Worked solutions Unit 3B

Contents

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The sounds of music

E1

$L = 42.0$ dB

$I_0 = 10^{-12}$ W m^{-2}

$$L = 10\log\left(\frac{I}{I_0}\right)$$

$$(42.0) = 10\log\left(\frac{I}{10^{-12}}\right)$$

$$(4.20) = \log\left(\frac{I}{10^{-12}}\right)$$

$$10^{4.20} = \frac{I}{10^{-12}}$$

$$I = 10^{4.20} \times 10^{-12} = 1.58 \times 10^{-8} \text{ W m}^{-2}$$

E2

$L = 98.0$ dB

$I_0 = 10^{-12}$ W m^{-2}

$r_1 = 3.00$ m

$r_2 = 5.00$ m

$$L = 10\log\left(\frac{I}{I_0}\right)$$

$$(98.0) = 10\log\left(\frac{I}{10^{-12}}\right)$$

$$10^{9.80} = \frac{I}{10^{-12}}$$

$$I = 10^{9.80} \times 10^{-12} = 6.31\times10^{-3} \text{ W m}^{-2}$$

$$I_1 r_1^2 = I_2 r_2^2$$

$$I_2 = \frac{I_1 r_1^2}{r_2^2} = \frac{(6.31\times10^{-3})(3.00^2)}{(5.00^2)}$$

$$I_2 = 2.27\times10^{-3} \text{ W m}^{-2}$$

E3

$T_2 = 3T_1$

$$f_1 = \frac{1}{2L}\sqrt{\frac{T_1}{\mu}}$$

$$f_2 = \frac{1}{2L}\sqrt{\frac{T_2}{\mu}}$$

$$f_2 = \frac{1}{2L}\sqrt{\frac{\mathbf{3T_1}}{\mu}}$$

$$f_2 = \sqrt{3}\times\frac{1}{2L}\sqrt{\frac{T_1}{\mu}}$$

$$f_2 = \sqrt{3}\times f_1$$

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E4

$L = 0.400$ m

$T = 120.0$ N

$m = 30.0 \times 10^{-2}$ kg

$$\mu = \frac{m}{L} = \frac{(30.0 \times 10^{-2})}{(0.400)} = 7.50 \times 10^{-2} \text{ kg m}^{-1}$$

$$f = \frac{1}{2L}\sqrt{\frac{T}{\mu}} = \frac{1}{2(0.400)}\sqrt{\frac{(120.0)}{(7.50 \times 10^{-2})}}$$

$$f = 50.0 \text{ Hz}$$

E5 **a**

$T_{air} = 26.0^{\circ}$C

$$v_{sound} = 331 + 0.6T = 331 + 0.6(26.0)$$

$$v_{sound} = 3.47 \times 10^{2} \text{ m s}^{-1}$$

$\lambda = 2L$

$f_1 = 100.0$ Hz

$$f_1 = \frac{v}{2L}$$

$$L = \frac{v}{2f_1} = \frac{(3.47 \times 10^{2})}{2(100.0)}$$

$$L = 1.73 \text{ m}$$

b

$\lambda = 4L$

$f_1 = 100.0$ Hz

$$f_1 = \frac{v}{4L}$$

$$L = \frac{v}{4f_1} = \frac{(3.47 \times 10^{2})}{4(100.0)}$$

$$L = 0.867 \text{ m}$$

E6

$L = 0.400$ m

$$f_1 = \frac{v}{2L} = \frac{(3.40 \times 10^{2})}{2(0.400)}$$

$$f_1 = 425 \text{ Hz}$$

$$f_3 = 3 \times f_1 = 3(425)$$

$$f_3 = 1.28 \times 10^{3} \text{ Hz}$$

E7

$f = 60.0$ Hz

assume $v = 346$ m s^{-1}

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

$$\lambda = \frac{v}{f} = \frac{(346)}{(60.0)} = 5.77 \text{ m}$$

size of shell = 6 m

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E8

$$T_{air} = 2.00^{\circ}\text{C} \qquad v_{sound} = 331 + 0.6T = 331 + 0.6(2.00)$$

$$v_{sound} = 3.32 \times 10^{2}\ \text{m s}^{-1}$$

$$\Delta t_{return} = 0.0300\ \text{s} \qquad v = \frac{s}{\Delta t_{to\ prey}}$$

$$\Delta t_{to\ prey} = 0.0150\ \text{s} \qquad s = v\Delta t_{to\ prey} = (3.32 \times 10^{2})(0.0150)$$

$$s = 4.98\ \text{m}$$

E9 To ensure that the air column inside their instrument maintains a constant temperature, this will ensure that the speed of sound in the instrument is also constant and therefore the resonant frequencies are in tune with the standard frequencies expected by the conductor.

E10 She should loosen the string slightly.

E11

$$m_1 = m_1 \qquad E_R = 100\left(\frac{m_1 - m_2}{m_1 + m_2}\right)^2$$

$$m_2 = 0.5m_1 \qquad E_R = 100\left(\frac{m_1 - 0.5m_1}{m_1 + 0.5m_1}\right)^2$$

$$E_R = 100\left(\frac{0.5m_1}{1.5m_1}\right)^2$$

$$E_R = 100\ (+0.33)^2$$

$$E_R = 11.1\%$$

E12

$$n_1 = 1.00 \qquad E_R = 100\left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2$$

$$n_2 = 1.33 \qquad E_R = 100\left(\frac{(1.00) - (1.33)}{(1.00) + (1.33)}\right)^2$$

$$E_R = 100\left(\frac{-0.33}{2.33}\right)^2$$

$$E_R = 100\ (-0.142)^2$$

$$E_R = 2.01\%$$

E13 Yuki should either loosen or tighten her violin string and listen to see if the number of beats increases or decreases. What she should be trying to achieve is to decrease the number of beats per second until no beats are heard. At this point the frequency of the tuning fork and of the violin string are the same.

E14 B

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E15 C

I would look for a low minimum power rating to avoid ‘clipping’ that could damage the tweeters. It is unlikely that I would turn up the speakers to maximum so I could get speakers that are less than the maximum power of the amplifier, so I would choose speakers C.

E16

$P = 80.0$ W $\qquad P = VI$ and $V = IR$

$R = 8.00\ \Omega \qquad P = I^2R$

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{(80.0)}{(8.00)}}$$

$$I = 3.16 \text{ A}$$

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The search for understanding

The questions in this context are largely based on opinion and discussion, with an emphasis on critical thinking and the formation of supported arguments. In most cases, the following answers consist only of lists of some relevant points which do not necessarily support only one conclusion.

It is important to note that although other information may be relevant if introduced to, or by, students, the suggested responses are based only on information that is either presented within the context or available to the general public.

E1 Before Thales theories may have suggested that the gods (or spirits; mythical creatures; magic) created the structure and nature of the Earth and the heavens.

E2 **a** The presence of condensation on cold objects, when organic matter is crushed it often contains liquids. Water itself, and the large number of other fluids. Death—animals lose fluid, including blood, as they die and break down, plants appear dry as they die. Mud loses water before becoming dust and disappearing in the wind. The clouds contain water (rain) and the air contains water (condensation). Ice to water to steam is an example of water taking different forms.

b Yes as it attempts to explain observations.

E3 **a** It illuminates objects, it cannot be seen as it passes by our eyes, it can be reflected from shiny objects and bend as it passes through transparent objects, shadows with distinct edges, so light is blocked from a straight path.

b **i** It illuminates objects – all three filaments interact.

It cannot be seen as it passes by our eyes – the filament from the object is not present

It can be reflected from shiny objects – the filaments reflect off the shiny surface.

It bends as it passes through transparent objects – the filaments are bent by the substance

When an object passes in front of what is being looked at, the filament could easily be cut to now be shorter (to see the closer object) and go no further (leave a shadow behind the object)

ii It illuminates objects – particles from your eye strike the object.

It cannot be seen as it passes by our eyes – the particles pass by our eyes.

It can be reflected from shiny objects – the particles bounce off the shiny surface.

It bends as it passes through transparent objects – the particles change direction as they enter the substance.

Particles directed at an object will not hit any part of a surface directly behind that object (shadows)

iii It illuminates objects – waves from a source strike the object then enter our eye.

It cannot be seen as it passes by our eyes – the wave from the object passes by our eyes.

It can be reflected from shiny objects – the waves reflect off the shiny surface.

It bends as it passes through transparent objects – the waves change direction as they enter the substance.

Waves do not pass beyond objects in their path (shadows); they do over longer distances, but other factors could then come into play

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E4 **a** As rocks are broken down, the smaller grains tend to become more and more similar in size (they resemble distinct particles). Some substances can be made by mixing other substances, suggesting that the final form of matter is not the same as the material from which it is built. Heating/burning changes substances, suggesting that different structures of the same material produce different properties

b The four distinct elements could be made up of either particles or continuous matter. The four elements could be four types of atom, instead of one as proposed. The four elements could be four basic ways of structuring the proposed identical atoms

E5 **a** Both Newton and Hooke describe light as being all of the same type regardless of the source. Both Newton and Hooke can explain reflection and mirrors, and refraction. Al-Haytham suggests that light slows down when it enters a more dense medium, Hooke's waves would slow down as they enter the greater resistance of a more dense medium, and Newton's particles speed up as they are affected by the attractive forces at a boundary with another medium

b Al-Haytham's work is very successful as it applies to the practical considerations of a wide variety of mirrors. Observations can be successfully explained. The explanation is only theory.

c Australian society is essentially of European origin our history is traditionally European (and European American) only. Al Haytham was not European and so not part of the debates of academics that tend to be discussed and become widely known. Communication between people in different parts of the world was not as quick and easy as it is now; al-Haytham's ideas may simply never have been taken to Europe. Europe was in the midst of the Middle Ages and was less concerned with scientific advances and was lax in the keeping of written records; Al-Haytham could have been known about without any written record. Along with the ideas of women not being taken seriously, the male European scholars who wrote our scientific history may not have considered ideas from the Middle East to be worthy of inspection.

E6 Filaments are instantaneous, particles and waves travel and so have a speed. Calculation of the speed of light as it moves into a more dense medium is important in deciding between waves, which should slow down, and particles, which should speed up.

E7 **a** Waves – as a wave moves out from a point source, the radius of the curve increases; the same wave energy is spread over a larger surface and so must be less at each point.

Particles – a spray of particles leaving a point would consist of slightly different directions; as they move further from their origin, the difference in direction remains unchanged while the particles spread further apart, and so there are less particles within the same area.

b Determining the distance to a known light source or determining the intensity of a light source at a known distance. Investigating the relative intensities of the stars, when other measurements are made to indicate relative distances.

E8 According to Newton, reflection is due to repulsive forces at the boundary and refraction is due to attractive forces at the boundary. How is it possible for the same particles to be both repelled and attracted by the forces at the same boundary?

E9 The speed of light in different media and/or as it crosses boundaries. A medium through which light travels (the ether) or diffraction (bending around edges).

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E10 **a** Both the wave and particle theories explain current observations. The particle theory does not require the missing diffraction effects or ether in order to be valid (note that because something has not been observed, it does not mean that it does not exist)

b Newton is well-respected and has presented a comprehensive theory, including an explanation of colour and the development of the successful reflecting telescope

E11 The diffraction effect may be very small, due to very small wavelengths, and so is unable to be measured with available resources.

E12 Roemer's use of a very, very large distance minimises the relative effects of small measurement errors.

E13 Two theories: continuous or indivisible particles. Atoms have been proposed since 440 BCE. Boyle, in 1661, explains gases as atoms and molecules moving around. Newton includes light as being particles (the same general idea although with no mass). There is no evidence to dispute the continuous theory as there has been no direct observation of atoms

E14 Lavoisier's accurate weights suggest a simple movement of matter from one place to another, with the total amount remaining constant.

E15 **a** Refraction; possible explanation for diffraction and colour; possible explanation for interference

b Newton's theory was suggested partly because of an absence of observed diffraction. If the observed pattern is of interference, then light cannot be made up of particles; particles are not able to interfere and cancel each other out

E16 Dalton's explanation is both comprehensive and successful when put to practical use (chemical reactions). It is not as easy to explain whole number ratio combinations when using continuous matter, but it is still a possibility. There has been no direct observation of the atom

E17 **a** Supporting the wave theory:

Diffraction of light, interference of light, Fresnel's mathematical basis for wave theory predicts the observations of light, electric and magnetic fields are suggested as a possible means for the propagation of waves, light slows down when travelling in a more dense medium, Maxwell's equations regarding electromagnetic waves match the properties of light, Hertz produced electromagnetic waves that have the same properties as light.

Discrediting the particle theory:

Interference patterns, Michelson's interferometer.

b There is a lot of support for waves, but more important is the existence of discrediting evidence regarding particles. The conclusion that light cannot be made up of particles does not automatically mean that it has a wave nature.

E18 Fresnel's model was derived from observations independent of wave theory. A mathematical basis provides a method for predicting outcomes with greater precision than observation alone.

E19 **a** Seemingly separate theories and phenomena may be linked; for example, the properties of light and matter may be related

b Phenomena that we see as separate may be intrinsically linked. There may be a single theory that is responsible for all that we observe (a grand unified theory)

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E20 No medium (e.g. ether) for the transmission of light waves has been found. Lines of electric and magnetic force could not be observed directly, but would only be detected via their effects on electric charges and/or magnetic materials—no medium for the propagation of waves can be found using traditional methods. The moving electric and magnetic fields of electromagnetic waves could produce their own medium through which to travel; that is, no pre-existing medium is necessary

E21 The wave theory suggests that light travels more slowly in a more dense medium; this is supported by Foucault's measurements. The particle theory suggests that light speeds up as it crosses into another medium, due to the attractive forces at the boundary; this is not supported by Foucault's measurements.

E22 No particles were observed. Particles don't generally cause things to glow and the glowing of the gas implies a gain of energy (rays/waves). The glowing appears to be caused by the electric current, and there is no indication that electricity involves particles. The shadow indicates straight line paths, which could be either waves or particles

E23 **a** The properties of electric current are known well enough for practical uses of electricity to be successful, e.g. light bulbs and street lighting. The nature of electric current is unknown and the cause of electric current is unknown

b Health risks are unknown if phenomena are not understood; for example, X-rays. Other effects are unknown if phenomena are not understood; for example, nuclear explosions. Electricity was used successfully for a long time before it was understood; its properties were clear, only the underlying process was missing. Even when a phenomenon is understood, risks and unknowns still exist; for example, it's clear how mobile phones work but their long-term effect on the human brain is not known. The development of applications of phenomena is often a step in the process of understanding the underlying principles. We have been using our knowledge of electric charge in many ways, including electricity and electronics as well as electromagnetism, but we don't know what causes charges to attract and repel each other. What would our lives be like if we continued to refuse to work with electric charges?

E24 Michelson's equipment was more precise and more accurate, therefore allowing fewer and smaller errors. Michelson removed the effects of human error based on reaction times. Michelson was the first to achieve what others had consistently failed to do; that is, measure the speed of light over an observable distance. Michelson's measurements were taken on Earth, and thus could not have been affected by light travelling through space. Michelson's measurements were clearly of the light itself, rather than some other possible characteristic of space.

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E25 The light will only reflect from the octagonal mirror to the distant mirrors and back, and then from the other side of the octagonal mirror to the telescope, when the octagonal mirror is in the position shown in figure su.15 at both times. The spinning will therefore create pulses of light that only reflect to the distant mirrors when the octagonal mirror is in the orientation shown, and these pulses of light will only then reflect to the telescope when the octagonal mirror is again in the shown orientation.

Assuming that a pulse of light is sent to the distant mirrors, the orientation shown in Figure su.15 will only occur again (for the light to reflect to the telescope) if, during the time taken for the light to reach the distant mirrors and return, the octagonal mirror:

- does not move (which would prove nothing)
- moves one-eighth of a rotation
- moves two-eighths of a rotation
- moves three-eighths of a rotation
- moves four-eighths of a rotation etc.

Therefore, if the octagonal mirror spins any eighth of a rotation during the time taken for the light to return from the distant mirrors, the pulse of light will return with the octagonal mirror in the correct position to reflect it to the telescope. Any rotation other than an eighth will not reflect the light to the telescope.

Importantly, each pulse of light will reach the telescope should any full eighth of a rotation occur in the time it takes for the light to travel. The rate of rotation used will vary however, making it difficult to determine the time taken. For example, if it were to actually take 1 s for the pulse of light to reach the telescope, then all of the following would give similar results:

- one-eighth of a rotation every second (i.e. 8 s per rotation)
- two-eighths of a rotation every second (i.e. 4 s per rotation)
- three-eighths of a rotation every second (i.e. 2.7 s per rotation)
- four-eighths of a rotation every second (i.e. 2 s per rotation) etc.

A one-eighth rotation will have been achieved when the rate of rotation has been reduced until the slowest rate that allows every pulse of light to reach the telescope is identified. This is the rate at which the octagonal mirror moves around one face only. At no point will there be a face in the correct position if a slower rate of rotation is used. Reaching this point means that both the rate of rotation and the eighth of a rotation used are known, giving a single possible value for the time taken for the light to travel its path.

E26 Maxwell produced mathematical equations based on electromagnetic properties, and found that the predicted properties of electromagnetic waves matched the properties of light. Hertz produced electromagnetic waves experimentally, using oscillating currents, and found that the properties of the electromagnetic waves matched the properties of light. Two different approaches, one theoretical and one experimental, that independently produce the same results tend to validate the underlying theory, rather than allowing the results to be explained by factors specific to one set of conditions.

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E27 Matter:

- particles/atoms consistently explain the properties of matter
- Boyle's theory of matter, as atoms moving around and colliding, successfully explains observations regarding the nature of matter
- Lavoisier's theory of the conservation of matter shows matter to be a constant presence
- Dalton's work with ratios of atoms in combination continues to be supported by the field of chemistry
- no direct observation of atoms has occurred—the evidence is circumstantial only.

The particle theory of matter has an abundance of support, but remains theory.

Light:

- that light has a speed supports both the particle and wave theories, but not the filament theory
- reflection can be explained by both wave and particle theories
- mirrors and lenses can be explained by both wave and particle theories
- Kepler's inverse square law of light intensity and distance can be explained by both wave and particle theories
- Foucault's determination of the change in the speed of light in refraction supports the wave theory over the particle theory
- diffraction effects support the wave theory over the particle theory
- interference effects can be successfully explained by the wave theory only
- Maxwell's equations can explain the properties of light by assuming that it consists of electromagnetic waves
- light has the same properties as the electromagnetic waves produced by Hertz
- Michelson and Morley's failure to detect the ether supports the particle theory, but Faraday suggests that electric and magnetic fields provide a means of propagating light waves without any other medium.

It is clear that light must have a wave nature.

E28 **a** The wave theory of light explains all of the observations so far, only the wave theory successfully explains interference effects.

b Thomson's plum pudding model of the atom provides support for the atomic theory of matter. The identification of electrons as distinct and identical particles provides evidence of the existence of fundamental particles. The particle theory of atoms is able to explain all of the observations so far.

c Results are reproducible. Forms of radiation can be used in experiments. There appear to be no adverse effects. The properties of the two identified forms of radiation have been identified. The cause of the radiation is not known.

d The properties of electric current are well understood. Practical uses have been successfully implemented for some time already. The discovery of the electron allows an explanation of the processes of electric charge and electricity.

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e **i** Spectral lines, both emission and absorption, the photoelectric effect and the origin of radiation.

ii Spectral lines are clearly related to light, and light is understood. The photoelectric effect is related to light and electricity, both of which are understood. Radiation is clearly related to atoms, and atoms are quite well understood. The details of the properties of these phenomena are known, with only the underlying theory needing to be identified

E29 Light is understood and matter is understood, however, the observations yet to be explained are related to phenomena that are understood. Other fields like motion and gravitation have been mastered, leading to feats of architecture and engineering. Experiments have been producing more accurate measurements, rather than new information. It is disturbing that with so much that is so clear, there are no real clues as to the underlying principles of spectral lines, the photoelectric effect and radiation.

E30 From the 1600s, gaps of 20–50 years between advances were not uncommon. These gaps are now more like 5–10 years, with annual advances occurring. The increase in the frequency of advances may be due to:

- greater investment in research at universities
- improved access to colleagues to share ideas and argue theories
- greater literacy rates leading to more academics doing research
- greater literacy rates leading to more widespread participation in the discussion of ideas
- improved design of equipment, based on previous advances, which can more easily test theories
- a recognition of the possible economic advantage in understanding, such as the widespread use of electricity, promoting interest in research.

E31 Lenard shows that the current wave theory of light not only cannot explain the photoelectric effect, but that the observations recorded are in fact in opposition to this theory.

E32 **a** Planck's theory relates to the energy possessed by objects, and works mathematically
Einstein's theory relates to the nature of light, and explains observations logically

b Very different approaches related to very different phenomena provide validation for a common underlying theory; the results cannot be explained away as a function of a particular type of experiment or selective observations.

E33 Planck first proposed the quantum, $E = hf$. Planck proposed a mathematical property, rather than suggesting that it was an actual physical property of matter. Einstein built his ideas from the idea of quanta originally proposed by Planck. Einstein determined that quanta were physical properties of light energy. Einstein proposed a comprehensive theory using quanta to explain the previously unexplained photoelectric effect.

E34 Relativistic effects are only noticeable when velocities near the speed of light are involved. We do not experience these speeds in our lives. Note that, although we are unaware of it, satellites travel at high speeds relative to us. Data transmissions must therefore account for relativistic effects; that is, we use special relativity everyday as we watch TV, use a GPS etc.

E35 Rather than providing an answer, Einstein's $E = mc^2$ provides a new dilemma of light having both wave and particle properties. The debate over wave or particle may be irrelevant; if energy and mass are interchangeable then waves and particles would be different forms of the same thing.

E36 Thomson's plum pudding model of the atom

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Cathode rays
Electric charge and electricity
The photoelectric effect
Nuclear radiation

E37 Rutherford's model of the atom needed the concept of an atom, and the suggestion that atoms contained electrons. The plum pudding model itself has little to do with Rutherford's experiment or the Solar System model of the atom that followed.

E38 Bohr's model of the atom needed the concept of an atom, and the knowledge that atoms contained electrons. Determining the different energies of the electrons need not have involved the concept of a nucleus. The model of electrons orbiting a positive nucleus provides a structure for how the atom possesses the electron energy levels that had been identified. Bohr was working with Rutherford and so knew of Rutherford's Solar System model.

E39 Einstein's photoelectrons receive their energy from photons, where a photon is either completely absorbed as part of an absorption spectrum or leaves the atom unaffected; that is, either the exact quantity of energy needed to jump a level is contained within the photon or no transfer of energy will occur.

The electrons in the Franck–Hertz experiment receive their energy from other electrons, which are able to give up only part of their energy and continue on their way; that is, any electron with energy above the minimum needed is capable of transferring some of its energy to an electron within the atom and then being re-emitted with the energy that remains.

E40 **a** Matter and energy are interchangeable (under the right conditions), and thus light and matter are able to demonstrate both wave and particle properties at different times.

b Light must contain wave properties to undergo interference and particle properties to create the photoelectric effect. The Compton effect suggests the particle property of momentum for photons of light. de Broglie provides a workable theory and equation for determining the wavelength of particles of matter. Electron microscopes are currently in use, and use the wave properties of an electron in the same way as a normal microscope uses the wave properties of visible light.

E41 Science traditionally deals with observable and testable facts. Precision and accuracy are generally presented as essential. Schools (and the media) tend to teach science as 'the right answer', rather than probable answers with necessary uncertainty.

E42 Quantum mechanics dominates at the micro level; that is, subatomic particles.

Newtonian physics dominates at the macro level; that is, observable to the average person. For example, it doesn't matter that an electron is only probably at a given position within an atom as long as the nail contains enough atoms to provide enough friction to hold the wall in place

E43 We live in the macro world where classical Newtonian physics rules. Matter waves, probabilities and uncertainties all come into play at such small magnitudes that we don't notice them. The field of electronics relies on the theories of quantum mechanics, and is widespread in our lives during this age of computers.

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E44 Einstein's work was based on thought experiments and relativity. $E = mc^2$ was proposed as a consequence of travelling near the speed of light, which we do not do. The nucleus of the atom was not discovered until 6 years after Einstein's theory, with protons and neutrons yet to be identified. What was happening to the nuclei of atoms involved in nuclear reactions was difficult to detect even in 1938.

E45 Even in 1927, the theories proposed (and since confirmed) are very abstract and difficult to comprehend. More recent theories are more complicated still, generally requiring knowledge of mathematics far greater than that of the average Year 11 or 12 student.

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Chapter 5 Wave properties and light

5.1 Wave properties

1 Both involve the transfer of energy from one place to another without the net movement of particles.

2 Mechanical waves involve the physical transfer of vibration from one particle to another particle within the medium. The bonds between solid particles are more stiff than the bonds between gas particles and so the energy will be transferred more rapidly in a solid. The particles in a solid are also closer than the particles in a gas and so the interactions between particles occur faster.

3

$N = 40 \text{ vibrations}$ $\quad f = \frac{N}{\Delta t} = \frac{(40)}{(0.250)}$

$\Delta t = 0.250 \text{ s}$ $\quad f = 160 \text{ Hz}$

$$T = \frac{1}{f} = \frac{1}{160} = 6.25 \times 10^{-3} \text{ s}$$

4

$f = 3 \text{ Hz}$ $\quad f = \frac{c}{\lambda}$

$l = 1.80 \text{ m}$ $\quad c = f\lambda = (3)(0.60)$

$\lambda = 0.60 \text{ m}$ $\quad c = 1.8 \text{ m s}^{-1}$

5 Decrease the frequency, as this would allow more time between each wave, therefore increasing the length of each wave.

6 C

7 C, E

8 A

9 B

10 **a** Sound energy to kinetic energy of the microphone to electrical energy of the signal.

b Maximum pressure variation occurs at: 0.50 s, 1.50 s, 2.50 s, 3.50 s, 4.50 s and 5.50 s.

5.2 Wave behaviour

1 **a**

$\Delta t = 4 \times 0.25 = 1.0 \times 10^{-3} \text{ s}$ $\quad \lambda = v\Delta t = (340)(1.0 \times 10^{-3})$

$v = 340 \text{ m s}^{-1}$ $\quad \lambda = 3.4 \times 10^{-1} \text{ m}$

b $\lambda = 3.4 \times 10^{-1} \text{ m}$

c $v = 340 \text{ m s}^{-1}$

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2 D. The maximum reflected signal strength occurs for 30.0°, so at 40.0° the amplitude would be less, but the frequency would remain the same.

3 **a**

$f = 2.00 \times 10^3$ Hz

$v = 340$ m s^{-1}

$$\lambda = \frac{v}{f} = \frac{(340)}{(2.00 \times 10^3)}$$

$\lambda = 1.70 \times 10^{-1}$ m

b $\lambda = 1.70 \times 10^{-1}$ m

c $v = 340$ m s^{-1}

4 **C**

5

$f = 880$ Hz

$v = 331 + (0.60 \times 20.0) = 3.43 \times 10^2$ m s^{-1}

$$\lambda = \frac{v}{f} = \frac{(3.43 \times 10^2)}{(880)}$$

$\lambda = 3.90 \times 10^{-1}$ m

6

$f = 880$ Hz

$v = 331 + (0.60 \times 30.0) = 3.49 \times 10^2$ m s^{-1}

$$\lambda = \frac{v}{f} = \frac{(3.49 \times 10^2)}{(880)}$$

$\lambda = 3.97 \times 10^{-1}$ m

7

$i = 50.0°$

$v_{cool} = 3.43 \times 10^2$ m s^{-1}

$v_{warm} = 3.49 \times 10^2$ m s^{-1}

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

$$\sin r = \frac{v_2 \sin i}{v_1} = \frac{(3.49 \times 10^2)(\sin 50.0°)}{(3.43 \times 10^2)}$$

$\sin r = 0.7794$

$r = 51.2°$

8

$r = 90.0°$

$v_{cool} = 3.43 \times 10^2$ m s^{-1}

$v_{warm} = 3.49 \times 10^2$ m s^{-1}

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

$$\sin i = \frac{v_1 \sin r}{v_2} = \frac{(3.43 \times 10^2)(\sin 90.0°)}{(3.49 \times 10^2)}$$

$\sin i = 0.98289$

$i = 79.4°$

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9 **a**

$$f = 1000 \text{ Hz} \qquad \lambda = \frac{v}{f} = \frac{(3.40 \times 10^{2})}{(1000)}$$

$$v = 3.40 \times 10^{2} \text{ m s}^{-1} \qquad \lambda = 3.40 \times 10^{-1} \text{ m}$$

b Since the aperture is approximately the same as the wavelength appreciable diffraction will occur, resulting in significant sound energy will arrive at positions P and R

10 **a**

$$f = 4.0 \times 10^{3} \text{ Hz} \qquad \lambda = \frac{v}{f} = \frac{(3.40 \times 10^{2})}{(4.0 \times 10^{3})}$$

$$v = 3.40 \times 10^{2} \text{ m s}^{-1} \qquad \lambda = 8.50 \times 10^{-2} \text{ m}$$

b Since the aperture is greater than the wavelength less diffraction will occur, resulting in less sound energy arriving at positions P and R

c Since less diffraction occurs, more sound energy arrives at point Q

5.3 Wave interactions

1 **a** True

b False

c True

d False

2 When the glass is exposed to sound of the same frequency as its natural frequency of vibration, resonance will occur. The amplitude of the vibrations then will increase if sufficient energy is supplied, the amplification from resonance will cause the glass to shatter.

3 The sound box of a guitar is tuned to resonate in the range of frequencies being produced by the guitar strings. Resonance within the sounding box amplifies the sound.

4 As a result of the superposition of two waves of equal amplitude and frequency travelling in opposite directions in the same medium.

5 **a** C

b B

c C

6 **a** At the centre.

b One quarter of the way along the string.

c One sixth of the way along the string.

7 **a**

$$n = 1 \qquad f_n = \frac{nv}{2L}$$

$$L = 5.00 \times 10^{-1} \text{ m} \qquad f_1 = \frac{1(300)}{2(5.00 \times 10^{-1})}$$

$$v = 300 \text{ m s}^{-1} \qquad f_1 = 3.00 \times 10^{2} \text{ Hz}$$

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b

$n = 2$ $\quad f_n = \dfrac{nv}{2L}$

$L = 5.00 \times 10^{-1}$ m $\quad f_2 = \dfrac{2(300)}{2(5.00 \times 10^{-1})}$

$v = 300$ m s^{-1} $\quad f_2 = 6.00 \times 10^2$ Hz

c

$f_1 = 3.00 \times 10^2$ Hz $\quad f_n = n \times f_1$

$f_3 = 3 \times (3.00 \times 10^2)$

$f_3 = 9.00 \times 10^2$ Hz

8 Resonance in air columns of a particular length is due to an incoming sound wave with the exact frequency required to match a resonant frequency of the pipe. This results in reflection of waves arriving at the ends of the column. The reflected waves are either phase shifted by 180° (open end) or not phase shifted (closed end). These reflected waves are superimposed on the incoming waves to produce a standing wave pattern. This amplifies the sound and results in resonance.

9 **a**

$n = 1$ $\quad \lambda_1 = \dfrac{2L}{n} = \dfrac{2(45.0 \times 10^{-2})}{1}$

$L = 45.0 \times 10^{-2}$ m $\quad \lambda_1 = 9.00 \times 10^{-1}$ m

b

$n = 2$ $\quad \lambda_1 = \dfrac{2L}{n} = \dfrac{2(45.0 \times 10^{-2})}{2}$

$L = 45.0 \times 10^{-2}$ m $\quad \lambda_1 = 4.50 \times 10^{-1}$ m

c

$n = 3$ $\quad f_n = \dfrac{nv}{2L}$

$L = 4.50 \times 10^{-1}$ m $\quad f_3 = \dfrac{3(330)}{2(4.50 \times 10^{-1})}$

$v = 330$ m s^{-1} $\quad f_3 = 1.10 \times 10^3$ Hz

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10 **a**

$n = 1$ $\quad f_n = \frac{nv}{4L}$

$L = 7.50 \times 10^{-1}$ m $\quad f_1 = \frac{1(330)}{4(7.50 \times 10^{-1})}$

$v = 330$ m s^{-1} $\quad f_1 = 1.10 \times 10^2$ Hz

b

$f_1 = 1.10 \times 10^2$ Hz $\quad f_n = n \times f_1$

$f_3 = 3 \times (1.10 \times 10^2)$

$f_3 = 3.30 \times 10^2$ Hz

c

$f_1 = 1.10 \times 10^2$ Hz $\quad f_n = n \times f_1$

$f_5 = 5 \times (1.10 \times 10^2)$

$f_5 = 5.50 \times 10^2$ Hz

$f_n = n \times f_1$

$f_7 = 7 \times (1.10 \times 10^2)$

$f_7 = 7.70 \times 10^2$ Hz

5.4 Electromagnetic radiation

1 **a** Radio waves – transmitting music and information over large distances
Infrared – remote control devices
Visible light – seeing
Ultraviolet – sterilising surfaces
X-ray – imaging broken bones

b Speed in a vacuum – 3.00×10^8 m s^{-1}.
Electric and magnetic field components.

2 **a**

$f = 5.60 \times 10^{14}$ Hz $\quad \lambda = \frac{c}{f} = \frac{(3.00 \times 10^8)}{(5.60 \times 10^{14})}$

$c = 3.00 \times 10^8$ m s^{-1} $\quad \lambda = 5.36 \times 10^{-7}$ m

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b

$f = 5.60 \times 10^{14}$ Hz $\qquad E = hf = (6.63 \times 10^{-34})(5.60 \times 10^{14})$

$h = 6.63 \times 10^{-34}$ J s $\qquad E = 3.71 \times 10^{-19}$ J

$$E = \frac{(3.71 \times 10^{-19})}{(1.60 \times 10^{-19})} = 2.32 \text{ eV}$$

3 A–E

4 **a** **i**

$V_0 = -1.95$ V $\qquad E_{k\,max} = 1.95$ eV

ii

$e = -1.60 \times 10^{-19}$ C $\qquad E_{k\,max} = eV_0$

$V_0 = -1.95$ V $\qquad E_{k\,max} = (-1.60 \times 10^{-19})(-1.95)$

$E_{k\,max} = 3.12 \times 10^{-19}$ J

b

$e = -1.60 \times 10^{-19}$ C $\qquad E_{k\,(max)} = \frac{1}{2} m v_{max}{}^2$

$E_{k\,(max)} = 3.12 \times 10^{-19}$ J $\qquad v_{max} = \sqrt{\frac{2E_{k\,(max)}}{m}} = \sqrt{\frac{2(3.12 \times 10^{-19})}{(9.11 \times 10^{-31})}}$

$m = 9.11 \times 10^{-31}$ kg $\qquad v_{max} = 8.28 \times 10^{5}$ m s^{-1}

5 C

6 **a** False

b True

c False

d True

7 E

8 B, E

9 **a**

$c = 3.00 \times 10^{8}$ m s^{-1} $\qquad f_0 = \frac{c}{\lambda} = \frac{(3.00 \times 10^{8})}{(652 \times 10^{-9})}$

$\lambda = 652 \times 10^{-9}$ m $\qquad f_0 = 4.60 \times 10^{14}$ Hz

b

$h = 4.14 \times 10^{-15}$ eV s $\qquad W = hf_0 = (4.14 \times 10^{-15})(4.60 \times 10^{14})$

$f_0 = 4.60 \times 10^{14}$ Hz $\qquad W = 1.90$ eV

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c

$h = 4.14 \times 10^{-15}$ eV s $\qquad E_{ph} = \dfrac{hc}{\lambda} = \dfrac{(4.14 \times 10^{-15})(3.00 \times 10^{8})}{(620 \times 10^{-9})}$

$\lambda_{orange} = 620 \times 10^{-9}$ m $\qquad E_{ph} = 2.00$ eV

d

$E_{ph} = 2.00$ eV $\qquad E_{k\,(max)} = E_{ph} - W = (2.00) - (1.90)$

$W = 1.90$ eV $\qquad E_{k\,(max)} = 0.0851$ eV

Note: be sure to use exact numbers to calculate the difference, not the rounded numbers.

e

$E_{k\,(max)} = 0.0851$ eV $\qquad E_{k\,(max)} = (0.0851)(1.60 \times 10^{-19}) = 1.36 \times 10^{-20}$ J

$m = 9.11 \times 10^{-31}$ kg $\qquad E_{k\,(max)} = \frac{1}{2} m v_{max}{}^{2}$

$$v_{max} = \sqrt{\frac{2E_{k\,(max)}}{m}} = \sqrt{\frac{2(1.36 \times 10^{-20})}{(9.11 \times 10^{-31})}}$$

$$v_{max} = 1.73 \times 10^{5} \text{ m s}^{-1}$$

$$\rho_{max} = m v_{max} = (9.11 \times 10^{-31})(1.73 \times 10^{5})$$

$$\rho_{max} = 1.58 \times 10^{-25} \text{ kg m s}^{-1}$$

10 a

$E_{k\,(max)} = 1.36 \times 10^{-20}$ J $\qquad E_{k\,(max)} = eV_0$

$e = -1.60 \times 10^{-19}$ C $\qquad V_0 = \dfrac{(1.36 \times 10^{-20})}{(-1.60 \times 10^{-19})}$

$$V_0 = -8.51 \times 10^{-2} \text{ V}$$

b The photoelectrons do not have sufficient kinetic energy to reach the anode.

c

$h = 6.63 \times 10^{-34}$ J s $\qquad E_{k\,(max)} = hf - W$

$f = 5.20 \times 10^{14}$ Hz $\qquad eV_0 = hf - W$

$W = 1.90$ eV $\qquad V_0 = \dfrac{hf - W}{e} = \dfrac{(6.63 \times 10^{-34})(5.20 \times 10^{14}) - (3.07 \times 10^{-19})}{(-1.60 \times 10^{-19})}$

$W = 3.07 \times 10^{-19}$ J $\qquad V_0 = -0.236$ V

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

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5.5 Electromagnetic radiation and matter

1 **a**

$f_{3-1} = 6.00 \times 10^{14}$ Hz $\quad E_{3-1} = hf = (6.63 \times 10^{-34})(6.00 \times 10^{14}) = 3.98 \times 10^{-19}$ J

$f_{2-1} = 4.00 \times 10^{14}$ Hz $\quad E_{2-1} = hf = (6.63 \times 10^{-34})(4.00 \times 10^{14}) = 2.65 \times 10^{-19}$ J

$h = 6.63 \times 10^{-34}$ J s $\quad E_{3-2} = E_{3-1} - E_{2-1} = (3.98 \times 10^{-19}) - (2.65 \times 10^{-19}) = 1.33 \times 10^{-19}$ J

$c = 3.00 \times 10^{8}$ m s^{-1}

$$\lambda = \frac{hc}{E_{3-2}} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(1.33 \times 10^{-19})}$$

$$\lambda = 1.50 \times 10^{-6} \text{ m}$$

b D

2 **a**

$E_2 = -3.39$ eV $\quad \Delta E = (E_2 - E_1) \times (1.60 \times 10^{-19})$

$E_1 = -13.6$ eV $\quad \Delta E = \left[(-3.39) - (-13.6)\right] \times (1.60 \times 10^{-19})$

$h = 6.63 \times 10^{-34}$ J s $\quad \Delta E = 1.63 \times 10^{-18}$ J

$c = 3.00 \times 10^{8}$ m s^{-1}

$$E_{\text{photon}} = hf = \Delta E$$

$$f = \frac{\Delta E}{h} = \frac{(1.63 \times 10^{-18})}{(6.63 \times 10^{-34})}$$

$$f = 2.46 \times 10^{15} \text{ Hz}$$

b

$E_3 = -1.51$ eV $\quad \Delta E = (E_3 - E_1) \times (1.60 \times 10^{-19})$

$E_1 = -13.6$ eV $\quad \Delta E = \left[(-1.51) - (-13.6)\right] \times (1.60 \times 10^{-19})$

$h = 6.63 \times 10^{-34}$ J s $\quad \Delta E = 1.93 \times 10^{-18}$ J

$c = 3.00 \times 10^{8}$ m s^{-1}

$$E_{\text{photon}} = \frac{hc}{\lambda} = \Delta E$$

$$\lambda = \frac{hc}{\Delta E} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(1.93 \times 10^{-18})}$$

$$\lambda = 1.03 \times 10^{-7} \text{ m}$$

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c

$E_\infty = 0\text{ eV}$ $\qquad$ $\Delta E = (E_\infty - E_1)$

$E_1 = -13.6\text{ eV}$ $\qquad$ $\Delta E = [(0) - (-13.6)]$

$\Delta E = 13.6\text{ eV}$

3 **a**

$E_4 = -0.88\text{ eV}$ $\qquad$ $\Delta E = (E_4 - E_1)$

$E_3 = -1.51\text{ eV}$ $\qquad$ $\Delta E = [(-0.88) - (-13.6)]$

$E_1 = -13.6\text{ eV}$ $\qquad$ $\Delta E = 12.7\text{ eV}$ not enough energy

$\Delta E = (E_3 - E_1)$

$\Delta E = [(-1.51) - (-13.6)]$

$\Delta E = 12.1\text{ eV}$ sufficient energy for $n = 1$ to 3

b No, as photons cannot give off a portion of their energy to the electron, it must transfer all of its energy.

c It would eject the electron causing the atom to become ionised. The ejected electron would have (14.0 – 13.6) = 0.40 eV of kinetic energy.

4 **a**

$E_4 = -0.88\text{ eV}$ $\qquad$ $\Delta E = (E_4 - E_1)$

$E_1 = -13.6\text{ eV}$ $\qquad$ $\Delta E = [(-0.88) - (-13.6)]$

$\Delta E = 12.7\text{ eV}$ to $n = 4$ level

b

$E_4 = -0.88\text{ eV}$ $\qquad$ $E_{ph} = (E_4 - E_1) = 12.72\text{ eV}$

$E_3 = -1.51\text{ eV}$ $\qquad$ $E_{ph} = (E_4 - E_2) = 2.51\text{ eV}$

$E_2 = -3.39\text{ eV}$ $\qquad$ $E_{ph} = (E_4 - E_3) = 0.63\text{ eV}$

$E_1 = -13.6\text{ eV}$ $\qquad$ $E_{ph} = (E_3 - E_1) = 12.09\text{ eV}$

$E_{ph} = (E_3 - E_2) = 1.88\text{ eV}$

$E_{ph} = (E_2 - E_1) = 10.21\text{ eV}$

5 Any excess energy above the ionisation energy is retained by the ejected electron in the form of kinetic energy, which may be any value, as kinetic energy is not quantised.

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6

$E_3 = 3.19$ eV $\quad \Delta E = (E_3 - E_1) \times (1.60 \times 10^{-19})$

$E_1 = 0$ eV $\quad \Delta E = \left[(3.19) - (0)\right] \times (1.60 \times 10^{-19})$

$h = 6.63 \times 10^{-34}$ J s $\quad \Delta E = 5.10 \times 10^{-19}$ J

$c = 3.00 \times 10^{8}$ m s^{-1}

$$E_{\text{photon}} = \frac{hc}{\lambda} = \Delta E$$

$$\lambda = \frac{hc}{\Delta E} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(5.10 \times 10^{-19})}$$

$$\lambda = 3.90 \times 10^{-7} \text{ m}$$

7

$E_{5\text{-}1}$, $E_{5\text{-}2}$, $E_{5\text{-}3}$, $E_{5\text{-}4}$

$E_{4\text{-}1}$, $E_{4\text{-}2}$, $E_{4\text{-}3}$

$E_{3\text{-}1}$, $E_{3\text{-}2}$

$E_{2\text{-}1}$

$= 10$ different photon energies

8 They will be able to emit more frequencies of light than they can absorb, if the sodium atoms are absorbing light in a low-energy state. Emitting light will result from transitions from higher energy levels to any lower energy level including the ground state; however, absorption can only occur from the ground state to a higher level. This is assuming that the valence electrons in the sodium atom are in the ground state to start with and are not in excited states due to heating.

9

Assume $E_7 = -0.1$ eV $\quad \Delta E = (E_7 - E_1) \times (1.60 \times 10^{-19})$

$E_2 = -3.4$ eV $\quad \Delta E = \left[(-0.1) - (-3.4)\right] \times (1.60 \times 10^{-19})$

$h = 6.63 \times 10^{-34}$ J s $\quad \Delta E = 5.28 \times 10^{-19}$ J

$c = 3.00 \times 10^{8}$ m s^{-1}

$$E_{\text{photon}} = \frac{hc}{\lambda} = \Delta E$$

$$\lambda = \frac{hc}{\Delta E} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(5.28 \times 10^{-19})}$$

$$\lambda = 3.77 \times 10^{-7} \text{ m}$$

$\lambda = 377$ nm which is outside the visible range (UV)

10 De Broglie proposed a model of the atom in which the electrons were viewed as matter waves with resonant wavelengths that determined the circumference of the energy levels. This is similar to the resonant wavelengths that fit the length of a violin string.

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5.6 X-rays

1 **a**

$\Delta V = 70.0 \times 10^{3}\ \text{V}$

$E_{\text{k (max)}} = 70.0 \times 10^{3}\ \text{eV}$

$E_{\text{k (max)}} = (70.0 \times 10^{3}) \times (1.60 \times 10^{-19})$

$E_{\text{k (max)}} = 1.12 \times 10^{-14}\ \text{J}$

b

$m_{e} = 9.11 \times 10^{-31}\ \text{kg}$

$E_{\text{k (max)}} = 1.12 \times 10^{-14}\ \text{J}$

$E_{\text{k (max)}} = \frac{1}{2} m v_{\text{max}}^{2}$

$v_{\text{max}} = \sqrt{\dfrac{2E_{\text{k (max)}}}{m}} = \sqrt{\dfrac{2(1.12 \times 10^{-14})}{(9.11 \times 10^{-31})}}$

$v_{\text{max}} = 1.57 \times 10^{8}\ \text{m s}^{-1}$

c

$E_{\text{ph (max)}} = E_{\text{k (max)}}$

$E_{\text{ph (max)}} = 70.0 \times 10^{3}\ \text{eV} \quad \text{or} \quad 1.12 \times 10^{-14}\ \text{J}$

2 **a**

$E_{\text{ph (max)}} = E_{\text{k (max)}}$

$E_{\text{ph (max)}} = 150 \times 10^{3}\ \text{eV} \quad \text{or} \quad 2.40 \times 10^{-14}\ \text{J}$

b

$h = 6.63 \times 10^{-34}\ \text{J s}$

$E_{\text{ph (max)}} = 2.40 \times 10^{-14}\ \text{J}$

$E_{\text{ph (max)}} = h f_{\text{max}}$

$f_{\text{max}} = \dfrac{E_{\text{ph (max)}}}{h} = \dfrac{(2.40 \times 10^{-14})}{(6.63 \times 10^{-34})}$

$f_{\text{max}} = 3.62 \times 10^{19}\ \text{Hz}$

c

$f_{\text{max}} = 3.62 \times 10^{19}\ \text{Hz}$

$c = 3.00 \times 10^{8}\ \text{m s}^{-1}$

$\lambda_{\text{min}} = \dfrac{c}{f_{\text{max}}} = \dfrac{(3.00 \times 10^{8})}{(3.62 \times 10^{19})}$

$\lambda_{\text{min}} = 8.29 \times 10^{-12}\ \text{m}$

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3 **a**

$h = 6.63 \times 10^{-34}$ J s

$E_{ph\,(max)} = 5.60 \times 10^{-15}$ J

$c = 3.00 \times 10^{8}$ m s^{-1}

$$E_{ph\,(max)} = hf_{max}$$

$$f_{max} = \frac{E_{ph\,(max)}}{h} = \frac{(5.60 \times 10^{-15})}{(6.63 \times 10^{-34})}$$

$$f_{max} = 8.45 \times 10^{18} \text{ Hz}$$

$$\lambda_{min} = \frac{c}{f_{max}} = \frac{(3.00 \times 10^{8})}{(8.45 \times 10^{18})}$$

$$\lambda_{min} = 3.55 \times 10^{-11} \text{ m}$$

b This is the wavelength of the most energetic photons that can be produced by the most energetic bombarding electrons. A smaller wavelength would have to come from a more energetic bombarding electron, which cannot be produced by this accelerating potential difference.

4 $f_{max} = 8.45 \times 10^{18}$ Hz

5 The two peaks in the spectrum are the line spectrum caused by the bombarding electrons ejecting inner orbital electrons from the molybdenum atoms. When these inner electrons are ejected they are replaced by outer electrons in transitions that produce high-energy x-ray photons.

6 **a**

The peak is around 3.1×10^{-11} m

$c = 3.00 \times 10^{8}$ m s^{-1}

$h = 6.63 \times 10^{-34}$ J s

$$E_{peak} = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(3.1 \times 10^{-11})}$$

$$E_{peak} = 6.42 \times 10^{-15} \text{ J}$$

$$E_{peak} = 4.01 \times 10^{4} \text{ eV}$$

b The peak in the spectrum is due the bombarding electrons ejecting inner orbital electrons from the barium atoms. When these inner electrons are ejected they are replaced by outer electrons in transitions that produce characteristic high energy x-ray photons of a particular wavelength due to the specific energy transition that occurs in barium, but not in any other atom.

c This is the wavelength of the most energetic photons that can be produced by the most energetic bombarding electrons. A smaller wavelength would have to come from a more energetic bombarding electron.

d

The smallest wavelength is around 2.5×10^{-11} m.

$h = 6.63 \times 10^{-34}$ J s

$c = 3.00 \times 10^{8}$ m s^{-1}

$$E_{max} = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(2.5 \times 10^{-11})}$$

$$E_{max} = 7.96 \times 10^{-15} \text{ J}$$

$$E_{max} = 4.97 \times 10^{4} \text{ eV}$$

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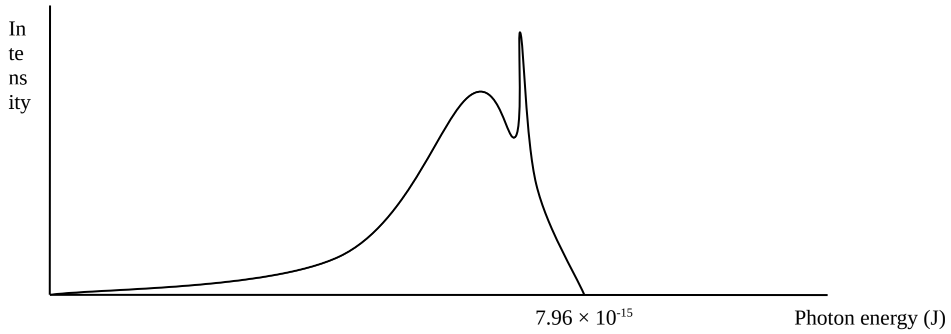
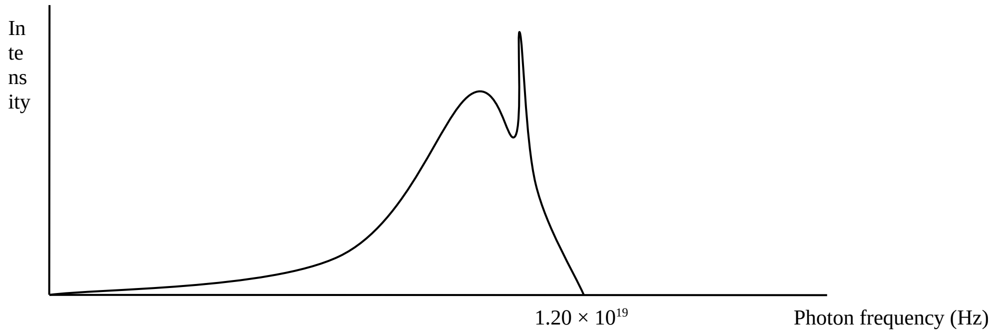
7 **a**



b



8 Tungsten is used because it has a very high melting point temperature. A great deal of heat is produced in the anode of an X-ray machine. Copper is used because it is a very good conductor of electricity and has a very high conductivity of heat. It conducts excess electrons away from the surface and it conducts excess heat away from the target site.

9 B

10 X-rays from an X-ray tube are produced in a single burst, while those generated by a synchrotron can be generated continuously for hours. X-rays from an X-ray tube can pass through lighter atoms, while those produced in a synchrotron are more likely to interact with these atoms. Synchrotron X-rays are 100 million times brighter than X-rays from traditional sources.

Chapter 5 Review

1 4.0 m

2 D

3 A

4 C

5 C, D

6

Assume $v = 346 \text{ m s}^{-1}$ $\qquad f = \dfrac{nv}{4L} = \dfrac{(1)(346)}{4(0.85)}$

$L = 0.85 \text{ m}$ $\qquad f = 1.02 \times 10^{2} \text{ Hz}$

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7

Assume $v = 346 \text{ m s}^{-1}$ $\qquad f = \frac{nv}{4L} = \frac{(3)(346)}{4(0.85)}$

$L = 0.85 \text{ m}$ $\qquad f = 3.05 \times 10^{2} \text{ Hz}$

8 a i

$\lambda = 580 \times 10^{-9} \text{ m}$ $\qquad E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(580 \times 10^{-9})}$

$h = 6.63 \times 10^{-34} \text{ J s}$ $\qquad E = 3.43 \times 10^{-19} \text{ J}$

$c = 3.00 \times 10^{8} \text{ m s}^{-1}$

ii

$$E = \frac{(3.43 \times 10^{-19})}{(1.60 \times 10^{-19})} = 2.14 \text{ eV}$$

b

$\lambda = 580 \times 10^{-9} \text{ m}$ $\qquad \rho = \frac{h}{\lambda} = \frac{(6.63 \times 10^{-34})}{(580 \times 10^{-9})}$

$h = 6.63 \times 10^{-34} \text{ J s}$ $\qquad \rho = 1.14 \times 10^{-27} \text{ kg m s}^{-1}$

c

$E = 3.43 \times 10^{-19} \text{ J}$ $\qquad N_{ph} = \frac{E_{total}}{E_{ph}} = \frac{(500)}{(3.43 \times 10^{-19})}$

$P = 500 \text{ W}$ $\qquad N_{ph} = 1.46 \times 10^{21} \text{ photons}$

9 a

$\lambda = 432 \times 10^{-9} \text{ m}$ $\qquad E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(432 \times 10^{-9})}$

$h = 6.63 \times 10^{-34} \text{ J s}$ $\qquad E = 4.60 \times 10^{-19} \text{ J}$

$c = 3.00 \times 10^{8} \text{ m s}^{-1}$

b

$\lambda = 432 \times 10^{-9} \text{ m}$ $\qquad \rho = \frac{h}{\lambda} = \frac{(6.63 \times 10^{-34})}{(432 \times 10^{-9})}$

$h = 6.63 \times 10^{-34} \text{ J s}$ $\qquad \rho = 1.53 \times 10^{-27} \text{ kg m s}^{-1}$

c

$E = 4.60 \times 10^{-19} \text{ J}$ $\qquad N_{ph} = \frac{E_{total}}{E_{ph}} = \frac{(230)}{(4.60 \times 10^{-19})}$

$P = 230 \text{ W}$ $\qquad N_{ph} = 5.00 \times 10^{20} \text{ photons}$

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d

$$E_{ph} = 4.60 \times 10^{-19} \text{ J} \qquad P_{ele} = \frac{N_{ph} \times E_{ph} \times 0.001}{100} = \frac{(5.00 \times 10^{20})(4.60 \times 10^{-19})(0.001)}{100}$$

$$N_{ph} = 5.00 \times 10^{20} \qquad P_{ele} = 2.30 \times 10^{-3} \text{ W}$$

$$\%\text{eff} = 0.001\%$$

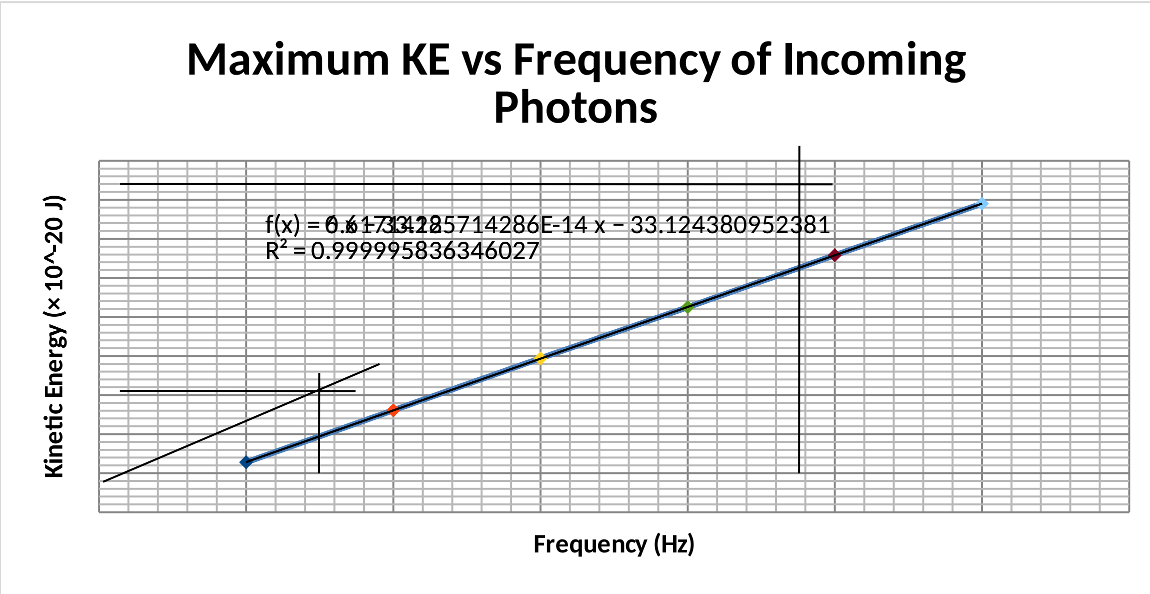
10 A

11 **a** The wave model predicts that light of any frequency will emit photoelectrons from a metallic surface if given sufficient time.

b The wave model predicts that the energy delivered to the electrons by a light beam of constant intensity will be proportional to time. This suggests that a low intensity light beam should take longer to eject photoelectrons from a metallic surface.

c According to the wave model of light, a higher intensity beam will deliver more energy to the electrons and will therefore produce photoelectrons with higher kinetic energy than a lower intensity beam.

12



a

$$\text{slope} = \frac{\Delta y}{\Delta x} = \frac{(7.0 \times 10^{-20} - 2.0 \times 10^{-20})}{(6.06 \times 10^{14} - 5.31 \times 10^{14})} = 6.7 \times 10^{-34} \text{ J s}$$

b The slope of the line is very close to Planck's constant.

c When the kinetic energy of the ejected electrons is zero the frequency of the incoming photons is 5.0×10^{14} Hz, this is the threshold frequency for rubidium.

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d

$\lambda = 680 \times 10^{-9}$ m $\qquad f = \dfrac{c}{\lambda} = \dfrac{(3.00 \times 10^{8})}{(680 \times 10^{-9})}$

$c = 3.00 \times 10^{8}$ m s^{-1} $\qquad f = 4.41 \times 10^{14}$ Hz

This is below the threshold frequency so it will not eject photoelectrons from rubidium.

13 a

$h = 6.63 \times 10^{-34}$ J s $\qquad W = hf_0 = (6.63 \times 10^{-34})(5.0 \times 10^{14})$

$f_0 = 5.0 \times 10^{14}$ Hz $\qquad W = \dfrac{(3.32 \times 10^{-19})}{(1.60 \times 10^{-19})}$

$W = 2.07$ eV or 3.32×10^{-19} J

b

$h = 6.63 \times 10^{-34}$ J s $\qquad E_{ph} = hf = (6.63 \times 10^{-34})(5.60 \times 10^{14})$

$f = 5.60 \times 10^{14}$ Hz $\qquad E_{ph} = 3.71 \times 10^{-19}$ J

$E_k = E_{ph} - W = (3.71 \times 10^{-19}) - (3.32 \times 10^{-19})$

$E_k = 3.98 \times 10^{-20}$ J

c

$E_{k\,(max)} = 3.98 \times 10^{-20}$ J $\qquad E_{k\,(max)} = \frac{1}{2} m v_{max}{}^{2}$

$m = 9.11 \times 10^{-31}$ kg $\qquad v_{max} = \sqrt{\dfrac{2E_{k\,(max)}}{m}} = \sqrt{\dfrac{2(3.98 \times 10^{-20})}{(9.11 \times 10^{-31})}}$

$v_{max} = 2.96 \times 10^{5}$ m s^{-1}

$\rho_{max} = mv_{max} = (9.11 \times 10^{-31})(2.96 \times 10^{5})$

$\rho_{max} = 2.69 \times 10^{-25}$ kg m s^{-1}

d

$E_{k\,(max)} = 3.98 \times 10^{-20}$ J $\qquad E_{k\,(max)} = eV_0$

$e = -1.60 \times 10^{-19}$ C $\qquad V_0 = \dfrac{(3.98 \times 10^{-20})}{(-1.60 \times 10^{-19})}$

$V_0 = -2.49 \times 10^{-1}$ V

14 C

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15

$$n_1 = -10.4 \text{ eV} \qquad f_{3-1} = \frac{E_{3-1}(1.60\times10^{-19})}{h} = \frac{[(-3.7)-(-10.4)](1.60\times10^{-19})}{(6.63\times10^{-34})}$$

$$n_2 = -5.5 \text{ eV} \qquad f_{3-1} = 1.62\times10^{15} \text{ Hz}$$

$$n_3 = -3.7 \text{ eV} \qquad f_{3-2} = \frac{E_{3-2}(1.60\times10^{-19})}{h} = \frac{[(-3.7)-(-5.5)](1.60\times10^{-19})}{(6.63\times10^{-34})}$$

$$f_{3-2} = 4.34\times10^{14} \text{ Hz}$$

$$f_{2-1} = \frac{E_{2-1}(1.60\times10^{-19})}{h} = \frac{[(-5.5)-(-10.4)](1.60\times10^{-19})}{(6.63\times10^{-34})}$$

$$f_{2-1} = 1.18\times10^{15} \text{ Hz}$$

16 There is no shortest wavelength, as this corresponds to the highest energy photon. Any photon over the ionisation level will result in ionisation and any remaining energy will be kept by the electron in the form of kinetic energy.

17 When the excited electron returns to the ground state it emits a photon of the same energy (10.2 eV) as it absorbed, however, the direction in which the photon is emitted is random. Some photons may travel in the same direction as the incoming photons, but when resolved in to the absorption spectrum, these few photons would be far less intense than the surrounding photons. The effect would be a black line at the frequency of light corresponding to the 10.2 eV photon.

18 **a**

$$c = 3.00\times10^{8} \text{ m s}^{-1} \qquad E_{ph} = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(3.00\times10^{-6})}$$

$$h = 6.63\times10^{-34} \text{ J s} \qquad E_{ph} = 6.63\times10^{-20} \text{ J}$$

$$\lambda = 3.00\times10^{-6} \text{ m} \qquad N_{ph} = \frac{(60.0)}{(6.63\times10^{-20})} = 9.05\times10^{20} \text{ photons}$$

$$P = 60.0 \text{ W}$$

b Infrared

19 **a**

$$f = 5.20\times10^{14} \text{ Hz} \qquad E_{ph} = hf = (6.63\times10^{-34})(5.20\times10^{14})$$

$$h = 6.63\times10^{-34} \text{ J s} \qquad E_{ph} = 3.45\times10^{-19} \text{ J}$$

$$P = 1000 \text{ W} \qquad N_{ph} = \frac{(1000.0)}{(3.45\times10^{-19})} = 2.90\times10^{21} \text{ photons}$$

b $P = 1000$ W

20 B

21 C

22 A

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23

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

$h = 6.63 \times 10^{-34}$ J s

$\lambda = 200 \times 10^{-9}$ m

$c = 3.00 \times 10^{8}$ m s^{-1}

$V_0 = -1.21$ V

$$W = E_{ph} - E_{k\,max}$$

$$W = \frac{hc}{\lambda} - eV_0 = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(200 \times 10^{-9})} - (-1.60 \times 10^{-19})(-1.21)$$

$$W = 8.019 \times 10^{-19} \text{ J} \quad \text{or} \quad 5.01 \text{ eV}$$

24 Only certain frequencies of light will cause photoelectrons to be emitted from a surface.

There is no time delay between the absorption of photons of different intensities and the emission of a photoelectron.

The maximum kinetic energy of the ejected photoelectrons is the same for different light intensities of the same frequency.

25 **a**

$E_4 = -1.6$ eV

$E_1 = -10.4$ eV

$h = 6.63 \times 10^{-34}$ J s

$c = 3.00 \times 10^{8}$ m s^{-1}

$$\Delta E = (E_4 - E_1) \times (1.60 \times 10^{-19})$$

$$\Delta E = \left[(-1.6) - (-10.4)\right] \times (1.60 \times 10^{-19})$$

$$\Delta E = 1.41 \times 10^{-18} \text{ J}$$

$$f = \frac{\Delta E}{h} = \frac{(1.41 \times 10^{-18})}{(6.63 \times 10^{-34})} = 2.12 \times 10^{15} \text{ Hz}$$

$$\lambda = \frac{c}{f} = \frac{(3.00 \times 10^{8})}{(2.12 \times 10^{15})} = 1.41 \times 10^{-7} \text{ m}$$

b

$E_2 = -5.5$ eV

$E_1 = -10.4$ eV

$h = 6.63 \times 10^{-34}$ J s

$c = 3.00 \times 10^{8}$ m s^{-1}

$$\Delta E = (E_2 - E_1) \times (1.60 \times 10^{-19})$$

$$\Delta E = \left[(-5.5) - (-10.4)\right] \times (1.60 \times 10^{-19})$$

$$\Delta E = 7.84 \times 10^{-19} \text{ J}$$

$$f = \frac{\Delta E}{h} = \frac{(7.84 \times 10^{-19})}{(6.63 \times 10^{-34})} = 1.18 \times 10^{15} \text{ Hz}$$

$$\lambda = \frac{c}{f} = \frac{(3.00 \times 10^{8})}{(1.18 \times 10^{15})} = 2.54 \times 10^{-7} \text{ m}$$

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c

$E_4 = -5.5$ eV $\qquad \Delta E = (E_4 - E_3) \times (1.60 \times 10^{-19})$

$E_3 = -10.4$ eV $\qquad \Delta E = [(-1.6) - (-3.7)] \times (1.60 \times 10^{-19})$

$h = 6.63 \times 10^{-34}$ J s $\qquad \Delta E = 3.36 \times 10^{-19}$ J

$c = 3.00 \times 10^8$ m s^{-1}

$$f = \frac{\Delta E}{h} = \frac{(3.36 \times 10^{-19})}{(6.63 \times 10^{-34})} = 5.07 \times 10^{14} \text{ Hz}$$

$$\lambda = \frac{c}{f} = \frac{(3.00 \times 10^8)}{(5.07 \times 10^{14})} = 5.92 \times 10^{-7} \text{ m}$$

26 a $\Delta V = 65.0$ V $\qquad E_k = 65.0$ eV or 1.04×10^{-17} J

b

$m_e = 9.11 \times 10^{-31}$ kg $\qquad E_{k\,(max)} = \frac{1}{2} m v_{max}{}^2$

$E_{k\,(max)} = 1.04 \times 10^{-17}$ J $\qquad v_{max} = \sqrt{\frac{2E_{k\,(max)}}{m}} = \sqrt{\frac{2(1.04 \times 10^{-17})}{(9.11 \times 10^{-31})}}$

$$v_{max} = 4.78 \times 10^6 \text{ m s}^{-1}$$

c

$m_e = 9.11 \times 10^{-31}$ kg $\qquad \lambda = \frac{h}{m v_{max}} = \frac{(6.63 \times 10^{-34})}{(9.11 \times 10^{-31})(4.78 \times 10^6)}$

$h = 6.63 \times 10^{-34}$ J s $\qquad \lambda = 1.52 \times 10^{-10}$ m

$v_{max} = 4.78 \times 10^6$ m s^{-1}

27 a

$E_4 = -1.60$ eV $\qquad \Delta E = (E_4 - E_1) \times (1.60 \times 10^{-19})$

$E_1 = -10.4$ eV $\qquad \Delta E = [(-1.60) - (-10.4)] \times (1.60 \times 10^{-19})$

$$\Delta E = 1.41 \times 10^{-18} \text{ J}$$

b

$E_{ph} = 1.41 \times 10^{-18}$ J $\qquad \lambda = \frac{hc}{E_{ph}} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{(1.41 \times 10^{-18})}$

$c = 3.00 \times 10^8$ m s^{-1} $\qquad \lambda = 1.41 \times 10^{-7}$ m

$h = 6.63 \times 10^{-34}$ J s

c $E_{min} = 10.4$ eV or 1.66×10^{-18} J

28 a

$E_{beam} = 7.00$ eV $\qquad E_e = (7.00) \times (1.60 \times 10^{-19})$

$$E_e = 1.12 \times 10^{-18} \text{ J}$$

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b

$$E_2 = -5.50 \text{ eV} \qquad \Delta E = (E_2 - E_1) \times (1.60 \times 10^{-19})$$
$$E_1 = -10.4 \text{ eV} \qquad \Delta E = \left[(-5.50) - (-10.4)\right] \times (1.60 \times 10^{-19})$$
$$\Delta E = 0.78 \times 10^{-18} \text{ J} \text{ can reach this level}$$

$$E_3 = -3.70 \text{ eV} \qquad \Delta E = (E_3 - E_1) \times (1.60 \times 10^{-19})$$
$$E_1 = -10.4 \text{ eV} \qquad \Delta E = \left[(-3.70) - (-10.4)\right] \times (1.60 \times 10^{-19})$$
$$\Delta E = 1.07 \times 10^{-18} \text{ J} \text{ can reach this level}$$

$$E_4 = -1.60 \text{ eV} \qquad \Delta E = (E_4 - E_1) \times (1.60 \times 10^{-19})$$
$$E_1 = -10.4 \text{ eV} \qquad \Delta E = \left[(-1.60) - (-10.4)\right] \times (1.60 \times 10^{-19})$$
$$\Delta E = 1.41 \times 10^{-18} \text{ J} \text{ this is too high}$$

Therefore the mercury atom could be excited to the $n = 3$ level.

c

$$E_2 = -5.50 \text{ eV} \qquad \Delta E = (E_2 - E_1) \times (1.60 \times 10^{-19})$$
$$E_1 = -10.4 \text{ eV} \qquad \Delta E = \left[(-5.50) - (-10.4)\right] \times (1.60 \times 10^{-19})$$
$$\Delta E = 0.78 \times 10^{-18} \text{ J} \quad \text{or} \quad 4.90 \text{ eV}$$

$$E_3 = -3.70 \text{ eV} \qquad \Delta E = (E_3 - E_1) \times (1.60 \times 10^{-19})$$
$$E_1 = -10.4 \text{ eV} \qquad \Delta E = \left[(-3.70) - (-10.4)\right] \times (1.60 \times 10^{-19})$$
$$\Delta E = 1.07 \times 10^{-18} \text{ J} \quad \text{or} \quad 6.70 \text{ eV}$$

$$E_3 = -3.70 \text{ eV} \qquad \Delta E = (E_3 - E_2) \times (1.60 \times 10^{-19})$$
$$E_2 = -5.50 \text{ eV} \qquad \Delta E = \left[(-3.70) - (-5.50)\right] \times (1.60 \times 10^{-19})$$
$$\Delta E = 2.88 \times 10^{-19} \text{ J} \quad \text{or} \quad 1.80 \text{ eV}$$

d

$$E_{ph} = 1.07 \times 10^{-18} \text{ J} \qquad \lambda = \frac{hc}{E_{ph}} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(1.07 \times 10^{-18})}$$
$$c = 3.00 \times 10^{8} \text{ m s}^{-1} \qquad \lambda = 1.86 \times 10^{-7} \text{ m}$$
$$h = 6.63 \times 10^{-34} \text{ J s}$$

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29

$E_e = 30.4$ eV

$$\lambda = \frac{hc}{E_{ph} + E_{1-\infty}} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(30.4)(1.60 \times 10^{-19}) + (10.4)(1.60 \times 10^{-19})}$$

$E_{1-\infty} = 10.4$ eV

$c = 3.00 \times 10^{8}$ m s^{-1} $\qquad \lambda = 3.05 \times 10^{-8}$ m

$h = 6.63 \times 10^{-34}$ J s

30 **a**

$E_{beam} = 4.00$ eV $\qquad E_e = (4.00) \times (1.60 \times 10^{-19})$

$E_e = 6.40 \times 10^{-19}$ J

This is less than the energy required to promote an electron to the $n = 2$ level so with no electrons being promoted no photons can be emitted.

b This is sufficient energy to ionise the mercury atoms. The liberated electrons are then free to conduct current along the tube.

c

$E_e = 6.20$ eV is sufficient to promote one of mercury's electron to $n = 2$.

$\therefore E_{ph} = 4.90$ eV

$E_{ph} = 7.84 \times 10^{-19}$ J

$$\lambda = \frac{hc}{E_{ph}} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(7.84 \times 10^{-19})}$$

$c = 3.00 \times 10^{8}$ m s^{-1} $\qquad \lambda = 2.54 \times 10^{-7}$ m

$h = 6.63 \times 10^{-34}$ J s

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Chapter 6 Matter, relativity and astronomy

6.1 Extending our model of matter

1 Strong nuclear 10^{38} : electromagnetic 10^{36} : weak nuclear 10^{32} : gravitational 1

2 **a** particle size $= \lambda = 5.00 \times 10^{[illegible]}$ m

b

$$c = 3.00 \times 10^{8} \text{ m s}^{-1} \qquad \lambda = \frac{c}{f} = \frac{(3.00 \times 10^{8})}{(3.00 \times 10^{19})}$$

$$f = 3.00 \times 10^{19} \text{ Hz} \qquad \lambda = 1.00 \times 10^{-11} \text{ m}$$

c

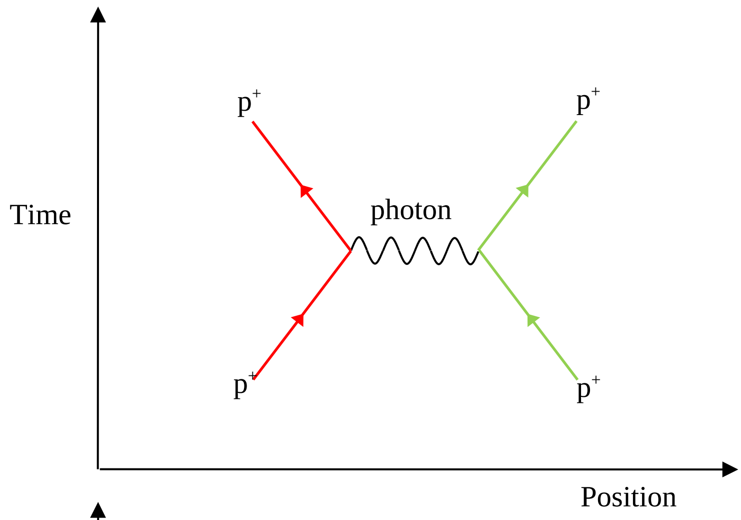
$$c = 3.00 \times 10^{8} \text{ m s}^{-1} \qquad \lambda = \frac{hc}{E_k}$$

$$f = 6.63 \times 10^{-34} \text{ J s} \qquad \lambda = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{\frac{1}{2}(1.6726 \times 10^{-27})(0.650 \times 3.00 \times 10^{8})^2}$$

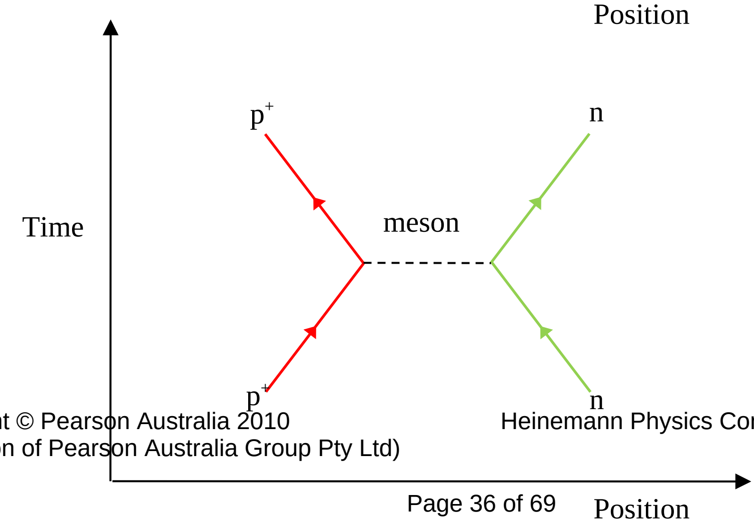
$$v = 0.650 \times c \text{ m s}^{-1} \qquad \lambda = 6.265 \times 10^{-15} \text{ m}$$

$$m_p = 1.6726 \times 10^{-27} \text{ kg}$$

3 **a** electrostatic repulsion between a proton and proton (not within a nucleus).



b



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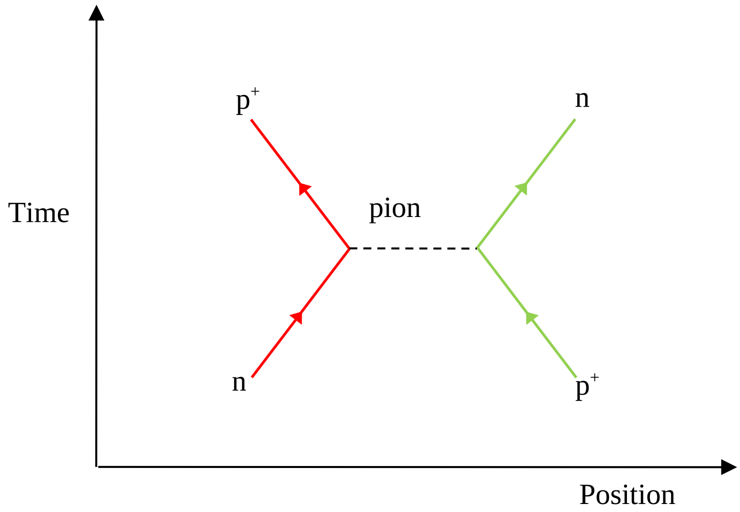
c



4 **a**

$m_{\bar{p}} = 1.6726 \times 10^{-27}$ kg $\qquad E = mc^2$

$m_{p^+} = 1.6726 \times 10^{-27}$ kg $\qquad E = (1.6726 \times 10^{-27} + 1.6726 \times 10^{-27})(3.00 \times 10^{8})^2$

$E = 3.0107 \times 10^{-10}$ J

b

$m_{\bar{n}} = 1.6749 \times 10^{-27}$ kg $\qquad E = mc^2$

$m_n = 1.6749 \times 10^{-27}$ kg $\qquad E = (1.6749 \times 10^{-27} + 1.6749 \times 10^{-27})(3.00 \times 10^{8})^2$

$E = 3.0148 \times 10^{-10}$ J

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5 **a**

$m_{e^+} = 9.11 \times 10^{-31}$ kg $\quad E_k = E_{ph} - E_{pair} = E_{ph} - mc^2$

$m_{e^-} = 9.11 \times 10^{-31}$ kg $\quad E_k = (1.20 \times 10^6)(1.60 \times 10^{-19}) - (2 \times 9.11 \times 10^{-31})(3.00 \times 10^8)^2$

$E_{ph} = 1.20 \times 10^6$ eV $\quad E_k = 2.80 \times 10^{-14}$ J

$E_k = 1.40 \times 10^{-14}$ J each particle

b

$m_{p^-} = 1.6726 \times 10^{-27}$ kg $\quad E_k = E_{ph} - E_{pair} = hf - mc^2$

$m_{p^+} = 1.6726 \times 10^{-27}$ kg $\quad E_k = (4.541 \times 10^{23})(6.63 \times 10^{-34}) - (2 \times 1.6726 \times 10^{-27})(3.00 \times 10^8)^2$

$f = 4.541 \times 10^{23}$ Hz $\quad E_k = 3.00 \times 10^{-16}$ J

$h = 6.63 \times 10^{-34}$ J s $\quad E_k = 1.50 \times 10^{-16}$ J each particle

c

$m_{\bar{n}} = 1.6749 \times 10^{-27}$ kg $\quad E_k = E_{ph} - E_{pair} = \dfrac{hc}{\lambda} - mc^2$

$m_n = 1.6749 \times 10^{-27}$ kg $\quad E_k = \dfrac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{(6.059 \times 10^{-16})} - (2 \times 1.6749 \times 10^{-27})(3.00 \times 10^8)^2$

$\lambda = 6.059 \times 10^{-16}$ m $\quad E_k = 2.68 \times 10^{-11}$ J

$h = 6.63 \times 10^{-34}$ J s $\quad E_k = 1.34 \times 10^{-11}$ J each particle

6 **a** down, down, up
b anti-up, anti-up, anti-down
c up, down, strange
d charm, anti-down

7 **a** proton
b rho-minus
c kaon-minus
d sigma-minus

6.2 Einstein's special theory of relativity

1 Galileo realised that a force changes motion, not caused it.

2 **a**

$r = 6.37 \times 10^6$ m $\quad v_{equ} = \dfrac{2\pi r}{T} = \dfrac{2\pi(6.37 \times 10^6)}{(24 \times 60 \times 60)} = 4.63 \times 10^2$ m s^{-1}

$v_{pole} = 0$ m s^{-1}

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b

$$r = 1.50 \times 10^{11} \text{ m} \qquad v_{\text{equ}} = \frac{2\pi r}{T} = \frac{2\pi(1.50 \times 10^{11})}{(365.25 \times 24 \times 60 \times 60)} = 2.99 \times 10^4 \pm 4.63 \times 10^2 \text{ m s}^{-1}$$

$$v_{\text{pole}} = 2.99 \times 10^4 \text{ m s}^{-1}$$

c The person at the equator has acceleration towards the centre of the Earth, both people also have an acceleration towards the Sun.

3

$$r = 1.50 \times 10^{11} \text{ m} \qquad v = \frac{2r}{\Delta t} = \frac{2(1.50 \times 10^{11})}{(22 \times 60)} = 2.27 \times 10^8 \text{ m s}^{-1}$$

$$\Delta t = 1.50 \times 10^{11} \text{ m}$$

$$\%\text{diff} = \frac{(3.00 \times 10^8) - (2.27 \times 10^8)}{(3.00 \times 10^8)} \times 100$$

$$\%\text{diff} = 24.2\%$$

4 The GPS picks up its signal from a satellite that is stationary in the Earth's frame of reference.

5 **a**

$$- \leftrightarrow + \qquad v_{\text{snd-you}} = v_{\text{snd-gnd}} + v_{\text{gnd-you}} = (+346) + (+30.0)$$

$$v_{\text{snd-gnd}} = +346 \text{ m s}^{-1} \qquad v_{\text{snd-you}} = 376 \text{ m s}^{-1}$$

$$v_{\text{gnd-you}} = +30.0 \text{ m s}^{-1}$$

b

$$- \leftrightarrow + \qquad v_{\text{snd-you}} = v_{\text{snd-gnd}} + v_{\text{gnd-you}} = (+346) + (-40.0)$$

$$v_{\text{snd-gnd}} = +346 \text{ m s}^{-1} \qquad v_{\text{snd-you}} = 306 \text{ m s}^{--1}$$

$$v_{\text{gnd-you}} = -40.0 \text{ m s}^{-1}$$

c

$$- \leftrightarrow + \qquad v_{\text{snd-you}} = v_{\text{snd-gnd}} + v_{\text{gnd-you}} = (+346) + (0)$$

$$v_{\text{snd-gnd}} = +346 \text{ m s}^{-1} \qquad v_{\text{snd-you}} = 346 \text{ m s}^{-1}$$

$$v_{\text{gnd-you}} = 0 \text{ m s}^{-1}$$

d

$$- \leftrightarrow + \qquad v_{\text{snd-you}} = v_{\text{snd-gnd}} + v_{\text{gnd-you}} = (+346) + (+30)$$

$$v_{\text{snd-gnd}} = +346 \text{ m s}^{-1} \qquad v_{\text{snd-you}} = 376 \text{ m s}^{-1}$$

$$v_{\text{gnd-you}} = +30 \text{ m s}^{-1}$$

6 A, D

7 **a** If there was an apparent force on you towards one of the walls of the room, or is a small pendulum maintains an angle to the vertical.

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b The motion of the merry-go-round is not constant as it is changing direction constantly, it is accelerating towards the centre of the circular path.

8 **a**

$- \leftrightarrow +$

$s_{\text{ball-train}} = 5.00 \text{ m}$

$\Delta t = 0.200 \text{ s}$

$v_{\text{train-Earth}} = +10.0 \text{ m s}^{-1}$

$v_{\text{ball-Earth}} = v_{\text{ball-train}} + v_{\text{train-Earth}}$

$v_{\text{ball-Earth}} = \left(-\dfrac{(5.00)}{(0.200)}\right) + (+10.0)$

$v_{\text{ball-Earth}} = (-25.0) + (+10.0)$

$v_{\text{ball-Earth}} = -15.0 \text{ m s}^{-1}$

b

$- \leftrightarrow +$

$v_{\text{ball-Earth}} = -15.0 \text{ m s}^{-1}$

$\Delta t = 0.200 \text{ s}$

$s_{\text{ball-Earth}} = v_{\text{ball-Earth}} \Delta t$

$s_{\text{ball-Earth}} = (-15.0)(0.200)$

$s_{\text{ball-Earth}} = 3.00 \text{ m}$

c $\Delta t = 0.200 \text{ s}$

9 **a** $c = 50.0 \text{ m s}^{-1}$

b $c = 50.0 \text{ m s}^{-1}$

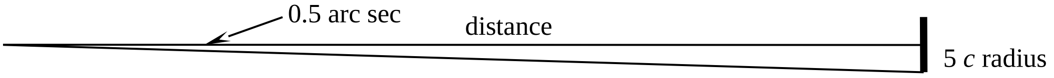
10 A

6.3 To the stars

1 3600 arc sec

2 1800 arc sec

3



$$\tan\left(\tfrac{1}{1800}\right) = \frac{5c \text{ radius}}{\text{distance}}$$

$$\text{distance} = \frac{(1\times10^{-2})}{\tan\left(\tfrac{1}{1800}\right)} = 1\times10^{3} \text{ m}$$

4 Hipparchus called the brightest stars ‘first magnitude’ (+1) and the dimmest ‘sixth magnitude’ (+6), brighter stars discovered after Hipparchus had to then have negative values relative to Hipparchus’s brightest.

5 The physics of heat transfer from hot bodies was well known, so accurate predictions could be made.

6 Nuclear forces are 10^4 times greater than electromagnetic forces, therefore there are 10^8 times more energy produced in nuclear reactions than chemical reactions.

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7 Hydrostatic equilibrium: in which the inward pressure from the weight of the matter is balanced by the outwards pressure of the radiation released by the nuclear reactions in the core. Assumptions about the mass, temperature, heat content, ability to transfer heat, and the pressure gradient and more.

8 Fusion occurs in the inner 0.25*R* of the Sun, energy flows from this region by radiative diffusion and then convection. EM radiation 'bounces' from particle to particle transferring heat energy in the process out to about 0.7*R*. Then hot gases rise from this region to the upper regions by convection. The hot gases on the surface radiate their energy out into space by EM radiation, including in a direction towards the Earth.

9 C

10 A

6.4 Fundamentals of astronomy

1 C

2 In Brisbane the SCP would be 27° above the horizon in the south, while in Perth the SCP is 32° above the horizon in the south.

3 **a** C

b D

4 **a** Pollux

b Formalhaut

5 Stars appear to move 1° further from their position at the same time in each subsequent night. Orion will be 7° further west of due north after one week.

6 Aquarius rose first, about 7 hours before Orion.

7 C

8 **a** It won't be able to be seen as it will be in line with the Sun and Earth.

b It is in a position known as 'opposition' only the superior planets can be seen in this position.

9 **a**

$$\text{Mercury: } \frac{l}{w} \times 100 = \frac{(0.387)}{(0.379)} \times 100 = 102.1\%$$

$$\text{Earth: } \frac{l}{w} \times 100 = \frac{(1.000)}{(0.999)} \times 100 = 100.1\%$$

$$\text{Mars: } \frac{l}{w} \times 100 = \frac{(1.524)}{(1.517)} \times 100 = 100.5\%$$

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b

$$\text{Mercury: } \Delta l = \frac{2.1}{100} \times w = \frac{2.1}{100} \times (10 \times 10^{-2}) = 2.1 \times 10^{-3} \text{ m}$$

$$\text{Earth: } \Delta l = \frac{0.1}{100} \times w = \frac{0.1}{100} \times (10 \times 10^{-2}) = 1 \times 10^{-4} \text{ m}$$

$$\text{Mars: } \Delta l = \frac{0.5}{100} \times w = \frac{0.5}{100} \times (10 \times 10^{-2}) = 5 \times 10^{-4} \text{ m}$$

10 a

$$R_E = 1.00 \text{ AU} \qquad \frac{R_E^3}{T_E^2} = \frac{R_A^3}{T_A^2}$$

$$T_E = 1.00 \text{ year} \qquad T_A = \sqrt{\frac{R_A^3 T_E^2}{R_E^3}} = \sqrt{\frac{(2.00)^3 (1.00)^2}{(1.00)^3}}$$

$$R_A = 2.00 \text{ AU} \qquad T_A = 2.83 \text{ Earth years}$$

b

$$R_E = 1.00 \text{ AU} \qquad \frac{R_E^3}{T_E^2} = \frac{R_A^3}{T_A^2}$$

$$T_E = 1.00 \text{ year} \qquad R_A = \sqrt[3]{\frac{R_E^3 T_A^2}{T_E^2}} = \sqrt[3]{\frac{(1.00)^3 (8.00)^2}{(1.00)^3}}$$

$$T_A = 8.00 \text{ year} \qquad R_A = 4.00 \text{ AU}$$

6.5 Hubble's universe

1 About 15 times the Milky Way galaxy away.
It would have an angular diameter of about 5°.
It is too far away so it is very faint.

2 The faint Cepheid is about twice the distance away than the brighter Cepheid.

3 a

$$r = 25 \times 10^3 \text{ pc} \qquad V = A \times h = \pi r^2 \times h = \pi (25 \times 10^3)^2 \times (1 \times 10^3)$$

$$h = 1 \times 10^3 \text{ pc} \qquad V = 1.96 \times 10^{12} \text{ pc}^3$$

b

$$V = \frac{1.96 \times 10^{12}}{100 \times 10^9} = 19.6 \text{ pc}^3 \text{ per star}$$

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c

$$V = 19.6\ \text{pc}^3 \text{ per star} \qquad V = \tfrac{4}{3}\pi r^3$$

$$r = \sqrt[3]{\frac{3V}{4\pi}} = \sqrt[3]{\frac{3(19.6)}{4\pi}}$$

$$r = 1.67\ \text{pc}$$

from one star to another is $2 \times r$

$\therefore$ distance $= 2(1.67) = 3.35$ pc

d The nearest stars to the Sun are about 1 pc away. The figure calculated above is an average distance as the inner stars are closer while the outer stars are sparser.

4

$$v_{galaxy} = \frac{\Delta\lambda}{\lambda}c = (0.10)(3.00 \times 10^8)$$

$$v_{galaxy} = 3.00 \times 10^7\ \text{m s}^{-1}$$

5

$$H_0 = 70\ \text{km s}^{-1}\ \text{Mpc}^{-1} \qquad v_{galaxy} = H_0 d = (70)(90)$$

$$d = 90\ \text{Mpc} \qquad v_{galaxy} = 6.3 \times 10^3\ \text{km s}^{-1}$$

$$v_{galaxy} = 6.3 \times 10^6\ \text{m s}^{-1}$$

$$v_{galaxy} = \frac{(6.3 \times 10^6)}{(3.00 \times 10^8)} \times 100 = 2.1\% \text{ of speed of light}$$

6 By looking at distant objects astronomers are looking far back in time to the early universe. We see distant objects as they were earlier in their life-cycle.

7 Steady State Theory: The Universe is infinite and eternal
Big Bang: The Universe is expanding.
Essentially the Big Bang theory is different to the Steady State theory in that the Steady State theory requires that matter is being continuously created.
Experiments on the large scales of distance and time that characterise the universe are extremely difficult to create.

8 There is no way to tell.

9 The wavelength of the radiation has increased due to the expansion of space.

10 This value leads to an age of the Universe of about 2 billion years. This is less than the age of the Earth.

Chapter 6 Review

1 Strong nuclear force – gluon
Electromagnetic force – photon
Weak nuclear force - W^+, W^- and Z^0
Gravitational force – graviton

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2 **a** $\lambda = 1.02 \times 10^{-10}$ m

b

$$c = 3.00 \times 10^{8}\ \text{m s}^{-1} \qquad E_k = \frac{hc}{\lambda} = \tfrac{1}{2}mv^2$$

$$h = 6.63 \times 10^{-34}\ \text{J s} \qquad v = \sqrt{\frac{2hc}{\lambda m}}$$

$$m_p = 1.6726 \times 10^{-27}\ \text{kg} \qquad v = \sqrt{\frac{2(6.63 \times 10^{-34})(3.00 \times 10^{8})}{(1.02 \times 10^{-10})(1.6726 \times 10^{-27})}}$$

$$\lambda = 1.02 \times 10^{-10}\ \text{m} \qquad v = 1.53 \times 10^{6}\ \text{m}$$

3

$$m_{e^+} = 9.11 \times 10^{-31}\ \text{kg} \qquad E_{total} = E_k + E_{pair} = \tfrac{1}{2}mv^2 + mc^2$$

$$m_{e^-} = 9.11 \times 10^{-31}\ \text{kg} \qquad E_{total} = \tfrac{1}{2}(2 \times 9.11 \times 10^{-31})(1.50 \times 10^{8})^2 + (2 \times 9.11 \times 10^{-31})(3.00 \times 10^{8})^2$$

$$c = 3.00 \times 10^{8}\ \text{m s}^{-1} \qquad E_{total} = (2.05 \times 10^{-14}) + (1.64 \times 10^{-13})$$

$$v = 1.50 \times 10^{8}\ \text{m s}^{-1} \qquad E_{total} = 1.84 \times 10^{-13}\ \text{J}$$

4 Bosons - mediate the strong nuclear, electromagnetic and weak nuclear forces.
Leptons – interact via the weak nuclear force, and if charged will interact via photons, each lepton has a corresponding neutrino.
Mesons – have a baryon number of zero, are made up of a quark and an anti-quark pair.
Baryons – have a baryon number of one, or negative one, if it is the antiparticle. Is made up of three quarks.

5 Proton – up, up, down.
Neutron – up, down, down.
Anti-proton – anti-up, anti-up, anti-down.
Anti-neutron – anti-up, anti-down, anti-down.

6 A, C

7 C

8 A, B, C

9 A, C

10 B

11 B

12 A

13 When stopped at the station (i) and when travelling at constant speed (iii) there will be no difference, when accelerating (ii) you would feel a force acting on you from the train pushing you in the direction that the train is accelerating.

14 In Perth the celestial equator is 58° above the northern horizon.
In Albany it would be less than this and in Kununurra it would be greater than this.

15 **a** Arcturus
b Betelgeuse
c Alpha Centauri
d Aldebaran

16 **a** RA 6 h 43 min, dec. –17°

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b RA 1 h 36 min, dec. –58°

c RA 18 h 35 min, dec. +39°

d RA 5 h 12 min, dec. –8°

17

$r_1 = 152.1 \times 10^6$ km

$v_1 = 29.3$ km s^{-1}

$r_2 = 147.1 \times 10^6$ km

$$\text{Area}_1 = \text{Area}_2$$
$$r_1 v_1 = r_2 v_2$$
$$v_2 = \frac{r_1 v_1}{r_2} = \frac{(152.1 \times 10^6)(29.3)}{(147.1 \times 10^6)}$$
$$v_2 = 30.3 \text{ km s}^{-1}$$

18

$R_\odot = 109 \times R_E$

$$\frac{\frac{4}{3}\pi R_\odot^{\ 3}}{\frac{4}{3}\pi R_E^{\ 3}} = \frac{R_\odot^{\ 3}}{R_E^{\ 3}} = \frac{(109 \times R_E)^3}{R_E^{\ 3}} = \frac{(1.30 \times 10^6) R_E^{\ 3}}{R_E^{\ 3}} = 1.30 \times 10^6$$

19

$m_\odot = 2 \times 10^{30}$ kg

$P_\odot = 4 \times 10^{26}$ W

$$E_{coal} = (2 \times 10^{30})(30 \times 10^6) = 6 \times 10^{37} \text{ J}$$
$$\Delta t = \frac{E_{coal}}{P_\odot} = \frac{(6 \times 10^{37})}{(4 \times 10^{26})} = 1.5 \times 10^{11} \text{ s}$$
$$\Delta t = 4.8 \times 10^3 \text{ years}$$

20

$m_\odot = 2 \times 10^{30}$ kg

$P_\odot = 4 \times 10^{26}$ W

$$E_H = (2 \times 10^{30})(6 \times 10^{14}) = 1.2 \times 10^{45} \text{ J}$$
$$\Delta t = \frac{E_{coal}}{P_\odot} = \frac{(1.2 \times 10^{45})}{(4 \times 10^{26})} = 3 \times 10^{18} \text{ s}$$
$$\Delta t = 95 \text{ billion years}$$

21 The spectra from these stars show lines similar to the spectra from our Sun and known elements.

22 The period of the Cepheid variables is related to luminosity, so distance can be found, they are also very bright.

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23 **a**

$r = 15 \times 10^3 \text{ pc} \qquad V = A \times h = \pi r^2 \times h = \pi(15 \times 10^3)^2 \times (1 \times 10^3)$

$h = 1 \times 10^3 \text{ pc} \qquad V = 7.07 \times 10^{11} \text{ pc}^3$

$$V = \frac{(7.07 \times 10^{11})}{(100 \times 10^9)} = 7.07 \text{ pc}^3 \text{ per star}$$

$$V = \tfrac{4}{3}\pi r^3$$

$$r = \sqrt[3]{\frac{3V}{4\pi}} = \sqrt[3]{\frac{3(7.07)}{4\pi}}$$

$$r = 1.19 \text{ pc}$$

From one star to another is $2 \times r \quad \therefore \text{distance} = 2(1.19) = 2.4 \text{ pc}$

The stars closer to the centre will be closer together, while those stars further out from the centre will be spaced further apart.

b The distance from our Sun to its nearest neighbour is about 1 pc, this is less than half of the average distance between stars in the Milky Way.

24 Temperature

Elements and their state

Pressure

Magnetic field

25

$v_{sound} = 346 \text{ m s}^{-1} \qquad v_{car} = \frac{\Delta\lambda}{\lambda} v_{sound} = (0.10)(346)$

$v_{car} = 34.6 \text{ m s}^{-1} \quad \text{or} \quad 124 \text{ km h}^{-1} \text{ towards us}$

26

$H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1} \qquad v_{LMC} = H_0 d = (70)(50 \times 10^{-3})$

$d_{LMC} = 50 \text{ kpc} = 50 \times 10^{-3} \text{ Mpc} \qquad v_{LMC} = 3.5 \text{ km s}^{-1}$

$d_{SMC} = 63 \text{ kpc} = 63 \times 10^{-3} \text{ Mpc}$

$v_{SMC} = H_0 d = (70)(63 \times 10^{-3})$

$v_{SMC} = 4.4 \text{ km s}^{-1}$

These are very small velocities on a galactic scale.

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27 Blueshifts imply that the galaxies are moving towards us, they must be moving towards us at a rate that is greater than rate at which the Universe is expanding.

28 The age of the Universe can also be found using the position on the H-R diagram and nuclear decay processes. All of these methods estimate an age of about 14 billion years.

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Chapter 7 Electric and magnetic fields

7.1 Force on charges in magnetic fields

1 C
2 A
3 **a** South
b C
4 A
5 **a** North
b A
6 A particle with no charge, like a neutron, as it will not experience any force due to moving in the magnetic field, therefore its path will not change.
7 C, D
8 A and B as the particle must have the opposite charge, or have the field in the opposite direction, to experience a force in the opposite direction.
9 **a** South
b **i** $2F$
ii $2F$
iii $4F$
10 **a** $2F$ north
b Greater radius

7.2 Particle accelerators

1 B
2 **a** Electrons leave the hot cathode of the evacuated tube and accelerate towards a positively charged anode. The electrons can be deflected as they pass through an electric field produced by a pair of oppositely charged parallel plates and a magnetic field generated by an electromagnet. They can be detected as they hit a fluorescent screen at the rear of the tube.
b The electrons are accelerated away from the negative cathode and towards a positively charged anode.

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3 The standing-wave linear accelerator consists of a large number of drift tubes, each separated by a gap. Electrons enter the cylinder and are accelerated towards the first drift tube by an electric field. An alternating potential difference is applied to each tube and is timed such that the electrons are accelerated across each gap between the drift tubes. Inside the drift tubes, they travel at a constant velocity as they are shielded from the effects of the electric field. The particles pick up more energy each time they leave the drift tubes, until they are accelerated out of the linac.

4 A circular accelerator, such as a cyclotron, can be used to accelerate particles within a more compact space than the equivalent operations of a very long linear accelerator.

5 **a**

$\Delta V = 10 \times 10^3$ V

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

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

$$E_k = W_d$$
$$\tfrac{1}{2}mv^2 = e\Delta V$$
$$v = \sqrt{\frac{2e\Delta V}{m}} = \sqrt{\frac{2(1.60\times10^{-19})(10\times10^3)}{(9.11\times10^{-31})}}$$
$$v = 5.93\times10^7 \text{ m s}^{-1}$$

b

$\boldsymbol{B}_\perp = 1.50$ T

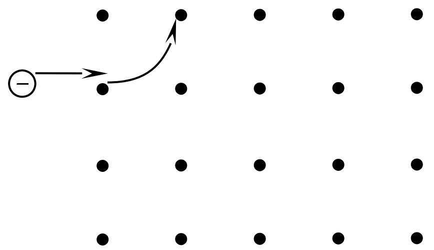
$e = 1.60 \times 10^{-19}$ C

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

$v = 5.93 \times 10^7$ m s^{-1}

$$r = \frac{mv}{e\boldsymbol{B}_\perp}$$
$$r = \frac{(9.11\times10^{-31})(5.93\times10^7)}{(1.60\times10^{-19})(1.50)}$$
$$r = 2.25\times10^{-4} \text{ m}$$

6 **a**



b The radius of the electron's path is dependent on its velocity and the magnitude of the magnetic field that is acting.

7 **a**

$\Delta V = 500$ V

$d = 3.5 \times 10^{-2}$ m

$$E = \frac{\Delta V}{d}$$
$$E = \frac{(500)}{(3.5\times10^{-2})}$$
$$E = 1.43\times10^4 \text{ V m}^{-1}$$

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b

$E = 1.43 \times 10^4$ V m^{-1}

$\boldsymbol{B}_\perp = 1.50 \times 10^{-3}$ T

$$\boldsymbol{F}_E = \boldsymbol{F}_B$$
$$qE = qv\boldsymbol{B}_\perp$$
$$v = \frac{E}{\boldsymbol{B}_\perp} = \frac{(1.43 \times 10^4)}{(1.50 \times 10^{-3})}$$
$$v = 9.52 \times 10^6 \text{ m s}^{-1}$$

8

$\Delta V = 2.50 \times 10^3$ V

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

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

$$E_k = W_d$$
$$\tfrac{1}{2}mv^2 = e\Delta V$$
$$v = \sqrt{\frac{2e\Delta V}{m}} = \sqrt{\frac{2(1.60 \times 10^{-19})(2.50 \times 10^3)}{(9.11 \times 10^{-31})}}$$
$$v = 2.96 \times 10^7 \text{ m s}^{-1}$$

9

$r = 4.60 \times 10^{-2}$ m

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

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

$v = 7.60 \times 10^6$ m s^{-1}

$$F_{B_\perp} = F_c$$
$$qv\boldsymbol{B}_\perp = \frac{mv^2}{r}$$
$$\boldsymbol{B}_\perp = \frac{(9.11 \times 10^{-31})(7.60 \times 10^6)}{(1.60 \times 10^{-19})(4.60 \times 10^{-2})}$$
$$\boldsymbol{B}_\perp = 9.41 \times 10^{-4} \text{ T}$$

10 **a**

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

$\boldsymbol{B}_\perp = 8.60 \times 10^{-3}$ T

$v = 7.00 \times 10^6$ m s^{-1}

$$F_B = qv\boldsymbol{B}_\perp = (1.60 \times 10^{-19})(7.00 \times 10^6)(8.60 \times 10^{-3})$$
$$F_B = 9.63 \times 10^{-15} \text{ N}$$

b

$F_B = 9.63 \times 10^{-15}$ N

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

$v = 7.00 \times 10^6$ m s^{-1}

$$F_B = F_c = \frac{mv^2}{r}$$
$$r = \frac{mv^2}{F_c} = \frac{(9.11 \times 10^{-31})(7.00 \times 10^6)^2}{(9.63 \times 10^{-15})}$$
$$r = 4.63 \times 10^{-3} \text{ m}$$

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7.3 Synchrotons

1 **a** **i** The linac consists of an electron gun, a vacuum system, focusing elements and RF (radio-frequency) cavities. Electrons escape from the electron gun as they boil off the heated filament of the assembly and then accelerate across the 100 keV potential difference. The electron beam travels through the ultra-high vacuum within the linac, to prevent energy loss through the interaction with air particles. As the electrons travel, focusing elements act on the beam to ensure it doesn't collide with the walls of the vacuum tube. RF (radio-frequency) cavities throughout the linac produce intense electromagnetic radiation of several hundred megahertz perpendicular to the electron beam. The RF radiation propagates through the linac as a travelling wave. Electrons are timed in pulses so that they travel through the linac in bunches, which are accelerated by the RF radiation. As a result, electrons are accelerated to close to the speed of light throughout their journey through the linac.

ii Each time the charged particles travel around the circular booster ring they receive an additional energy burst from a radio-frequency (RF) chamber.

iii In the storage ring of the synchrotron, electrons revolve around for hours at a time at speeds close to the speed of light. A series of magnets make them bend in an arc as they travel through the ring. It is when the electrons change direction that they emit synchrotron radiation.

iv The beamline is the path taken by synchrotron light as it exits the storage ring towards an experimental station (or endstation).

b **i** The strength of the magnetic field used in the circular booster ring is periodically increased as the velocity of the electrons increases to account for energy losses due to the increasing effects of relativity which result from the increased velocity and relativistic mass by this stage.

ii Electrons move from a heated filament inside the electron gun within the linac.

iii RF cavities accelerate electrons within the linac.

iv Insertion devices are located in the straight section of the storage ring.

2 **a** The precise configuration of the bending, focussing and steering magnets found in the storage ring.

b The specification of the lattice sets the parameters for the synchrotron light produced.

3 **a** Due to the presence of an oscillating electromagnetic field produced by the transformers extra energy is given to the electrons.

b The particles would gradually lose their energy through collisions with other atoms and the production of synchrotron light. Their orbital speed would be slowed and they would cease to produce synchrotron light.

c By replenishing the energy lost via a burst of energy from the RF cavity, the charged particles continue to move at the same speed in a path of constant radius in the storage ring. The particles of a cyclotron increase their energy with each revolution and so their radius of orbit increases each revolution.

4 To minimise energy losses through collisions between electrons and gas molecules.

5 B

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6 An undulator consists of some hundred low-power magnetic poles aligned closely together in rows. The effect of the undulator is to deflect the electrons more gently, thus producing a much narrower beam of brighter synchrotron radiation that is enhanced at specific wavelengths. This is in contrast to a bending magnet which produces a continuous broad cone of much less bright synchrotron light. The output from a wiggler is radiation that is not as bright as from the undulator, but brighter than that from the bending magnet. The wiggler forms a broad band of incoherent synchrotron light.

7 **a** 3 GeV

b Pharmaceutical development, mining and mineral exploration, manufacturing microstructures etc.

8 **a**

$\Delta V = 120 \times 10^3$ V $\qquad E_k = W_d$

$e = 1.60 \times 10^{-19}$ C $\qquad \frac{1}{2}mv^2 = e\Delta V$

$m = 9.11 \times 10^{-31}$ kg $\qquad v = \sqrt{\dfrac{2e\Delta V}{m}} = \sqrt{\dfrac{2(1.60 \times 10^{-19})(120 \times 10^3)}{(9.11 \times 10^{-31})}}$

$v = 2.05 \times 10^8 \text{ m s}^{-1}$

b For electrons being accelerated across a potential difference of 2.5 keV, the effects of relativity will come into play. The effective mass of the electrons will be greater than their rest mass. As a result, they will not reach the velocity calculated in part a (for such a potential difference the electrons will reach about 80% of the calculated velocity).

9 **a**

$\boldsymbol{B}_\perp = 1.50$ T $\qquad r = \dfrac{mv}{e\boldsymbol{B}_\perp}$

$e = 1.60 \times 10^{-19}$ C $\qquad r = \dfrac{(9.11 \times 10^{-31})(0.999\ 999\ 9855 \times 3.00 \times 10^8)}{(1.60 \times 10^{-19})(1.50)}$

$m = 9.11 \times 10^{-31}$ kg $\qquad r = 1.14 \times 10^{-3}$ m

$v = 99.999\ 998\ 55\%$ of $c = 0.9999999855$

b At velocities close to the speed of light the effects of relativity have a large impact on the radius of the electron beam. Because the mass of the electrons is about 6000 times greater than their rest mass it follows that the expected path radius will also be some 6000 times greater than predicted in part a. Because the bending magnets are only found in sections of the storage ring the actual path is greater still.

10 Similarities include: Same basic design, a linac, booster ring, storage ring and a number of beamlines and a third generation source.

Differences include: Delta power output is 1.5 GeV compared to the proposed 3 GeV for the Australian Synchrotron. Delta has less beamlines, and is half the size of the Australian Synchrotron. Delta is oval shaped while the Australian Synchrotron is symmetrical through all axes.

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7.4 Mass spectrometry

1

$$m_p = 1.67 \times 10^{-27}\ \text{kg} \qquad r = \frac{mv}{qB_\perp}$$

$$B_\perp = 0.600\ \text{T} \qquad r = \frac{(1.67 \times 10^{-27})(1.50 \times 10^3)}{(1.60 \times 10^{-19})(0.600)}$$

$$v = 1.50 \times 10^3\ \text{m s}^{-1} \qquad r = 2.61 \times 10^{-5}\ \text{m}$$

$$q = 1.60 \times 10^{-19}\ \text{C}^{-1}$$

2

$$m_p = 1.67 \times 10^{-27}\ \text{kg} \qquad \tfrac{1}{2}mv^2 = q\Delta V$$

$$B_\perp = 0.450\ \text{T} \qquad v = \sqrt{\frac{2q\Delta V}{m}} = \sqrt{\frac{2(1.60 \times 10^{-19})(2.55 \times 10^3)}{(1.67 \times 10^{-27})}} = 6.99 \times 10^5\ \text{m s}^{-1}$$

$$\Delta V = 2.55 \times 10^3\ \text{V} \qquad r = \frac{mv}{qB_\perp} = \frac{(1.67 \times 10^{-27})(6.99 \times 10^5)}{(1.60 \times 10^{-19})(0.600)}$$

$$q = 1.60 \times 10^{-19}\ \text{C} \qquad r = 1.22 \times 10^{-2}\ \text{m}$$

3

$$r_O = 0.850\ \text{m} \qquad v = \frac{rqB_\perp}{m} \text{ and } v = \sqrt{\frac{2q\Delta V}{m}}$$

$$B_\perp = 7.20 \times 10^{-2}\ \text{T} \qquad \frac{rqB_\perp}{m} = \sqrt{\frac{2q\Delta V}{m}}$$

$$\Delta V = 1.10 \times 10^4\ \text{V} \qquad \frac{r^2q^2B_\perp^{\,2}}{m^2} = \frac{2q\Delta V}{m}$$

$$q = 1.60 \times 10^{-19}\ \text{C}^{-1} \qquad \frac{r^2qB_\perp^{\,2}}{m} = 2\Delta V$$

$$m = \frac{r^2qB_\perp^{\,2}}{2\Delta V} = \frac{(0.850)^2(1.60 \times 10^{-19})(7.20 \times 10^{-2})^2}{2(1.10 \times 10^4)}$$

$$m = 2.72 \times 10^{-26}\ \text{kg}$$

4 Positive

5 The direction of the magnetic field would need to be reversed and the voltage used to accelerate the ions would need to be reversed too.

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6

$m_p = 1.67 \times 10^{-27}$ kg

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

$v = 2.00 \times 10^{6}$ m s^{-1}

$$\tfrac{1}{2}mv^2 = q\Delta V$$

$$\Delta V = \frac{\frac{1}{2}mv^2}{q} = \frac{\frac{1}{2}(1.67 \times 10^{-27})(2.00 \times 10^{6})^2}{(1.60 \times 10^{-19})}$$

$$\Delta V = 2.09 \times 10^{4} \text{ V}$$

7

$m_p = 1.67 \times 10^{-27}$ kg

$r = 0.555$ m

$v = 2.00 \times 10^{6}$ m s^{-1}

$q = 1.60 \times 10^{-19}$ C^{-1}

$$\boldsymbol{B}_{\perp} = \frac{mv}{qr}$$

$$\boldsymbol{B}_{\perp} = \frac{(1.67 \times 10^{-27})(2.00 \times 10^{6})}{(1.60 \times 10^{-19})(0.555)}$$

$$\boldsymbol{B}_{\perp} = 3.76 \times 10^{-2} \text{ T}$$

8 No. If both particles were accelerated with the same (but opposite) accelerating potential then they would have very different speeds due to their very different masses. The velocity selector would only allow significant numbers of only one of them to pass into the spectrograph. If significant numbers of each particle were allowed into the spectrograph at the same velocity then the radii of the two pathways would be very different due to the same (but opposite) magnetic flux density on the different masses.

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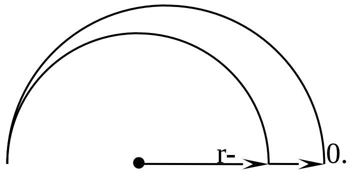
9 If the separation is 0.330 mm for a half turn, the difference in radius between the two paths would be 0.165 mm.



$$m_{CO} = 28.0106 \text{ u} \qquad \frac{v}{qB_{\perp}} = \frac{r_{CO}}{m_{CO}} = \frac{r_{N_2}}{m_{N_2}}$$

$$m_{N_2} = 28.0134 \text{ u} \qquad r_{N_2} = \frac{(r_{N_2} - 0.165\times10^{-3})m_{N_2}}{m_{CO}}$$

$$r_{CO} = r_{N_2} - 0.165\times10^{-3} \text{ m} \qquad r_{N_2} = \frac{(r_{N_2} - 0.165\times10^{-3})(28.0134)}{(28.0106)}$$

$$28.0106r_{N_2} = 28.0134r_{N_2} - 4.6222\times10^{-3}$$

$$2.8\times10^{-3}r_{N_2} = 4.6222\times10^{-3}$$

$$r_{N_2} = \frac{(4.6222\times10^{-3})}{(2.8\times10^{-3})}$$

$$r_{N_2} = 1.65 \text{ m}$$

This is the larger radius of the two particles; therefore the radius of the mass spectrometer must be greater than, or equal to this value.

Chapter 7 Review

1 B

2 The radius of curvature of both electron beams is the same therefore the velocity of both beams must be equivalent Using the right-hand rule $\boldsymbol{B}_x$ must be out of the page for the electron beam to bend up the page, and $\boldsymbol{B}_y$ must be into the page for the electron beam to bend down the page.

3 C

4 A

5

$$\Delta V = 15.0\times10^{3} \text{ V m}^{-1} \qquad \boldsymbol{F}_E = \frac{q\Delta V}{d} = \frac{(1.60\times10^{-19})(15.0\times10^{3})}{(12.0\times10^{-2})}$$

$$q = 1.60\times10^{-19} \text{ C} \qquad \boldsymbol{F}_E = 2.00\times10^{-14} \text{ N}$$

$$d = 12.0\times10^{-2} \text{ m}$$

6 B

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7

$\Delta V = 28.0 \times 10^3$ V $\qquad E_k = W_d$

$e = 1.60 \times 10^{-19}$ C $\qquad \frac{1}{2}mv^2 = e\Delta V$

$m = 9.11 \times 10^{-31}$ kg $\qquad v = \sqrt{\dfrac{2e\Delta V}{m}} = \sqrt{\dfrac{2(1.60 \times 10^{-19})(28.0 \times 10^3)}{(9.11 \times 10^{-31})}}$

$v = 9.92 \times 10^7$ m s^{-1}

8

$\Delta V = 28.0 \times 10^3$ V $\qquad E = \dfrac{\Delta V}{d} = \dfrac{(28.0 \times 10^3)}{(20.0 \times 10^{-2})}$

$d = 20.0 \times 10^{-2}$ m $\qquad E = 1.40 \times 10^5$ V m^{-1}

9 D

10

$v = 4.20 \times 10^6$ m s^{-1} $\qquad \boldsymbol{F}_c = \boldsymbol{F}_B$

$\boldsymbol{B}_\perp = 1.20$ T $\qquad \dfrac{mv^2}{\mathrm{r}} = qv\boldsymbol{B}_\perp$

$m_e = 9.11 \times 10^{-31}$ kg $\qquad r = \dfrac{m\mathrm{v}}{q\boldsymbol{B}_\perp} = \dfrac{(9.11 \times 10^{-31})(4.20 \times 10^6)}{(1.60 \times 10^{-19})(1.20)}$

$q_e = 1.60 \times 10^{-19}$ C $\qquad r = 1.99 \times 10^{-5}$ m

11

$\lambda = 6.80 \times 10^{-11}$ m $\qquad E = \dfrac{hc}{\lambda} = \dfrac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{(6.80 \times 10^{-11})}$

$h = 6.63 \times 10^{-34}$ J s $\qquad E = 2.93 \times 10^{-15}$ J

$E = \dfrac{2.93 \times 10^{-15}}{1.60 \times 10^{-19}} = 1.83 \times 10^4$ eV

12 A

13

$\lambda = 9.80 \times 10^{-10}$ m $\qquad E_k = E_{ph} - W = \dfrac{hc}{\lambda} - W$

$c = 3.00 \times 10^8$ m s^{-1} $\qquad E_k = \dfrac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{(9.80 \times 10^{-10})} - (4.20)(1.60 \times 10^{-19})$

$W = 4.20$ eV $\qquad E_k = 2.02 \times 10^{-16}$ J

$h = 6.63 \times 10^{-34}$ J s

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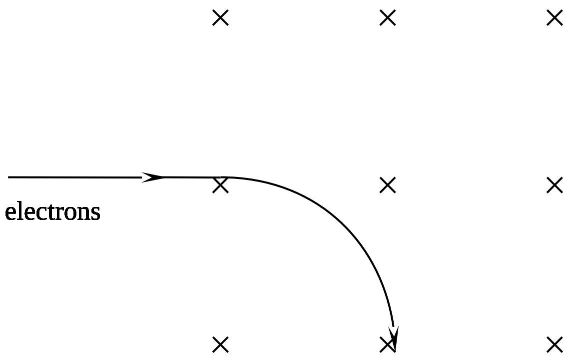
14



15

$\Delta V = 3.00\times10^{3}\ \text{V}$

$\boldsymbol{B}_{\perp} = 1.60\times10^{-3}\ \text{T}$

$v = 3.23\times10^{7}\ \text{m s}^{-1}$

$q = 1.60\times10^{-19}\ \text{C}$

$$\boldsymbol{F}_{E} = \boldsymbol{F}_{B}$$

$$\frac{q\Delta V}{d} = qv\boldsymbol{B}_{\perp}$$

$$d = \frac{\Delta V}{v\boldsymbol{B}_{\perp}} = \frac{(3.00\times10^{3})}{(3.23\times10^{7})(1.60\times10^{-3})}$$

$$d = 5.81\times10^{-2}\ \text{m}$$

16

$r = 6.00\times10^{-2}\ \text{m}$

$\boldsymbol{B}_{\perp} = 1.50\times10^{-4}\ \text{T}$

$\frac{q}{m} = 1.76\times10^{11}\ \text{C kg}^{-1}$

$$\boldsymbol{F}_{c} = \boldsymbol{F}_{B}$$

$$\frac{mv^{2}}{r} = qv\boldsymbol{B}_{\perp}$$

$$v = \frac{qr\boldsymbol{B}_{\perp}}{m} = \frac{q}{m}r\boldsymbol{B}_{\perp} = (1.76\times10^{11})\times(6.00\times10^{-2})(1.50\times10^{-4})$$

$$v = 1.58\times10^{6}\ \text{m s}^{-1}$$

17

$m_{1} = 5$

$m_{2} = 3$

$r_{2} = 155\times10^{-3}\ \text{m}$

$$\frac{v}{q\boldsymbol{B}_{\perp}} = \frac{r_{1}}{m_{1}} = \frac{r_{2}}{m_{2}}$$

$$r_{1} = \frac{r_{2}m_{1}}{m_{2}} = \frac{(155\times10^{-3})(5)}{(3)}$$

$$r_{1} = 2.58\times10^{-1}\ \text{m}$$

$$d = 2(2.58\times10^{-1}) = 5.17\times10^{-1}\ \text{m}$$

This assumes that the particles in the mass spectrograph have a semicircular path

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18

$r_{He} = 40.2 \times 10^{-3}$ m

$\boldsymbol{B}_{\perp} = 0.160$ T

$\Delta V = 500.0$ V

$q = 1.60 \times 10^{-19}$ C^{-1}

$$v = \frac{rq\boldsymbol{B}_{\perp}}{m} \text{ and } v = \sqrt{\frac{2q\Delta V}{m}}$$

$$\frac{rq\boldsymbol{B}_{\perp}}{m} = \sqrt{\frac{2q\Delta V}{m}}$$

$$\frac{r^2 q^2 \boldsymbol{B}_{\perp}^{\ 2}}{m^2} = \frac{2q\Delta V}{m}$$

$$\frac{r^2 q \boldsymbol{B}_{\perp}^{\ 2}}{m} = 2\Delta V$$

$$m = \frac{r^2 q \boldsymbol{B}_{\perp}^{\ 2}}{2\Delta V} = \frac{(40.2 \times 10^{-3})^2 (1.60 \times 10^{-19})(0.160)^2}{2(500.0)}$$

$$m = 6.62 \times 10^{-27} \text{ kg}$$

19

$r_{O} = 0.850$ m

$\boldsymbol{B}_{\perp} = 7.20 \times 10^{-2}$ T

$E = 11.0 \times 10^3$ eV

$q = 1.60 \times 10^{-19}$ C^{-1}

$$v = \frac{rq\boldsymbol{B}_{\perp}}{m} \text{ and } v = \sqrt{\frac{2Eq}{m}}$$

$$\frac{rq\boldsymbol{B}_{\perp}}{m} = \sqrt{\frac{2Eq}{m}}$$

$$\frac{r^2 q^2 \boldsymbol{B}_{\perp}^{\ 2}}{m^2} = \frac{2Eq}{m}$$

$$\frac{r^2 q \boldsymbol{B}_{\perp}^{\ 2}}{m} = 2E$$

$$m = \frac{r^2 q \boldsymbol{B}_{\perp}^{\ 2}}{2E} = \frac{(0.850)^2 (1.60 \times 10^{-19})(7.20 \times 10^{-2})^2}{2(11.0 \times 10^3)}$$

$$m = 2.72 \times 10^{-26} \text{ kg}$$

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Chapter 8 Working in physics

8.1 Measurements and units

1 **a** Acceleration is derived.
b Magnetic field intensity is derived.
c Force is derived.
d Density is derived.
e Time is fundamental.
f Torque is derived.

2

$$\text{width: } 945 \text{ cm} = 945 \times 10^{-2} \text{ m} = 9.45 \text{ m}$$
$$\text{length: } 468 \text{ cm} = 468 \times 10^{-2} \text{ m} = 4.68 \text{ m}$$
$$\text{height: } 255 \text{ cm} = 255 \times 10^{-2} \text{ m} = 2.55 \text{ m}$$

3

$$\text{width: } 945 \text{ cm} = 945 \times 10^{-2} \text{ m} = 9.45 \times 10^{3} \text{ mm}$$
$$\text{length: } 468 \text{ cm} = 468 \times 10^{-2} \text{ m} = 4.68 \times 10^{3} \text{ mm}$$
$$\text{height: } 255 \text{ cm} = 255 \times 10^{-2} \text{ m} = 2.55 \times 10^{3} \text{ mm}$$

4

$$\text{width: } 945 \text{ cm} = 945 \times 10^{-2} \text{ m} = 9.45 \times 10^{6}\ \mu\text{m}$$
$$\text{length: } 468 \text{ cm} = 468 \times 10^{-2} \text{ m} = 4.68 \times 10^{6}\ \mu\text{m}$$
$$\text{height: } 255 \text{ cm} = 255 \times 10^{-2} \text{ m} = 2.55 \times 10^{6}\ \mu\text{m}$$

5

$$\text{width} = 9.45 \text{ m} \qquad V = w \times L \times h$$
$$\text{length} = 4.68 \text{ m} \qquad V = (9.45)(4.68)(2.55)$$
$$\text{height} = 2.55 \text{ m} \qquad V = 1.13 \times 10^{2} \text{ m}^3$$

6

$$\text{width} = 9.45 \times 10^{3} \text{ mm} \qquad A = w \times L$$
$$\text{length} = 4.68 \times 10^{3} \text{ mm} \qquad A = (9.45 \times 10^{3})(4.68 \times 10^{3})$$
$$A = 4.42 \times 10^{7} \text{ mm}^2$$

7

$$V_{\text{fuel prior}} = 7682 \text{ L} \qquad m_{\text{fuel prior}} = V_{\text{fuel prior}} \times \text{conversion factor}$$
$$\text{conversion factor} = 0.803 \text{ kg L}^{-1} \qquad m_{\text{fuel prior}} = (7682)(0.803)$$
$$m_{\text{fuel prior}} = 6.17 \times 10^{3} \text{ kg}$$

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8

$$m_{\text{fuel prior}} = 6.17 \times 10^3 \text{ kg}$$
$$m_{\text{fuel required}} = 2.23 \times 10^4 \text{ kg}$$

$$m_{\text{fuel to add}} = m_{\text{fuel required}} - m_{\text{fuel prior}}$$
$$m_{\text{fuel to add}} = (2.23 \times 10^4) - (6.17 \times 10^3)$$
$$m_{\text{fuel to add}} = 1.61 \times 10^4 \text{ kg}$$

9

$$m_{\text{fuel to add}} = 1.61 \times 10^4 \text{ kg}$$
$$\text{conversion factor} = 0.803 \text{ kg L}^{-1}$$

$$V_{\text{fuel to add}} = \frac{m_{\text{fuel to add}}}{\text{conversion factor}} = \frac{1.61 \times 10^4}{0.803}$$
$$V_{\text{fuel to add}} = 2.01 \times 10^4 \text{ L}$$

10

$$E = hf$$
$$h = \frac{E}{f} = \frac{\text{J}}{\text{s}^{-1}} = \text{J s}^{-1}$$

8.2 Data

1

$$\text{uncertainty}(\%) = \frac{0.5}{24.8} \times 100$$
$$\text{uncertainty}(\%) = 2.02\%$$

Note that the value 0.5 and 100 are exact numbers.

2

$$\text{uncertainty } (\%) = \frac{0.5}{35} \times 100$$
$$\text{uncertainty } (\%) = 1.4\%$$

Note that the value 0.5 and 100 are exact numbers.

3

$$\text{diameter uncertainty } (\%) = \pm 2.02\%$$
$$\text{length uncertainty } (\%) = \pm 1.4\%$$

$$V = \pi r^2 \times L$$
$$V \text{ uncertainty } (\%) = 2(2.02) + (1.4)$$
$$V \text{ uncertainty } (\%) = 5.4\%$$

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4

V uncertainty (%) $= 5.4\%$

length $= 35 \times 10^{-2}$ m

diameter $= 24.8 \times 10^{-3}$ m

radius $= 12.4 \times 10^{-3}$ m

$V = \pi r^2 \times L$

$V = \pi(12.4 \times 10^{-3})^2 \times (35 \times 10^{-2})$

$V = 1.7 \times 10^{-4}$ m^3

$$V \text{ uncertainty} = (1.7 \times 10^{-4}) \times \frac{5.4}{100}$$

$$V \text{ uncertainty} = \pm 9.2 \times 10^{-6} \text{ m}^3$$

5

$$\text{mass uncertainty (\%)} = \frac{50}{1200} \times 100$$

$$\text{mass uncertainty (\%)} = 4.2\%$$

$$\text{speed uncertainty (\%)} = \frac{1}{18} \times 100$$

$$\text{speed uncertainty (\%)} = 5.6\%$$

$$\text{radius uncertainty (\%)} = \frac{3}{46} \times 100$$

$$\text{radius uncertainty (\%)} = 6.5\%$$

Note that the values 50, 1, 3 and 100 are exact numbers.

6

$m = 1200$ kg

$v = 18$ m s^{-1}

$r = 46\,m$

$$F = \frac{mv^2}{r}$$

$$F = \frac{(1200)(18)^2}{(46)}$$

$$F = 8.5 \times 10^3 \text{ N}$$

7

mass uncertainty (%) $= \pm 4.2\%$

speed uncertainty (%) $= \pm 5.6\%$

radius uncertainty (%) $= \pm 6.5\%$

$$F = \frac{mv^2}{r}$$

$$F \text{ uncertainty (\%)} = (4.2) + 2(5.6) + (6.5)$$

$$F \text{ uncertainty (\%)} = 21.8\%$$

8

F uncertainty (%) $= 21.8\%$

$F = 8.5 \times 10^3$ N

$$F \text{ uncertainty} = (8.5 \times 10^3) \times \frac{21.8}{100}$$

$$F \text{ uncertainty} = 1.8 \times 10^3 \text{ N}$$

9 Answers depend on your experimental data.

10 Answers depend on your experimental data.

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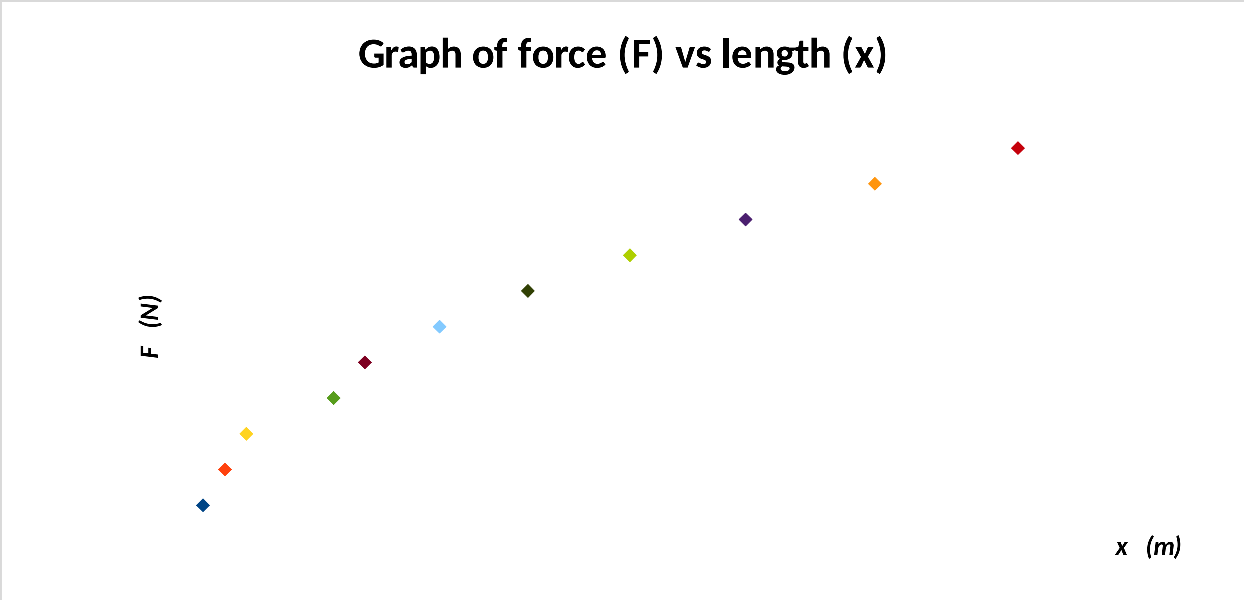
8.3 Graphical analysis of data

1



There seem to be some data points that should be excluded.

2

$F = a\sqrt{x} + b$

↑ ↑ ↑ ↑

$y = m \quad x + c$

Therefore they should plot $\boldsymbol{F}$ against $\sqrt{x}$

3

Applied force (F) **(N)**	**Square root of length** $(\sqrt{x})$ $(m^{\frac{1}{2}})$
10.0	0.056
20.0	0.119
30.0	0.158
40.0	0.263
50.0	0.291
60.0	0.350
70.0	0.408
80.0	0.467
90.0	0.526
100.0	0.584
110.0	0.643

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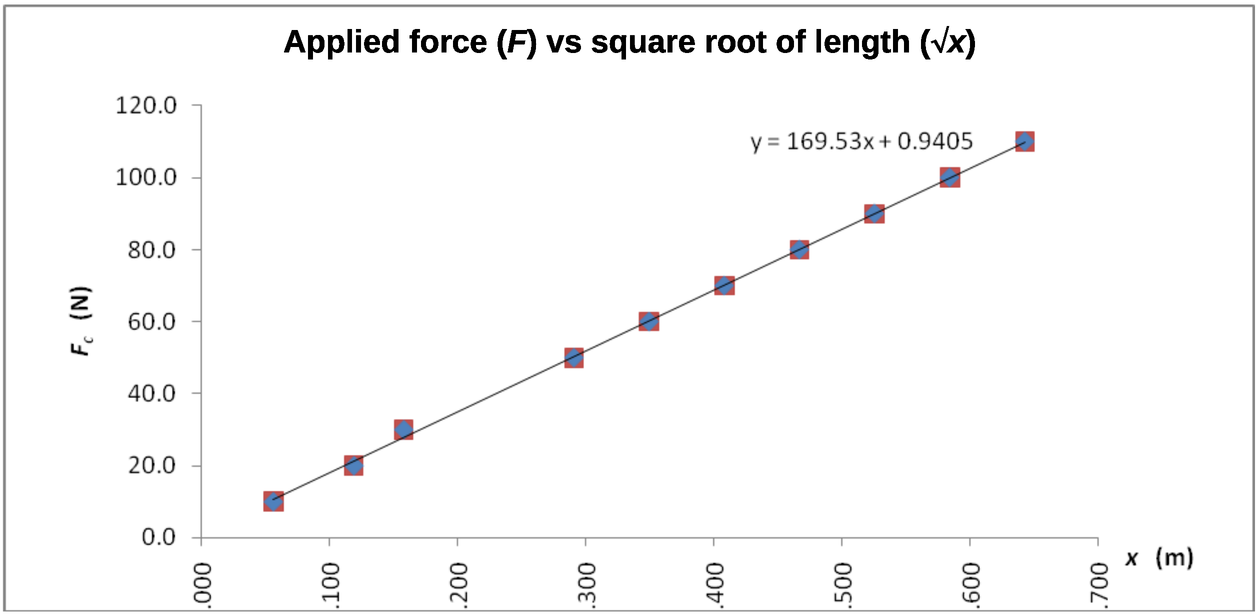
4



5

$$y = 169.53x + 0.9405$$
$$F = 169\sqrt{x} + 0.941$$

Hence, gradient =170 N m^{-1}

6

$$y = 169.53x + 0.9405$$
$$F = 169\sqrt{x} + 0.941$$

Hence, *y*-axis intercept =0.941 N

7

$$F = 169\sqrt{x} + 0.941$$

8 a = 170, b = 0.941

9

$$F_c = \frac{mv^2}{r}$$

$$F_c = \frac{m}{r}v^2 + 0$$

$$\uparrow \quad \uparrow \quad \uparrow \quad \uparrow$$

$$y = m\ x + c \qquad 1.3.10$$

Hence, we need to plot $\boldsymbol{F}_c$ against $\boldsymbol{v}^2$ to get a linear graph.

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10

$$\text{slope} = \frac{m}{r}$$

Hence, the slope is the ratio between m and r with the units of kg m^{-1}.

8.4 Writing scientific reports

1 Aim, Apparatus, Method, Results, Analysis, Conclusion

2
- **a** False
- **b** True
- **c** False
- **d** True
- **e** True
- **f** False

3
1. A pendulum was set up as shown in the diagram.
2. The mass of a full set of slotted masses was determined.
3. The set of slotted masses were attached as the pendulum bob.
4. The pendulum string was made such that the masses were clear of the ground as it swung.
5. The length of the pendulum was measured from the retort arm to the base of the set of slotted masses.
6. The pendulum bob was pulled to one side such that the bob was displaced by 2 cm horizontally from its original position.
7. The stopwatch was started as the bob was released.
8. The time was recorded for 20 oscillations of the pendulum bob.
9. The period for each oscillation was calculated by dividing the time in step 8 by 20.
10. Steps 8 and 9 were repeated twice more to determine an average period for one oscillation.
11. Steps 6–10 were repeated for displacements of 4, 6, 8 and 12 cm.

Chapter 8 Review

1

$V = 569 \text{ mm}^3$

$V = 569(\times 10^{-3})^3 \text{ m}^3$

$V = 569 \times 10^{-9} \text{ m}^3$

2

$\boldsymbol{F} = 2.80 \times 10^{-3} \text{ N}$

$I = 2.60 \text{ A}$

$l = 4.30 \times 10^{-3} \text{ m}$

$\boldsymbol{F} = Il\boldsymbol{B}_{\perp}$

$$\boldsymbol{B}_{\perp} = \frac{(2.80 \times 10^{-3})}{(2.60)(4.30 \times 10^{-3})}$$

$\boldsymbol{B}_{\perp} = 2.50 \times 10^{-1} \text{ T}$

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3

$$\boldsymbol{F} = 2.80 \times 10^{-3}\ \text{N} \qquad \boldsymbol{F}:\ \%\ \text{uncertainty} = \frac{(0.10 \times 10^{-3})}{(2.80 \times 10^{-3})} \times 100 = 3.57\%$$

$$I = 2.60\ \text{A} \qquad I:\ \%\ \text{uncertainty} = \frac{(0.05)}{(2.60)} \times 100 = 1.92\%$$

$$l = 4.30 \times 10^{-3}\ \text{m} \qquad l:\ \%\ \text{uncertainty} = \frac{(0.20 \times 10^{-3})}{(4.30 \times 10^{-3})} \times 100 = 4.65\%$$

4

$$\boldsymbol{B}_\perp : \%\ \text{uncert} = (\boldsymbol{F}\ \%\ \text{uncert}) + (I\ \%\ \text{uncert}) + (l\ \%\ \text{uncert})$$

$$\boldsymbol{B}_\perp : \%\ \text{uncert} = (3.57) + (1.92) + (4.65) = 10.1\%$$

5

$$\boldsymbol{B}_\perp : \text{abs uncert} = (2.50 \times 10^{-1})\frac{10.1}{100}$$

$$\boldsymbol{B}_\perp : \text{abs uncert} = \pm 2.54 \times 10^{-2}\ \text{T}$$

6

$$v = \frac{\sqrt{B}}{\rho} \quad \therefore \quad B = v^2 \rho^2$$

$$B = (\text{m s}^{-1})^2 (\text{kg m}^{-3})^2$$

$$B = \text{m}^2\ \text{s}^{-2}\ \text{kg}^2\ \text{m}^{-6}$$

$$B = \text{kg}^2\ \text{m}^{-4}\ \text{s}^{-2}$$

7 Lachlan

8 Joshua

9 Tom

10 Charlie

11

$$v = 346\ \text{m s}^{-1} \qquad \Delta t_{\text{lane 1}} = \frac{s}{v} = \frac{(2.00)}{(346)}$$

$$s_{\text{lane 1}} = 2.00\ \text{m} \qquad \Delta t_{\text{lane 1}} = 0.00578\ \text{s}$$

$$s_{\text{lane 1}} = 25.0\ \text{m}$$

$$\Delta t_{\text{lane 8}} = \frac{s}{v} = \frac{(25.0)}{(346)}$$

$$\Delta t_{\text{lane 8}} = 0.0723\ \text{s}$$

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12

$v = 346 \text{ m s}^{-1}$

$s = 50.00 \text{ m}$

$$\Delta t_{\text{lane 1}} = \frac{s}{v} = \frac{(50.00)}{(346)}$$
$$\Delta t_{\text{lane 1}} = 0.145 \text{ s}$$
$$s^2_{\text{lane 8}} = (50.00)^2 + (25.00)^2$$
$$s_{\text{lane 8}} = \sqrt{(50.00)^2 + (25.00)^2}$$
$$s_{\text{lane 8}} = 55.90 \text{ m}$$

$$\Delta t_{\text{lane 8}} = \frac{s}{v} = \frac{(55.90)}{(346)}$$
$$\Delta t_{\text{lane 8}} = 0.162 \text{ s}$$

13

$\Delta t_{\text{lane 1 swimmer}} = 0.00578 \text{ s}$

$\Delta t_{\text{lane 1 timer}} = 0.145 \text{ s}$

$\Delta t_{\text{lane 8 swimmer}} = 0.0723 \text{ s}$

$\Delta t_{\text{lane 8 timer}} = 0.162 \text{ s}$

$$\Delta t_{\text{lane 1}} = \Delta t_{\text{lane 1 timer}} - \Delta t_{\text{lane 1 swimmer}} = (0.145) - (0.00578)$$
$$\Delta t_{\text{lane 1}} = 0.1387 \ s$$
$$\Delta t_{\text{lane 8}} = \Delta t_{\text{lane 8 timer}} - \Delta t_{\text{lane 8 swimmer}} = (0.162) - (0.0723)$$
$$\Delta t_{\text{lane 8}} = 0.0893 \ s$$

With a greater difference in time between the swimmer starting and the timer timing, lane 1 has an advantage.

14

$\Delta t_{\text{lane 1 timer 1}} = 35.05 \pm 0.20 \text{ s}$

$\Delta t_{\text{lane 1 timer 2}} = 35.03 \ \pm 0.20\text{s}$

$\Delta t_{\text{lane 8 timer 1}} = 35.05 \pm 0.20 \text{ s}$

$\Delta t_{\text{lane 8 timer 2}} = 35.06 \pm 0.20 \text{ s}$

$$\text{average } \Delta t_{\text{lane 1}} = \frac{\Delta t_{\text{lane 1 timer 1}} + \Delta t_{\text{lane 1 timer 2}}}{2} = \frac{(35.05) + (35.03)}{2}$$
$$\text{average } \Delta t_{\text{lane 1}} = 35.04 \ \pm 0.40 \ s$$
$$\text{average } \Delta t_{\text{lane 8}} = \frac{\Delta t_{\text{lane 8 timer 1}} + \Delta t_{\text{lane 8 timer 2}}}{2} = \frac{(35.05) + (35.06)}{2}$$
$$\text{average } \Delta t_{\text{lane 8}} = 35.055 \ \pm 0.40 \text{ s}$$

Lane 1 probably won the race.

15

$$v^2 = u^2 + 2as$$
$$v^2 = 2as + u^2$$
$$y = mx + c$$

a v^2

b s

c $2a$

d u^2

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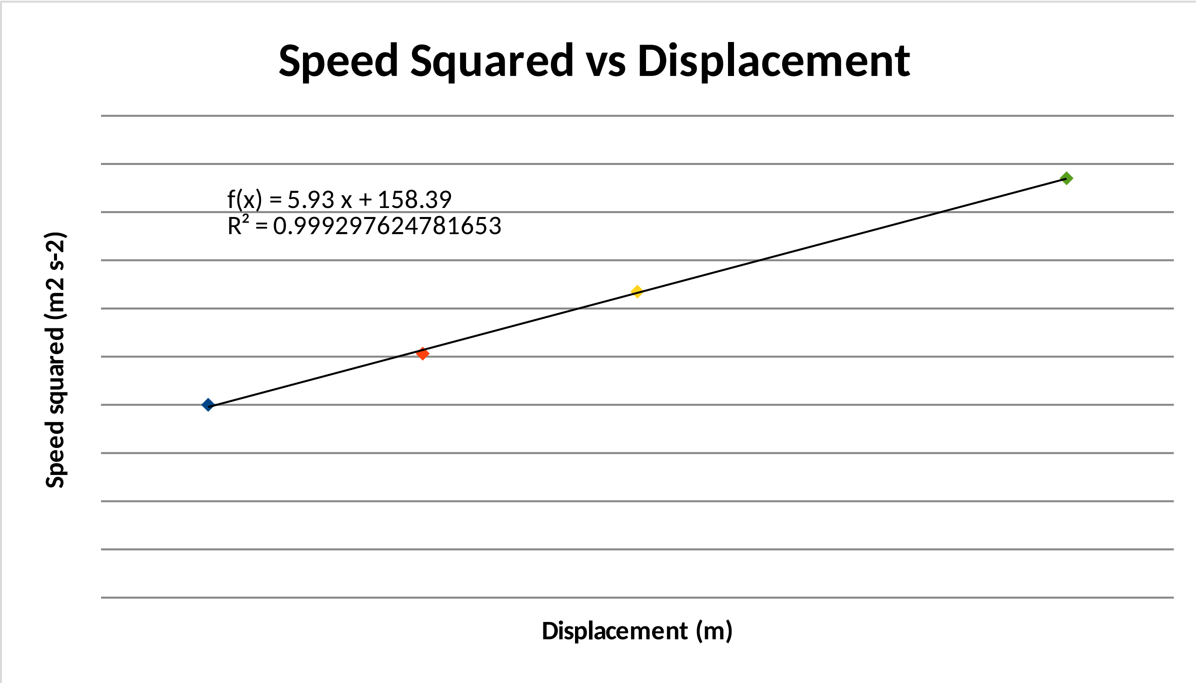
16

Displacement (s) (m)	**Speed (*v*) (m s^{-1})**	**Speed squared (v^2) (m^2 s^{-2})**
40.0	20.0	400.0
60.0	22.5	506.3
80.0	25.2	635.0
100.0	25.8	665.6 exclude
120.0	29.5	870.3

17



18 $y = 5.93x + 158.39$

19 **a** 5.93 m s^{-2}

b 158.39 m^2 s^{-2}

20

$$2a = 5.93$$

$$a = \frac{(5.93)}{2} = 2.97 \text{ m s}^{-2}$$

21

$$u^2 = 158.39$$

$$u = \sqrt{158.39} = 1.26 \times 10^1 \text{ m s}^{-1}$$

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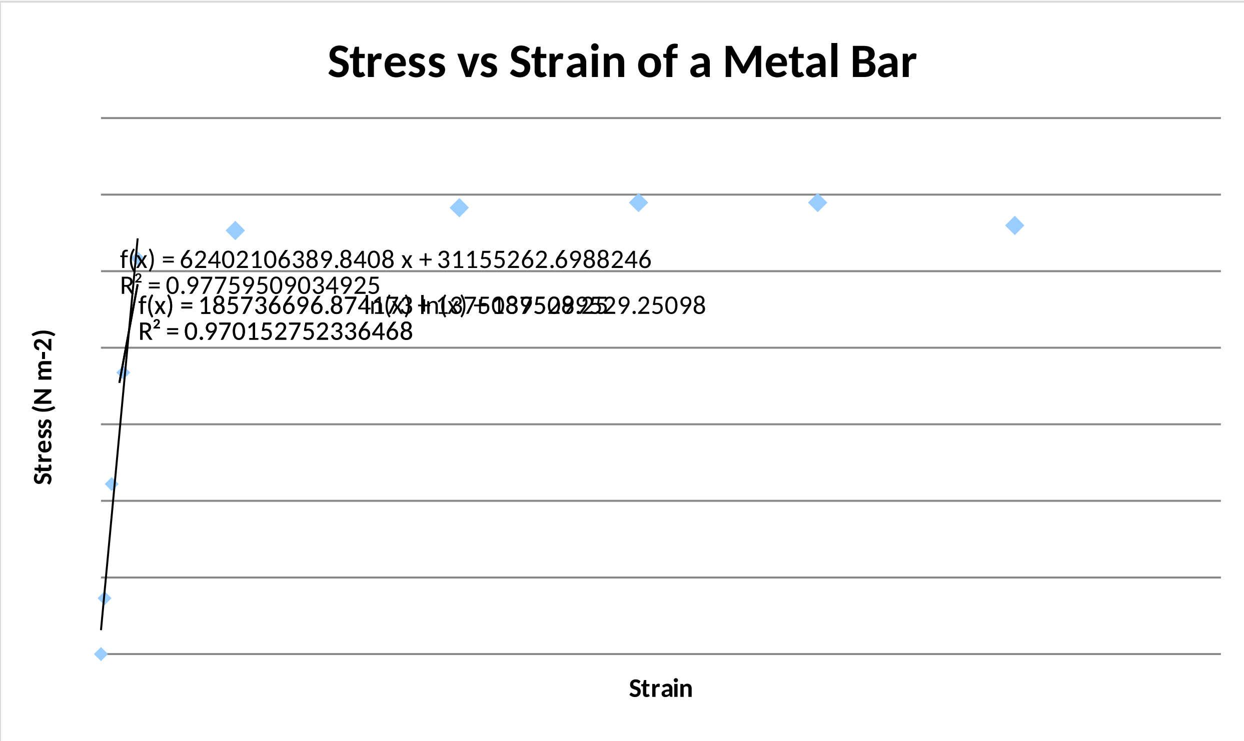
22

Load force (F_L) (kN)	Length (l) (m)	Stress (F m^{-2})	Strain
0.0	50.00	0.00	0.00
2.2	50.04	7.29×10^7	8.00×10^{-4}
6.7	50.12	2.22×10^8	2.40×10^{-3}
11.1	50.25	3.68×10^8	5.00×10^{-3}
15.6	50.41	5.17×10^8	8.20×10^{-3}
16.7	51.50	5.53×10^8	3.00×10^{-2}
17.6	54.00	5.83×10^8	8.00×10^{-2}
17.8	56.00	5.90×10^8	1.20×10^{-1}
17.8	58.00	5.90×10^8	1.60×10^{-1}
16.9	60.2	5.60×10^8	2.04×10^{-1}

23



24 Young's modulus = 6.24×10^{10} N m^{-2}

25

$$T = \sqrt{\frac{l}{k}}$$

$$T^2 = \frac{l}{k}$$

$$T^2 = \frac{1}{k}\, l \;+\; 0$$

$$y = m\;\; x \;+\; c$$

Therefore, graph T^2 ion the y-axis and l on the x-axis to graph a straight line.

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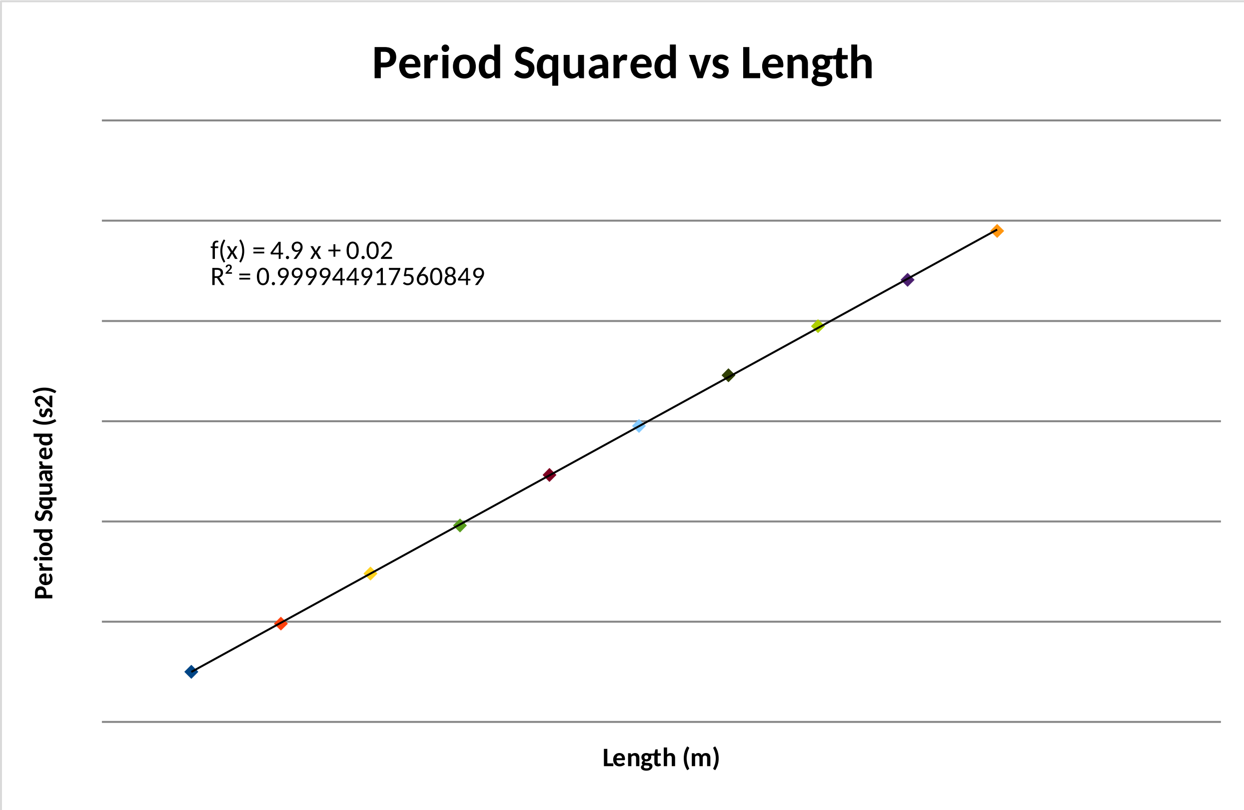
26 Slope of the line represents $\frac{l}{k}$

27



28

$$\frac{1}{k} = 4.9046$$

$$k = 0.204 \text{ m s}^{-2}$$

29 Mass has no affect on the period of a pendulum.

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