2023/74466

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

# PHYSICS

# ATAR course examination 2023

# Marking key

Marking keys are an explicit statement about what the examining panel expect of candidates when they respond to particular examination items. They help ensure a consistent interpretation of the criteria that guide the awarding of marks.

**Section One: Short response** **30% (59 Marks)**

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**Question 1** **(5 marks)**

(a) Which way will the coil rotate when observed from X? Circle your answer. (1 mark)

| Description | Marks |
|---|---|
| clockwise | 1 |
| **Total** | **1** |

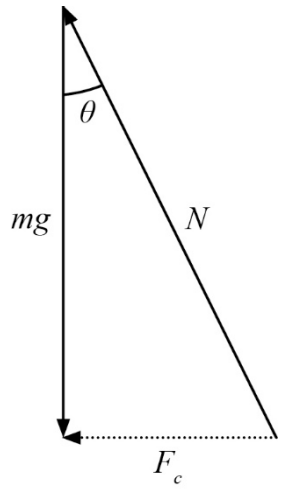
(b) Calculate the magnitude of the initial torque on the coil in the position shown in the diagram. (4 marks)

| Element | Description | Marks |
|---|---|---|
| Calculates current | $I = \frac{V}{R} = \frac{6.00}{3.00} = 2.00$ A | 1 |
| Substitutes $BI\ell$ for $F$ | Torque = $2rBI\ell N$ | 1 |
| Substitutes values | Torque = $50 \times 3.70 \times 10^{-3} \times 2.00 \times (0.0860)^2$ | 1 |
| Calculates answer | Torque = $2.74 \times 10^{-3}$ N m | 1 |
| **Total** | | **4** |

**Question 2** **(4 marks)**

(a) Complete the vector diagram, showing how these two forces result in a centripetal force. Indicate where the angle $\theta$ is on your diagram. (2 marks)

| Description | Marks |
|---|---|
| $\theta$ is in correct position | 1 |
| net force is horizontal and labelled $F_c$ | 1 |
| **Total** | **2** |




(b) With reference to your diagram in part (a), describe why increasing the angle of the track allows the cars to go around the same radius curve at a greater speed. (2 marks)

| Description | Marks |
|---|---|
| as $\theta$ increases and $mg$ remains constant, $F_c$ increases | 1 |
| $F_c = mv^2/r$. If $m$ and $r$ remain constant, then for $F_c$ to increase $v$ must increase | 1 |
| **Total** | **2** |

**Question 3** **(4 marks)**

Calculate the magnitude of the acceleration of the tram.

| Element | Description | Marks |
|---|---|---|
| Realises net force is vector addition of tension and weight | | 1 |
| Uses $\tan\theta$ | $\tan\theta = \frac{ma}{mg}$ | 1 |
| Rearranges for $a$ | $a$ = tan 15.5° × 9.80 | 1 |
| Calculates answer | $a$ = 2.72 m s$^{-2}$ | 1 |
| | **Total** | **4** |

**Question 4** **(4 marks)**

Calculate the wavelength of a photon with an energy of 1.81 keV.

| Element | Description | Marks |
|---|---|---|
| Converts to joules | 1810 × 1.60 × 10$^{-19}$ = 2.896 × 10$^{-16}$ J | 1 |
| Substitutes $\frac{c}{\lambda}$ for $f$ | $E = \frac{hc}{\lambda}$ | 1 |
| Rearranges for $\lambda$ | $\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{2.896\times10^{-16}}$ | 1 |
| Calculates answer | $\lambda$ = 6.87 × 10$^{-10}$ m | 1 |
| | **Total** | **4** |

**Question 5** **(6 marks)**

Calculate how far above the castle wall the ball passes ($h$).

| Element | Description | Marks |
|---|---|---|
| Calculates horizontal component of velocity | $v_H$ = 45.8 × cos 50.0° = 29.4 m s$^{-1}$ | 1 |
| Calculates vertical component of velocity | $v_V$ = 45.8 × sin 50.0° = 35.1 m s$^{-1}$ | 1 |
| Calculates $t$ from horizontal | $t = \frac{1.50\times10^{2}}{29.4} = 5.10$ s | 1 |
| Substitutes correct values for vertical displacement after $t$ | $s_V$ = (35.1 × 5.10) – (4.90 × (5.10)$^2$) + 3.50 | 1 |
| Calculates vertical displacement | $s_V$ = 179.01 – 127.5 + 3.50 = 55.06 m | 1 |
| Calculates clearance | 55.06 – 51.0 = 4.06 m | 1 |
| | **Total** | **6** |

**Question 6** **(6 marks)**

(a) Describe how, and under what circumstances, electrons are liberated from the target by incoming photons. (2 marks)

| Description | Marks |
|---|---|
| the incoming photons are completely absorbed by electrons in the target metal | 1 |
| if the photon energy is larger than the work function of the metal, an electron is released from the metal | 1 |
| **Total** | **2** |

(b) Discuss how the maximum kinetic energy of the liberated electrons is experimentally determined. (4 marks)

| Description | Marks |
|---|---|
| a reverse potential is applied which turns the anode into a negatively charged cathode | 1 |
| as the reverse potential increases, fewer electrons have the necessary kinetic energy (KE) to reach it | 1 |
| when KE = $Vq$, 0 current is recorded | 1 |
| this is the maximum KE of a liberated electron | 1 |
| **Total** | **4** |

**Question 7** **(7 marks)**

(a) State Lenz's law. (2 marks)

| Description | Marks |
|---|---|
| the direction of the induced current by a changing magnetic field is such that the magnetic field created opposes the changes in the initial magnetic field | 1–2 |
| **Total** | **2** |
| Note: must have all components of the Law to achieve full marks | |

(b) With reference to Lenz's law, explain why the needle in the galvanometer moves to the left, i.e. the current in the galvanometer flows right to left. (3 marks)

| Description | Marks |
|---|---|
| as the north pole of the magnet approaches, the area in the solenoid experiences a change in flux | 1 |
| this induces a north pole at the left end of the solenoid | 1 |
| current flows from right to left in the galvanometer in order to achieve this | 1 |
| **Total** | **3** |

(c) Explain why the emf induced in the coil is not constant, even though the speed of the magnet remains constant. (2 marks)

| Description | Marks |
|---|---|
| the magnetic field around the magnet is not uniform | 1 |
| therefore the rate of change of flux is not constant so neither is the induced emf in the solenoid | 1 |
| **Total** | **2** |

**Question 8** **(6 marks)**

Using the graph above, estimate the distance in kilometres to a galaxy that is receding at 4.5% of the speed of light.

| Element | Description | Marks |
|---|---|---|
| Calculates recessional velocity | $0.045 \times 3.00 \times 10^8 = 1.35 \times 10^7$ m s$^{-1}$ | 1 |
| Converts to km s$^{-1}$ | $1.35 \times 10^4$ km s$^{-1}$ | 1 |
| Locates correctly on $y$-axis | | 1 |
| Reads corresponding value on $x$-axis | Roughly 22 Megaparsecs | 1 |
| Calculates distance | $22 \times 3.09 \times 10^{19} = 6.798 \times 10^{20}$ km | 1 |
| 2 significant figures | $6.8 (\pm 0.3) \times 10^{20}$ km | 1 |
| | **Total** | **6** |

**Question 9** **(3 marks)**

Derive an expression for $d_2$ in terms of $d_1$, $t_1$ and $t_2$. Show your reasoning and state any assumptions. (Hint: It is not necessary to use length contraction or time dilation.)

| Description | Marks |
|---|---|
| every observer measures the speed of light as $c$ | 1 |
| therefore $d_1/t_1 = c$, and $d_2/t_2 = c = d_1/t_1$ | 1 |
| rearrange for $d_2$ : $d_2 = d_1/t_1 \times t_2$ | 1 |
| **Total** | **3** |

**Question 10** **(4 marks)**

Estimate the de Broglie wavelength for a standard men's basketball travelling at 10.0 m s$^{-1}$.

| Element | Description | Marks |
|---|---|---|
| Estimates mass of basketball | Range: 0.20 – 2.00 kg | 1 |
| Substitutes $mv$ for $p$ in equation (using 0.60 kg) | $\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{0.60 \times 10.0}$ | 1 |
| Calculates answer | $\lambda = 1.105 \times 10^{-34}$ m | 1 |
| 2 significant figures | $\lambda = 1.1 \times 10^{-34}$ m | 1 |
| | **Total** | **4** |
| Note: If using 0.20 kg, $\lambda = 3.3 \times 10^{-34}$ m. If using 2.0 kg, $\lambda = 3.3 \times 10^{-35}$ m., | | |

**Question 11** **(4 marks)**

Identify the category to which they belong in the second column and state whether or not they are bound by the strong nuclear force in the third column.

| Description | | | Marks |
|---|---|---|---|
| **Particle** | **Category (meson, baryon or lepton)** | **Bound by strong nuclear force (yes or no)** | |
| Proton | baryon | yes | 1 |
| Pion | meson | yes | 1 |
| Neutrino | lepton | no | 1 |
| Muon | lepton | no | 1 |
| | | **Total** | **4** |

**Question 12** **(6 marks)**

Derive an expression for the velocity of the bar in terms of $m$, $g$, $R$, $B$ and $\ell$ given the velocity is constant.

| Element | Description | Marks |
|---|---|---|
| Equates $F_{up}$ to $F_{down}$ | | 1 |
| Substitutes correct expressions for forces | $BI\ell = mg$ | 1 |
| Uses Ohm's Law to get expression for current | $I = \frac{\text{emf}}{R}$ | 1 |
| Substitutes $Bv\ell$ for emf | | 1 |
| Combines equations | $B \times Bv\ell \times \frac{\ell}{R} = mg$ | 1 |
| Simplifies and isolates $v$ | $v = \frac{mgR}{B^2\ell^2}$ | 1 |
| | **Total** | **6** |

**Section Two: Problem-solving** **50% (93 Marks)**

**Question 13** **(17 marks)**

(a) Calculate the strength of the magnetic field 35.0 cm from the wire. (3 marks)

| Element | Description | Marks |
|---|---|---|
| Uses correct equation | $B = \frac{u_0 I}{2\pi r}$ | 1 |
| Substitutes correct constant and simplifies | $B = \frac{4\pi \times 10^{-7} \times 2.51}{2\pi \times 0.350}$ $= \frac{2 \times 10^{-7} \times 2.51}{0.350}$ | 1 |
| Calculates answer | $1.43 \times 10^{-6}$ T | 1 |
| | **Total** | **3** |

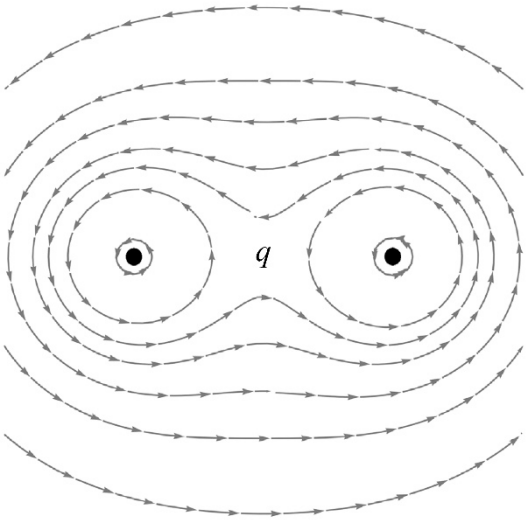
(b) Calculate the force experienced by the particle as it moves through this magnetic field. Include the direction of the force in your answer. If you could not obtain an answer to part (a), use $2.51 \times 10^{-6}$ T. (3 marks)

| Element | Description | Marks |
|---|---|---|
| Substitutes correct values into $F = Bvq$ | $F = 4.80 \times 10^{-19} \times 1.57 \times 10^{4} \times 1.43 \times 10^{-6}$ | 1 |
| Calculates answer | $F = 1.08 \times 10^{-20}$ N | 1 |
| Includes direction | down | 1 |
| | **Total** | **3** |
| Note: if uses $2.51 \times 10^{-6}$ T, $F = 1.89 \times 10^{-20}$ N | | |

(c) With reference to **two** relevant equations on the data sheet, discuss why the path the particle takes is not circular. (5 marks)

| Description | Marks |
|---|---|
| $B = \frac{u_0 I}{2\pi r}$ and $r = \frac{mv}{Bq}$ | 1 |
| $B$ is inversely proportional to $r$ so as $r$ increases, $B$ decreases | 1 |
| $B$ is not constant as particle moves away from the wire | 1 |
| $r = \frac{mv}{Bq}$ assumes $B$, $q$ and $m$ are constant | 1 |
| $B$ is not constant therefore motion is not circular | 1 |
| **Total** | **5** |

(d) (i) Draw the composite magnetic field generated by the two current-carrying wires. Indicate clearly the location of the charge $q$ on your diagram. (4 marks)




| Description | Marks |
|---|---|
| Fields must be anti-clockwise shown with arrows | 1 |
| Must show composite field lines around each wire | 1 |
| At least two composite field lines must be shown that do not touch or cross | 1 |
| Drawing must show $q$ equidistant from each wire | 1 |
| **Total** | **4** |

(ii) Describe why the charge $q$ experiences no net force in this position. (Ignore any gravitational effects.) (2 marks)

| Description | Marks |
|---|---|
| at the location of the charge, the two fields cancel each other out (neutral point) | 1 |
| therefore the charge experiences no net force | 1 |
| **Total** | **2** |

**Question 14** **(13 marks)**

(a) (i) Calculate the velocity of A (in m $s^{-1}$) as measured by B. (4 marks)

| Element | Description | Marks |
|---|---|---|
| Uses correct equation | $u' = \dfrac{u - v}{1 - \dfrac{uv}{c^2}}$ | 1 |
| Inserts correct values | $= \dfrac{0.700\,c - (-0.700\,c)}{1 - (-0.700 \times 0.700)}$ | 1 |
| Calculates answer in terms of $c$ | $= 0.940\,c$ | 1 |
| Converts to m $s^{-1}$ | $= 2.82 \times 10^8$ m $s^{-1}$ | 1 |
| | **Total** | **4** |

(ii) Explain why the magnitude of the velocity of B as measured by A would be the same as your answer for part (a)(i), only in the opposite direction. (3 marks)

| Description | Marks |
|---|---|
| there is no preferred frame of reference | 1 |
| each spaceship sees the other receding from them | 1 |
| due to symmetry $\lvert v \rvert$ will be the same | 1 |
| **Total** | **3** |

(b) Calculate the duration of one second on A as measured by the observer S. (3 marks)

| Element | Description | Marks |
|---|---|---|
| Uses correct equation and values | $t = \dfrac{t_0}{\sqrt{1 - \dfrac{v^2}{c^2}}}$<br>$t = \dfrac{1}{\sqrt{1 - 0.700^2}}$ | 1–2 |
| Calculates answer | $t = 1.40$ s | 1 |
| | **Total** | **3** |

(c) Calculate the length of spaceship B as measured by A. If you could not obtain an answer to part (a)(i), use 0.870 $c$. (3 marks)

| Element | Description | Marks |
|---|---|---|
| Uses correct equation and values | $\ell = \ell_0 \sqrt{1 - \dfrac{v^2}{c^2}}$<br>$\ell = 5.00 \times 10^2 \times \sqrt{1 - 0.940^2}$ | 1–2 |
| Calculates answer | $\ell = 171$ m | 1 |
| | **Total** | **3** |
| Note: if uses 0.870 $c$, $\ell = 247$ m | | |

**Question 15** **(14 marks)**

(a) Calculate the radius of Curly's orbit. (5 marks)

| Element | Description | Marks |
|---|---|---|
| Uses Kepler's 3rd law | $\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$ | 1 |
| Rearranges for $r^3$ | $r^3 = \frac{GMT^2}{4\pi^2}$ | 1 |
| Converts hours to seconds | $T = 7.50 \times 60 \times 60 = 2.70 \times 10^4$ s | 1 |
| Substitutes correct values into equation | $r = \left(6.67\times10^{-11}\times2.37\times10^{24}\times\frac{(2.70\times10^4)^2}{4\pi^2}\right)^{\frac{1}{3}}$ | 1 |
| Calculates value for $r$ | $r = 1.43 \times 10^7$ m | 1 |
| | **Total** | **5** |

(b) Calculate the distance between the centre of mass of Mo and the centre of mass of Stoogus. (4 marks)

| Element | Description | Marks |
|---|---|---|
| Uses correct equation | $g = \frac{GM}{r^2}$ | 1 |
| Rearranges for $r^2$ | $r^2 = \frac{GM}{g}$ | 1 |
| Substitutes correct values | $r = \sqrt{\left(\frac{6.67\times10^{-11}\times2.37\times10^{24}}{4.50\times10^{-3}}\right)}$ | 1 |
| Calculates answer | $= 1.87 \times 10^8$ m | 1 |
| | **Total** | **4** |

**Question 15** (continued)

(c) (i) Derive the mathematical relationship between a moon's orbital speed $v$ and its distance $r$ from the planet's centre of mass. (3 marks)

| Element | Description | Marks |
|---|---|---|
| Uses Kepler's 3rd Law and rearranges for $T$ | $T^2 = \frac{4\pi^2 r^3}{GM}$ | 1 |
| Substitutes $\frac{2\pi r}{v}$ for $T$ | $\frac{4\pi^2 r^2}{v^2} = \frac{4\pi^2 r^3}{GM}$ | 1 |
| Simplifies and isolates $v^2$ | $v^2 = \frac{GM}{r}$ | 1 |
| | **Total** | **3** |

Alternative solution

| Element | Description | Marks |
|---|---|---|
| States $F_c$ is provided by the $F_g$ | $F_c = F_g$ | 1 |
| Expands formulae correctly | $\frac{mv^2}{r} = \frac{GMm}{r^2}$ | 1 |
| Simplifies and isolates $v$ | $v^2 = \frac{GM}{r}$ | 1 |
| | **Total** | **3** |

(ii) Use this relationship from part (c)(i) to identify which moon of Stoogus has the greatest orbiting speed. Justify your answer. (2 marks)

| Description | Marks |
|---|---|
| Larry is travelling the fastest | 1 |
| As $G$ and $M$ are constant, as $r$ decreases, velocity increases | 1 |
| **Total** | **2** |

**Question 16** **(18 marks)**

(a) Show how the students derived this relationship. (4 marks)

| Element | Description | Marks |
|---|---|---|
| Substitutes $f\lambda$ for $v$ | $f\lambda = \sqrt{\frac{T}{\mu}}$ | 1 |
| Substitutes $2L$ for $\lambda$ | $f2L = \sqrt{\frac{T}{\mu}}$ | 1 |
| Squares both sides | $f^2 4L^2 = \frac{T}{\mu}$ | 1 |
| Isolates $T$ correctly | $T = (4L^2\mu)f^2$ | 1 |
| | **Total** | **4** |

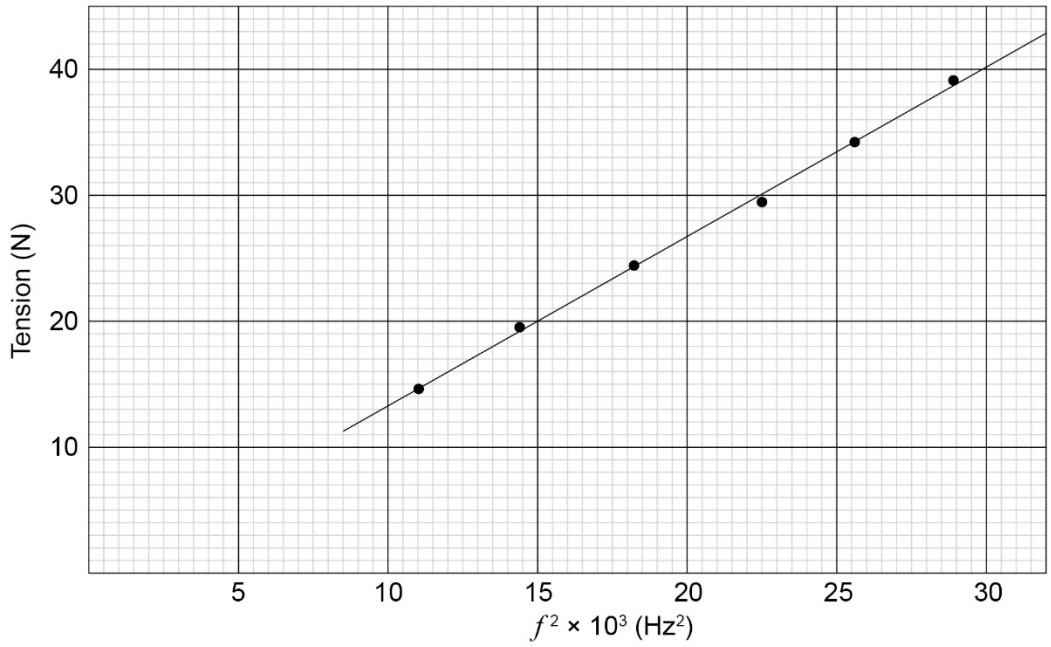
(b) Make the adjustments to the data and place the results in the table below. Give your answers to **three** significant figures and express $f^2$ in scientific notation. (4 marks)

| **Mass (kg)** | 1.50 | 2.00 | 2.50 | 3.00 | 3.50 | 4.00 |
|---|---|---|---|---|---|---|
| **Tension (N)** | 14.7 | 19.6 | 24.5 | 29.4 | 34.3 | 39.2 |
| $f^2$ **(Hz$^2$)** | $1.10 \times 10^4$ | $1.44 \times 10^4$ | $1.82 \times 10^4$ | $2.25 \times 10^4$ | $2.56 \times 10^4$ | $2.89 \times 10^4$ |

| Description | Marks |
|---|---|
| Converts mass to tension (× 9.80) | 1 |
| Squares frequencies | 1 |
| Scientific notation | 1 |
| 3 significant figures | 1 |
| **Total** | **4** |

**Question 16** (continued)

(c) Graph your data on the axes provided. Include a line of best fit. (3 marks)




| Description | Marks |
|---|---|
| Plots all points | 1 |
| Plots accurately | 1 |
| Accurate line of best fit | 1 |
| **Total** | **3** |

(d) Use the gradient of your line of best fit to calculate the mass per unit length in kg m$^{-1}$ of the steel wire. Indicate clearly the two points used and express your answer to the appropriate number of significant figures. (5 marks)

| Element | Description | Marks |
|---|---|---|
| Indicates clearly two points used (not data points) | | 1 |
| Calculates gradient of line of best fit | $\Delta y/\Delta x = (1.30 - 1.40) \times 10^{-3}$ N Hz$^{-2}$ | 1 |
| Calculates $\mu$ using the gradient | $\mu = m/(4 \times 0.450^2) = 1.69 \times 10^{-3}$ | 1 |
| Answer within range | $(1.60 - 1.73) \times 10^{-3}$ kg m$^{-1}$ | 1 |
| 2 or 3 significant figures only (must be consistent with values read from graph) | | 1 |
| **Total** | | **5** |

(e) Describe their assumption. (2 marks)

| Description | Marks |
|---|---|
| the wire stretches when increased weight is added | 1 |
| the mass per unit length will also change as it stretches | 1 |
| **Total** | **2** |

**Question 17** **(14 marks)**

(a) By taking moments around $B$, calculate the horizontal component of the reaction force of $T$ on the gate. Include a direction in your answer. (5 marks)

| Element | Description | Marks |
|---|---|---|
| Correctly identifies moments around $B$ | $mg$ and horizontal component of $R_T$ | 1 |
| Substitutes correct values into moments equation, specifically distances to pivot | $\Sigma acm = \Sigma cm$<br>$R_{HT}$ × 1.20 = 25.7 × 9.80 × 0.50 | 1–2 |
| Calculates correct answer for $R_{HT}$ | $R_{HT}$ = 105 N | 1 |
| Includes direction | left | 1 |
| | **Total** | **5** |

(b) Calculate the overall reaction force of $T$ on the gate. Include an angle to the horizontal in your answer. If you could not obtain an answer to part (a), use 1.40 × $10^2$ N. (5 marks)

| Element | Description | Marks |
|---|---|---|
| Uses Pythagoras to solve for net overall reaction force | | 1 |
| Substitutes correct values | $R_{net}^2 = (25.7 \times 9.8)^2 + 105^2$ | 1 |
| Calculates answer | $R_{net}$ = 273 N | 1 |
| Uses correct trig function to calculate $\theta$ | e.g. $\tan\theta$ = 251.9/105 | 1 |
| Calculates $\theta$ | $\theta$ = 67.4º | 1 |
| | **Total** | **5** |
| If used 1.40 × $10^2$ N, $R_{net}$ = 288 N, $\theta$ = 60.9º | | |

(c) Discuss how the angle in part (b) would be affected if the top hinge was fixed at the top of the gate. Include a mathematical expression in your explanation. (4 marks)

| Element | Description | Marks |
|---|---|---|
| Uses moments equation from part (a) | $\Sigma acm = \Sigma cm$<br>$R_{HT}$ × 1.20 = 25.7 × 9.80 × 0.50 | 1 |
| $\Sigma cm$ is constant | | 1 |
| If we increase $d$ from 1.20 to 1.40 m, $R_{HT}$ will decrease | | 1 |
| If $R_{HT}$ decreases, $\theta$ increases | | 1 |
| | **Total** | **4** |

Alternative solution

| Element | Description | Marks |
|---|---|---|
| Uses moments equation from part (a) and uses distance = $d$ | $\Sigma acm = \Sigma cm$<br>$R_{HT} \times d$ = 25.7 × 9.80 × 0.50 | 1 |
| $\Sigma cm$ is constant | $R_{HT}$ = 126/$d$ | 1 |
| If we increase d from 1.20 to 1.40 m, $R_{HT}$ will decrease | $\tan\theta$ = $Rv/Rh$<br>= 252/(126/$d$) = 2$d$ | 1 |
| If $d$ increases, $\tan\theta$ and hence $\theta$ increases | | 1 |
| | **Total** | **4** |

**Question 18** **(17 marks)**

(a) (i) Calculate the downward force exerted on the proton by the electric field. (3 marks)

| Element | Description | Marks |
|---|---|---|
| Uses $E = \frac{V}{d} = \frac{F}{q}$ to get expression for $F$ | $F = \frac{Vq}{d}$ | 1 |
| Substitutes correct values into equation | $F = \frac{4.80 \times 10^{3} \times 1.60 \times 10^{-19}}{4.00 \times 10^{-2}}$ | 1 |
| Calculates correct answer | $F = 1.92 \times 10^{-14}$ N | 1 |
| | **Total** | **3** |

(ii) Choose which mathematical relationship (A, B, C or D) describes the path taken by the proton when it enters the field. Circle your answer. (1 mark)

| Description | Marks |
|---|---|
| D. $y \propto x^2$ | 1 |
| **Total** | **1** |

(b) Given that the proton does not exit the field before hitting the bottom plate, how far from the righthand end of the bottom plate does the proton land? Ignore any effects due to gravity. (7 marks)

| Element | Description | Marks |
|---|---|---|
| Uses $s = ut + 0.5at^2$ to calculate time to hit plate | | 1 |
| Uses $u = 0$ | | 1 |
| Uses $a = F/m$ | | 1 |
| Uses $s = 2.00 \times 10^{-2}$ m | $0.02 = 0 + 0.5\left(\frac{1.92 \times 10^{-14}}{1.67 \times 10^{-27}}\right)t^2$ | 1 |
| Isolates $t$ correctly | $t = \sqrt{\frac{0.04}{1.15 \times 10^{13}}}$ | 1 |
| Calculates $t$ correctly | $t = 5.90 \times 10^{-8}$ s | 1 |
| Calculates distance using $s = vt$ | $s = 1.79 \times 10^{6} \times 5.90 \times 10^{-8} = 0.106$ m | 1 |
| | **Total** | **7** |

(c) Calculate the velocity of the proton just before it strikes the bottom plate. Include an angle in your answer. (6 marks)

| Element | Description | Marks |
|---|---|---|
| Calculates $v_v$ using $v = u + at$ where $u = 0$ | | 1 |
| Uses $t$ from part (b) | $v_v = 0 + (1.15 \times 10^{13}) \times 5.90 \times 10^{-8}$ $= 6.78 \times 10^5$ m s$^{-1}$ | 1 |
| Uses Pythagoras to calculate $v_{net}$ | $v_{net}^2 = (6.78 \times 10^5)^2 + (1.79 \times 10^6)^2$ | 1 |
| Calculates correct answer | $v_{net} = 1.91 \times 10^6$ m s$^{-1}$ | 1 |
| Uses a correct trig function | e.g. $\tan\theta = \dfrac{6.78 \times 10^5}{1.79 \times 10^6}$ | 1 |
| Calculates angle correctly | $\theta = 20.7°$ | 1 |
| | **Total** | **6** |

**Section Three: Comprehension** **20% (41 Marks)**

**Question 19** **(21 marks)**

(a) Discuss how the diagram in Figure 2 on page 31, shows that the two charged particles produced in the collision have different momenta. (4 marks)

| Description | Marks |
|---|---|
| the radius of the circular path of each particle is given by $r = \frac{mv}{Bq}$ | 1 |
| $m$ and $q$ are the same for $e^-$ and $e^+$ as is $B$ | 1 |
| different radii means different velocities | 1 |
| momentum ($p$) = $mv$ so different $v$, same $m$ means different $p$ | 1 |
| **Total** | **4** |

(b) Explain how one proton and one pion can be converted into one proton and five pions. (3 marks)

| Description | Marks |
|---|---|
| $E = mc^2$ | 1 |
| energy and mass are interchangeable | 1 |
| some of the energy of the incoming pion is converted to the mass of the extra pions | 1 |
| **Total** | **3** |

(c) Why do the lambda and kaon particles leave no tracks in the bubble chamber? (2 marks)

| Description | Marks |
|---|---|
| the tracks are produced by charged particles causing the unstable medium to 'boil' | 1 |
| lambda and kaon particles are neutral so they do not cause the medium to boil | 1 |
| **Total** | **2** |

(d) Is charge conserved in the overall reaction? Justify your answer with a calculation of the total charge before and after the collision. (4 marks)

| Description | Marks |
|---|---|
| before: $\pi^+$ (+1) and p (+1) = +2 | 1 |
| after: 2 × $\pi^-$ (–2) , p (+1) and 3 × $\pi^+$ (+3) | 1 |
| total after: +2 | 1 |
| therefore, yes, charge is conserved | 1 |
| **Total** | **4** |

(e) List a possible quark composition of the $\pi^+$ and $\pi^-$ particles. (3 marks)

| Description | Marks |
|---|---|
| pion+ must contain one of $u$, $c$ or $t$ only | 1 |
| pion+ must contain one of an anti $d$, $s$ or $b$ only | 1 |
| pion– must be anti-particle version of pion+ | 1 |
| **Total** | **3** |

(f) The approximate mass of the incoming $\pi^+$ is $2.48 \times 10^{-28}$ kg. If the radius of the circular path the pion is taking is 2.30 mm and it has a forward velocity of $3.70 \times 10^5$ m s$^{-1}$, estimate the strength of the magnetic field in the bubble chamber. (5 marks)

| Element | Description | Marks |
|---|---|---|
| Rearranges $r = \frac{mv}{Bq}$ to isolate $B$ | $B = \frac{mv}{rq}$ | 1 |
| Uses $2.30 \times 10^{-3}$ m for $r$ | | 1 |
| Uses $1.60 \times 10^{-19}$ for $q$ | | 1 |
| Calculates answer | $B = \frac{2.48 \times 10^{-28} \times 3.70 \times 10^5}{2.30 \times 10^{-3} \times 1.60 \times 10^{-19}} = 0.249$ T | 1 |
| 2 or 3 significant figures | 0.25 T | 1 |
| | **Total** | **5** |

**Question 20** **(20 marks)**

(a) With reference to Figure 3 on page 35, discuss how unpolarised light can become polarised. (4 marks)

| Description | Marks |
|---|---|
| the material consists of long chain polymers | 1 |
| electrons in these chains are free to move along the chains but not between them | 1 |
| a light wave's electric field does work on these electrons and causes them to absorb the waves' energy | 1 |
| therefore, light waves which are polarised parallel to the chains get absorbed and those travelling perpendicular pass through undisturbed | 1 |
| **Total** | **4** |

(b) Define the axis of a polarising filter and describe its function. (2 marks)

| Description | Marks |
|---|---|
| the axis of a polarising filter is perpendicular to the long chain polymers in the filter | 1 |
| it allows light waves travelling parallel to it to pass through | 1 |
| **Total** | **2** |

(c) According to Malus' Law, at what angle to the direction of polarisation of the incident light should the axis of a polarising filter be oriented in order to

(i) allow the light to pass without reduction in intensity? (1 mark)

| Description | Marks |
|---|---|
| 0° | 1 |
| **Total** | **1** |

(ii) completely block the passage of the light? (1 mark)

| Description | Marks |
|---|---|
| 90° | 1 |
| **Total** | **1** |

(d) Use Malus' Law to calculate the angle between the direction of polarisation of the incident light and the axis of a polarising filter if the incoming light has its intensity reduced by 75.0%. (4 marks)

| Element | Description | Marks |
|---|---|---|
| Uses 0.25 $I_0$ for $I$ | $0.25\ I_0 = I_0 \cos^2\theta$ | 1 |
| Cancels $I_0$ | $\cos^2\theta = 0.25$ | 1 |
| Takes the square root of both sides | $\cos\theta = 0.50$ | 1 |
| Calculates angle | $\theta = 60.0°$ | 1 |
| | **Total** | **4** |

(e) (i) Explain how inserting the third filter allowed light to hit the screen when no light was hitting it before. (3 marks)

| Description | Marks |
|---|---|
| the polarised light hitting the third filter strikes the axis of polarization at 45.0° | 1 |
| a component of the light is transmitted to the last screen at 45.0° to the axis of polarisation | 1 |
| therefore a component of light emerges from the last filter and hits the screen | 1 |
| **Total** | **3** |

(ii) What percentage of the original light is hitting the screen with the third filter in place? (2 marks)

| Description | Marks |
|---|---|
| $\frac{1}{2}\times\frac{1}{2}\times\frac{1}{2}=\frac{1}{8}$ | 1 |
| $\frac{1}{8}\times 100 = 12.5\%$ | 1 |
| **Total** | **2** |

(f) A photon's energy is given by $E = hf$. When light passes through a polarising filter, the total energy transmitted is reduced but the frequency of each photon remains the same. Using the particle model of light, account for the reduction in transmitted energy. (3 marks)

| Description | Marks |
|---|---|
| the total amount of energy is proportional to the number of photons emerging per second | 1 |
| the intensity is reduced by reducing the number of photons per second rather than reducing the energy of each photon | 1 |
| therefore the frequency and hence wavelength of each photon is unaffected by polarisation | 1 |
| **Total** | **3** |

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