ACADEMIC ASSOCIATES
Make Success a Reality

PHYSICS

UNIT 3 and 4 Semester Two 2019

Marking Key

Marking keys outline the expectations of examination responses. They help to ensure a consistent interpretation of the criteria that guide the awarding of marks.

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Section One: Short response **30% (54 Marks)**

Question 1 **(4 marks)**

Give one example where each of the following light-based phenomena can be observed:

(a) Dispersion (1 mark)

Description	Marks
States suitable example E.g: Rainbow, white light through triangular prism, etc.	1
Total	**1**

(b) Reflection (1 mark)

Description	Marks
States suitable example E.g: Mirror, shiny surface, etc.	1
Total	**1**

(c) Refraction (1 mark)

Description	Marks
States suitable example E.g: Light through glass, water, etc.	1
Total	**1**

(d) Polarisation (1 mark)

Description	Marks
States suitable example E.g: Sunlight reflection from water surface, polarioid film/sunglasses, etc.	1
Total	**1**

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Question 2 **(6 marks)**

A photoemissive metal plate is used as the target sample in a photoelectric effect experiment. When 320 nm light is used, a 0.685 V stopping voltage is required. When 250 nm light is used, the stopping voltage is 1.77 V.

(a) Explain why decreasing the wavelength of the light increases the stopping voltage. (3 marks)

Description	Marks
Relates a decrease in wavelength to an increase in light energy "The energy of a photon of light in inversely proportional to the wavelength ($E = \frac{hc}{\lambda}$)	1
Relates the increase in light energy to more energetic electrons "Higher energy photons can eject photoelectrons with more energy."	1
Relates faster electrons needing a larger stopping voltage/electric field to stop the electrons "To bring these faster electrons to a stop requires a larger stopping voltage."	1
Total	**3**

(b) Calculate the work function of the photoemissive metal plate. (3 marks)

Description	Marks
$E_k = hf - W$	1
$E_k = \frac{hc}{e\lambda} - W$ $0.685 = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{1.60\times10^{-19}\times320\times10^{-9}} - W$ $W = 3.20\ eV$	1-2
Total	**3**
Note: May also use the other pair of wavelength/stopping voltage values to obtain same answer.	

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Question 3 **(4 marks)**

Muon's produced in a CERN experiment are travelling at $0.920c$ relative to the particle accelerator. They cover a 728 km distance as measured from the reference frame of the particle accelerator before hitting their intended target. Calculate the time the muon's spend on their journey to the intended target from the reference frame of the muon.

Description	Marks
$t = \frac{s}{v} = \frac{7.28\times10^5}{0.920\times3.00\times10^8} = 2.638\times10^{-3}\ s$	1-2
$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$ $t_0 = t\sqrt{1-\frac{v^2}{c^2}}$ $t_0 = 2.638\times10^{-2}\times\sqrt{1-\frac{0.92^2c^2}{c^2}} = 1.03\times10^{-3}\ s$	1-2
Total	**4**

Question 4 **(4 marks)**

In 2019, a dark matter detector that had been running for two years has not detected any dark matter but has detected 126 incredibly rare cases of xenon decay. In xenon decay, a pair of electrons are captured simultaneously by two protons and emit two neutrinos.

$$e + e + p + p \rightarrow \nu_e + \nu_e + n + n$$

Confirm whether this reaction is possible by checking conservation of baryon number and lepton number.

Description	Marks
Baryon number $LHS = 0 + 0 + 1 + 1 = 2$ $RHS = 0 + 0 + 1 + 1 = 2$ Possible	1-2
Lepton number $LHS = 1 + 1 + 0 + 0 = 2$ $RHS = 1 + 1 + 0 + 0 = 2$ Possible	1-2
Total	**4**

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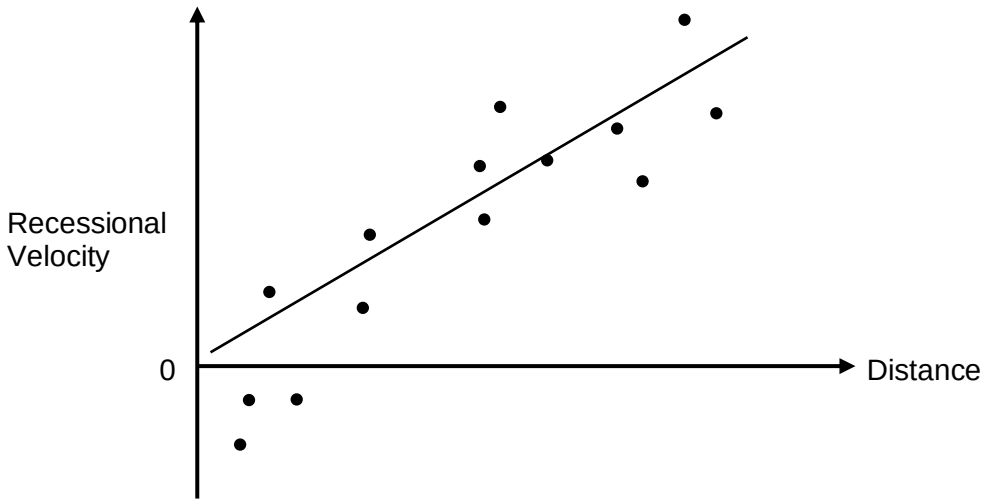
Question 5 **(5 marks)**

The graph below reveals the relationship between distance of galaxies from Earth and each galaxy's recessional velocity from Earth.



(a) Explain what causes the relationship revealed in the graph. (3 marks)

Description	Marks
States the core reason "Space is expanding."	1
Describes how expansion of space can explain relationship "As space expands, it increases the distance between the galaxies. The further away a galaxy is, the greater the rate of expansion of space between the Earth and the galaxy, giving the galaxy a larger recessional velocity."	1-2
Total	**3**

(b) Explain why the cluster of galaxies closest to Earth have a negative recessional velocity despite your answer to part (a). (2 marks)

Description	Marks
Compares a small expansion of space to velocity through space "These galaxies are close enough that the expansion of space between them and Earth is small and, they can still have a velocity through space towards the Earth"	1-2
Total	**2**

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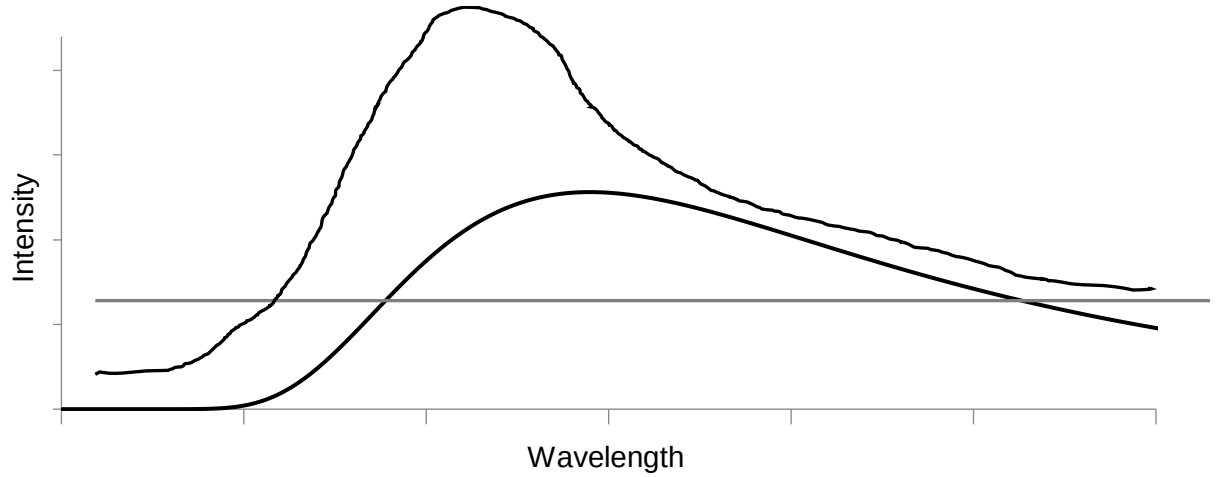
Question 6 **(5 marks)**

Stars are approximate black bodies. Their colour can be used as reliable method of determining the temperature of a star – a red star is cooler than a blue star. The spectrum of a red star is shown below.



(a) On the same axes, draw the spectrum observed for a blue star. You may assume the stars are identical apart from their temperature. (2 marks)

Description	Marks
Curve is of a black body, with a peak shifted to the left compared to red star	1
Blue curve is always above red curve	1
Total	**2**

(b) Explain how colour is an indication of the temperature of these stars. (3 marks)

Description	Marks
Relates temperature to energy and peak frequency/wavelength "Hotter black bodies have on average more energetic photons emitted, produce peak intensity at lower wavelengths/higher frequencies"	1-2
Relates peak frequency/wavelength to colour "Blue light has a higher frequency than red light, thus the blue star is hotter."	1
Total	**3**

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Question 7 **(6 marks)**

An electron annihilates with its antiparticle, the positron to produce two gamma rays. In the rest frame of the annihilation, the two gamma rays have equal energy.

(a) Calculate the rest energy of an electron. (2 marks)

Description	Marks
$E = mc^2$ $E = 9.11 \times 10^{-31} \times (3.00 \times 10^8)^2 = 8.20 \times 10^{-14}\ J$	1-2
Total	**2**

(b) If the electron and positron **each** had 2.05×10^{-13} J of kinetic energy prior to the annihilation, calculate the frequency of the pair of gamma rays in the frame of the annihilation. (4 marks)

Description	Marks
Energy prior to collision $E = 2mc^2 + 2E_k$ $E = 2 \times 8.20 \times 10^{-14} + 2 \times 2.05 \times 10^{-13} = 5.74 \times 10^{-13}\ J$	1-2
Energy shared between equally between photons, find frequency $E = hf$ $\frac{5.74 \times 10^{-13}}{2} = 6.63 \times 10^{-34} f$ $f = 4.33 \times 10^{20}\ Hz$	1-2
Total	**4**

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Question 8 **(5 marks)**

A volley ball is served by hitting it at 12.8 m s^{-1} at 25.0^0 above the horizontal. The server made contact with the volleyball when it was 2.35 m above the ground. Find the horizontal range of the volleyball serve. Air resistance can be ignored.

Description	Marks
Find time in air** $u_v = 12.8 \times sin25 = 5.409\ m\ s^{-1}$ $s_v = u_v t + \frac{1}{2}at^2$ $-2.35 = 5.409t + \frac{1}{2}(-9.8)t^2$ Solving the quadratic, $t = 1.438\ s$ **May also use approaches such as $t = t_{up} + t_{down}$ or using $v^2 = u^2 + 2as$ followed by $v = u + at$ to determine time in air	1-3
Find horizontal range $s_h = u_h t$ $s_h = 12.8cos25 \times 1.438 = 16.7\ m$	1-2
Total	**5**

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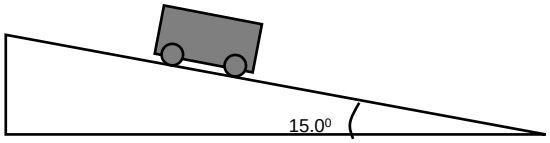
Question 9 **(4 marks)**

A boy pulls his 12.0 kg red cart up an incline of 15.0^0. While the cart moves up the incline, the friction between the wheels and the ground is 150 N and the boy pulls at 205 N along the incline. Calculate the acceleration of the cart.



Description	Marks
Weight parallel to incline $W_{\|\|} = mgsin\theta$ $W_{\|\|} = 12.0 \times 9.8 \times sin15 = 30.4\ N$	1
Adds forces $\sum F = F_{boy} - F_{frict} - W_{\|\|}$ $\sum F = 205 - 150 - 30.4 = 24.6\ N$	1-2
Calculates acceleration $a = \frac{\sum F}{m} = \frac{24.6}{12.0} = 2.05\ m\ s^{-2}$	1
Total	**4**

Question 10 **(5 marks)**

Electric cars utilise regenerative braking. By referring to both Faraday's law and Lenz's law, explain the physical principles that help to recharge the battery and assist with slowing the car down.

Description	Marks
Correctly refers to Faraday's law inducing an emf in the coil due to rotation in a field "While braking, the rotating coil experiences a change in flux which induces an emf, causing the motor to also behave like a generator (Faraday's law)"	1-2
States the induced emf recharges the battery "The emf drives a current and recharges the battery"	1
Correctly refers to Lenz's law applying a force against motion, assisting with braking "Lenz's law describes that the direction of the induced current will be such that it creates a resistive force against the motion of the coil, helping to slow the car down"	1-2
Total	**5**

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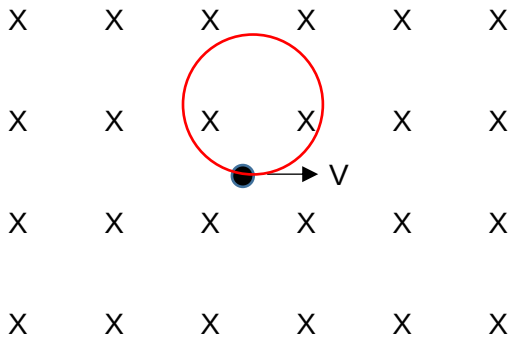
Question 11 **(6 marks)**

A single charged sodium ion (Na^+) is moving at 1250 m s^{-1} within a 0.866 T magnetic field as shown below. The sodium ion has a 3.82×10^{-26} kg mass.



(a) In the diagram above, draw the path the sodium ion follows. (2 marks)

Description	Marks
Draws a circle (accept partial curve, taking ion outside field shown)	1
Circular path is counter clockwise (taking ion above its position shown in diagram)	1
Total	**2**

(b) Calculate the wavelength of the sodium ion. (2 marks)

Description	Marks
$\lambda = \frac{h}{mv}$ $\lambda = \frac{6.63\times10^{-34}}{3.82\times10^{-26}\times1250} = 1.39\times10^{-11}\ m$	1-2
Total	**2**

(c) Calculate the radius of the ion's movement. (2 marks)

Description	Marks
$r = \frac{mv}{qB}$ $r = \frac{3.82\times10^{-26}\times1250}{1.60\times10^{-19}\times0.866} = 3.45\times10^{-4}\ m$	1-2
Total	**2**

End of Section One

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Section Two: Problem-solving **(90 Marks)**

Question 12 **(12 marks)**

Rovers have been sent to Mars to obtain samples from the planet's surface. One such rover is approaching the surface of Mars at 25.0 m s^{-1} at an altitude of 300 m. The internal components of the rover require that the rover contacts the surface at no greater than 0.850 m s^{-1} to remain intact. To achieve this, a parachute is opened at this altitude to reduce the speed of the 1050 kg rover.

These details may be used to help answer the following questions:

- Mass of Mars: 6.42×10^{23} kg
- Radius of Mars: 3.38×10^{6} m

(a) Find the gravitational field strength at the surface of Mars. (3 marks)

Description	Marks
$g = \frac{GM}{r^2}$	1
$g = \frac{6.67\times10^{-11}\times6.42\times10^{23}}{(3.38\times10^{6})^2} = 3.75\ N\ kg^{-1}$	1-2
Total	**3**

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(b) Show by calculation that the work done by the parachute to ensure the rover makes contact with the surface at a safe speed is approximately 1.50 MJ. You may assume the gravitational field strength is constant between the ground and the 300 m altitude. (4 marks)

Description	Marks
$W = E_{top} - E_{bottom}$	1
$W = (\frac{1}{2}mu^2 + mgh) - \frac{1}{2}mv^2$	1
$W = \frac{1}{2} \times 1050 \times 25.0^2 + 1050 \times 3.75 \times 300 - \frac{1}{2} \times 1050 \times 0.850^2 = 1.51 \times 10^6\ J$	1-2
Total	**4**

(c) Hence calculate the average air resistance acting against the parachute from the 300 m altitude until the rover makes contact with the ground. (2 marks)

Description	Marks
$W = Fs$	1
$F = \frac{W}{s} = \frac{1.51 \times 10^6}{300} = 5.03 \times 10^3\ N$	1
Total	**2**

(d) Was the assumption made in part (b) reasonable? Justify your response. (3 marks)

Description	Marks
Yes	1
States gravitational field strength won't change very much "The gravitational field strength only changes minimally between the surface and an altitude of 300 m"	1
Justifies by comparing distances (with or without exact numbers) "This is because the altitude is insignificant compared to the radius/distance from the centre of mass of Mars."	1
Total	**3**

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Question 13 **(11 marks)**

Beta decay is the ejection of an electron from the nucleus of a radioisotope. The beta particle (electron) speed can vary, but for this question, assume they are ejected at 0.990c.

(a) Calculate the energy of the beta particle. (3 marks)

Description	Marks
$E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}}$	1
$E = \frac{9.11\times10^{-31}\times(3.00\times10^{8})^2}{\sqrt{1-\frac{0.99^2\cancel{c^2}}{\cancel{c^2}}}} = 5.81\times10^{-13}\ J$	1-2
Total	**3**

(b) Two beta particles are ejected towards each other from two nuclei that are at rest relative to each other.

Calculate the speed of one beta particle as measured from the reference frame of the other. Give your answer to 6 significant figures and in terms of c. (3 marks)

Description	Marks
$u' = \frac{u-v}{1-\frac{vu}{c^2}}$ (quoting either addition formula is fine, but will influence which values should be used in next step)	1
$u' = \frac{-0.99c-0.99c}{1-\frac{0.99\cancel{c}\times(-)0.99\cancel{c}}{\cancel{c^2}}}$ * $u' = -0.999949\ c$ (positive or negative answer is fine as depends on which particle students solve for). $\therefore speed\ is\ 0.999949\ c$ *Students who do not apply correct sign to values may end up with "zero velocity" due to numerator equating to 0.	1-2
Total	**3**

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(c) Calculate the magnitude of the momentum of a beta particle as measured from the reference frame of the nucleus. (3 marks)

Description	Marks
$p = \frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}$	1
$p = \frac{9.11\times10^{-31}\times0.99\times3.00\times10^{8}}{\sqrt{1-\frac{0.99^2\cancel{c^2}}{\cancel{c^2}}}} = 1.92\times10^{-21}\ kg\ m\ s^{-1}$	1-2
Total	**3**

(d) Calculate the quantity of mass lost by the nucleus due to the beta decay event. (2 marks)

Description	Marks
Uses energy of beta,from part a, converting to an equivalent mass value $E = mc^2$ $m = \frac{E}{c^2} = \frac{5.81\times10^{-13}}{(3.00\times10^{8})^2} = 6.46\times10^{-30}\ kg$	1-2
Total	**2**

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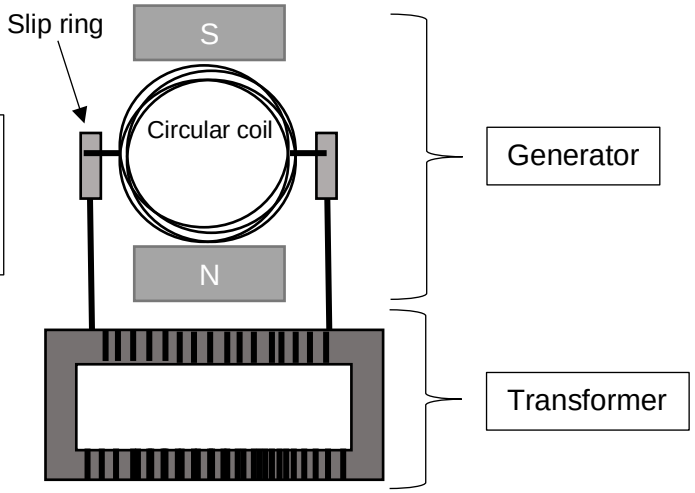
Question 14 **(13 marks)**

To help students' visualise the workings of a generator, a demonstration generator is built using the design shown in the diagram below.

Generator coil number:	18
Generator coil radius:	0.0700 m
Magnetic flux density:	3.00 mT



The demonstration generator is not capable of a high voltage output. To increase the output voltage, the demonstration generator was connected to a transformer. The primary to secondary windings ratio was 1:53, resulting in an rms output voltage of the transformer of 2.36 V.

(a) Explain in detail how the rotation of the generator coil results in the generation of a sinusoidal current delivered to the transformer.

(5 marks)

Description	Marks
Rotation causes a change in flux within the coil "As the coil rotates, the area of the coil perpendicular to the field lines of the magnets changes, therefore changing the amount of flux in the coil."	1-2
Refers to Faraday's law, resulting in emf "The change in flux induces an emf in the coil"	1
Refers to a current being driven by the emf to the transformer "The emf drives a current through the slip rings to the transformer"	1
Makes suitable connections between rotation of coil and slip rings resulting in an alternating current output "The rotation of the coil results in an alternating current and the slip rings provide a frictionless contact that allows this current to pass this current from the generator to the transformer.	1
Total	**5**

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(b) Calculate the maximum flux that can be encased by the generator coils. (2 marks)

Description	Marks
$A = \pi r^2$ $A = 3.1415 \times 0.07^2 = 1.539 \times 10^{-2}\ m^2$	1
$\Phi_B = BA$ $\Phi_B = 3 \times 10^{-3} \times 1.539 \times 10^{-2} = 4.617 \times 10^{-5} = 4.62 \times 10^{-5}\ Wb$	1
Total	**2**

(c) Calculate the rms voltage output by the generator. (2 marks)

Description	Marks
$\frac{V_p}{V_s} = \frac{N_p}{N_s}$	1
$V_p = \frac{N_p}{N_s} \times V_s$ $V_p = \frac{1}{53} \times 2.36 = 4.453 \times 10^{-2} = 4.45 \times 10^{-2}\ V$	1
Total	**2**

(d) Calculate the frequency of the rotation of the generator coils. If you could not obtain an answer to part (c), you may use a value of 4.00×10^{-2} V. (4 marks)

Description	Marks
Find peak voltage output $\varepsilon_{peak} = 4.453 \times 10^{-2} \times \sqrt{2} = 6.297 \times 10^{-2}\ V$	1-2
Find frequency $\varepsilon = 2\pi BANf$ (taking BA from part (b), or calculating here) $f = \frac{\varepsilon}{2\pi BAN} = \frac{6.297 \times 10^{-2}}{2\pi \times 4.62 \times 10^{-5} \times 18} = 12.1\ Hz$ (or 10.9 Hz if used assumed value)	1-2
Total	**4**

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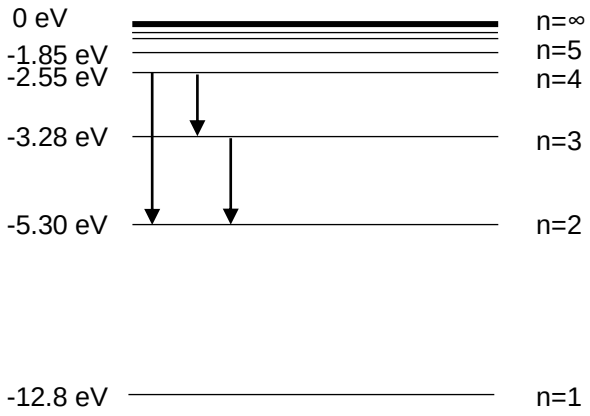
Question 15 **(14 marks)**

Consider the energy level diagram below, with a single electron in the ground state.



(a) Calculate how much energy is required to move from the ground state to the n=2 energy level. (1 mark)

Description	Marks
$-5.30 + (-)12.8 = 7.50\ eV$	1
Total	**1**

(b) On the energy level diagram, draw all the possible transitions an electron can make as it changes from the n=4 level to the n=2 level. (1 mark)

Description	Marks
All transitions shown, no extra.	1
Total	**1**

(c) Calculate the largest wavelength of all possible photons produced as an electron makes a transition between n=4 and n=2. (4 marks)

Description	Marks
Uses smallest energy transition $E = -2.55 + (-)3.28 = 0.730\ eV$	1
Converts to joules $E = 0.730 \times 1.6 \times 10^{-19} = 1.168 \times 10^{-19}\ J$	1
Calculates wavelength $E = hf\ and\ f = c/\lambda$ $E = \frac{hc}{\lambda}$ $\lambda = \frac{hc}{E} = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{1.168\times10^{-19}} = 1.70 \times 10^{-6}\ m$	1-2
Total	**4**

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(d) An EMR source is used to promote an electron from the ground state to n=4. Which part of the electromagnetic spectrum does the EMR belong? Justify your answer with a calculation. (4 marks)

Description	Marks
Finds energy difference $E = -2.55 + (-)12.8 = 10.25\ eV$	1
Converts to joules $10.25 \times 1.6 \times 10^{-19} = 1.64 \times 10^{-18}\ J$	1
Determines frequency (or wavelength) $f = \frac{E}{h} = \frac{1.64 \times 10^{-18}}{6.63 \times 10^{-34}} = 2.47 \times 10^{15}\ Hz$	1
Matches frequency (or wavelength) to spectrum on formulae and data sheet "Ultraviolet"	1
Total	**4**

(e) "To ensure the photons from the EMR source are able to excite electrons from the ground state to n=4, we should increase the frequency of the EMR source slightly".
Comment on the suitability of this suggestion. (4 marks)

Description	Marks
States changing the frequency increases/changes the energy "Increasing the frequency will increase the energy of the photons ($E = hf$)	1
Describes the energy requirements for excitation of electrons by incident photons "When photons are used to excite an electron, the photon energy must match the difference in energy between the levels exactly. Having more energy will result in the excitation not occurring at all.	1-2
Refers back to question "Thus increasing the frequency of the EMR source is not a good idea"	1
Total	**4**

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Question 16 **(13 marks)**

In large synchrotron particle accelerators, protons are accelerated to high velocities which are then forced into paths such that the protons collide, converting the energy of the collision into matter. Much like an atom, most of a proton is empty space. A collision between protons is two protons passing close enough that their fundamental particles can interact.

(a) Explain why neutrons are not used in synchrotron particle accelerators. (3 marks)

Description	Marks
Neutrons have no charge.	1
Describes need for electric charge due to basic principles of particle accelerator technology (electric and magnetic fields) "Particle accelerators use electric and magnetic fields to create the acceleration of a charged particle and to keep it confined within a ring"	1-2
Total	**3**

(b) A proton contains only up and down quarks. State the quark composition of a proton and demonstrate that the combined electric charge of quarks in a proton matches that of a proton. (2 marks)

Description	Marks
A proton is an up, up down combination of quarks	1
$U + U + D = \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$	1
Total	**2**

(c) Calculate the mass of a proton giving your answer in MeV/c^2 (3 marks)

Description	Marks
Finds energy of rest mass of proton $E = mc^2 \ = 1.67 \times 10^{-27}(3.00 \times 10^8)^2 = 1.503 \times 10^{-10}\ J$	1
Conversion into final units $E(eV) = \frac{1.503 \times 10^{-19}}{1.6 \times 10^{-19}} = 9.394 \times 10^8$ $E(MeV) = \frac{9.394 \times 10^8}{10^6} = 939\ MeV$ $\therefore m = \frac{E}{c^2}\ (using\ c = 1.0c)$ $m = 939\ MeV\ c^{-2}$	1-2
Total	**3**

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(d) Calculate the difference in mass between a proton and its constituent quarks, giving your answer in MeV/c^2. (2 marks)

Description	Marks
$m_{quarks} = 2.3 + 2.3 + 4.8 = 9.40\ MeV\ c^{-2}$	1
$\Delta m = 939 - 9.4 = 929.6 = 930\ MeV\ \ c^{-2}$	1
Total	**2**

(e) Explain the difference between the mass of a proton and the combined mass of its constituent quarks. (3 marks)

Description	Marks
Identifies that the invariant/rest mass of the quarks is not the only factor "The sum of the quark mass is only an indication of the mass of the quarks while at rest."	1
Describes **at least one** additional source of energy/mass that contributes to proton mass "The quarks will be in motion, their kinetic energies contributing to the energy/mass of the proton. " **AND/OR** "The field of gluons that mediates the strong nuclear force between the quarks contributes to the energy/mass of the proton."	1-2
Total	**3**

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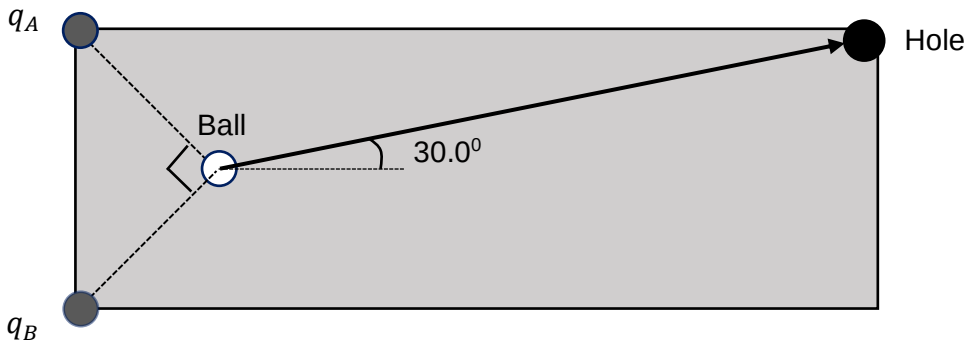
Question 17 **(12 marks)**

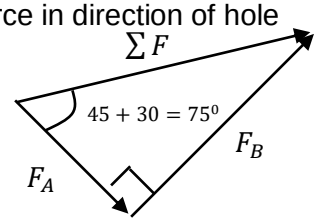
An educational software package helps students understand electromagnetic principles by simulating a mini golf course. In this simulation, rather than hitting a ball into a hole with a putter, students must use electric charges to apply a force onto a charged golf ball to direct the ball towards the hole. Unlike real golf, there is no friction and the ball will not overshoot the hole because it is going too fast.



The charges q_A and q_B are located on the corners of the short edge of the putting area, equidistant from a golf ball. These charges share the same sign of charge as the golf ball, thus each repels the golf ball. Let the force acting on the golf ball due to charge q_A be called F_A and the force acting on the golf ball due to charge q_B, F_B. Charge q_A is 260 nC and the golf ball has a 140 nC charge.

(a) To putt the golf ball towards the hole, the ball must travel 30.0^0 above the horizontal line, as indicated in the diagram. Show that the ratio of electric forces acting on the golf ball, $\frac{F_B}{F_A}$ is approximately 3.73 for a successful putt. Include a vector diagram as part of your answer.

Note that the diagram above indicates that a line from charge A to the ball and a line from charge B to the ball are at right angles to each other. (2 marks)

Description	Marks
Provides a labelled diagram showing understanding that two electrical forces combine to give net force in direction of hole 	1
$tan\theta = \frac{F_B}{F_A}$ $\therefore \frac{F_B}{F_A} = \tan 75 = 3.73$	1
Total	**2**

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(b) Hence, calculate the electric charge of q_B. (3 marks)

Description	Marks
Uses Coloumb's law to compare forces of both charges, reducing problem to the ratio of charges matching ratio of forces $F_B = 3.73F_A$ $\frac{\cancel{kq}q_B}{\cancel{r^2}} = 3.73\frac{\cancel{kq}q_A}{\cancel{r^2}}$	1-2
$q_B = 3.73q_A = 3.73 \times 260 \times 10^{-9} = 9.70 \times 10^{-7}\ C$	1
Total	**3**

(c) Assume that the distance from each charge q_A and q_B to the golf ball is 5.00 cm. Calculate the strength of the electric field at the golf ball's starting position due to the combined effect of charges q_A and q_B. (4 marks)

Description	Marks
Solves for either F_A or F_B (or both) $F_A = \frac{1}{4\pi\varepsilon_0} \times \frac{qq_A}{r^2}$ $F_A = \frac{1}{4\pi \times 8.85 \times 10^{-12}} \times \frac{140 \times 10^{-9} \times 260 \times 10^{-9}}{0.05^2} = 0.1309\ N$ AND/OR $F_B = \frac{1}{4\pi\varepsilon_0} \times \frac{qq_B}{r^2}$ $F_B = \frac{1}{4\pi \times 8.85 \times 10^{-12}} \times \frac{140 \times 10^{-9} \times 970 \times 10^{-9}}{0.05^2} = 0.4882\ N$	1-2
Uses trig rules (sin/cos/tan or Pythagoras) to solve for the net force $\sum F = \frac{F_A}{cos\theta} = \frac{0.1309}{cos75} = 0.5058\ N$	1
Solves for electric field strength $E = \frac{F}{q} = \frac{0.5058}{140 \times 10^{-9}} = 3.61 \times 10^6\ NC^{-1}$	1
Total	**4**

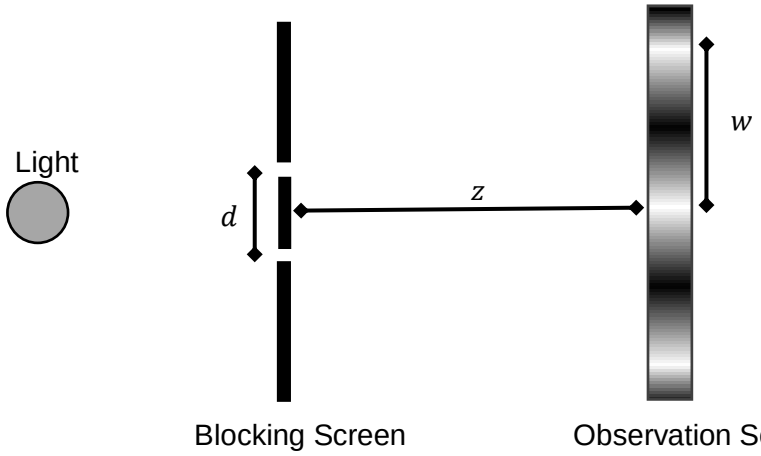
(d) To complete the simulated putt, the students also must indicate how long charge q_A and q_B must remain active. Would you advise the students to activate the charges for a short time (just enough to start the ball moving) or a long time (until the ball is approximately half way to the hole) to ensure a successful putt? Justify your response. (3 marks)

Description	Marks
A short time	1
Describes that the ball's change in position affects direction of net force, leading to a missed shot. "If the charges are left active for a long time, the direction of the forces applied to the ball will change as the ball changes position. This can cause the net force of the ball to act in a direction away from the hole, causing the ball to move off course and miss the hole. "	1-2
Total	**3**

See next page

Question 18 **(15 marks)**

Young's double slit experiment is used as evidence of the wave nature of light. The experiment requires a monochromatic light source, a blocking screen with a pair of thin, parallel slits and an observation screen.



When the light is turned on, the observation screen has a repeating pattern of bright and dim fringes. The theoretical relationship between the distance between bright fringes (w), the separation of the slits (d) and the distance between the blocking screen and observation screen (z) is:

$$w = \frac{z\lambda}{d}$$

A 560 nm light was used and the distance between the fringes was recorded as the distance between the screens was increased. The results are given below.

z (m)	w ($\times 10^{-3}$ m)
1.2	4.7
1.5	5.6
1.9	7.0
2.5	9.0
3.5	12.7

(a) Explain the processes that occur that change the original light source into a pattern of bright and dim fringes. (3 marks)

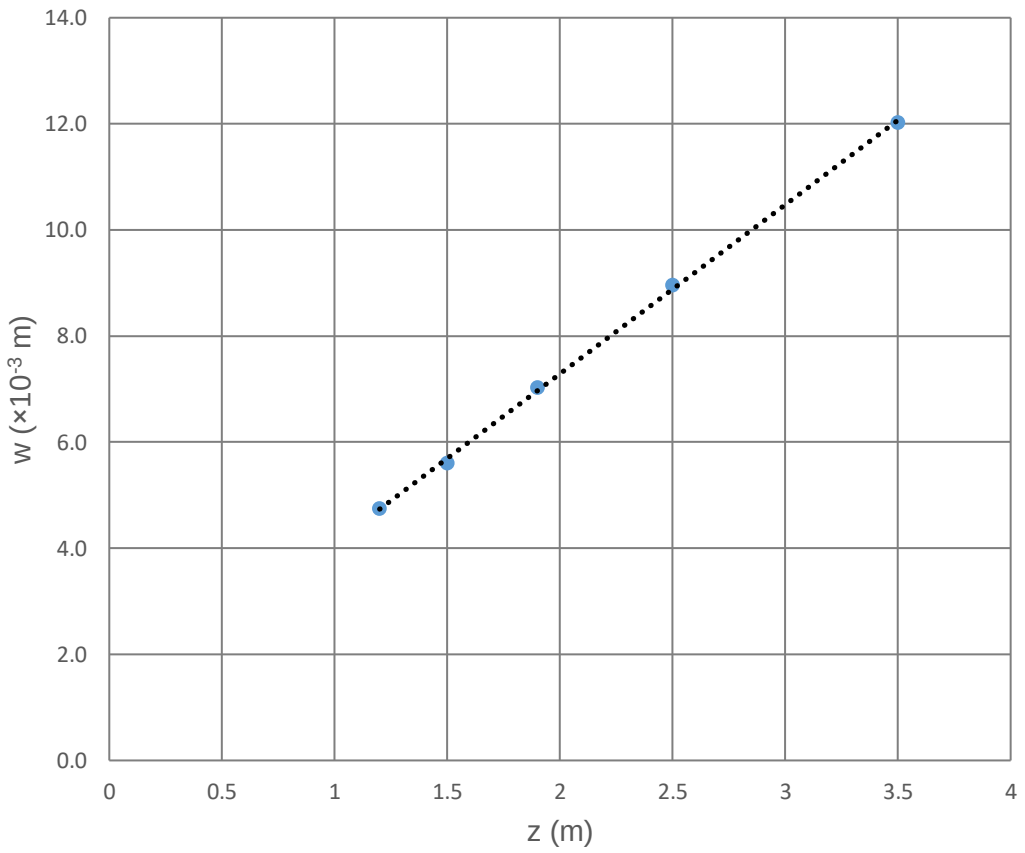
Description	Marks
States that diffraction occurs through slits "As long as the wavelength of the light is similar in size to the width of a slit, the light diffracts through the slit."	1
States two slits results in wave interfering on the far side of blocking screen "The diffracted wave from both slits will spread out, cross paths and interfere with each other"	1
States the interference can be constructive (bright) or destructive (dim) "When the interference is constructive, the light will produce a bright fringe, when destructive interference occurs, a dim fringe is the result.	1
Total	**3**

See next page

(b) Show that as long as z, d and λ are measured in metres, the formula for calculating the width between the fringes will return a value in metres. (1 mark)

Description	Marks
Shows dimensional analysis – showing how some units cancel to leave the final units as m $w = \frac{z\lambda}{d} = \frac{m \cancel{m}}{\cancel{m}} = m$	1
Total	**1**

(c) Draw a graph of w against z, with w on the y-axis. 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
Accuracy of plotted points	1
Line of best fit	1
Total	**5**

See next page

Question 18 (continued)

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

Description	Marks
Draws construction lines	1
$grad = \frac{rise}{run} \approx 0.0032$ If answer is 3.2 due to ignoring scale of w values, only 1 mark	1-2
Total	**3**

(e) Use the gradient from part (d) and the provided equation to calculate the width between the slits in this experiment. (3 marks)

Description	Marks
$grad = \frac{\lambda}{d}$	1
$d = \frac{\lambda}{grad} = \frac{560 \times 10^{-9}}{0.0032} = 0.00015 = 1.50 \times 10^{-4}\ m$	1-2
Total	**3**

End of Section Two

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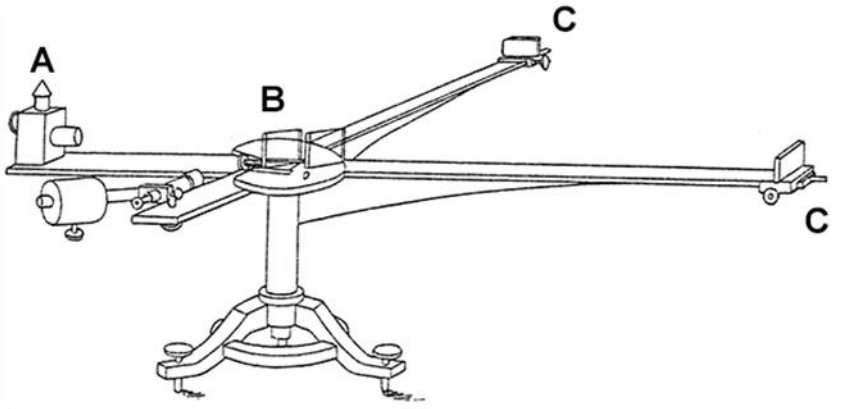
Section Three: Comprehension **20% (36 Marks)**

Question 19 **(17 marks)**

Experimental evidence supporting special relativity

Prior to the development of Einstein's theory of special relativity, it was proposed that light travelled through a medium called the luminiferous aether. Light needed a medium (according to physicists of the 1800s) because light had wave like behaviour. Wave models required the aether to exist, but no one could detect it. It was assumed the Earth moved through this aether and since the Earth orbits the Sun, the relative motion through the aether would be seasonal. The Michelson-Morley experiment, conducted in 1887, was an attempt to detect the velocity of the aether relative to the Earth.



Original sketch of experimental setup of the Michelson-Morley experiment.

A. Oil Lamp
B. Beam Splitter
C. Mirrors

In the experiment, a source of white light from an oil lamp was passed through a beam splitter- each beam heads towards a reflective mirror spaced equally from the splitter. One beam has a velocity aligned with the direction the aether's velocity (longitudinal beam) while the other beam's velocity was perpendicular to the velocity of the aether (transverse beam). The longitudinal beam is now like a kayaker paddling upstream – the kayaker has a velocity he/she can achieve in still water (the light's speed in the aether, which was believed to be c) but the velocity of the kayaker relative to the shore is reduced because of the water's opposing flow (the aether flows against the light, reducing the light's speed). The transverse beam is only minimally affected as it is trying to "cross the river".

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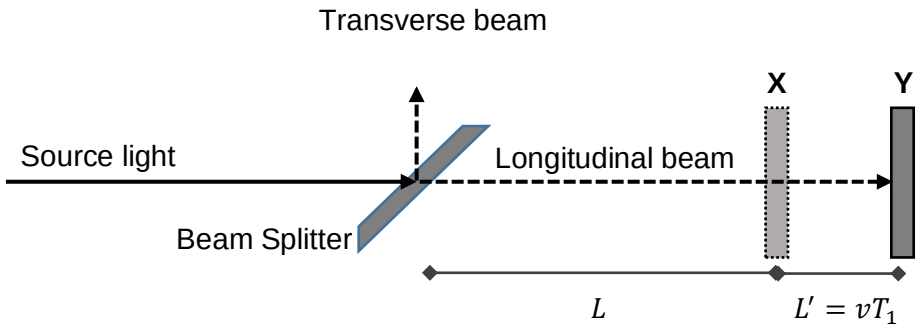
Question 19 (continued)

Mathematically, if the aether was flowing past the experiment at speed v, it is just as valid to say the experiment is moving in the other direction at speed v. The light moves at a speed c **within** the aether. When the longitudinal light passes through the beam splitter, a mirror is a distance L from the splitter but is moving away from the light with a velocity v. In the time it takes for the beam to reach the mirror, T_1, the mirror has moved at distance vT_1 from its original position.



X – mirror position when source light reaches beam splitter

Y – mirror position when longitudinal beam reaches mirror

This allows for an expression for the time it takes for the beam to reach the mirror, $T_1 = \frac{L}{c-v}$.
The equipment of the day did not allow for such precise measurements of time. This is why the transverse beam was required. As the longitudinal and transverse beams recombined after being reflecting at the equally spaced mirrors, the intensity of the recombined light would reveal the phase difference between the two beams, indicating the difference in travel time of the beams and thus velocity of the experiment through the aether.

By measuring results over many months, Michelson and Morley expected to find a variety recombined intensities, thus a variety of results for v, the speed of the aether. However, the results revealed that the aether had no velocity – that is, both beams of light always had the same speed no matter when the experiment was conducted – contradicting everything that physicists of the time expected of the aether. This is now regarded as the most famous "failed" experiment in history.

(a) The "failed" Michelson-Morley experiment was the basis for one of Einstein's postulates of special relativity.

(i) Contrast what Michelson and Morley hoped to find in this experiment with the final outcome. (2 marks)

Description	Marks
States the intention of the experiment "Michelson and Morley were attempting to find the velocity of the aether"	1
States the findings of the experiment "The experiment showed the aether had no velocity; it was always stationary with the Earth."	1
Total	**2**

See next page

Question 19 (continued)

(ii) State the postulate this 'failed' experiment supports

(1 mark)

Description	Marks
States the 2nd postulate "The speed of light is the same for all observers/frames"	1
Total	**1**

(b) Assuming light does travel through an aether, show, via full working, that the time the longitudinal beam takes to move from the splitter to the mirror is $\frac{L}{c-v}$.

(3 marks)

Description	Marks
Starts from relationship between lengths $L_{total} = L + L'$	1
Suitable, clear mathematical steps $cT_1 = L + vT_1$ $cT_1 - vT_1 = L$ $T_1(c - v) = L$ $T_1 = \frac{L}{c-v}$	1-2
Total	**3**

(c) Assuming light travels through an aether, the anticipated **total** time it takes for the longitudinal beam to return to the splitter is **not** $2 \times \frac{L}{c-v}$ (twice the time it took to move from splitter to mirror). Explain. (3 marks)

Description	Marks
States reflection occurs at the mirror "The light after leaving the splitter is reflected by the mirror"	1
States that reflected light moves with aether flow. "When the beam reflects it will be going in the same direction as the aether flows".	1
Refers back to original question "This will give the light a faster velocity as measured on Earth, with a speed c+v."	1
Total	**3**

See next page

(d) Physicists in the 1800s assumed light used the luminiferous aether as a medium. If this was true, explain how using a beam splitter and recombination of longitudinal and transverse beams would result in changes in light intensity. (5 marks)

Description	Marks
Describes that each beam has a different velocity due to relative motion through aether "The velocity of the longitudinal beam flowing in the direction of the aether's velocity will be adjusted by the aether. The transverse beam is not affected the same way, thus having a different velocity"	1-2
Describes how length and speed interact to affect time of beam – thus phase difference "With the same distance, but different speeds, the time for each beam to return to the splitter will be different - This puts the beams out of phase (a phase difference)"	1-2
When beams are out of phase, intensity of combined light is reduced due to destructive interference	1
Total	**3**

(e) Even if the experiment was a "success", the results were expected to change from one month to the next. Explain why. (3 marks)

Description	Marks
States the velocity of the aether is relative to Earth "The experiment conducted on Earth would be moving through the aether with the Earth."	1
States that Earth's velocity is not constant "As the Earth's velocity changes as it orbits the Sun, the velocity through the aether would also be affected"	1
Refers back to question, connecting velocity through aether with results of experiment "The experimental results will show the velocity of the aether based on the current velocity of the Earth around the Sun.	1
Total	**3**

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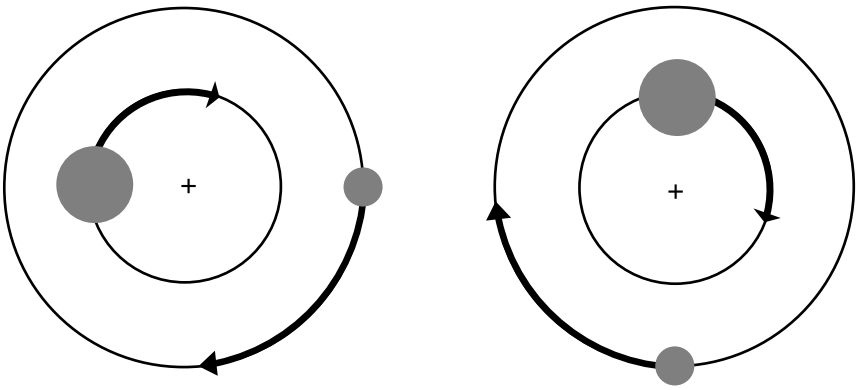
Question 20 **(19 marks)**

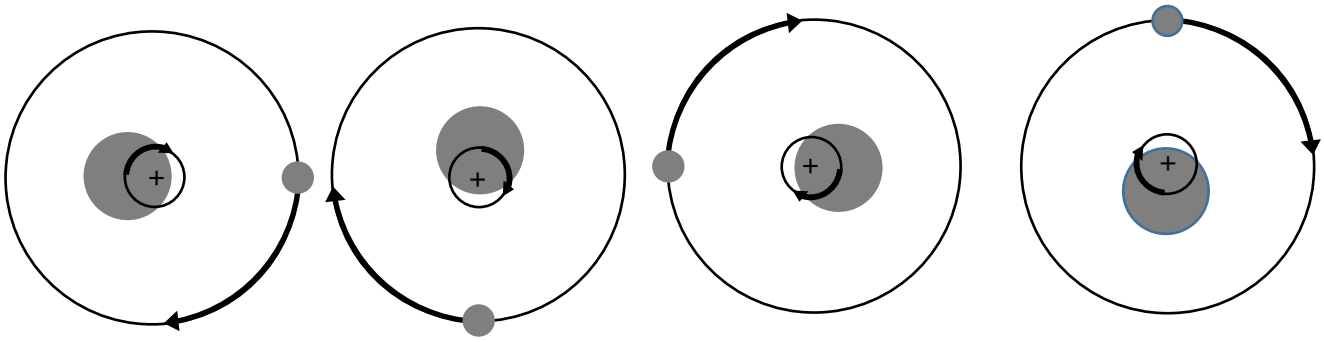
The barycentre – the true centre of a circular orbit

Physics Unit 3 covers uniform circular motion due to gravitational forces acting on a satellite. The analysis of these problems is simplified by assuming the orbital radius is the distance between the centre of mass of the two bodies (e.g. Earth and Moon). However, consider this – as the Earth pulls on the Moon to give the Moon its centripetal force, the Moon also pulls on the Earth. Wouldn't the Earth then begin to accelerate towards the Moon? In truth, it does. When any two celestial objects orbit each other, they orbit around a common central point, called the barycentre.



The two-body system diagrams above show that as the two bodies orbit the barycentre, their centres of mass are always radially opposite each other – each body has the same orbital period. Each body applies a gravitational force on the other, pulling it towards the barycentre. The bigger mass is always closer to the barycentre than the smaller mass.

Since the Earth is much more massive than the Moon, the barycentre is inside of the Earth. This causes the Moon to orbit around the Earth, while the Earth appears to "wobble", as shown in the diagrams below. The Earth is still in a state of uniform circular motion about the barycentre and can be analysed as such.



For these two-body system, the barycentre can be calculated from knowledge of the masses and total distance separating the two bodies:

$$r_1 = \frac{d}{1 + \frac{m_1}{m_2}}$$

m_1 and m_2 are the masses of body 1 and body 2
r_1 is the distance from the centre of m_1 to the barycentre
d is the separation of the centre of masses of m_1 and m_2

See next page

(a) Discuss whether the following statements are physically sound for a two-body system consisting of the Earth and Moon:

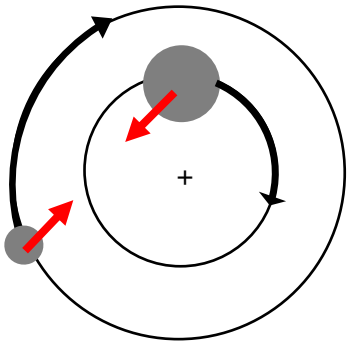
(i) "Both the Earth and the Moon experience the same magnitude of gravitational force". (3 marks)

Description	Marks
States this statement is sound "This statement is physically sound"	1
Provides suitable argument justifying the statement "According to Newton's 3rd Law, every action has an equal but opposite reaction. The same magnitude of gravitational force that the Earth pulls on the Moon will be applied to the Earth by the Moon"	1-2
Total	**3**

(ii) "Both the Earth and Moon experience the same magnitude of centripetal acceleration." (3 marks)

Description	Marks
States this statement is **not** sound "This statement is **not** physically sound"	1
Provides suitable argument that finds fault with the statement "Despite both bodies having the same forces, they have different masses on which the force is applied. According to Newton's 2nd law, acceleration is inversely proportional to mass" OR "Centripetal acceleration depends on radius and they have different orbital radius" - 1 mark only	1-2
Total	**3**

(b) By drawing gravitational forces for the two-body system shown below, explain why it is **not** possible to have the bodies in the position shown in the diagram. (3 mark)



Description	Marks
Draws two vectors, directed from centres of mass towards other body's centre of mass. No penalty for mismatched size of vectors.	1
Describes need for net force to be directed towards centre which doesn't occur here "This is not possible as for circular motion as each body needs to have a net force acting towards the (bary)centre of the orbit. Here, the gravitational forces are not acting towards the centre of the orbit."	1-2
Total	**3**

See next page

Question 20 (continued)

(c) Calculate the distance from the centre of the Earth to the barycentre of the Earth Moon system. (3 marks)

Description	Marks
Uses $d = 3.84 \times 10^8\ m$ $m_1 = 5.97 \times 10^{24}\ kg$ $m_2 = 7.35 \times 10^{22}\ kg$	1
$r_1 = \frac{d}{1+\frac{m_1}{m_2}}$ $r_1 = \frac{3.84\times10^8}{1+\frac{5.97\times10^{24}}{7.35\times10^{22}}} = 4.67 \times 10^6\ m$	1-2
Total	**3**

(d) Knowledge of the barycentre location allows the speed at which the Earth is orbiting the barycentre to be determined.

(i) Show that the velocity of the Earth with respect to the barycentre of the Earth-Moon system is $v = \sqrt{\frac{Gm_{moon}r_1}{d^2}}$. (2 marks)

Description	Marks
Equates centripetal force acting on Earth to gravitational force $F_c = F_g$ $\frac{m_E v^2}{r_1} = \frac{Gm_E m_m}{d^2}$	1
Cancels Earth mass and rearranges for v $\frac{\cancel{m_E}v^2}{r_1} = \frac{G\cancel{m_E}m_m}{d^2}$ $v = \sqrt{\frac{Gm_m r_1}{\mathrm{d}^2}}$	1
Total	**2**

(ii) Hence, calculate the velocity of the Earth around the barycentre of the Earth-Moon system. If you could not obtain an answer to part (c), you may use 4.60×10^6 m. (2 marks)

Description	Marks
Uses correct r and r' values from part c and formula and data sheet $v^2 = \frac{Gm_m r_1}{d^2} = \frac{6.67\times10^{-11}\times7.35\times10^{22}\times4.67\times10^6}{(3.84\times10^8)^2} = 1.553 \times 10^2$ $v = \sqrt{1.553 \times 10^2} = 12.5\ m\ s^{-1}$ Or $12.4\ m\ s^{-1}$ if used data in question	1-2
Total	**2**

See next page

(e) Prove that if the two-body system is made of two bodies of identical mass, the barycentre is exactly equidistant from each body. (3 marks)

Description	Marks
$r_1 = \frac{d}{1+\frac{m_1}{m_2}}$ $and\ m_1 = m_2$	1
$r_1 = \frac{d}{1+\frac{m}{m}} = \frac{d}{1+1}$ $r_1 = \frac{d}{2}$	1
States that the calculated 'r' applies to both bodies (or also calculates r_2) "As m_1 and m_2 are indistinguishable/interchangeable, this is also the distance from the other body to the barycentre. Both bodies are $\frac{d}{2}$ from barycentre"	1
Total	**3**

End of questions