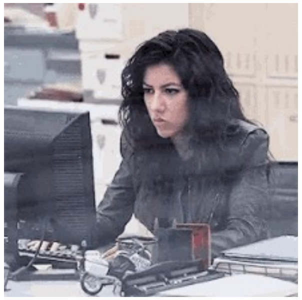
HSC PHYSICS
MOD 7 CRASH COURSE

ANGENI BAI

Who Am I?

Hey I'm Angeni! (or call me Genie ☺)

- Graduated last year!
  - 99.80 ATAR
  - State rank 11th in Mathematics (but I like Physics more lol)
- Studying Computer Science as a Co-op Scholar at University of New South Wales
  - Beep boop… $$$



- Things I'm trying to get good at
  - Playing guitar 🤘
  - Cooking 👩‍🍳 – to justify all the Bon Appetit binges
  - Skateboarding 🛹 – my Ollie is coming along…

Today's Lecture – Nature of Light

I'm not quite following syllabus order, but it is all here

Block #1: EM Spectrum + Wave Model of Light

- The development of the model
- Wave behaviours

Block #2: Quantum Model of Light

- The Photoelectric Effect
- Black Body Radiation
- Spectral Analysis

Block #3: Special Relativity

- Einstein's postulates
- Energy/mass equivalence

Today's Lecture – Nature of Light

- Words in red are key words you should be able to define!
- This is a **whole module** in 2.5 hours (weow)
  - It's ok not to understand everything now
  - This lecture is just giving you a foundation so learning later will be easier!
- The slides will be available afterwards
  - So don't worry about copying down *everything* ☺

Today's Lecture – Not Just Content!

This is a weird time to be doing the HSC, so I'll also be covering a bit on study tips, motivation and mental health!

After Break #1:

- Making the most of studying from home
- Keeping mental health in check

After Break #2:

- How to study *effectively* for physics

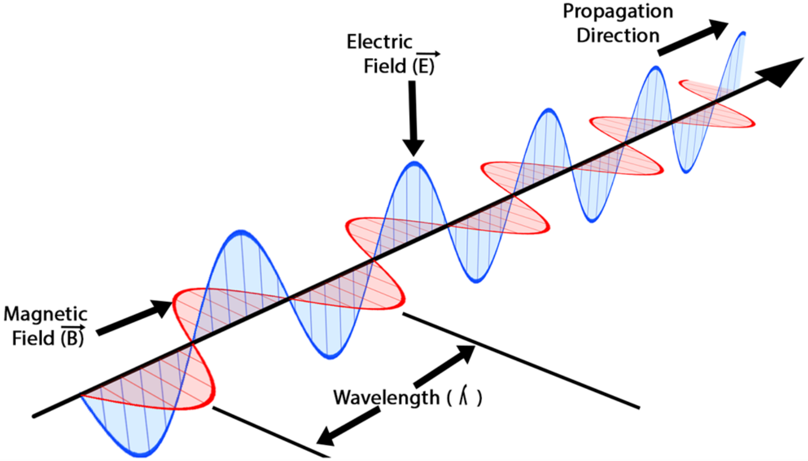
ELECTROMAGNETIC WAVES

Light as an Electromagnetic Wave

We now know that light is an electromagnetic wave.

What exactly is an electromagnetic wave?

A wave consisting of electric and magnetic fields, oscillating at **right angles** to each other, which can **self-propagate** through empty space



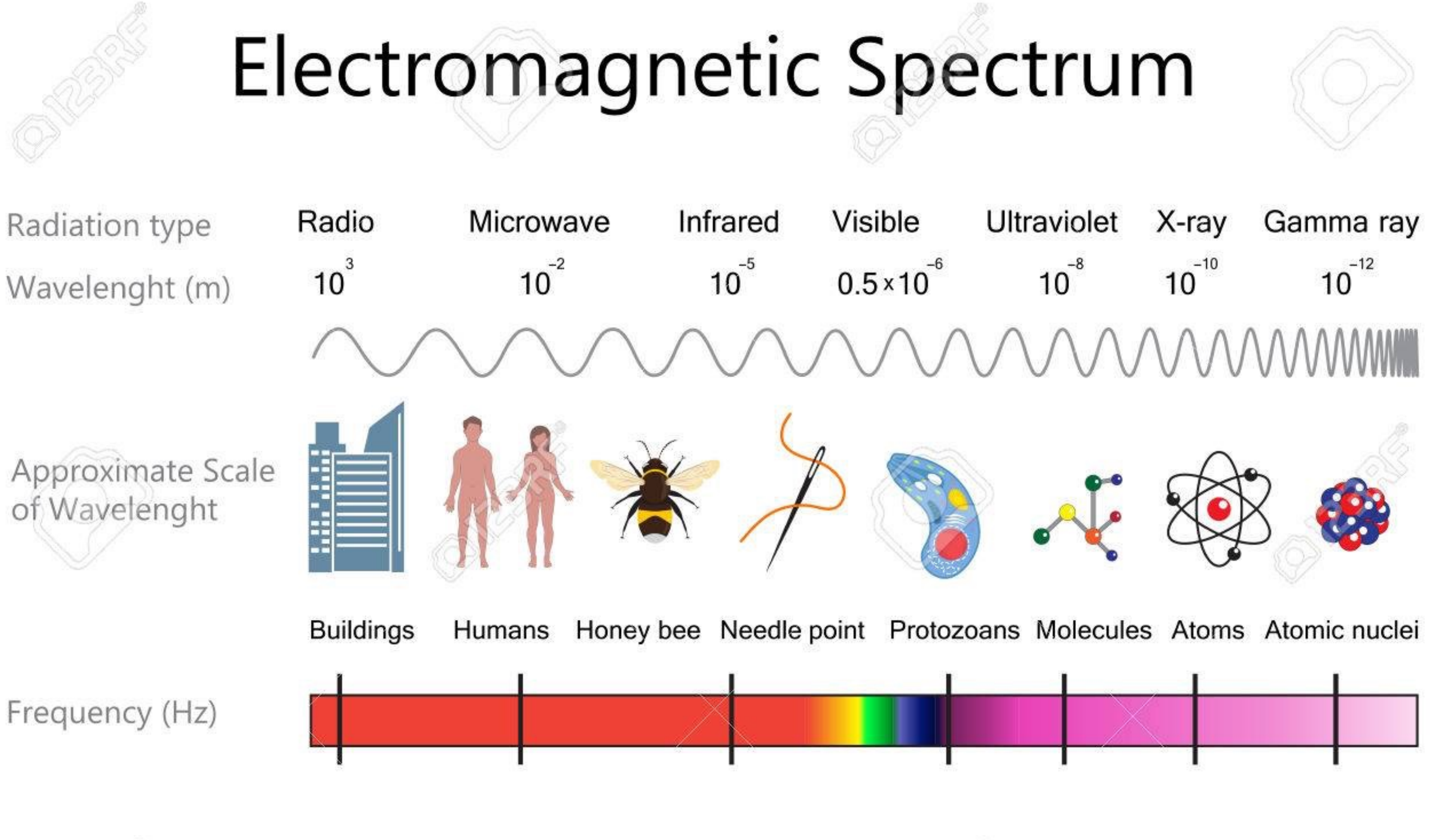
Light as an Electromagnetic Wave

Let's unpack what we mean by **self-propagate**

- A point charge produces an electric field (Gauss' Law)
- An accelerating point charge produces a changing electric field (also Gauss' Law)
- A changing electric field produces a changing magnetic field (Ampere's Law)
- A changing magnetic field produces a changing electric field (Faraday's Law)

And the last two steps repeat - so the EM wave creates itself!

Light as an Electromagnetic Wave



Light as an Electromagnetic Wave

These electromagnetic waves were first predicted by James Clerk Maxwell!

- Put together the four equations to **unify** electricity and magnetism for the first time
- Described electromagnetic waves as **self-propagating** waves with electric and magnetic fields oscillating at right-angles to one another
- Rearranged the equations to predict that EM waves should travel at a speed given by:

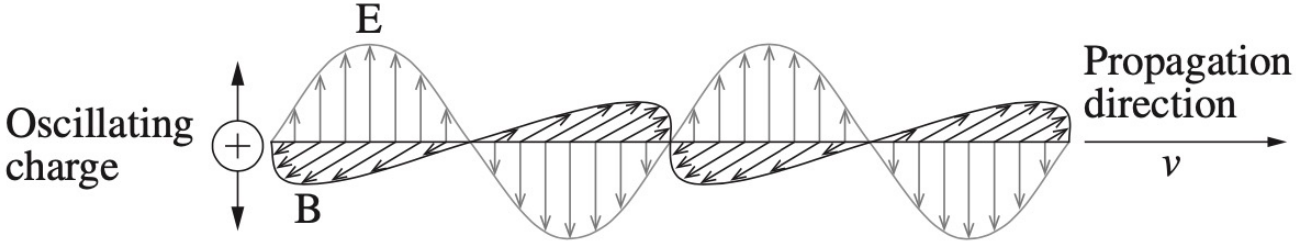
$$\frac{1}{\sqrt{\epsilon_0 \mu_0}} \approx 3\times 10^8\ m/s$$

Light as an Electromagnetic Wave

HSC 2019

Question 25 (4 marks)

The diagram shows a model of electromagnetic waves. **4**

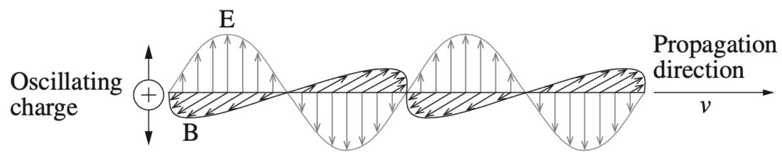


Relate this model to predictions made by Maxwell.

Light as an Electromagnetic Wave

Question 25 (4 marks)

The diagram shows a model of electromagnetic waves. **4**



Relate this model to predictions made by Maxwell.

Sample Answer

Maxwell predicted that an electromagnetic wave would consist of an electric field oscillating perpendicular to a magnetic field. This is shown in the model, where the electric field in the vertical direction is perpendicular to the magnetic field in the horizontal direction.

Maxwell predicted that an electromagnetic wave would be produced by an oscillating charge. This model shows this, with the electromagnetic wave beginning from the point where the charge is oscillating.

Measuring the Speed of Light

The speed of light has been measured **many**, many times by various physicists over the years, with varying degrees of accuracy.

- **Galileo** tried to do it by measuring the time taken for light from an uncovered lamp to reach an observer many kilometres away (really crap)
- **Roemer** used the orbit of one of Jupiter's moons (pretty decent)
- **Fizeau** used a clever setup involving a rotating cogwheel (actually quite accurate!)

WAVE MODEL OF LIGHT

The Development of the Model

There was initially a lot of doubt as to whether light was a wave or whether it was a particle.

- Newton believed it was a particle called a corpuscle
- Huygens believed it was a **wave**

VS.

The Development of the Model

There was initially a lot of doubt as to whether light was a wave or whether it was a particle.

- Newton believed it was a particle called a corpuscle
- Huygens believed it was a wave

Standard wave behaviours could be explained by both models.

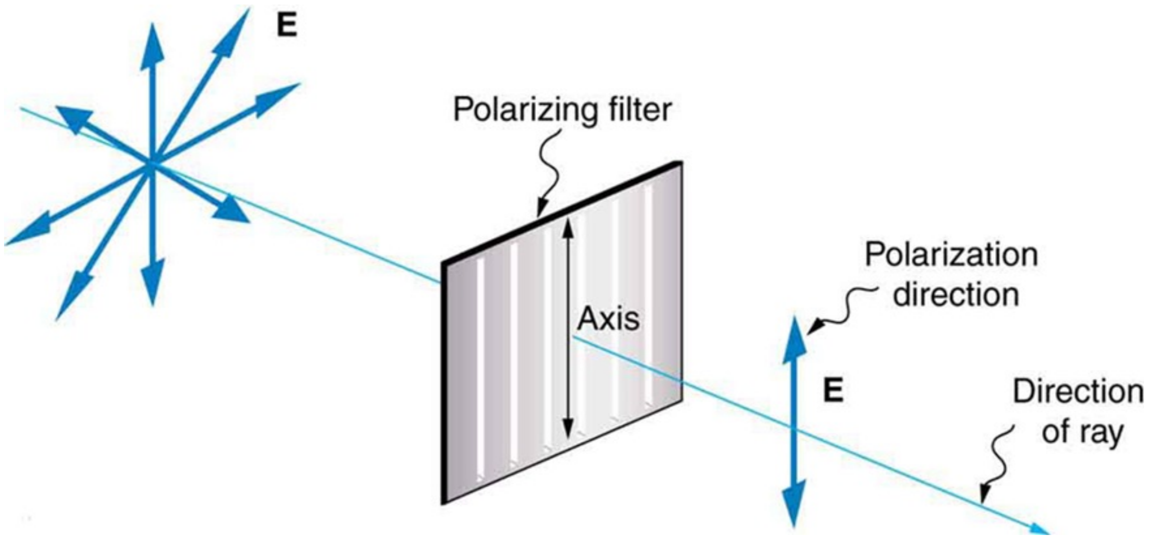
- Reflection
- Refraction
- Diffraction

But less standard behaviours, like polarisation and interference, could only be explained by the wave model.

Polarisation

The polarisation of a light wave refers to the direction of oscillation of its electric field.

- Normally, light is unpolarised
- We can polarise it by using a polarising filter – we sometimes call the waves **plane polarised**



https://www.geogebra.org/m/Z6TQuS2F

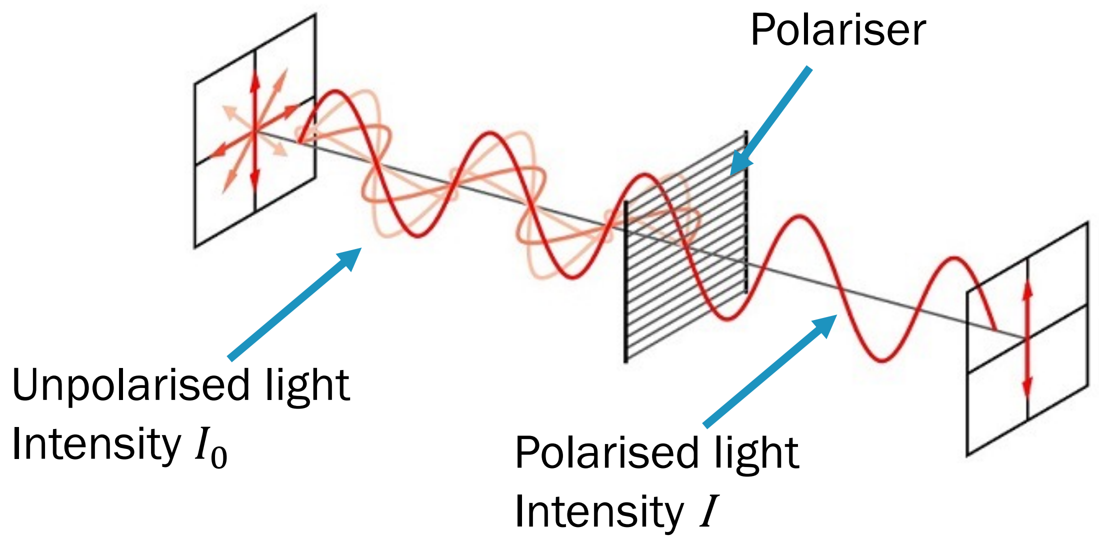
Polarisation

Polarisation of **unpolarised light:**

$$I = 0.5I_0$$

I_0 - initial intensity of light

I – Intensity of light leaving polariser

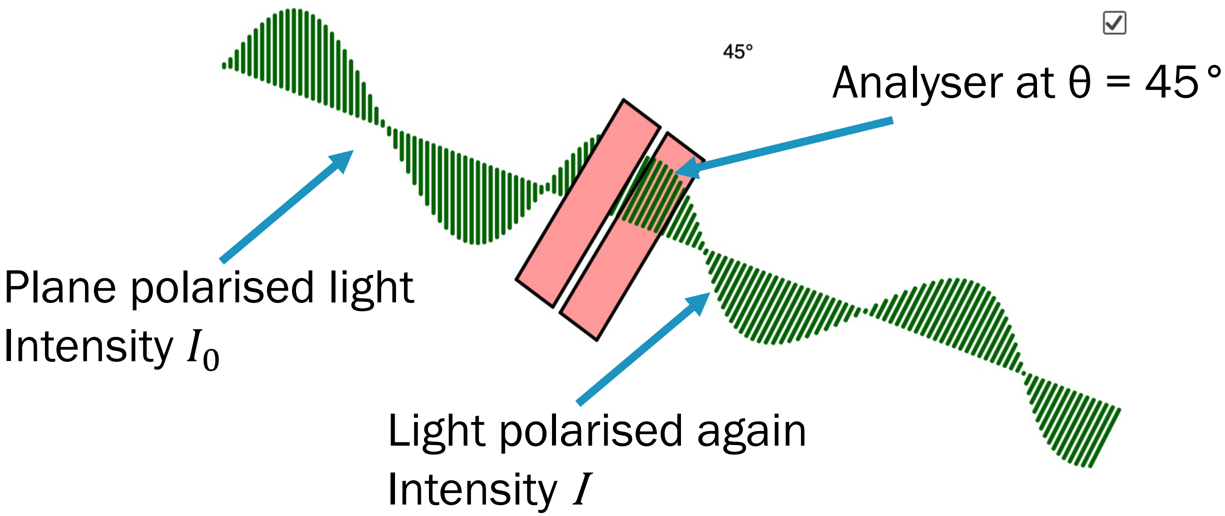


Polarisation

Polarisation of **already polarised light:**

$$I = I_0 \cos^2 \theta$$

Where θ is the angle between the polarisation direction of the incident light and the filter. This is **Malus' Law**.



Slido Question!

Unpolarised light is passed through a polariser, so that it is now plane polarised in the vertical direction. As it leaves, it passes through a second polarising filter.

At what angle should the direction of polarisation in the second filter be so that **no light** passes out? (1 mark)

Sample Answer

90º

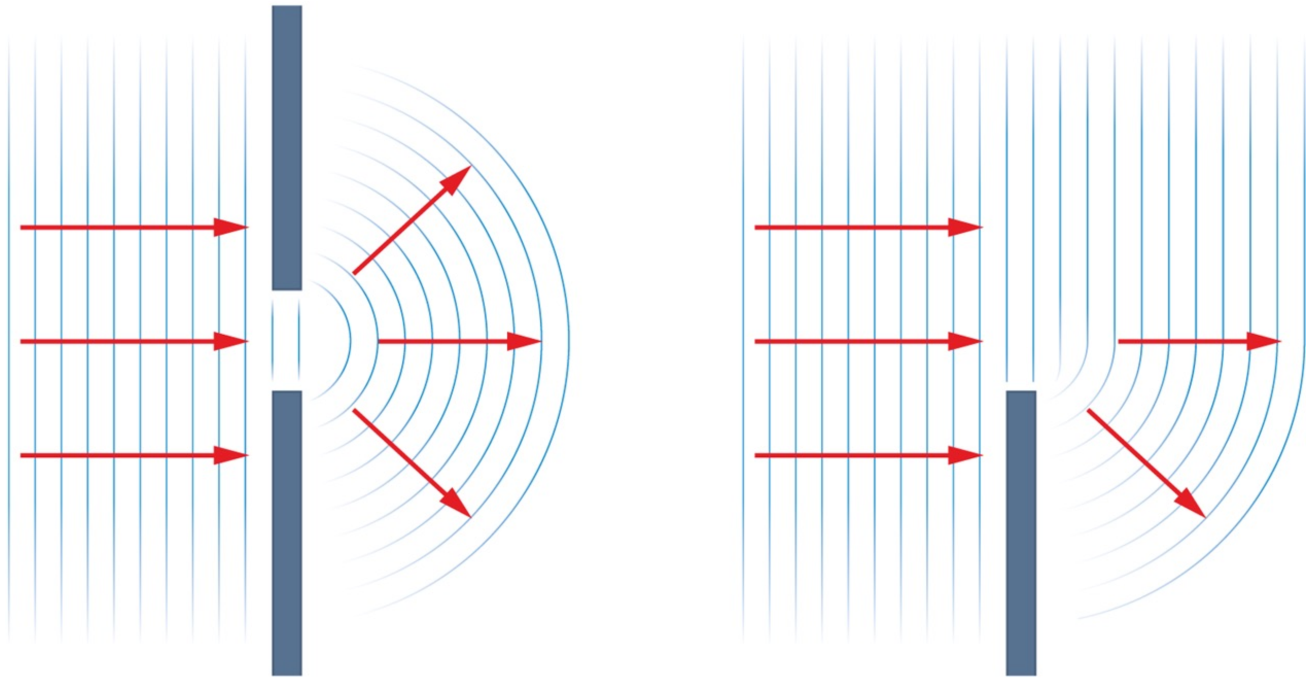
Mathematically - cos theta is 0 when theta is 90 degrees

Conceptually – when filter is perpendicular, there isn't any light in horizontal direction, so nothing gets through

Wave Behaviour

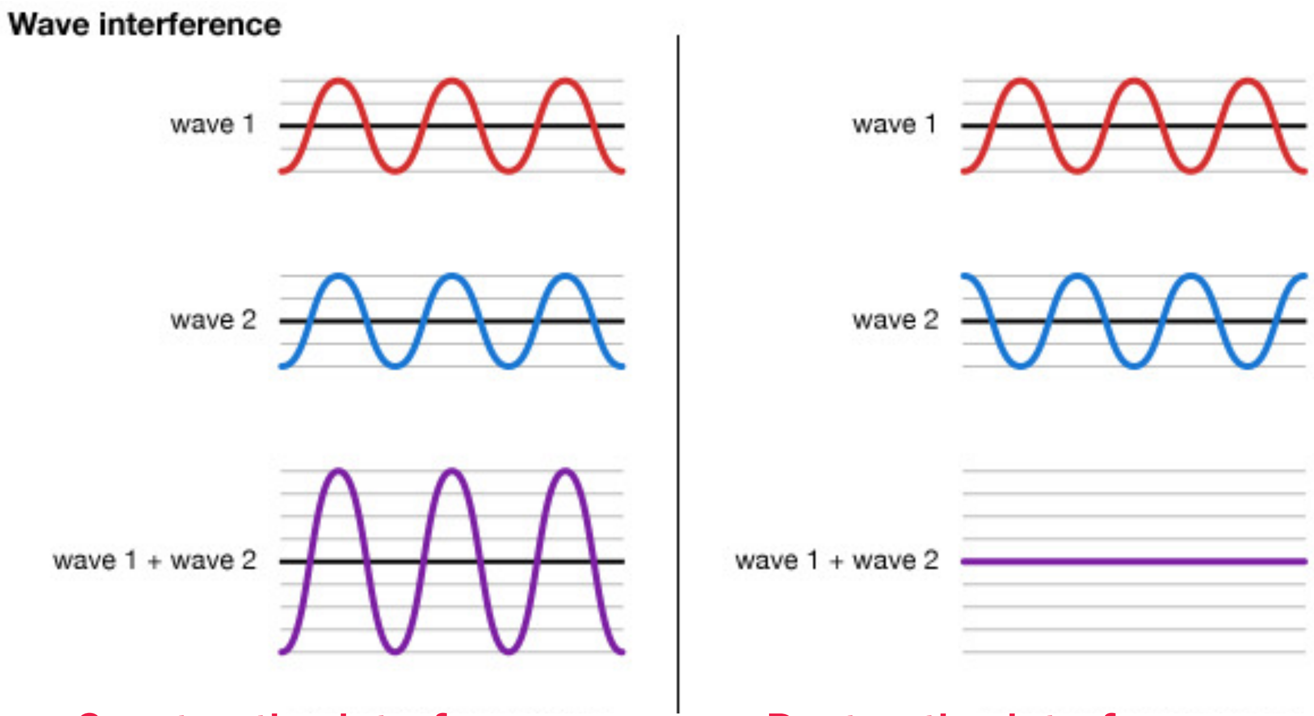
A quick recap on wave diffraction and interference

Diffraction – when waves bend around obstacles



Wave Behaviour

Interference – when waves meeting together collapse into a single wave



Constructive interference

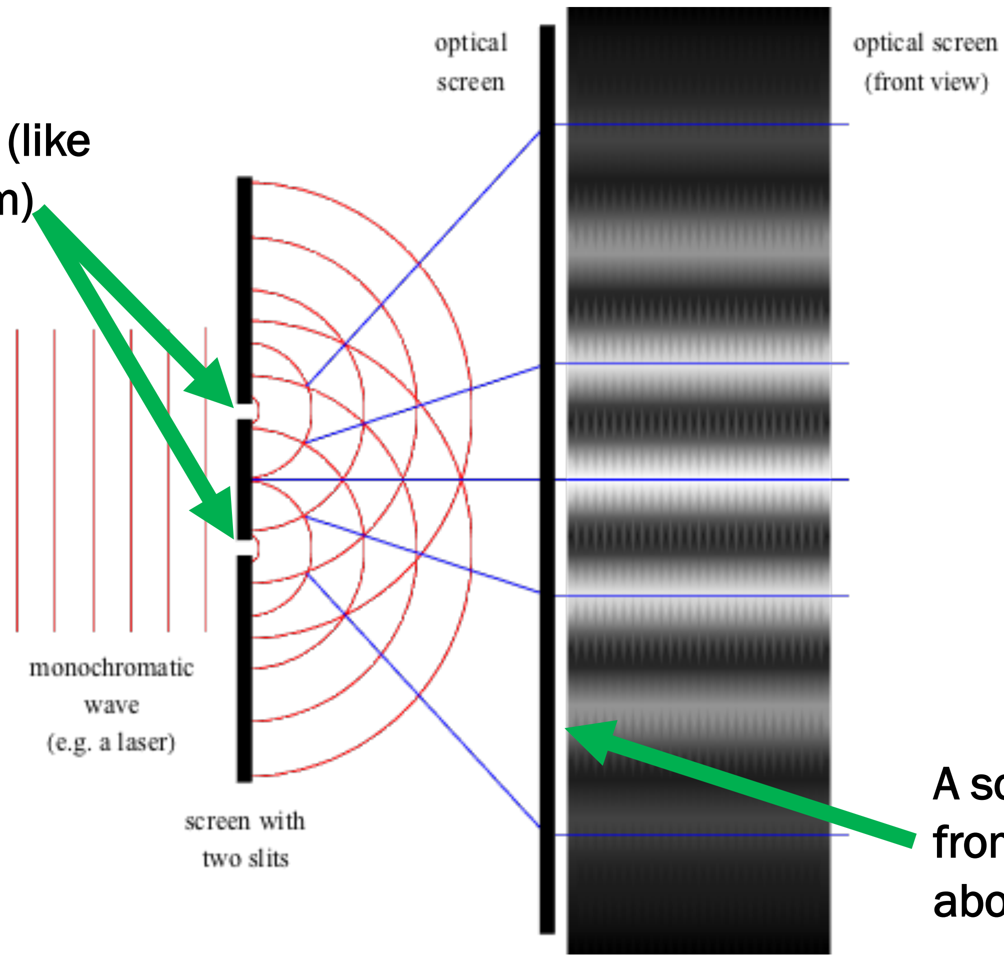
- The waves are in phase

Destructive interference

- The waves are out of phase

The Double Slit Experiment

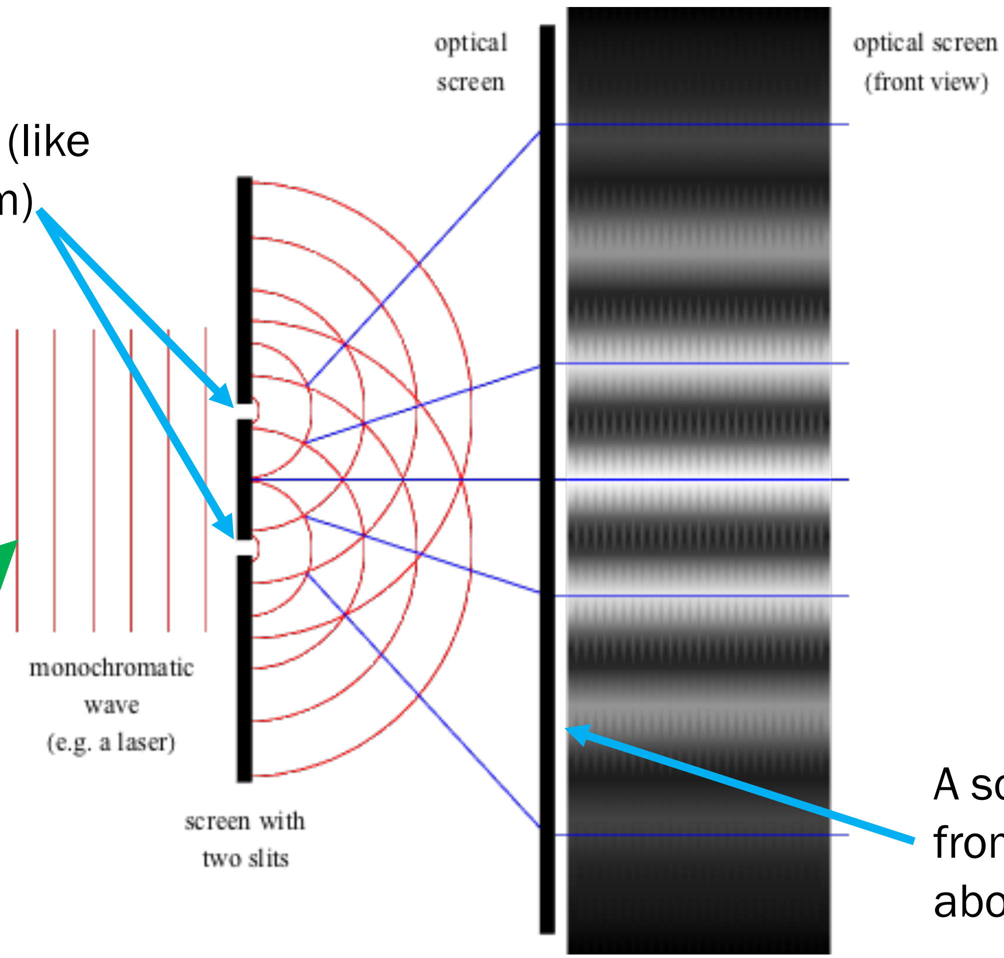
Two slits really close together (like less than a mm)



A screen really far from the slits (like about a metre away)

The Double Slit Experiment

Two slits really close together (like less than a mm)



A single source of light waves

A screen really far from the slits (like about a metre away)

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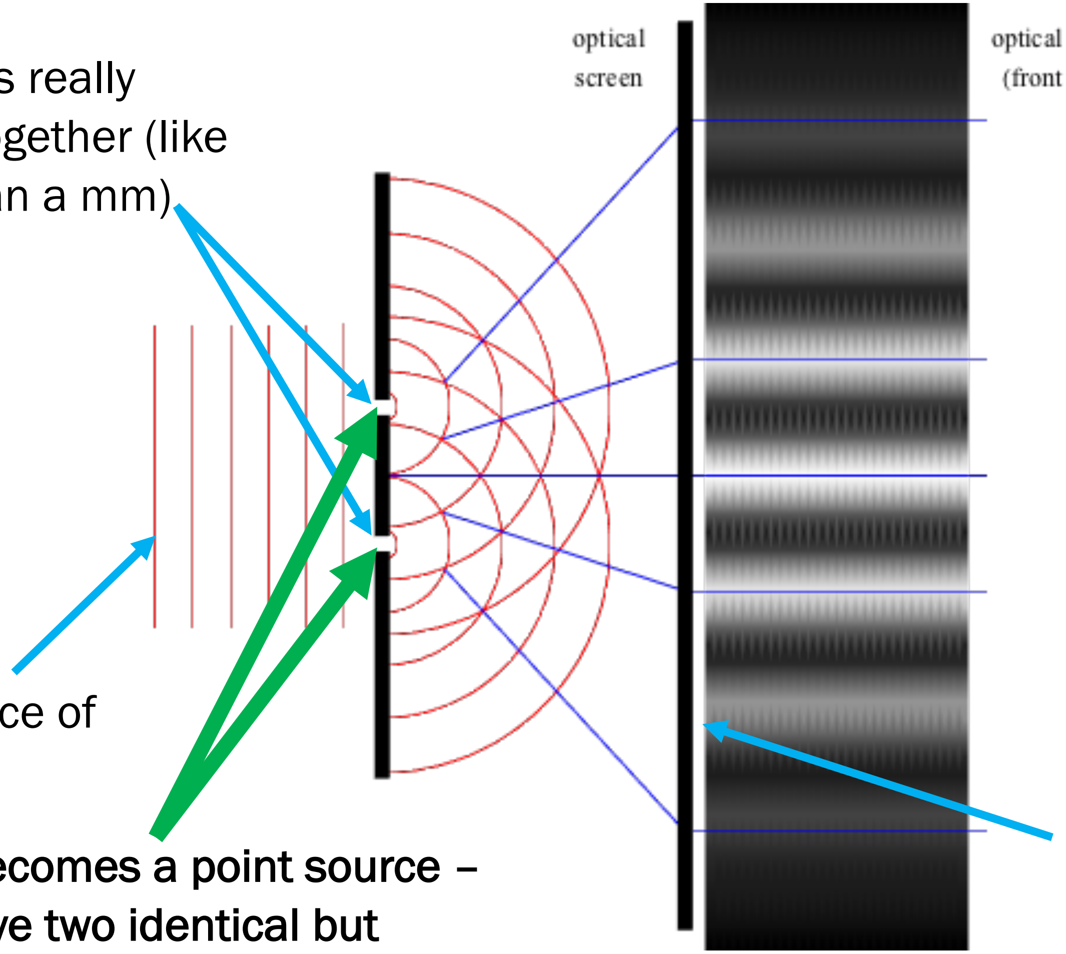


A single source of light waves

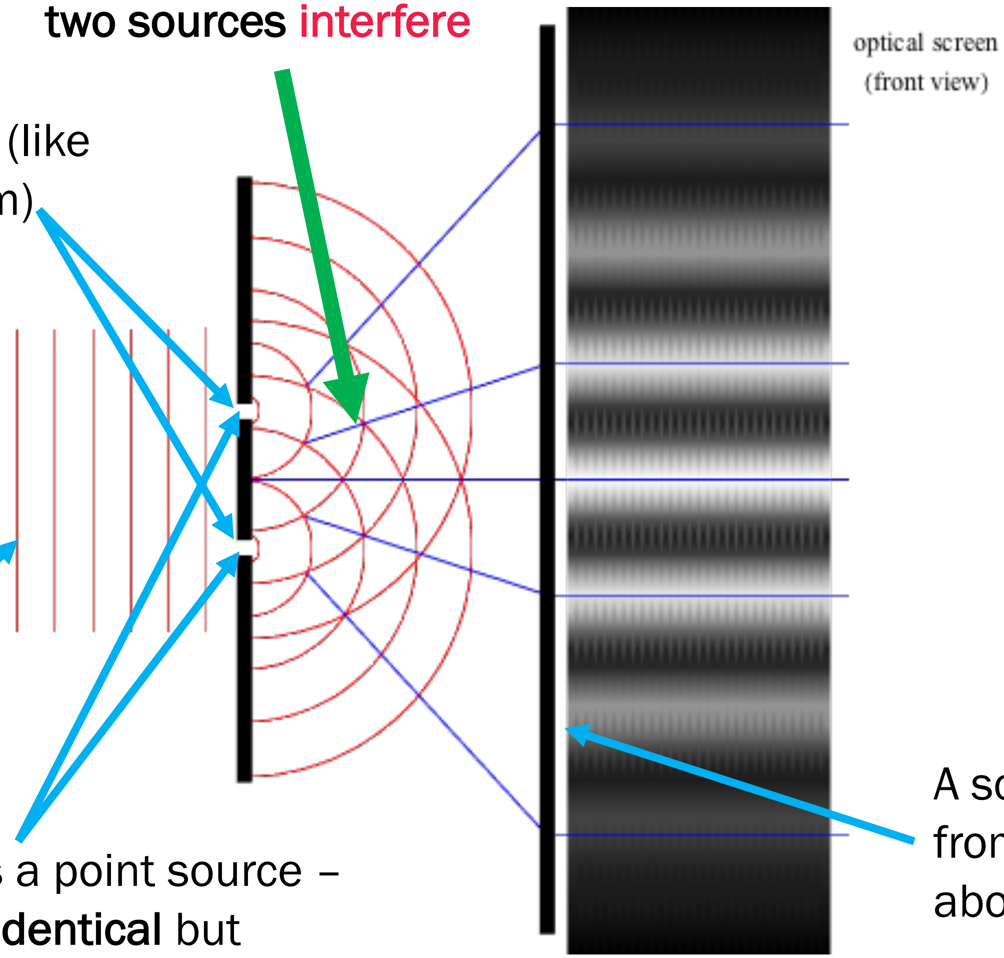
Each slit becomes a point source – now we have two identical but independent sources of light

A screen really far from the slits (like about a metre away)

The Double Slit Experiment

The waves from the two sources interfere

Two slits really close together (like less than a mm)



A single source of light waves

A screen really far from the slits (like about a metre away)

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The Double Slit Experiment

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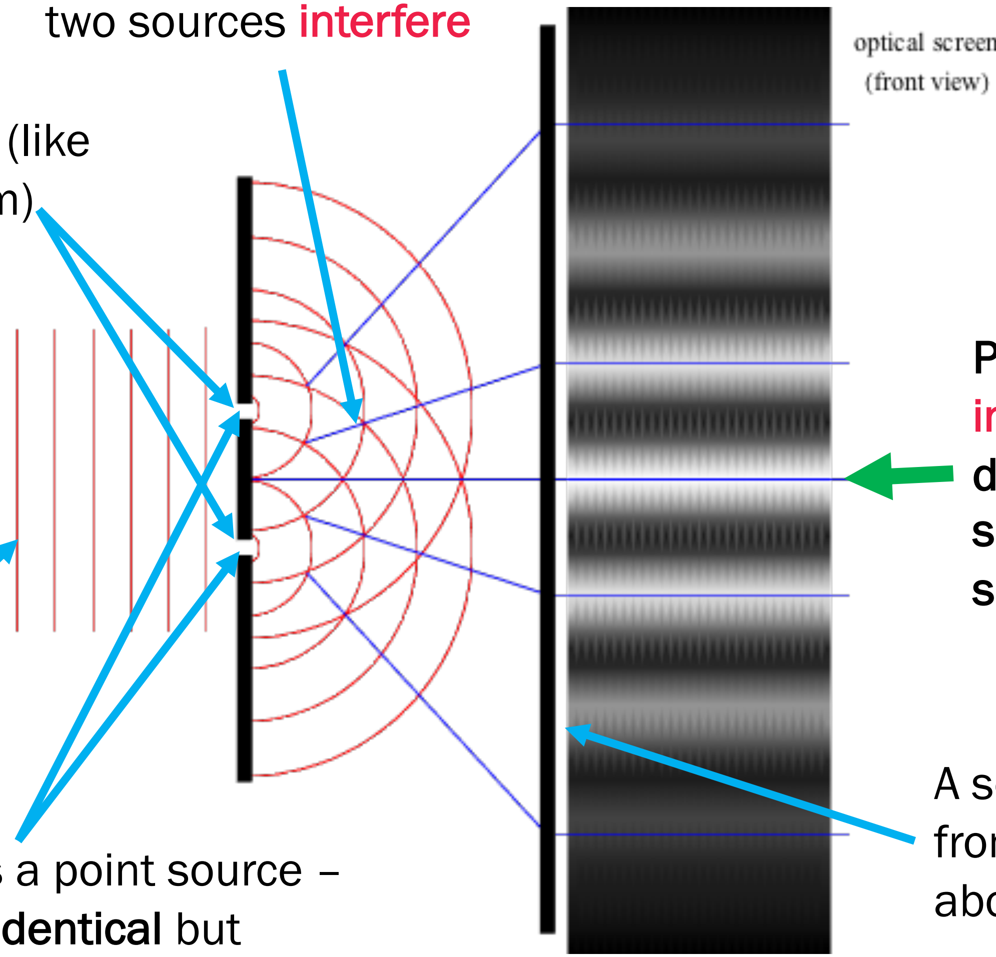


Producing an interference pattern of dark and bright spots/bands on the screen

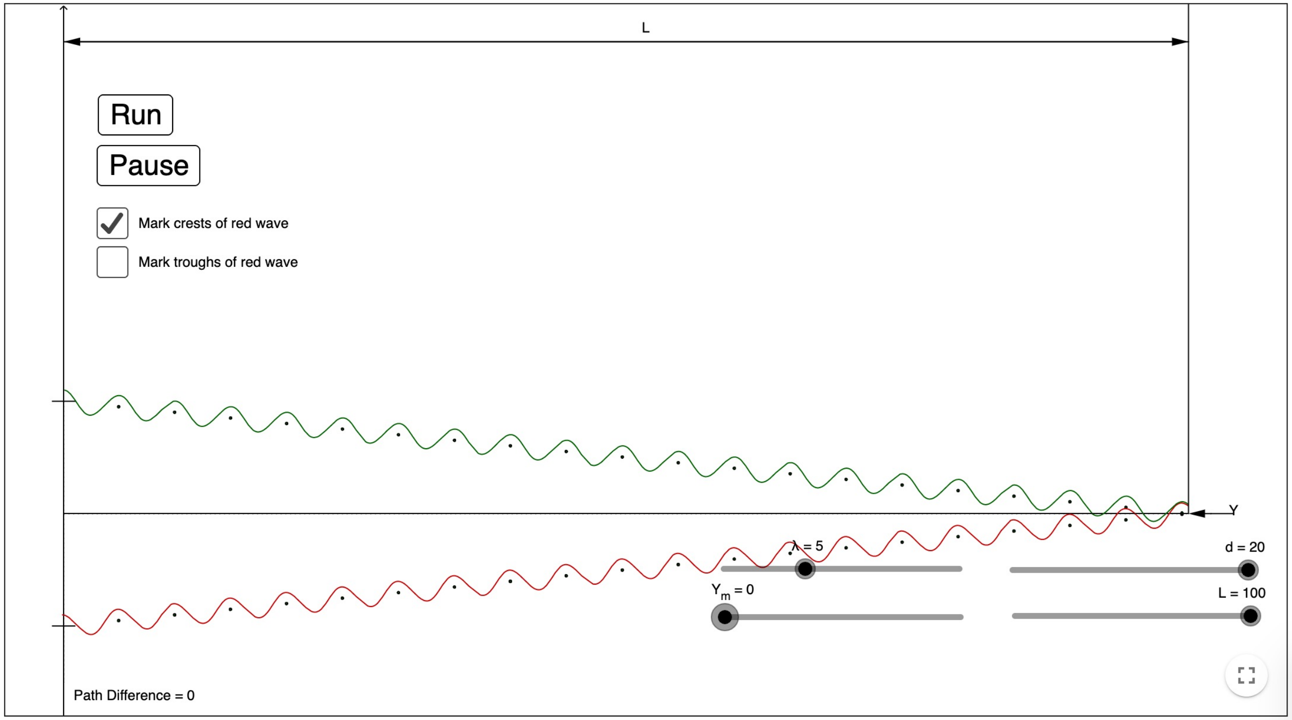
A single source of light waves

A screen really far from the slits (like about a metre away)

Each slit becomes a point source – now we have two **identical** but **independent** sources of light

The Double Slit Experiment

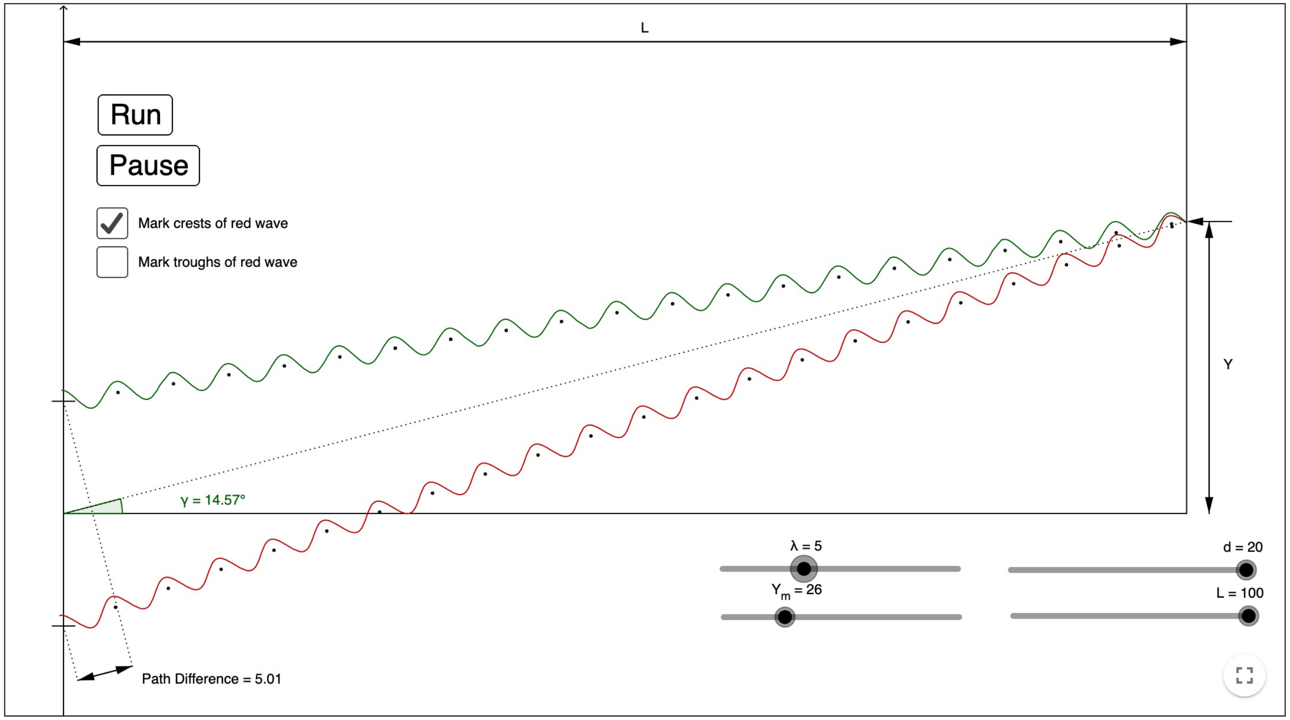
The interference pattern on the screen is caused by the <u>different distances</u> travelled by the light to each point on the screen



Same distance travelled → waves still in phase → constructive interference → bright spot on the screen

The Double Slit Experiment

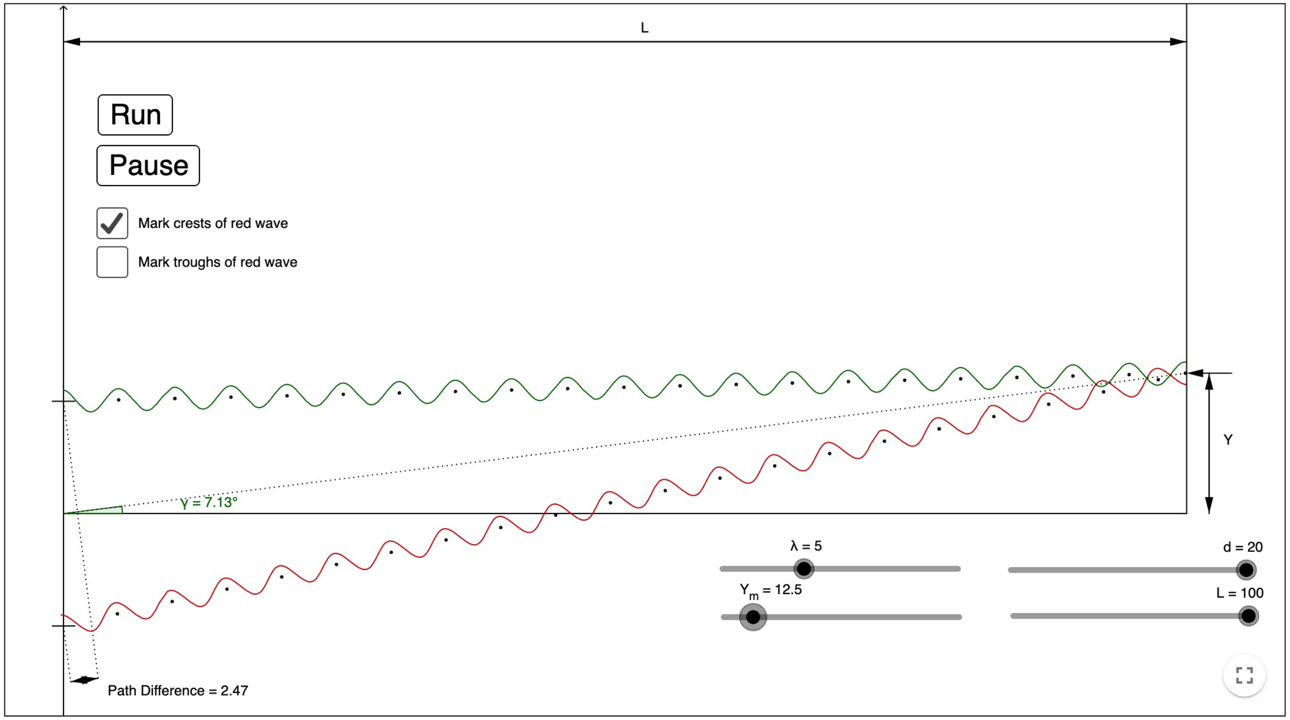
The interference pattern on the screen is caused by the <u>different distances</u> travelled by the light to each point on the screen



Wave 2 travels extra λ m→ waves still in phase → constructive interference → bright spot on the screen

The Double Slit Experiment

The interference pattern on the screen is caused by the <u>different distances</u> travelled by the light to each point on the screen



Wave 2 travels extra ½ λ m→ waves out of phase → destructive interference → dark spot on the screen

The Double Slit Experiment

We can predict the location of the maxima (bright spots) on the pattern using the formula

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

d – distance between the two slits

θ – angle from the centre line

λ – the wavelength of light

m – the order of the maxima. The 1^{st} maxima is found when m=1, the 2^{nd} maxima is found when m=2, etc.

The Double Slit Experiment

Similarly, the minima (dark spots) on the pattern are found using the formula

$$d \sin \theta = \left(m + \frac{1}{2}\right)\lambda$$

d – distance between the two slits

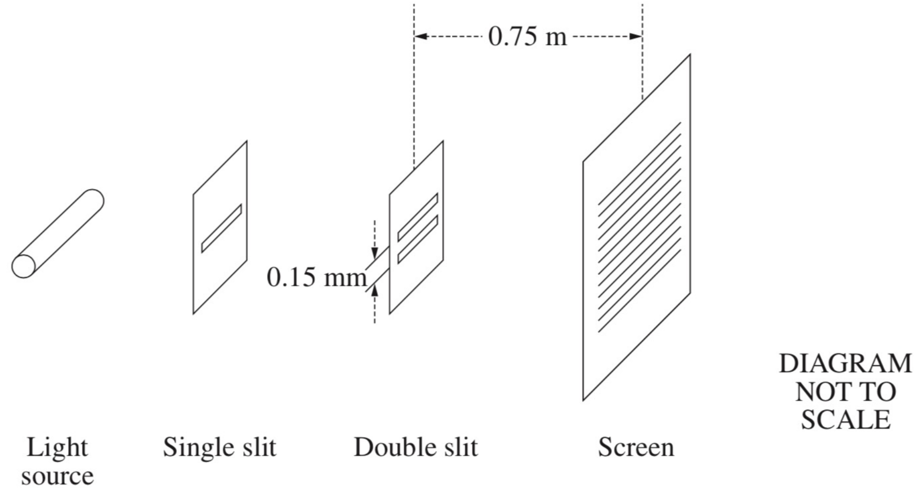
θ – angle from the centre line

λ – the wavelength of light

m – the order of the minima. The 1st minima is found when m=1, the 2nd maxima is found when m=2, etc.

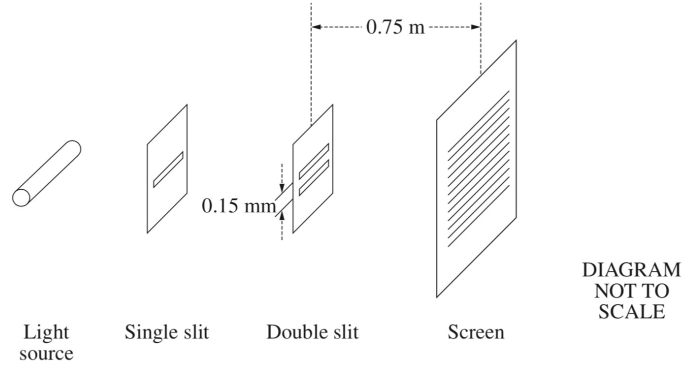
The Double Slit Experiment

NESA 2017 (3 Marks): The diagram shows a light source, slits and a translucent screen arranged for an experiment on light. Light and dark bands form on the screen. The light has a wavelength of 590nm.



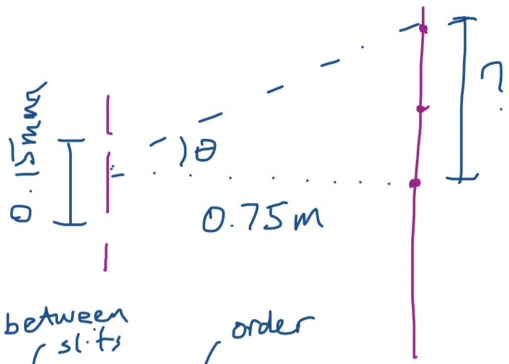
The distance between the centres of the double slit is 0.15mm, and the distance between the double slit and the screen is 0.75m. Calculate the distance on the screen from the centre of the central maximum to the centre of a second-order bright band.

The Double Slit Experiment



$\lambda = 590\text{nm}$

Sample Answer



between slits → d, order → m, wavelength → λ

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

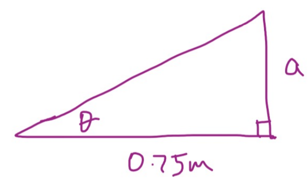
↑ solve for theta

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

$$= \frac{2 \times 590 \times 10^{-9}\,m}{0.15 \times 10^{-3}}$$

$$\theta = \sin^{-1}\left(7.86\ldots \times 10^{-3}\right)$$

$$= 0.4507\ldots$$



$$\tan\theta = \frac{a}{0.75}$$

$$a = 0.75\tan\theta$$

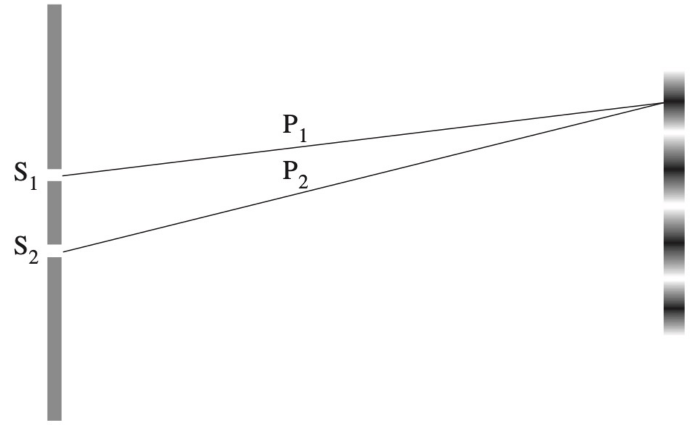
$$= 5.90018\ldots \times 10^{-3}$$

$$= 5.9 \times 10^{-3}\,m$$

Slido Question!

NESA 2017

Monochromatic light of wavelength λ strikes a double slit and produces bright and dark fringes on a screen. Light from slit S_1 travels along path P_1 and light from slit S_2 travels along P_2 to produce the dark fringe shown.



What is the difference in length between P_1 and P_2?

Sample Answer

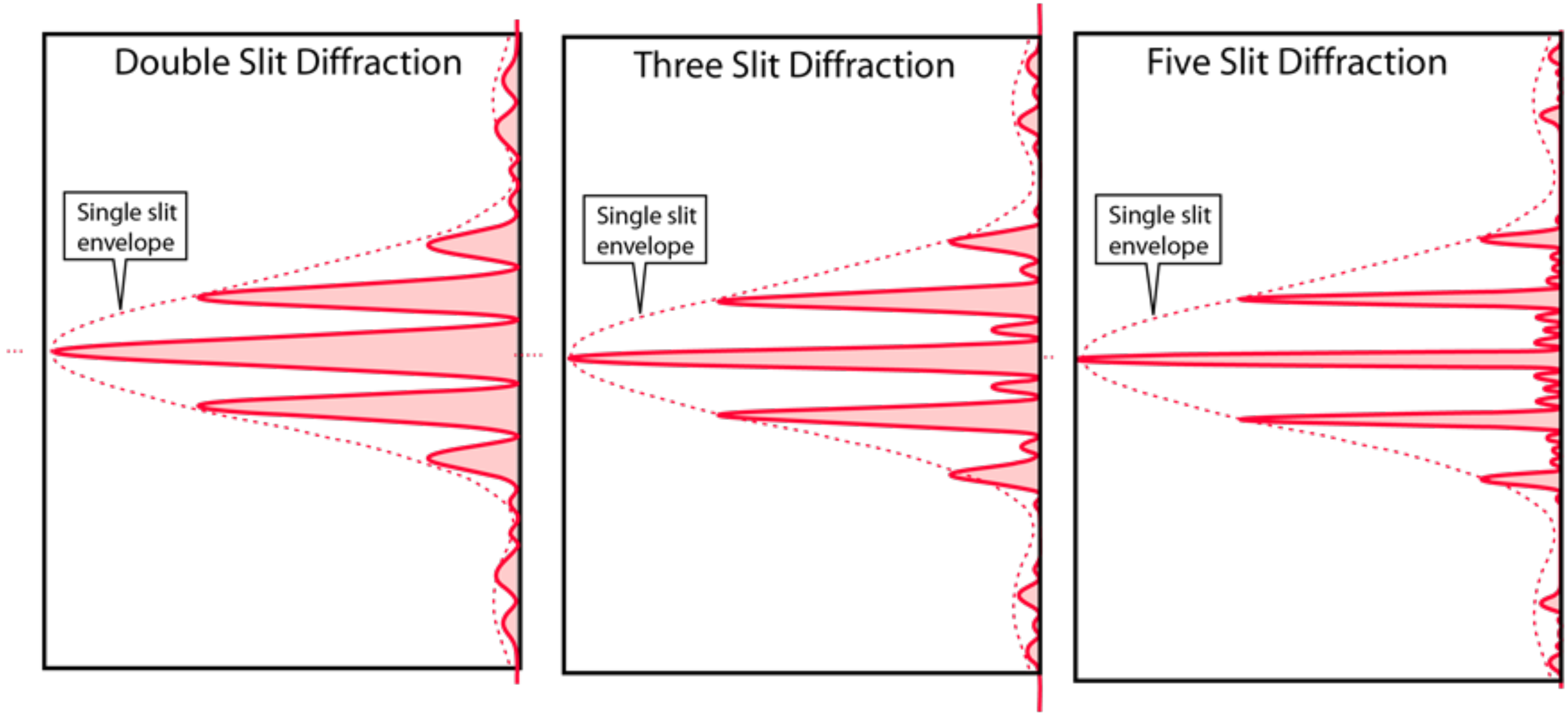
Dark fringes when the path lengths differ by half a wavelength

First order → $\lambda/2$

Second order → $\lambda/2 + \lambda$ → **$3\lambda/2$**

The Double Slit Experiment

- The resolution of a diffraction pattern can be improved by instead using a **diffraction grating** with more slits!



TIPS FOR STUDY AND STRESS

Study? Idk her...

Take advantage of being at home!

- No commuting
- Fewer extracurriculars
- Freedom to study when you want

You now have way more time to study

… and to procrastinate

Study? Idk her…

You've probably heard these before…

- Keep studying and non-studying spaces separate
- Lock away those distractions
- Work in timed blocks and take plenty of breaks!
- Get on a call with friends and study together!

It will take trial and error to figure out what works for YOU

Study? Idk her…

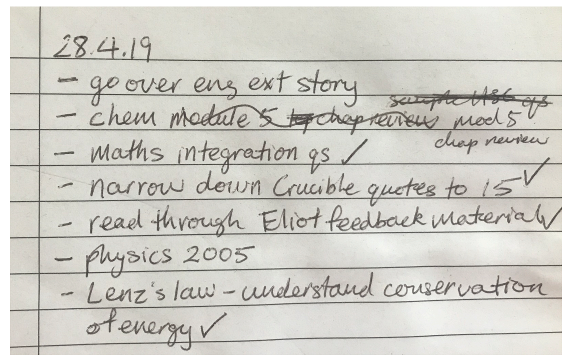
Strategies that worked for me:

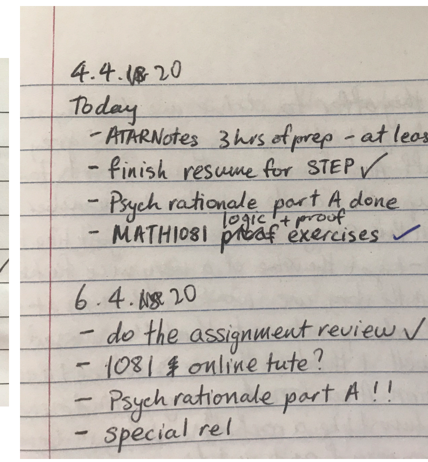
Studying on the train

- No internet = no distractions!

Loads of to-do lists

- So at least I knew *what* I was procrastinating





Pomodoro timer

- 25 minute intervals

Halfway Health Check

<u>Year 12 stress is not like normal stress</u>

- You can't run on 100% all the time – it is okay to take a day off when you're not feeling it
- Pause and reflect
    - Do I feel okay?
    - What is stressing me out?
    - What can I do about it?
- Communicate – check in with the people around you!
- Sometimes you don't feel like talking to the people you know
    - Headspace – free service to have a chat with a mental health professional anonymously

THE QUANTUM MODEL

The Quantum Model

Features of the Model

- Light consists of small, discrete energy packets called photons
- The energy in each photon is related to the frequency of the light (equation will come in a bit)
- The intensity/amplitude of the light wave is related to the number of photons
- Photons are a fundamental particle, meaning they cannot be divided. They must be emitted/absorbed in full.
  - This is the All or Nothing Principle

The Photon Model

The photon model of light was motivated by several failures of the wave model of ‘classical’ Physics.

- The Ultraviolet Catastrophe
- The Photoelectric Effect

We will explore both of these, and how the photon model is able to explain them while the wave model fails.

The Ultraviolet Catastrophe

A black body is a perfect absorber and emitter of electromagnetic radiation.

- Nothing reflects, it is only absorbed and then re-emitted
- Only theoretical – Stars are a good ***approximate*** black body

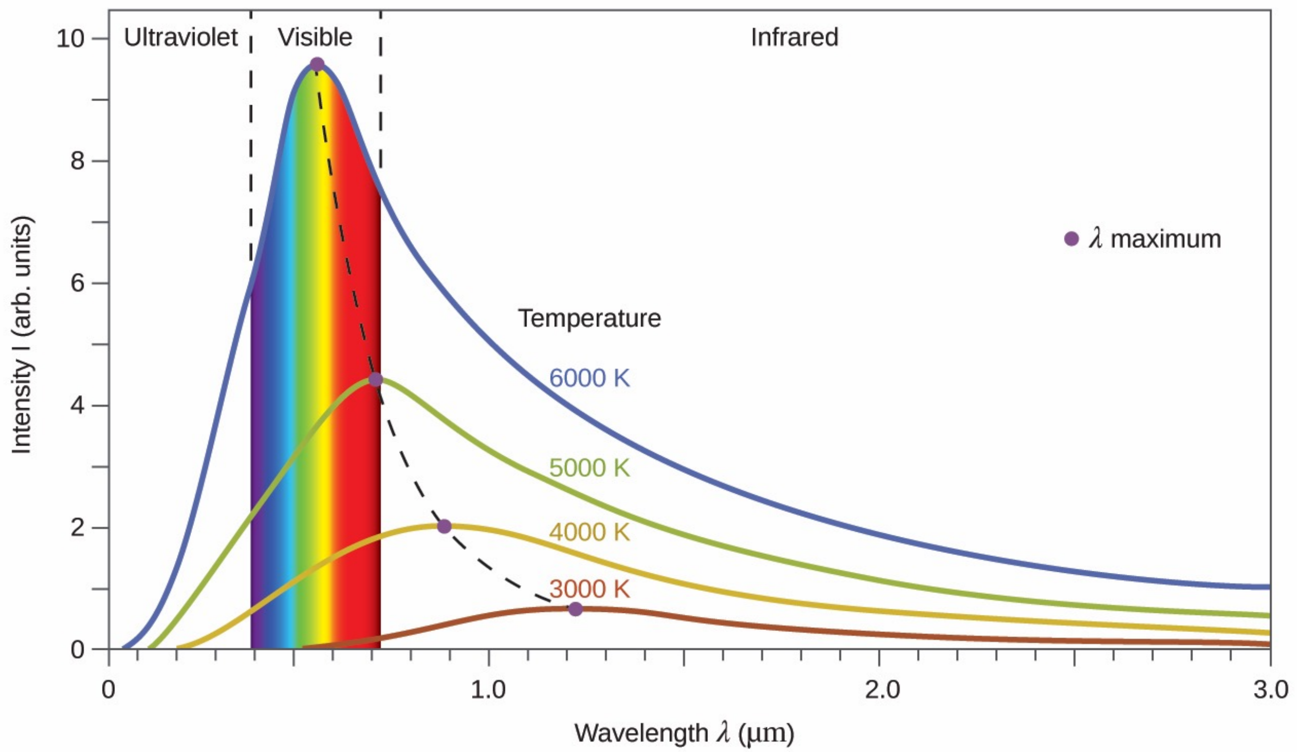
Black bodies emit radiation across the electromagnetic spectrum.

- We can graph these as a black body radiation curve

The Ultraviolet Catastrophe

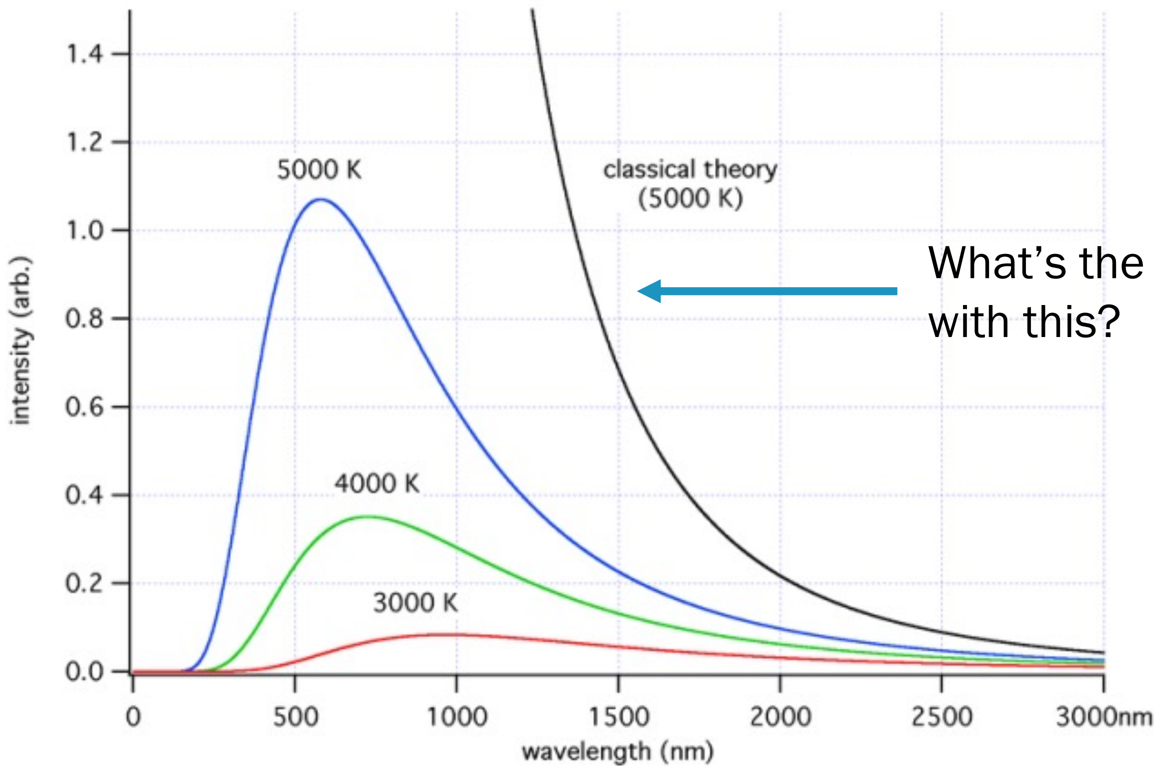
Black body radiation curve

- x-axis: wavelength of radiation
- y-axis: intensity (units are arbitrary)



The Ultraviolet Catastrophe

Scientists tried to use the wave (classical) model of light to predict the black body radiation curve.

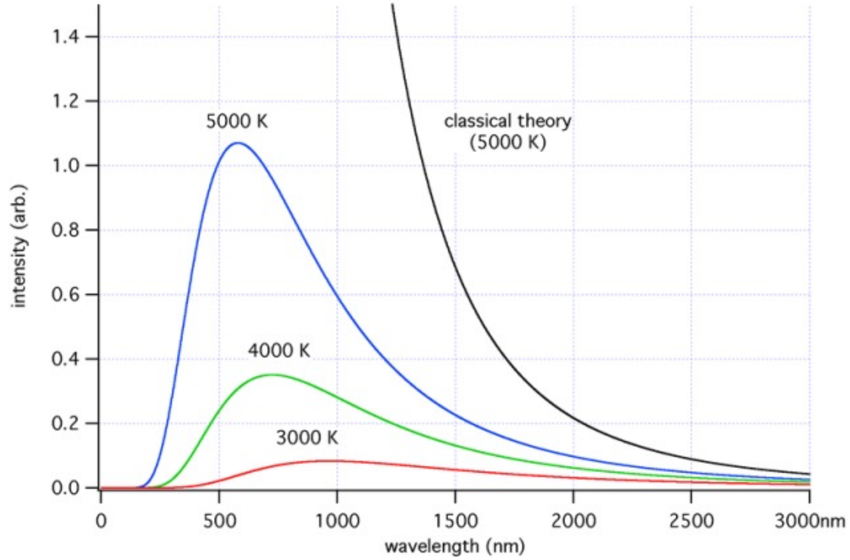


What's the problem with this?

The Ultraviolet Catastrophe

Problem #1: classical theory *didn't* match these observed curves.

Problem #2: Classical theory thought energy would increase exponentially with frequency → this suggests *infinite* energy, which violates conservation of energy



This failure became known as the ultraviolet catastrophe

The Ultraviolet Catastrophe

Max Planck came up with a mathematical trick to fix it.

- Consider the radiation to be emitted in discrete packets, called quanta
- The energy of each quanta was attached to frequency:

$$E = hf$$

where $h = 6.626 \times 10^{-34}$, this is Planck's Constant (we'll revisit this in Module 8)

- This allowed him to formulate a new law for the curves (**Planck's Law**, which we don't learn)

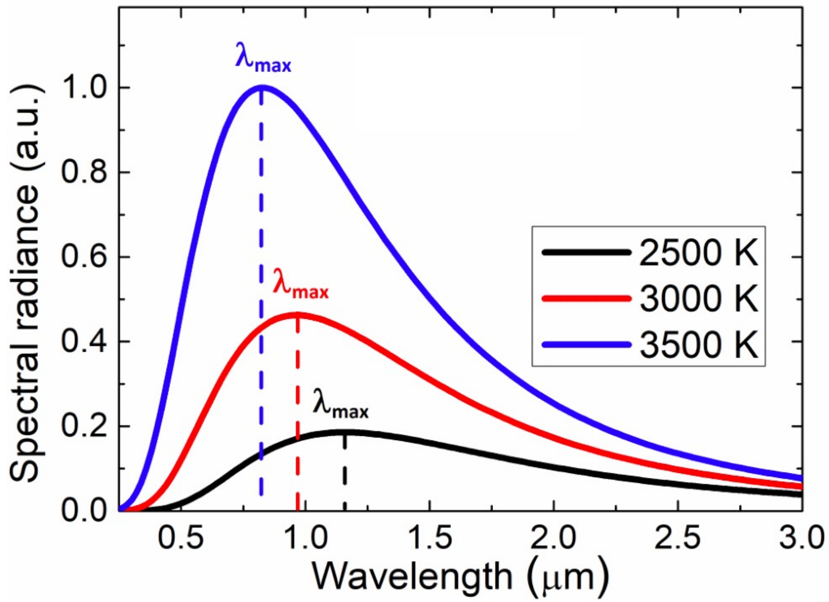
The Ultraviolet Catastrophe

We do learn Wien's law to find the location of the **peaks** on the radiation curves.

Wavelength of the radiation of peak intensity → $\lambda_{max} = \frac{b}{T}$

Wien's constant: 2.898×10^{-3} m K

Temperature (in Kelvins)



Note: spectral radiance instead of intensity on the y-axis

The Ultraviolet Catastrophe

We do learn Wien's law to find the location of the **peaks** on the radiation curves.

Wavelength of the radiation of peak intensity → $\lambda_{max} = \frac{b}{T}$

b: Wien's constant: 2.898×10^{-3} m K

T: Temperature (in Kelvins)

Example: Find the characteristic wavelength of our sun, which has a temperature of 5505°C.

Sample Answer

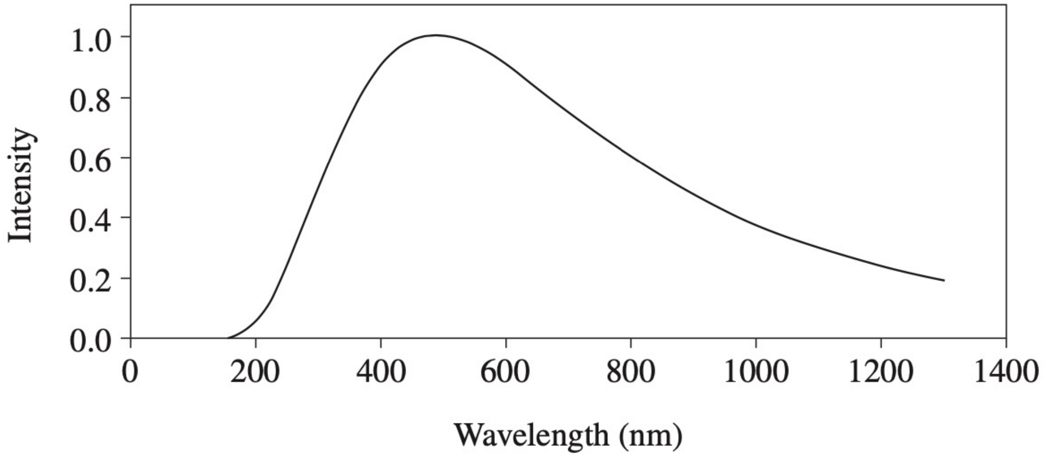
T = 5778 K

Sub into Wien's law to find λ: 5.0155×10^{-7}m = 502 nm

Slido Question!

NESA 2017

The graph shows the electromagnetic radiation emitted from a black body cavity.



What is the best estimate of the temperature of this black body?

A. 5.9×10^3 K

B. 7.2×10^3 K

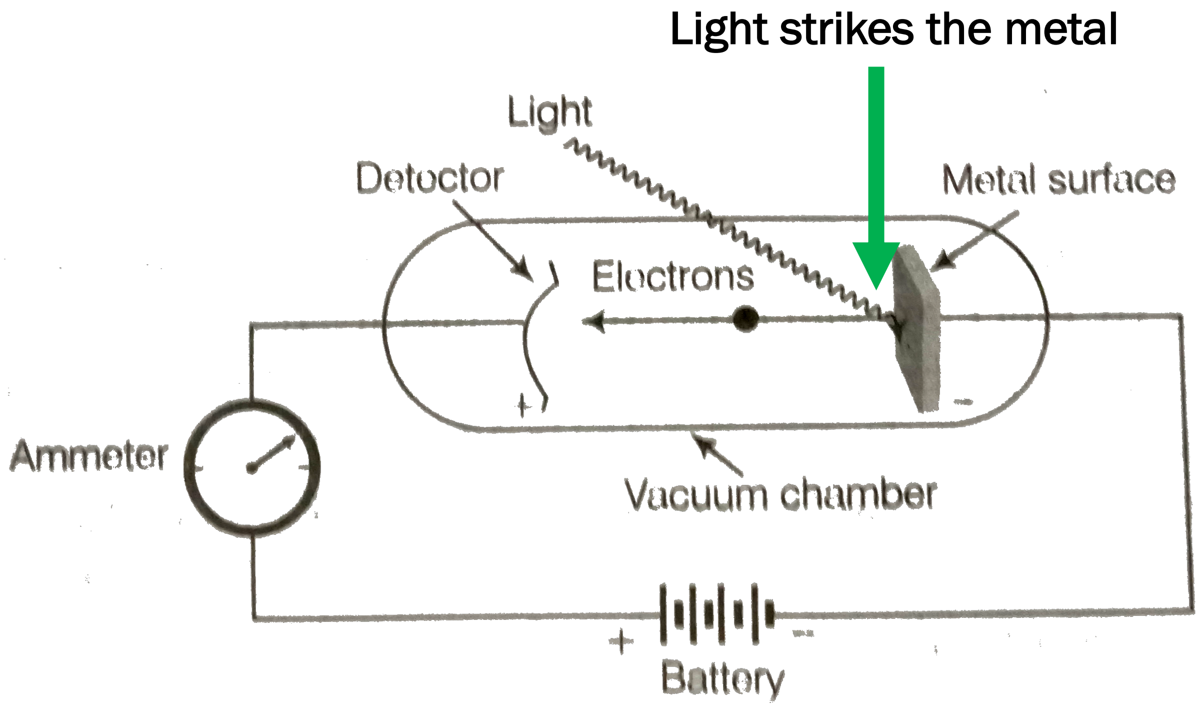
C. 1.7×10^5 K

D. 5.9×10^6 K

The Photoelectric Effect

Another unsolved problem of the 19th/20th century was the **photoelectric effect**.

Experimental setup:



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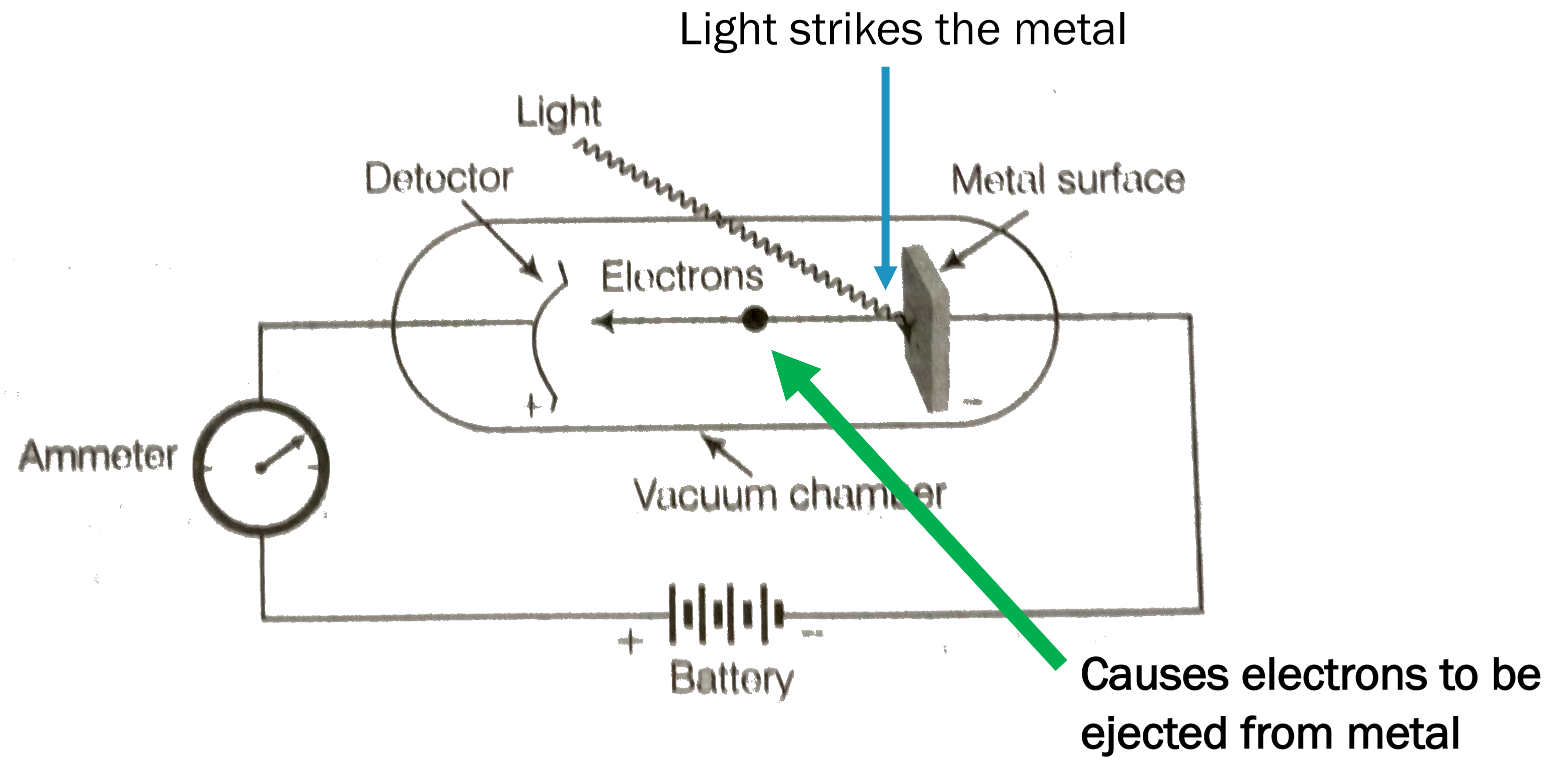

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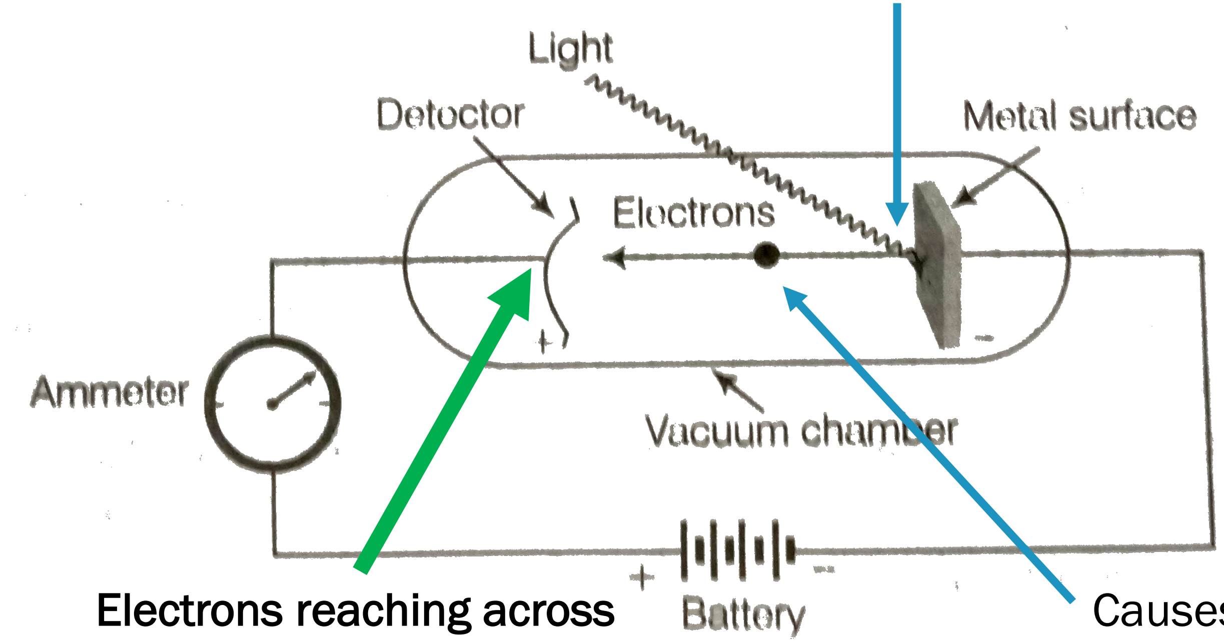

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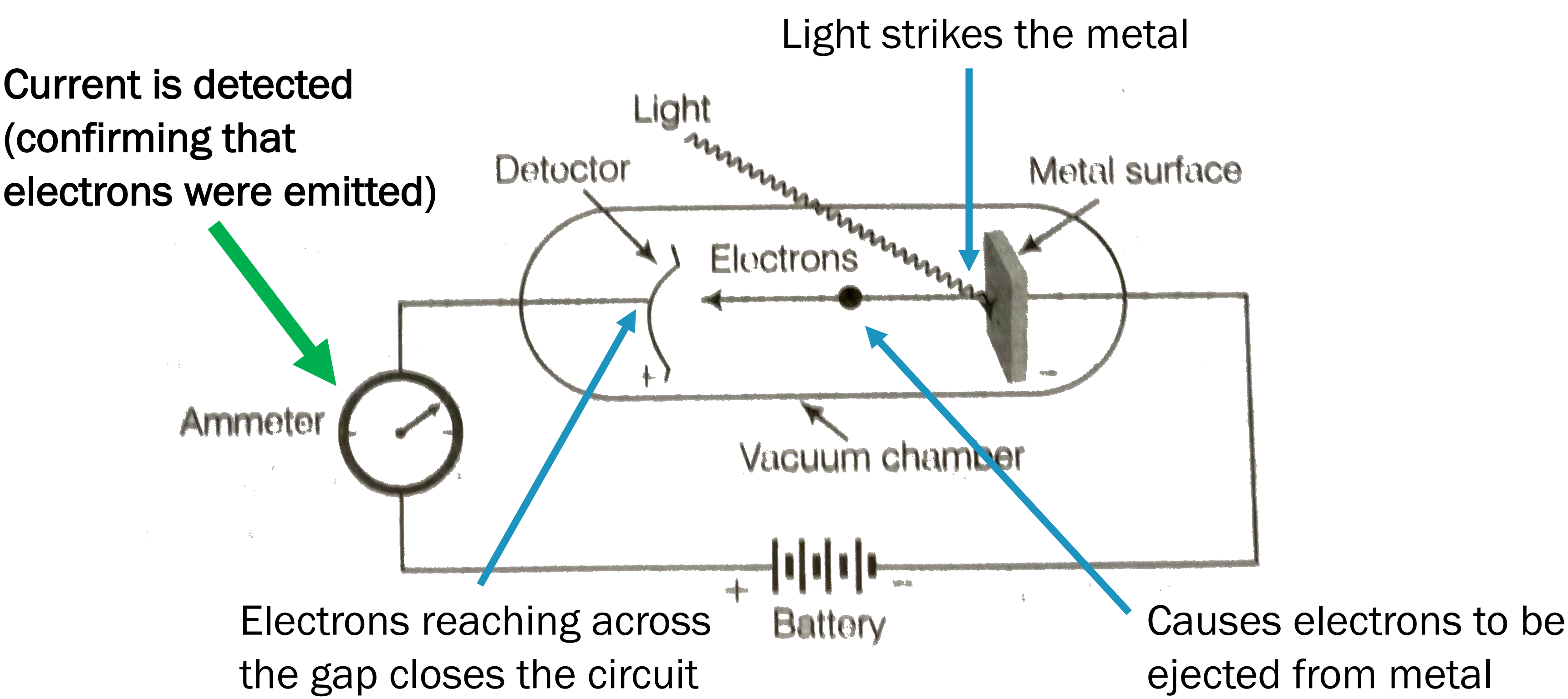


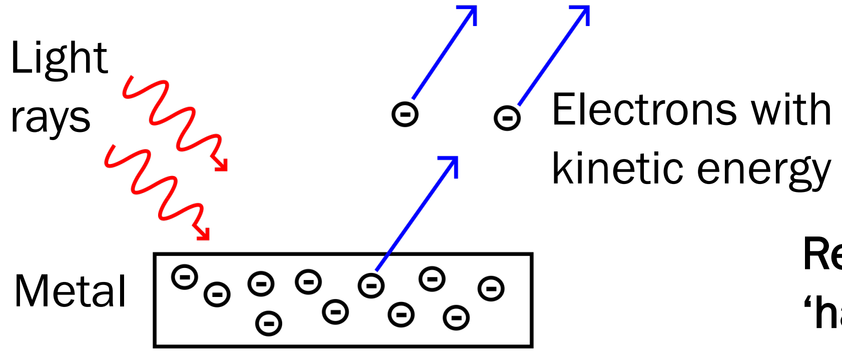
The Photoelectric Effect

Expectation vs. Reality

EXPECTATION (wave model of light)	REALITY (particle model of light)
Light of **greater intensity** emits *higher energy* electrons	Light of **greater intensity** • **DOESN'T** affect electron energy • Increases the current (ie. Causes **MORE ELECTRONS** to be emitted)
Exposing the metal to light for *longer* allows energy to *build up* in electrons, until enough for electron to escape	The emission of electrons was always **INSTANTANEOUS** from the moment light struck metal
Energy of emitted electrons would be dependent on the *intensity* of light	**Energy** of emitted electrons was dependent on the **FREQUENCY** of light

The Photoelectric Effect

Explaining reality:



Remember Planck's 'hack': $E = hf$

- Light hits the metal as **photons**, carrying 'packets' of energy
  - The size of this energy packet is dependent on the light's **frequency!**
- Each electron **absorbs** this energy from one photon
- A certain amount of energy is required to 'free' it from the metal
- The excess energy from the photon is converted into the electron's **kinetic energy**

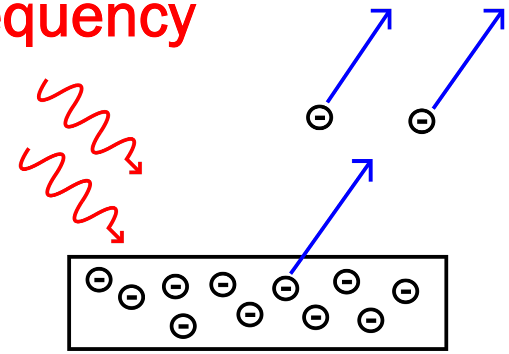
The Photoelectric Effect

So the (kinetic) energy of emitted photoelectrons is dependent on the energy of the photon it absorbs, and the amount of energy it takes to ‘break the electron free.’

$$E_K = hf - \phi$$

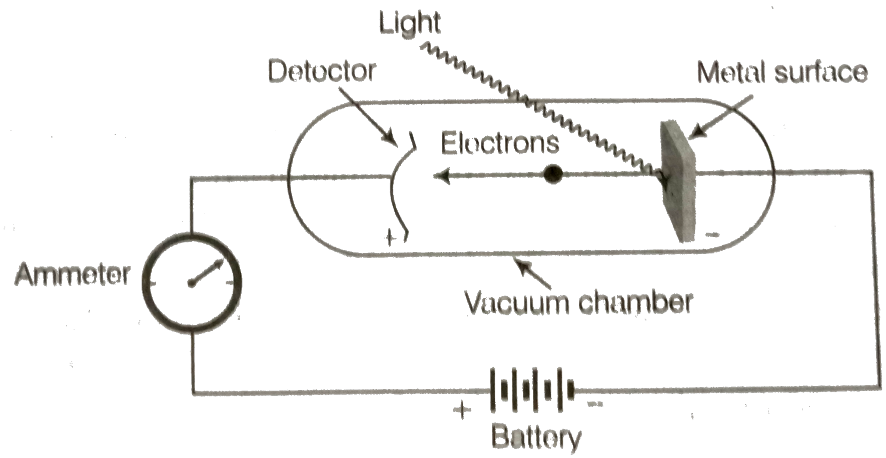
We call ϕ the **work function** of the metal.

- The minimum frequency required to overcome the work function ($hf = \phi$) is called the **threshold frequency**



Slido Question!

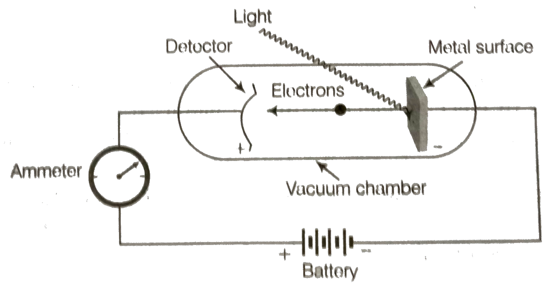
A beam of monochromatic light strikes a piece of aluminium in a vacuum chamber, as shown in the diagram below.



What does the frequency of this light need to be, so that current will flow in the circuit?

The work function of aluminium is 6.54×10^{-19} J.

Slido Question!



What does the frequency of this light need to be, so that current will flow in the circuit?

The work function of aluminium is 6.54×10^{-19} J.

Sample Answer

$E_K = hf - \phi$

Minimum is where $E_K = 0$

$hf = \phi$

$f = \frac{\phi}{h}$

$= \frac{6.54 \times 10^{-19}\ J}{6.626 \times 10^{-34}\ Js}$

$= 9.870 \ldots \times 10^{14}$

$= 9.87 \times 10^{14}\ Hz$

Spectral Analysis

Now that we know the photon model, we can use it to study the properties of matter based on how it interacts with EM radiation.

- This is called spectroscopy

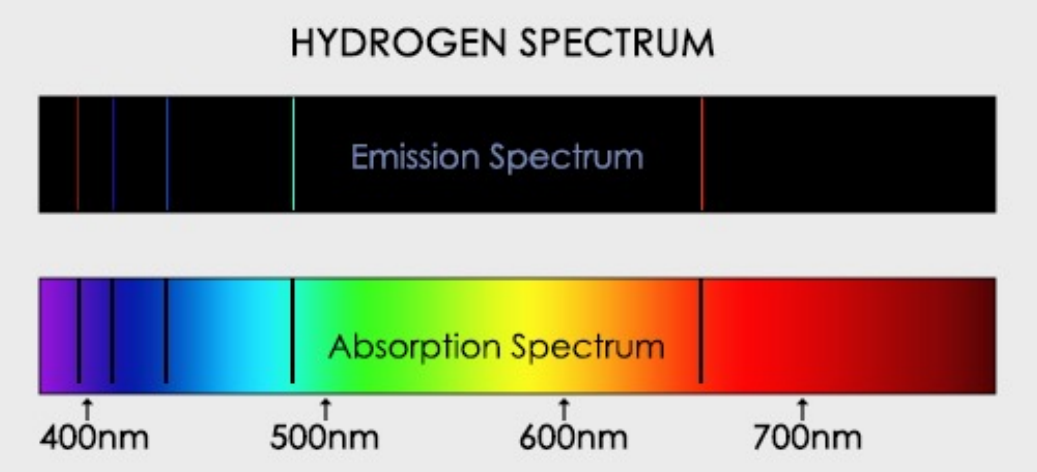
As discussed earlier, the photons emitted/absorbed by atoms have a frequency related to the energy of the transitioning electron ($\Delta E = hf$):

- These energies are indicative of the atom itself!
- We call the associated frequencies spectral lines

Spectral Analysis

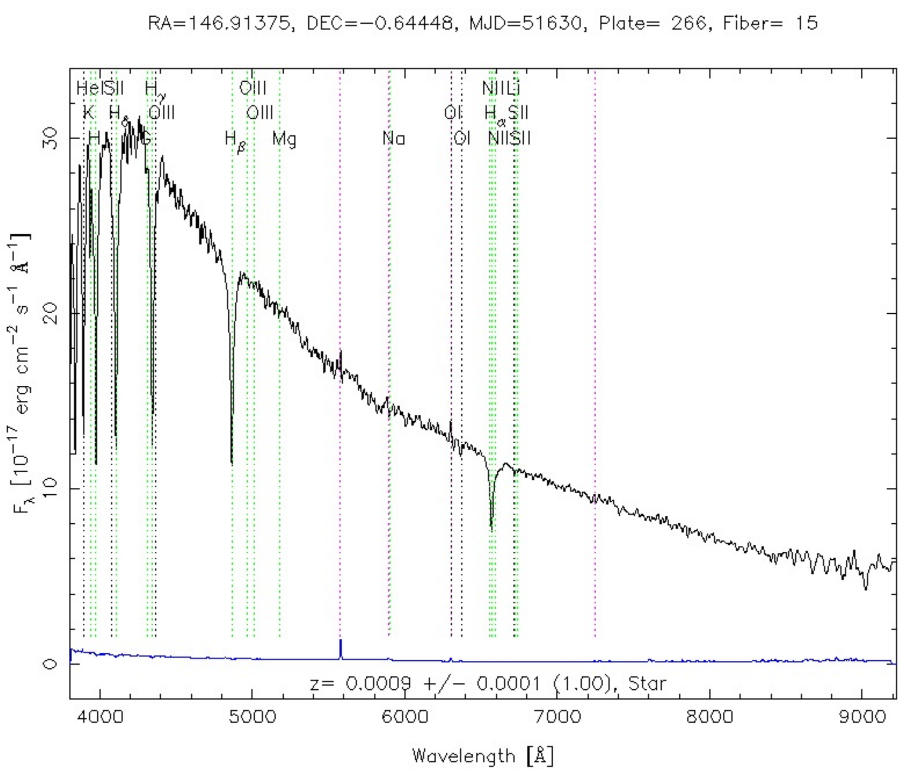
We can do two things:

- Detect the frequencies of radiation absorbed when light is bounced off/shone through a substance. This is an **absorption spectrum**
- Excite the substance (heat it up), and detect the frequencies of radiation emitted by the substance as it relaxes. This is an **emission spectrum**



Spectral Analysis

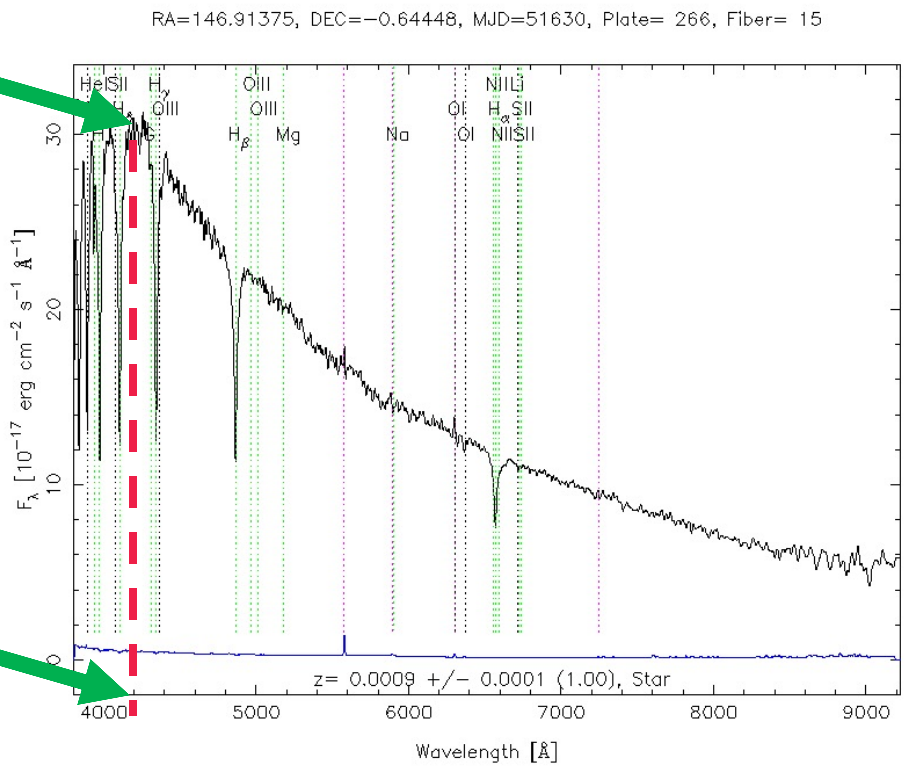
This is particularly useful for analysing stars - We can tell a lot about a star from its spectrum, which consists of a black body radiation curve ‘corrupted’ by spectral lines!



Spectral Analysis

Temperature: The peak of the radiation curve (as discussed) is indicative of the temperature of the star

Peak

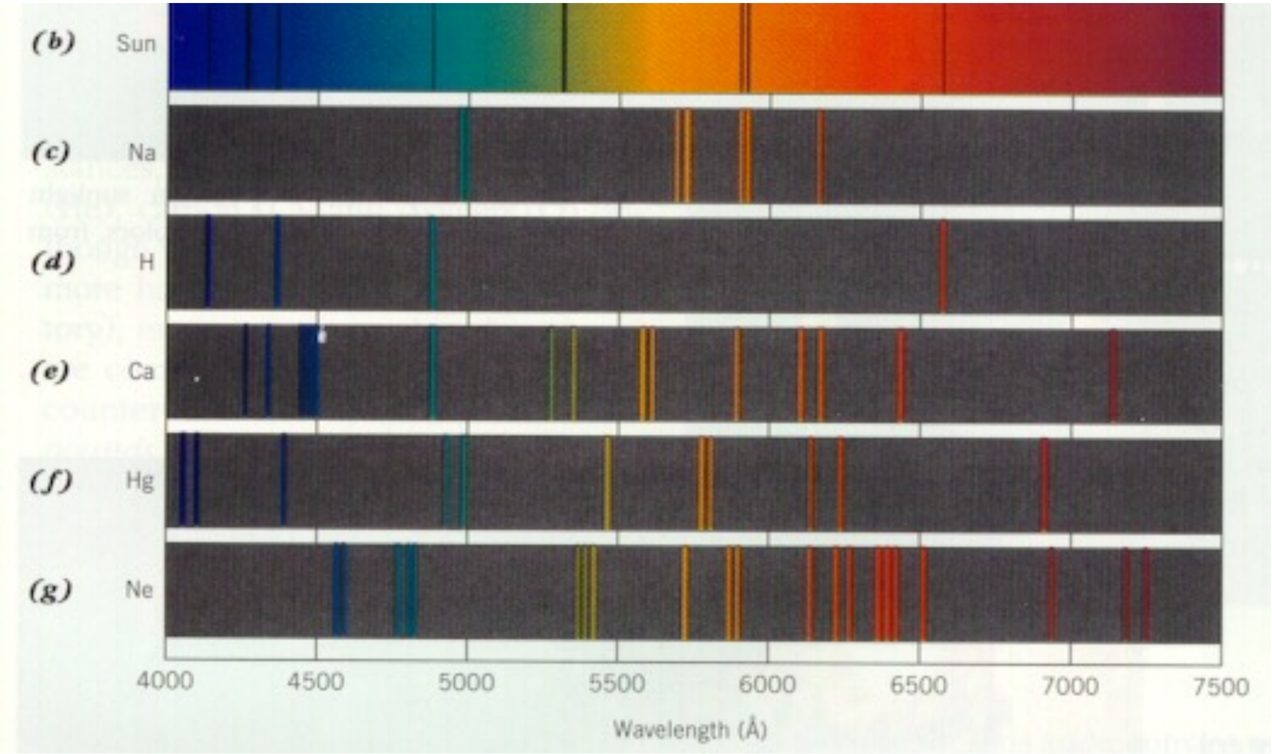


λ_{max} can be used to calculate temp

Spectral Analysis

Composition: The positions of the spectral lines tells us what elements are in the star

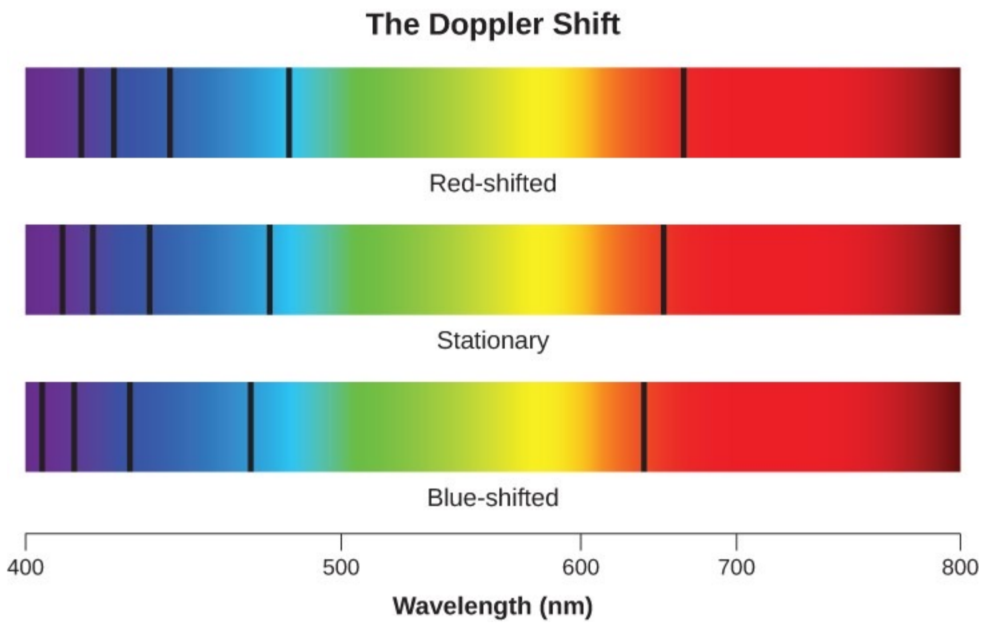
– Elements have unique spectral lines



Spectral Analysis

Translational velocity: The Doppler Effect causes the spectrums of moving stars to be *shifted*

- Stars moving away: red-shifted (towards longer wavelengths)
- Stars moving towards us: blue-shifted (towards shorter wavelengths)
- Amount of shift is relative to velocity



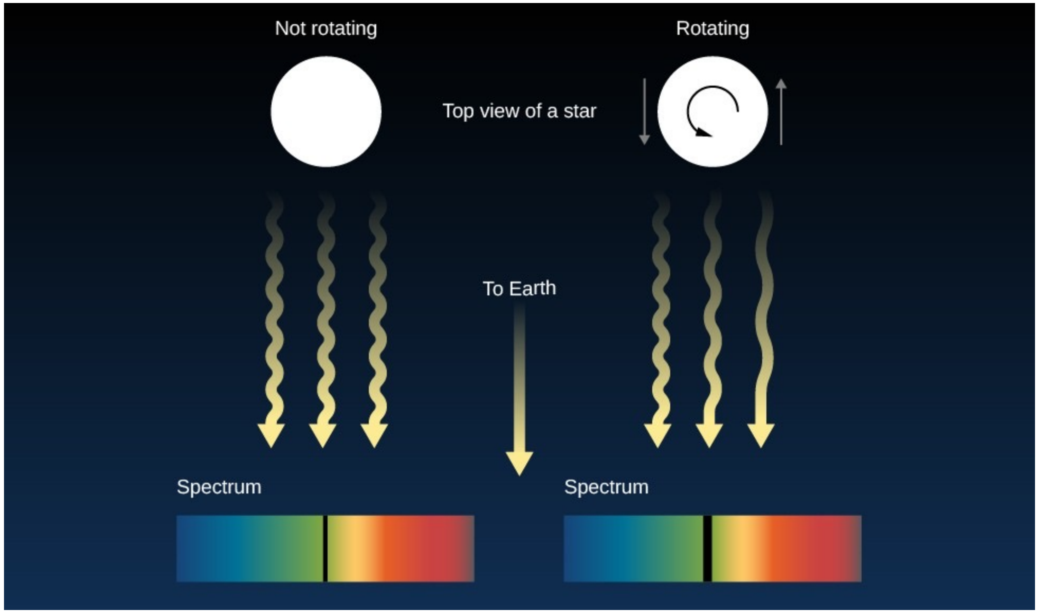
Spectral Analysis

Translational velocity: The Doppler Effect causes the spectrums of moving stars to be *shifted*

Spectral Analysis

Rotational velocity: Width of spectral lines are proportional to rotational velocity

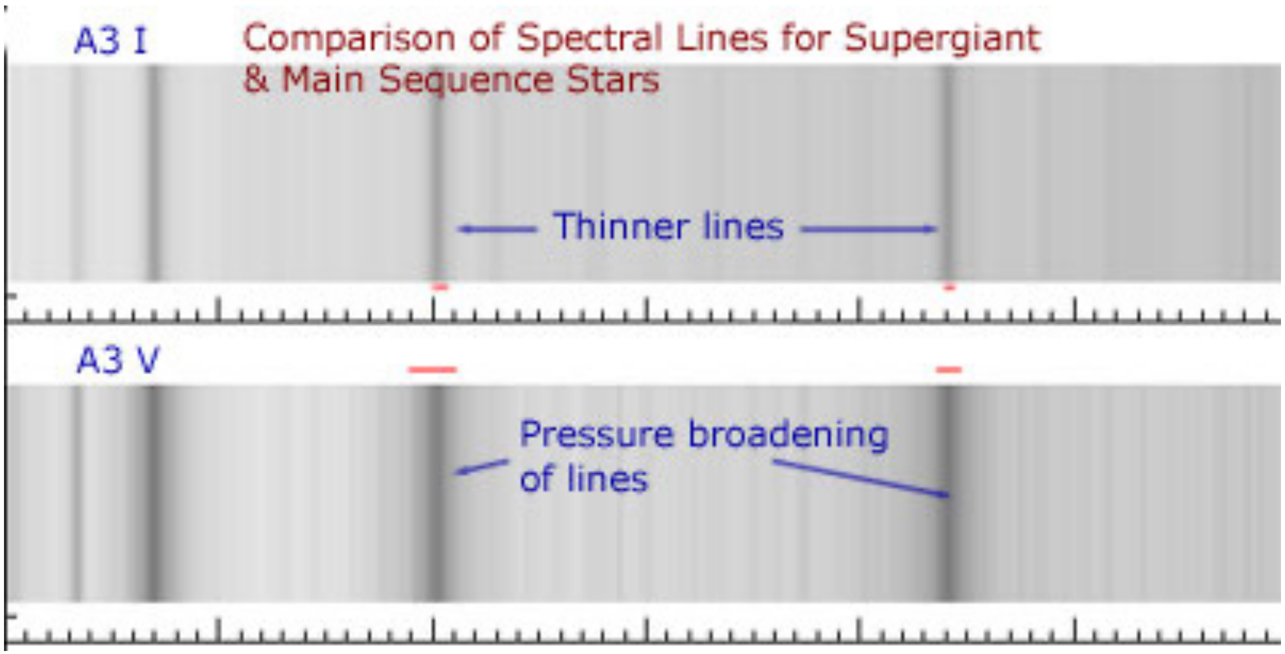
- Also due to Doppler Effect
- Spectra from one side of the star is blue-shifted, while the other side is red-shifted



Spectral Analysis

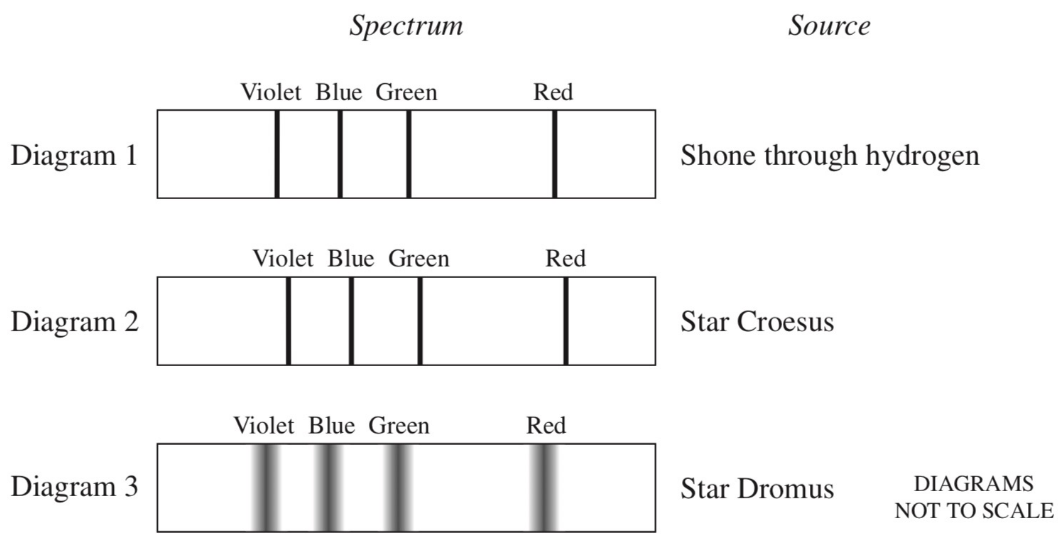
Density: Denser stars have more blurred spectral lines

– There's more uncertainty in the interactions between atoms and their energy changes



Slido Question!

NESA 2017 What can we say about these stars?



Sample Answer

Croesus
- red-shifted → moving away from us

Dromus
- blue-shifted → moving towards us
- spectral widening → star is rotating

STUDY PROPERLY

Studying Properly

Study isn't the same for every subject.

- English is essay driven, so you spend a lot of time gathering evidence/developing arguments
- Humanities are content driven, so you spend a lot of time memorizing
- Mathematics is skills driven, you spend all your time practicing

Science (Physics) is all about the *understanding*!

Studying Properly

Consider Physics study in terms of the three types of questions you'll get served:

- Calculations
- Regurgitations
- Explanations

Your study should be (roughly) equally divided between all three of these!

Studying Properly

CALCULATIONS:

- Derive your formulas
- Practice them!

Studying Properly

REGURGITATIONS:

- Syllabus based study:
  - Notes
  - **Palm Cards**
  - Posters
- Practice exams:
  - Get them marked/look at exemplars!

Studying Properly

EXPLANATIONS:

- Understand your content:
  - Watch videos
  - Teach people!!
- Go through all your pracs too!

Closing Comments

- Two tips to rule them all:
  1. Know your key words!
  2. Practice as much as you can!
- Hang in there! This course is tough – Work hard, you'll get there ☺

SPECIAL RELATIVITY

Special Relativity

In 1905, Einstein proposed two postulates, which have insanely strange results for time and space:

1. The speed of light is an **absolute constant**, the same in all reference frames
2. All inertial frames of reference are equivalent.

Special Relativity

1. The speed of light is an **absolute constant**, the same in all reference frames

- Scientists were already starting to suspect this from their experimental results
- Speed of light = c = 3×10^8 m/s

Special Relativity

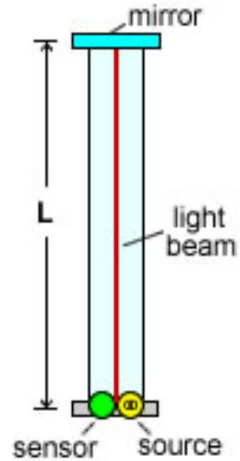
2. All inertial frames of reference are equivalent.

- What does **inertial** mean?
  - Non-accelerating
  - Travelling at a constant velocity (or at rest)
- If I’m in a room and unable to see the outside world, I wouldn’t know if the room was at rest, or moving at constant velocity
- All of Newton’s laws hold up within an inertial frame of reference

A Thought Experiment

Why is this such a big deal? Consider the **train thought experiment!**

Light clock: 1 'tick' = time taken for a beam of light to bounce back

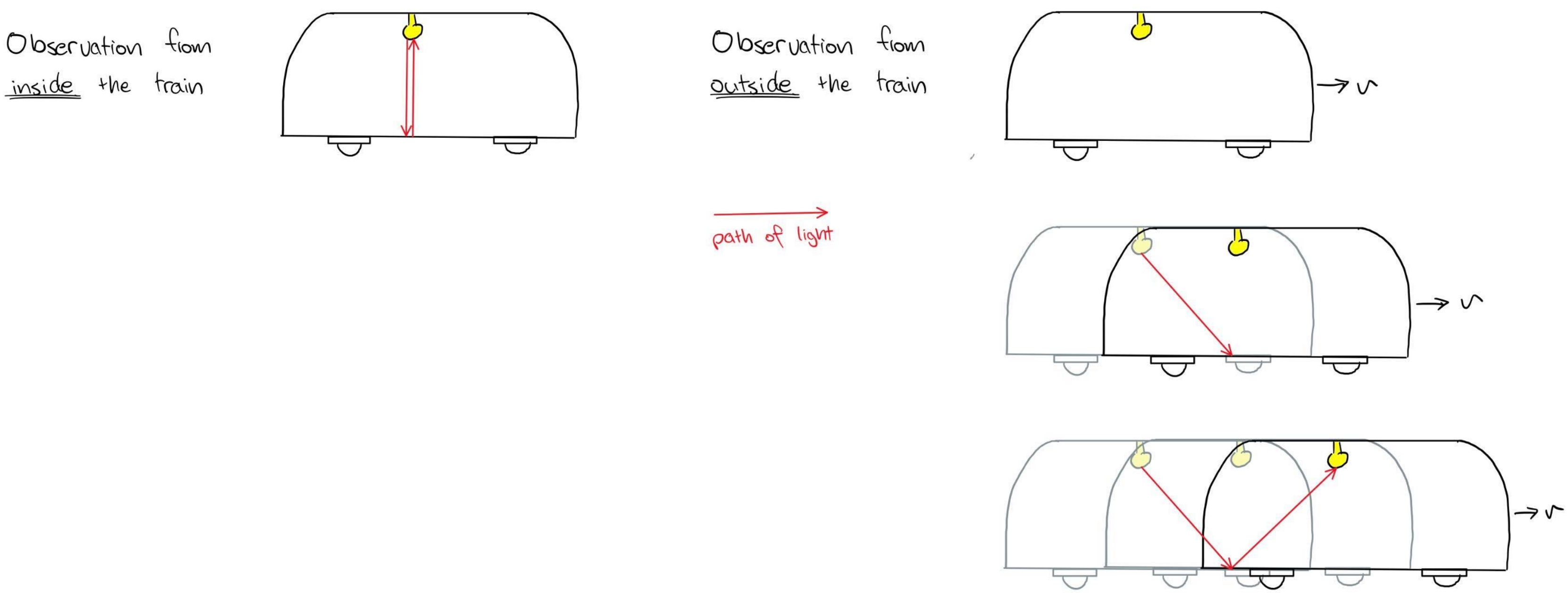


(a)

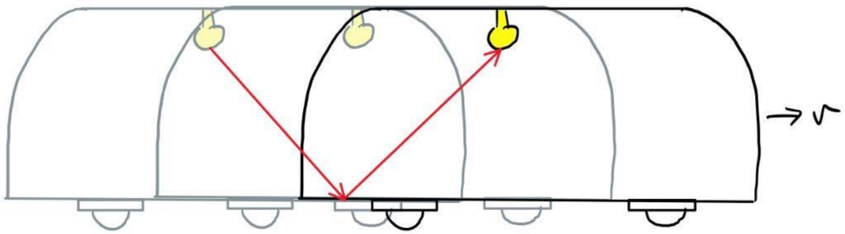
A Thought Experiment

Why is this such a big deal? Consider the **train thought experiment!**

Light clock in a train moving at high speed:



A Thought Experiment



The **observer outside the train** sees the light travelling a GREATER distance than the distance seen by the **observer inside the train.**

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Travelled by light is greater

But speed of light needs to be a constant (Postulate 1)

Meaning a LONGER time has been taken for a single tick in the light clock

Time Dilation

Time dilation – time passes more slowly for fast-moving reference frames

t_0 – **proper time** (time in the reference frame at rest relative to the light clock)

t – measured time (time measured by the observer)

v – velocity of the moving frame (relative to observer)

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Length Contraction

Likewise, length measurements become relative as well.

Length contraction – lengths are measured to be shorter for fast-moving reference frames

L_0 – **proper length** (length in the reference frame at rest relative to the object)

L – measured length (length measured by the observer)

$$L = L_0 \sqrt{1 - \frac{v^2}{c^2}}$$

Special Relativity

The hardest part of questions involving these results is deciding which is the **relativistic quantity** (l, t) and which is the **rest quantity** (l_0, t_0).

- Remember, it's relative!
- If I'm measuring the length of a spaceship moving at $0.2c$, **my reference frame is relativistic**, because it is moving with respect to me.
- If I'm inside that spaceship, **my reference frame is the rest frame**, because there is no relative motion involved

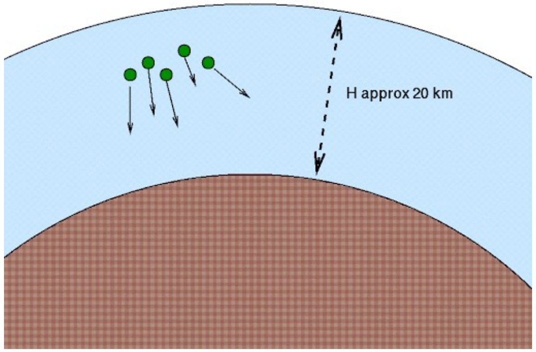
Special Relativity

We can (and have) proved this with experiments, long after Einstein first formulated the theory.

- Observed change in lifetime of high speed particles (EG – muons)
- Atomic clock experiments (EG – Hafele + Keating)
- Can't accelerate things to go faster than the speed of light (no matter how hard we try…)
- The relativistic Doppler effect

Special Relativity

Muon Decay

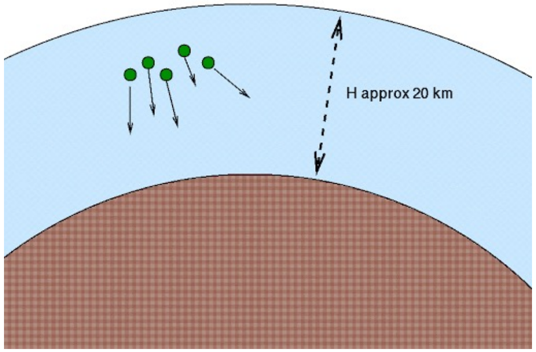


- Muons are tiny particles produced in space
  - Produced 10 km (10^4 m) above the Earth
  - Average decay in 2.2 x 10^{-6} seconds
  - Travel at 0.98c (98% of the speed of light)
- Distance it travels before decay, in *non-relativistic* circumstances:
  - $d = 0.98\times 3\times 10^8 \mathrm{m}/s \times 2.2\times 10^{-6} s = 646.8\mathrm{m}$ → which would reach nowhere near the surface of the Earth 10km away
- BUT scientists did find them close to Earth's surface! Thanks to special relativity!

Special Relativity

Muon Decay

- Muons are tiny particles produced in space
  - Produced 10 km (10^4 m) above the Earth
  - Average decay in 2.2 x 10^{-6} seconds
  - Travel at 0.98c (98% of the speed of light)

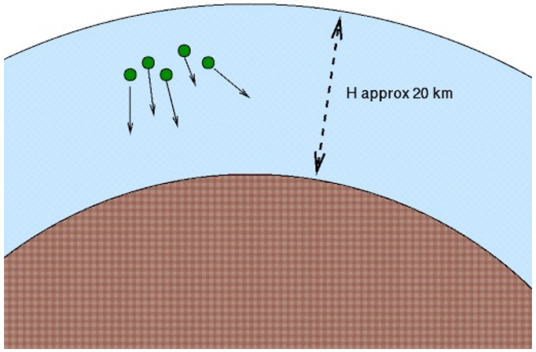


- **From the perspective of the muon:**
  - The distance to the Earth is length contracted
  - The *proper distance* to Earth is from a reference frame *at rest* relative to the Earth
  - **So what's the distance to Earth that the muon sees?**

$$L = L_0\sqrt{1-\frac{v^2}{c^2}}$$

Special Relativity

Muon Decay



- Muons are tiny particles produced in space
  - Produced 10 km (10^4 m) above the Earth
  - Average decay in 2.2 x 10^{-6} seconds
  - Travel at 0.98c (98% of the speed of light)
- **From the perspective of an observer on Earth:**
  - The time taken for a muon to decay is dilated
  - The *proper time* of decay is taken from the frame of reference *at rest* relative to the muon
  - **So what's the lifetime of a moving muon from Earth's perspective?**

$$t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Slido Question!

A next-gen spacecraft developed by NASA has a rest length of 50m. This craft can reach speeds of $0.2c$. What would be its length while travelling at this speed, as measured by:

a) Someone back on earth?

b) Someone on the craft?

a) Spacecraft is moving relative to Earth, so from Earth's frame of reference, we'll measure a contracted length

$$L = L_0 \sqrt{1 - \frac{v^2}{c^2}}$$

L ↑ contracted length – measured from frame of reference moving relative to spacecraft (ie Earth)

L_0 ← proper length – length measured from frame of reference at rest relative to spacecraft

$$L = 50 \sqrt{1 - \frac{(0.2c)^2}{c^2}}$$

$= 48.989\ldots$

$= 49\text{ m}$

b) To someone on the craft, the spacecraft isn't moving relative to them. So they measure the rest length. 50 m

Slido Question!

A radioactive particle has a half life of $2.5\mu s$ while at rest in a laboratory. This same particle is accelerated to a high speed by a particle accelerator, increasing its half life to $10\mu s$. How fast was it travelling relative to the observer?

Proper time – time measured in reference frame at rest relative to particle

$t_0 = 2.5\mu s$

Half-life appears to be $10\mu s$ because time dilation has occurred when we're observing from a frame of reference that's moving relative to it.

$t = 10\mu s$

Time dilation formula

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

Rearrange to solve for v

$$\sqrt{1-\frac{v^2}{c^2}} = \frac{t_0}{t}$$

$$1-\frac{v^2}{c^2} = \frac{t_0^2}{t^2}$$

$$\frac{v^2}{c^2} = 1 - \frac{t_0^2}{t^2}$$

$$v = c\sqrt{1-\frac{t_0^2}{t^2}}$$

$$= 3.0\times10^8\sqrt{1-\frac{2.5^2}{10^2}}$$

$$= 2.9047\ldots\times10^8$$

$$= 2.9\times10^8\ ms^{-1}$$

Relativistic Momentum

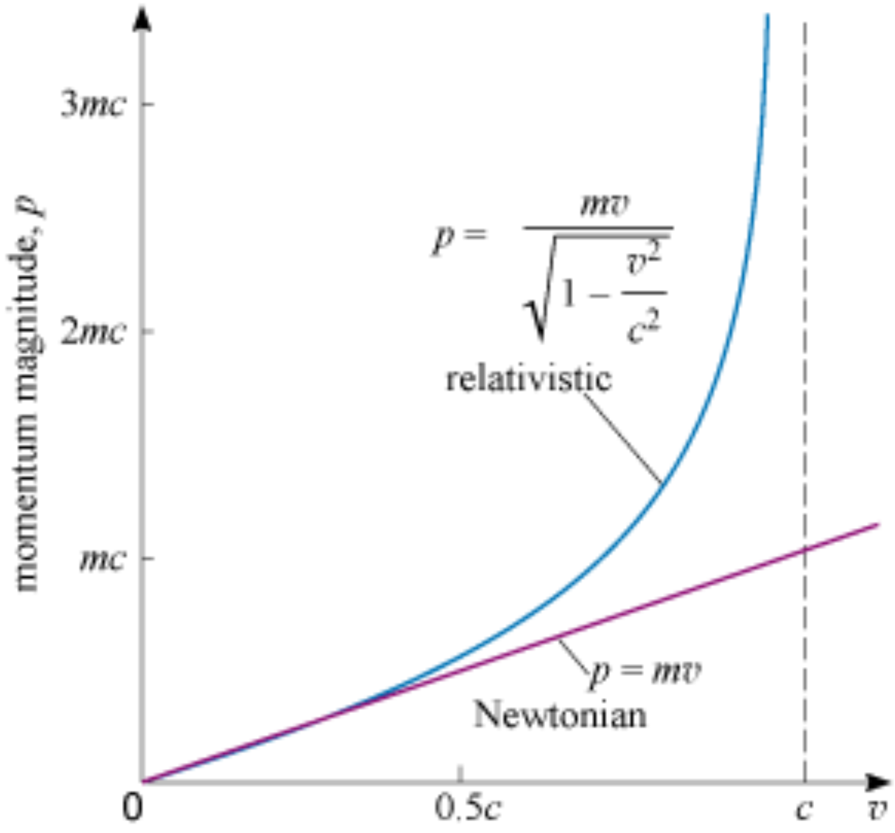
The concept of relativistic momentum is the concept of momentum, adjusted for the effects of special relativity.

- Instead of just *mass*, we have ***relativistic mass***

$$\rho = m_v v = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{\rho_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

- This imposes a limit on velocity!

Relativistic Momentum



c is the speed limit for velocity!

Special Relativity

Special relativity is a very tricky concept to get your head around - it's ok if it doesn't make complete sense now!

- Watch this video (or search up Simple Relativity): https://www.youtube.com/watch?v=TgH9KXEQ0YU
- Pretend you're Einstein – try stepping through the logic of a thought experiment
- If maths helps you understand things – try deriving the formulas for time dilation and length contraction
- Explain/discuss/argue with friends (or teachers if you're brave)!

1. Define key terms
2. Outline (as per key verb)
3. Show how thought experiment predicts time dilation

HSC 2019

Question 27 (6 marks)

(a) Outline a thought experiment that relates to the prediction of time dilation. **3**

Sample Answer

Time dilation is when time appears to move more slowly in a frame of reference moving relative to the observer's frame of reference. This is a result of Einstein's two postulates: the speed of light is the same in all frames of reference, and all frames of reference are equivalent.

In a thought experiment involving light bouncing between the floor and the ceiling of a train, an observer inside the train sees the light moving straight up and down. However, when the train is moving near the speed of light, an outside observer sees the light moving in a triangular path. Since a greater distance has been travelled but the speed of light must remain constant, this means that the outside observer measures a greater time for the light to bounce up and down. This is time dilation.

Special Relativity

HSC 2019

1. Define key terms
2. Outline (as per key verb)
3. Show how thought experiment predicts time dilation

(b) Outline experimental evidence that validated the prediction of time dilation. **3**

Sample Answer

Time dilation is when time appears to move more slowly in a frame of reference moving relative to the observer's frame of reference. Scientists were able to measure the number of muons that reached the Earth after being produced in the upper atmosphere. They knew the half-life of muons, and that they travelled at close to the speed of light. They could calculate the prediction for the number of muons reaching Earth assuming non relativistic effects, as well as by taking time dilation into account. The actual number of muons they measured was consistent with the prediction taking time dilation into account, hence experimentally validating time dilation.

Mass/Energy Equivalence

You've probably seen this formula (and might even know what it means):

$$E = mc^2$$

The energy contained in a particle/object is proportional to its mass.

- One kilogram of mass contains 9 billion billion joules of energy, heaps!
- Implications will be explored in Module 8…

Great work everyone!

Now go have some fun with physics ☺