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

PHYSICS

ATAR course examination 2018

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.

2018/60317

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

Question 1 **(4 marks)**

(a) Determine the primary to secondary turns ratio of the step-up transformer used at the power station. (2 marks)

Description	Marks
$\frac{V_p}{V_s} = \frac{N_p}{N_s}$ $\frac{415}{11\ 000} = \frac{N_p}{N_s}$	1
$\frac{N_p}{N_s} = 3.77 \times 10^{-2}$ Ratio = 1:26.5	1
Total	**2**

(b) Determine the current available at the output of the step-up transformer. (2 marks)

Description	Marks
$P_p = P_s = V_s I_s$ $300 \times 10^3 = 11000 \times I_s$	1
$I_s = \frac{300 \times 10^3}{11 \times 10^3} = 27.3$ A	1
Total	**2**

Question 2 **(6 marks)**

(a) Calculate the current drawn by each motor when operating at maximum power output. (4 marks)

Description	Marks
$P_{OUT} = V_{BACK} \times I$	1–2
$I = \frac{P_{OUT}}{V_{BACK}} = 57.7\ A$	1–2
or	
$V_{EFF} = V_S - V_{BACK} = 600 - 520 = 80\ V$	1–2
$I = \frac{V}{R} = \frac{80}{1.39} = 57.6\ A$	1–2
Total	**4**

(b) After operating for a while one of the motors becomes jammed. Describe, with a reason, what happens to the current in that motor when it becomes jammed. (2 marks)

Description	Marks
the current will increase significantly	1
as now there is no back emf to oppose the applied voltage	1
Total	**2**

Question 3 **(6 marks)**

(a) State why **all** photoelectrons emitted from the silicon do not have the same kinetic energy for a given incident wavelength. (1 mark)

Description	Marks
electrons not on the surface will require more energy to escape the crystal lattice structure **or** work function is the minimum energy required	1
Total	**1**
Accept other relevant answers	

(b) Determine the maximum energy in joules of the highest energy incident photons. (2 marks)

Description	Marks
$E = hf = \dfrac{hc}{\lambda}$	1
$= \dfrac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{510.6 \times 10^{-9}} = 3.90 \times 10^{-19}$ J	1
Total	**2**

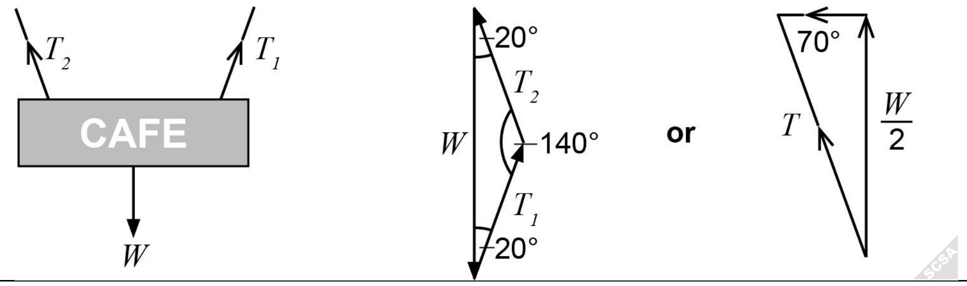
(c) Calculate the work function of the silicon in joules. (3 marks)

Description	Marks
$E_k = hf - W$ $W = hf - E_k$	1
$= \dfrac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{510.6 \times 10^{-9}} - 5.36 \times 10^{-20}$ $= 3.90 \times 10^{-19} - 5.36 \times 10^{-20}$	1
$= 3.36 \times 10^{-19}$ J	1
Total	**3**

Question 4 (7 marks)

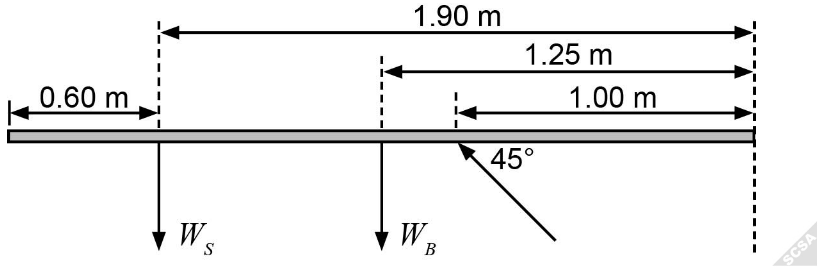
(a) Calculate the tension in each of the light steel cables supporting the sign. (3 marks)

Description	Marks
$\sum F_v = 0$	1
therefore $2\ T \sin 70^o = W_s$ therefore $T = \dfrac{4 \times 9.8}{2 \sin 70^o}$	1
20.9 N	1
Total	**3**



(b) Calculate the compression force in the steel bracket BC, if the force only acts along BC. (4 marks)

Description	Marks
Take moments about D $\sum T_{cw} = \sum T_{acw}$	1
$W_s \times 1.90 + W_B \times 1.25 = F_{Br} \times 1.00 \times \sin 45°$	1–2
therefore $F_{Br} = \dfrac{4 \times 9.8 \times 1.9 + 15 \times 9.8 \times 1.25}{1.00 \times \sin 45°}$ 365 N	1
Total	**4**



Question 5 **(3 marks)**

Calculate the force exerted on one of these dust particles by the field when it is between the parallel vertical metal plates. The horizontal distance between the plates is 47.5 cm.

Description	Marks
$F/q = V/d$	1
$F = Vq/d = (50 \times 10^3 \times 1.00 \times 10^{-8})/0.475$	1
$= 1.05 \times 10^{-3}$ N	1
Total	**3**

Question 6 **(6 marks)**

(a) Discuss how the pattern in Diagram 2 was produced. (5 marks)

as the light 'wave' passes by the edges of the (spherical) object diffraction occurs	1
waves interfere on screen	1
constructive interference occurs and gives rise to the light areas (circles)	1
destructive interference occurs and gives rise to the dark areas (circles)	1
the bright dot (in the middle) all waves are in phase (path difference is zero)	1
Total	**5**

(b) From this experiment, what conclusion can be made regarding the nature of light? (1 mark)

Description	Marks
that light has wave properties and behaves as a wave	1
Total	**1**

Question 7 **(5 marks)**

(a) Determine the peak voltage output of this alternator. (1 mark)

Description	Marks
$V_{\text{RMS}} = \dfrac{V_{\text{PEAK}}}{\sqrt{2}} \quad V_{\text{PEAK}} = \sqrt{2} \times V_{\text{RMS}}$ $= \sqrt{2} \times 14.5\text{ V} = 20.5\text{ V}$	1
Total	**1**

(b) Calculate the magnetic field strength needed to produce this peak output voltage. If you were unable to obtain an answer for part (a), use 25.0 V. (4 marks)

Description	Marks
$f = \frac{600}{60}$ cps = 10 Hz (period = 0.1 s)	1
$A = 2 \times 7 \times 10^{-2} \times 6 \times 10^{-2}$ $= 8.4 \times 10^{-3}\text{ m}^2$	1
$\varepsilon_{\text{MAX}} = 2\pi NBA_{\perp}f$ $20.5 = 2\pi \times 320 \times \left(7 \times 10^{-2} \times 2 \times 6 \times 10^{-2}\right) \times \dfrac{600}{60} \times B$	1
$B = \dfrac{20.5}{2\pi \times 320 \times 8.4 \times 10^{-3} \times 10} = 0.121\text{ T}$ (0.148T)	1
Total	**4**

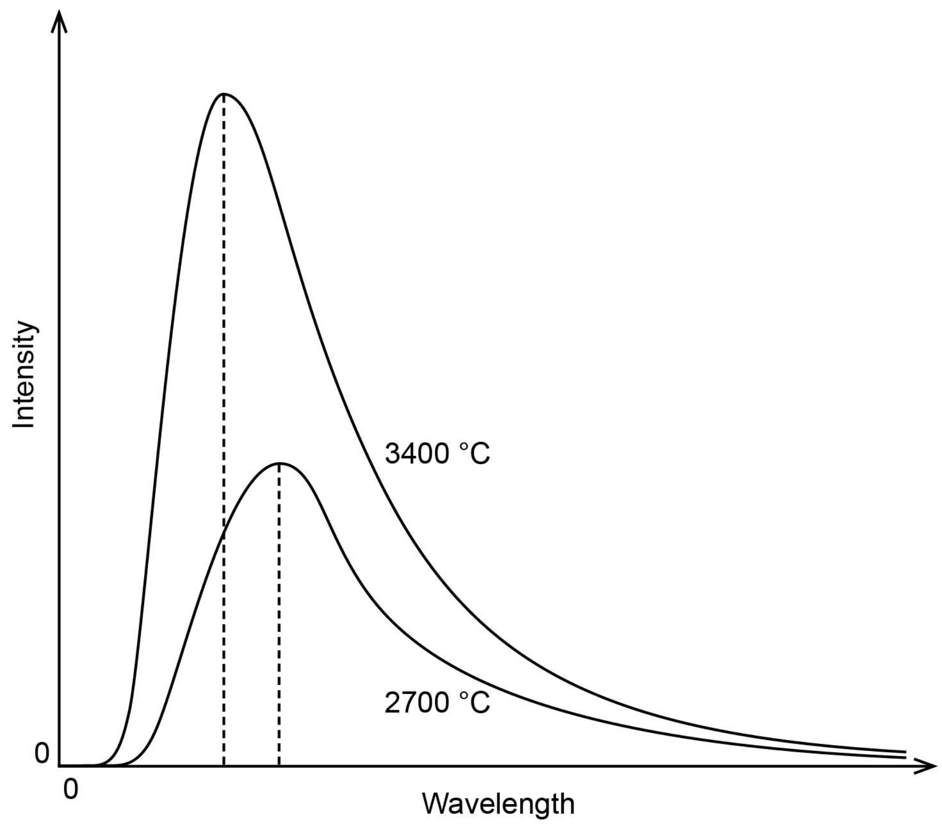
Question 8 **(5 marks)**

(a) Describe why the colour and intensity of the tungsten changes as it is heated. (2 marks)

Description	Marks
as the molecules are heated they vibrate faster and thus produce a higher frequency (accelerate and decelerate more rapidly the greater the deceleration the greater the frequency of light produced)	1
as the temperature increases there are more molecules vibrating at faster speeds and so the intensity of the higher frequencies increases	1
or	
black body radiation where the dominant wavelength decreases as the temperature increases hence the colour changes	1
as the temperature increases the power increases and hence an increase in intensity	1
Total	**2**

(b) Use the axes below to sketch labelled graphs of intensity against wavelength for the two observed spectra at 2700 °C and 3400 °C. (3 marks)

Description	Marks
shows higher temperature curve has a higher peak intensity at shorter wavelength	1
shows lower temperature curve has a lower peak intensity at longer wavelength	1
appropriate shape of curves	1
Total	**3**



Note: No labels award maximum of 1 mark for shape

Question 9 **(6 marks)**

(a) Compare the acceleration of cars A and B. Include an equation in your answer. (3 marks)

Description	Marks
$a_c = \frac{v^2}{r}$	1
as r_A < r_B and v is constant for both vehicles and the same speed then $a_c \propto \frac{1}{r}$	1
therefore a_c A> a_c B since r_A < r_B	1
Total	**3**

(b) How can the roundabout be redesigned to enable cars to travel safely at a higher speed? Explain your answer. Calculations are not required. (3 marks)

Description	Marks
the roundabout will need to be banked/inclined plane	1
this means that the normal force can provide a horizontal component inwards which contributes to the centripetal force required	1
thus the friction force needed can stay within safe limits. (On a horizontal track, friction is the only force providing centripetal force.)	1
or	
make the surface rougher	1
this will increase friction	1
thus the friction force is larger and can stay within safe limits. (On a horizontal track, friction is the only force providing centripetal force.)	1
Total	**3**

Question 10 **(7 marks)**

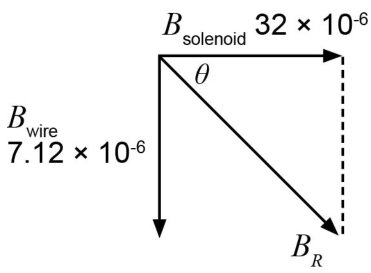
(a) Use the information above to calculate

(i) the magnitude of the magnetic field at point A due to the current in the conductor. (2 marks)

Description	Marks
$B = \frac{\mu_o}{2\pi} \frac{I}{r}$	1
$= \frac{4\pi \times 10^{-7}}{2\pi} \times \frac{285 \times 10^{-3}}{8 \times 10^{-3}} = 71.2 \times 10^{-7}$ $= 7.12 \times 10^{-6}$ T	1
Total	**2**

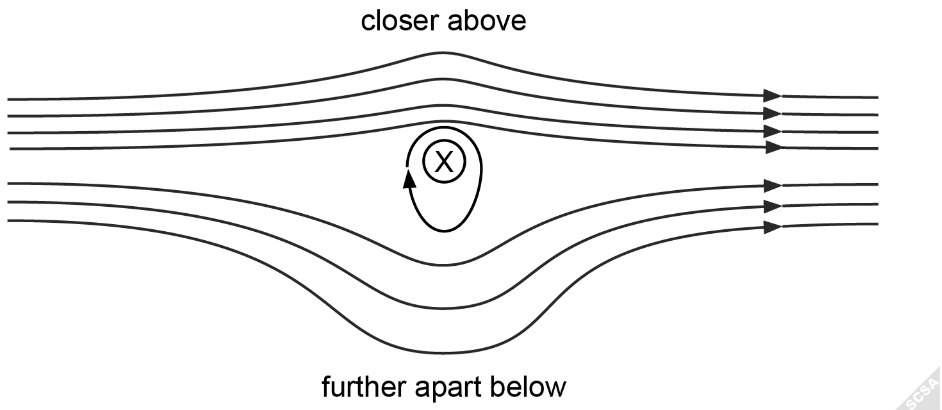
(ii) the magnitude and direction of the resultant magnetic field at point A. If you were unable to obtain an answer to part (a)(i), use 6.00×10^{-6} T. Include a diagram in your answer. (3 marks)

Description	Marks
vector diagram as below	1
$B_R = \sqrt{(32 \times 10^{-6})^2 + (7.12 \times 10^{-6})^2}$ $= 32.8 \times 10^{-6}$ T $= 3.28 \times 10^{-5}$ T	1
$\tan\theta = \frac{7.12}{32} = 0.223$ $\theta = 12.5°$ (below horizontal towards the right)	1
Total	**3**



(b) Sketch the resultant magnetic field around the conductor. (2 marks)

Description	Marks
shows magnetic lines closer above than below the conductor	1
overall shape is consistent	1
Total	**2**



Section Two: Problem-solving 50% (89 Marks)

Question 11 (13 marks)

(a) Determine the initial vertical velocity of the firework rocket. (2 marks)

Description	Marks
$30.0 \times \sin 70°$	1
$28.2\ m\ s^{-1}$	1
Total	**2**

(b) Calculate the height of point B. (3 marks)

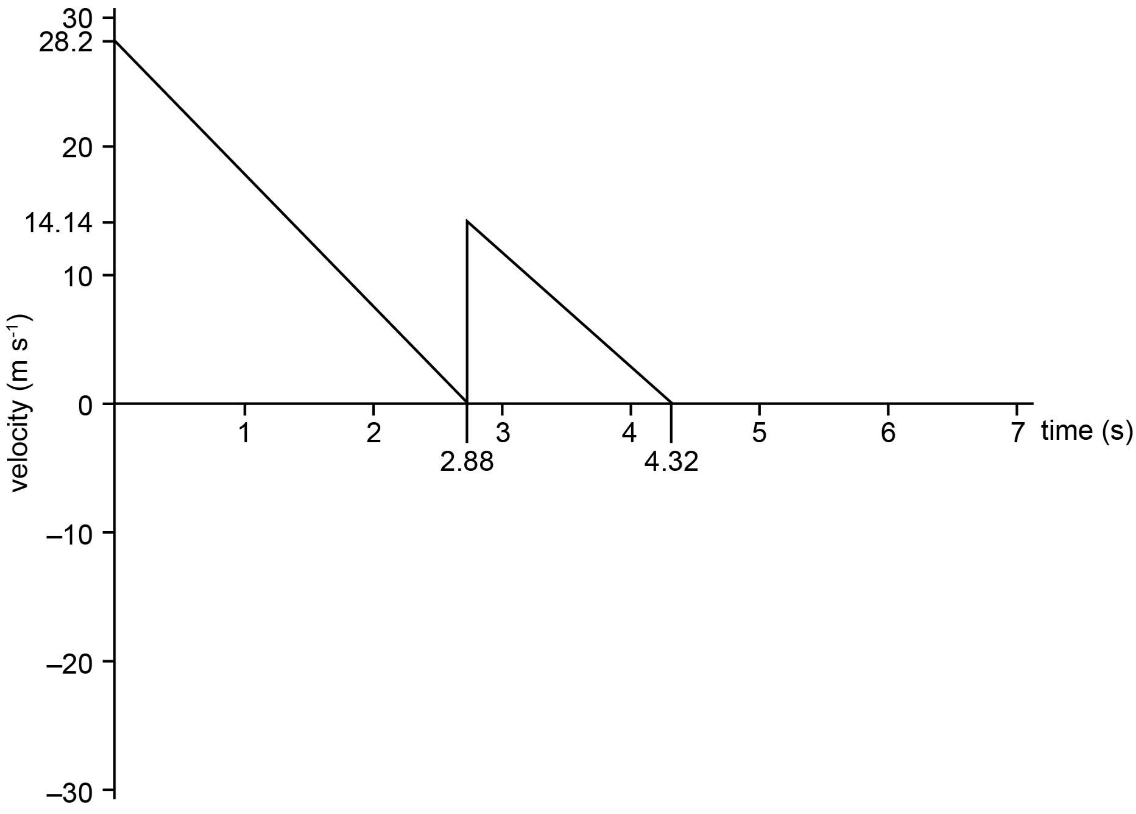
Description	Marks
$v^2 = u^2 + 2as$ $0^2 = 28.19^2 + 2 \times (-9.80) \times s$ $794.7 = 19.62\ s$	1–2
$s = 40.5$ m	1
Total	**3**

(c) Calculate the total time it takes for the firework rocket to reach point C where it explodes. (5 marks)

Description	Marks
Time taken to reach point B $v = u + at$ $0 = 28.19 - 9.80\ t$ $t = \frac{28.2}{9.8}$	1
$t = 2.88$ s	1
Time taken to reach point C $20 \sin 45° = 14.14$ $v = u + at$ $0 = 14.1 - 9.80\ t$ $t = \frac{14.1}{9.8}$	1
$t = 1.44$	1
Total time $2.88 + 1.44 = 4.32$ s	1
Total	**5**

(d) Use the axes below to sketch a graph of vertical velocity against time of the firework from immediately after it is launched at point A until it reaches point C. Use appropriate values and ignore all effects due to air resistance (3 marks)

Description	Marks
Correct velocity values; 28.2, 14.1	1
Correctly time values; 2.88, 4.32	1
Sketches graph as straight lines	1
Total	**3**



Question 12 **(8 marks)**

(a) Calculate the magnitude of the momentum of each photon. (2 marks)

Description	Marks
$\lambda = \frac{h}{p} \quad p = \frac{h}{\lambda}$	1
$= \frac{6.63 \times 10^{-34}}{4.87 \times 10^{-9}} =$ 1.36 × 10^{-27} N s	1
Total	**2**

(b) Calculate the recoil velocity of the mirror when the beam of light reflects from it. (4 marks)

Description	Marks
$\Delta p_{PHOTON} = \frac{2h}{\lambda}$	1
$\Delta p_{TOTAL} = 2 \times \frac{h}{\lambda} \times 2.5 \times 10^{18} = m\Delta v$	1
$= 2 \times \frac{6.67 \times 10^{-34}}{487 \times 10^{-9}} \times 2.5 \times 10^{18} = 3 \times 10^{-9} \times \Delta v$	1
$\Delta v = \frac{2 \times 1.36 \times 10^{-27} \times 2.5 \times 10^{18}}{3 \times 10^{-9}} = 2.27 \text{ m s}^{-1}$	1
Total	**4**

(c) Outline **two** possible limitations of using solar sail technology to propel a spacecraft. (2 marks)

Description	Marks
Any **two** of the following: • photon density decreases rapidly with distance from the sun • need a large sail to provide enough force to accelerate even a moderate mass • light from other stars will affect it when far away from a sun • force from the sail must be larger than the force of gravity from the sun or other celestial bodies • large and fragile sails affected by space debris • cant sail towards the sun • difficult to steer	1–2
Total	**2**
Accept other relevant answers	

Question 13 **(10 marks)**

(a) Calculate the orbital speed of the satellite. (3 marks)

Description	Marks
$r = 300 \times 10^3 + r_{\text{Earth}}$ $= 300 \times 10^3 + 6.37 \times 10^6 = 6.67 \times 10^6$	1
$\frac{m_s v^2}{r} = \frac{G M_{\text{Earth}} m_{\text{satellite}}}{r^2}$ $v = \sqrt{\frac{G M_{\text{Earth}}}{r}}$ $v = \sqrt{\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{6.67 \times 10^6}}$	1
$v = 7.73 \times 10^3$ m s^{-1}	1
Total	**3**

(b) Calculate the orbital period of the satellite. (2 marks)

Description	Marks
$T = \frac{2\pi r}{v} = \frac{2\pi \times 6.67 \times 10^6}{7.73 \times 10^3}$	1
$= 5421$ s $= 5.42 \times 10^3$ s	1
Total	**2**

(c) Calculate the gravitational acceleration experienced by the satellite in orbit. (2 marks)

Description	Marks
$g = \frac{GM}{r^2}$ or $a = \frac{v^2}{r}$	1
$g = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(6.67 \times 10^6)^2}$ or $\frac{(7.73 \times 10^3)^2}{6.67 \times 10^6}$ = 8.95 m s^{-2}	1
Total	**2**

(d) Calculate the altitude of the international space station based on an orbital period of 94.7 minutes. (3 marks)

Description	Marks
$r_{ss}^3 = \frac{T_{ss}^2}{T_s^2} \times r_s^3$	1
$= \left(\frac{5682}{5421}\right)^2 \times \left(6.67 \times 10^6\right)^3$ $= 6.88 \times 10^6 - 6.37 \times 10^6$	1
$= 510$ km $= 5.10 \times 10^5$ m	1
Total	**3**

Question 14 **(13 marks)**

(a) Calculate the velocity of any electron emitted from the ground state mercury atom. (3 marks)

Description	Marks
$E_k = E_e - E_{ionisation}$ $= 17.9 \times 10^{-19} – 16.7 \times 10^{-19}$ $= 1.2 \times 10^{-19}$	1
$\frac{1}{2}mv^2 = 1.2 \times 10^{-19}$	1
$v = \sqrt{\dfrac{2 \times 1.2 \times 10^{-19}}{9.11 \times 10^{-31}}}$ $= 5.13 \times 10^5 \text{ m s}^{-1}$	1
Total	**3**

(b) Describe why some of the mercury atoms in the tube need to be ionised. (2 marks)

Description	Marks
to create free electrons	1
to hit other mercury atoms to excite electrons and produce more photons **or** to create charges for pathway for electrical current **or** to produce high energy photons for fluorescence to occur	1
Total	**2**

(c) Calculate the possible energies the incident electron can have after this collision. (3 marks)

Description	Marks
1 →2 $\Delta E = (16.7 - 9.25) \times 10^{-19}$ J $= 7.45 \times 10^{-19}$ J	1
$\Delta E = (10.5 - 7.45) \times 10^{-19}$ J $= 3.05 \times 10^{-19}$ J (scattered electron)	1
or J $= 10.5 \times 10^{-19}$ J (elastic collision)	1
Total	**3**

(d) Determine the part of the spectrum to which the lowest energy emitted photons belong when subject to an incident electron with energy 10.5×10^{-19} J. (2 marks)

Description	Marks
$f = E/h = 7.45 \times 10^{-19}/6.63 \times 10^{-34} = 1.12 \times 10^{15}$ Hz or $\lambda = 2.67 \times 10^{-7}$ m	1
This is UV therefore all transitions to the ground state must be UV.	1
Total	**2**

(e) Explain how the emitted photons produced by the mercury atoms produce visible light in the fluorescent material. (3 marks)

Description	Marks
the high energy photons (UV) are absorbed causing the electrons of the fluorescent material to jump to a higher state	1
these electrons then fall back to the ground state in a series of steps	1
emitting light some of which is in the visible spectrum	1
Total	**3**

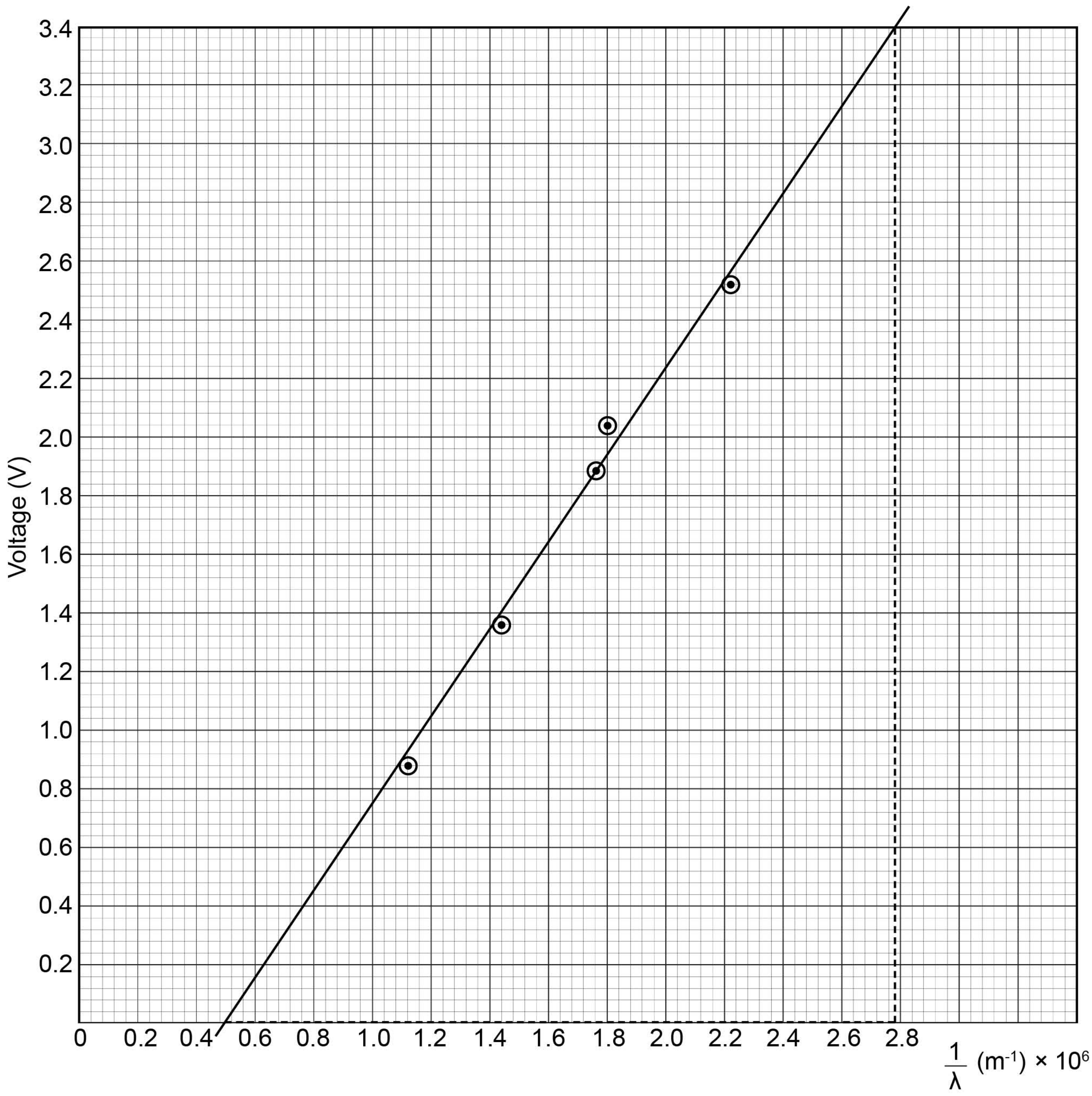
Question 15 **(19 marks)**

(a) Complete the table above for values of 1/λ. (2 marks)

Description	Marks
10^6	1
2.22 (2.2), 1.82 (1.8), 1.75 (1.8), 1.45 (1.4), 1.12 (1.1)	1
Total	**2**

(b) Plot a graph of voltage against 1/λ, with voltage on the y-axis, and draw a line of best fit. Error bars are not required. (5 marks)

Description	Marks
axes correct labels	1
axes correct units	1
appropriate scale	1
plotting	1
line of best fit	1
Total	**5**



Question 15 (continued)

(c) Use the graph to calculate the gradient of the line of best fit. Show construction lines. (3 marks)

Description	Marks
drawing construction lines	1
formulae and working gradient = 3.4 – 0.0/2.78 – 0.50	1
= 1.49 (1.5) × 10^{-6} V m (range 1.4 × 10^{-6} to 1.6 × 10^{-6} V m)	1
Total	**3**

(d) Use the gradient from part (c) and the provided equation to calculate a value for Planck's constant. (3 marks)

Description	Marks
$h = \frac{q_e V_0 \lambda}{c}$ $h = \frac{q_e \times gradient}{c}$	1
$= \frac{1.6 \times 10^{-19} \times 1.49 \times 10^{-6}}{3 \times 10^{8}}$	1
= 7.9 × 10^{-34} J s	1
Total	**3**

(e) From your graph, determine the value for k in this experiment. (2 marks)

Description	Marks
showing working on graph or calculation	1
a value of approximately 0.7 ± 0.1 (0.60 → 0.95)	1
Total	**2**

(f) Describe **two** possible sources of experimental error in the performance of this experiment and how they might be modified to produce a more accurate result. (4 marks)

Description	Marks
Source/s of error	
Any **two** of the following: • accuracy of wavelength • accuracy of voltage readings • energy required to start LED lights (may not be same for each light)	1–2
Produce/s (a) more accurate result/s	
Any **two** of the following: • repeat readings of voltage • repeat reading of wavelength • use more accurate voltage devices • repeat the experiment several times and average the results • use a wider/greater range of LED lights	1–2
Total	**4**
Accept other relevant answers	

Question 16 **(12 marks)**

(a) Calculate the velocity of the other spacecraft relative to Earth. (3 marks)

Description	Marks
$u = \dfrac{v + u'}{1 + \dfrac{vu'}{c^2}}$ $= \dfrac{0.72c - 0.695c}{1 + \dfrac{0.72c \times (-0.695c)}{c^2}} = \dfrac{0.025}{0.4996}$	1–2
= 0.050c	1
Total	**3**
Note: two marks if identifies *u'* and *v* correctly	

(b) Calculate the number of years for your spacecraft to journey from Earth to Alpha Centauri as measured by an observer on Earth. (3 marks)

Description	Marks
$v = \dfrac{s}{t}$ $t = \dfrac{s}{v} = \dfrac{4.13 \times 10^{16}}{0.72 \times 3 \times 10^{8}} = \dfrac{4.13 \times 10^{16}}{2.16 \times 10^{8}}$	1
$= 1.912 \times 10^{8}\ s$	1
$= \dfrac{1.912 \times 10^{8}}{365.25 \times 24 \times 60 \times 60}$ = 6.06 years	1
Total	**3**

(c) Calculate the number of years the journey will take for those on the spacecraft travelling at 0.720c relative to Earth. (3 marks)

Description	Marks
$t = \dfrac{t_o}{\sqrt{1 - \dfrac{v^2}{c^2}}}$	1
$6.06 = \dfrac{t_o}{\sqrt{1 - \dfrac{v^2}{c^2}}}$ $t_o = 6.06\sqrt{1 - \dfrac{v^2}{c^2}}$ $= 6.06\sqrt{1 - 0.72^2}$	1
= 4.20 years only 4.20 years seem to have passed on the ship	1
Total	**3**
Note: if do not use t = 6.06 years then maximum of one mark	

Question 16 (continued)

(d) For those on the spacecraft travelling to Alpha Centauri at 0.720c relative to Earth, calculate the time they would have observed to have elapsed on Earth during the journey from Earth to Alpha Centauri. (3 marks)

Description	Marks
$t_o = t \times \sqrt{\left(1 - \frac{0.72^2}{1}\right)}$	1
= 4.20 × 0.694	1
= 2.91 years	1
Total	**3**
Note: if do not use t = 4.20 years then maximum of 1 mark	

Question 17 **(14 marks)**

(a) Use the equation above to describe how the nucleus of the fluorine-18 decays to produce oxygen-18. Name the other particles produced. (3 marks)

Description	Marks
a proton turns into a neutron	1
emitting a positron	1
and an electron neutrino	1
Total	**3**

(b) Name the force and force particle that mediate the interaction described in part (a). (2 marks)

Description	Marks
Force: weak	1
Force particle: W^+ boson (accept W or Z boson)	1
Total	**2**

(c) Use your knowledge of the Standard Model to prove that this emission obeys the conservation of baryon number and charge. Assume all quarks have a baryon number equal to ⅓. (4 marks)

Description	Marks
baryon number on left hand side = +1 (proton) or +18 (F)	1
baryon number on right hand side = +1 (neutron) or +18 (O)_	1
charge on left hand side = +1 on left hand side (proton) or +9 (F)	1
charge on right hand side = +1 on right hand side (positron) or +8(O) +1 (positron)	1
Total	**4**
Note: if mix whole atom and single reaction in conservation rules then maximum of three marks	

(d) Discuss the interactions that must occur to produce two gamma rays travelling in opposite directions to each other. (5 marks)

Description	Marks
a positron and an electron must meet/interact due to electromagnetic forces	1
as positron is electron anti-particle	1
they will annihilate producing energy in the form of photons	1
to conserve energy two high energy photons must be produced	1
two photons travel in opposite directions to conserve momentum	1
Total	**5**

Section Three: Comprehension **20% (37 Marks)**

Question 18 **(16 marks)**

(a) Use mathematical reasoning to explain why scientists might have believed that the stars at the outer edges would leave the rotating galaxy. (5 marks)

Description	Marks
For the stars to rotate then $F_c = F_g$	1
therefore $\frac{M_{star}\, v^2}{r_{star}} = \frac{G\, M_{galaxy}\, M_{star}}{r_{star}}$	1
$v = \sqrt{\frac{G\, M_{galaxy}}{r_{star}}}$	1
using the mass of the galaxy and radius of the outer stars they found that v measured by the Doppler shift was greater than $\sqrt{\frac{G\, M_{galaxy}}{r_{star}}}$ for the measured mass and radius	1–2
Total	**5**

(b) What hypothesis was made to account for the observation that stars on the outer edge did not leave the rotating galaxy? (2 marks)

Description	Marks
there must be other matter with mass (other than can be seen)	1
dark matter (that cannot be seen)	1
Total	**2**

(c) Describe how red shift and blue shift are produced and how this informs astronomers on Earth that galaxies are rotating. (5 marks)

Description	Marks
Red shift	
red shift is produced when an object emitting light is moving away from the observer	1
and the wavelength of emitted light increases	1
Blue shift	
blue shift is produced when an object emitting light is moving toward the observer	1
and the wavelength of the emitted light is decreased	1
Galaxy rotation	
as one side of a galaxy is red shifted and the other is blue shifted it indicates circular motion	1
Total	**5**

(d) Discuss how Hubble's Law supports the Big Bang theory. (4 marks)

Description	Marks
Hubble's law suggests cosmological red shift is caused by the stretching/expansion of photons of light from galaxies as space/time itself expands **or** Hubble's law also explains that galaxies further away are travelling faster than those nearby this causes the photons wavelength to increase/red shift	1–2
this provides evidence that galaxies are moving further apart and therefore the universe is expanding in all directions	1
this supports the Big Bang theory hypothesis that all galaxies must have originated from a singularity if galaxies trajectories are traced back to their origin	1
Total	**4**

Question 19 **(21 marks)**

(a) Determine the kinetic energy, in joules, that each proton has on leaving the electric field prior to entering the four accelerating radio frequency chambers of the LHC. (2 marks)

Description	Marks
E = 90.0 keV $E = 90 \times 10^3 \times 1.6 \times 10^{-19}$ J **or** $W = Vq$ $W = 90 \times 10^3 \times 1.6 \times 10^{-19}$ J **or** $E_k = \frac{1}{2} m v^2$ $= \frac{1}{2} \times 1.67 \times 10^{-27} \times (0.014 \times 3 \times 10^8)^2$	1
$= 1.44 \times 10^{-14}$ J	1
Total	**2**

(b) Calculate the energy per second in watts consumed per proton to increase its kinetic energy from 450 GeV to 6.50 TeV in the LHC. (4 marks)

Description	Marks
ΔE_k = Energy gained per proton $= (6.50 \times 10^{12} - 450 \times 10^9)$ $= 6.05 \times 10^{12}$ eV	1
$= 6.05 \times 10^{12} \times 1.60 \times 10^{-19}$ J $= 9.68 \times 10^{-7}$ J	1
$= \frac{\Delta E}{t}$ $= \frac{9.68 \times 10^{-7}}{20 \times 60}$	1
$= 8.07 \times 10^{-10}$ W	1
Total	**4**

(c) Determine the relativistic momentum of a proton in the LHC with a velocity of $0.99999998c$. (2 marks)

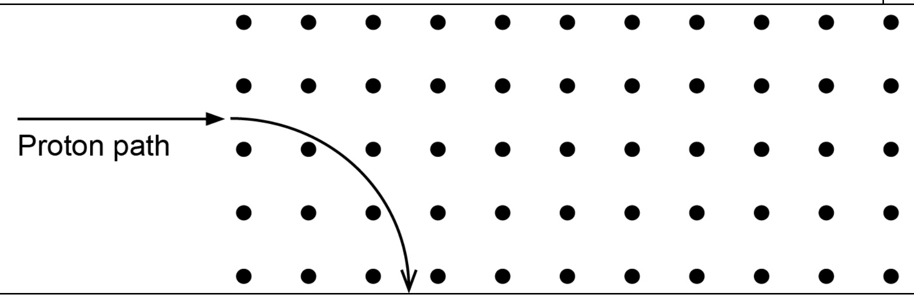
Description	Marks
$p = \frac{1.67 \times 10^{-27} \times 0.99999998c}{\sqrt{1 - 0.99999998^2}}$	1
$= 2.50 \times 10^{-15}$ N s	1
Total	**2**

(d) Calculate the magnetic field strength required to maintain the protons on the required path in the LHC. If you were unable to obtain an answer for part (c), use 3.50×10^{-15} N s. (3 marks)

Description	Marks
$B = \frac{mv}{rq} = \frac{\boldsymbol{p}}{\boldsymbol{rq}}$	1
$\frac{\mathbf{2.50 \times 10^{-15}}}{\mathbf{4.3 \times 10^{3} \times 1.60}\ \boldsymbol{x}\ \mathbf{10^{-19}}}$ alternative $\frac{\mathbf{3.50 \times 10^{-15}}}{\mathbf{4.3 \times 10^{3} \times 1.60}\ \boldsymbol{x}\ \mathbf{10^{-19}}}$	1
= 3.64 T (5.09 T)	1
Total	**3**

(e) The diagram below represents a magnetic field directed vertically out of the page. A proton in the LHC enters this magnetic field at an angle of 90° to the direction of the field. On the diagram below, continue the path of this proton when in the magnetic field. (1 mark)

Description	Marks
as per diagram below	1
Total	**1**



(f) Describe with clear reasoning, what happens to the centripetal force on a proton in the LHC as the kinetic energy of the proton increases from 450 GeV to 4.50 TeV. (3 marks)

Description	Marks
as the kinetic energy increases the relativistic momentum increases **or** as the kinetic energy increases the velocity increases and (relativistic) mass increases	1 – 2
therefore $F_c = \frac{mv^2}{r}$ then F_c must increase	1
Total	**3**

Question 19 (continued)

(g) Describe why the mass of the products after a successful collision of the two protons is greater than the rest mass of the two protons before the collision. (2 marks)

Description	Marks
some of the kinetic energy of the colliding protons becomes the mass after the collision.	2
reference to mass-energy equivalence $E = mc^2$	1
Total	**2**
Note: 1 mark if only references mass-energy equivalence	

(h) If the rest mass energy of a proton is 938 MeV, calculate the velocity the proton reaches when accelerated to a kinetic energy of 1.4 GeV. (4 marks)

Description	Marks
.938 + 1.4 = 2.338 GeV (= 3.7408 × 10^{-10} J)	1
$\frac{E}{mc_2} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ $\frac{3.7408\times10^{-10}}{1.67\times10^{-27}\times9\times10^{-16}} = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ $2.489 = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ $0.4018 = 1-\left(\frac{v^2}{c^2}\right)^{\frac{1}{2}}$ $1-\frac{v^2}{c^2} = 0.1614$	1–2
$\frac{v^2}{c^2} = 0.8386$ $v = 0.916c$	1
Total	**4**
Note: If simply substitutes the value for kinetic energy into the total energy formula then a maximum of two marks awarded.	

ACKNOWLEDGEMENTS

Question 8(b) Graph adapted from: Kule, D. (2010). File: Black body.svg [Graph]. In *Wikimedia.* Retrieved October, 2018, from https://commons.wikimedia.org/wiki/File:Black_body.svg
Used under Creative Commons Attribution-ShareAlike 3.0 Unported licence

Question 17(a) Text under 'Description' adapted from: Beta decay. (2012). In *Wikiversity*. Retrieved October, 2018, from https://en.wikiversity.org/wiki/Beta_decay
Used under Creative Commons Attribution-ShareAlike 3.0 Unported licence

Published by the School Curriculum and Standards Authority of Western Australia
303 Sevenoaks Street
CANNINGTON WA 6107