ↳ as T ↑ e^- absorb thermal E and jump to conduction band + leave behind +ve holes. both e^- + holes act as charge carriers so resistance significantly ↓. ↑ in collision is insignificant N ↑

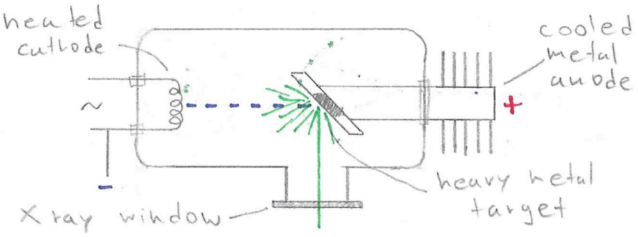
- Brehmstrahlung radiation - from deceleration of charged particles
  ↳ range of decelerations of e^- so gives continuous distribution of λ of photons produced

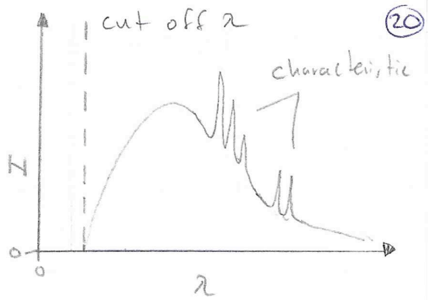
- cut off wavelength - highest E photon when all E_k of $\overset{\text{single}}{e^-}$ goes to E of single produced photon

  $W = qV$ $E_\gamma = \frac{hc}{\lambda}$ $\lambda = \frac{hc}{qV}$

- characteristic radiation - e^- from beam collide with valence e^- giving them E_k to excite them
  - e^- de-excite and emit γ giving line spectrum

- X rays emitted in all directions + 1% input power goes to X rays so rest is lost as heat





- cooling anode - copper good heat conductor
  - fins to ↑ SA + black surface + water cooling
  - andde spun to ↑ target area

- intensity - (mA) - tube current   - hardness - (kV) - tube voltge

- Attenuation of X ray photons
  ↳ some γ absorbed but individual E_γ constant $I = I_0 e^{-\mu x}$

- Halve value thickness - $x_{\frac{1}{2}}$
  ↳ distance in medium which wave has to travel for transmitted intensity to decrease to ½ original $x_{\frac{1}{2}} = \frac{\ln 2}{\mu}$

- sharpness - good definition of edges between 2 body parts (features)
  ↳ limiting aperture (overlapping metal plates)
  ↳ small area of target anode

- contrast - difference in degree of blackening between neighbouring features
  ↳ collimator grid - only transmits normal rays
  ↳ contrast medium - e.g. barium meal

- reduce exposure
  ↳ aluminium filter across window - filters out soft X rays
  ↳ high sensitivity detector or flourescent backing

- voxel - 3 dimensional imaginary cubes

- ray sum - resultant attenuation of X ray beam passing through all voxels along a line

- background intensity - sum of readings in each detector position

- CT scan
  ↳ ✓ better detail, 3D, most organs visible
  ↳ ✗ requiers no motion, high dose, risk of childhood cancer if pregnant

- principles of CT
  1.) X ray images taken of crossection in one plane
  2.) repeated at different angles in same plane
  3.) data recorded + processed
  4.) detailed 2D image of each crossection produced
  5.) repeated for sucessive crossections (planes)
  6.) 3D image build up
  7.) final image viewed from different angles/rotated
  8.) computer used to process + store large sets of data

- total mass + energy of isolated system is constant

- mass of nucleus allways < total mass of nucleons making it up

- mass defect - Δm
  ↳ difference between mass of nucleus and total mass of its nucleons

  $\Delta m = \Sigma m_{nucleons} - m_{nucleus}$ $E = mc^2$

- binding energy - E_B
  ↳ energy required to separate all nucleons of nucleus to ∞

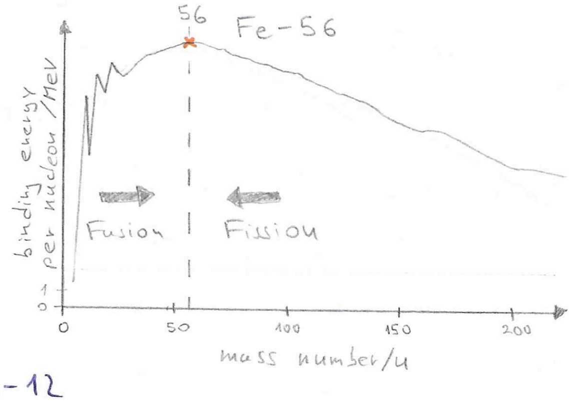
  $E_B = \Delta m c^2$ in MeV $E_B = \Delta m \times 934$

  $E_{BN} = \frac{E_B}{A}$

- binding energy per nucleon - E_{BN}
  ↳ indicates how tightly nucleons are bonded on average

- maximum E_B per nucleon at Fe-56
  ↳ most stable and potential well is deepest

  $E_{BN} \approx 8.818$ MeV



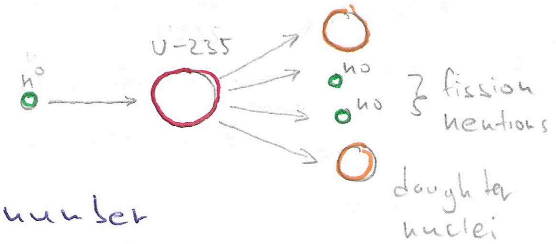
- mass excess
  ↳ $m_{nucleus}$ - nucleon number (A)
  ↳ if +ve has more E_B per nucleon than C-12 likely to be unstable

- Fission - splitting of heavy unstable nuclei into lighter approximately same size nuclei
  ↳ spontaneous or induced

- Fusion - combining of 2 lighter nuclei to form a single heavier nucleus
  ↳ occurs only if nuclei have sufficient E to overcome electrostatic repulsio to get close enough to be attracted by strong nuclear force

- reaction energetically feasible if E_B products > E_B reactants
  - ↳ energy released given as -ve ΔE_B or $(M \text{ products} - M \text{ reactants}) c^2$

- smallest amount of mass required to reach chain reaction - critical mass



- A - nucleon number Z - proton number N - neutron number

- radioactive decay
  - ↳ random disintegration of unstable nucleus by emission of particles or photon (EM E) to give more stable nucleus

- activity - A
  - ↳ number of unstable radioactive nuclei which decay per unit time [A] = Bucquerel (Bq)
  - ↳ depends on: decay constant - λ, no of unstable nuclei - N

- decay constant - λ
  - ↳ constant probability of decay per unit time
  - ↳ remains constant

$$A = \lambda N$$

$$A = -\frac{dN}{dt}$$

- random decay
  - ↳ constant P per unit time of nucleus but can't determine which particular nucleus decays next

- spontaneous decay
  - ↳ unaffected by presence of other nuclei or environment / conditions e.g.) chem reaction, temp, pressure

- halve life - $t_{\frac{1}{2}}$
  - ↳ time taken for no of radioactive particles in sample to halve from initial value
  - ↳ time taken for activity of radioactive sample to halve from original value

$N = N_0 e^{-\lambda t}$ $A = A_0 e^{-\lambda t}$ $t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$