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

PHYSICS

ATAR course examination 2022

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% (58 Marks)**

Question 1 **(5 marks)**

Light with a wavelength of 341 nm is shone onto a potassium metal plate in a photoelectric cell, causing a photocurrent to flow. The work function of potassium is 2.30 eV. Calculate the maximum speed of the electrons emitted by the plate.

Element	Description	Marks
Uses photoelectric effect equation	$E = hf - W$	1
Converts eV to Joules	$2.30 \times 1.60 \times 10^{-19} = 3.68 \times 10^{-19}$ J	1
Calculates the energy of incoming photon.	$E = \frac{hc}{\lambda} = 3.00 \times 10^{8} \times 6.63 \times 10^{-34}/341 \times 10^{-9}$ $= 5.83 \times 10^{-19}$ J	1
Calculates kinetic energy of electron	$KE_e = (5.83 - 3.68) \times 10^{-19} = 2.15 \times 10^{-19}$ J	1
Calculates the velocity of the electron	$v = \sqrt{\frac{2 \times 2.15 \times 10^{-19}}{9.11 \times 10^{-31}}}$ $= 6.87 \times 10^{5}$ m s^{-1}	1
	Total	**5**

Question 2 **(4 marks)**

Patrick and Daksh are sitting on a seesaw discussing physics. They decide to place the uniform 15.0 kg beam on the pivot as shown in the diagram below. Daksh estimates that the system is balanced and tells Patrick to lift his feet off the ground. As usual, Daksh is correct and the system is balanced with neither of them touching the ground. Daksh has a mass of 60.0 kg. What is Patrick's mass?

Element	Description	Marks
Takes moments around the pivot	$\Sigma cm = \Sigma acm$	1
Includes mass of beam		1
Uses correct distances from pivot	$m_p g \times 3.00 = (m_b g \times 1.00) + (m_d g \times 5.00)$	1
Calculates the correct answer	$m_p = 105$ kg	1
	Total	**4**
Note: If mass of beam is not included, award maximum 2 marks.		

Question 3 **(4 marks)**

A simple AC generator is shown in the diagram below. A coil is manually rotated in a fixed magnetic field, producing an alternating current in the external circuit. Explain how the alternating current is produced, making specific references to the labelled parts in the diagram.

Description	Marks
As the coil rotates, each side travels up or down, cutting across the magnetic flux present.	1
The current induced in each side of the coil changes direction every half turn of the coil.	1
Each side of the coil is attached to the external circuit by a slip ring.	1
The slip ring maintains sliding contact with the carbon brushes so the current in each ring changes direction every half turn, which produces an AC current.	1
Total	**4**

Question 4 **(5 marks)**

(a) Calculate the mass of the particle. (4 marks)

Element	Description	Marks
Isolates m from equation	$m = rBq/v$	1
Divides 9.14 cm by 2 and converts to m.		1
Puts correct values into equation	$m = 0.0457 \times 3.50 \times 10^{-4} \times 1.60 \times 10^{-19}/2.81 \times 10^{6}$	1
Calculates correct answer	$m = 9.11 \times 10^{-31}$ kg	1
	Total	**4**

(b) Which of the following could the particle be? Circle your answer. (1 mark)

Description	Marks
D Positron	1
Total	**1**

Question 5 **(5 marks)**

(a) Using the appropriate component of the magnetic field, calculate the electromotive force (EMF) induced between the ends of the aircraft's wings. (4 marks)

Element	Description	Marks
Converts km hr^{-1} to m s^{-1}	$7.20 \times 10^{2} \div 3.6 = 2.00 \times 10^{2}$ m s^{-1}	1
Calculates vertical component of B	$B \cos 33.0° = 4.90 \times 10^{-5}$ T	1
Substitutes values into correct equation, using calculated component	EMF = $4.90 \times 10^{-5} \times 2.00 \times 10^{2} \times 50.0$	1
Calculates correct answer	EMF = 0.490 V	1
	Total	**4**

(b) A wire runs between the ends of the wings, parallel to each wing, so as to set up a complete circuit. A sensitive ammeter is placed in the circuit. If the total resistance of the circuit is 1.78 Ω, what will be the reading on the ammeter? (1 mark)

Description	Marks
0.00 A	1
Total	**1**

Question 6 **(6 marks)**

Two identical 25.0 g coins are placed on a rotating disc, 0.30 m and 1.20 m respectively from the centre of the disc. The disc begins to rotate. When the frequency of rotation reaches 2.00 Hz, the outer coin flies off the disc. Calculate the frequency of rotation when the inner coin flies off.

Element	Description	Marks
Realises the centripetal force is supplied by the frictional force	$m_1 v_1^2/0.30 = m_2 v_2^2/1.20$	1
Cancels m and obtains ratio of velocities.	$v_2^2/v_1^2 = 4$ $v_2/v_1 = 2$ or $v_2 = 2v_1$	1
Substitutes $2\pi r/T$ for v		1
Uses 0.500 s for T_2	$1.20/0.500 = 2 \times 0.30/T_1$	1
Calculates T_1	$T_1 = 0.250$ s	1
Calculates frequency of rotation	$f = 1/T_1 = 4.00$ Hz	1
	Total	**6**

Question 7 **(4 marks)**

(a) In which direction is the initial movement of the bar? Circle your answer. (1 mark)

Description	Marks
Left	1
Total	**1**

(b) Explain why the bar moved when the circuit was turned on. (3 marks)

Description	Marks
There is a magnetic field between the poles of the magnet.	1
Moving charged particles generate a magnetic field.	1
The two magnetic fields interact, producing a force to the left.	1
Total	**3**

Alternate solution:

Description	Marks
The bar has a flow of current which is moving through the magnetic field between the poles of the magnet.	1
Charges moving through a magnetic field experience a force given by $F = qvB$ ($F = BIL$ on the rod)	1
The force on the charges (rod) will be perpendicular to their motion and the external magnetic field.	1
Total	**3**

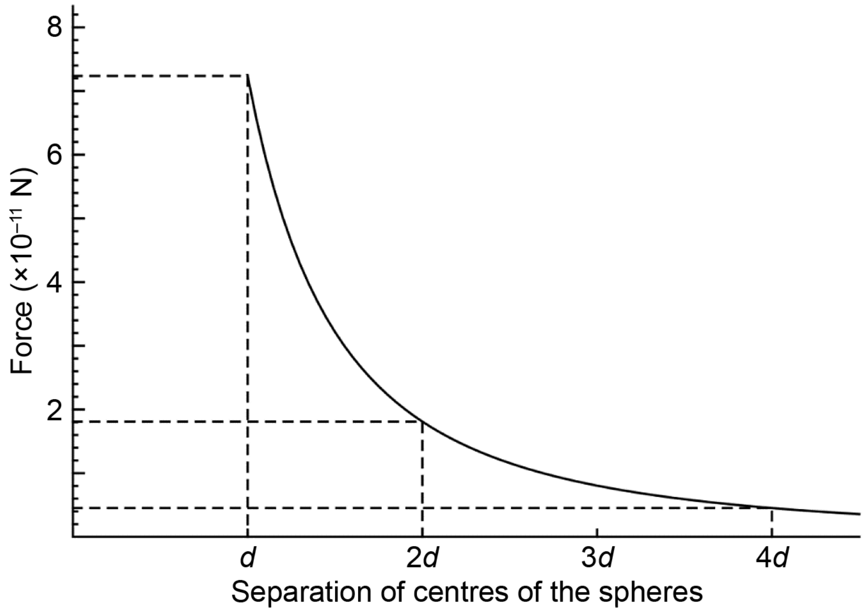
Question 8 **(7 marks)**

(a) If each sphere has a mass of 12.50 kg and a diameter of 2.00 m, calculate the gravitational force between them. (3 marks)

Element	Description	Marks
Uses 12.0 m as d		1
Uses gravitational force formula correctly	$F = 12.50 \times 12.50 \times 6.67 \times 10^{-11}/144.0$	1
Calculates correct answer	7.24×10^{-11} N	1
	Total	**3**

(b) On the axes below, show how the gravitational force between the two spheres varies as they move apart. Indicate the magnitude of the forces on the y-axis at the points 2d and 4d on the x-axis. If you could not obtain an answer to part (a), use 7.50×10^{-11} N. (4 marks)

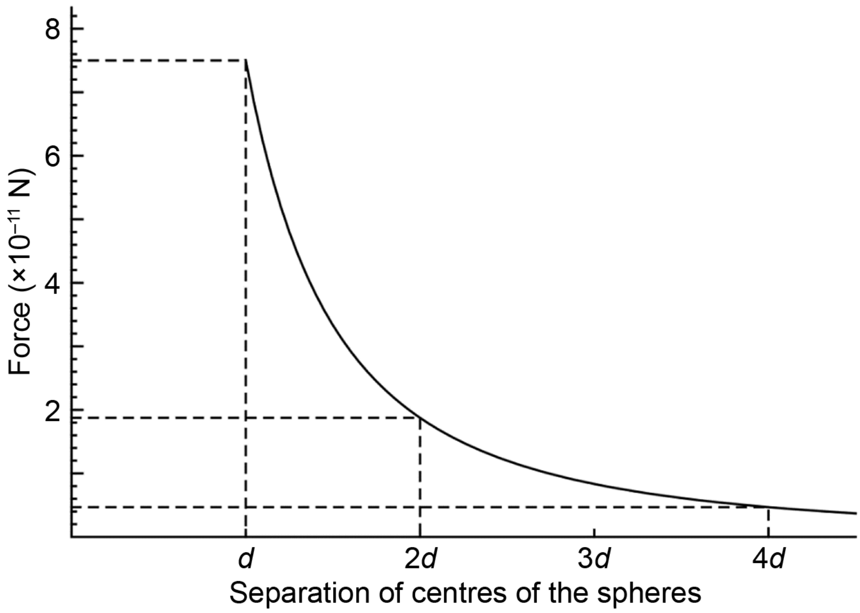
Description	Marks
three points plotted	1
indicates on y-axis, or shows by calculation, correct values	1
accurately plotted	1
curve accurately drawn indicating relationship	1
Total	**4**



$F(d) = 7.24 \times 10^{-11}$ N, $F(2d) = 1.81 \times 10^{-11}$ N, $F(4d) = 0.45 \times 10^{-11}$ N

Question 8 (continued)

If used $F(d) = 7.50 \times 10^{-11}$ N:



$F(d) = 7.50 \times 10^{-11}$ N, $F(2d) = 1.88 \times 10^{-11}$ N, $F(4d) = 0.47 \times 10^{-11}$ N

Question 9 **(5 marks)**

Two parallel conducting metal plates are held at a potential difference of 10.0 V. An electron in a vacuum arrives at a small hole in the first plate at point A with 20.0 eV of kinetic energy, and travels through an electric field to B as shown in the diagram. Calculate the de Broglie wavelength of the electron as it exits at B.

Element	Description	Marks
Reduces kinetic energy of electron by 10.0 eV	20.0 – 10.0 eV	1
Converts eV to Joules	$10.0 \times 1.60 \times 10^{-19} = 1.60 \times 10^{-18}$ J	1
Calculates exit velocity of electron	$v = \sqrt{\dfrac{2 \times 1.60 \times 10^{-18}}{9.11 \times 10^{-31}}}$ $= 1.87 \times 10^{6}\ \text{m s}^{-1}$	1
Uses De Broglie equation and substitutes values correctly	$\lambda = 6.63 \times 10^{-34}/9.11 \times 10^{-31} \times 1.87 \times 10^{6}$	1
Calculates correct answer	3.89×10^{-10} m	1
	Total	**5**
Note: If candidate adds 10 eV, $\lambda = 2.24 \times 10^{-10}$ m, award maximum 4 marks. If candidate uses 20 eV, award maximum 3 marks.		

Question 10 **(7 marks)**

(a) At what angle θ must the shooter fire the arrow above horizontal for it to hit the centre of the target? (4 marks)

Element	Description	Marks
Calculates time for target to reach destination	32.0/8 = 4.00 s	1
Uses correct vertical component		1
Uses vertical displacement of velocity	$-30.0 = 50.0 \sin\theta \times 4.00 - 4.90 \times 16.00$	1
Calculates correct angle	$\theta = 14.0°$	1
	Total	**4**
Accept other relevant methods of calculation e.g. using horizontal component.		

(b) With the use of a calculation, confirm that the arrow hits the target. (3 marks)

Element	Description	Marks
Uses correct horizontal component		1
Uses horizontal component of velocity	$s = vt = 50.0 \times \cos 14.0° \times 4.00 = 194$ m	1
Confirms arrow hits target	194 is between 193 and 197 m	1
	Total	**3**
Note: Candidate must use the alternate component of velocity in part (b) to the component they used in part (a).		

Question 11 **(6 marks)**

(a) How long does Salman measure Priyanka's ruler to be? (2 marks)

Element	Description	Marks
Uses correct equation and places correct values in correct place	$l = l_0 \sqrt{1 - 0.800^2}$	1
Calculates correct answer	l = 0.60 m	1
	Total	**2**

(b) How long does Priyanka measure Salman's ruler to be? (1 mark)

Description	Marks
0.60 m	1
Total	**1**

(c) When Priyanka returns, she and Salman compare the results of their measurements. How are they able to explain their seemingly contradictory results? (3 marks)

Description	Marks
To successfully measure the length of the ruler moving relative to them, they determine the position of the ends of the ruler at the same time and measure the distance between these two positions.	1
Each thought the other's measurements were not made simultaneously.	1
Therefore they both measure the other's ruler as a different length to 1.00 m.	1
Total	**3**

Section Two: Problem-solving **50% (91 Marks)**

Question 12 **(12 marks)**

(a) Calculate the tension in each chain when the father sits on the plank, assuming the supports do not tip over. (4 marks)

Element	Description	Marks
Uses sum of vertical forces = 0		1
Correct equation	$2T \times \cos 30.0° = \Sigma mg$	1
Includes mass of plank		1
Correctly calculates answer	$T = 82.0 \times 9.80/(2 \cos 30.0°) = 464$ N	1
	Total	**4**

(b) Calculate the horizontal component of the tension in each chain. (1 mark)

Description	Marks
$T_h = T \times \sin 30.0° = 464 \times 0.500 = 232$ N	1
Total	**1**

(c) With the use of a calculation, confirm that the supports do tip over when the father sits on the plank. Take moments around P. (5 marks)

Element	Description	Marks
Takes moments around inside base of support	$\Sigma cm > \Sigma acm$ if tips over	1
Uses 1.50 m as distance to pivot of T_h		1
Uses 0.40 m as distance to pivot of m_s		1
Correctly calculates moments	232 × 1.50 > 70.0 × 9.80 × 0.400	1
Confirms support tips over	348 N m > 274 N m	1
	Total	**5**

(d) Without the use of additional calculations, describe how the tension in each chain would be affected if a 50.0 kg person sitting at A moved to B? Select either increases, decreases or remains constant. (2 marks)

Chain 1	Chain 2
decreases	increases

Description	Marks
chain 1 decreases	1
chain 2 increases	1
Total	**2**

Question 13 **(14 marks)**

(a) What is the original energy of the photon in eV? (3 marks)

Element	Description	Marks
Substitutes $\frac{c}{\lambda}$ for f in $E = hf$	$E = \frac{hc}{\lambda}$	1
Calculates correct answer in Joules	$E = 3.00 \times 10^{8} \times 6.63 \times 10^{-34}/7.040 \times 10^{-11}$ $= 2.82 \times 10^{-15}$ J	1
Converts to eV	$E = 1.77 \times 10^{4}$ eV	1
	Total	**3**

(b) What is the momentum of the photon before the collision? (2 marks)

Element	Description	Marks
Uses de Broglie and isolates p	$p = \frac{h}{\lambda}$	1
Calculates correct answer	$p = 6.63 \times 10^{-34}/7.040 \times 10^{-11}$ $= 9.42 \times 10^{-24}$ N s	1
	Total	**2**

(c) Explain why the wavelength of the photon is greater after the collision. (3 marks)

Description	Marks
Conservation of Energy means the energy gained by the electron comes from the photon.	1
$E = \frac{hc}{\lambda}$	1
As energy has decreased, wavelength must increase.	1
Total	**3**

Alternate solution:

Description	Marks
Photon transfers momentum to the electron.	1
Conservation of Momentum means photon rebounds with less momentum.	1
From $\lambda = \frac{h}{p}$, λ must increase.	1
Total	**3**

(d) Calculate the speed of the electron after the collision. (Hint: use the principles of conservation of energy.) (6 marks)

Element	Description	Marks
Energy lost by the photon is gained by the electron		1
Correct formula	$E_e = \frac{hc}{\lambda_1} - \frac{hc}{\lambda_2}$	1
Uses correct wavelengths	$3.00 \times 10^{8} \times 6.63 \times 10^{-34} \times (1/7.040 \times 10^{-11} - 1/7.525 \times 10^{-11})$	1
Calculates correct energy	$E = 1.82 \times 10^{-16}$ J	1
Isolates v from KE equation	$v = \sqrt{\frac{2 \times 1.82 \times 10^{-16}}{9.11 \times 10^{-31}}}$	1
Calculates correct answer	$v = 2.00 \times 10^{7}$ m s^{-1}	1
	Total	**6**

Question 14 **(15 marks)**

(a) In the reaction, the quark composition of a neutron changes from udd to uud. Show how the reaction conserves both baryon number and lepton number by filling in the table below. (6 marks)

	n^0	$\rightarrow$	p^+	+	e^-	+	$\bar{\nu}_e$
Baryon number	+1	$\rightarrow$	+1	+	0	+	0
Lepton number	0	$\rightarrow$	0	+	+1	+	-1

Description	Marks
Baryon number for neutron = ⅓ + ⅓ + ⅓ = 1	1
Baryon number for proton = ⅓ + ⅓ + ⅓ = 1	1
All baryon numbers correct	1
Baryon number conserved	1
Lepton numbers correct	1
Lepton number conserved	1
Total	**6**

(b) The mass of a stationary neutron is 1.675×10^{-27} kg. The mass of a proton is 1.673×10^{-27} kg. The mass of an electron is 9.109×10^{-31} kg. If we assume the total energy of the anti-neutrino is 0 J, calculate the total kinetic energy of the particles emitted in keV. (5 marks)

Element	Description	Marks
Uses total energy equation to determine $\Delta mc^2 = \Delta\Sigma KE$		1
Calculates Δm	$1.675 \times 10^{-27} - 1.673 \times 10^{-27} - 9.109 \times 10^{-31}$ $= 1.0891 \times 10^{-30}$ kg	1
Converts to energy	$1.0891 \times 10^{-30} \times 9.000 \times 10^{16}$ $= 9.8019 \times 10^{-14}$ J	1
Converts to eV	$9.8019 \times 10^{-14}/1.600 \times 10^{-19}$ $= 6.1262 \times 10^{5}$ eV	1
Expresses answer in keV	613 keV	1
	Total	**5**

Question 14 (continued)

(c) If the electron accounts for 90.0% of the kinetic energy produced, calculate the velocity of the emitted proton in terms of c. If you could not determine an answer for part (b), use 581 keV (9.30×10^{-14} J). (4 marks)

Element	Description	Marks
Calculates 10.0% of energy from part (b)	$0.100 \times 9.8019 \times 10^{-14}$ $= 9.8019 \times 10^{-15}$	1
Rearranges equation correctly	$v = \sqrt{\frac{2 \times 9.8019 \times 10^{-15}}{1.673 \times 10^{-27}}}$	1
Calculates correct answer	$v = 3.423 \times 10^{6}$ m s^{-1}	1
Expresses answer in terms of c	$v = 0.0114\ c$	1
	Total	**4**
Note: If used 5.81×10^{5} eV, $v = 3.33 \times 10^{6}$ m s^{-1} = $0.0111\ c$		

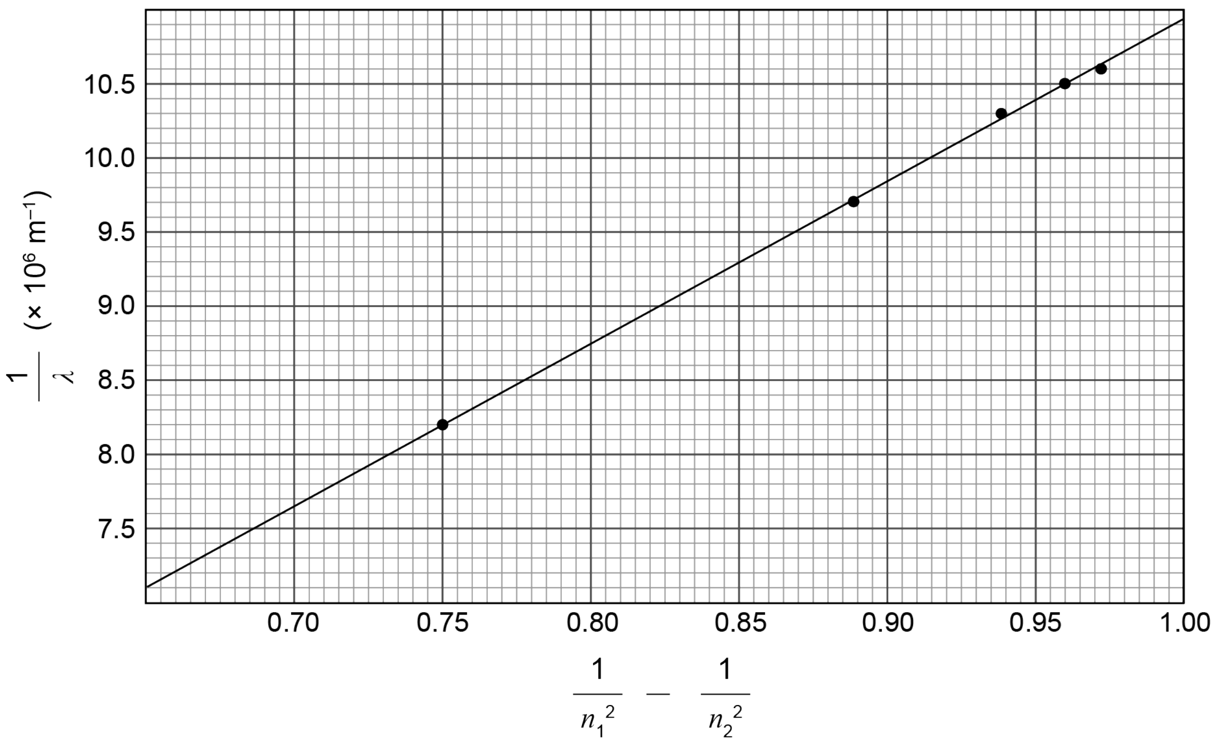
Question 15 **(19 marks)**

(a) Fill in the table below using the values in Figure 1. Give your answers to **three** significant figures. (5 marks)

Δn	2→1	3→1	4→1	5→1	6→1
$\frac{1}{n_1^2} - \frac{1}{n_2^2}$	0.750	0.889	0.938	0.960	0.972
$\frac{1}{\lambda}$ (10^6 m^{-1})	8.20	9.71	10.3	10.5	10.6

Description	Marks
first row correct (1 mark off for each incorrect answer, maximum 2)	1–2
second row correct (1 mark off for each incorrect answer, maximum 2)	1–2
3 significant figures	1
Total	**5**

(b) Graph $\frac{1}{\lambda}$ vs $\frac{1}{n_1^2} - \frac{1}{n_2^2}$ on the grid below. Label the axes clearly and draw a line of best fit. (5 marks)



Description	Marks
y–axis labelled correctly with correct units	1
x–axis labelled correctly with no units	1
all points plotted	1
points plotted accurately	1
line of best fit	1
Total	**5**

Question 15 (continued)

(c) Use your line of best fit to calculate Rydberg's constant. Indicate clearly the points you have used. Give your answer to **two** significant figures. (5 marks)

Description	Marks
clearly indicates the 2 points used (must not be data points).	1
uses correct formula for gradient ($\Delta y/\Delta x$)	1
calculates gradient. (1.1 +/- 0.1 × 10^7 m^{-1})	1
multiplies gradient by ch. $1.1 \times 10^7 \times 3.00 \times 10^8 \times 6.63 \times 10^{-34} = 2.2 \times 10^{-18}$ J	1
2 significant figures	1
Total	**5**

(d) Identify and explain **two** differences you would see between the graph of $\frac{1}{\lambda}$ vs $\frac{1}{n_1^2} - \frac{1}{n_2^2}$ for hydrogen and the helium ion. (4 marks)

Description	Marks
One	
The gradient will be 4 times greater for He^+ than hydrogen.	1
Therefore Z for He^+ is 2 therefore coefficient of x variable is × 4.	1
Two	
The wavelengths will be shorter and the range of values on the y-axis will be greater.	1
Therefore the energy differences between levels for He^+ are greater than for hydrogen.	1
Total	**4**

Question 16 **(15 marks)**

(a) Calculate the power output of both stations in kW. (2 marks)

Element	Description	Marks
Uses $P = VI$	$P = 480 \times 100 = 48\ 000$ W	1
Converts to kW	48.0 kW	1
	Total	**2**

(b) If the resistance of the transmission lines between the pylons is $2.19 \times 10^{-4}\ \Omega\ m^{-1}$, estimate the efficiencies of both systems by calculating power loss in the wires. Assume negligible power losses in the lines to the pylons from the station, and from the pylons to the houses. (6 marks)

Element	Description	Marks
Calculates total resistance of 20.0 km of line	$2.19 \times 10^{-4} \times 10\ 000 \times 2 = 4.38\ \Omega$	1
$P_{lost} = I^2R$ for DC	$P = 100.0^2 \times 4.38$ $P = 4.38 \times 10^4$ W	1
Efficiency for DC	$100 - (4.38 \times 10^4/4.80 \times 10^4) \times 100$ $= 8.8\%$	1
$P_{lost} = I^2R$ for AC	$P = 10.0^2 \times 4.38 = 438$ W	1
Efficiency for AC	$100 - (438/4.80 \times 10^4) \times 100 = 99\%$	1
2 significant figures		1
	Total	**6**

(c) Figure 3 shows a step-up transformer. One of the features that increases efficiency is the laminated soft iron core. Explain why laminating the core increases the transformer's efficiency. (3 marks)

Description	Marks
Changing magnetic fields induce eddy currents in the metal.	1
This heats up the metal and power is lost.	1
A laminated core reduces the magnitude of the eddy currents and therefore reduces power lost as heat.	1
Total	**3**

(d) Explain why transformers require AC current to function in electricity transmission. (4 marks)

Description	Marks
A current-carrying conductor has a magnetic field around it.	1
An alternating current produces an alternating magnetic field.	1
This changing magnetic field induces an EMF in the secondary coil.	1
The EMF allows current to flow in the transmission lines.	1
Total	**4**

Question 17 **(16 marks)**

(a) Calculate the tension in the string when θ = 30.0°. (4 marks)

Element	Description	Marks
Uses correct relationship	$\cos 30.0° = mg/T$	1
Isolates T correctly	$T = mg/\cos 30.0°$	1
Converts to kg	$T = 0.255 \times 9.80/\cos 30.0°$	1
Calculates correct answer	T = 2.89 N	1
	Total	**4**

(b) Calculate the radius of the circular path the 'bob' is moving in when the angle is 30.0°. (2 marks)

Element	Description	Marks
Uses correct identity	$\sin 30.0° = r/L$	1
Calculates correct answer	$r = L \sin 30.0°$ = 0.600 m	1
	Total	**2**

(c) Calculate the new angle between the pendulum string and the vertical if the frequency of rotation is doubled. (6 marks)

Element	Description	Marks
Calculates new period	$T = 1/0.980 = 1.02$ s	1
Uses correct relationship	$\tan \theta = mv^2/r/mg = v^2/rg$	1
Substitutes $2\pi r/T$ for v	$9.80 \tan \theta = 4\pi^2 r/T^2$	1
Substitutes $L \sin \theta$ for r	$9.80 \sin \theta/\cos \theta = 4\pi^2 \times 1.20 \sin \theta/T^2$	1
Simplifies and isolates $\cos \theta$	$\cos \theta = 9.80 \times 1.02^2/(4\pi^2 \times 1.20)$	1
Calculates correct angle	θ = 77.6°	1
	Total	**6**
Note: If assumes r or v remains constant, award maximum 3 marks.		

(d) Explain why θ can never equal 90.0°, regardless of how great the frequency of the pendulum becomes. You may use mathematical relationships in your answer. (4 marks)

Description	Marks
Tension consists of two components, vertical and horizontal.	1
The vertical component counters mg.	1
When angle = 90°, the vertical component = 0.	1
This means there is nothing holding the weight of the 'bob', which is impossible.	1
Total	**4**

Alternate solution:

Description	Marks
$\cos \theta = mg/T$	1
$T = mg/\cos \theta$	1
As θ approaches 90°, T approaches infinity.	1
Infinite T is impossible.	1
Total	**4**

Section Three: Comprehension **20% (38 Marks)**

Question 18 **(21 marks)**

(a) Explain how a PN junction produces visible light. (4 marks)

Description	Marks
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	1
	1
	1
Total	**4**

(b) LEDs and incandescent light bulbs are equally efficient at converting energy drawn from the mains into different types of energy. Why then does the passage on page 33 state that LEDs are far more efficient than incandescent light bulbs? Reference must be made to the graphs of intensity versus wavelength. (4 marks)

Description	Marks
The graphs show the majority of wavelengths produced by an LED are in the visible range.	1
A significant proportion of wavelengths produced by an incandescent globe are outside the visible range.	1
An LED has far greater efficacy. It produces more Lumens per Watt.	1
LEDs are therefore more efficient in terms of useful output/input. (60 W vs 10 W)	1
Total	**4**

(c) The efficacy of a particular LED is 120 lumens W^{-1}. Using information in the passage and table on page 33, calculate how much current would need to run through a blue SiC LED light bulb operating at minimum V_F to produce 840 lumens. (4 marks)

Element	Description	Marks
Calculates power needed	840/120 = 7.00 W	1
Uses correct voltage	V_F = 3.60 V	1
Uses $P = VI$ and isolates I	I = 7.00/3.60	1
Calculates correct answer	I = 1.94 A	1
	Total	**4**

Question 18 (continued)

(d) With the use of a calculation and data from the table on page 33, show how the minimum V_F for SiC crystals is large enough to produce photons with the lowest energy required for blue light. (4 marks)

Element	Description	Marks
Calculates energy of electron	$E = Vq = 3.60 \times 1.60 \times 10^{-19}$ $= 5.76 \times 10^{-19}$ J	1
Substitutes $\frac{c}{\lambda}$ for f into $E = hf$	$E = \frac{hc}{\lambda}$	1
Isolates λ and calculates it	$\lambda = 3.00 \times 10^{8} \times 6.63 \times 10^{-34}/5.76 \times 10^{-19}$ $= 3.45 \times 10^{-7}$ m	1
States wavelength is shorter than 5.05×10^{-7} m therefore energetic enough		1
	Total	**4**

(e) Using the efficiencies stated in the passage, estimate the mass of coal the world could save per year if 100% of lighting was provided by LEDs. (5 marks)

Element	Description	Marks
Calculates energy for lighting	$194 \times 10^{18} \times 0.15 = 2.91 \times 10^{19}$ J	1
Calculates energy from incandescent globes	$2.91 \times 10^{19} \times 0.60 = 1.746 \times 10^{19}$ J	1
Uses 50/60 ratio from passage to calculate energy savings	$1.746 \times 10^{19} \times 5/6 = 1.455 \times 10^{19}$ J	1
Calculates mass of coal saving	$(1.455 \times 10^{19}/21 \times 10^{9}) \times 0.8$ $= 5.54 \times 10^{8}$ Tonnes	1
2 significant figures	5.5×10^{8} Tonnes	1
	Total	**5**

Question 19 **(17 marks)**

(a) (i) Using Kepler's 2nd Law, describe the relationship between the distance a planet is from the Sun it orbits and its orbiting speed by filling the blank below. (1 mark)

As the distance from the planet increases, the orbiting speed _______________.

Description	Marks
decreases	1
Total	**1**

(ii) Without completing a calculation, justify this relationship with reference to Figure 1. (3 marks)

Description	Marks
The shaded areas in the diagram show the same time interval.	1
The satellite further from the Sun travels less distance in the same time.	1
Therefore the further from the Sun, the lower the speed.	1
Total	**3**

(b) Using the instructions given in the article, derive Kepler's 3rd Law from first principles, showing each step of the derivation. The final expression must match the equation in the Formulae and Data booklet. Assume the orbit is perfectly circular and the mass of the satellite is insignificant compared to the mass of the body it is orbiting. (5 marks)

Element	Description	Marks
Equates gravitational force to centripetal force.	$mMG/r^2 = mv^2/r$	1
Cancels mass and r	$MG/r = v^2$	1
Substitutes $2\pi r/T$ for v	$MG/r = 4\pi^2r^2/T^2$	1
Simplifies by cross multiplying	$T^2MG = 4\pi^2r^3$	1
Rearranges to match formula on data sheet	$T^2/r^3 = 4\pi^2/GM$	1
	Total	**5**

Question 19 (continued)

(c) Using moments, estimate how far the barycentre of the Earth–Moon system is from the centre of the Earth. (4 marks)

Element	Description	Marks
Uses moments around barycentre to solve problem	$\Sigma cm = \Sigma acm$	1
Uses d and $(3.84 \times 10^8 - d)$ as distances	$5.97 \times 10^{24} \times g \times d$ $= 7.35 \times 10^{22} \times g \times (3.84 \times 10^8 - d)$	1
Solves for d	$d = 4.7 \times 10^6$ m	1
2 significant figures		1
	Total	**4**

Alternate solution:

Element	Description	Marks
Uses moments around centre of Earth to solve problem	$\Sigma cm = \Sigma acm$	1
Uses $\Sigma m \times g \times d$ as acm	$(5.97 \times 10^{24} + 7.35 \times 10^{22}) \times g \times d$ $= 7.35 \times 10^{22} \times g \times 3.84 \times 10^8$	1
Solves for d	$d = 4.7 \times 10^6$ m	1
2 significant figures		1
	Total	**4**

(d) With the use of a calculation and your answer to part (c), show that the Moon is travelling roughly 81 times faster than Earth as they orbit the barycentre. (4 marks)

Element	Description	Marks
Realises the period for both Earth and Moon are identical	T = 28 days (± 1 day only)	1
Uses $T = 2\pi r/v$	$2\pi r_m/v_m = 2\pi r_E/v_E$	1
Simplifies and uses correct radii	v_m/v_E $= (3.84 \times 10^8 - 4.670 \times 10^6)/4.670 \times 10^6$	1
Calculates correct answer	$v_m/v_E = 81.2$	1
	Total	**4**
Note: If used 4.81×10^6, $v_m/v_E = 78.8$, therefore roughly 80 times.		

ACKNOWLEDGEMENTS

Question 18(a) Answer adapted from: Baguley, R., & McDonald, C. (2014). *Appliance Science: The Illuminating Physics Behind LED Lights*. Retrieved April, 2022, from https://www.cnet.com/home/kitchen-and-household/appliance-science-how-led-lights-work/

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