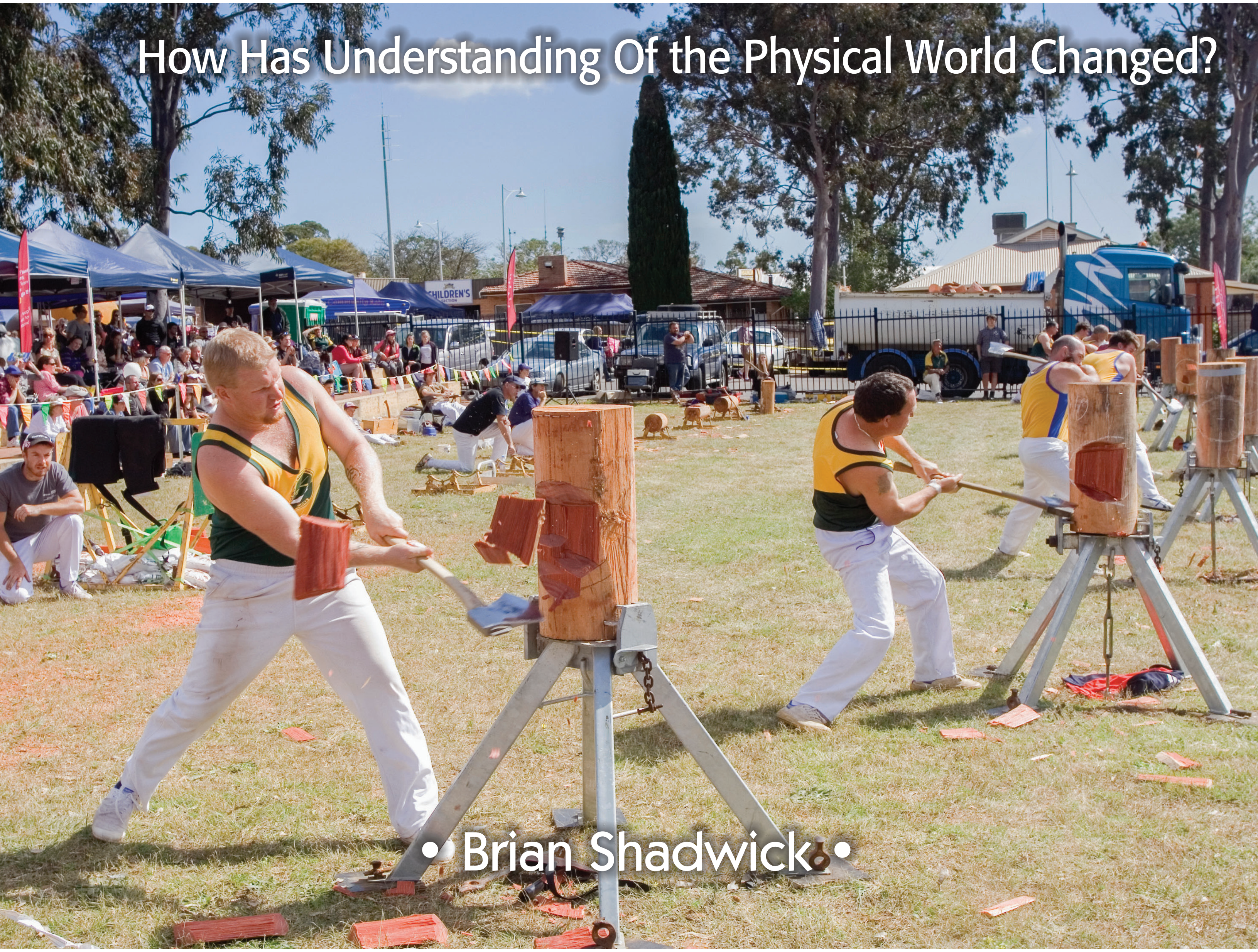
DOT POINT

VCE PHYSICS UNIT 4 AREA OF STUDY 1

How Has Understanding Of the Physical World Changed?



• Brian Shadwick •

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Contents

Words to Watch iv

Light As a Wave

1. Light As a Wave 2
Light as a transverse electromagnetic wave

2. Standing Waves 4
Superposition of waves
Standing waves

3. Analysing Standing Waves 7
Analysing standing waves

4. Diffraction 9
Diffraction

5. Young's Experiment 12
Young's double slit experiment
Constructive and destructive interference
Factors affecting the interference pattern

Light As a Particle

6. Photons 16
Quantised energy of photons

7. Photoelectric effect 17
Albert Einstein and the photoelectric effect
Analysing the photoelectric effect

8. Analysing Photoelectric Effect Data 23
Analysing photoelectric effect data

9. Limitations Of the Wave Model 25
The photoelectric effect and the wave model

Matter As Particles Or Waves

10. Electron Diffraction 28
Electron diffraction and wave nature of matter

11. Diffraction Patterns 30
Diffraction by photons and electrons

12. De Broglie Wavelength 32
De Broglie wavelength

Similarities Between Light and Matter

13. Quantisation and Light 34
Light and quantisation

14. Momentum Of Photons and Matter 35
Momentum of photons and matter

15. Atomic Spectra 36
Atomic spectra

16. Interpreting Spectra 38
Spectra and energy of photons

17. Electron Orbital Changes 40
Analysing electron orbital changes

18. Electron Standing Waves 44
Electron standing waves

19. Dual Nature Of Light 45
Diffraction and the dual nature of light

Einstein's Special Theory Of Relativity

20. Limitations Of Classical Mechanics 48
Limitations of classical mechanics at near light speed

21. Frames Of Reference 49
Frames of reference
The principle of relativity

22. Speed Of Light 52
Einstein's first thought experiment
Einstein's postulates

23. Michelson-Morley Experiment 55
The Michelson-Morley experiment

24. Proper Time 56
Einstein's second thought experiment

25. Time Dilation 58
t_v or not t_v? That is the question!

26. Length Contraction 60
Length contraction

27. Special Relativity 63
Examples of special relativity

28. Special Relativity Versus Classical Physics 64
Special relativity versus classical physics

Relationship Between Energy and Mass

29. Relativistic Mass 66
Relativistic mass

30. Energy-Mass Relationship 68
Mass conversion in the Sun
Mass defect
Mass defect and nuclear reactions

Answers 70

Index 96

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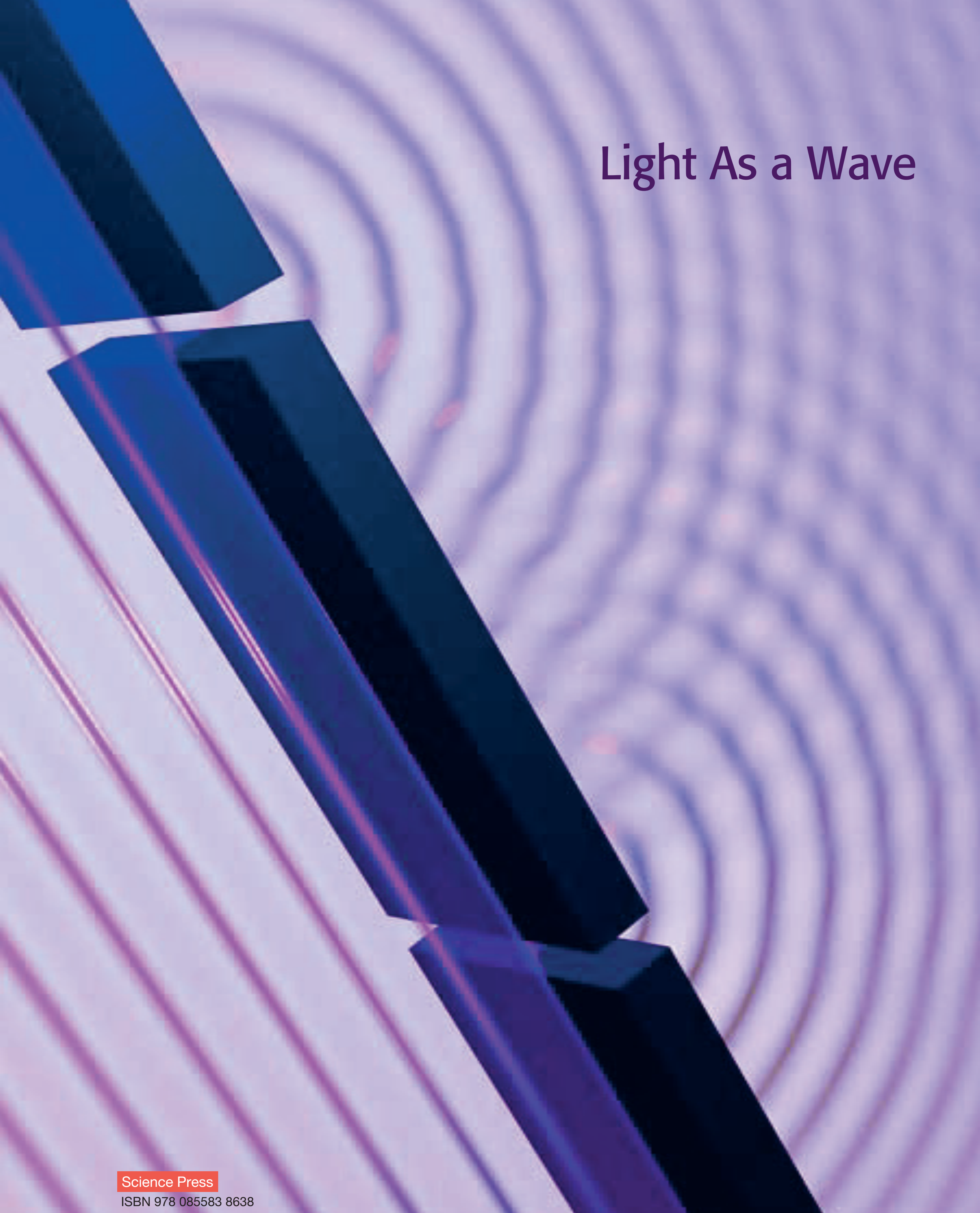

Light As a Wave

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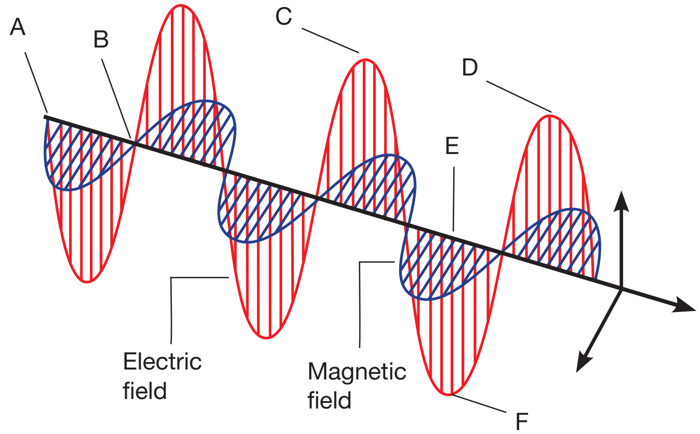
2. Consider the diagram which represents an electromagnetic wave in the air. The scale of the diagram is 1 cm = 10^{-11} m.



(a) What is the distance AB on this diagram?

(b) What distance is represented by CD?

(c) What is represented by the distance EF?

(d) What is the wavelength of the wave?

(e) How many wave pulses are shown in the diagram?

(f) How many wavelengths are shown in the diagram?

(g) What is the speed of this wave in air? Justify your answer.

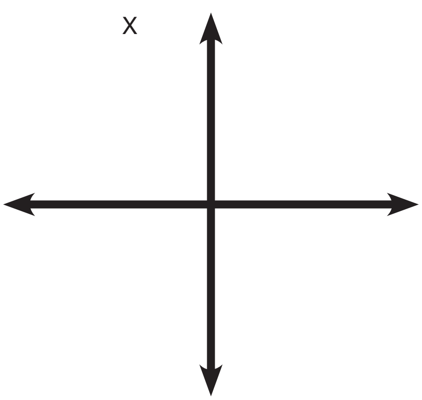
(h) Using the wave equation, $v = f\lambda$, calculate its frequency.

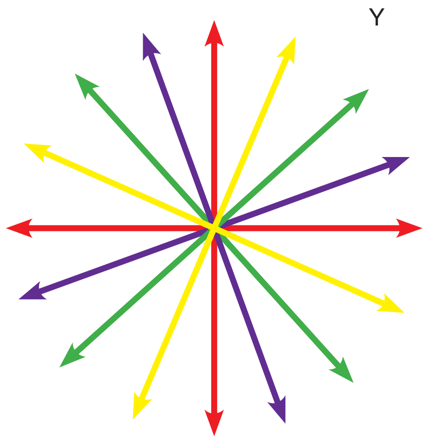
(i) If the frequency of this wave in air was doubled, what would happen to its speed? Explain your answer.

(j) If the frequency of this wave in air was doubled, what else would change? Explain your answer.

3. We usually always simplify the way we describe electromagnetic radiation by defining it as being composed of alternating electric and magnetic fields at right angles to each other, and represent it by the diagram above (Question 2) or by a simple diagram like that shown in diagram X.

A more correct representation of an electromagnetic wave would be as in diagram Y. Explain why.





4. Outline two mechanisms by which electromagnetic radiation is produced by matter.

5. (a) What is the distinguishing property of all electromagnetic radiation?

(b) A scientist discovered a new radiation which travelled at 2.1×10^8 m s^{-1} through a glass slab and at 2.8×10^8 m s^{-1} through the air. He claimed it was a new, previously undiscovered band of the electromagnetic spectrum. Evaluate his statement.

(c) What is the possibility of scientists discovering a new band of electromagnetic radiation in the electromagnetic spectrum?

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2. Standing Waves

Explain the formation of a standing wave resulting from the superposition of a travelling wave and its reflection.

Superposition of waves

Superposition

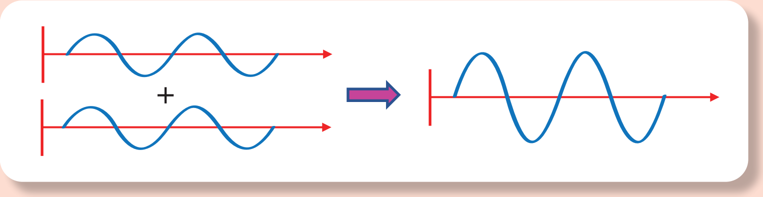
- When two (or more) sources of vibration each produce a wave in a medium, the waves interfere with each other.
- The amplitude of the combined wave is equal to the sum of the amplitudes of the component waves as stated by the **principle of superposition** as follows.

> When two waves meet, the resultant displacement of any particle in the medium is equal to the vector sum of the displacements of the particle in each wave.

- This process is called **superposition** and the combination wave is the **resultant wave**.
- While waves interfere when they occupy the same positions in a medium, they continue on their respective journeys unaltered, except for the time they interfere.

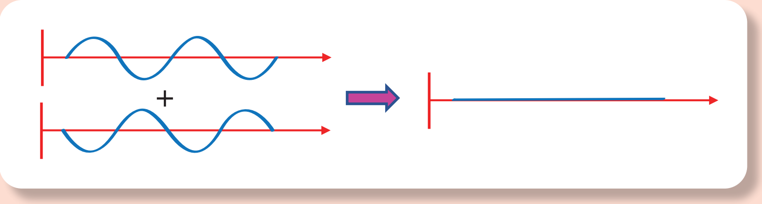
Constructive superposition (reinforcement)

- Occurs when the displacements of the particle in the two waves are both positive or both negative, so that the net displacement is the sum of the two.
- These waves are said to be **in phase**.



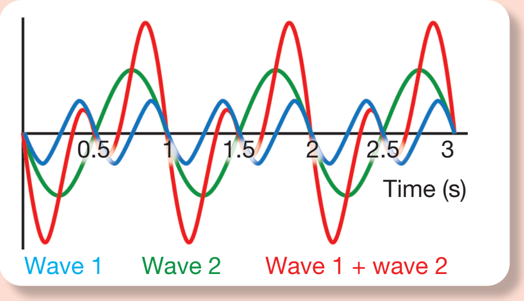
Destructive superposition (cancellation)

- Occurs when the displacements of the particle in the two waves are in opposite directions, so that the net displacement is the difference between of the two.
- These waves are said to be 180°, or π or 0.5λ or $0.5T$ out of phase.



Partial superposition (a mixture of reinforcement and cancellation)

- Occurs when the displacements of the particle in the two waves are out of phase by some different amount than the clear-cut examples above.
- In these cases, the superposition will give a more complex resultant as you will discover in doing the examples on the next page.



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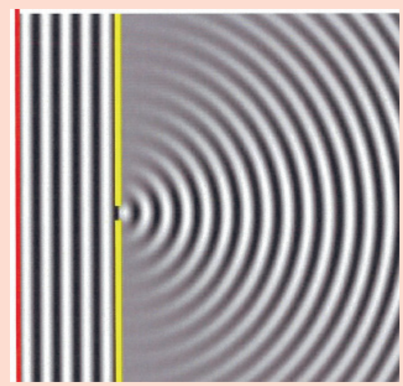
4. Diffraction

Investigate and explain theoretically and practically diffraction as the directional spread of various frequencies with reference to different gap width or obstacle size, including the qualitative effect of changing the $\frac{\lambda}{w}$ ratio, and apply this to limitations of imaging using electromagnetic waves.

Diffraction

Diffraction involves a change in the direction of travel of waves as they pass through an opening or around the edge of a barrier in their path. The opening or edge acts as point source for the diffracted wave which spreads out in concentric circles.

Properties of diffraction



- The wider the opening, the less the diffraction.
- The greater the wavelength, the greater the diffraction.
- If the slit width is greater than the wavelength, nodal lines are formed.
- For single slit diffraction $n\lambda = d \sin \Theta$

  Where n = node number

  λ = wavelength

  d = slit width

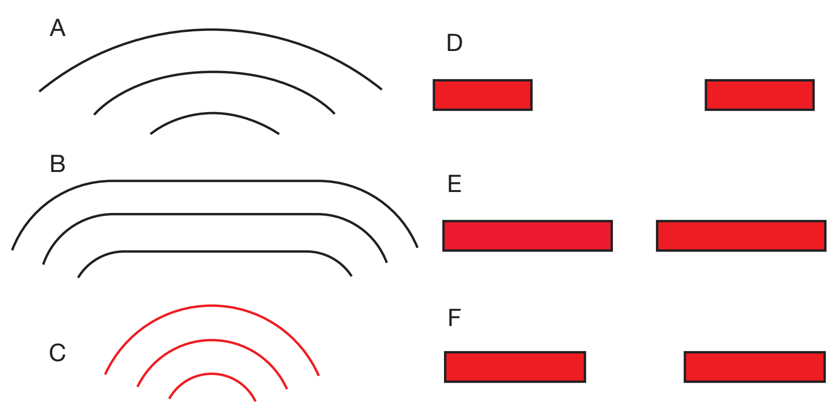
  Θ = angle of diffraction

The extent to which the diffracted wave passing through the slit spreads out depends on the width of the slit and the wavelength of the waves. The narrower the slit, the more diffraction there is and the shorter the wavelength the less diffraction there is. The degree to which diffraction occurs is as follows.

Diffraction $\propto \frac{\lambda}{w}$

Where λ is the wavelength of the wave and w is the width of the slit.

1. Consider the diagrams.
Match the diffraction patterns A, B and C with the correct gap width, D, E and F.



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5. Young's Experiment

Explain the results of Young's double slit experiment with reference to:

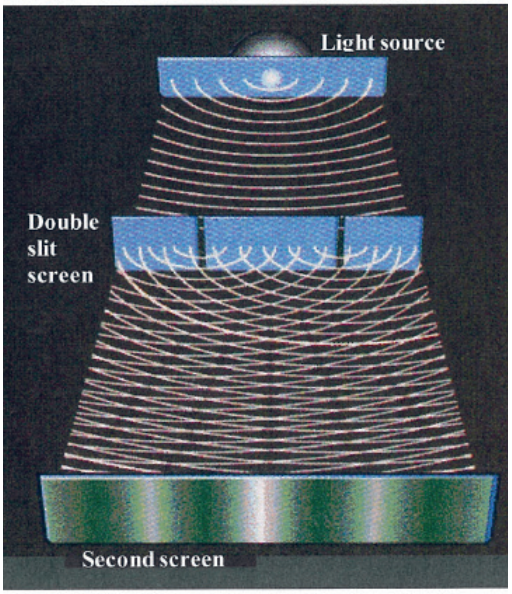
- evidence for the wave-like nature of light
- constructive and destructive interference of coherent waves in terms of path differences: $n\lambda$ and $(n + \frac{1}{2})\,\lambda$ respectively, where $n = 0, 1, 2, \ldots$
- effect of wavelength, distance of screen and slit separation on interference patterns: $\Delta x = \frac{\lambda L}{d}$ when $L >> d$.

Young's double slit experiment

Consider the following summary of Young's double slit experiment and then answer the questions which follow it.

In his experiment Young placed a light source some distance behind a screen which had a pair of closely spaced pinhole slits in it.

Light emerged from the pinholes and produced an interference pattern on a second screen. The pattern on the second screen consisted of sequences of bright, dark and grey coloured bands.

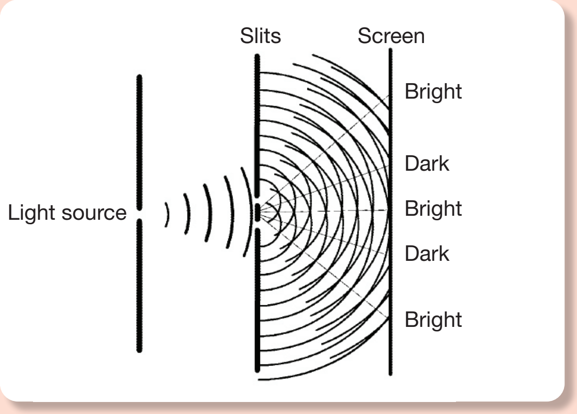


1. Explain why the pattern on the second screen shows some bright bands, some dark bands and lots of varying shades of grey bands.
2. How did Young explain these different bands?
3. Explain Young's conclusion about the nature of light from this experiment.

Constructive and destructive interference

Young's experiment

- In 1802 Thomas Young presented a paper in which he proposed that light must have a wave nature.
- He placed a light source behind a screen which had a pair of closely spaced pinhole slits in it.
- Light emerged from the pinholes and produced an interference pattern on a second screen.
- Young explained this by proposing that each slit acted as a point source of light and produced concentric, spherical waves travelling to the screen.
- The waves from the two sources interfered with each other sometimes constructively (the bright lines) and sometimes destructively (the dark lines). This is an example of diffraction.



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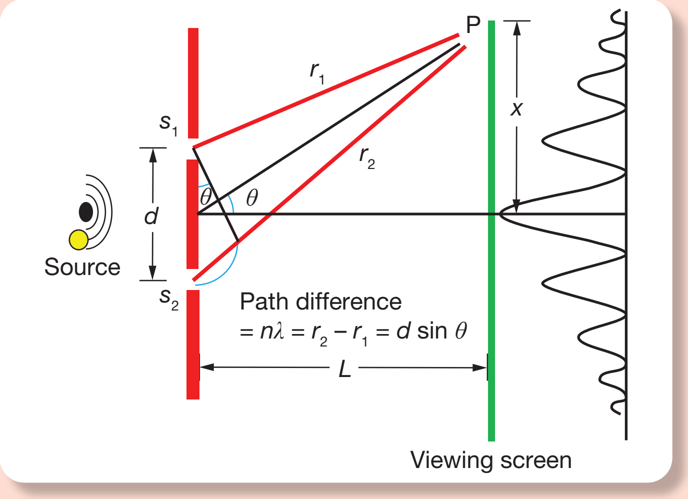
Understanding Young's experiment

- Assume that the light source produces waves which hit the two slits S_1 and S_2, distance d apart, and that the two circular waves formed at the slits are in phase with each other.
- The light coming from pinhole S_1 travels farther than light coming from pinhole S_2.
- Depending on the path difference the beams may hit X in phase, out of phase or somewhere in-between.
- **If in phase** – constructive interference at P and a bright spot forms on the screen at P.
- **If out of phase** – destructive interference at P and a dark spot forms on the screen at P.



- **If they have some other phase difference** – partial interference occurs and the spot at P will be a shade of grey.
- The same logic applies for the light at any other point on the screen.
- The difference in phase of the two beams reaching X can then be calculated using the following equation.

$$n\lambda = d\sin\theta = \frac{dx}{L} \text{ (for a bright band)}$$

$$\left(n - \frac{1}{2}\right)\lambda = d\sin\theta = \frac{dx}{L} \text{ (for a dark band)}$$

Where n = node number

λ = wavelength

d = slit width

1. The diagram shows the interference pattern typically formed from a double slit diffraction barrier.

(a) Which 'band' in the diagram is the central maximum?

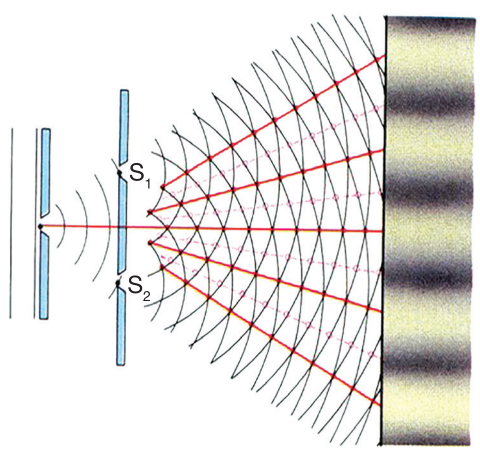
(b) Which band(s) represent first order maxima?

(c) Which band(s) represents the nodal line $n = 2$?

(d) Explain how antinodal lines form and identify the bands which represent antinodal lines.

(e) What is the path difference for the waves from S_1 and S_2 band 8?

(f) Which band(s) have a path difference of 2?



2. Green light (wavelength = 525 nm) is shone through a double slit barrier where the slits are 0.8 mm apart. The screen is 0.75 m from the barrier.

(a) Find the separation between the central maximum and the centre of the first bright spot.

(b) Find the separation between the central maximum and the centre of the third dark band.

(c) What will be these separations for red light of wavelength 680 nm?

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Light As a Particle

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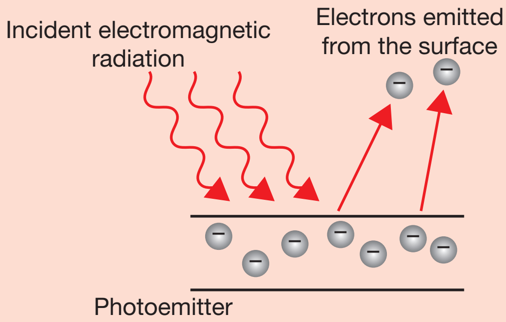
7. Photoelectric Effect

Analyse the photoelectric effect with reference to:

- evidence for the particle-like nature of light
- kinetic energy of emitted photoelectrons: $E_{k\ max} = hf - \phi$, using energy units of joule and electron volt
- effects of intensity of incident irradiation on the emission of photoelectrons.

Albert Einstein and the photoelectric effect

Photoelectric effect – when light of an appropriate frequency is shone onto a metal surface, electrons are emitted from that surface.



Observations to be explained

(a) If the light intensity falling on the photocathode is increased, the current flowing increased, but

(b) The energy of each electron did not increase.

(c) As the anode voltage increased, the photocurrent increased to a maximum value.

(d) If the polarity of the anode voltage is reversed, there is a value for each metal which stops the photoelectric current, the **stopping voltage**.

(e) If the frequency of the incident light on the photocathode drops below a **threshold frequency** (f_o), no photoelectrons are emitted, no matter how intense the light.

(f) The minimum energy needed to emit photoelectrons is called the **work function** (Φ) of the metal.

Einstein's proposals 1905

- **Generalised** the concept of quanta to all electromagnetic radiation, including light, and
- Applied Planck's quantum theory to explain the **photoelectric effect**.
- Proposed that light existed as quantised particles which he called **photons**.
- The energy of a photon is $\boldsymbol{E = hf}$, which is partly used to break the electron away from its atom.
- The specific energy involved to break the electron away from its atom is called the **work function**, (Φ).
- When photons collide with electrons in a photoemitter either all their energy is transferred to the electron (if the frequency was above the **threshold frequency**, (f_o) or no energy is transmitted to the electron (if the frequency was below the threshold frequency, f_o).
- Excess energy gives the photoelectron its kinetic energy ($\boldsymbol{KE = hf - \Phi}$).
- **Intense light** is **more photons**, each with the same energy.
- As intensity of light above the threshold frequency increased, photoemission increased as more photoelectrons could be emitted, but only to a maximum value.
- Photons of light below the threshold frequency did not carry sufficient energy, so no photoelectrons could be emitted regardless of the intensity of the light.

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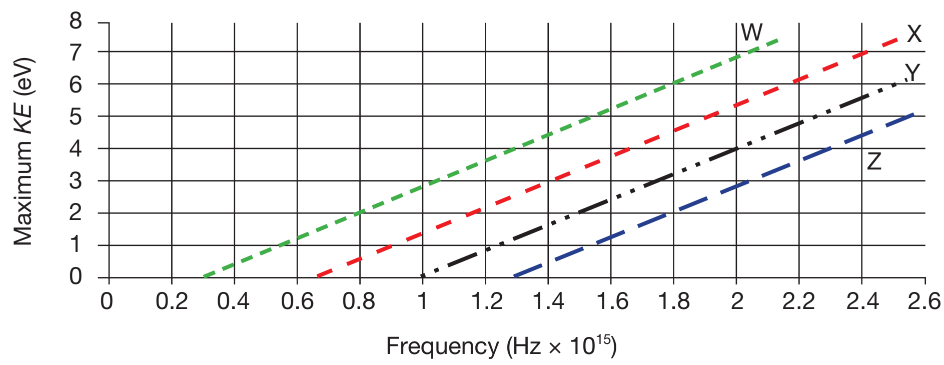
8. The graph shows the response of four photoemitters to incident light.

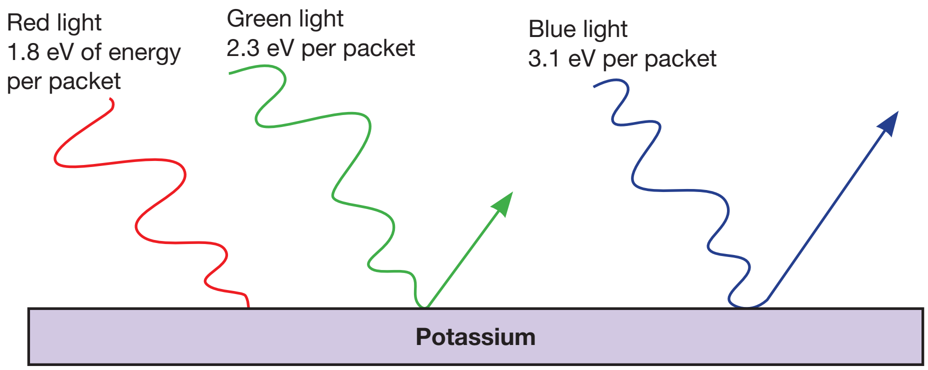


(a) Which of these photoemitters has the lowest threshold energy? Justify your answer.

(b) Light above the threshold frequency of all four is shone onto each emitter. Which will produce the largest current? Justify your answer.

(c) Which of the four emitters has a threshold energy of 2.9 eV? Justify your answer.

9. The diagram shows the energy of four photons incident on the same photoemitter surface (potassium). The work function of the potassium is 2 eV.



(a) Which photon of incident light will emit photoelectrons with the highest energy? Justify your answer.

(b) Calculate the work function of the potassium in joules.

(c) Calculate the energy of each photon in joules.

(d) Calculate the wavelength of each photon.

(e) Calculate the kinetic energy of the photoelectrons in electron volts and joules.

10. (a) The work function energy of a metal is 3.5×10^{-19} J and the incident radiation has a frequency of 7.0×10^{14} Hz. Calculate the maximum kinetic energy of an ejected photoelectron.

(b) The intensity of the incident radiation is doubled but the wavelength is kept constant. State the effect this has on each of the following.

(i) The energy of each photon.

(ii) The maximum kinetic energy of each photoelectron.

(iii) The current in the photocell.

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9. Why does the current produced in a photocell increase if the intensity of the incident light on it is increased?

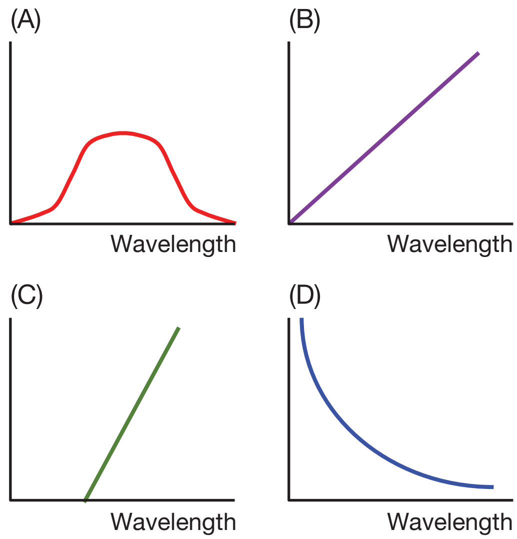
(A) Increased intensity means higher frequency incident light.

(B) Increased intensity means lower frequency incident light.

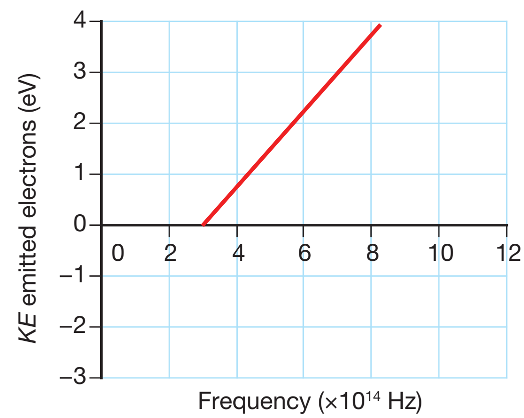
(C) Increased intensity of incident light means more incident photons.

(D) Increased intensity of incident light means incident photons with higher energy values.

10. Which graph best shows the relationship between the energy (y-axis) carried by a photon and the wavelength (x-axis) of the photon?



11. The graph shows the kinetic energy of electrons emitted by a particular photoemitter when light of different frequencies shines on it.



Which statement about this photoemitter is correct?

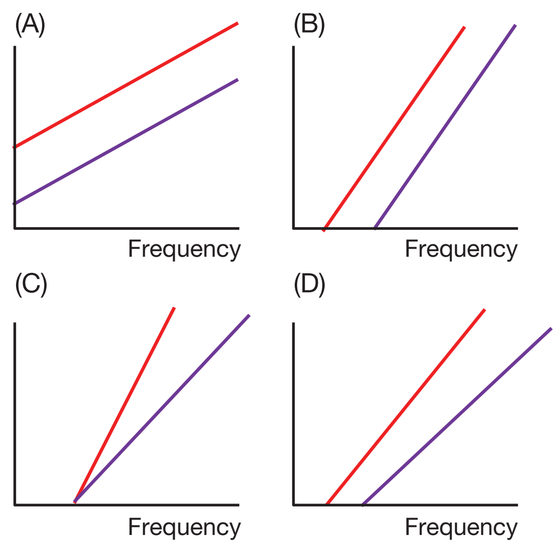
(A) Its threshold frequency is 3000 nm.

(B) Its work function is about 1.2 eV.

(C) The maximum energy of the emitted electrons is 4 eV.

(D) Its threshold energy is −4.0 eV.

12. Which graph best shows the relationship between the kinetic energy of photoelectrons and the frequency of the incident radiation for two different metals?



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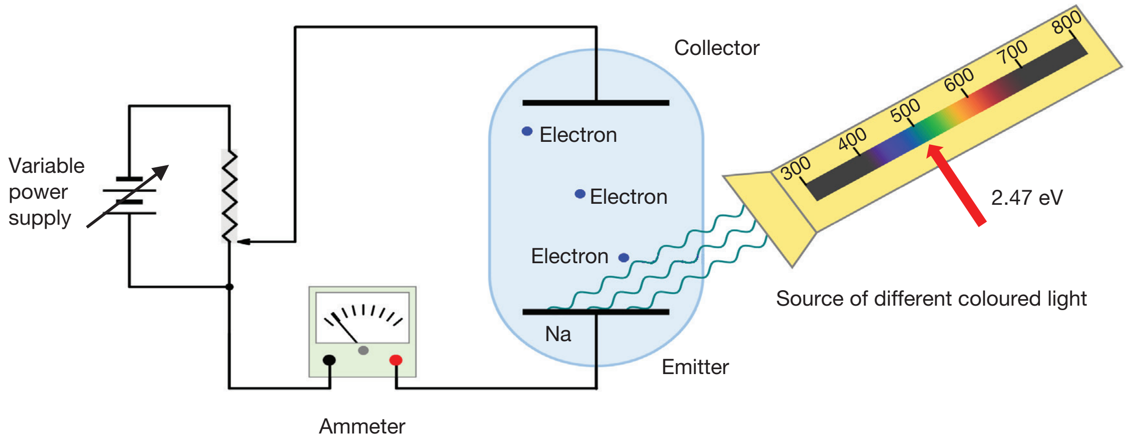
8. Analysing Photoelectric Effect Data

Analyse the photoelectric effect with reference to experimental data in the form of graphs of photocurrent versus electrode potential, and of kinetic energy of electrons versus frequency.

Analysing photoelectric effect data

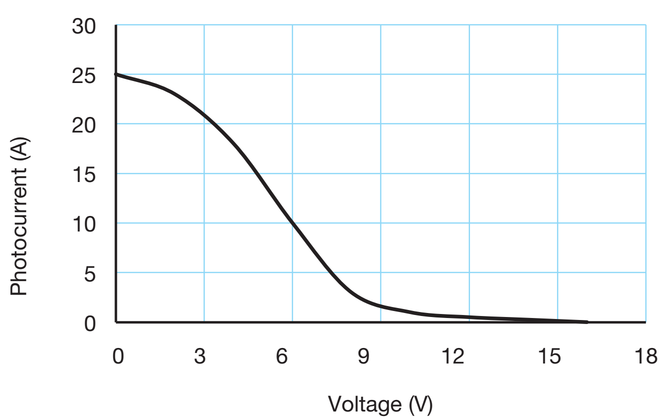
1. Some students set up the apparatus shown below to study the relationship between the frequency and intensity of incoming light and the maximum kinetic energy of emitted photoelectrons in the photoelectric effect. Assume that all filters give light of the same intensity.

(a) What is the frequency of the light photons incident on the emitter of the photocell at the setting shown in the diagram?



(b) While this light was shining on the emitter, the variable voltage supply was turned on and gradually increased from zero to a maximum amount. The photocurrent flowing was measured at various voltages, and the results plotted on the graph shown.

Explain why the current decreases and drops to zero as the voltage increases.



(c) In this part of the experiment, the current dropped to zero when the applied voltage was 14.5 V. What two things does this 14.5 V represent?

(d) Use the information in the graph to calculate the speed of the electrons as they leave the emitter.
Take their mass as 9.1×10^{-31} kg.

The students then changed the frequency of the incident light falling on a different emitter and measured the stopping voltage for each frequency. Their results are shown in the table.

Frequency of incident light (Hz)	Stopping voltage (V)	Kinetic energy of photoelectrons (eV)
4.5×10^{14}	1.3	
5.1×10^{14}	1.5	
6.1×10^{14}	2.0	
6.9×10^{14}	2.5	
7.5×10^{14}	2.8	

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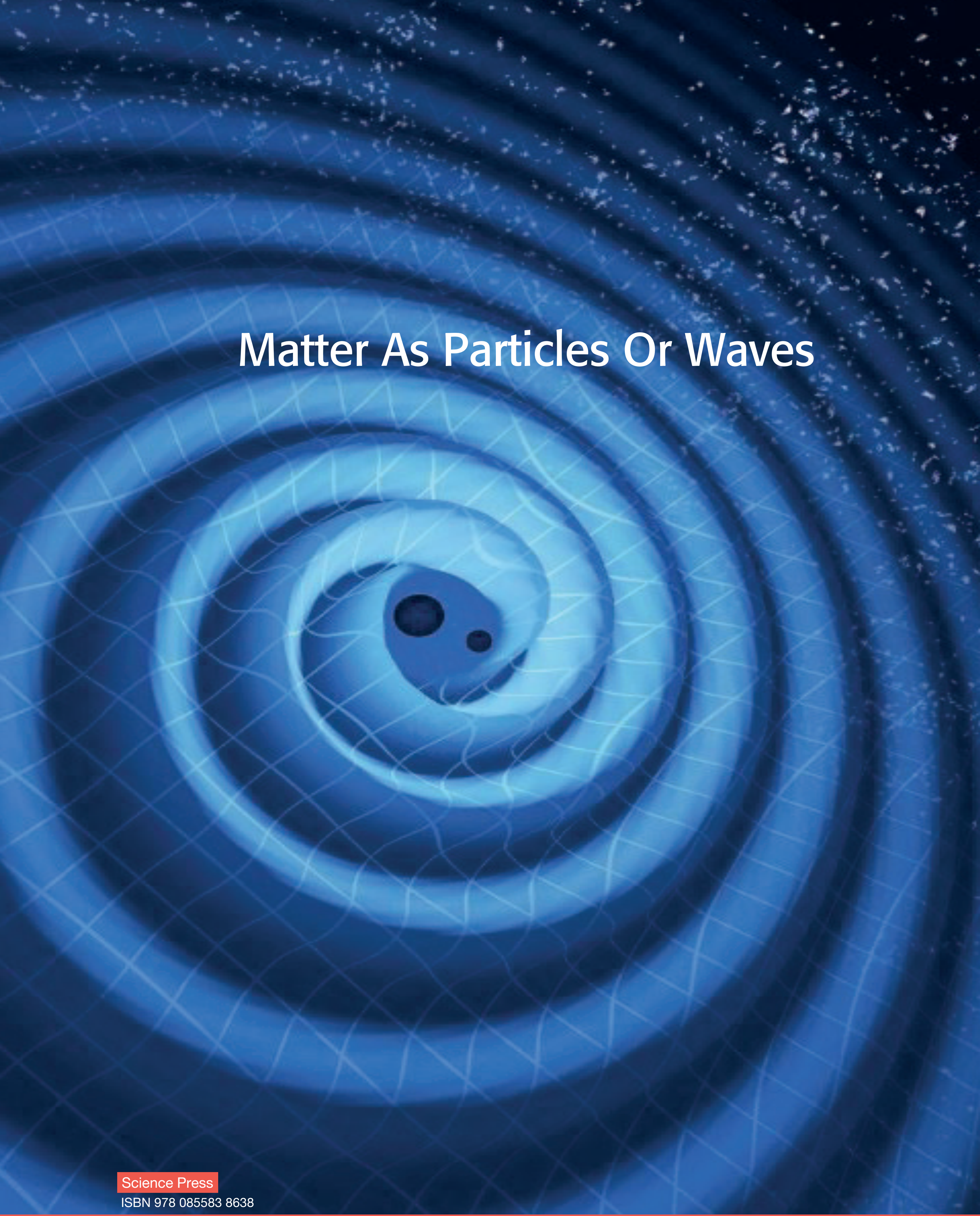

Matter As Particles Or Waves

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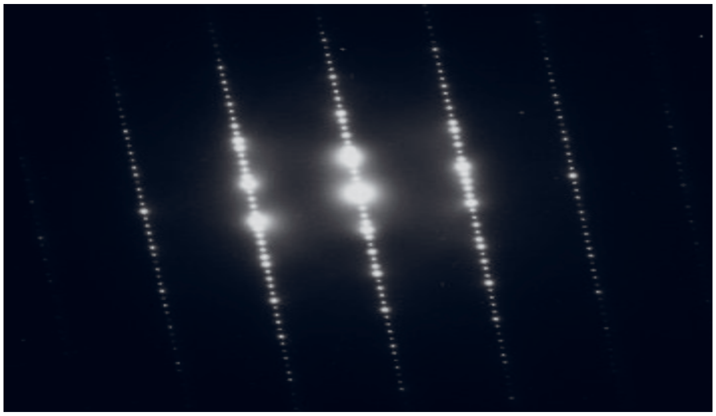
4. A photograph taken during an experiment to study the diffraction of electrons, shows the interference pattern which was formed.

Explain why this photograph provides evidence for the wave nature of electrons.

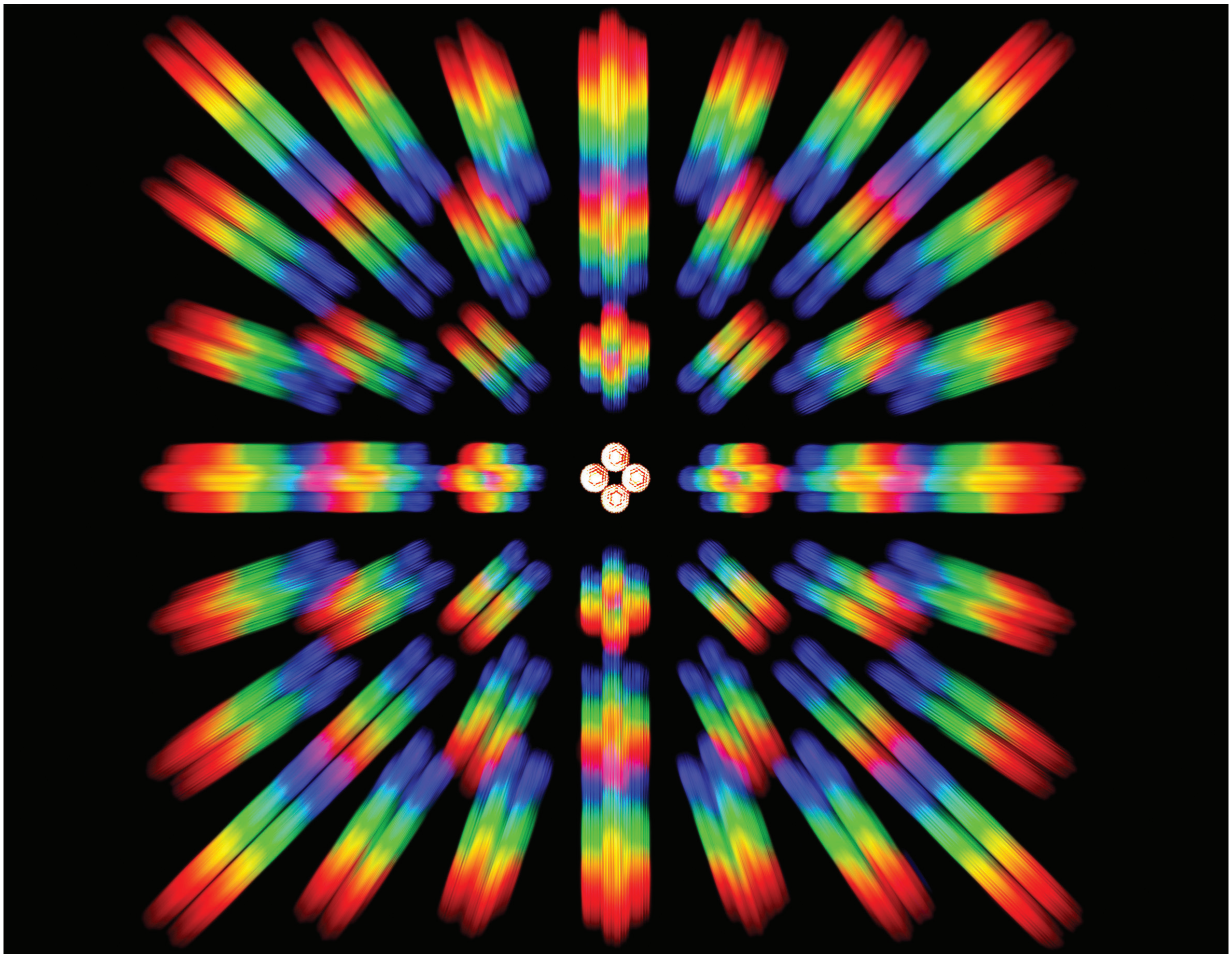


5. Recall that the diffraction pattern obtained during experiments is governed by the equation:

Diffraction $\propto \frac{\lambda}{w}$ This holds for any form of diffraction including electron diffraction. Given this:

(a) What will be the wavelength of the incident radiation used?

(b) What will be the slit width? Justify your answer.



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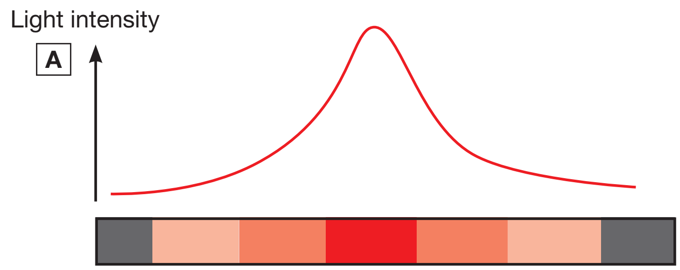
11. Diffraction Patterns

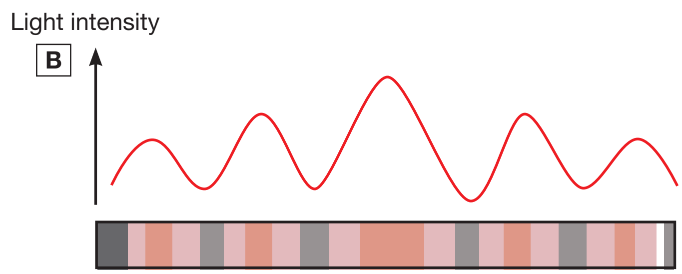
Distinguish between the diffraction patterns produced by photons and electrons.

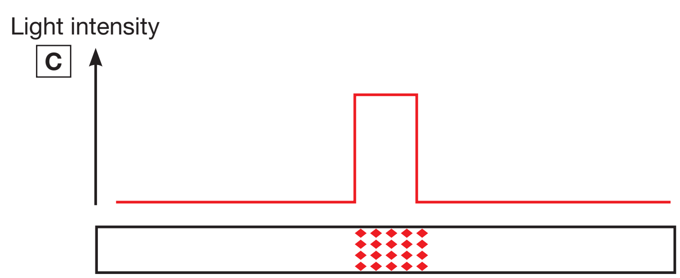
Diffraction by photons and electrons

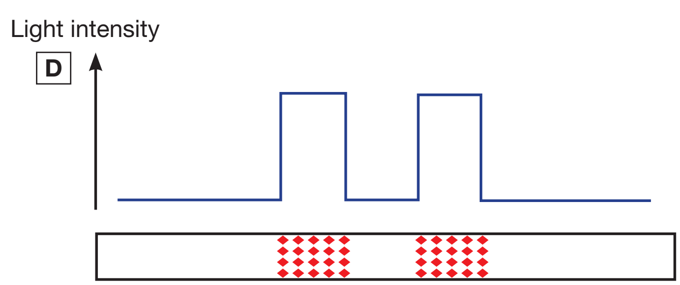
The questions on this page relate to the diffraction pattern diagrams shown.

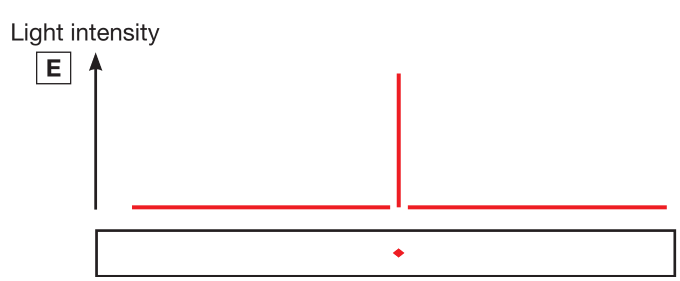
For each question answer A, B, C, D or E.











Light as a wave

1. (a) Which of the diffraction pattern diagrams shows the results of a typical **single slit diffraction** experiment of light like those first done by Thomas Young in 1802?

(b) Which of the diffraction pattern diagrams shows the results of a typical **double slit diffraction** experiment of light like those first done by Thomas Young in 1802?

Light as particles

2. (a) Which of the diffraction pattern diagrams shows the results expected from a **double slit diffraction** experiment using a **beam of photons** if we consider them to be **particles**?

(b) Which of the diffraction pattern diagrams shows the **actual** results of a **double slit diffraction** experiment using a **beam of particle photons**?

3. (a) Which of the diffraction pattern diagrams shows the results **expected** from a **single slit diffraction** experiment using a **beam of photons** if we consider them to be **particles**?

(b) Which of the diffraction pattern diagrams shows the **actual** results of a **single slit diffraction** experiment using a **beam of photons**?

4. (a) Which of the diffraction pattern diagrams shows the results **expected** from a **single slit diffraction** experiment using a **single photon** if we consider it to be a **particle**?

(b) Which of the diffraction pattern diagrams shows the **actual** results of a **single slit diffraction** experiment using a **single photon**?

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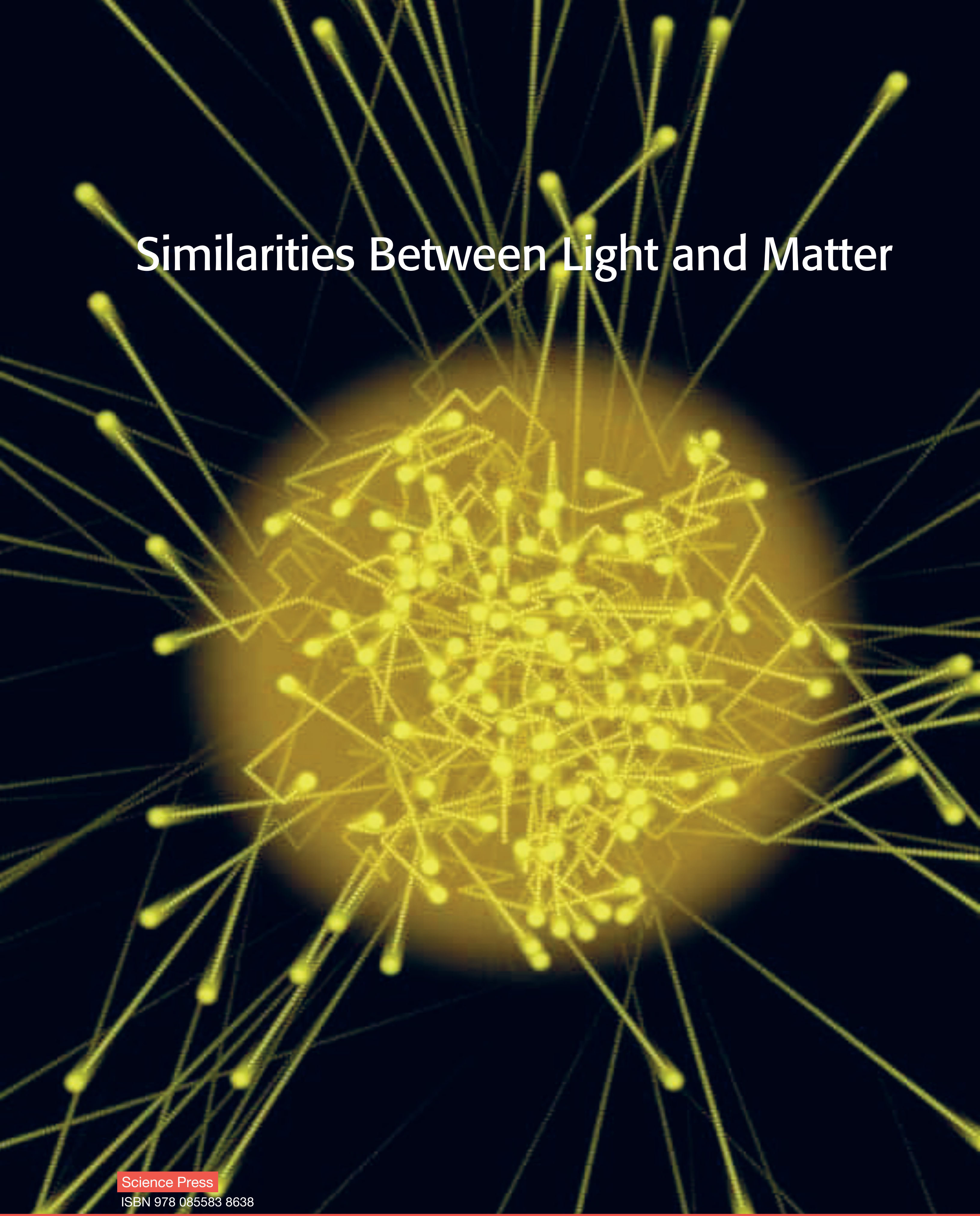
Similarities Between Light and Matter



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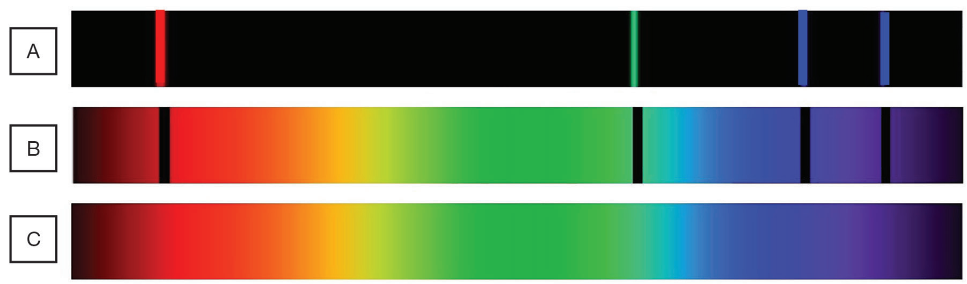
1. What is an atomic spectrum and how does it form?

2. Identify the three different types of atomic spectra and briefly describe each.

3. Describe the relationship between the emission and absorption spectra of the same element.

4. (a) Identify the type of spectrum shown in the diagram below.

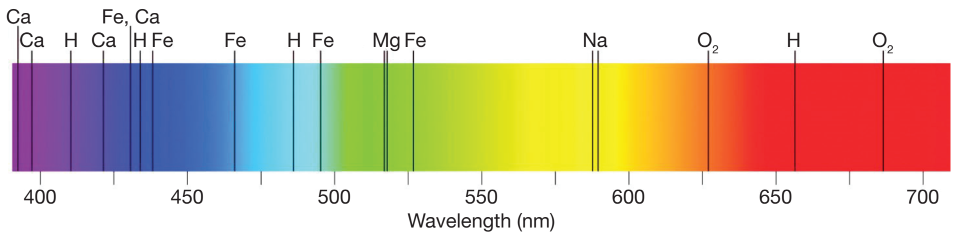


(b) Which end of each of these spectra is the high frequency end?

(c) Which end of each of these spectra is the long wavelength end?

(d) What can you infer from the absorption and emission spectra A and B in this diagram? Justify your answer.

5. Consider the spectrum shown below.

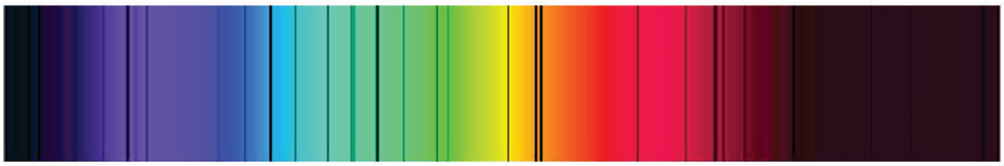


(a) What type of spectrum is this? Justify your answer.

(b) Each of the black lines in the spectrum has been identified as belonging to a particular element. How can we be certain that this information is correct?

(c) There are four lines in this spectrum for calcium (Ca), two for oxygen (O_2), and four for iron (Fe). How can one element have more than one spectral line?

6. The diagram below shows a spectrum of the Sun. As a hot body, the Sun's spectrum should be a continuous spectrum. Suggest at least one reason why the black lines appear in this spectrum. Justify your answer.


Spectrum of the Sun

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16. Interpreting Spectra

Interpret spectra and calculate the energy of absorbed or emitted photons: $E = hf$.

Spectra and energy of photons

Published in 1901, Planck's idea had the atoms inside the cavity oscillating back and forth and emitting radiation in a similar way to a radio antenna. Like antennas, the oscillating atoms could also **receive** electromagnetic (in this case, heat) radiations from their surroundings.

The revolutionary idea in his explanation however, in order to explain the pattern of emitted radiation, was that the electromagnetic energy associated with the oscillation of the atoms was **quantised**. It could only have energy values consistent with the following equation.

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

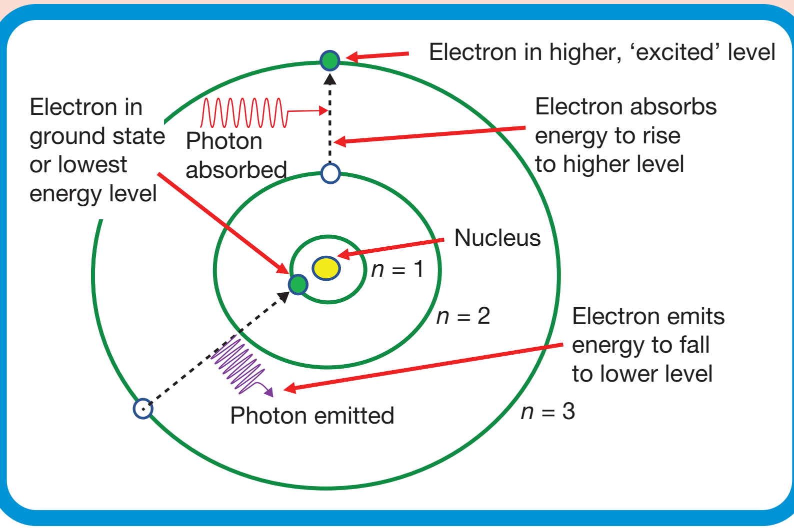
Where E = energy of the photon (J)

f = frequency of the light (Hz)

h = Planck's constant = 6.63×10^{-34} (J s)

c = velocity of light = 3×10^{8} m s^{-1}

Bohr applied this idea to the electrons in atoms and used it to account for the energy absorbed by electrons when they moved to higher energy orbits, and the photons emitted from atoms when electrons fell to lower energy levels.



1. Complete a copy of the table below by calculating the missing values.

	Energy (eV)	Energy (J)
(a)	250	
(b)	3.2×10^{3}	
(c)	8×10^{12}	
(d)		1
(e)		4.0×10^{-14}
(f)		4.8×10^{-8}

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2. Complete a copy of the table below by calculating the missing values.

	Energy	Wavelength (m)	Frequency (Hz)
(a)	140 eV		
(b)	1.0 eV		
(c)	1.64 eV		
(d)	8×10^{-12} J		
(e)	2×10^{-18} J		
(f)	6×10^{-16} J		
(g)			2×10^{8}
(h)			4×10^{16}
(i)			9×10^{21}
(j)		2×10^{-7}	
(k)		4×10^{-11}	
(l)		5.0	

3. Calculate the photon energy in joules and electron volts of:

(a) A radio wave of frequency 5×10^{6} Hz.

(b) A microwave of frequency 2×10^{10} Hz.

(c) Red light of frequency 4.5×10^{14} Hz.

(d) Yellow light of wavelength 500 nm.

(e) Green light of wavelength 450 nm.

(f) Blue light of wavelength 400 nm.

(g) Ultraviolet light of wavelength 250 nm.

(h) X-rays of frequency 2×10^{19} Hz.

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Answers

1. Light As a Wave

Light as a transverse electromagnetic wave

1.

	Completed sentences
(a)	All electromagnetic waves can travel through a vacuum.
(b)	Electromagnetic waves travel at the speed of light (3×10^8 m s^{-1}) in a vacuum – they slow down a little in other media.
(c)	Electromagnetic waves are self propagating alternating electric and magnetic fields.
(d)	Because the motion of the changing magnetic and electric fields are at right angles to the direction in which they carry energy, electromagnetic waves are also classified as transverse waves.
(e)	Because electromagnetic waves are really hard to draw, we usually draw them as transverse matter waves.
(f)	The flaw in doing this is that the energy carried by a transverse wave is indicated by the amplitude of the wave.
(g)	In electromagnetic waves, the energy is directly proportional to the frequency of the photons which make up the radiation.
(h)	The wavelength of an electromagnetic wave is the distance between the peaks of successive magnetic or electric field pulses.
(i)	We usually refer to the intensity of an electromagnetic wave rather than to its amplitude.
(j)	The intensity of an electromagnetic wave depends on the number of photons in the beam.
(k)	Each photon will have energy dependent on its frequency.
(l)	The period of an electromagnetic wave is the time for one wavelength to pass a given point.
(m)	The frequency of an electromagnetic wave is the number of wavelengths that pass a point each second.
(n)	The frequency of electromagnetic waves is measured in hertz (Hz).

2. (a) Half a wavelength

(b) Wavelength

(c) Amplitude

(d) About 3.8×10^{-11} m

(e) 3

(f) 3

(g) 3×10^8 m s^{-1} because this is the speed of all electromagnetic waves in air.

(h) 7.89×10^{18} Hz

(i) Stays the same because the medium stays the same.

(j) Its wavelength would halve to maintain constant speed in the air.

3. The concept of electromagnetic radiation is difficult to visualise. For simplicity, accept it as oscillations in two perpendicular planes only – these planes representing the average of half its vibrations in a horizontal plane and half of its vibrations in a vertical plane. In reality, the wave is composed of many sets of perpendicular planes of oscillation.

4. (i) Electromagnetic radiation is emitted from matter when excited electrons (electrons in higher energy levels than their normal position) fall back into their lower position. The energy they absorbed to excite them is released as electromagnetic radiation.

(ii) It is a simple fact of physics that accelerating charges emit electromagnetic radiation (e.g. synchrotron radiation – see later). So electrons circling around the path inside a synchrotron, because they are continually emitting energy which can be harnessed and used in experiments.

5. (a) All electromagnetic radiations travel at 3×10^8 m s^{-1} in a vacuum.

(b) The radiation cannot be part of the electromagnetic spectrum because its speed in air is too low. However, the slower speed in the glass slab could be correct and the denser glass would decrease its speed.

(c) This is a bit of a trick question, because the bands in the electromagnetic spectrum are based on our use of the particular wavelengths in the band. A 'new band' would simply be the discovery of new uses for some wavelengths, not the discovery of new wavelengths.

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25. Time Dilation

t_v or not t_v? That is the question!

1.

Time on spaceship (s)	Speed of ship	Length of 1 second on spaceship as perceived by observer on Earth	Time dilation effect (%)
1	0.1 *c*	1.005	100.5
1	0.3 *c*	1.048	104.8
1	0.5 *c*	1.155	115.5
1	0.7 *c*	1.400	140.0
1	0.9 *c*	2.294	229.4
1	0.99 *c*	7.089	708.9

2. At low object speeds, time dilation effect is small, rising exponentially after speeds greater than 0.9 *c*.

3. (a) Planet is moving relative to the ship, so the pilot would see t_v on his clock. So, the reading on the planet clock must be less than 1.2.

Ship time is $t_v = \dfrac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$; $1.2 = \dfrac{t_0}{\sqrt{1-\frac{0.2^2}{1^2}}}$

$= 1.176$ s

(b) Remember, the clock in the frame of reference of the observer is always measuring t_v, so again, the 1.2 s is $t_v = 1.176$ s.

4. (a) The Earth observer's 3.5 s is t_v, so the time this observer measures on the UFO clock will be

$t_0 = t_v\dfrac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = 3.5\sqrt{1-\dfrac{(0.4\ c)^2}{c^2}} = 3.5 \times 0.917$

$= 3.21$ s

(b) The UFO pilot's 3.5 s is t_v, so the time the pilot measures on the Earth clock will be t_o, therefore, as before: $t_0 = t_v\dfrac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$= 3.5\sqrt{1-\dfrac{(0.4\ c)^2}{c^2}} = 3.5 \times 0.917 = 3.21$ s

5. (a) The pilot's 9.6 s is t_v, so the time the pilot measures on the planet clock will be t_o, therefore

$t_0 = t_v\dfrac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = 9.6\sqrt{1-\dfrac{(0.6\ c)^2}{c^2}} = 9.6 \times 0.8$

$= 7.68$ s

(b) The planet observer's 9.6 s is t_o, so the time on his own clock on the Earth will be t_v, therefore,

$t_v = \dfrac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \dfrac{9.6}{\sqrt{1-\frac{(0.6\ c)^2}{c^2}}} = \dfrac{9.6}{0.8} = 12.0$ s

6. (a) The year on the ship as measured by an Earth observer would be t_o, and the 4 years would be t_v.

Therefore, from $t_0 = t_v\dfrac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$

$1 = 4\sqrt{1-\frac{v^2}{c^2}}$, which, given that $c = 1$,

simplifies to $1 = 4\sqrt{1 - v^2}$

Squaring both sides, we get $1 = 16\ (1 - v^2)$

From which $v^2 = \dfrac{15}{16}$

Therefore $v = 0.968\ c$

(b) The 4 years on the ship as measured by the pilot would be t_v, and the 1 year would be t_0.

Therefore, from $t_0 = t_v\sqrt{1-\frac{v^2}{c^2}}$

$1 = 4\sqrt{1-\frac{v^2}{c^2}}$, which, given that $c = 1$,

simplifies to $1 = 4\sqrt{1 - v^2}$

Squaring both sides, we get $1 = 16\ (1 - v^2)$

From which $v^2 = \dfrac{15}{16}$

Therefore $v = 0.968\ c$ as before

7. $5.6 \times 10^7 = \dfrac{5.6 \times 10^7}{3.0 \times 10^8} = 0.187\ c$

(a) Time on Earth as measured by the astronaut is t_0,

Therefore $t_0 = t_v\sqrt{1-\frac{v^2}{c^2}} = 10\sqrt{1-\dfrac{(0.187\ c)^2}{c^2}}$

$= 10 \times 0.982 = 9.82$ hours

(b) The 10 hours timed by the Earth observer on the ship clock is t_o, therefore, time on Earth clock is t_v,

Therefore, $t_v = \dfrac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \dfrac{10}{\sqrt{1-\frac{(0.187\ c)^2}{c^2}}}$

$= 10.18$ hours

8. (a) The photon is at rest relative to his own watch, therefore there will be no time dilation effect on that watch for him. It is only an observer outside the photon's frame of reference that would see the watch as stopped.

(b) If the observer was outside the photon's frame of reference, then because the photons travel at the speed of light, the Lorentz factor, $\frac{v^2}{c^2}$ in the time dilation equation becomes equal to 1.

The expression in the time dilation equation,

$\sqrt{1-\frac{v^2}{c^2}}$ becomes simply $\sqrt{1 - 1}$, so the denominator in the equation becomes zero, so the time recorded on the watch as seen by the external observer will be indeterminate, or effectively the watch runs so slowly that it stops.

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26. Length Contraction

Length contraction

1.

Speed of spaceship (c)	Length of ship as seen by pilot (m)	Length as seen by observer at rest (m)	Height of ship as observed by observer at rest (m)
At rest	200	200	50
0.1	200	199	50
0.25	200	193.65	50
0.5	200	173.21	50
0.8	200	120	50
0.9	200	87.18	50

2. (a) The desk is at rest relative to John, so its proper length is 1.8 m.

(b) Jenny is moving relative to the desk (well – the desk is moving relative to her, but it is the same thing mathematically), so

From $L_v = \frac{L_o}{\gamma}$

$\gamma = \frac{1}{(\sqrt{1-0.25^2})} = \frac{1}{(\sqrt{1-0.0625})}$

So, $L_v = \frac{1.8}{\frac{1}{(\sqrt{0.9375})}} = 1.8 \times \sqrt{0.9375} = 1.74$ m

3. (a) Its pilot – 120 m.

(b) From $L_v = \frac{L_o}{\gamma}$

$\gamma = \frac{1}{(\sqrt{1-0.8^2})} = \frac{1}{(\sqrt{0.36})} = \frac{1}{0.6}$

So, $L_v = 120 \div \frac{1}{0.6} = 120 \times 0.6 = 72$ m

Therefore, length of ship as seen by observer on the space platform = 72 m.

(c) From $L_v = \frac{L_o}{\gamma}$

$\gamma = \frac{1}{(\sqrt{1-0.8^2})} = \frac{1}{(\sqrt{0.36})} = \frac{1}{0.6}$

So, $L_v = 1800 \div \frac{1}{0.6} = 1800 \times 0.6 = 1080$ m

Therefore, length of station as seen by pilot = 1080 m.

(d) An observer on the space platform = 1800 m.

4. (a) $L_v = 120000\sqrt{1-\frac{(0.35c)^2}{c^2}} = 120000 \times 0.9367 = 112\,410$ km

(b) $L_v = 100\sqrt{1-\frac{(0.35c)^2}{c^2}} = 100 \times 0.9367 = 93.67$ m

5. (a) 56 m (speed is too slow for a significant relativistic effect).

(b) 3000 km (speed is too slow for a significant relativistic effect).

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Index

absorption spectrum 36
analysing standing waves 7
antinodes 6
atomic spectra 36
Bohr, Niels 34
bright band 13
classical mechanics 48
classical physics 64
constructive interference 12
constructive superposition 4
continuous spectrum 36
dark band 13
de Broglie wavelength 32, 44
de Broglie, Louis 44
destructive interference 12
destructive superposition 4
diffraction 9-14 ,28-31, 45-46
diffraction patterns 30
double slit experiment 12, 30
dual nature of light 25, 45
Einstein, Albert 17, 34
Einstein's first thought experiment 52
Einstein's postulates 54
Einstein's second thought experiment 51
Einstein's special theory of relativity 47-64
electron diffraction 28
electron orbital changes 40
electron standing waves 44
emission spectrum 36
energy and mass 65-69
energy of photons 38
energy-mass relationship 68
frames of reference 49
fundamental vibration 7
harmonics 7
interference pattern 14
interpreting spectra 38
length contraction 60
light and quantisation 34
light as a particle 15-26, 30
light as a wave 1, 14, 30
light speed 52
limitations of classical mechanics 48
limitations of wave model 25
mass conversion in the Sun 68
mass defect 68
matter as particles or waves 27-32
Michelson-Morley experiment 55
momentum of photons and matter 35
nodes 6,7
nuclear reactions 69
null result 55
partial superposition 4
photoelectric effect 17
photons 16, 17, 30, 35, 38
Planck, Max 16
principle of relativity 51
proper time 56
quantisation and light 34
quantised energy of photons 16
relativistic mass 66
relativity 47-64
rest mass 66
resultant wave 4
similarities between light and matter 33-46
single slit diffraction 9, 30
special relativity 63
special theory of relativity 47-64
spectra 36-39
speed of light 52
standing waves 4, 6, 44
stopping voltage 17
superposition of waves 4
threshold frequency 17
time dilation 58
transverse electromagnetic wave 2
wave model 2-14, 25
wave nature of matter 28
work function 17
Young's experiment 12

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