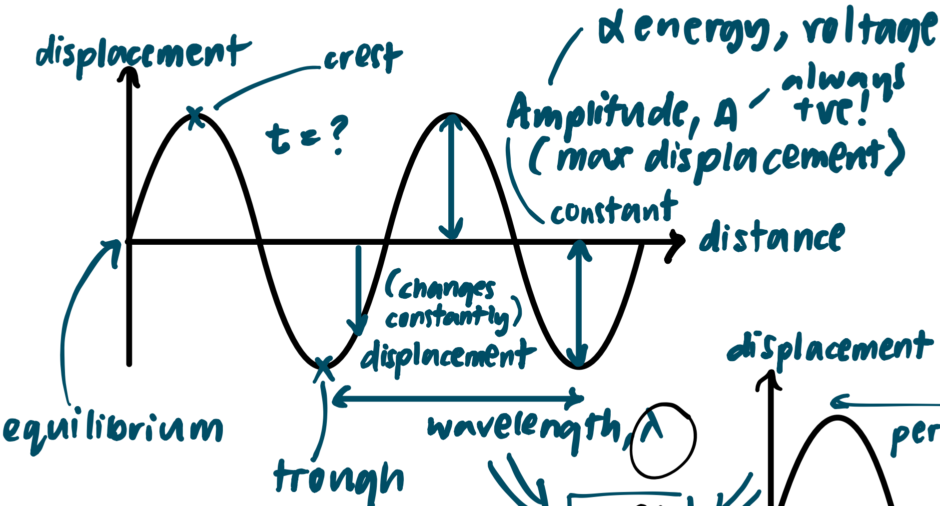
PROGRESSIVE WAVES

└ 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

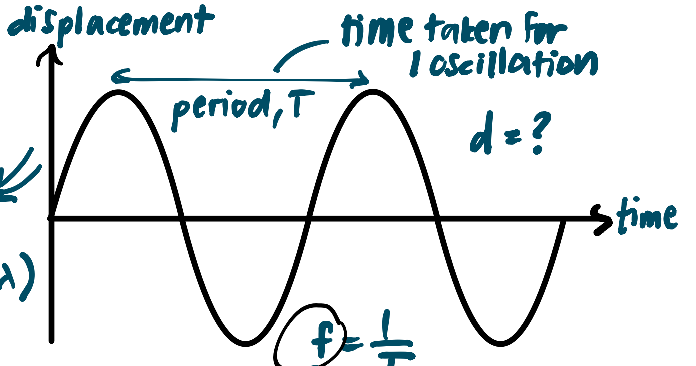


speed!

$$\boxed{v = f\lambda}$$

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

Displacement-time graph
y-axis — x-axis



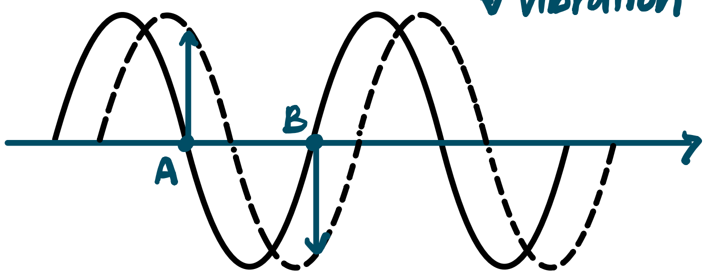
$$f = \frac{1}{T}$$

number of oscillations per unit time

[TRANSVERSE WAVES]

from left to right

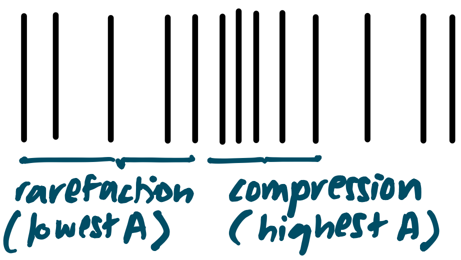
↕ direction of vibration



90°

particles vibrate / oscillate perpendicular to the direction of wave velocity

[LONGITUDINAL WAVES]



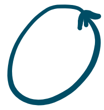
↔ direction of vibration

particles vibrate / oscillate parallel to the direction of wave velocity

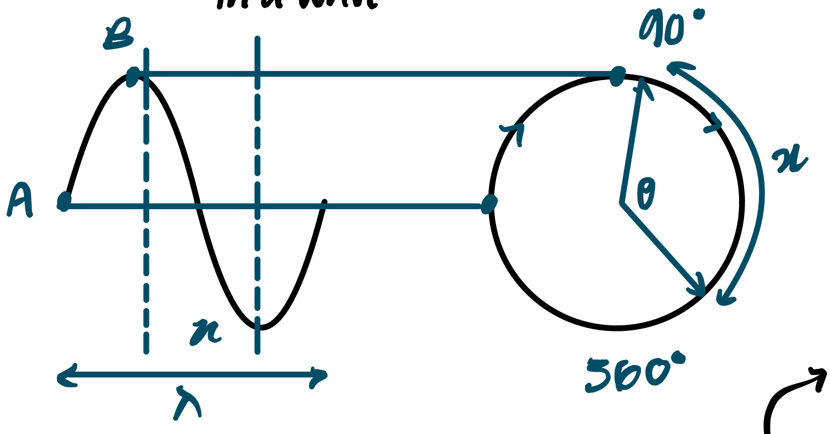
PROGRESSIVE WAVES

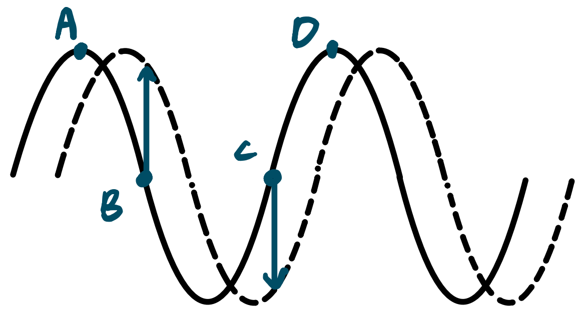
Phase difference

degree / radians



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





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)

$\boxed{E \propto f}$

↑ f
can cause cancer (mutation of DNA)

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

λ

> 0.1 m — Radio waves — longest λ
(oscillating charges

> 1 mm (1×10^{-3}) — Microwaves = natural f of H_2O } resonance
↑E, ↑heat

> 700 nm (7×10^{-7}) — Infrared — heat! (produced by humans)

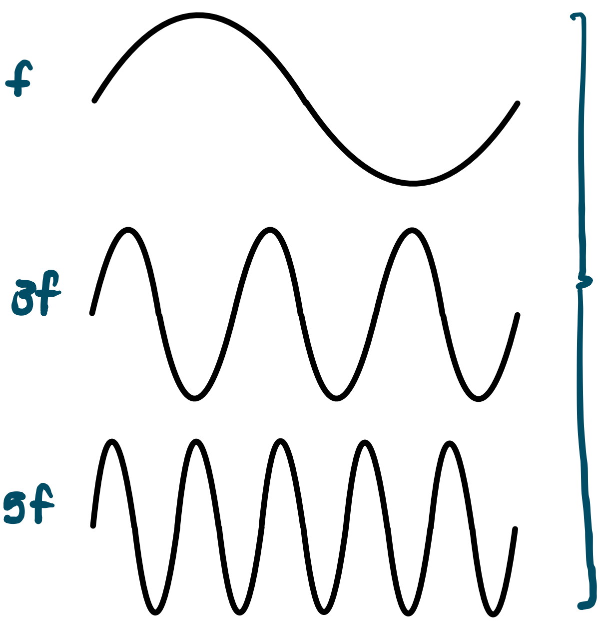
400 nm – 700 nm — Visible light — excited electrons within atoms
ROYGBIV

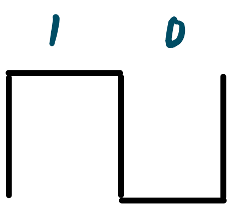
< 400 nm (4×10^{-7}) — Ultraviolet — discharge tube, fluorescent layer → visible light

< 10 nm (1×10^{-8}) — X-rays

< 0.1 nm (1×10^{-10}) — Gamma rays — inside sun / kill cancer
short λ = can aim at specific locations precisely

Superposition!
to produce binary signals





(phase-locking)

WAVE INTENSITY

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

surface area (perpendicular to source)

how much energy is absorbed?

time of exposure

how much? how close to the source?

* Describe the power carried by waves through intensity
* State how intensity reduces with distance

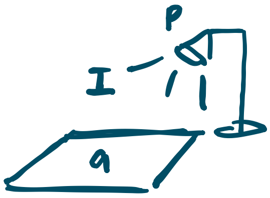
$E = kIat$, $k = 1$

$E = Iat$

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

Rate of energy ⇒ Power, P

$P = Ia$

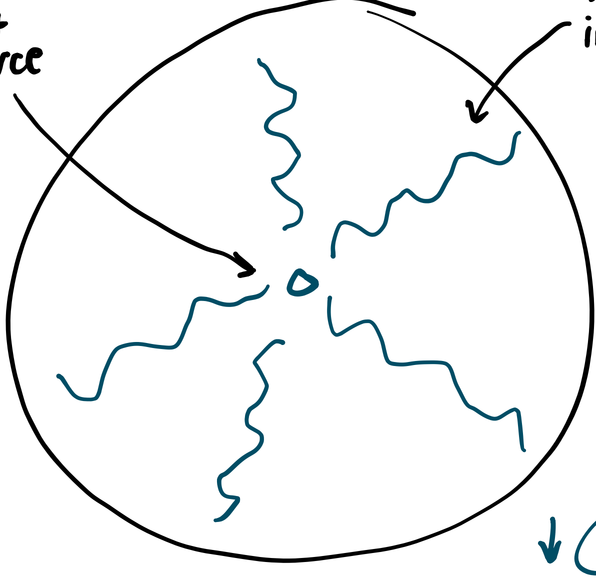


$I = \frac{P}{a}$

Intensity (Wm^{-2})
- the rate of energy transmitted (power) per unit area at right angles to the wave velocity
  - right angles: perpendicular to source
  - velocity: vector; direction

Point source

wave transmitted in all directions ⇓ sphere shape!

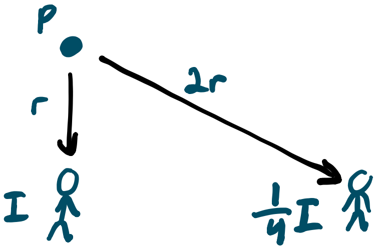


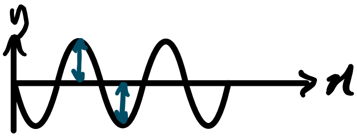
$I = \frac{P_{local}}{a_{local}}$

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

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

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





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

$I \propto P$

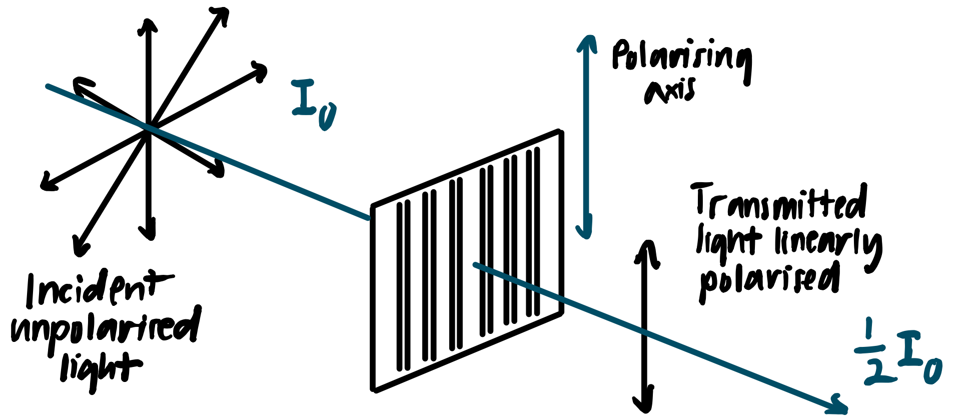
$\propto$ Energy of oscillation $\propto$ amplitude

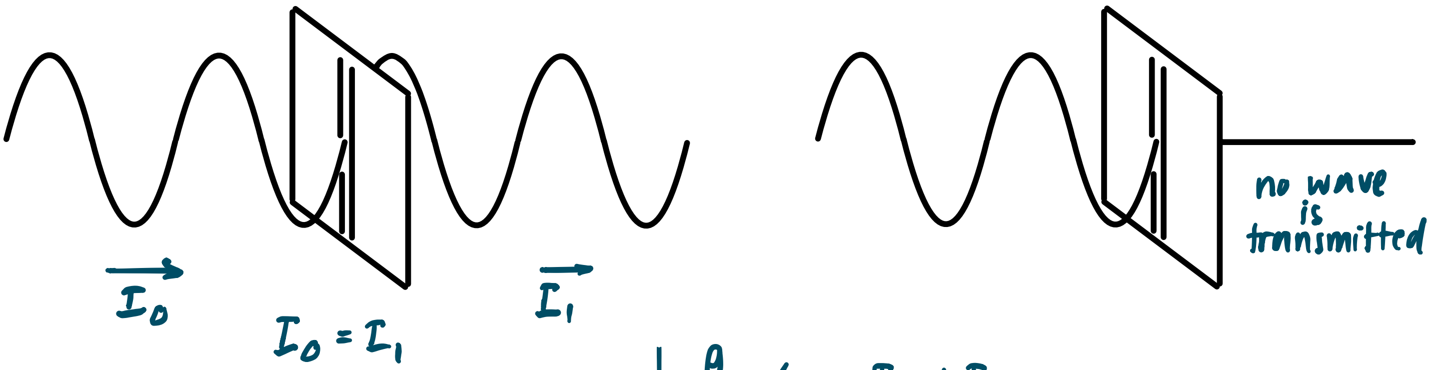
$\propto \frac{1}{2}k(x_{max})^2$ (Hooke's Law; max displacement)

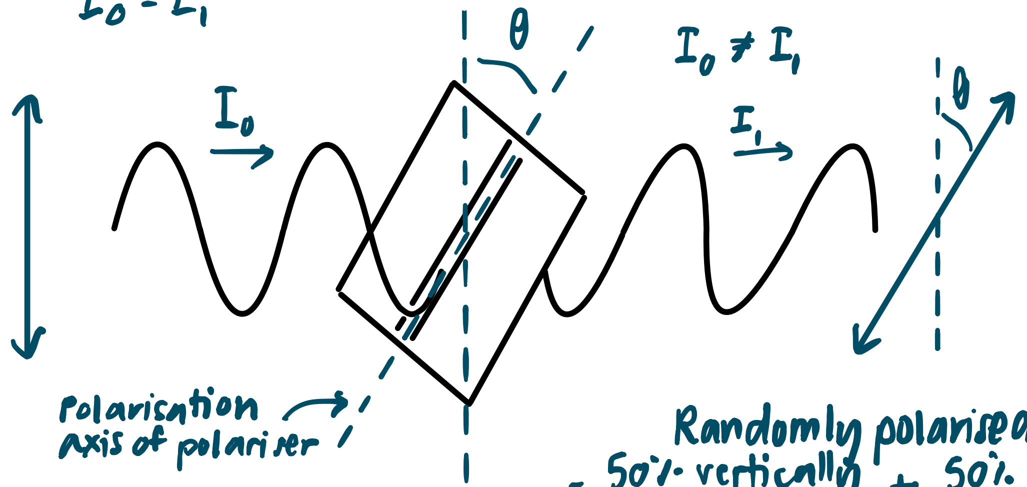
$\propto A^2$

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







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

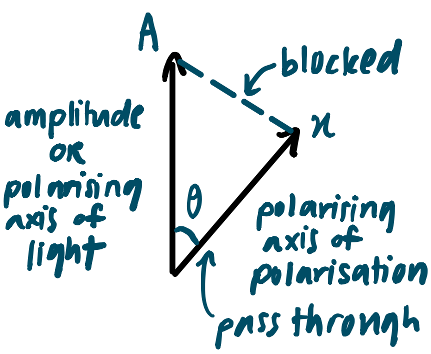
$$F = qE$$

charge (scalar)

force (vector)

energy (vector)

magnitude & direction ? ← amplitude



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

$$x = A\cos\theta$$

$$I_0 \propto A_0^2 \qquad I_1 \propto (A\cos\theta)^2$$

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

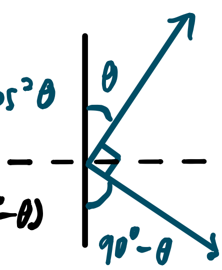
$$I_0 = cA_0^2 \qquad I_1 = cA^2\cos^2\theta$$

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

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

Malus' Law

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



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

$\frac{1}{2}I_0\cos^2(90° - \theta)$

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

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

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

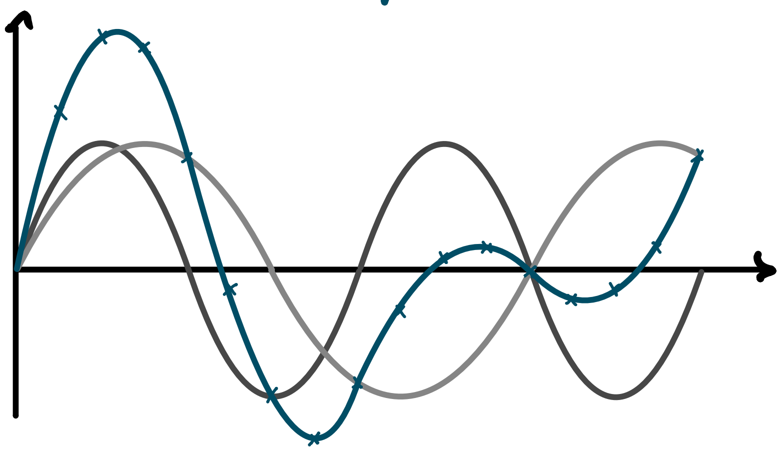
SUPERPOSITION

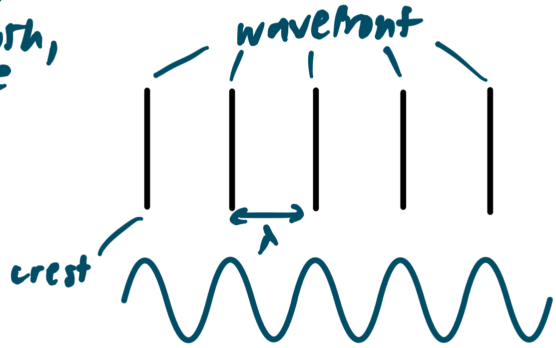
when two/more waves meet, resultant displacement = sum of displacement of individual waves

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

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

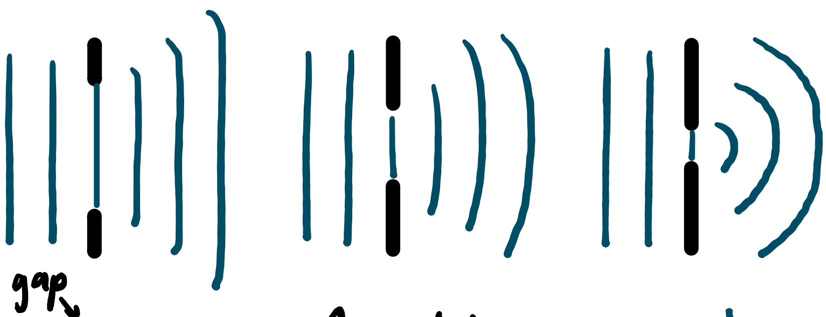
* Explain and use the principle of superposition of waves





[DIFFRACTION]

└ spreading of waves as it passes through a gap

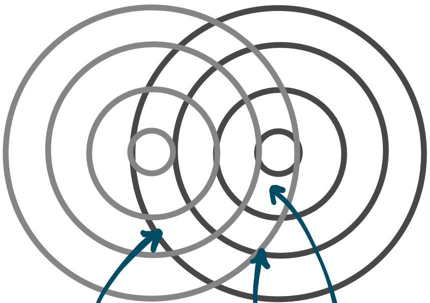


$a \gg \lambda$ $\uparrow a, \downarrow \lambda$ $a \approx \lambda$

$a < \lambda$, wave does not pass through

[INTERFERENCE]

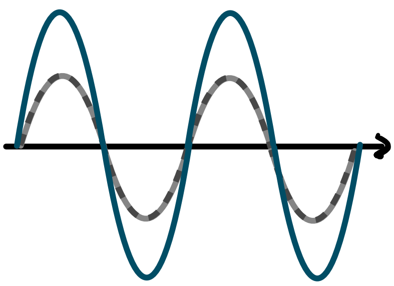
(two or more waves meet or overlap



destructive interference (crest + trough)

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

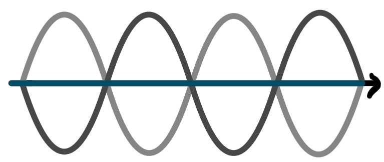
CONSTRUCTIVE INTERFERENCE



$A + A = 2A$

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

DESTRUCTIVE INTERFERENCE

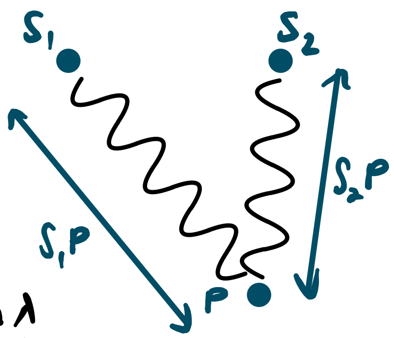


$A - A = 0$

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

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

[PATH DIFFERENCE]



in λ → $|S_1P - S_2P|$

PHASE DIFFERENCE

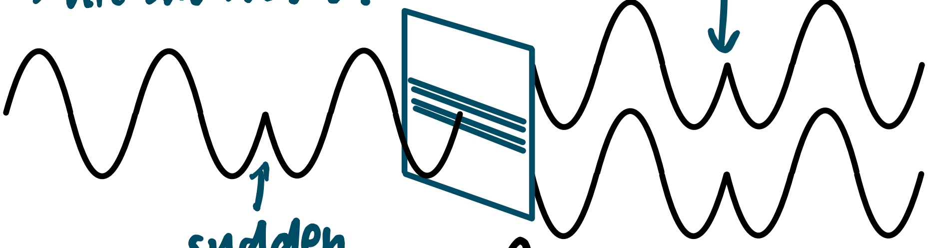
$$\theta = \frac{|S_1P - S_2P|}{\lambda} \times 360°$$

[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

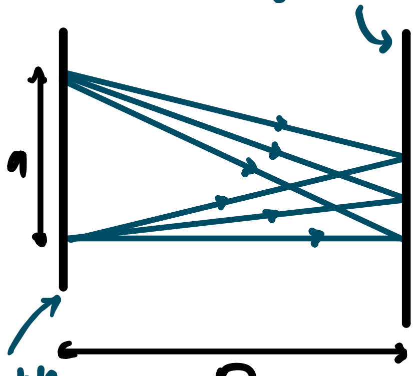
YOUNG'S DOUBLE-SLIT EXPERIMENT

require monochromatic source (ie. laser!)

determining wavelength, λ

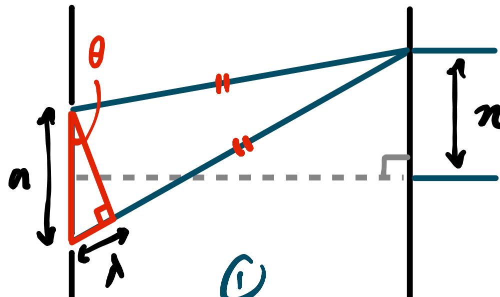
$$\boxed{\lambda = \frac{ax}{D}}$$

screen

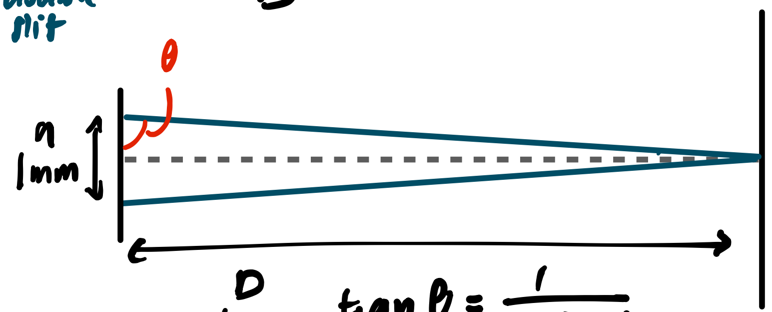


constructive
A bright ← path difference = 0
B dark ← $\frac{1}{2}\lambda$
C bright ← λ
destructive

distance between AB & BC
↳ fringe separation, x

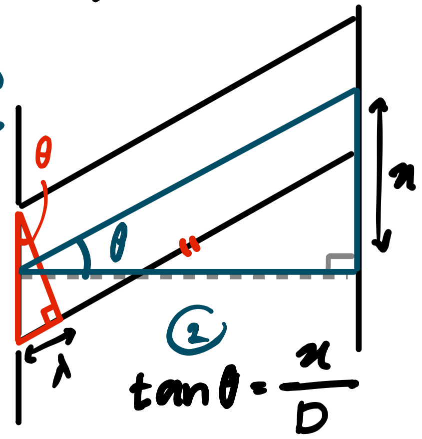


① $\sin\theta = \frac{\lambda}{a}$



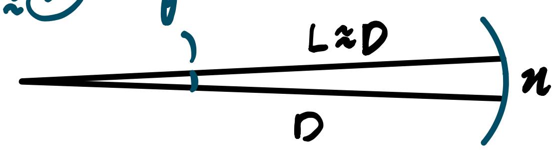
$\tan\theta = \frac{1}{0.001}$

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



② $\tan\theta = \frac{x}{D}$

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)

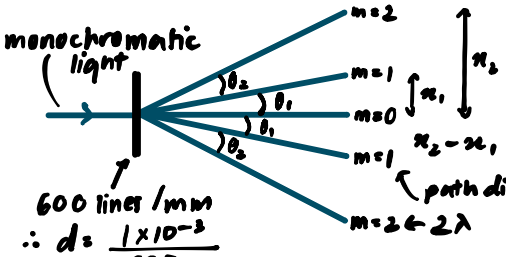
$\sin\theta \approx \tan\theta$

Diffraction gratings (large angle)

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

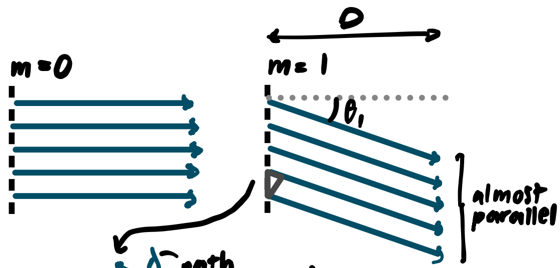
$x = \frac{ax}{D}$ is not applicable

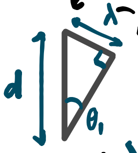
large number of equally spaced lines



600 lines/mm

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



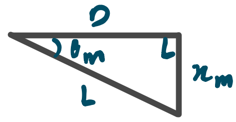


$$\sin\theta = \frac{\lambda}{d}$$

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

$m\lambda = d\sin\theta$

order	path diff.
0	0λ
1	λ
2	2λ
3	3λ



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

Two-slits vs Diffraction grating

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

Max number of maxima, m

$\sin\theta < 1$

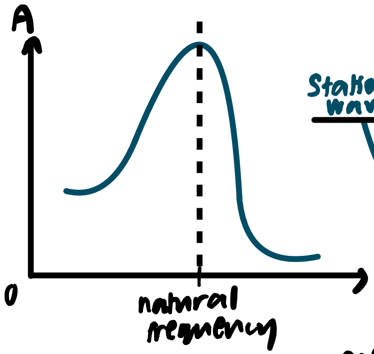
$\frac{m\lambda}{d} < 1$

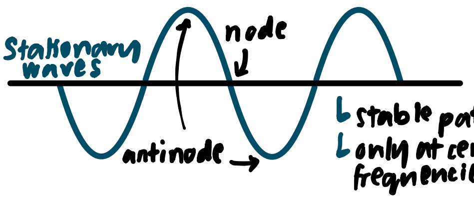
$$\boxed{m < \frac{d}{\lambda}}$$

STATIONARY WAVES

Resonance

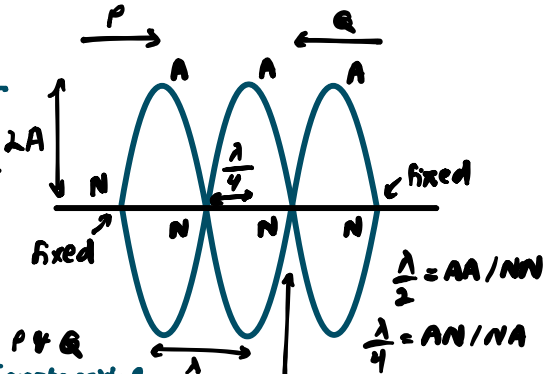
- occurs when a system is forced to oscillate at its natural frequency by a driving force
  - natural freq. = driving freq.
  - amplitude grows drammatically
  - energy is transferred from driver to system





- stable pattern
- only at certain frequencies

two fixed / closed ends



$\frac{\lambda}{2}$ = AA / NN

$\frac{\lambda}{4}$ = AN / NA

P & Q

Constructive interference

at $t = 0$ & $t = \frac{T}{2}$

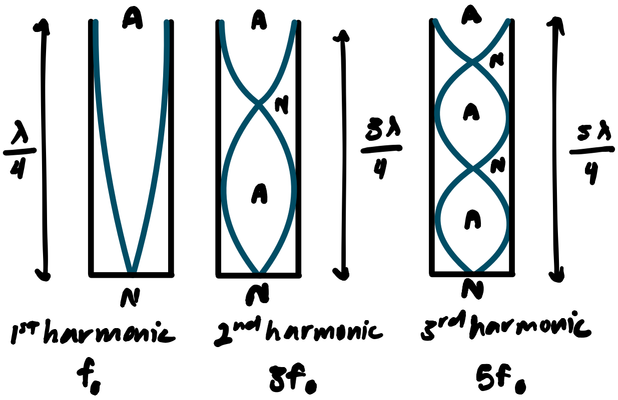
(phase diff. = 0)

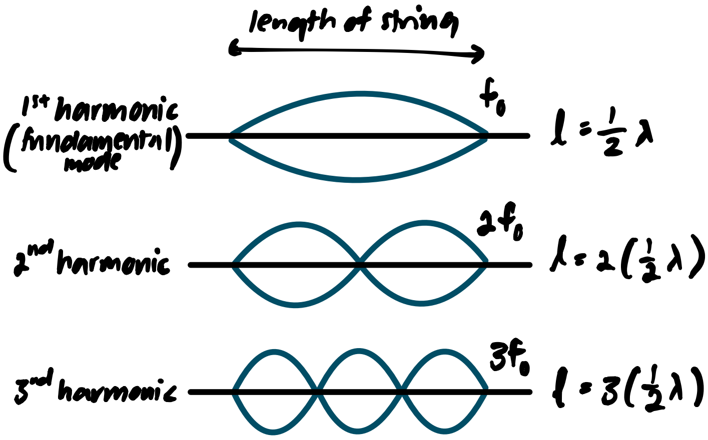
Destructive interference

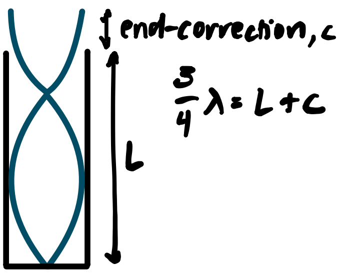
at $t = \frac{T}{4}$ & $t = \frac{3T}{4}$

(phase diff. = 180)

one fixed/closed end



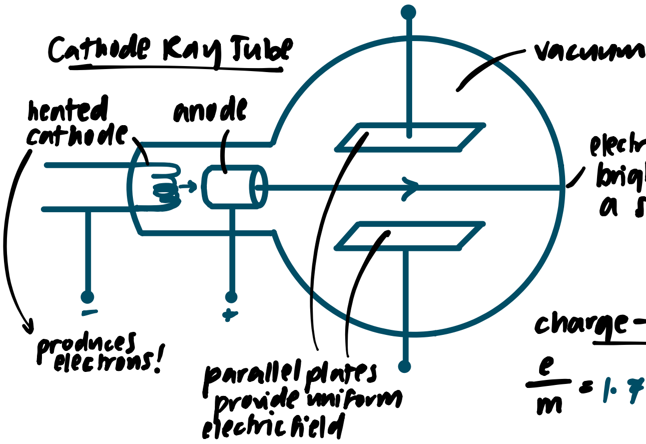


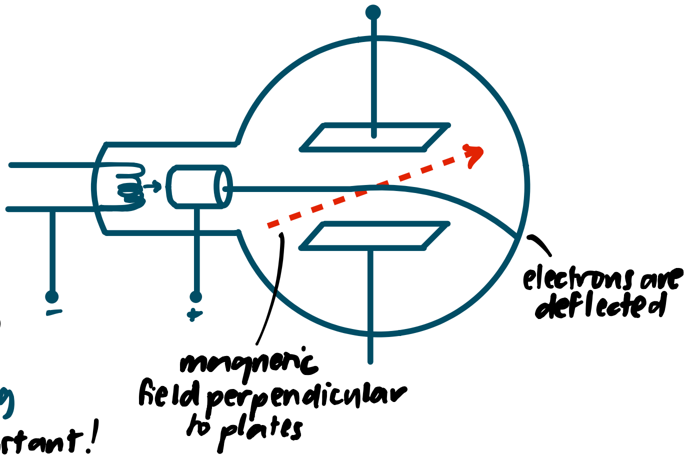


$\frac{3}{4}\lambda = L + c$

ELECTRONS AND THE STRUCTURE OF ATOM

Cathode Ray Tube





charge-mass ratio

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

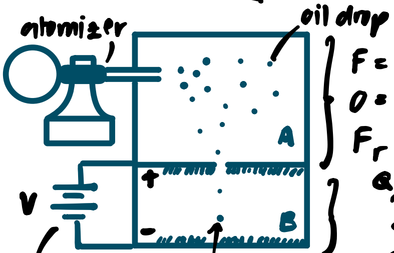
$m = \frac{e}{1.76 \times 10^{11}}$

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

mass of 1 electron is

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

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)

adjusted so that oil drop is stationary

hit w B-ray (oil drop becomes -vely charged)

Nucleon → Nucleon Number / Mass Number, A

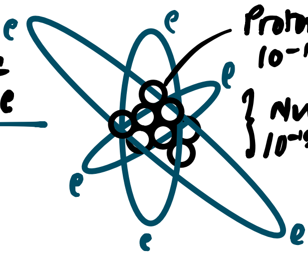
$A = N + Z$
↑ neutron ↑ proton

$^{A}_{Z}X$
↑ symbol of elements

Proton / Neutron 10^{-15}

Nucleus $10^{-15} - 10^{-14}$

Order of magnitude in m

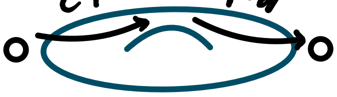


Atom : 10^{-10}

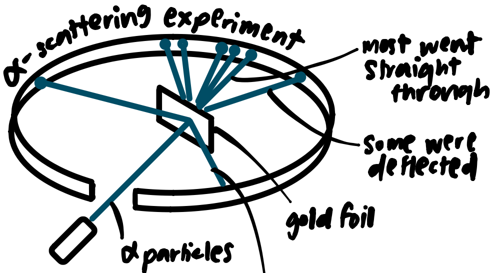
Molecule : $10^{-10} - 10^{-6}$

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

cymbal-shaped

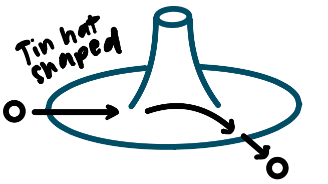


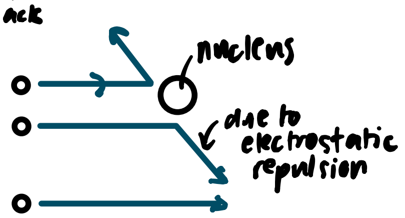
α-scattering experiment



1 in 20000 bounce back

Tin hat shaped



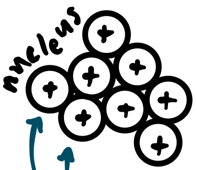


	Relative Mass	Charge
Proton (p)	1	+e
Neutron (n)	1	0
Electron (e)	1/1840	-e
Alpha-particle (α)	4	+2e

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

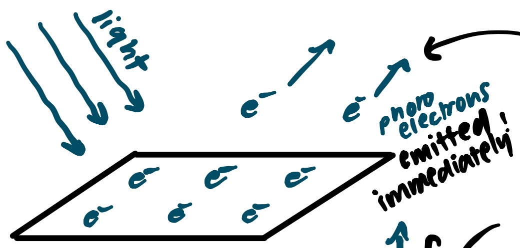
if number of protons and neutrons are not balanced

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)

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

$\uparrow >$ e^- emitted

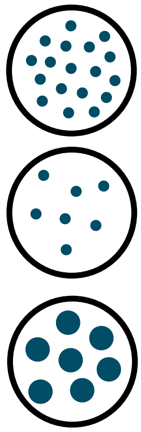
$L \propto E \propto I$

$\downarrow <$ e^- emitted

$\boxed{E = hf}$

Planck's constant 6.63×10^{-34} Js

(packet) a quantum of EM energy — one photon per electron



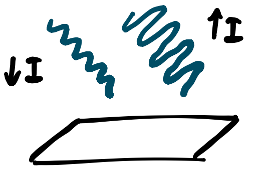
$\uparrow I, \downarrow f$
$\uparrow$ photoelectron
$\downarrow K_E$

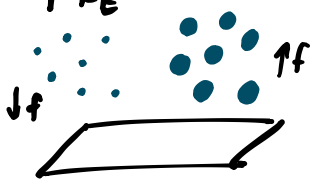
$\downarrow I, \downarrow f$
$\downarrow$ photoelectron
$\downarrow K_E$

$\downarrow I, \uparrow f$
$\downarrow$ photoelectron
$\uparrow K_E$

Observations!

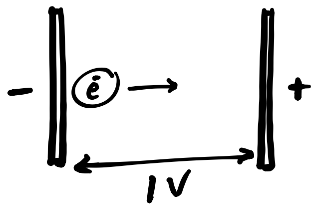
Wave theory (dependent on intensity)	vs	Particle theory (dependent on frequency)
✗ any frequency		✓ $\downarrow$ frequency, $\downarrow$ energy
✗ waiting time required		✓ whole photon is absorbed
✓ $\uparrow$ intensity, $\uparrow$ energy		✓ $\uparrow$ intensity, $\uparrow$ photons / second
✗ $\uparrow$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





Electron-volt (eV)

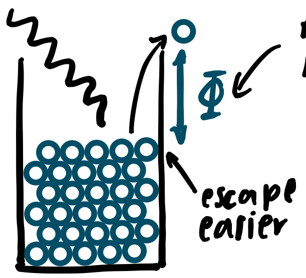
energy transfered when an electron travels through a potential difference of 1V



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

energy!

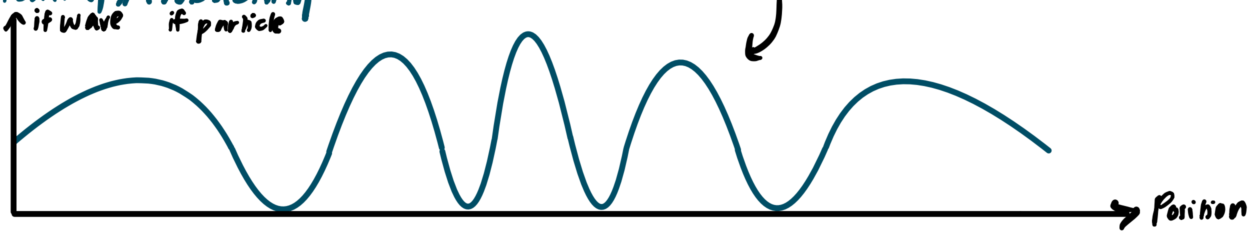
Work Function



minimum energy required by an electron to escape metal surface

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

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! — $p = \frac{E}{c}$

momentum & energy

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

$p = mv$

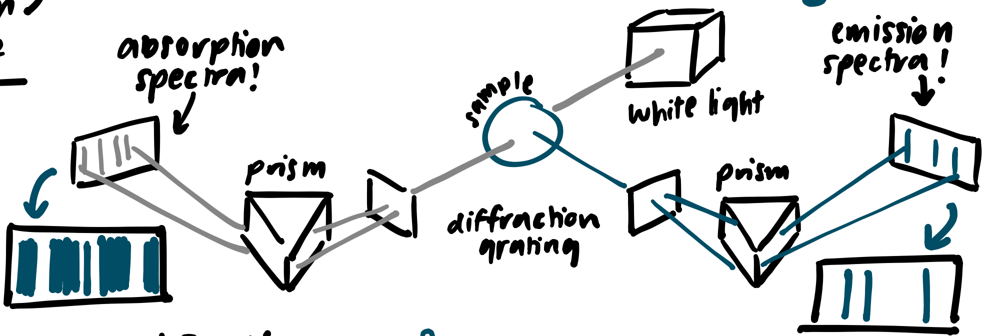
$v = \frac{p}{m}$

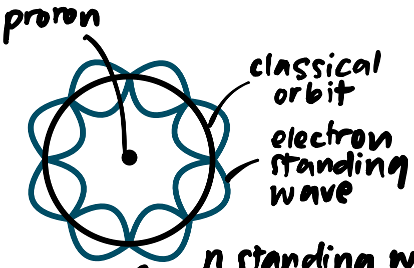
$E = \frac{1}{2}m\left(\frac{p}{m}\right)^2$

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

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

LINE SPECTRA





n standing waves

8 waves!

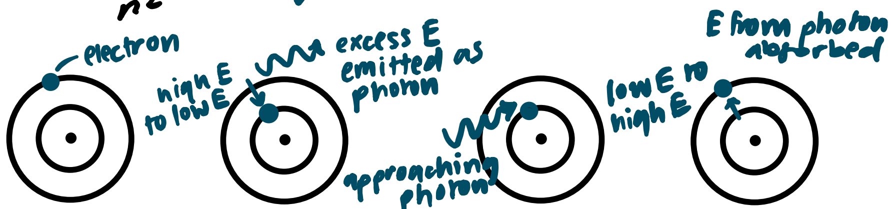
quantum number, n = 8

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

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

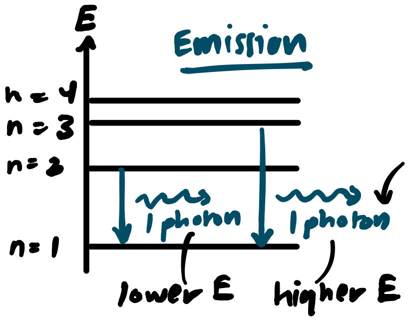
discrete energy

lowest n = 1 (ground state)



Emission spectra

Absorption spectrum



E of photon = diff. in E level

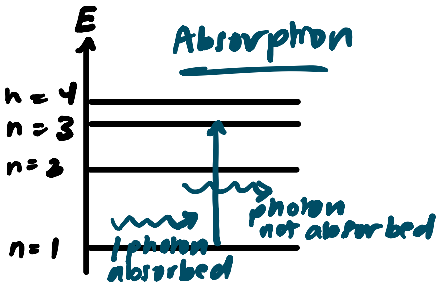
$\Delta E = |E_2 - E_1|$

ΔE = photon energy

$\Delta E = hf$

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

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



(exactly the right E (resonance)