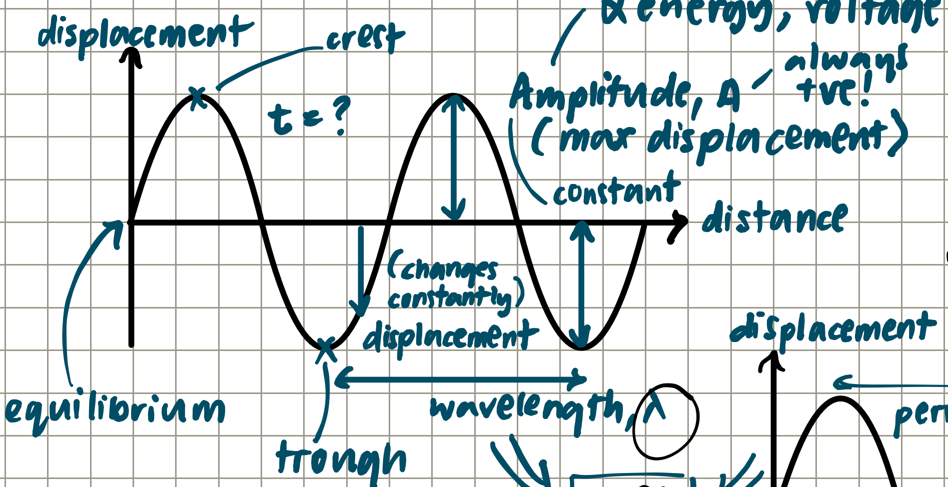
PROGRESSIVE WAVES

└ waves that move through a material (medium) from one position to another

√ energy
X matter

- * Describe the motion of transverse and longitudinal waves
- * Describe waves in terms of their wavelength, amplitude, frequency, speed, and phase
- * State the nature of electromagnetic waves

Displacement - distance graph
y-axis x-axis

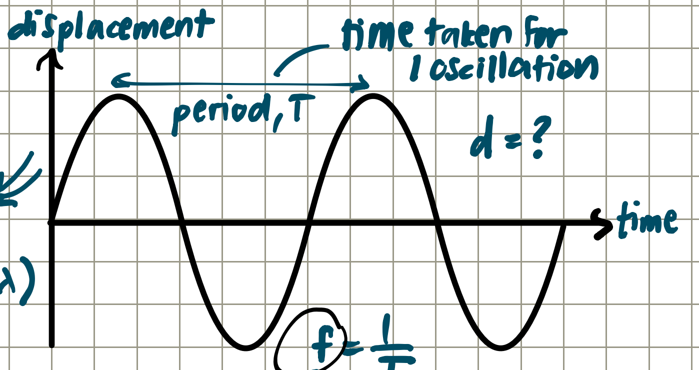


speed!

$\boxed{v = f\lambda}$

$v = \frac{\lambda}{T} = \frac{1}{T}(\lambda)$

Displacement - time graph
y-axis x-axis

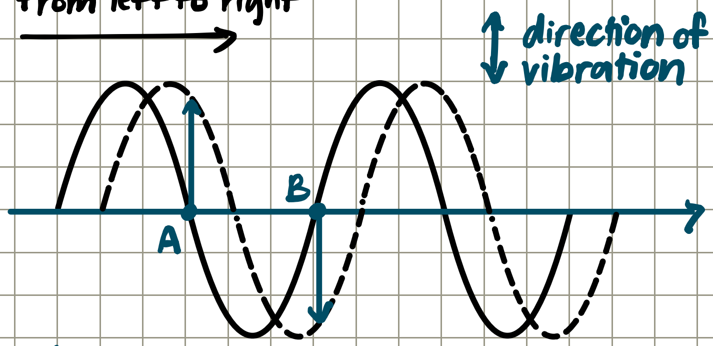


$f = \frac{1}{T}$

number of oscillations per unit time

[TRANSVERSE WAVES]

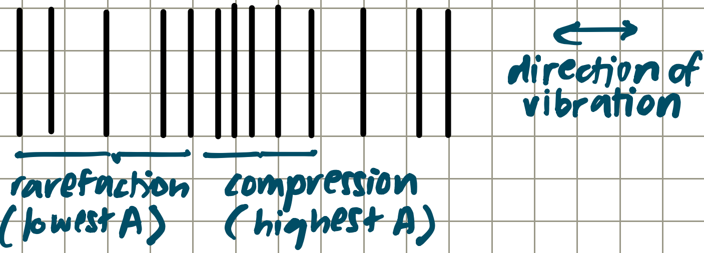
from left to right



90°

particles vibrate / oscillate perpendicular to the direction of wave velocity

[LONGITUDINAL WAVES]



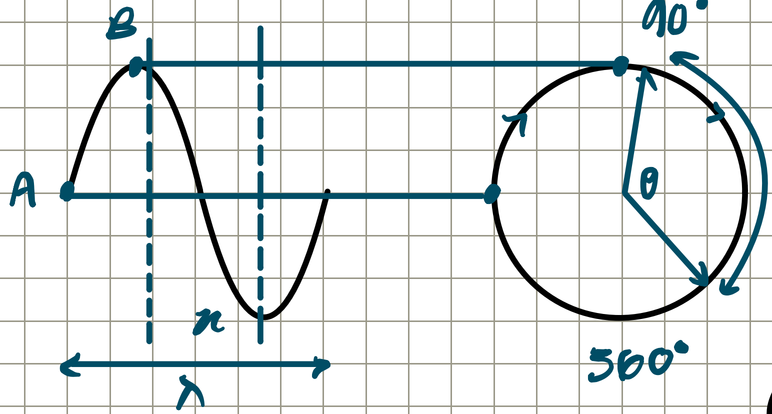
particles vibrate / oscillate parallel to the direction of wave velocity

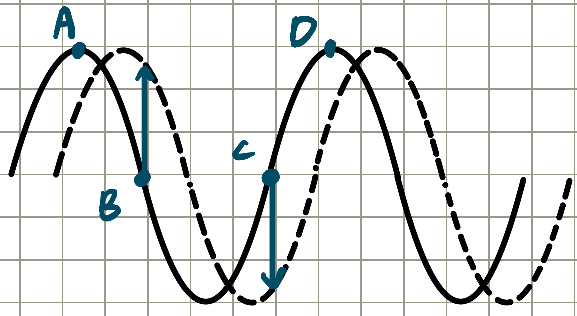
PROGRESSIVE WAVES

Phase difference

↳ a fraction of a cycle between 2 oscillating particles / 2 points in a wave

degree / radians





A & D are in phase
B & C are not in phase

$$\boxed{\frac{x}{\lambda} = \frac{\theta}{360^\circ}}$$

V = $3.0 \times 10^8\ ms^{-1}$
C
constant!
(travels w/o medium)

[ELECTROMAGNETIC WAVES]

transverse!

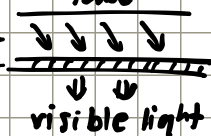
Electric current ⇌ Magnetic field } produces each other

constantly changing directions (oscillating / vibrating)

$\boxed{E \propto f}$

SPECTRUM $c = f\lambda,\ f \propto \frac{1}{\lambda}$

λ		
> 0.1 m	Radiowaves (oscillating charges	longest λ
> 1 mm (1×10^{-3})	Microwaves = natural f of H_2O	} resonance ↑E, ↑heat
> 700 nm (7×10^{-7})	Infrared - heat! (produced by humans	
400 nm – 700 nm	Visible light - ROYGBIV	excited electrons within atoms
< 400 nm (4×10^{-7})	Ultraviolet	fluorescent layer — discharge tube — visible light
< 10 nm (1×10^{-8})	X-rays	
< 0.1 nm (1×10^{-10})	Gamma rays (inside sun)	kill cancer



↑ f can cause cancer (mutation of DNA)

short λ = can aim at specific locations precisely

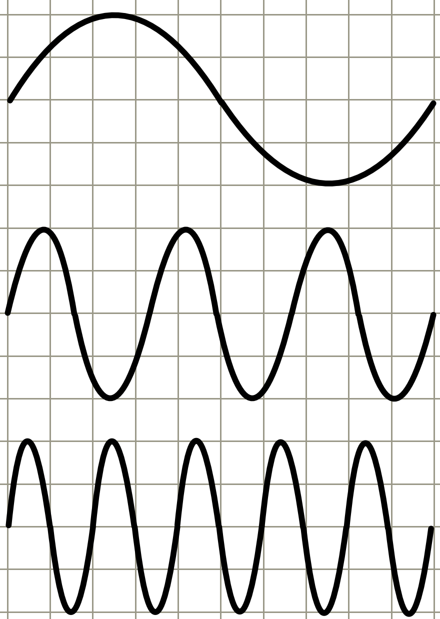
Superposition!

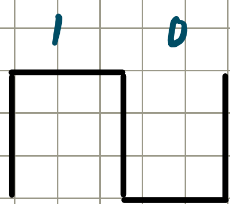
to produce binary signals

f

3f

5f





(phase-locking)

WAVE INTENSITY

$\boxed{E \propto t a I}$

surface area (perpendicular to source)

time of exposure

how much energy is absorbed?

how much? how close to the source?

★ Describe the power carried by waves through intensity

★ State how intensity reduces with distance

$E = kIat,\ k = 1$

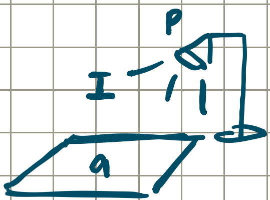
$E = Iat$

$\frac{E}{t} = Ia$

Rate of energy ⇒ Power, P

$P = Ia$

$I = \frac{P}{a}$



Intensity (Wm^{-2})

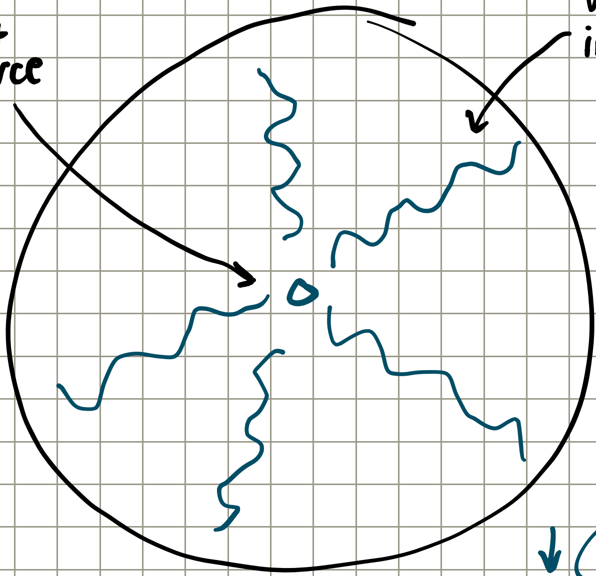
└ the rate of energy transmitted per unit area at right angles to the wave velocity

power

perpendicular to source

vector; direction

Point source



wave transmitted in all directions

⇓

sphere shape!

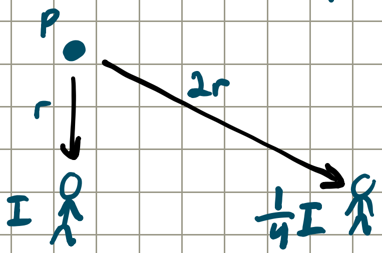
$I = \frac{P_{local}}{a_{local}}$

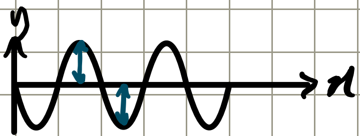
$I = \frac{P_{source}}{a_{global}}$, $a_{global} = 4\pi r^2$

constant

$I = \frac{P_{source}}{4\pi r^2}$

$\boxed{I \propto \frac{1}{r^2}}$





$\boxed{I \propto A^2}$

$I \propto P$

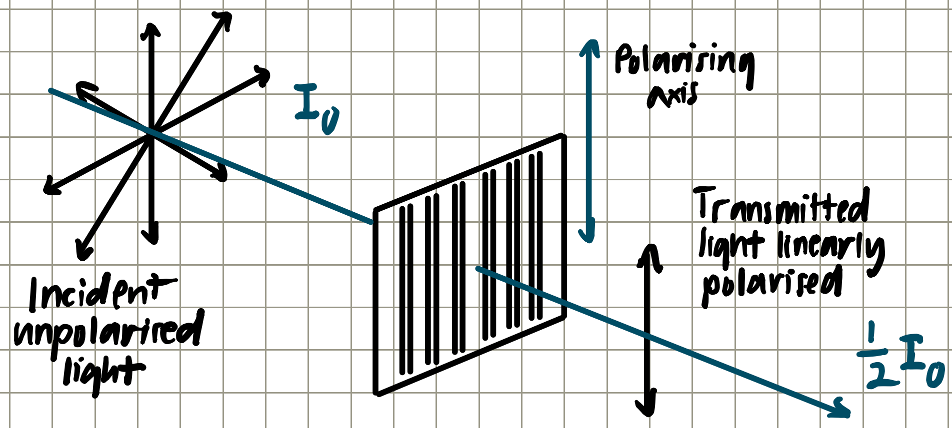
$\propto$ Energy of oscillation $\propto$ amplitude

$\propto \frac{1}{2}k(x_{max})^2$ max displacement

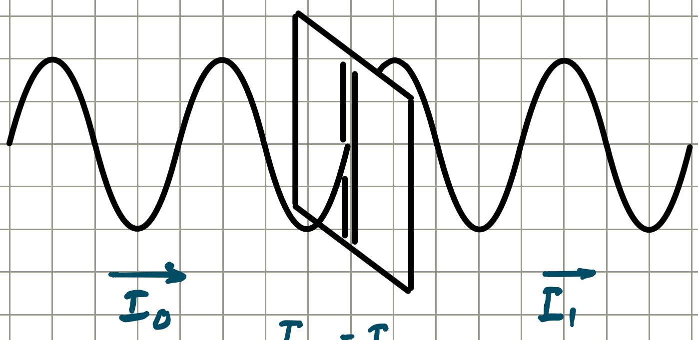
Hooke's Law

$\propto A^2$

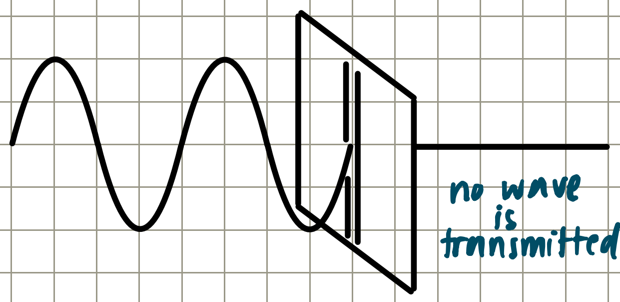
POLARISATION



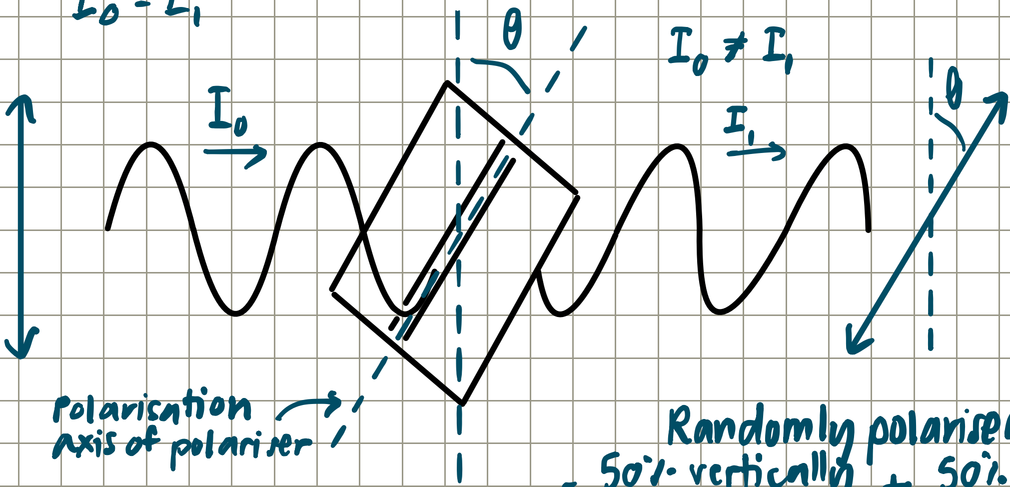
- ★ Understand that polarisation is a phenomenon associated with transverse waves
- ★ Recall and use Malus' law to calculate the intensity of a plane polarised wave after transmitting through a polariser



$I_0 = I_1$



$I_0 \neq I_1$



Polarisation axis of polariser

Randomly polarised light = 50% vertically polarised + 50% horizontally polarised

charge (scalar)

$F = qE$

force (vector)

energy (vector)

magnitude & direction ← amplitude ?

$I_1 \propto (A\cos\theta)^2$

$I_0 \propto A_0^2$ $\quad$ $I_1 \propto A^2\cos^2\theta$

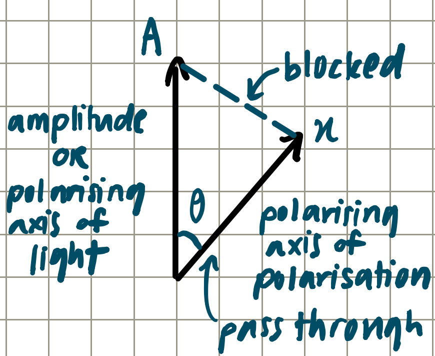
$I_0 = cA_0^2$ $\quad$ $I_1 = cA^2\cos^2\theta$

$$\frac{I_1 = \cancel{c}\cancel{A^2}\cos^2\theta}{I_0 = \cancel{c}\cancel{A^2}}$$

$$\frac{I_1}{I_0} = \cos^2\theta$$

Malus' Law

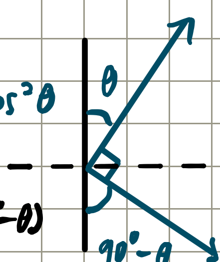
$$\boxed{I_1 = I_0\cos^2\theta}$$



$\cos\theta = \frac{x}{A}$

$x = A\cos\theta$

$\frac{1}{2}I_0\cos^2\theta$



$\frac{1}{2}I_0\cos^2(90°-\theta)$

$= \frac{1}{2}I_0\sin^2\theta$

$\frac{1}{2}I_0\cos^2\theta + \frac{1}{2}I_0\sin^2\theta$

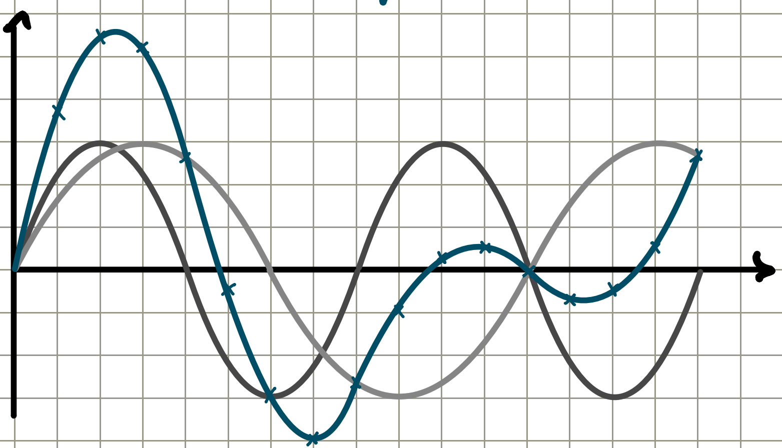
$= \frac{1}{2}I_0$

SUPERPOSITION

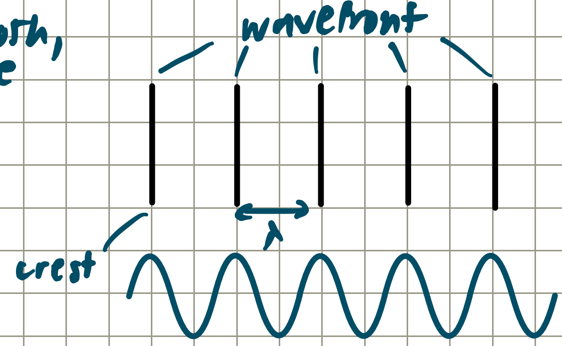
when two/more waves meet, resultant displacement = sum of displacement of individual waves

$$\underbrace{f(x)}_{\text{resultant}} = \underbrace{f_1(x) + f_2(x)}_{\text{components}}$$

* if components' wave are smooth, resultant wave is smooth



* Explain and use the principle of superposition of waves



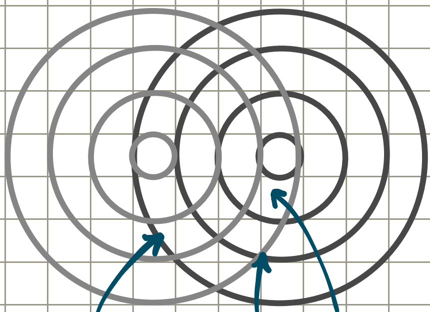
[DIFFRACTION]

└ spreading of waves as it passes through a gap

a < λ, wave does not pass through

[INTERFERENCE]

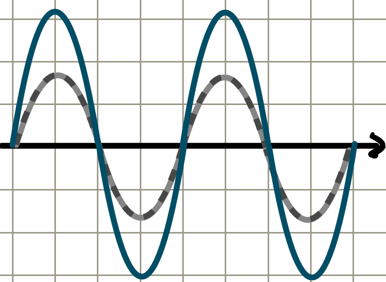
(two or more waves meet or overlap



destructive interference (crest + trough)

constructive interference (crest + crest) OR (trough + trough)

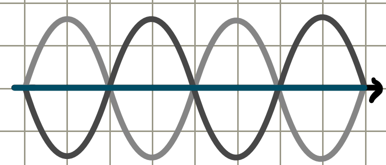
CONSTRUCTIVE INTERFERENCE



A + A = 2A

$$|S_1P - S_2P| = n\lambda$$

DESTRUCTIVE INTERFERENCE

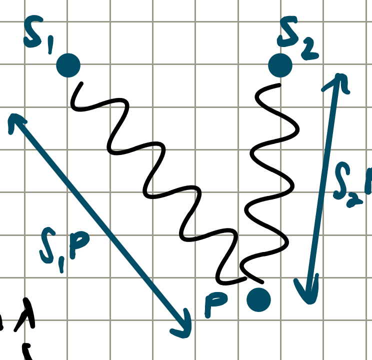


A − A = 0

$$|S_1P - S_2P| = \left(n + \tfrac{1}{2}\right)\lambda$$

$n = 0, 1, 2, 3 \ldots$

[PATH DIFFERENCE]



in λ → $|S_1P - S_2P|$

PHASE DIFFERENCE

$$\theta = \frac{|S_1P - S_2P|}{\lambda} \times 360^\circ$$

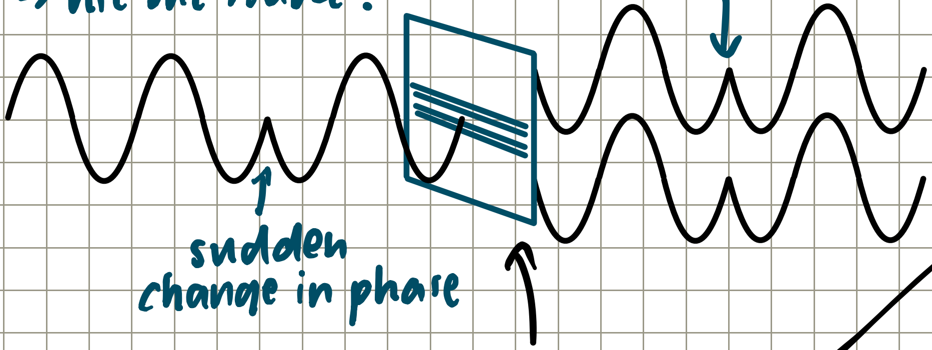
[coherent source
└ same frequency
└ zero / constant phase difference

INTERFERENCE OF WAVES

↳ only possible if the two sources are COHERENT
- same frequency / wavelength
- constant phase difference

how? → use one source!

- ✱ Explain and elaborate the Young's double slit interference pattern
- ✱ Solve problems involving the Young's double slit interference pattern



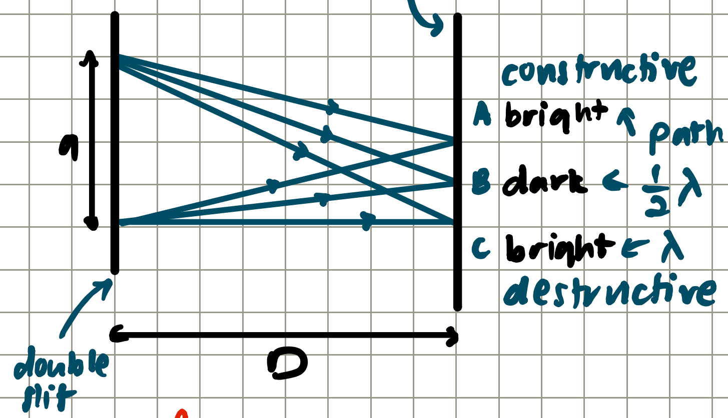
YOUNG'S DOUBLE-SLIT EXPERIMENT

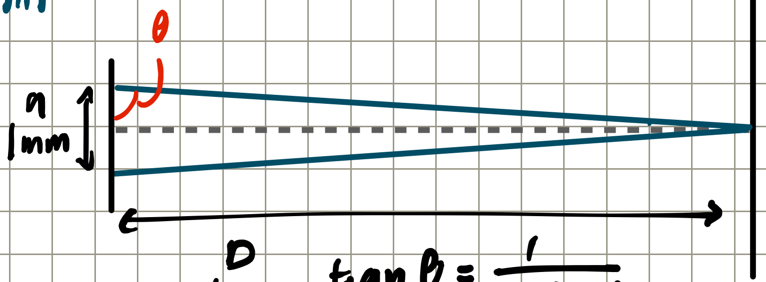
require monochromatic source (ie. laser!)

determining wavelength, λ

$$\boxed{\lambda = \frac{ax}{D}}$$

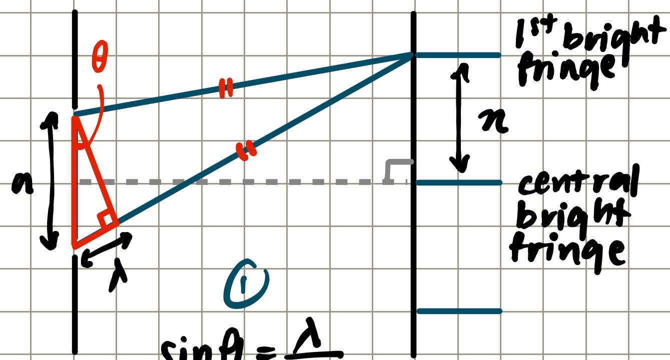
distance between AB & BC
↳ fringe separation, x



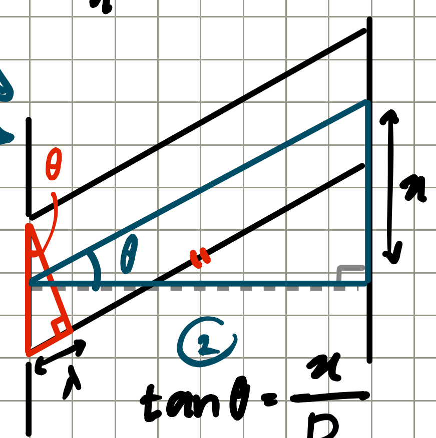


$$\tan\theta = \frac{1}{0.001}$$

$$\theta \approx 89.9° \Rightarrow 90°$$

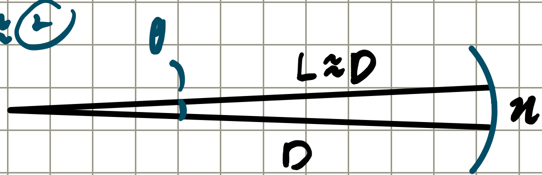


$$\sin\theta = \frac{\lambda}{a}$$



$$\tan\theta = \frac{x}{D}$$

① ≈ ②



circular measure

$$x = D\theta$$

$$\theta = \frac{x}{D} = \tan\theta$$

$$\theta \approx \frac{x}{L} = \sin\theta$$

$$\tan\theta = \sin\theta$$

$$\frac{\lambda}{a} = \frac{x}{D}$$

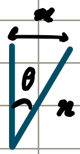
$$\boxed{\lambda = \frac{ax}{D}}$$

DIFFRACTION GRATINGS

$$x = \frac{\lambda D}{a}$$ } Two-slits (small angle)

$\sin\theta \approx \tan\theta$

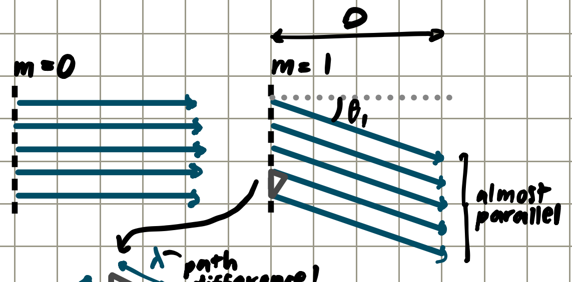
Diffraction gratings (large angle)



$\sin\theta \neq \tan\theta$

$x = \frac{ax}{D}$ is not applicable

large number of equally spaced lines

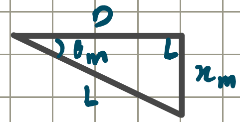


$\sin\theta = \frac{\lambda}{d}$

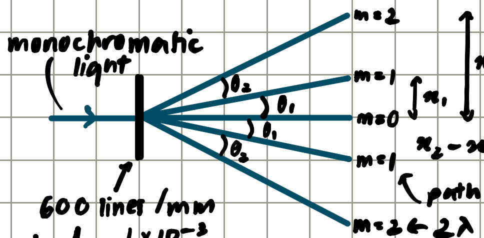
$\therefore \lambda = d\sin\theta$

$\llcorner\ m\lambda = d\sin\theta$

order	path diff.
0	0λ
1	λ
2	2λ
3	3λ



$\tan\theta_m = \frac{x_m}{D}$



$x_2 - x_1 \neq x_1$

600 lines/mm

$\therefore d = \frac{1\times10^{-3}}{600}$

Two-slits vs Diffraction grating

Two-slits	Diffraction grating
blurry	sharp & bright
small angle	large angle

Max number of maxima, m

$\sin\theta < 1$

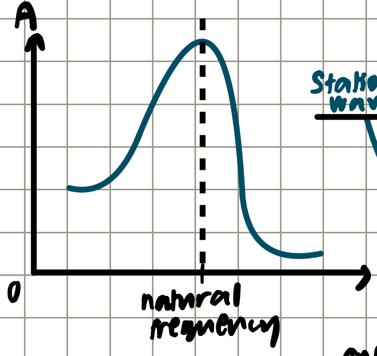
$\frac{m\lambda}{d} < 1$

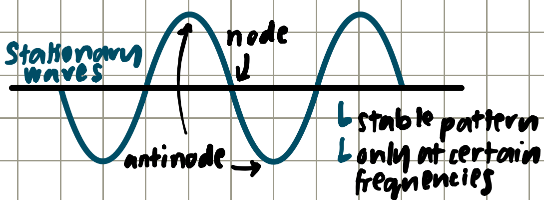
$$\boxed{m < \frac{d}{\lambda}}$$

STATIONARY WAVES

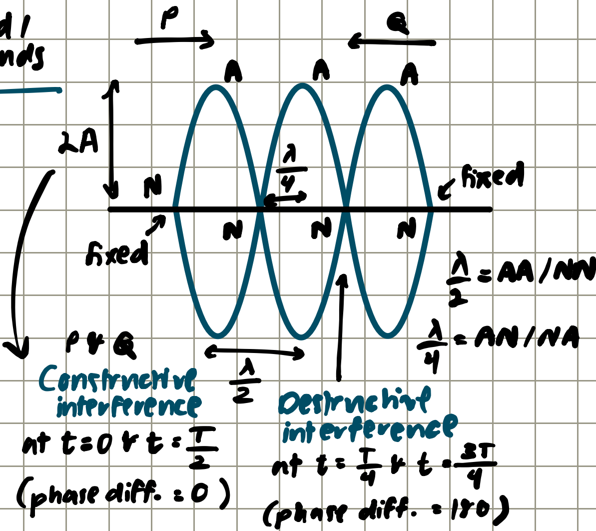
Resonance

- occurs when a system is forced to oscillate at its natural frequency by a driving force
  - natural freq. = driving freq.
  - amplitude grows drammatically
  - energy is transferred from driver to system

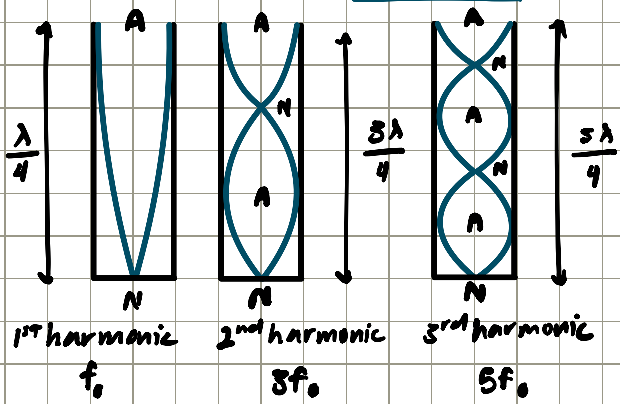


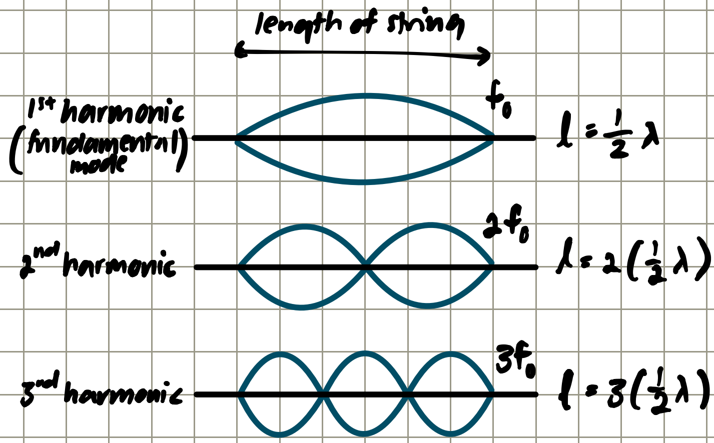


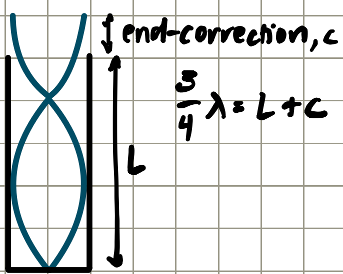
two fixed / closed ends



one fixed / closed end



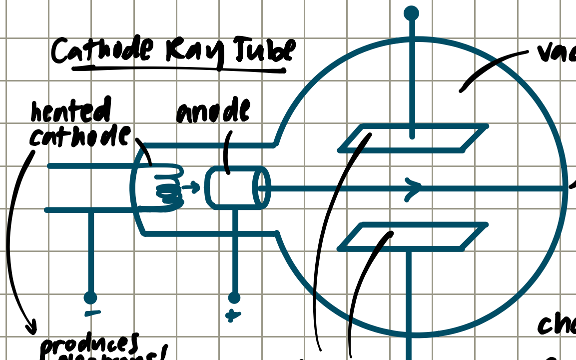


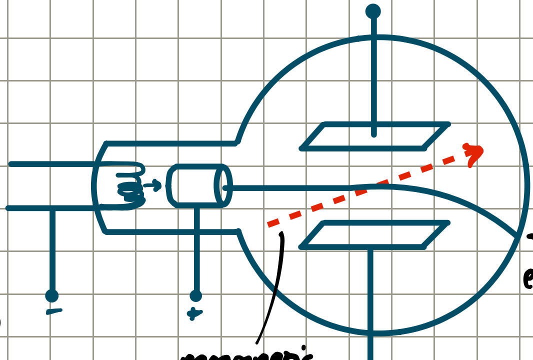


$$\frac{3}{4}\lambda = L + c$$

ELECTRONS AND THE STRUCTURE OF ATOM

Cathode Ray Tube

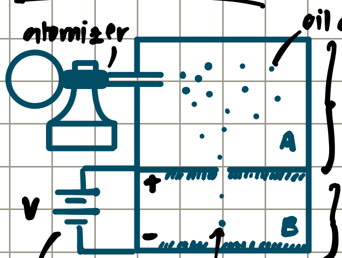




charge-mass ratio

$\frac{e}{m} = 1.76 \times 10^{11}\ C/kg$ → constant!

Millikan's Oil Drop



$F = F_r - mg$
$0 = F_r - mg$ (constant velocity)
$F_r = mg$

QE, v=0, mg

$QE = mg$

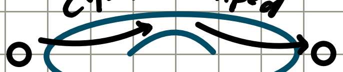
$Q = \frac{mg}{E}$ = multiples of $1.60 \times 10^{-19}\ C$ (charge of 1 electron)

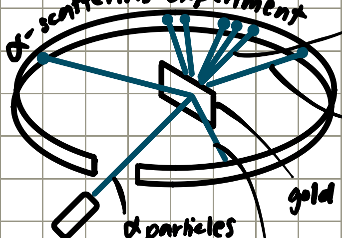
$m = \frac{e}{1.76 \times 10^{11}}$

$m = \frac{1.60 \times 10^{-19}}{1.76 \times 10^{11}}$

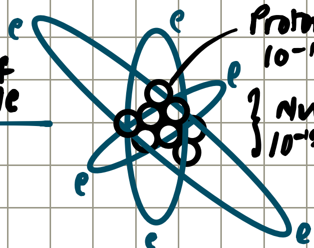
mass of 1 electron is

$m = 9.11 \times 10^{-31}\ kg$





Order of magnitude in m



Atom : 10^{-10}

Molecule : $10^{-10} - 10^{-6}$

Nucleon → Nucleon Number / Mass Number, A

$A = N + Z$ (N: neutron, Z: proton)

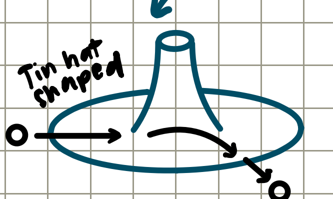
$^{A}_{Z}X$ ← symbol of elements

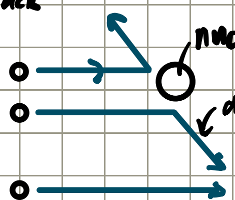
Isotopes
- same element
- same Z ← chemical property
- different A & N ← nuclear property { mass, density, boiling point

	Relative Mass	Charge
Proton (p)	1	+e
Neutron (n)	1	0
Electron (e)	1/1840	-e
Alpha-particle (α)	4	+2e

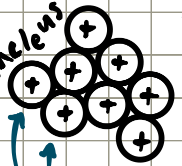
Alpha-particle: Helium nucleus $^{4}_{2}He$

$e = 1.60 \times 10^{-19}\ C$





density of proton $= \rho = \frac{m}{V} = 7.8 \times 10^{17}\ kgm^{-3}$



same charges should repel!

1. strong nuclear force hold protons and neutrons together — short range (10^{-14} m)
2. repulsive electrostatic force
3. gravitation between mass (attractive)
4. electromagnetic between charged objects (attractive & repulsive)

Z > 83
- nucleus too large
- unstable nuclei
- RADIOACTIVE DECAY

fast α radiation or slow

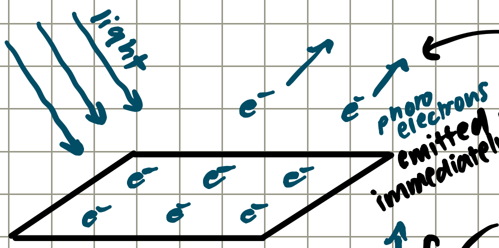
β radiation — weak nuclear force

if number of protons and neutrons are not balanced

γ radiation after, to release excess energy — speed of light

PHOTOELECTRIC EFFECT

— an interaction between a photon and an electron in a metal, in which an electron is removed from the surface



requires threshold frequency (minimum)

$\uparrow$ > e^- emitted

$\downarrow$ < e^- emitted

$L \propto E \propto I$

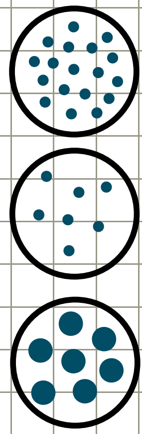
$\uparrow f \begin{cases} \uparrow E = \uparrow Pt = \uparrow IAt \\ \uparrow E = \frac{1}{2} m \uparrow v^2 \end{cases}$ } K_E

$\boxed{E = hf}$

Planck's constant 6.63×10^{-34} Js

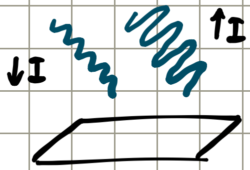
(packet) a quantum of EM energy

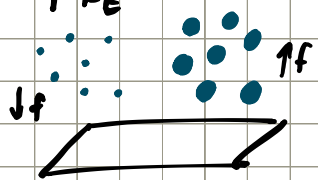
one photon per electron



Observations!

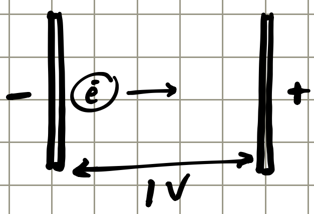
Wave theory (dependent on intensity)	vs	Particle theory (dependent on frequency)
✗ any frequency		✓ ↓ frequency, ↓ energy
✗ waiting time required		✓ whole photon is absorbed
✓ ↑ intensity, ↑ energy		✓ ↑ intensity, ↑ photons/second
✗ ↑ intensity, ↑ K_E		✓ ↑ frequency, ↑ K_E





Electron-volt (eV)

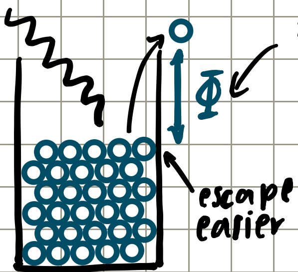
energy transfered when an electron travels through a potential difference of 1V



$1eV = QV$
$= 1.6 \times 10^{-19} \times 1$
$= 1.6 \times 10^{-19}$ J

energy!

Work Function

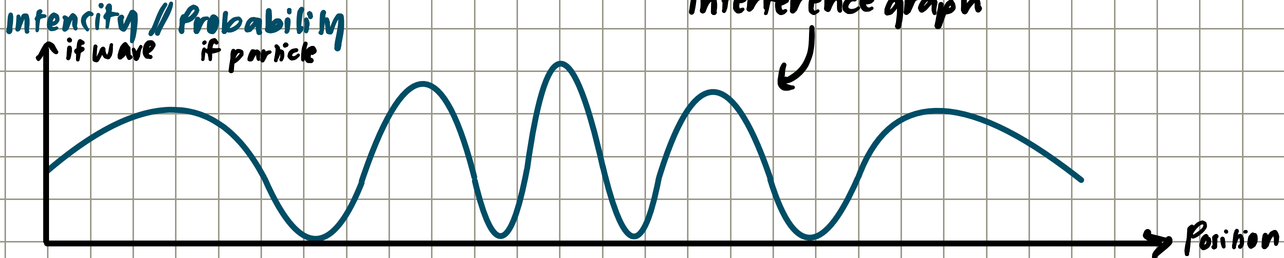


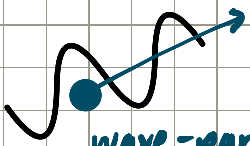
Φ — minimum energy required by an electron to escape metal surface

$\boxed{K_{max} = hf - \Phi}$

WAVE-PARTICLE DUALITY

Interference graph





wave-particle duality

De Broglie Wavelength

$\lambda = \frac{h}{mv}$

wave — particle (momentum)

$p = \frac{h}{\lambda}$

effect (dependent variable) — cause (independent variable)

$c = f\lambda$

$\lambda = \frac{c}{f}$

energy

$p = \frac{hf}{c}$

$E = mc^2$

$\frac{E}{c} = mc$

momentum!

$p = \frac{E}{c}$

LINE SPECTRA

momentum & energy

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

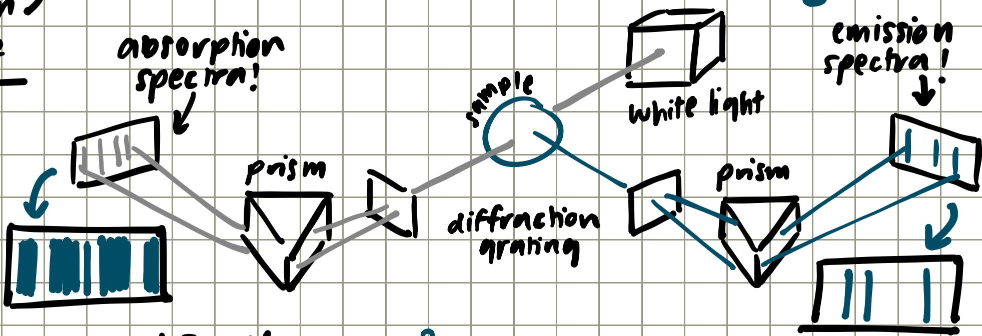
$p = mv$

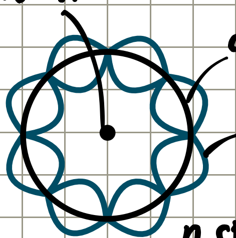
$v = \frac{p}{m}$

$E = \frac{1}{2}m\left(\frac{p}{m}\right)^2$

$= \frac{1}{2}\frac{mp^2}{m^2}$

$E = \frac{p^2}{2m}$





n standing waves

8 waves!

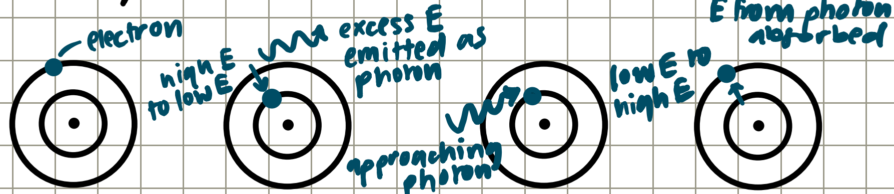
quantum number, n = 8

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

* $E_n = -\frac{2.179 \times 10^{-18}}{n^2}\,J$

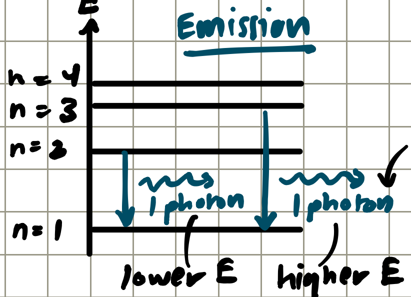
discrete energy

lowest n = 1 (ground state)



Emission spectra

Absorption spectrum



E of photon = diff. in E level

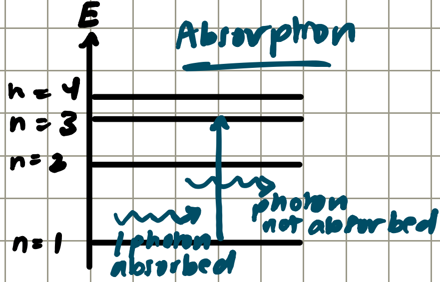
$\Delta E = |E_2 - E_1|$

ΔE = photon energy

$\Delta E = hf$

$\Delta E = \frac{hc}{\lambda}$

$\lambda = \frac{hc}{\Delta E}$



(exactly the right E (resonance)