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Government of **Western Australia**
School Curriculum and Standards Authority

PHYSICS

ATAR course examination 2024

Marking key

The examining panel provide a provisional marking key. The marking key is refined or modified as necessary in the light of sample marking and discussion between the chief examiner and the chief marker.

Section One: Short response **30% (55 Marks)**

Question 1 **(4 marks)**

(a) In what direction is the force on the wire acting? (1 mark)

Description	Marks
B. Downward	1
Total	**1**

(b) Calculate the magnitude of the force on the wire. (3 marks)

Element	Description	Marks
Uses correct equation	$F = I\ell B$	1
Substitutes values	$F = (2.54)(0.250)(3.78\times10^{-3})$	1
Calculates answer	$F = 2.40\times10^{-3}$ N	1
Total		**3**

Question 2 **(5 marks)**

(a) Define the term 'black body'. (2 marks)

Description	Marks
Any two of	
• a black body allows all incident radiation to pass into it (no reflected energy) • a black body absorbs all the incident radiation (no energy is transmitted through the body) • a black body re-emits all incident radiation	1–2
Total	**2**

(b) With reference to the graph above, explain how a star's colour indicates their surface temperature. (3 marks)

Description	Marks
a star's colour is determined by the wavelengths of radiation it emits	1
from the graph, as surface temperature increases, the peak intensity of radiation occurs at lower wavelengths	1
therefore, a star's colour changes (red → blue) as surface temperature increases	1
Total	**3**

Question 3 **(7 marks)**

Express v_2 in terms of v_1. Assume there is no air resistance and the sponge lands in the middle of the bucket. Show all working.

Element	Description	Marks
Uses correct equation for t	$s = ut + \frac{1}{2}at^2$	1
Substitutes $u = 0$ m s^{-1}		1
Rearrange for t_1, time to fall from height h	$h = \frac{1}{2}gt_1^{\,2}$ $t_1 = \sqrt{\frac{2h}{g}}$	1
Substitutes $\sqrt{\frac{2h}{g}}$ for t_1 into equation for v_1, the velocity to cover distance R	$v_1 = \frac{R}{t_1} = \frac{R}{\sqrt{\frac{2h}{g}}}$	1
Rearrange for t_2, time to fall from height $\frac{1}{2}h$	$\frac{1}{2}h = \frac{1}{2}gt_2^{\,2}$ $t_2 = \sqrt{\frac{h}{g}}$	1
Substitutes $\sqrt{\frac{h}{g}}$ for t_2 into equation for v_2, the velocity to cover distance R	$v_2 = \frac{R}{t_2} = \frac{R}{\sqrt{\frac{h}{g}}}$	1
Divides two expressions to obtain ratio	$\frac{v_2}{v_1} = \frac{\frac{R}{\sqrt{\frac{h}{g}}}}{\frac{R}{\sqrt{\frac{2h}{g}}}} = \sqrt{2} = 1.41$ $v_2 = 1.41v_1$	1
	Total	**7**

Question 4 **(3 marks)**

Explain how this separation enabled the formation of hadrons.

Description	Marks
the strong nuclear force is mediated by the exchange of gluons	1
quarks could now exchange gluons and interact	1
hadrons are formed by quarks exchanging gluons and binding together	1
Total	**3**

Question 5 **(4 marks)**

Calculate the maximum tension in the string if the maximum speed the keys reach is 4.65 m s^{-1}

Element	Description	Marks
Use expression for net force acting on keys at bottom of circle	$F_{net} = \frac{mv^2}{r} = F_T - mg$	1
Rearrange for F_T	$F_T = mg + \frac{mv^2}{r}$	1
Substitute values into expression	$F_T = (0.120)(9.80) + \frac{(0.120)(4.65)^2}{0.370}$	1
Calculates F_T	$F_T = 8.19$ N	1
	Total	**4**

Question 6 **(5 marks)**

(a) Identify a possible third quark. (1 mark)

Element	Description	Marks
Identifies a third quark of charge $+\frac{2}{3}$	u or c or t	1
	Total	**1**

(b) Determine the quark composition of the hadron's anti-particle and its charge. (2 marks)

Element	Description	Marks
States quark composition	anti u + anti b + anti third quark	1
States quark charge	-1 e	1
	Total	**2**

(c) The up quark in the hadron decays by the weak interaction into a down quark, a positron, and a neutrino. Show that both charge and lepton number are conserved in this reaction. (2 marks)

Element	Description	Marks
Shows charge conserved	$+\frac{2}{3} = -\frac{1}{3} + (+1) + 0 = +\frac{2}{3}$	1
Shows electron lepton number conserved	$0 = 0 + (-1) + (+1) = 0$	1
	Total	**2**

Question 7 **(4 marks)**

Calculate the initial speed of the ball when hit.

Element	Description	Marks
Determines expression for vertical component of speed	$v_v = v_0 \sin 50.0^\circ$	1
Substitutes values for maximum vertical displacement into $v^2 = u^2 + 2as$	$0 = (v_0 \sin 50.0^\circ)^2 + 2(-9.80)(21.5)$	1
Rearranges for v_0	$v_0 = \sqrt{\frac{421.4}{(\sin 50.0^\circ)^2}}$	1
Calculates initial speed	$v_0 = 26.8 \text{ m s}^{-1}$	1
	Total	**4**

Question 8 **(6 marks)**

(a) Derive the following expression that relates the angle of lean θ, to the speed v of the cyclist, the radius r of the circular path of the cyclist's centre of mass and the acceleration due to gravity g.

$$\tan\theta = \frac{v^2}{rg}$$ (3 marks)

Element	Description	Marks
Equates friction force to centripetal force	$F_{\text{friction}} = F_c = R\sin\theta = \frac{mv^2}{r}$	1
Equates normal force to weight force	$F_{\text{normal}} = R\cos\theta = mg$	1
Divides F_{friction} by F_{normal} to obtain $\tan\theta = \frac{v^2}{rg}$	$\frac{R\sin\theta}{R\cos\theta} = \frac{\frac{mv^2}{r}}{mg}$ $\tan\theta = \frac{v^2}{rg}$	1
	Total	**3**

(b) With reference to the expression given in part (a), explain how the cyclist could go around the same corner at a greater speed. (3 marks)

Description	Marks
$\tan\theta = \frac{v^2}{rg}$, if r and g are constant then v^2 is proportional to $\tan\theta$	1
as the angle θ increases, $\tan\theta$ increases	1
therefore, by leaning over more, the cyclist can go around the corner at greater speed	1
Total	**3**

Alternative solution

Description	Marks
the centripetal force, F_c, is supplied by the horizontal component of the sideways frictional force between the tyres and the road	1
by leaning over, the cyclist increases the horizontal component of the sideways frictional force	1
as $F_c = \frac{mv^2}{r}$, if m and r are constant, increasing F_c will increase the speed required to go around the corner	1
Total	**3**

Question 9 **(6 marks)**

(a) Is the transformer in the diagram above a step-up or step-down transformer? (1 mark)

Description	Marks
B. Step-down	1
Total	**1**

(b) Where would be the **most** likely placement of such a transformer in the electricity transmission process? (1 mark)

Description	Marks
C. After distribution	1
Total	**1**

(c) Use a calculation to show how the transformer is 100% efficient. (2 marks)

Element	Description	Marks
Identifies 100% efficient means power in equals power out	$V_{in} \times I_{in} = V_{out} \times I_{out}$	1
Substitutes values	$1000 \times 2 = 200 \times 10 = 2000$ W	1
	Total	**2**

(d) In real life, 100% efficiency is impossible to achieve. Describe **one** way transformers lose efficiency. (2 marks)

Description	Marks
electrical energy converted to heat	1
Any one of	
• eddy currents in core • resistive heating in coils • hysteresis in core	1
Total	**2**

Question 10 **(7 marks)**

Given $\text{density} = \dfrac{\text{mass}}{\text{volume}}$, calculate the density of the cube in g cm^{-3}. Include the absolute uncertainty in your answer.

Element	Description	Marks
Calculates % uncertainty in ℓ	$\ell = \pm \dfrac{0.05}{1.33} = \pm 3.76\%$	1
Calculates volume of cube	$V = \ell^3 = 1.33^3 = 2.35$ cm^3	1
Calculates % uncertainty in V	$V = \pm 3(3.76\%) = \pm 11.3\%$	1
Calculates % uncertainty in m	$m = \pm \dfrac{0.1}{16.4} = \pm 0.610\%$	1
Calculates density of cube	$\rho = \dfrac{m}{V} = \dfrac{16.4}{2.35} = 6.97$ g	1
Calculates % uncertainty in ρ	$0.610\% + 11.3\% = \pm 11.9\%$	1
Calculates absolute uncertainty	$\rho = 6.97 \pm 0.83$ g cm^{-3}	1
	Total	**7**
Note: if uses min/max method $\rho = 7.01 \pm 0.83$ g cm^{-3}		

Question 11 **(4 marks)**

(a) Describe the other key observation, detailing the nature of the measurements made. (2 marks)

Description	Marks
the spectral lines observed from galaxies did not match those for the same elements on Earth	1
they were moved to the red end of the spectrum; red-shifted	1
Total	**2**

(b) Describe the interpretation of these observations and how they show that the universe is expanding. (2 marks)

Description	Marks
the greater the distance of galaxies, the greater the red shift, therefore, the faster they were travelling away from us	1
this is consistent with uniform expansion of the entire universe	1
Total	**2**

Section Two: Problem-solving **50% (96 Marks)**

Question 12 **(17 marks)**

(a) Describe **two** reasons why the ions would take different paths in the magnetic field given that $r = \frac{mv}{qB}$. (4 marks)

Description	Marks
Any two of (2 x 2 marks)	
• the two isotopes have different masses • the lighter isotope would deflect more • the ions have different random initial speeds before being accelerated by the electric field • variation in the final speed would cause different radius path • the two isotopes have different masses • the acceleration in the electric field would be different; therefore, exit velocities would also be different	1–4
Total	**4**

(b) Calculate the velocity of a Cℓ-35 ion when it leaves the electric field if it entered with a velocity of 4.51×10^4 m s^{-1}. Ignore relativistic effects. (7 marks)

Element	Description	Marks
Uses equation for initial kinetic energy of ion	$E_{k(\text{i})} = \frac{1}{2}mu^2$	1
Calculates mass of Cℓ-35 ion	$m = (34.97)(1.6605 \times 10^{-27}) = 5.807 \times 10^{-26}$ kg	1
Calculates initial kinetic energy of ion	$E_{k(\text{i})} = \frac{1}{2}(5.807 \times 10^{-26})(4.51 \times 10^4)^2 = 5.91 \times 10^{-17}$ J	1
Determines equation for final kinetic energy of ion	$E_{k(\text{f})} = E_{k(\text{i})} + Vq$	1
Calculates final kinetic energy of ion	$E_{k(\text{f})} = 5.91 \times 10^{-17} + (1.00 \times 10^4)(1.60 \times 10^{-19})$ $E_{k(\text{f})} = 1.66 \times 10^{-15}$ J	1
Substitutes $E_{k(\text{f})}$ into equation $E_{k(\text{f})} = \frac{1}{2}mv^2$	$1.66 \times 10^{-15} = \frac{1}{2}(5.807 \times 10^{-26})v^2$	1
Calculates velocity	$v = 2.39 \times 10^5$ m s^{-1}	1
Total		**7**

Question 12 (continued)

(c) Calculate the radius of the circular path taken by this Cℓ-35 isotope in the magnetic field. If you could not obtain an answer to part (b) on page 14, use 3.72×10^5 m s^{-1}. (3 marks)

Element	Description	Marks
Uses appropriate formula	$r = \frac{mv}{qB}$	1
Substitutes values	$r = \frac{(5.807\times10^{-26})(2.39\times10^{5})}{(1.60\times10^{-19})(0.930)}$	1
Calculates answer	$r = 9.33\times10^{-2}$ m	1
	Total	**3**
Note: if uses $v = 3.72 \times 10^5$ m s^{-1} then $r = 0.145$ m		

(d) Explain why there is a range of masses in the printout instead of clearly-defined lines, as in the graph above left. (3 marks)

Description	Marks
ions of both isotopes have varying initial velocities before acceleration by the electric field	1
hence, ions of both isotopes have a range of velocities entering the magnetic field	1
this causes a small variation in their radii and a spread in relative abundance	1
Total	**3**

Alternative solution

Description	Marks
ions travelling through an electric and/or magnetic field can interact with each other	1
this interaction will change velocities of ions	1
hence, cause variation in their radii and a spread in relative abundance	1
Total	**3**

Question 13 **(16 marks)**

(a) Calculate the tension either of the strings OP or OQ. (3 marks)

Element	Description	Marks
Equates vertical forces	$F_{OP}\cos\theta = mg$	1
Substitute values	$F_{OP}\cos 37.0^\circ = (0.650)(9.80)$	1
Calculates answer	$F_{OP} = 7.98$ N	1
	Total	**3**

(b) (i) Explain why the tension in strings OP and OQ does not change despite the tensions in RP and QS changing. RP and QS remain horizontal and θ remains constant. (3 marks)

Description	Marks
balls P and Q attract each other with horizontal electrostatic forces	1
tension in RP and QS increase to balance electrostatic forces	1
tension in OP and OQ remain the same as vertical component balances weight of ball	1
Total	**3**

Alternative solution

Description	Marks
$\cos\theta = \dfrac{mg}{T}$	1
$T = \dfrac{mg}{\cos\theta}$	1
as m, g and θ do not change, T remains constant	1
Total	**3**

Question 13 (continued)

(ii) Calculate the tension in either RP or QS after the balls have been charged. The tensions are equal in magnitude. (6 marks)

Element	Description	Marks
Calculates distance between balls	$r = (2)(0.500)(\sin 37.0^\circ) = 0.602$ m	1
Uses Coulomb's Law	$F_e = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$	1
Calculates electrostatic force	$F_e = \left(\frac{1}{4\pi(8.85\times10^{-12})}\right)\frac{(3.51\times10^{-5})(2.03\times10^{-5})}{(0.602)^2}$ $F_e = 17.7$ N	1
Horizontal forces on ball balance	$F_{RP} = F_{OP}\sin 37.0^\circ + F_e$	1
Substitute values	$F_{RP} = 7.98\sin 37.0^\circ + 17.7$	1
Calculates answer	$F_{RP} = 22.5$ N	1
	Total	**6**

(c) (i) Calculate the charge on each ball after they have touched. (2 marks)

Element	Description	Marks
Determines that charges partially neutralise	$(-3.51+2.03)\times10^{-5} = -1.48\times10^{-5}$ C	1
Spreads remaining charge evenly over both balls	$q = \frac{1}{2}(-1.48\times10^{-5}) = -7.40\times10^{-6}$ C	1
	Total	**2**

(ii) Describe why the balls come to rest in the position shown in the diagram above. (2 marks)

Description	Marks
both balls now have the same charge so repel each other	1
the balls move apart until a new equilibrium position is reached	1
Total	**2**

Question 14 **(14 marks)**

(a) Calculate the momentum of either proton in the laboratory's frame of reference. (3 marks)

Element	Description	Marks
Uses relativistic momentum formula	$p_{\text{v}} = \dfrac{mv}{\sqrt{\left(1-\dfrac{v^2}{c^2}\right)}}$	1
Substitutes values	$p_{\text{v}} = \dfrac{(1.67\times10^{-27})(0.9500)(3.00\times10^{8})}{\sqrt{\left(1-\dfrac{\left((0.9500)(3.00\times10^{8})\right)^2}{(3.00\times10^{8})^2}\right)}}$	1
Calculates answer	$p_{\text{v}} = 1.52\times10^{-18}$ kg m s^{-1}	1
	Total	**3**

(b) Determine the total momentum of the two protons as measured in the laboratory frame of reference. (1 mark)

Element	Description	Marks
Uses conservation of momentum, proton momenta vectors cancel	0 kg m s^{-1}	1
	Total	**1**

(c) Calculate the momentum of one proton in the other proton's frame of reference. Give your answer to **four** significant figures. (6 marks)

Element	Description	Marks
Uses relative velocity formula	$u' = \dfrac{u-v}{1-\dfrac{uv}{c^2}}$	1
Substitutes values	$u' = \dfrac{0.9500\ c-(-0.9500\ c)}{1-(0.9500)(-0.9500)}$	1
Calculates relative velocity	$u' = 0.998686\ c$	1
Substitutes values into relativistic momentum formula	$p = \dfrac{(1.67\times10^{-27})(0.998686)(3.00\times10^{8})}{\sqrt{\left(1-\dfrac{\left((0.998686)(3.00\times10^{8})\right)^2}{(3.00\times10^{8})^2}\right)}}$	1
Calculates answer	$p = 9.763\times10^{-18}$ kg m s^{-1}	1
4 significant figures		1
	Total	**6**

Question 14 (continued)

(d) Calculate the total energy of the particles produced in the collision, as measured by the observer in the laboratory. Give your answer to **three** significant figures. (4 marks)

Element	Description	Marks
Uses conservation of energy	total energy of particles = total energy of protons $\times 2$	1
Substitutes values	$E_t = \dfrac{(1.67\times10^{-27})(3.00\times10^{8})^2}{\sqrt{1-\dfrac{\left((0.9500)\left(3.00\times10^{8}\right)\right)^2}{3.00\times10^{8}}}}\times 2$	1
Calculates answer	$E_t = 9.63\times10^{-10}$ J	1
3 significant figures		1
	Total	**4**

Question 15 **(18 marks)**

(a) Calculate the wavelength of light produced by the downward transition from level 3 to level 2. (4 marks)

Element	Description	Marks
Calculates energy level difference	$\Delta E = -4.29 - (-7.59) = 3.30$ eV	1
Converts to joules	$(3.30)(1.60\times10^{-19}) = 5.28\times10^{-19}$ J	1
Substitutes into wavelength formula	$\lambda = \frac{hc}{E} = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{5.28\times10^{-19}}$	1
Calculates answer	$\lambda = 3.77\times10^{-7}$ m	1
	Total	**4**

(b) Calculate the maximum speed of a liberated electron when this wavelength of light is incident on the sodium plate in the photoelectric cell. (4 marks)

Element	Description	Marks
Calculates E_k of photoelectron	$E_k = hf - W = 3.30 - 2.28 = 1.02$ eV	1
Converts to joules	$(1.02)(1.60\times10^{-19}) = 1.632\times10^{-19}$ J	1
Substitutes into speed formula	$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2(1.632\times10^{-19})}{9.11\times10^{-31}}}$	1
Calculates answer	$v = 5.99\times10^{5}$ m s^{-1}	1
	Total	**4**
Note: if photoelectric effect is ignored, award maximum 2 marks		

(c) Calculate the stopping voltage for the electron produced in part (b) on page 20. (2 marks)

Element	Description	Marks
Stopping voltage $\frac{\Delta E_k}{e}$	$V_s = \frac{1.02 \text{ eV}}{e}$	1
Calculates answer	$V_s = 1.02$ V	1
	Total	**2**

(d) Explain why increasing the brightness of the incident light will not affect the stopping voltage. (4 marks)

Description	Marks
increasing brightness of light increases number of incident photons	1
but photon energy remains 3.30 eV	1
more electrons ejected but all with the same maximum kinetic energy of 1.02 eV	1
so, stopping voltage remains the same	1
Total	**4**

Question 15 (continued)

(e) (i) Identify which transition would require the stopping voltage to be the largest. (1 mark)

Element	Description	Marks
Largest transition	4 → 1	1
	Total	**1**

(ii) Explain your answer to part (e)(i). (3 marks)

Description	Marks
this transition produces the most energetic photons (with 14.25 eV)	1
so ejected photoelectrons have the largest possible kinetic energy	1
hence requiring the largest voltage to stop them reaching the anode	1
Total	**3**

Question 16 **(19 marks)**

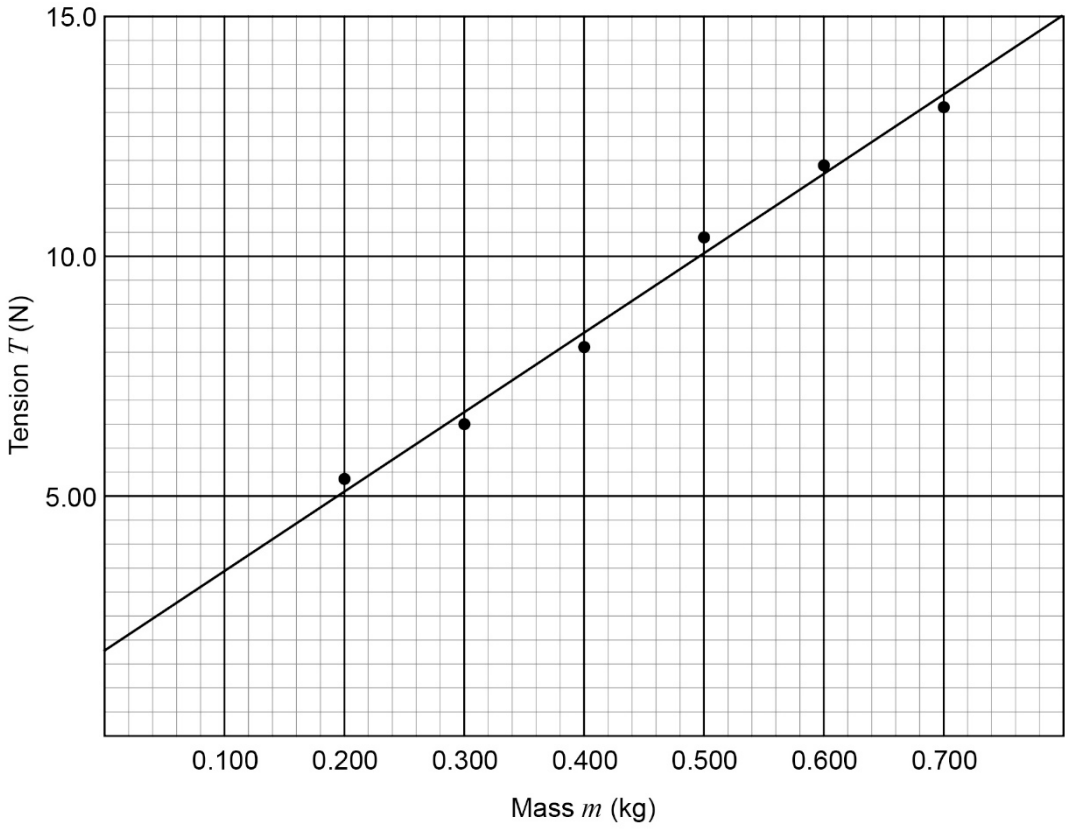
(a) Calculate the distance r from the pivot to the wire. (2 marks)

Element	Description	Marks
Uses trigonometric equation to determine r	$r = \ell \sin 35.0^\circ = (0.760)(\sin 35.0^\circ)$	1
Calculates answer	$r = 0.436$ m	1
	Total	**2**

(b) Graph T versus m on the grid below. Include a line of best fit. (3 marks)

Description	Marks
Plots all points	1
Plots points accurately	1
Draws an accurate line of best fit	1
Total	**3**

Mass m (kg)	0.200	0.300	0.400	0.500	0.600	0.700
Tension T (N)	5.30	6.50	8.10	10.4	11.9	13.2



Question 16 (continued)

(c) Calculate the gradient of your line of best fit from part (b) on page 23. Indicate clearly on the graph the **two** points used in your calculation. Express the gradient to **three** significant figures and include the unit for the gradient. (5 marks)

Element	Description	Marks
Indicates clearly two points used (not data points)		1
Uses correct formula for gradient of line of best fit	$\frac{\Delta T}{\Delta m}$	1
Calculates gradient of line of best fit (allowed range)	16.6 ± 1.0	1
Units for gradient	N kg^{-1} or m s^{-2}	1
3 significant figures		1
	Total	**5**

(d) Use the calculated gradient from part (c) to estimate the students' experimental value for g. Give your answer to **two** significant figures. (4 marks)

Element	Description	Marks
Uses correct expression for gradient	gradient $= \frac{g\ell}{r}$	1
Substitutes correct values	$g = \frac{(16.6)(r)}{\ell} = \frac{(16.6)(0.436)}{0.760}$	1
Calculates answer	$g = 9.5 \text{ m s}^{-2}$	1
2 significant figures		1
	Total	**4**

(e) Use the line of best fit from part (b) on page 23 and the value of g found in part (d) to calculate the distance d from the pivot to the centre of mass of the piece of wood. Give your answer to **two** significant figures. (5 marks)

Element	Description	Marks
States value of y-axis intercept	intercept $= 1.8$	1
Uses correct expression for intercept	intercept $= \frac{Mgd}{r}$	1
Substitutes values	$d = \frac{1.8r}{Mg} = \frac{(1.8)(0.436)}{(0.257)(9.6)}$	1
Calculates answer	$d = 0.32$ m	1
2 significant figures		1
	Total	**5**

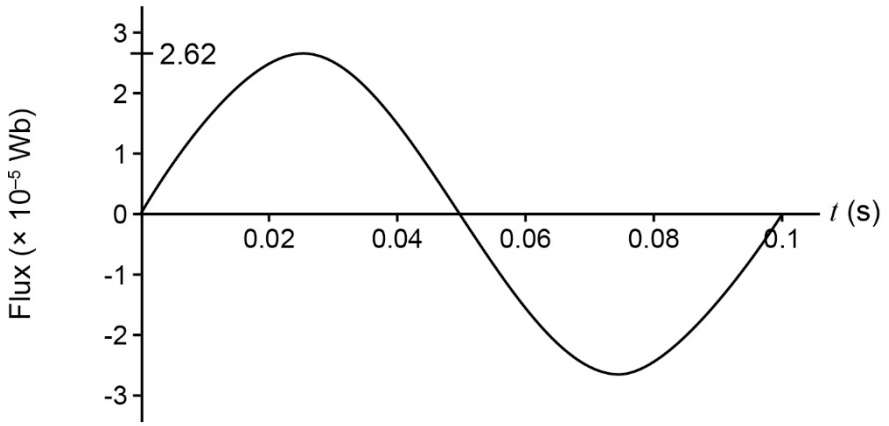
Question 17 **(12 marks)**

(a) Calculate the maximum amount of flux passing through the coil at any time in a complete rotation. (3 marks)

Element	Description	Marks
Uses correct equation for max flux	$\phi = BA_{\perp}$	1
Substitutes values	$\phi = (2.37\times10^{-3})(0.130)(0.0850)$	1
Calculates answer	$\phi = 2.62\times10^{-5}$ Wb	1
	Total	**3**

(b) On the axes below, graph the flux passing through the coil during one complete rotation. Take the starting position shown in the diagram on page 26. Include your value from part (a) on the y-axis and place actual time values on the x-axis. (4 marks)

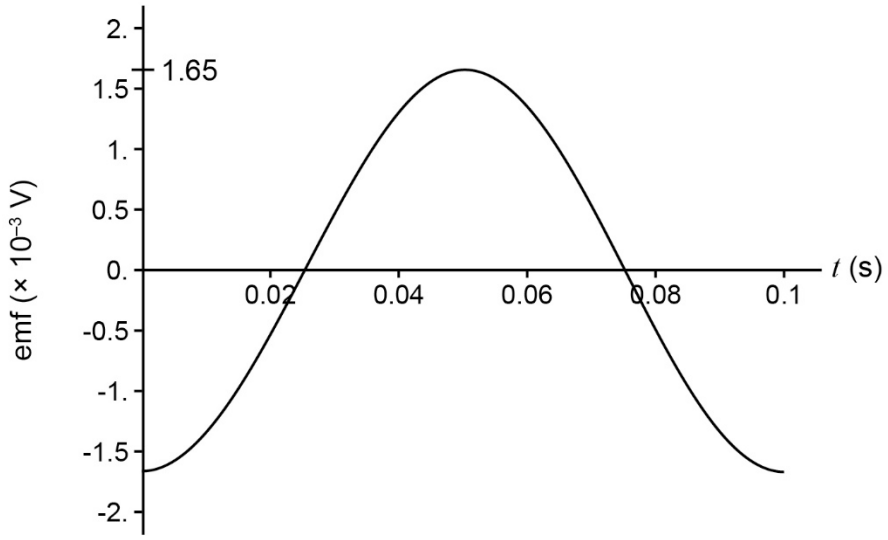
Description	Marks
Draws sine curve	1
Draws one complete cycle	1
Maximum value on y-axis is given by max $\phi = 2.62\times10^{-5}$ Wb	1
Period = $\frac{1}{10}$ Hz $= 0.10$ s on x-axis	1
Total	**4**



Question 17 (continued)

(c) On the axes below, graph the emf induced in the coil as it goes through one complete rotation. Take the starting position shown in the diagram on page 26. Include values on both axes. (5 marks)

Description	Marks
Draws cosine curve	1
Draws curve with opposite sign to curve in part (a)	1
Draws one complete cycle in 0.10 s on x-axis	1
Maximum value $\varepsilon_{max} = 2\pi NBAf = 2\pi(1)(2.62\times10^{-5})(10.0) = 1.65\times10^{-3}$ V	1
Maximum value on graph is consistent to ε_{max} calculation	1
Total	**5**



Section Three: Comprehension **20% (39 Marks)**

Question 18 **(21 marks)**

(a) (i) Calculate the momentum of a photon of frequency of 5.12×10^{16} Hz. (4 marks)

Element	Description	Marks
Uses de Broglie's equation and isolates for p	$p = \frac{h}{\lambda}$	1
Substitutes $\frac{c}{f}$ for λ	$p = \frac{hf}{c}$	1
Substitutes correct values	$p = \frac{(6.63\times10^{-34})(5.12\times10^{16})}{3.00\times10^{8}}$	1
Calculates answer	$p = 1.13\times10^{-25}$ kg m s^{-1}	1
	Total	**4**

(ii) Calculate how many photons with the same frequency as in part (a)(i) on page 29 would be produced per second by a 10.0 W laser. (3 marks)

Element	Description	Marks
Calculates energy of one photon	$E_{\text{photon}} = hf = \left(6.63\times10^{-34}\right)\left(5.12\times10^{16}\right)$ $E_{\text{photon}} = 3.3945\times10^{-17}$ J	1
Uses $E = Pt$ to calculate number of photons, n	$n = \frac{(10.0)(1.00)}{3.3945\times10^{-17}}$	1
Calculates answer	$n = 2.95\times10^{17}$	1
	Total	**3**

(b) Calculate the percentage of speed it loses when it absorbs the incoming photon. (5 marks)

Element	Description	Marks
Uses conservation of momentum	$p(\text{before}) = p(\text{after})$	1
Substitutes correct values with correct sign convention	$p(\text{atom before}) - 1.13\times10^{-25} = p(\text{atom after})$ or $m_A u - 1.13\times10^{-25} = m_A v$	1
Rearranges for v	$v = \frac{m_A u - 1.13\times10^{-25}}{m_A}$	1
Calculates v correctly	$v = \frac{(6.80\times10^{-27})(5.70\times10^{2}) - 1.13\times10^{-25}}{6.80\times10^{-27}}$ $v = 553.4$ m s^{-1}	1
Calculates % loss	$\frac{570 - 553.4}{570}\times100\% = 2.91\%$	1
	Total	**5**
Note: accept range 2.91% – 2.98% for % loss, depending on rounding		

Question 18 (continued)

(c) Explain the mechanism required for cooling to occur. (5 marks)

Description	Marks
photon and atom travelling in opposite directions produces blue shift	1
blue shift means increase in frequency and therefore the energy of the photon	1
increasing energy of photon means it is absorbed by atom	1
absorption of photon means momentum of atom is decreased	1
decreased momentum means decreased speed and therefore reduced kinetic energy and temperature	1
Total	**5**

(d) (i) What effect would this have on the temperature of the gaseous sample? (1 mark)

Description	Marks
A. Increase	1
Total	**1**

(ii) Explain your answer to part (d)(i). (3 marks)

Description	Marks
increasing frequency of laser photons means photon must be red shifted to be absorbed	1
red shift means atom is moving in same direction as photon	1
after absorption, momentum of atom is increased and hence, kinetic energy is increased	1
Total	**3**

Question 19 **(18 marks)**

(a) Explain why de Broglie's theory that electrons can be treated as waves led to the introduction of quantum numbers. (3 marks)

Description	Marks
waves undergo constructive and destructive interference	1
only certain whole numbers of wavelengths can form standing waves in fixed circular orbits	1
this introduced quantum numbers (n), that is $n\lambda=2\pi r$	1
Total	**3**

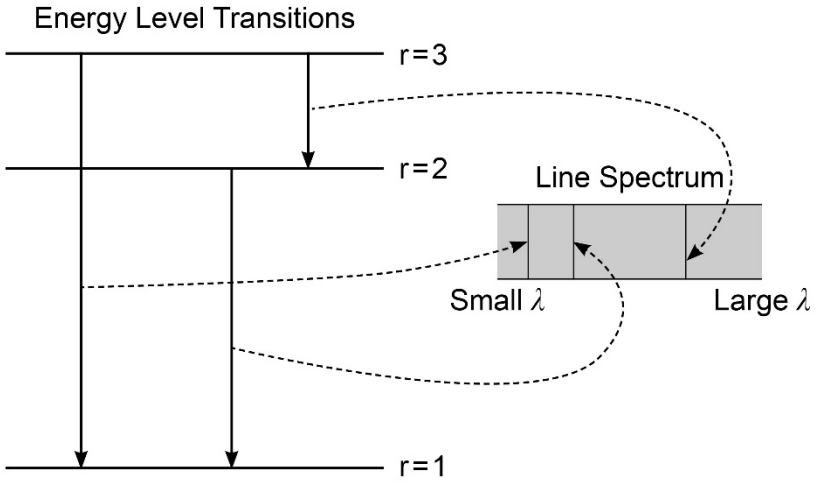
(b) Derive Equation 3 from Equation 2 and the equation for kinetic energy. (5 marks)

Element	Description	Marks
Isolates v from Equation 2	$v=\frac{nh}{2\pi r m_e}$	1
Squares both sides	$v^2=\frac{n^2h^2}{4\pi^2r^2m_e^{\,2}}$	1
Divides both sides by 2	$\frac{v^2}{2}=\frac{n^2h^2}{8\pi^2r^2m_e^{\,2}}$	1
Brings one m_e to left hand side	$\frac{m_e v^2}{2}=\frac{n^2h^2}{8\pi^2r^2m_e}$	1
States conclusion	$KE=\frac{n^2h^2}{8\pi^2r^2m_e}$	1
	Total	**5**
Note: other sequences could be used		

Question 19 (continued)

(c) With the use of a diagram, describe the experimental evidence stated in the text on page 32 that supports the quantisation of electron energy. (5 marks)

Description	Marks
Diagram shows both energy levels and emission spectrum present	1–2
Diagram shows downward transitions of electrons	1
Shows how those energy transitions correspond to specific wavelengths on emission spectrum	1
States only certain wavelengths are observed from a specific atom	1
Total	**5**



(d) Calculate the wavelength of an electron travelling at 0.750 c. (5 marks)

Element	Description	Marks
Uses Lorentz's equation	$p = \dfrac{mv}{\sqrt{1-\dfrac{v^2}{c^2}}}$	1
Substitutes correct values	$p = \dfrac{(9.11\times10^{-31})(0.750)(3.00\times10^{8})}{\sqrt{1-(0.750)^2}}$	1
Calculates answer correctly	$p = 3.099\times10^{-22}$ kg m s^{-1}	1
Uses de Broglie's equation	$\lambda = \dfrac{6.63\times10^{-34}}{3.099\times10^{-22}}$	1
Calculates answer	$\lambda = 2.14\times10^{-12}$ m	1
	Total	**5**

ACKNOWLEDGEMENTS

Question 19(a) Information from: Rioux, F. (n.d.). 2.5: A de Broglie-Bohr Model for the Hydrogen Atom - Version 4. *Quantum Tutorials.* Retrieved April, 2024, from https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Quantum_Tutorials_(Rioux)/02%3A_Atomic_Structure/2.05%3A_The_de_Broglie-Bohr_Model_for_the_Hydrogen_Atom_-_Version_4
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