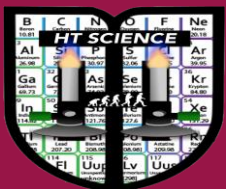


# Silent Starter

		A	B	C	D
1-	Which of the following is a property of all waves?	They transfer matter	They transfer energy	They have mass	They are visible
2-	What is amplitude?	The distance between two crests	The number of waves per second	The maximum displacement from the equilibrium position	The speed of a wave
3-	What is the unit of frequency?	Metre (m)	Second (s)	Newton (N)	Hertz (Hz)
4-	What does wavelength measure?	The distance between identical points on adjacent waves	The height of a wave	The speed of a wave	The energy transferred
5-	Which equation links wave speed (v), frequency (f) and wavelength (λ)?	$v = f \times \lambda$	$v = f\lambda$	$v = f/\lambda$	$v = \lambda/f$
6-	Which type of wave is transverse?	Sound wave	Light wave	Compression wave	Seismic P-wave
7-	Which type of wave is longitudinal?	Light wave	Water surface wave	Radio wave	Sound wave
8-	If frequency increases while wave speed stays constant, what happens to wavelength?	It increases	It decreases	It stays the same	It doubles
9-	Which of the following is an electromagnetic wave?	Sound	Light	Water	Ultrasound
10-	Which statement about particles is correct?	Particles always move in waves	Particles have a definite position at any instant	Particles cannot carry energy	Particles must have no mass
11-	Which subatomic particle has a negative charge?	Electron	Neutron	Proton	Photon
12-	Which particle is found in the nucleus and has no charge?	Electron	Photon	Neutron	Positron
13-	Which property can both waves and particles transfer?	Mass	Energy	Density	Volume

Learning objectives:



# Interference, Diffraction and Wave–Particle Duality

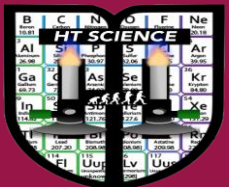
## Learning objectives

- ❑ Explain how the double-slit experiment shows that light behaves as a wave.
- ❑ Use the double-slit equation to solve problems involving interference patterns.
- ❑ Explain evidence for wave–particle duality and identify whether experiments show wave-like or particle-like behaviour.

## Key words:

- Interference
- Diffraction
- Constructive interference
- Destructive interference
- Fringe Pattern

Learning objectives:



# Explanation

Question:

Which of the following are examples of wave behaviour?

**Diffraction**

**Gravity**

**Mass**

**Weight**

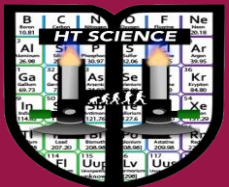
**Electric charge**

**Reflection**

**Momentum**

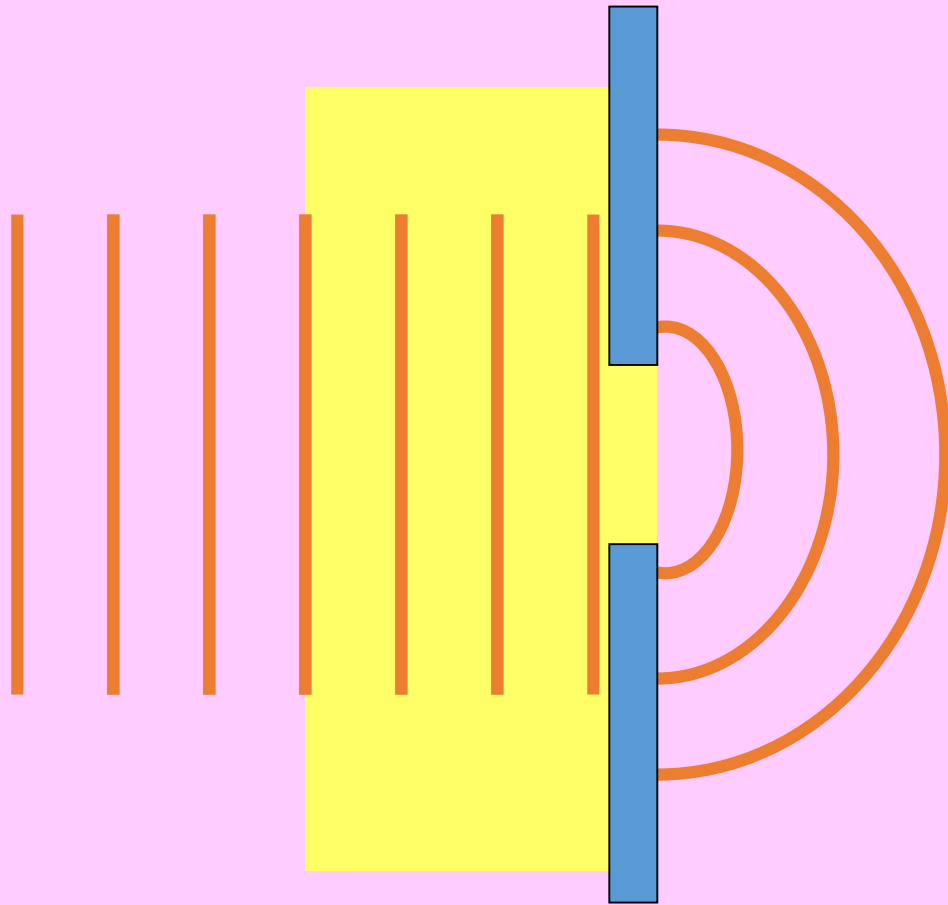
**Refraction**

Learning objectives:



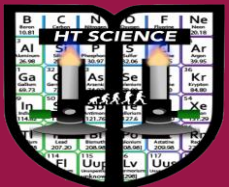
## Explanation

# Diffraction : Wave behaviour



**Diffraction occurs when waves pass through gaps and spread out.**

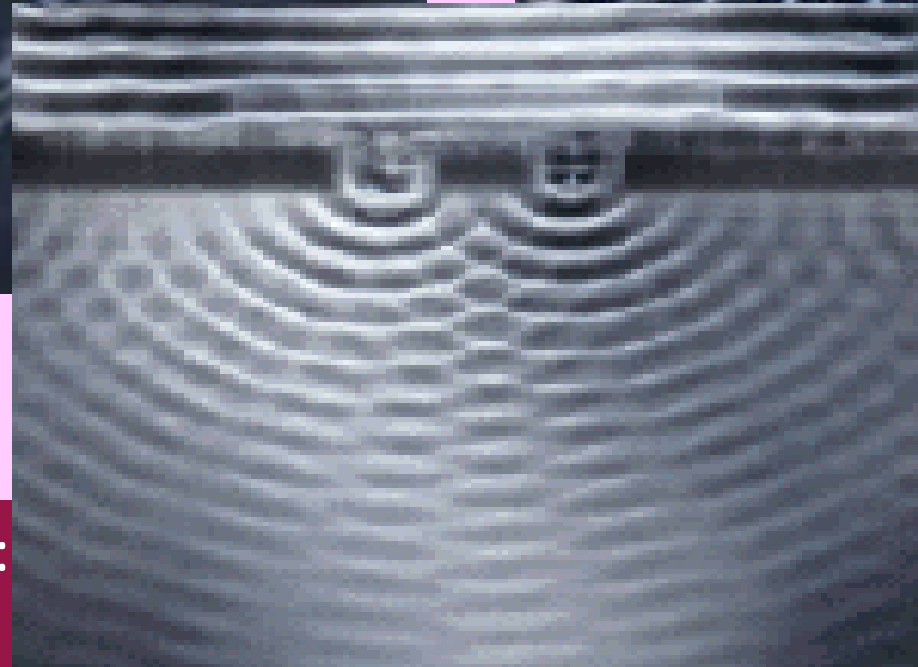
Learning objectives:



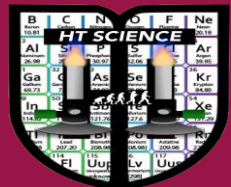
## Explanation

# What happens when 2 waves meet?

**They Superpose !!!**



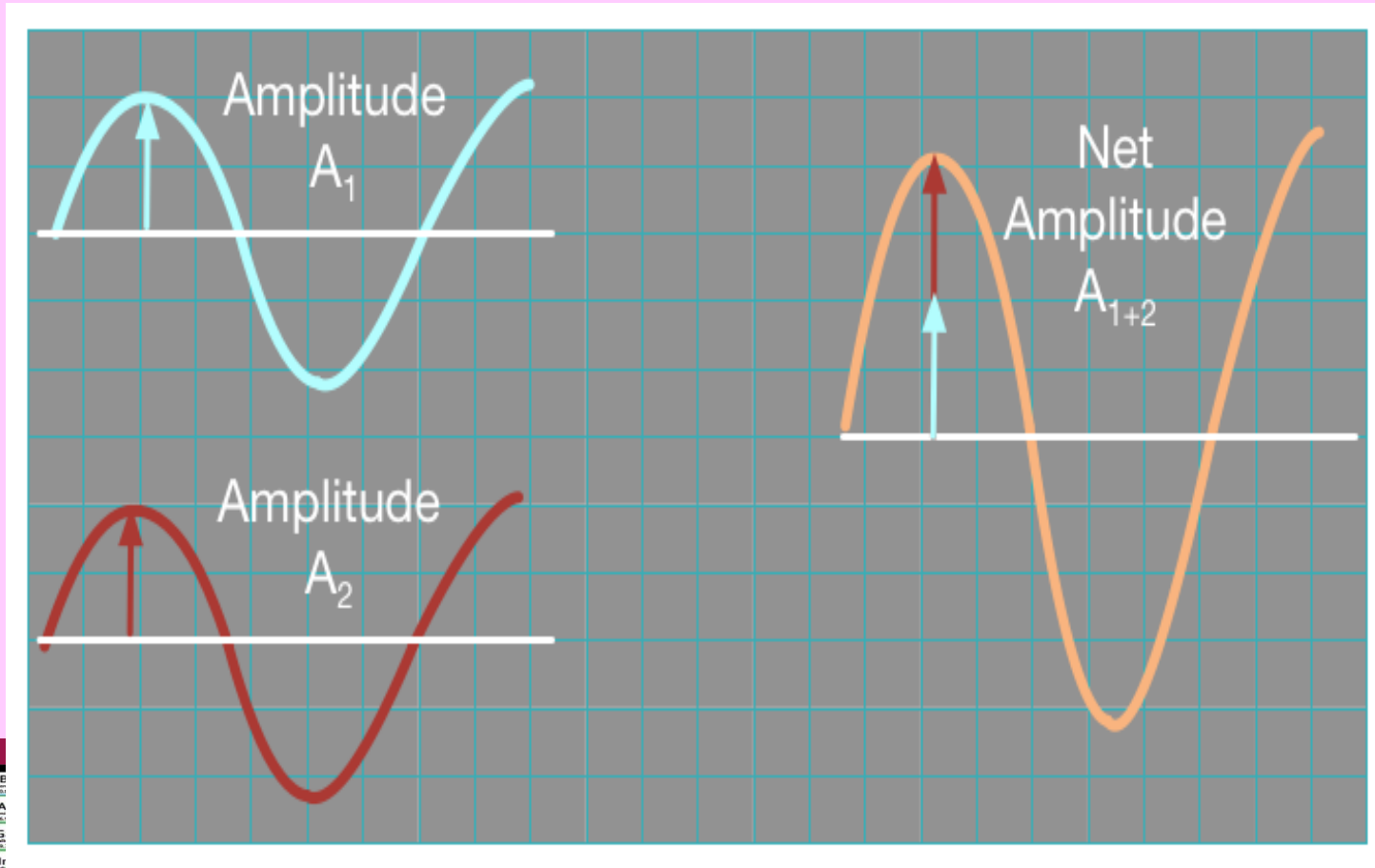
Learning objectives:



## Explanation

# Superposition & Constructive interference

When two waves meet whilst travelling through the same medium, they interact and superimpose.



Constructive interference is when waves superimpose to create a larger oscillation.

Question:

What is the name of the phenomenon that occurs when two waves of equal amplitude meet completely out of phase (the crest meets the trough), producing a resultant wave with zero amplitude?

Destructive interference

## Explanation

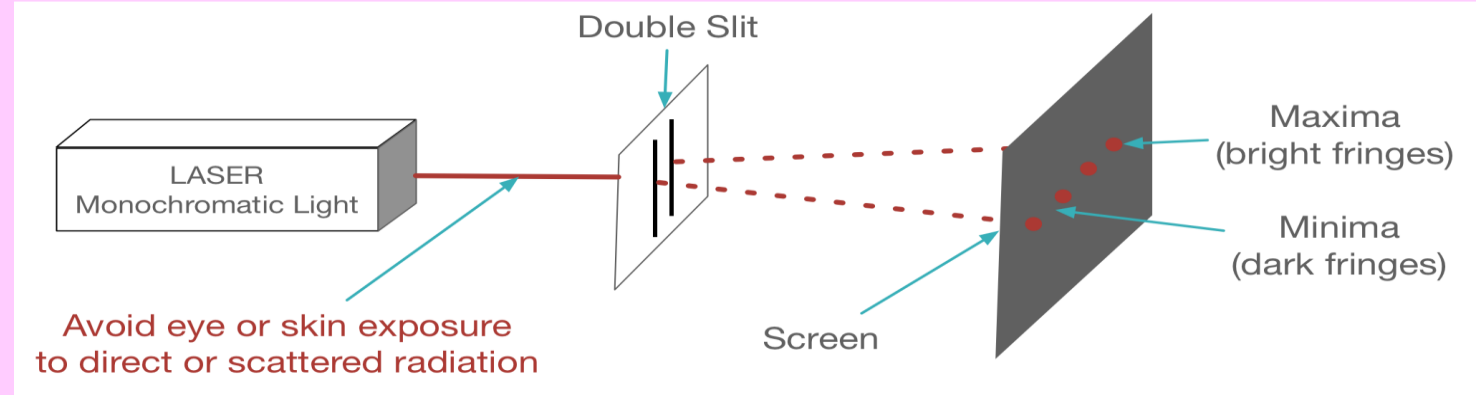
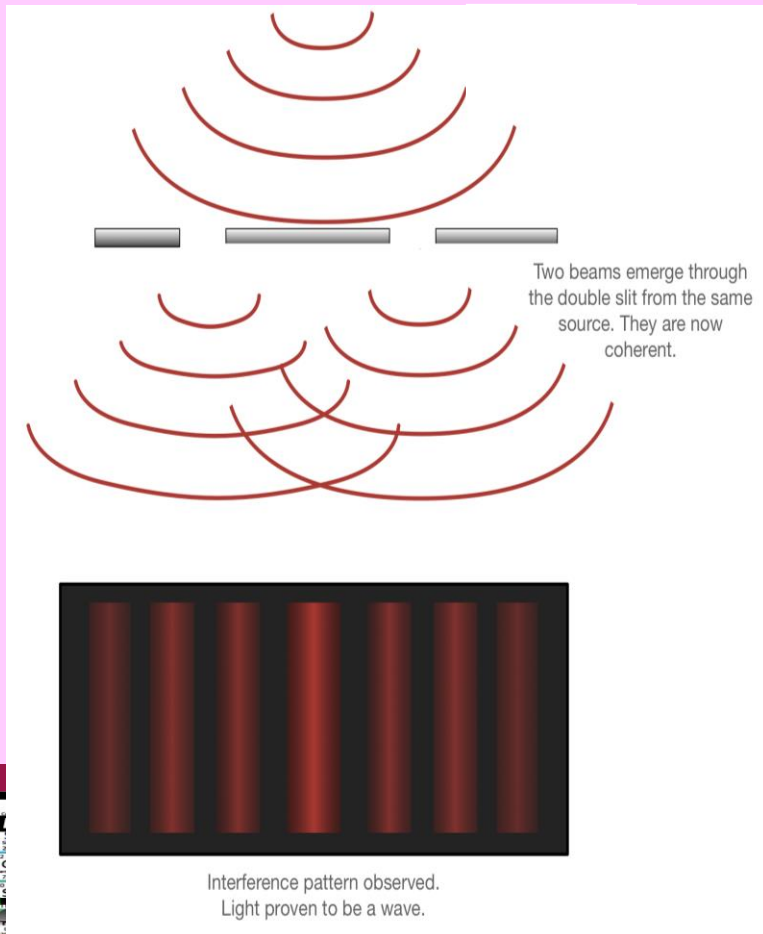
# Thomas Young, English Scientist, 1773-1829



- Thomas Young was a doctor but surprisingly gave an important physics lecture in 1801.
- Young showed a very convincing experiment that light is a wave.

# Explanation Young's Double Slits Experiment

- Thomas Young performed a version of an interference experiment with light at the beginning of the 19th century.

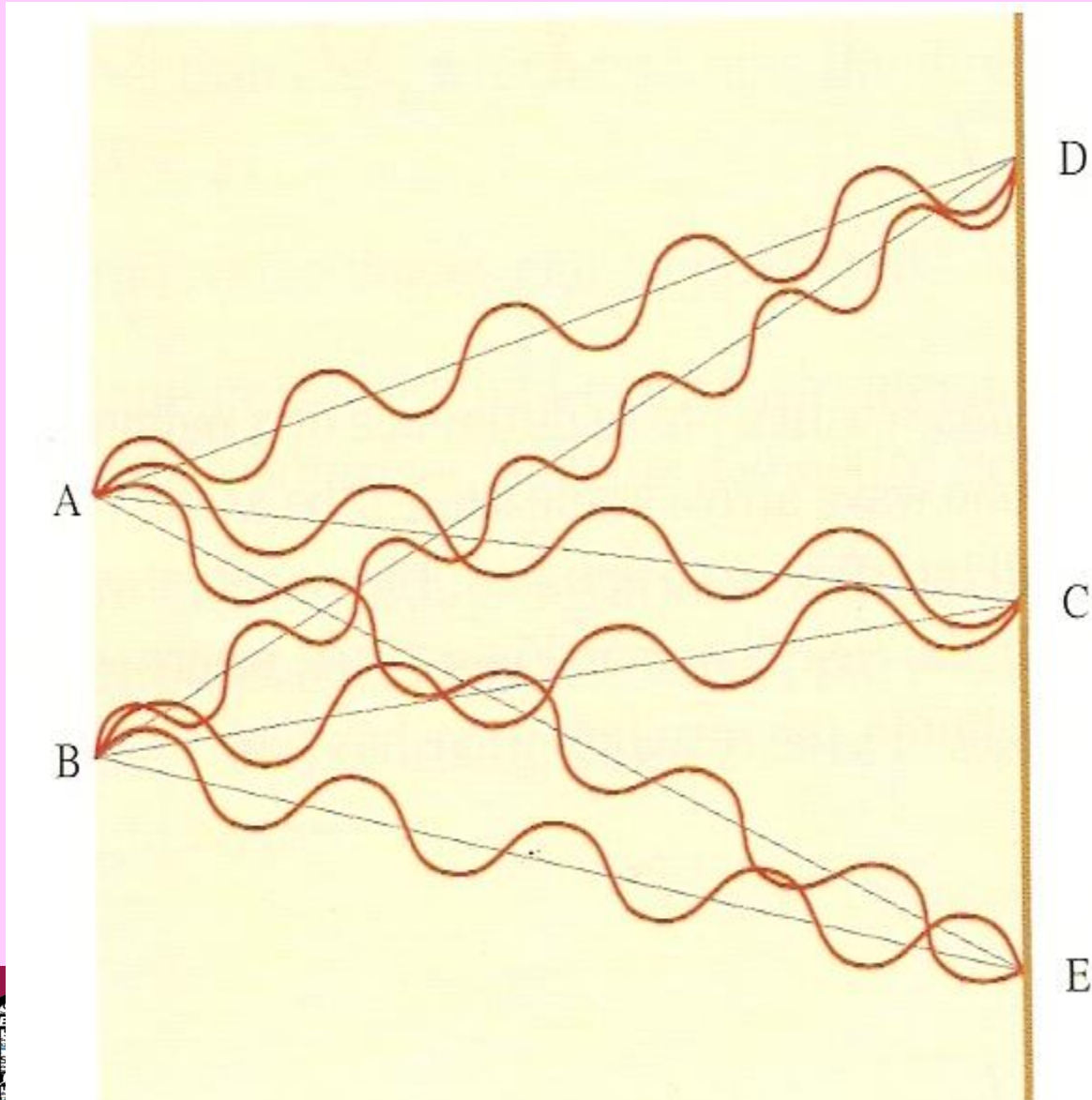


After passing a single wave source through two slits, two new sources of waves were created after they diffracted.

An interference pattern of clear **bright (constructive interference)** and **dark fringes (destructive interference)** on a screen.

This was proof that light is a wave !!!

# Explanation



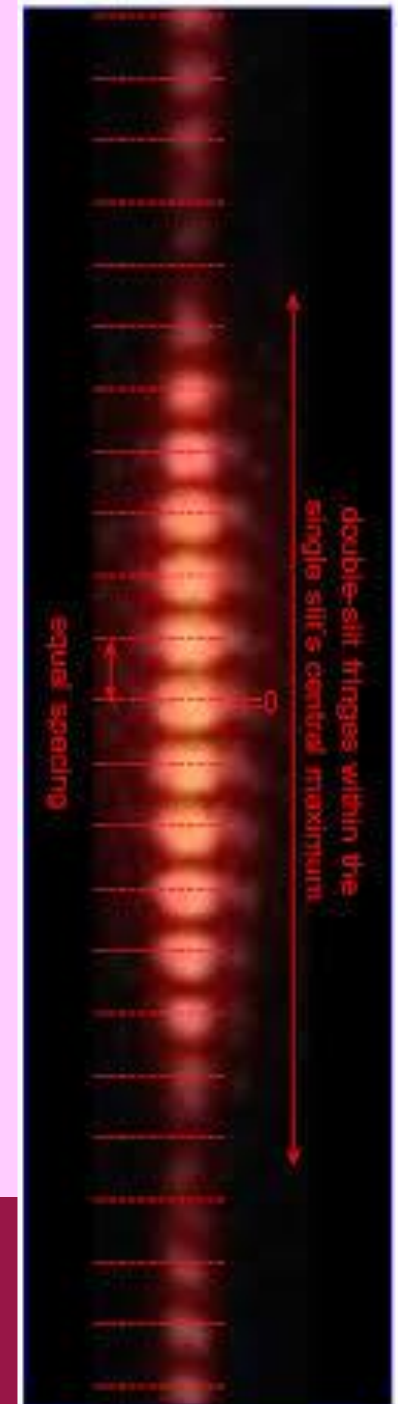
D. Constructive interference

Destructive interference

C. Constructive interference

Destructive interference

E. Constructive interference



## Explanation

# The two slit diffraction Equation

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

Note that the distance between fringes,  $x$ , is measured as the distance between minima or maxima.

Where:

$\lambda$  = wavelength of the wave

$a$  = spacing between double slits ( slit separation)

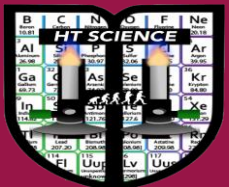
$x$  = spacing between fringes ( fringe width/separation )

$D$  = distance from slits to screen.

**Question** : In a Young's double-slit experiment, what three factors can be changed to increase the distance  $x$  between adjacent bright fringes?

- Increase the wavelength ( $\lambda$ )
- Increase the distance between the slits and the screen ( $D$ )
- Decrease the slit separation ( $a$ )

Learning objectives:



## Explanation

# The two slit diffraction Equation

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

Note that the distance between fringes,  $x$ , is measured as the distance between minima or maxima.

Where:

$\lambda$  = wavelength of the wave

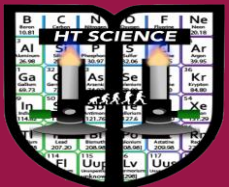
$a$  = spacing between double slits ( slit separation)

$x$  = spacing between fringes ( fringe width/separation )

$D$  = distance from slits to screen.

**Question** : In a Young's double-slit experiment, what three factors can be changed to increase the distance  $x$  between adjacent bright fringes?

Learning objectives:



## Checking Progress

Interference occurs when two or more waves overlap. When this happens, the waves combine to produce a pattern of **bright** and dark regions.

This happens because waves carry energy and can add together when they meet.

When two waves meet **in phase**, their peaks and troughs line up. This produces a larger wave with a larger amplitude. This is called constructive interference and it forms a **bright fringe** in a light interference pattern.

When two waves meet **out of phase**, the peak of one wave meets the trough of another wave. The waves cancel each other out and the resulting wave has a much smaller amplitude. This is called destructive interference and it forms a dark fringe.

A common way to observe interference with light is using two slits or openings that allow light to pass through. The light spreads out and overlaps, creating a pattern on a screen.

The pattern produced consists of alternating bright and dark fringes.

For a stable interference pattern to form, the light sources must have a constant phase difference between them.

Interference patterns show that light behaves as a wave.

### Word bank :

1. waves
2. destructive
3. dark
4. larger
5. energy
6. smaller
7. trough
8. slits
9. dark
10. dark
11. bright
12. phase
13. wave
14. constructive

## ▼ Question

In a Young double-slit experiment, electromagnetic radiation is incident on a double slit. The following results are obtained.

distance from slits to screen = 3.5 m

distance between slits = 1.5 mm

distance between central fringe and 6th order fringe = 9 mm

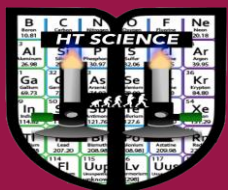
What is the wavelength of the radiation?

- A**  $6.4 \times 10^{-7}$  m
- B**  $3.9 \times 10^{-6}$  m
- C**  $6.4 \times 10^{-1}$  m
- D**  $2.3 \times 10^{-5}$  m

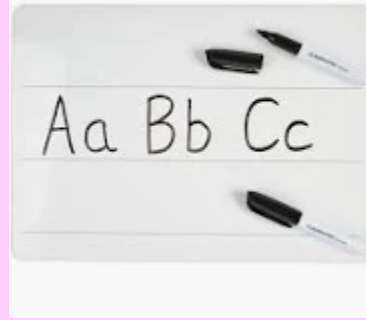
Your answer

**[1]**

## ▼ Mark Scheme



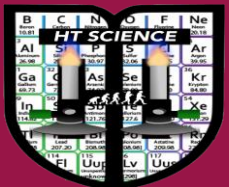
## Explanation



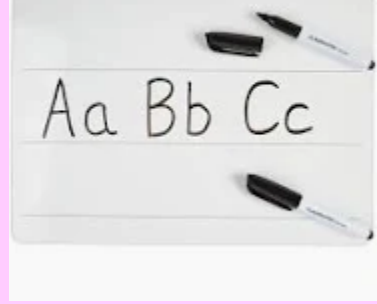
What causes the **bright fringes** in a double-slit interference pattern?

- A. Destructive interference
- B. Reflection of light
- C. Constructive interference
- D. Diffraction only

Learning objectives:



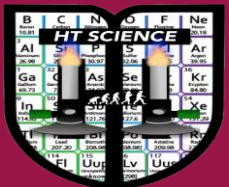
# Explanation



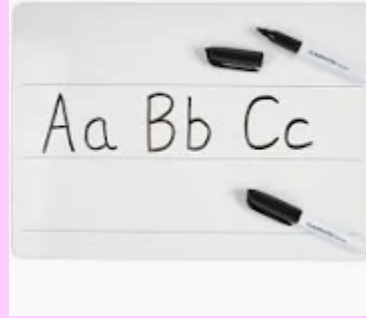
What causes the **dark fringes** in the interference pattern?

- A. Reflection
- B. Diffraction
- C. Constructive interference
- D. Destructive interference

Learning objectives:



# Explanation



The distance between two adjacent bright fringes is called:

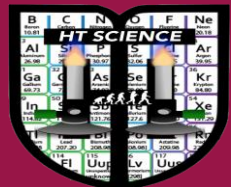
A. Wavelength

B. Fringe separation

C. Amplitude

D. Intensity

Learning objectives:



## Explanation

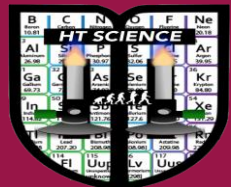


If the **wavelength of light increases**, what happens to the fringe separation?

- A. It increases
- B. It decreases
- C. It stays the same
- D. It becomes zero

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

Learning objectives:



# Explanation

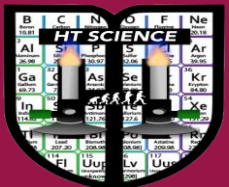


If the **distance between the slits increases**, what happens to the fringe separation, for a constant wavelength?

- A. It increases
- B. It decreases**
- C. It stays constant
- D. It doubles

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

Learning objectives:



## Explanation

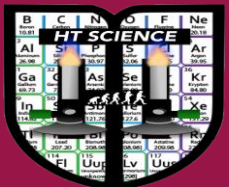


If the **screen is moved further away**, what happens to the fringe spacing ( constant wavelength) ?

- A. It increases
- B. It decreases
- C. It stays the same
- D. It disappears

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

Learning objectives:



## Explanation



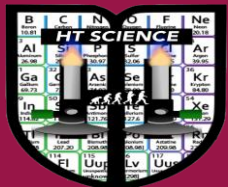
What type of waves demonstrate interference in Young's experiment?

A. Longitudinal waves only

B. Mechanical waves only

C. Electromagnetic waves behaving as waves

D. Particles only



Learning objectives:

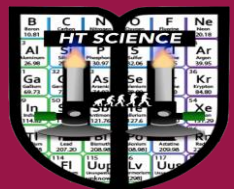
# Explanation



The double-slit experiment provides evidence that light behaves as:

- A. A particle only
- B. A wave
- C. A solid
- D. A gas

Learning objectives:



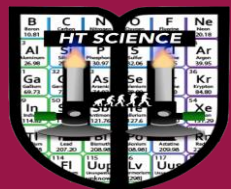
## Explanation

You have seen that light can behave like a wave through phenomena such as diffraction and interference.

Surprisingly, particles of matter such as electrons can also behave as waves.

(in experimental context only)

Learning objectives:



# Explanation



Louis De-Broglie , 1892- 1987, French Physicist , best known for his research on quantum theory and for predicting the wave nature of electrons. He was awarded the 1929 Nobel Prize for Physics.

In the early 20th century, scientists began to question whether particles behaved strictly like solid objects.

Louis de Broglie proposed a revolutionary idea:

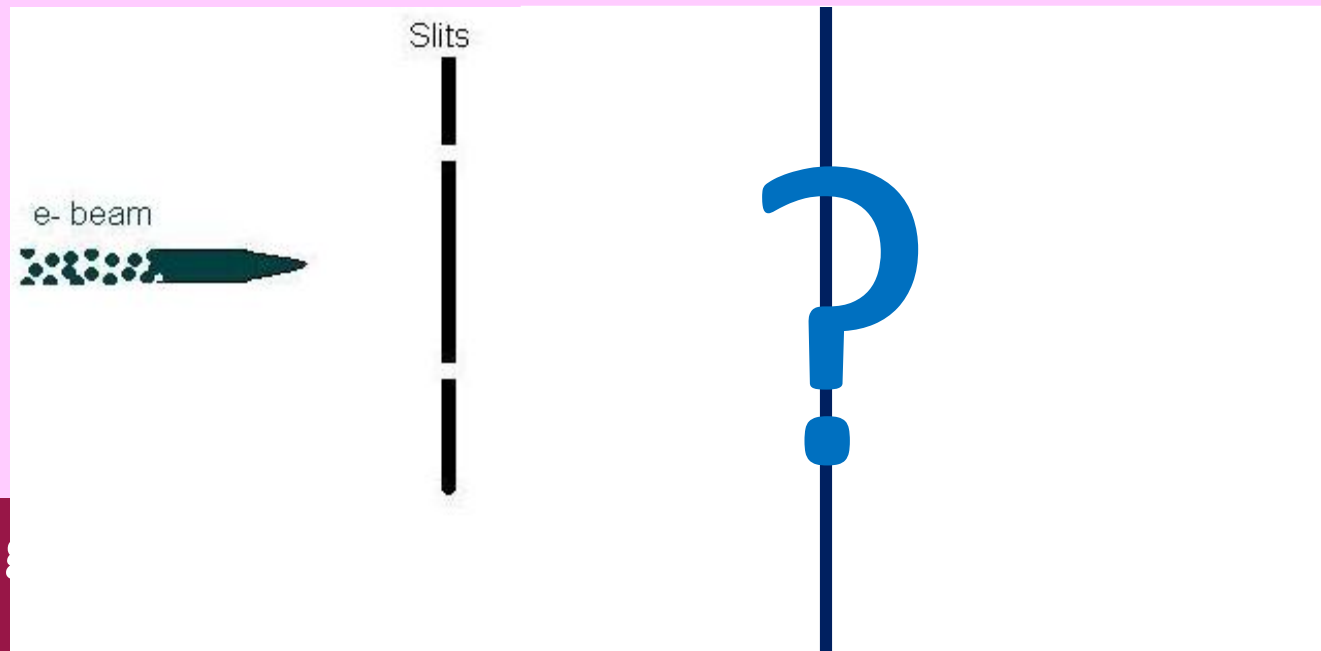
if light (which was known as a wave) could also behave like a particle ( photons) , then perhaps particles could also behave like waves.

De Broglie suggested that all particles, including electrons, have a wavelength associated with them , called the De-Broglie wavelength.

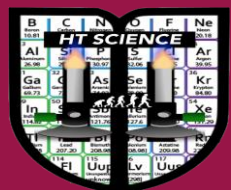
## Explanation

## Question

What pattern would be observed on a screen if a beam of electrons passed through a double-slit apparatus?



Learning



# Explanation

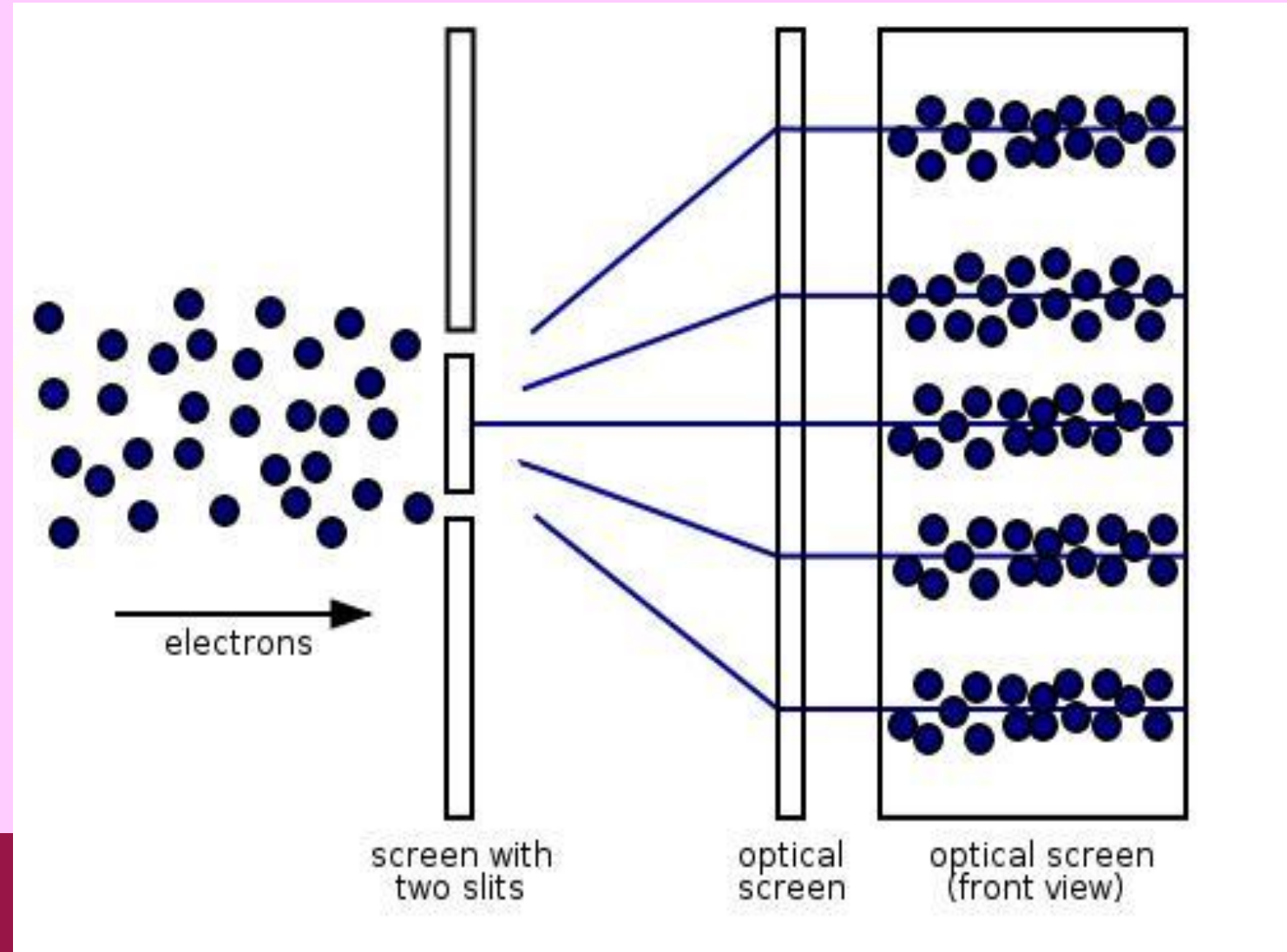
# Electron diffraction

For centuries, scientists debated whether light was a wave or a particle.

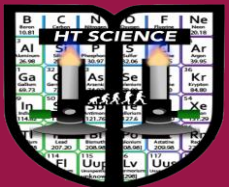
Experiments seemed to show that it behaved like a wave, until new evidence revealed that it could also act like a stream of tiny particles called **photons**.

Then came an even bigger surprise: **electrons**, which were thought to be particles, were found to behave like waves under certain conditions.

This strange behaviour led to the concept of **wave-particle duality**, a cornerstone of quantum physics.



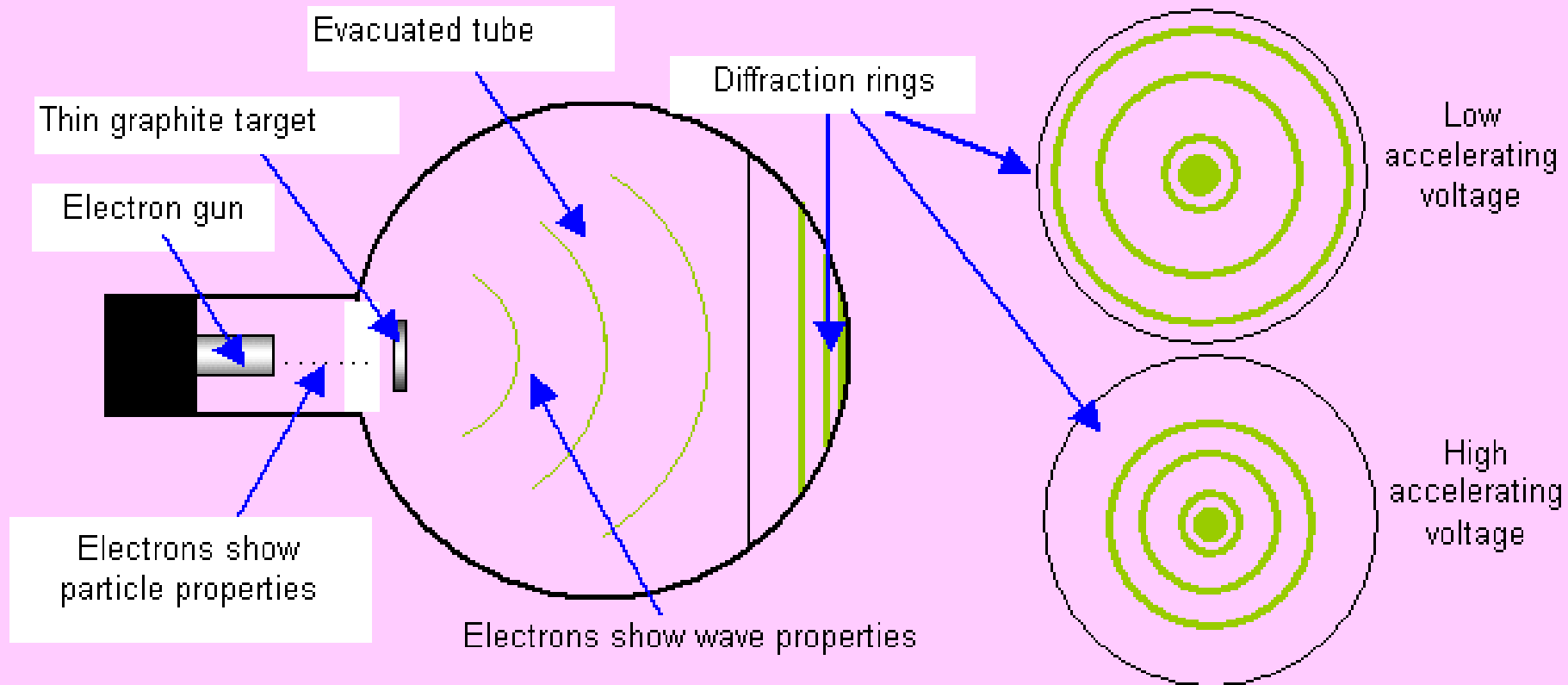
Learning objectives:



# Explanation

## The electron diffraction experiment.

Electron diffraction is one of the **strongest pieces of evidence** for wave–particle duality.



When a beam of **electrons accelerated through a p.d** passes through a thin material (like graphite), instead of travelling straight through like tiny particles, they **spread out and form a light interference pattern of rings or fringes maxima (constructive interference) and minima (destructive interference) on screen** .



# Explanation

## The electron diffraction experiment.

### Why is this important?

Diffraction is a property that was originally only associated with **waves**.

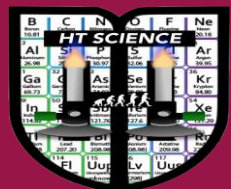
So when electrons (which we think of as particles) produce diffraction patterns, it shows:

👉 **Electrons behave like waves**



Learning objectives:

<https://www.youtube.com/watch?v=IYnU4T3jbgA>



## Checking Progress

### ▼ Question

State **one** piece of evidence for the wave-like behaviour of electrons.

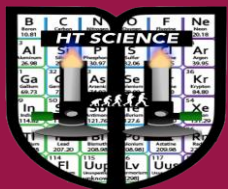
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[1]

### ▼ Mark Scheme

[Redacted Mark Scheme]



## Checking Progress

### ▼ Question

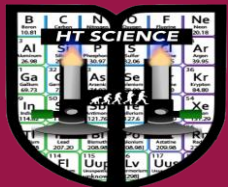
What can be deduced from the diffraction of electrons by graphite atoms?

- A Electrons are electromagnetic waves.
- B Electrons can also become photons.
- C Electrons interact with photons on a one-to-one basis.
- D Electrons show wave-like behaviour.

Your answer

[1]

### ▼ Mark Scheme

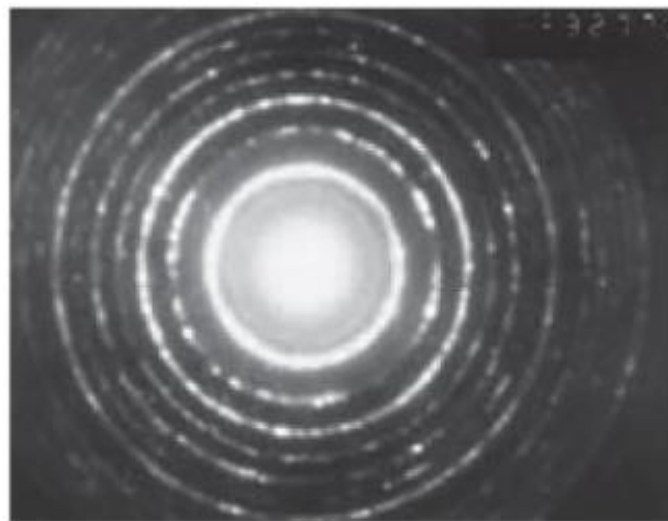


Le

## Checking Progress

### Question

The picture shows an electron diffraction pattern produced by graphite in a cathode-ray tube.



Answer: i) Any four from:

In an evacuated tube

(Electrons released by) thermionic emission / (low voltage supply causes) emission of electrons from cathode / filament / electron gun

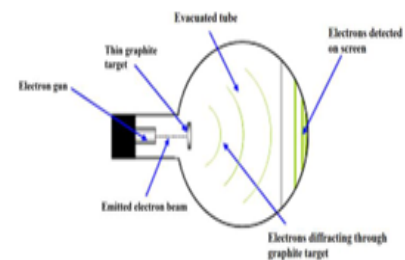
Electrons accelerated towards anode / electrons accelerated through (high) pd / electric field

Diffacted through a graphite (target) / graphite is thin

Electrons detected on a (phosphor) screen / electrons produce visible light on impact with screen

Marks: i) 4x81

Guidance: i) ALLOW marking points as labels on the diagram or as the answer lines.



Describe the experiment that produces this pattern. Draw a labelled diagram of the apparatus to help you.

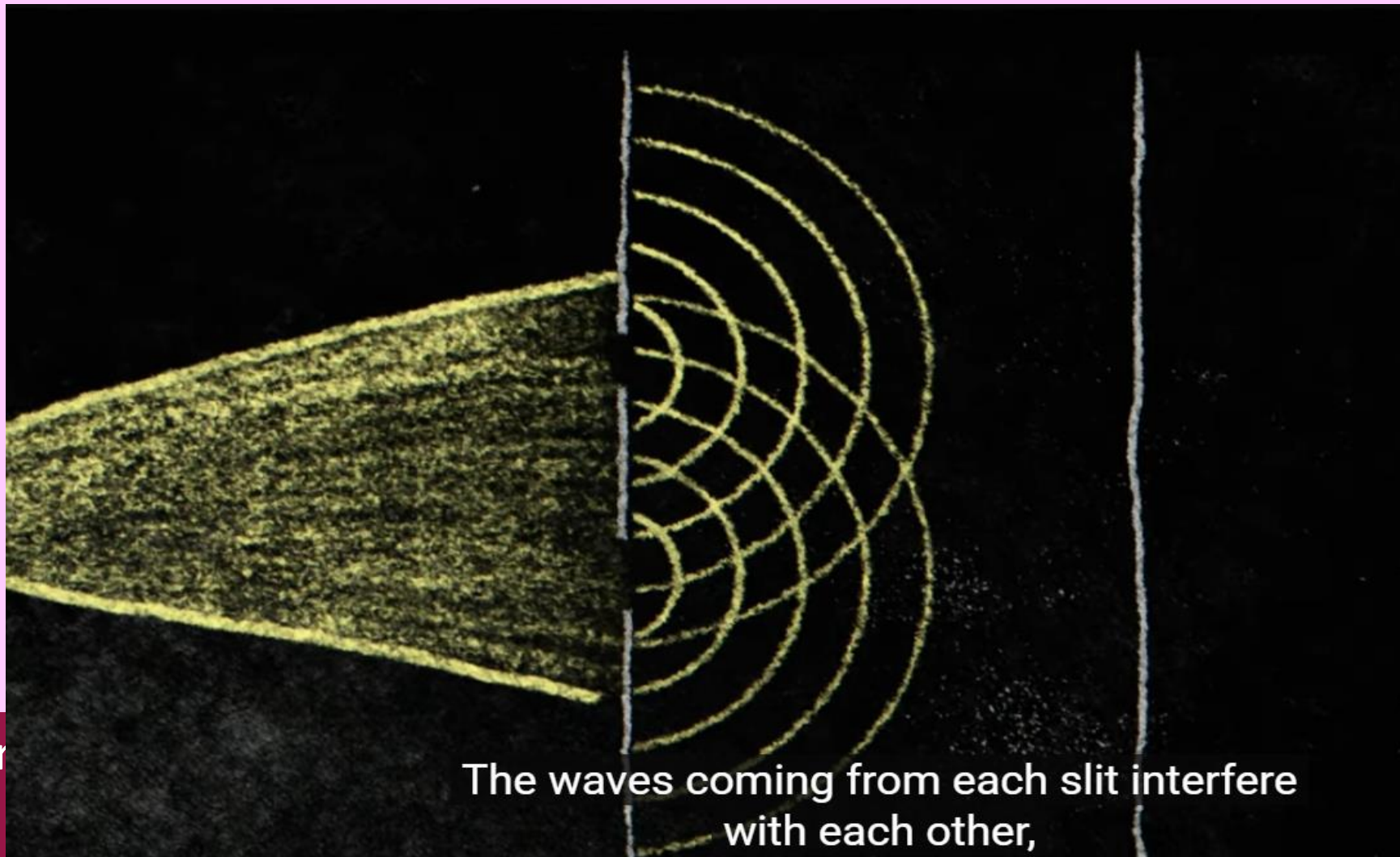
Key words : electrons / emission/ emitted / filament / electron gun / Accelerated / high p.d / diffraction/Diffracted / graphite / detected / detection/ screen / visible light

**The electron gun emits electrons from the heated filament which are accelerated through high p.d and then are diffracted through a graphite to be detected on a screen where they produce visible light rings on impact with the screen .**

[4]

# Explanation

<https://www.youtube.com/watch?v=DfQH3o6dKss>



The waves coming from each slit interfere with each other,

Learn

