Please check the examination details below before entering your candidate information

Candidate surname	Matheson	Other names	Lewis

Centre Number: 3 5 8 9 7

Candidate Number: 9 3 2 3

Pearson Edexcel Level 3 GCE

Time 1 hour 45 minutes

Paper reference **9PH0/02**

Physics

Advanced

PAPER 2: Advanced Physics II

ALevelPhysicsOnline.com

You must have:
Scientific calculator, ruler

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- In the question marked with an **asterisk (*)**, marks will be awarded for your ability to structure your answer logically, showing how the points that you make are related or follow on from each other where appropriate.
- The list of data, formulae and relationships is printed at the end of this booklet.

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- You are advised to show your working in calculations, including units where appropriate.

Turn over ▶

Answer ALL questions.

All multiple choice questions must be answered with a cross in the box ☒ for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 A skydiver steps out of an aeroplane and falls from rest, towards the ground. Her parachute opens a short time after she reaches terminal velocity.

Which of the following statements is correct for the vertical acceleration a of the skydiver until her parachute opens?

- ☒ ✓ **A** a decreases to zero
- ☐ **B** a increases to a maximum
- ☐ **C** a is constant and equal to g
- ☐ **D** a is constant but less than g

'a' starts at a maximum value, then decreases as drag increases with velocity.

(Total for Question 1 = 1 mark)

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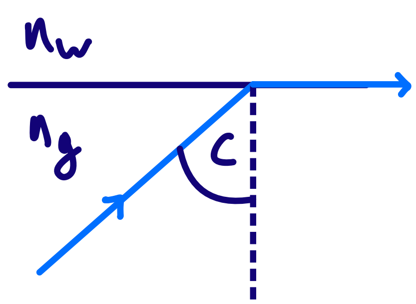
2 Light travelling in glass of refractive index n_g is incident at a boundary with water of refractive index n_w. The critical angle for the boundary is C.

Which of the following expressions is correct for this boundary?

- ☐ **A** $\sin C = \frac{1}{n_g}$
- ☒ ✓ **B** $\sin C = \frac{n_w}{n_g}$
- ☐ **C** $\sin C = \frac{n_g}{n_w}$
- ☐ **D** $\sin C = \frac{1}{n_w}$



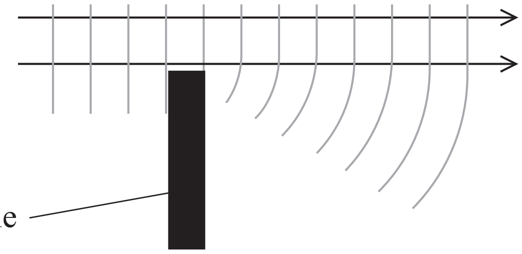
$n_g \sin\theta_g = n_w \sin\theta_w$

$n_g \sin C = n_w \sin 90$

$\sin C = \frac{n_w}{n_g}$

(Total for Question 2 = 1 mark)

3 Sound waves can diffract around obstacles as shown in the diagram.



The diffraction effect is

- **A** greater for large amplitude sound waves.
- **B** greater for low frequency sound waves.
- **C** independent of the frequency of the sound waves.
- **D** independent of the speed of the sound waves.

(Total for Question 3 = 1 mark)

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4 Which of the following is a valid unit for luminosity?

- **A** $W m^{-2}$
- **B** $N m s^{-2}$
- **C** $J s^{-1}$
- **D** $J m^{-2}$

(Total for Question 4 = 1 mark)

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5 Betelgeuse is a red giant star.

The surface temperature of Betelgeuse is T_B and the surface area of Betelgeuse is A_B. The surface temperature of the Sun is T_S and the surface area of the Sun is A_S.

Which row in the table shows a correct comparison of the surface temperature and surface area of Betelgeuse with those of the Sun?

	$T_B > T_S$	$A_B > A_S$
A	false	false
B	false	true
C	true	false
D	true	true

(Total for Question 5 = 1 mark)

6 In a particular radioactive decay, there is a mass decrease equivalent to 0.05 u.

Which of the following expressions gives the energy released in MeV?

☐ **A** $\dfrac{0.05 \times 1.66 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-19}}$

☐ **B** $\dfrac{0.05 \times 1.67 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-19}}$

☒ ✓ **C** $\dfrac{0.05 \times 1.66 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-13}}$

☐ **D** $\dfrac{0.05 \times 1.67 \times 10^{-27} \times (3 \times 10^{8})^{2}}{1.6 \times 10^{-13}}$

m (in kg) = $0.05 \times 1.66 \times 10^{-27}$

E (in J) = mc^2

E = $0.05 \times 1.66 \times 10^{-27} \times (3.00 \times 10^{8})^2$

E (in MeV)

= $\dfrac{0.05 \times 1.66 \times 10^{-27} \times (3.00 \times 10^{8})^2}{1.60 \times 10^{-19} \times 10^{6}}$

(Total for Question 6 = 1 mark)

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7 Air is trapped in a glass tube. When the air is forced into a smaller volume at a constant temperature, the pressure increases.

Which of the following statements about air molecules is a reason why the pressure the trapped air exerts on the tube increases?

☐ **A** The molecules have a greater mean kinetic energy. ✗

☐ **B** The molecules make more frequent collisions with each other. ✗

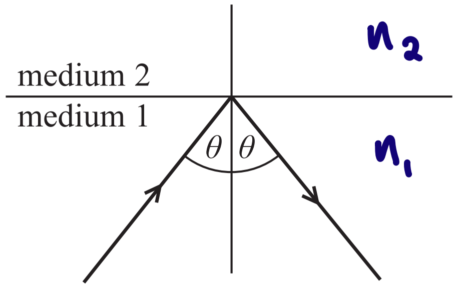
☒ ✓ **C** The molecules make more frequent collisions with the walls of the tube. ✓

☐ **D** The molecules experience a greater change in momentum when they collide with the tube. ✗

(Total for Question 7 = 1 mark)

P 6 9 4 4 2 A 0 4 3 2

8 Total internal reflection occurs when light is incident on the boundary between medium 1 and medium 2, as shown.



The refractive index of medium 1 is n_1 and the refractive index of medium 2 is n_2.

The critical angle for the boundary is C.

Which row of the table is correct?

☐	**A**	$\theta < C$	$n_1 > n_2$
☐	**B**	$\theta < C$	$n_2 > n_1$
☐	**C**	$\theta > C$	$n_1 < n_2$
☒	**D**	$\theta > C$	$n_2 < n_1$

TIR ∴ $\theta > C$

$\sin C = \frac{n_2}{n_1} < 1$

∴ $n_2 < n_1$

(Total for Question 8 = 1 mark)

9 The focal length and power of a converging glass lens are determined for the lens in air. The lens is then immersed in water.

Which row in the table shows how the focal length and power of the lens change?

	Focal length	Power of lens
☒ **A**	decreases	decreases
☒ **B**	decreases	increases
☒ **C**	increases	decreases
☒ **D**	increases	increases

air ⟶ water

$n \uparrow \therefore \lambda \downarrow \therefore$ refracts less

$\therefore$ focal length increases

$P = \frac{1}{f} \therefore P$ decreases

(Total for Question 9 = 1 mark)

10 A student used a Geiger-Müller (GM) tube to determine a value for the background count. He recorded the count for 2 minutes, every 15 minutes, as shown in the table.

Time / min	Count for 2 min
0	34
15	39
30	28

The counts are not the same.

Which of the following is the reason for this?

☒ **A** The background count rate is random.

☒ **B** The counter is incorrectly calibrated.

☒ **C** The temperature has not stayed constant.

☒ **D** There is a systematic error in the measurement.

(Total for Question 10 = 1 mark)

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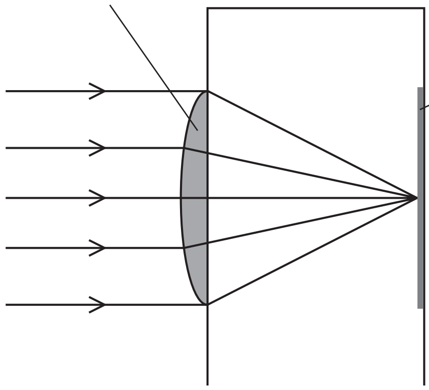
11 The lens of a mobile phone camera has a focal length of 4.25 mm. Light is focused onto light sensors at the back of the camera, as shown.



(a) The camera is initially focused on an object in the far distance.

Calculate the displacement of the lens that would be required to focus on an object 25.0 cm from the camera.

(4)

$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ $\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{4.25\times10^{-3}} - \frac{1}{0.250}$

$v = \frac{1}{231.3} = 4.3235\times10^{-3}$

$v - f = (4.3235 - 4.25)\times10^{-3} = 7.350\times10^{-5}$ m

Displacement of lens = 7.35×10^{-5} m

(b) State why the lens and the light sensors in a mobile phone camera can be positioned a fixed distance apart.

(1)

For most objects, $u \gg f$ so $v \approx f$.

(Total for Question 11 = 5 marks)

12 In February 2021 the spacecraft Perseverance Rover landed on Mars. When the spacecraft was 11.0 km above the surface of Mars, parachutes opened to slow the descent. The parachutes detached from the spacecraft when it was 2.1 km above the surface of Mars.

Calculate the change in gravitational potential energy of the spacecraft during the parachute section of its descent.

mass of spacecraft = 1030 kg
mass of Mars = 6.39×10^{23} kg
radius of Mars = 3390 km

$$\Delta V_g = -\frac{GM}{r_2} - \left(-\frac{GM}{r_1}\right) = GM\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$= 6.67\times10^{-11} \times 6.39\times10^{23} \times \left(\frac{1}{(11.0+3390)\times10^3} - \frac{1}{(2.1+3390)\times10^3}\right)$$ ✓

$= -32{,}881\ \text{J kg}^{-1}$

$\Delta E_g = \Delta V_g \times m = -32{,}881 \times 1030$ ✓ $= -3.387\times10^7$ J

Change in gravitational potential energy of the spacecraft = -3.4×10^7 J ✓

(Total for Question 12 = 3 marks)

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13 Actinium-225 and bismuth-210 are radioactive isotopes. A sample of each isotope is prepared so that each sample has the same number of nuclei initially.

Explain why the activity of each sample would be the same after 10 days.

half-life of actinium-225 = 10 days A
half-life of bismuth-210 = 5 days B

$\lambda = \frac{\ln 2}{t_{1/2}}$ $\lambda_A = \frac{\ln 2}{10}$ ✓ $A_A = \lambda_A N_A = \frac{\ln 2}{10} N_A$ ✓

$\lambda_B = \frac{\ln 2}{5}$ $A_B = \lambda_B N_B = \frac{\ln 2}{5} N_B$

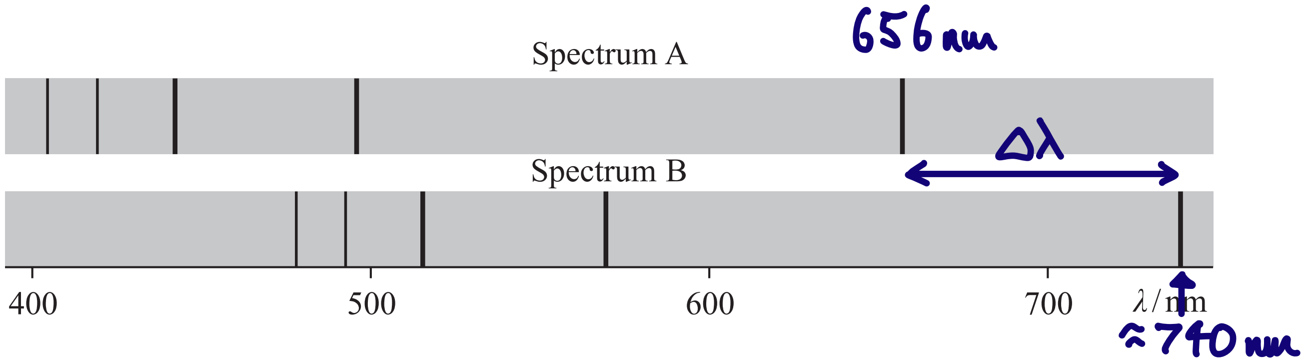
After 10 days, $N_A = \frac{N}{2}$ and $N_B = \frac{N}{2^2} = \frac{N}{4}$ ✓

$A_A = \frac{\ln 2}{10} \cdot \frac{N}{2} = \frac{\ln 2 . N}{20}$

(Total for Question 13 = 4 marks)

$A_B = \frac{\ln 2}{5} \cdot \frac{N}{4} = \frac{\ln 2 . N}{20}$ $\therefore$ $A_A = A_B$ ✓

14 The diagram shows the spectra produced by two stars. Spectrum A is produced from the light from the Sun and spectrum B is produced from the light from a distant star.



The dark lines are produced when light from the core of the star is absorbed by hydrogen atoms in the outer regions of the star. Light is then re-radiated, but in all directions, giving rise to the dark lines in the spectrum.

(a) Explain why the long wavelength lines are shifted by a greater amount than the short wavelength lines.

(2)

$z = \Delta\lambda / \lambda$ = constant for all λ ✓ ∴ for a longer wavelength, the change in wavelength will be greater. ✓

(b) One of the lines in the hydrogen spectrum occurs at a wavelength of 656 nm in the laboratory.

Explain what conclusion can be made from the shift in wavelength of this line in spectrum B. Your answer should include a calculation.

(4)

$$\frac{\Delta\lambda}{\lambda} = \frac{740 - 656}{656} = 0.128 = \frac{v}{c}$$ ✓ ✓

$v = 0.128 \times 3.00 \times 10^{8} = \underline{3.84} \times 10^{7}\ \text{m s}^{-1}$ ✓

Wavelength increased ∴ star is moving away from the Earth. ✓

(Total for Question 14 = 6 marks)

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15 Aluminium is one of the most widely recycled metals. Aluminium cans are heated from room temperature until all the aluminium has melted. The molten aluminium is then used to make new cans. This process uses only 5% of the energy needed to extract aluminium from raw materials.

On a website it is claimed that recycling one aluminium can of mass 14 g saves enough energy to listen to music on a mobile phone continuously for 7 days.

Assess the validity of this claim.

melting point of aluminium = 660 K
specific heat capacity of aluminium = 902 J kg^{-1} K^{-1}
specific latent heat of aluminium = 396 kJ kg^{-1}
room temperature = 293 K
mobile phone p.d. = 3.7 V
mobile phone current = 120 mA

Need to heat Al then change its state.

$\therefore \Delta E = mc\Delta\theta + mL_f$ ✓ ✓

$= 0.014 \times 902 \times (660-293) + 0.014 \times 396 \times 10^3$

$= 10{,}178$ J (to recycle 1 can)

$= 10{,}178 \div 0.05 = 203{,}570$ J (to extract Al)

E saved $= 203{,}570 - 10{,}178 = 1.934 \times 10^5$ J ✓

$E_{music} = VIt$ ✓ $= 3.7 \times 120 \times 10^{-3} \times 7 \times 24 \times 60^2$

$= 2.685 \times 10^5$ J ✓

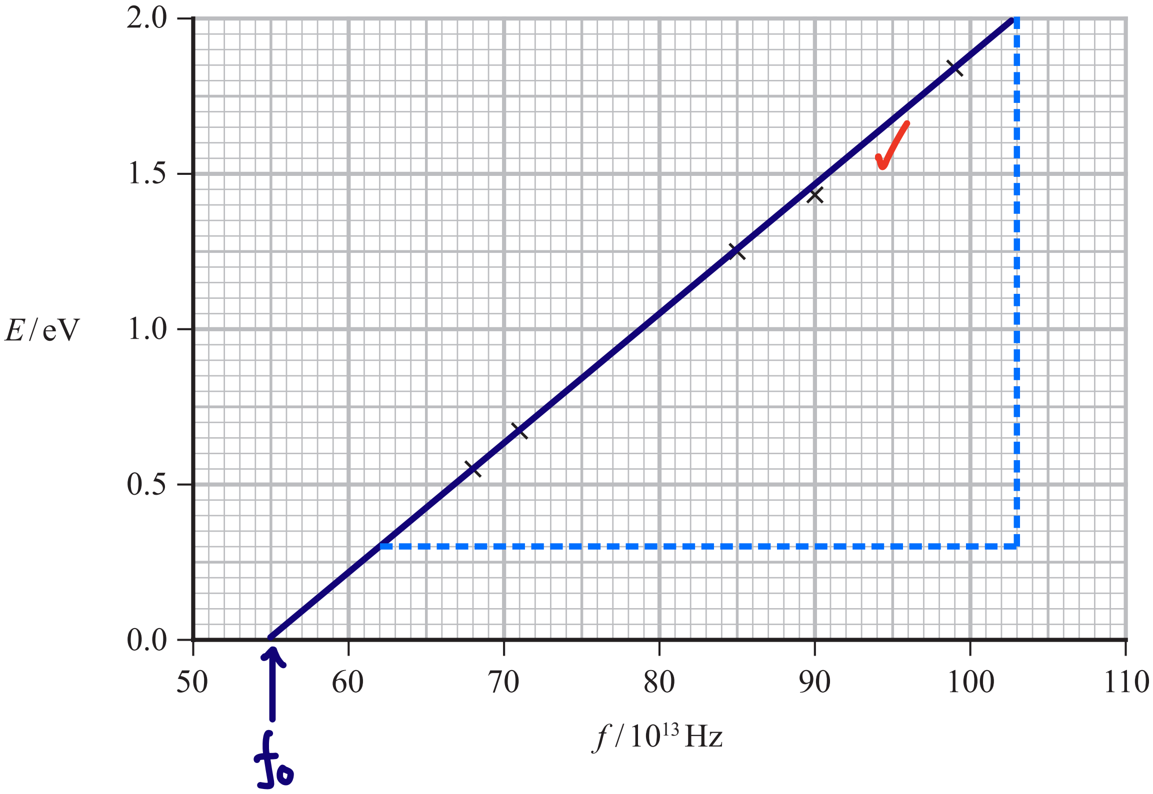
$2.685 \times 10^5 > 1.934 \times 10^5$

$\therefore$ claim not valid ✓

(Total for Question 15 = 6 marks)

16 In an investigation of the photoelectric effect, electromagnetic radiation of frequency f was directed onto a metal plate. The maximum kinetic energy E of the photoelectrons emitted from the metal plate was determined. The procedure was repeated for a range of frequencies.

The graph shows how E depended upon f.



(a) Determine a value for the Planck constant, h, in J s.

(4)

$hf = \phi + E_K$ $E_K = hf - \phi$
$y = mx + c$

$h = \text{gradient} = \frac{2.0 - 0.3}{(103-62) \times 10^{13}} = 4.146 \times 10^{-15}$ eV s

h (in Js) $= 4.146 \times 10^{-15} \times 1.60 \times 10^{-19} = 6.634 \times 10^{-34}$ Js

$h =$ 6.6×10^{-34} J s

(b) The table gives data for different metal surfaces.

Metal surface	Work function / eV
Caesium	2.0
Calcium	2.9
Magnesium	3.7

Deduce which metal was being used in the investigation.

(3)

When $E_K = 0$ $\phi = hf_0 = 6.63 \times 10^{-34} \times 55 \times 10^{13}$ ✓

$= 3.647 \times 10^{-19}$ J

in eV $\div 1.60 \times 10^{-19} = 2.279$ eV ✓

∴ closest to Caesium ✓

(Total for Question 16 = 7 marks)

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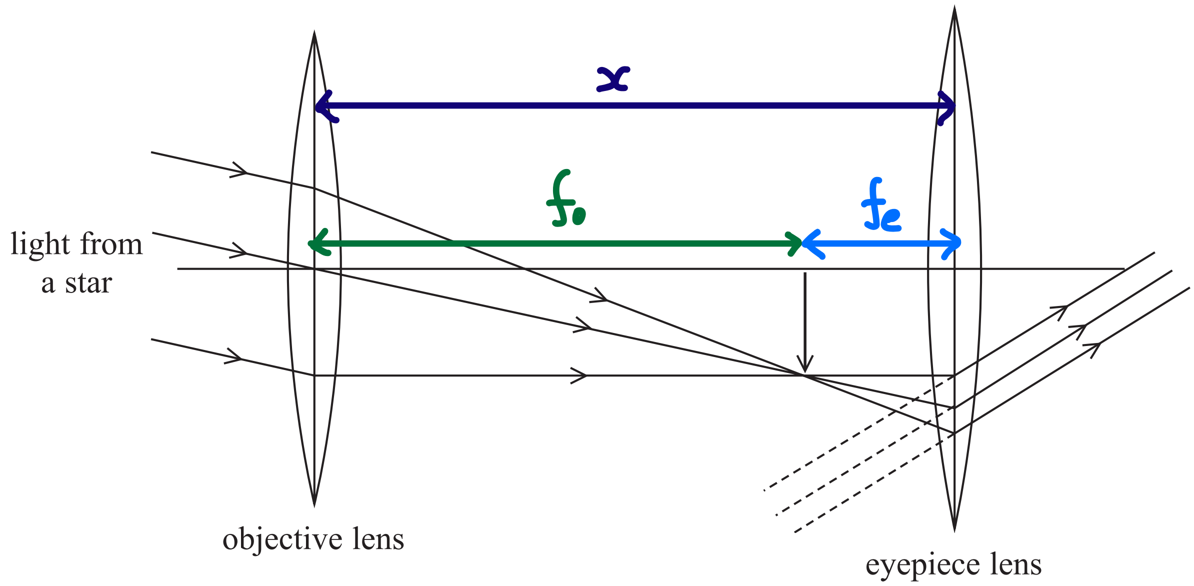
17 A simple astronomical refracting telescope consists of two converging lenses. Light from a star is brought to a focus by the objective lens and then viewed through an eyepiece lens as shown.



(a) (i) In the arrangement shown, the final image is formed at infinity.

Explain why the separation of the objective and eyepiece lenses is equal to the sum of their focal lengths.

(2)

Object is at infinity ∴ image formed at focal length of objective lens (f_o). ✓

Image formed by eyepiece is at infinity, because the object of this is at the focal point (distance f_e). ∴ $x = f_o + f_e$ ✓

(ii) State why the final image is inverted.

(1)

Rays cross over each other after they go through the objective lens. ✓

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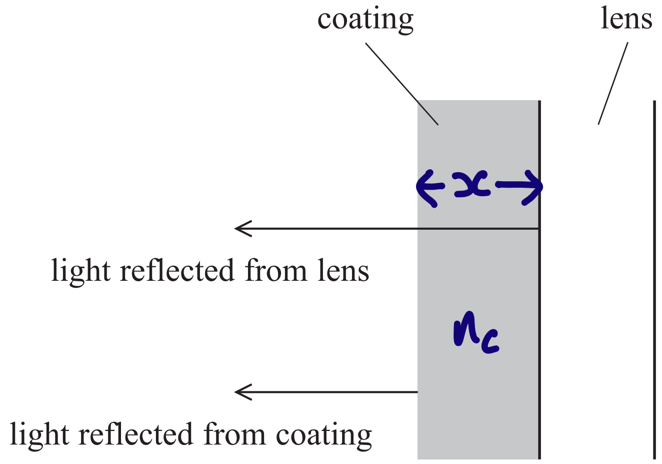
P 6 9 4 4 2 A 0 1 4 3 2

(b) Glass lenses used for optical instruments often have an anti-reflective coating. The coating is a thin layer of a transparent substance with refractive index n_c.

Light is reflected from the coating surface and from the lens surface as shown. The reflected light interferes destructively.



When a single-layer coating is used, the coating thickness is chosen to eliminate reflections for green light, which is in the middle of the visible spectrum.

(i) Calculate the minimum thickness d of the coating required for the reflection of green light to be eliminated.

frequency of green light = 6.00×10^{14} Hz
$n_c = 1.38$

(4)

$n_c = \frac{c}{v}$ ✓ and $v = f\lambda$ ✓ $\therefore n_c = \frac{c}{f\lambda}$

$\lambda = \frac{c}{f n_c} = \frac{3.00 \times 10^8}{6.00 \times 10^{14} \times 1.38} = 3.623 \times 10^{-7}$ m

The light from the lens must destructively interfere with the light from the coating. This occurs when the path difference = $\lambda/2$ and the distance is $2x$. ✓

$\therefore x = \frac{\lambda}{4} = \frac{3.623 \times 10^{-7}}{4} = 9.058 \times 10^{-8}$ m

$d = $ 9.1×10^{-8} m ✓

(ii) State why white light reflected from coated lenses is seen as purple.

(1)

As the green light is reduced, this leaves the red and blue which mix and appear magenta in the reflected light. ✓

(Total for Question 17 = 8 marks)

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18 The harp is a musical instrument with many strings, as shown.

(Source: © Peter Voronov/Shutterstock)

All the strings are under tension.

The strings on one type of harp are made from nylon of density 1070 kg m^{-3}. One string has a diameter of 1.14 mm.

(a) (i) Show that the mass per unit length μ of the string is about 1.1×10^{-3} kg m^{-1}.

(2)

$\rho = \frac{m}{V}$ and $V = \frac{\pi d^2 L}{4}$ $\rho = \frac{4m}{\pi d^2 L}$

$\mu = \frac{m}{L} = \frac{\rho \pi d^2}{4} = \frac{1070 \times \pi \times (1.14 \times 10^{-3})^2}{4} = 1.092 \times 10^{-3}$ kg m^{-3} $\approx 1.1 \times 10^{-3}$

(ii) When the middle of the string is plucked, a note of frequency 440 Hz is produced.

Calculate the tension in the string.

length of string = 41.0 cm

(4)

$L = \frac{\lambda}{2}$ ✓ $v = f\lambda$ ✓ $v = \sqrt{\frac{T}{\mu}}$ ✓

$f\lambda = \sqrt{\frac{T}{\mu}}$ $2fL = \sqrt{\frac{T}{\mu}}$

$T = 4f^2L^2\mu = 4 \times 440^2 \times (41.0 \times 10^{-2})^2 \times 1.092 \times 10^{-3}$

$T = 142.2$ N

Tension in string = 142 N ✓

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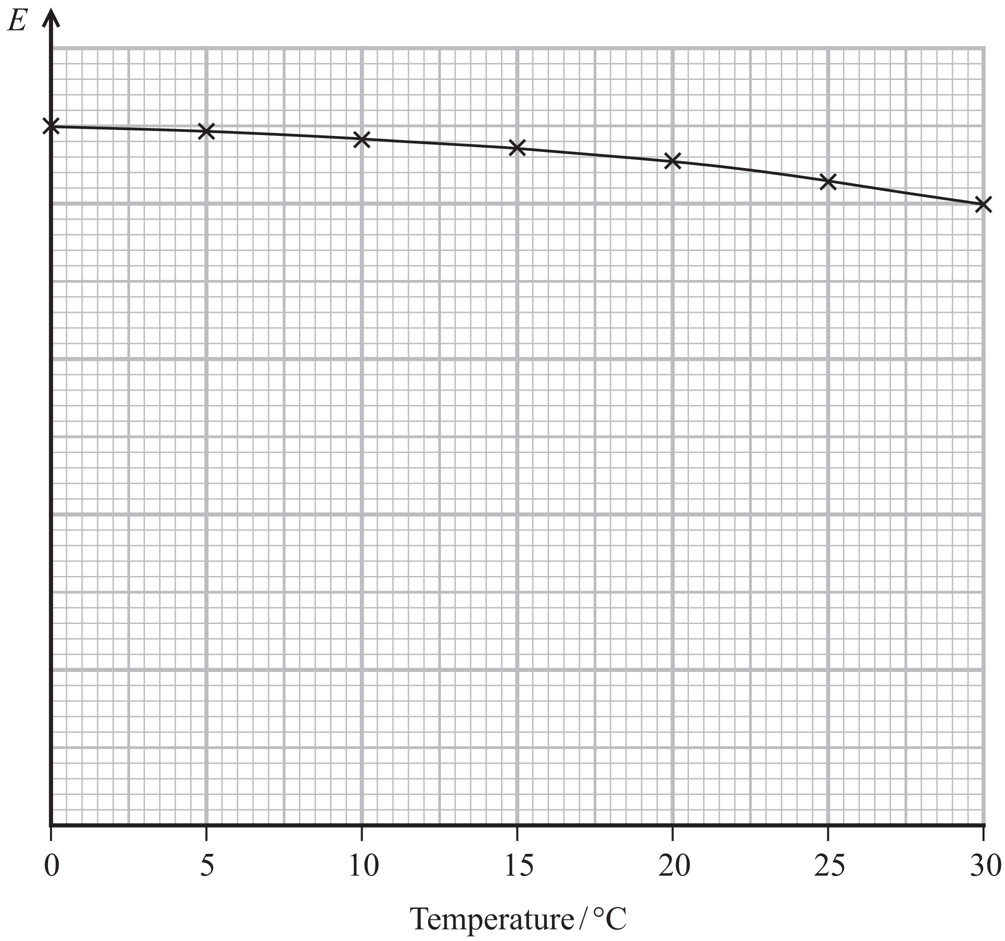
(b) The graph shows how the Young modulus E of the nylon varies with temperature.



When the harp is played, the temperature of the string increases.

Explain how this temperature change would affect the frequency of the note produced when the string is plucked.

(3)

As the temperature increases, the Young modulus decreases. ✓ As $E = Fx/\Delta x A$, ∴ $E \propto F$, so the tension decreases. ✓ $T = 4L^2 f^2 \mu$, ∴ $T \propto f^2$, so the frequency of the note also decreases (as the wavelength is constant). ✓

(Total for Question 18 = 9 marks)

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19 A fine-beam tube is used for investigating properties of electrons.

An electron beam is produced inside a spherical glass bulb. The bulb contains neon gas at a very low pressure.

(a) The neon gas is at a pressure of 1.25 Pa and a temperature of 25 °C.

Calculate the number N of neon atoms inside the bulb.

bulb diameter = 16.0 cm

(4)

$V = \frac{4}{3}\pi r^3$ ✓ $pV = NkT$ ✓

$N = \frac{4p\pi r^3}{3kT} = \frac{4 \times 1.25 \times \pi \times (0.080)^3}{3 \times 1.38 \times 10^{-23} \times (25 + 273)} = 6.519 \times 10^{17}$ ✓

$N =$ 6.5×10^{17} ✓

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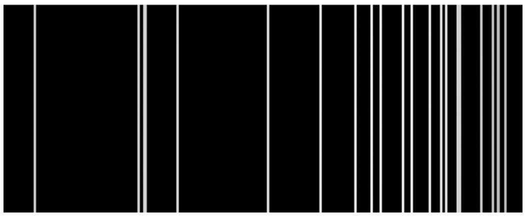
*(b) Interactions between electrons and the neon atoms in the tube make the beam visible. Part of the spectrum of visible light produced by these interactions is shown.



(Source: © MoFarouk/Shutterstock)

Explain the process that results in the emission of this spectrum. Your answer should include reference to energy levels in atoms.

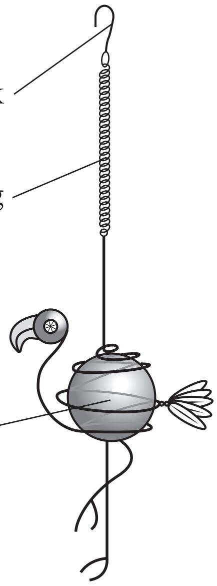
(6)

Electrons in the neon atoms absorb energy due to collisions with electrons in the tube ✓, causing them to jump to higher energy levels. ✓ A photon is released ✓ when the atom de-excites and the electron drops back down.

The energy levels are discrete ✓ ∴ the frequency of the emitted photon is determined by the difference between energy levels ✓ ∴ a limited number of energy level changes so only specific frequencies emitted. ✓

(Total for Question 19 = 10 marks)

20 A garden ornament consists of a metal flamingo suspended from a spring as shown. The spring is hung from a support using the hook.



(a) The mass of the flamingo is 65 g. When the flamingo is suspended vertically the spring extends by 8.5 cm.

The flamingo is pulled downwards by a small extra displacement and then released. The flamingo undergoes simple harmonic motion vertically.

The instructions state that the flamingo will oscillate with a frequency of 2.5 Hz.

Deduce whether this statement is correct.

(5)

$W = mg$ ✓ $F = k\Delta x$ ✓ $k = \frac{mg}{\Delta x} = \frac{0.065 \times 9.81}{0.085}$

$k = 7.502\ \text{Nm}^{-1}$

$T = 2\pi\sqrt{\frac{m}{k}}$ ✓ $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ ✓ $= \frac{1}{2\pi}\sqrt{\frac{7.502}{0.065}}$

$f = 1.710\ \text{Hz} \neq 2.5\ \text{Hz}$

∴ instructions incorrect ✓

(b) After being set into vertical oscillation, the flamingo comes to rest after a short time.

Explain why the flamingo comes to rest.

(2)

There is damping due to air resistance ✓ ∴ energy is removed from the oscillating system. ✓

(c) In a slight breeze the flamingo swings from side to side and behaves as a simple pendulum.

(i) Show that the period of oscillation of the flamingo pendulum is about 2.2 s.

pendulum length = 1.25 m

(2)

$T = 2\pi\sqrt{\frac{L}{g}}$ ✓ $= 2\pi\sqrt{\frac{1.25}{9.81}} = 2.243\ s$ ✓ $\approx 2.2\ s$

(ii) The amplitude of oscillation of the flamingo pendulum is 7.5 cm.

Calculate the maximum velocity of the flamingo pendulum.

(3)

$\omega = \frac{2\pi}{T}$ ✓ $= \frac{2\pi}{2.243} = 2.801\ rad\ s^{-1}$

$V_{max} = \omega A$ ✓ $= 2.801 \times 0.075 = 0.2101\ ms^{-1}$

Maximum velocity = 0.21 ✓ ms^{-1}

(Total for Question 20 = 12 marks)

21 A hundred years ago, a method to determine the age of certain rocks was developed. An unstable isotope of rubidium is present in some rocks when they form. Over time the rubidium decays to a stable isotope of strontium.

(a) Rubidium decays to strontium via β^- decay. Complete the nuclear equation representing the decay.

$$^{87}_{37}\mathrm{Rb} \rightarrow {}^{87}_{38}\mathrm{Sr} + {}^{0}_{-1}\beta^- + \bar{\nu}_e$$

✓ ✓

(2)

(b) A sample of Moon rock from the Apollo 11 mission was analysed to determine the age of the rock. When the sample was analysed the number of rubidium atoms was N_R and the number of strontium atoms was N_S.

As strontium atoms have all been produced from the decay of rubidium, the original number of rubidium atoms in the sample was $(N_R + N_S)$.

From the analysis of the sample, it was determined that $\frac{N_S}{N_R} = 0.0532$

Deduce whether this ratio is consistent with the Earth and the Moon forming at the same time.

age of Earth = 4.5×10^9 years
half-life of rubidium isotope = 4.88×10^{10} years

(5)

$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{4.88 \times 10^{10}} = 1.42 \times 10^{-11}\ \mathrm{yr}^{-1}$ ✓

$N = \frac{N_R}{N_R + N_S} N_0 \qquad \frac{N_0}{N} = \frac{N_R + N_S}{N_R} = 1 + \frac{N_S}{N_R} = 1.0532$ ✓

$N = N_0 e^{-\lambda t}$ ✓ $\quad \frac{N}{N_0} = e^{-\lambda t} \quad \ln\left(\frac{N}{N_0}\right) = -\lambda t \quad \ln\left(\frac{N_0}{N}\right) = \lambda t$

$t = \ln\left(\frac{N_0}{N}\right) \div \lambda = \ln 1.0532 \div 1.42 \times 10^{-11} = 3.649 \times 10^9\ \mathrm{yr}$ ✓

$3.649 \times 10^9 \neq 4.5 \times 10^9$ ∴ not consistent as about a billion years apart ✓

(c) Give a reason why the half-life of the rubidium isotope is hard to determine.

(1)

Activity is very small ✓ (so hard to measure accurately).

(d) Recent investigations suggest that the half-life of the rubidium isotope may be larger than the traditionally accepted value.

Explain how this would affect the ages obtained by this dating method.

(2)

If $t_{1/2}$ is larger, λ will be smaller as $\lambda \propto \frac{1}{t_{1/2}}$ ✓

$N = N_0 e^{-\lambda t}$ ∴ calculated value of time would be greater ✓

(Total for Question 21 = 10 marks)

TOTAL FOR PAPER = 90 MARKS

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List of data, formulae and relationships

Acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$	(close to Earth's surface)
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$	
Coulomb law constant	$k = \dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9} \text{ N m}^2 \text{ C}^{-2}$	
Electron charge	$e = -1.60 \times 10^{-19} \text{ C}$	
Electron mass	$m_e = 9.11 \times 10^{-31} \text{ kg}$	
Electronvolt	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$	
Gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$	
Gravitational field strength	$g = 9.81 \text{ N kg}^{-1}$	(close to Earth's surface)
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$	
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$	
Proton mass	$m_p = 1.67 \times 10^{-27} \text{ kg}$	
Speed of light in a vacuum	$c = 3.00 \times 10^{8} \text{ m s}^{-1}$	
Stefan-Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$	
Unified atomic mass unit	$u = 1.66 \times 10^{-27} \text{ kg}$	

Mechanics

Kinematic equations of motion

$$s = \frac{(u + v)t}{2}$$

$$v = u + at$$

$$s = ut + \tfrac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

Forces

$$\Sigma F = ma$$

$$g = \frac{F}{m}$$

$$W = mg$$

moment of force = Fx

Momentum

$$p = mv$$

Work, energy and power

$$\Delta W = F\Delta s$$

$$E_k = \tfrac{1}{2}mv^2$$

$$\Delta E_{grav} = mg\Delta h$$

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

$$P = \frac{W}{t}$$

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

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Electric circuits

Potential difference

$$V = \frac{W}{Q}$$

Resistance

$$R = \frac{V}{I}$$

Electrical power and energy

$$P = VI$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

$$W = VIt$$

Resistivity

$$R = \frac{\rho l}{A}$$

Current

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = nqvA$$

Materials

Density

$$\rho = \frac{m}{V}$$

Stokes' law

$$F = 6\pi\eta rv$$

Hooke's law

$$\Delta F = k\Delta x$$

Young modulus

$$\text{Stress } \sigma = \frac{F}{A}$$

$$\text{Strain } \varepsilon = \frac{\Delta x}{x}$$

$$E = \frac{\sigma}{\varepsilon}$$

Elastic strain energy

$$\Delta E_{el} = \tfrac{1}{2}F\Delta x$$

Waves and particle nature of light

Wave speed

$$v = f\lambda$$

Speed of a transverse wave on a string

$$v = \sqrt{\frac{T}{\mu}}$$

Intensity of radiation

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

Power of a lens

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

$$P = P_1 + P_2 + P_3 + \ldots$$

Thin lens equation

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Magnification for a lens

$$m = \frac{\text{image height}}{\text{object height}} = \frac{v}{u}$$

Diffraction grating

$$n\lambda = d \sin\theta$$

Refractive index

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$n = \frac{c}{v}$$

Critical angle

$$\sin C = \frac{1}{n}$$

Photon model

$$E = hf$$

Einstein's photoelectric equation

$$hf = \phi + \tfrac{1}{2}mv^2_{max}$$

de Broglie wavelength

$$\lambda = \frac{h}{p}$$

Further mechanics

Impulse

$$F\Delta t = \Delta p$$

Kinetic energy of a non-relativistic particle

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

Motion in a circle

$$v = \omega r$$

$$T = \frac{2\pi}{\omega}$$

$$F = ma = \frac{mv^2}{r}$$

$$a = \frac{v^2}{r}$$

$$a = r\omega^2$$

$$F = mr\omega^2$$

Fields

Coulomb's law

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$$

Electric field strength

$$E = \frac{F}{Q}$$

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$E = \frac{V}{d}$$

Electric potential

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

Capacitance

$$C = \frac{Q}{V}$$

Energy stored in a capacitor

$$W = \tfrac{1}{2}QV$$

$$W = \tfrac{1}{2}CV^2$$

$$W = \tfrac{1}{2}\frac{Q^2}{C}$$

Capacitor discharge

$$Q = Q_0 e^{-t/RC}$$

$$I = I_0 e^{-t/RC}$$

$$V = V_0 e^{-t/RC}$$

$$\ln Q = \ln Q_0 - \frac{t}{RC}$$

$$\ln I = \ln I_0 - \frac{t}{RC}$$

$$\ln V = \ln V_0 - \frac{t}{RC}$$

In a magnetic field

$$F = BIl \sin\theta$$

$$F = Bqv \sin\theta$$

Faraday's and Lenz's laws

$$\mathscr{E} = \frac{-d(N\phi)}{dt}$$

Root-mean-square values

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

Nuclear and particle physics

In a magnetic field

$$r = \frac{p}{BQ}$$

Thermodynamics

Heating

$$\Delta E = mc\Delta\theta$$

$$\Delta E = L\Delta m$$

Molecular kinetic theory

$$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$$

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

Ideal gas equation

$$pV = NkT$$

Stefan-Boltzmann law

$$L = \sigma AT^4$$

$$L = 4\pi r^2\sigma T^4$$

Wien's law

$$\lambda_{max}T = 2.898 \times 10^{-3}\ \text{m K}$$

Space

Intensity

$$I = \frac{L}{4\pi d^2}$$

Redshift of electromagnetic radiation

$$z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$$

Cosmological expansion

$$v = H_0 d$$

Nuclear radiation

Mass-energy

$$\Delta E = c^2\Delta m$$

Radioactive decay

$$A = \lambda N$$

$$\frac{dN}{dt} = -\lambda N$$

$$\lambda = \frac{\ln 2}{t_{1/2}}$$

$$N = N_0\ e^{-\lambda t}$$

$$A = A_0\ e^{-\lambda t}$$

Gravitational fields

Gravitational force

$$F = \frac{Gm_1m_2}{r^2}$$

Gravitational field strength

$$g = \frac{Gm}{r^2}$$

Gravitational potential

$$V_{grav} = \frac{-Gm}{r}$$

Oscillations

Simple harmonic motion

$$F = -kx$$

$$a = -\omega^2 x$$

$$x = A\cos\omega t$$

$$v = -A\omega\sin\omega t$$

$$a = -A\omega^2\cos\omega t$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega}$$

$$\omega = 2\pi f$$

Simple harmonic oscillator

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$T = 2\pi\sqrt{\frac{l}{g}}$$

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