

Name	Date started	Target end date
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GCE A LEVEL – CIRCULAR MOTION QUESTION PACK

Legacy PH4 · New spec Unit 3 Topic 1 · A2 unit, 25% of A-level

REVISE
.wales

PHYSICS – UNIT 3 · CIRCULAR MOTION

3.1 Circular motion – angular kinematics, centripetal force and orbital motion

Angular displacement and velocity, centripetal acceleration and force, vertical and horizontal circles, plus orbital applications (satellites, binary systems, galaxy rotation curves).

NEW 2015 SPEC · UNIT 3 TOPIC 1

Estimated time for entire question pack: ~3h 8m

Derived from the legacy PH4 paper's pace of 120 marks in 1h 45m.

You are advised to **not** attempt to complete all of this in one sitting.

ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every question from the legacy WJEC PH4 papers (2008 modular spec) that maps onto new-spec Unit 3 Topic 1 (3.1).

Questions are ordered chronologically within each section.

INSTRUCTIONS

Use black ink or black ball-point pen. Answer all questions in the spaces provided.

The number of marks is given in brackets at the end of each question or part-question. A calculator is required. The Data Booklet is allowed.

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Q	Source	Max	Mark	Q	Source	Max	Mark
1	PH4 Jun 13 Q4	18		7	PH4 Jun 11 Q5	16	
2	PH4 Jun 15 Q5	9		8	PH4 Jun 12 Q7	11	
3	PH4 Jan 12 Q4	13		9	PH4 Jun 13 Q6	11	
4	PH4 Jun 15 Q7	10		10	PH4 Jun 14 Q7	10	
5	PH4 Jun 14 Q3	5		11	PH4 Jan 14 Q7	10	
6	PH4 Jan 13 Q5	10		12	PH4 Jun 10 Q7	11	
Total						134	

Circular Motion – what the new spec asks

WJEC GCE A Level Physics (from 2015) · Unit 3: Oscillations & Nuclei · Topic 3.1.

Angular kinematics **A**

- Radian measure of angle; $\theta = s/r$ and 2π rad = 1 rev.
- Angular velocity $\omega = \Delta\theta/\Delta t$; relation to T and f: $\omega = 2\pi/T = 2\pi f$.
- Tangential speed $v = \omega r$.

Centripetal acceleration & force **A**

- $a = v^2/r = \omega^2 r$, directed towards the centre.
- $F = mv^2/r = m\omega^2 r$; identify the physical source of F.
- Vertical-circle constraints: minimum speed for loop = \sqrt{gr} .

Orbital motion **B**

- Gravity providing centripetal force: $GMm/r^2 = mv^2/r$.
- Derive $v = \sqrt{GM/r}$ and Kepler 3: $T^2 \propto r^3$.
- Geostationary orbit: T = 24 h, derive r from $\omega^2 = GM/r^3$.

Binary systems & galaxy rotation **C**

- Two bodies orbit a common centre of mass: $m_1 r_1 = m_2 r_2$.
- Doppler shift from a star's wobble as an exoplanet detection method.
- Galaxy-rotation curves: observed $v(r)$ implies dark matter beyond luminous mass.

Circular Motion in one page

Quick-reference notes – revisit before each section.

Angular kinematics

θ in radians: $\theta = s/r$.

$\omega = \Delta\theta/\Delta t$ (rad s⁻¹).

$\omega = 2\pi/T = 2\pi f$.

$v = \omega r$.

Centripetal acceleration

$a = v^2/r = \omega^2 r$.

Speed constant; velocity not (direction changes).

Centripetal force

$F = mv^2/r = m\omega^2 r$.

Source: tension, friction, gravity, normal contact, lift, etc.

If F vanishes \Rightarrow tangential flight (Newton I).

Vertical circle

Bottom: $N - mg = mv^2/r \Rightarrow N = m(g + \omega^2 r)$.

Top: $N + mg = mv^2/r \Rightarrow N = m(\omega^2 r - g)$.

Min speed at top: $v_{\min} = \sqrt{gr}$.

Orbits

$GMm/r^2 = mv^2/r \Rightarrow v = \sqrt{GM/r}$.

$T^2 = 4\pi^2 r^3 / (GM)$ – Kepler 3.

Closer orbits are faster.

Geostationary

$\omega = 7.27 \times 10^{-5}$ rad s⁻¹.

$r^3 = GM_E/\omega^2 \Rightarrow h \approx 3.6 \times 10^7$ m above equator.

Binary systems

$m_1 r_1 = m_2 r_2$, same T for both.

Lighter body has the larger r and the larger v .

Separation $d = r_1 + r_2$.

Doppler & exoplanets

$\Delta\lambda/\lambda = v/c$.

Periodic red/blue shift \Rightarrow planet exists.

Shift amplitude \Rightarrow star's orbital speed \Rightarrow planet mass (with T).

Galaxy rotation

$v(r) = \sqrt{GM(r)/r}$ for enclosed mass.

v stays roughly flat at large $r \Rightarrow$ more mass than luminous matter explains.

Section index

Use this index to jump straight to the section you need.

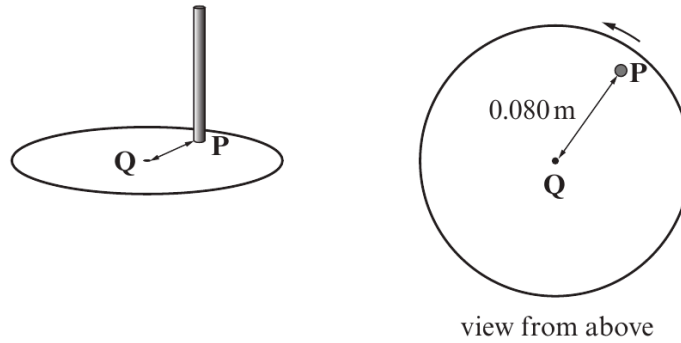
Section	Questions	Marks
A Angular motion & centripetal force	Qs 1-2	27 marks
B Orbital motion & Kepler's laws	Qs 3-9	76 marks
C Binary systems & galaxy rotation	Qs 10-12	31 marks

SECTION A

Circular motion fundamentals

Questions 1 – 2 · 27 marks

4. A rod is attached vertically to a horizontal turntable at point **P**, 0.080 m from the centre **Q**.



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- (a) (i) The turntable rotates around **Q** at 45 rotations per minute. Show that its angular speed ω is 4.71 rad s^{-1} . [2]

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- (ii) Calculate the speed v of the rod. [2]

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- (iii) Calculate the acceleration of the rod. [2]

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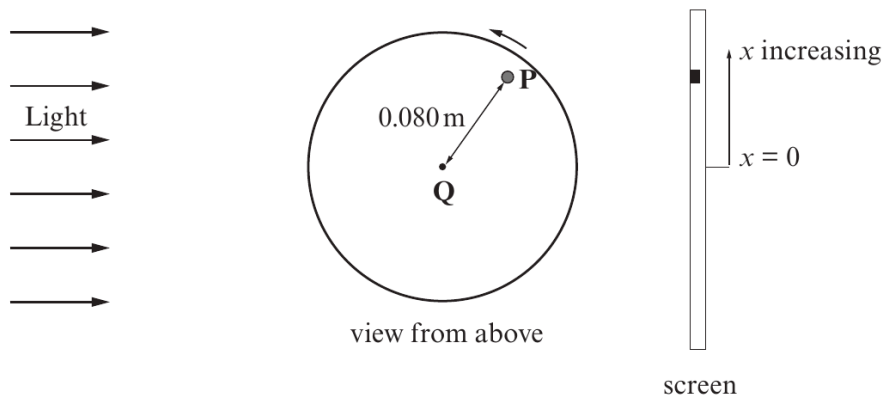
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- (iv) State the direction of the acceleration of the rod. [1]

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- (b) When the rod is illuminated from the side its shadow on a screen oscillates with Simple Harmonic Motion (SHM).

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The displacement x in metres of the centre of the shadow from the centre of oscillation and the acceleration a of the shadow may be written

$$x = A\sin(\omega t) \quad \text{and} \quad a = -\omega^2 A\sin(\omega t)$$

where t is time in seconds, A is the amplitude of oscillation and $\omega = 4.71 \text{ rad s}^{-1}$.

- (i) Write the value of A [1]
- (ii) Calculate the value of the period of oscillation. [1]
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- (iii) Calculate the acceleration of the shadow at time $t = 0.20 \text{ s}$. [2]
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(iv) State what is meant by *Simple Harmonic Motion* (SHM). [2]

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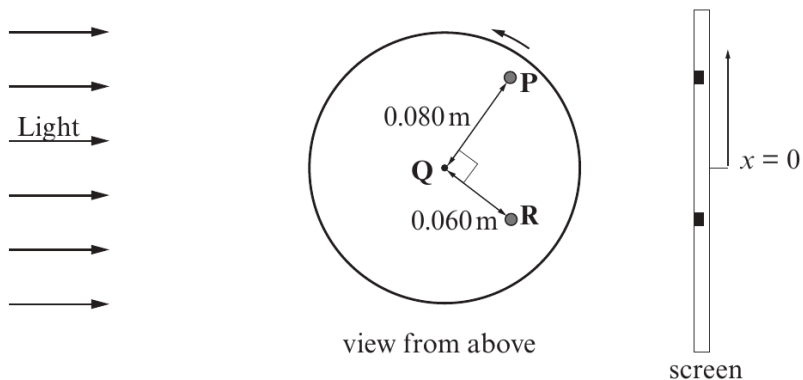
(v) Show clearly that the expressions for x and a agree with the definition of SHM. [2]

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(c) A second rod is now attached vertically to the turntable at point **R**, 0.060 m from centre **Q**, such that angle **PQR** is a right angle.

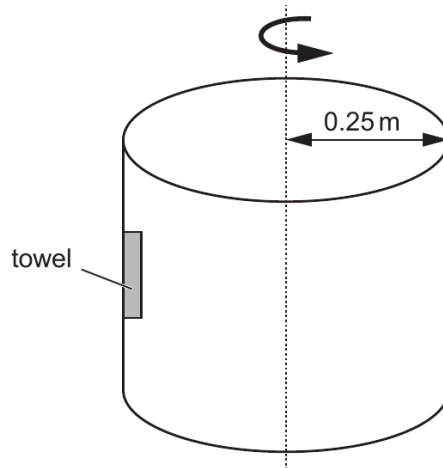


Complete the expression for the displacement of the shadow of the second rod at time t seconds by inserting numerical values in the boxes. [3]

$$x_R = \boxed{} \sin \left(\boxed{} t - \boxed{} \right)$$

5. (a) The drum of a top-loading washing machine spins around a vertical axis. The drum has a radius of 0.25 m and spins at a rate of 1 200 revolutions per **minute**.

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Determine the centripetal force on a damp towel, of mass 0.8 kg, on the inner wall of the drum. [4]

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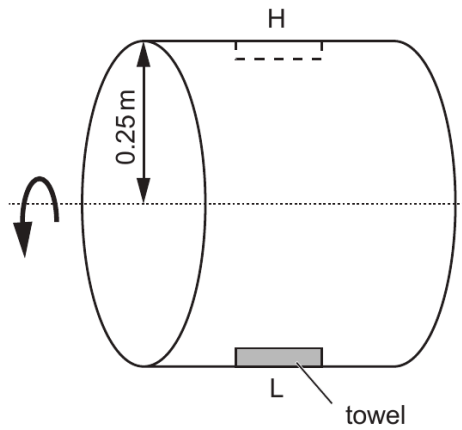
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- (b) The drum of a front-loading washing machine also has a radius of 0.25 m and spins at the same rate of 1 200 revolutions per minute.



By considering the forces on the towel, determine the force exerted by the wall of the drum on the towel when the towel is at its:

- (i) lowest point in the rotation (L); [2]

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- (ii) highest point in the rotation (H). [1]

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- (c) As the drum spins, the lid of a nearby saucepan is heard to vibrate. The vibration reduces when the spinning rate decreases. Explain both of these effects. [2]

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SECTION B

Orbital applications – satellites, planets & galaxies

Questions 3 - 9 · 76 marks

4. The first step in deriving the relationship between the height of a satellite above the Earth's surface, h , and the period of its orbit around the Earth is to note that the centripetal force is provided by the gravitational force:

$$\frac{Gm_1m_2}{r^2} = m_2\omega^2r$$

- (a) Explain briefly the meaning of each term in the equation. [4]

m_1

m_2

r

ω

- (b) Use the above equation to derive the relationship between the height, h , of a satellite above the Earth's surface and its orbital period, T , [4]

$$h + R_E = \sqrt[3]{\frac{Gm_1T^2}{4\pi^2}}$$

where R_E is the radius of the Earth.

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- (c) The mass of the Earth is 6.0×10^{24} kg and its radius is 6.4×10^6 m. Calculate the height of a geostationary satellite above the Earth's surface. [2]

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- (d) The mass of the satellite is 850 kg. Calculate the increase in its potential energy when it was initially moved from the Earth's surface to the geostationary orbit. [3]

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7. The Moon has an orbital period of about 27.3 days. The mass of the Earth is 6.00×10^{24} kg and the mass of the Moon is 7.34×10^{22} kg.

(a) Show that the distance between the Moon and the Earth is approximately 385 000 km. [3]

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(b) (i) Determine the distance of the centre of mass of the Earth-Moon system from the centre of the Earth. [2]

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(ii) Comment on your answer to (b)(i) given that the radius of the Earth is approximately 6370 km. [1]

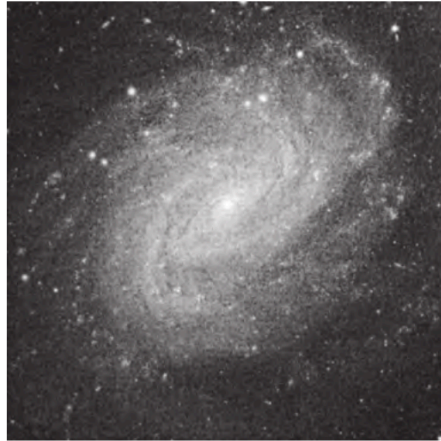
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3. A spiral galaxy is analysed and its mass is estimated as 3.5×10^{41} kg.



- (a) Use the equation $v = \sqrt{\frac{GM}{r}}$ to **estimate** the orbital speed of dust particles at a distance of 9.3×10^{20} m from the centre of the galaxy. [2]

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- (b) The **measured** velocity of the dust particles is different. Explain how dark matter is thought to be responsible for the difference between the **measured** and the **estimated** velocities. [3]

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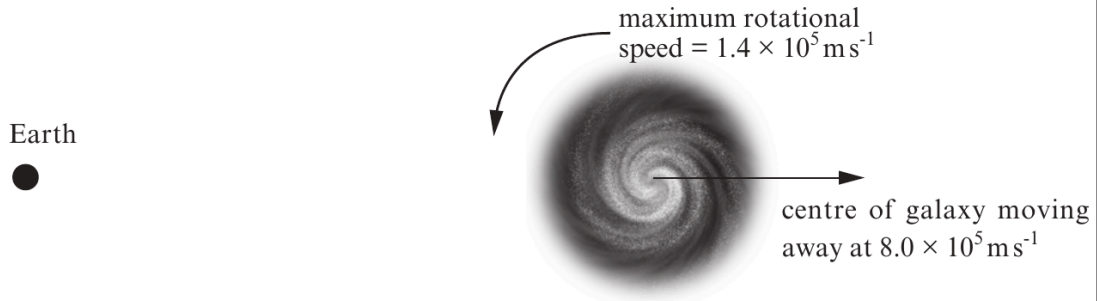
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5. A spiral galaxy is moving away from the Earth and rotating as shown.



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- (a) Calculate the maximum and minimum red shift measured by an Earth observer when light of wavelength 656 nm is analysed from this spiral galaxy. [3]

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- (b) The mass of the spiral galaxy is estimated to be 8.0×10^{39} kg (based upon the amount of light that it emits). Use this figure to calculate the gravitational force exerted on a unit mass at a distance of 1.5×10^{20} m from the centre of the spiral galaxy. [2]

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- (c) (i) Show that, for an object in a circular orbit of radius, r , about a body of mass, M , the orbital speed v is given by $v = \sqrt{\frac{GM}{r}}$. [2]

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- (ii) For this galaxy, the maximum rotational speed is $1.4 \times 10^5 \text{ m s}^{-1}$ and this was measured at a radius of $1.5 \times 10^{20} \text{ m}$. Use the equation $v = \sqrt{\frac{GM}{r}}$ to investigate whether dark matter might exist in this spiral galaxy. [3]

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5. (a) Two planets, P and Q, orbit a star of mass M . The planets' masses are very much less than M .

(i) P's orbit is **non-circular**. Use Kepler's laws to describe with words and **diagrams**

(I) the path the planet takes, [2]

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(II) the variation in the planet's speed. [2]

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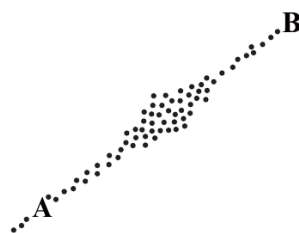
(ii) (I) Q's orbit is a circle of radius r . Show that Q's speed is given by $v = \sqrt{\frac{GM}{r}}$. [1]

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(II) Explain why this reasoning would be invalid if Q's mass were not very small compared with M . [2]

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- (b) (i) A galaxy is seen edge-on from the Earth. Light emitted from hydrogen atoms in the regions **A** and **B** is examined. [**A** and **B** are equal distances from the centre of the galaxy.] A line of wavelength 656.28 nm in the hydrogen spectrum is seen to be red-shifted to 658.36 nm in light from **A** and to 657.44 nm in light from **B**.



Calculate

- (I) the radial velocities of **A** and **B**, that is their velocity components away from us. [2]

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- (II) the mean radial velocity of the galaxy, [1]

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- (III) the speed due to the rotation of **A** or **B** around the centre of the galaxy. [1]

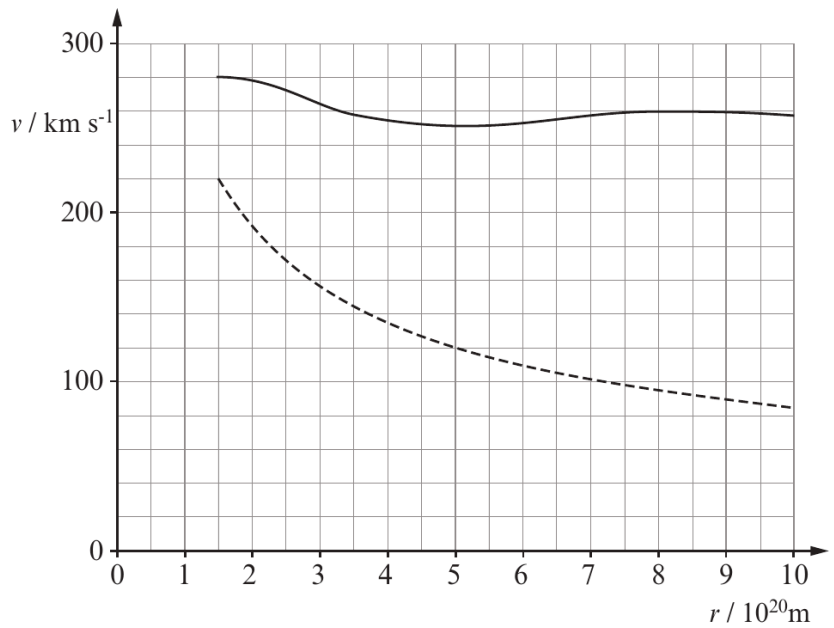
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- (ii) The **broken** line on the graph shows how the rotation speeds, v , of bodies in the outer regions of the galaxy depend on their distances, r , from the centre of the galaxy, according to the equation

$$v = \sqrt{\frac{GM}{r}}$$

[M is an estimate of the galaxy's mass, based on the radiation emitted by the galaxy.]



- (I) Calculate M .

[3]

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- (II) The full line on the graph is drawn using the rotation speeds actually observed. What does it tell us about the *actual* mass of the galaxy and its distribution within the galaxy compared with the mass and distribution on which the broken line is based?

[2]

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7.

	Mean radius of planetary orbit / m	Orbital period / year
Earth	149.6×10^9	1.00
Jupiter	778.6×10^9	11.86

(a) State Kepler's three laws of planetary motion. [3]

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(b) Show that the data above are consistent with Kepler's third law. [3]

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(c) Explain what is meant by centripetal acceleration.

[1]

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(d) Calculate the mass of the Sun.

[4]

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**THERE ARE NO MORE QUESTIONS
IN THE EXAMINATION**

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6. Information about the Earth, Jupiter and the Sun is given in the table:

	Radius / m	Mass / kg	Distance from the Sun / m
Earth	6.37×10^6	5.97×10^{24}	1.50×10^{11}
Jupiter	6.99×10^7	1.90×10^{27}	7.79×10^{11}
Sun	6.96×10^8	1.99×10^{30}	–

(a) Determine the following at the position of the Earth.

(i) The gravitational field strength of the Sun. [2]

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(ii) The gravitational potential due to the Sun. [2]

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(b) (i) Show clearly that the centre of mass of the Sun-Jupiter system lies outside the Sun. [3]

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(ii) Estimate the speed of the Sun's core around this centre of mass.

[4]

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SECTION C

Binary systems – mutual orbits & the Doppler method

Questions 10 – 12 · 31 marks

- (d) The planet is 5 times closer to the star than the Earth is to the Sun but the star emits $\frac{1}{20}$ of the electromagnetic radiation of the Sun. Discuss whether or not this planet is hotter or colder than the Earth. [2]

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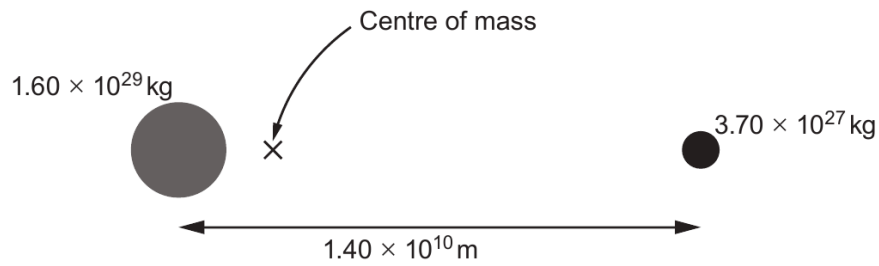
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7. A star and planet travel in circular orbits about their mutual centre of mass.



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(a) Calculate the period of orbit of the planet-star system and convert your answer to days (your answer will need to be accurate to 3 significant figures for full marks). [3]

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(b) Calculate the radius of: [3]

(i) the orbit of the star;

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(ii) the orbit of the planet.

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(c) (i) Show that the orbital speed of the star is around 600 m s^{-1} .

[2]

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(ii) Calculate the Doppler shift for a wavelength of $1.875 \mu\text{m}$ due to the orbital speed of the star (assuming that the system is viewed edge-on).

[2]

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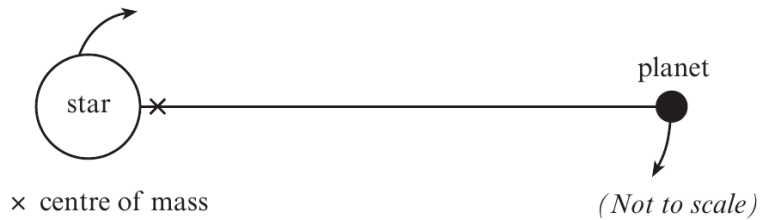
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END OF PAPER

7. A star of mass 2.2×10^{30} kg has a companion planet. The star and planet orbit a common centre of mass with an orbital period of 1090 days.



- (a) If the star's orbital speed is 45.5 m s^{-1} , determine the radius of the star's orbit.

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[3]

- (b) (i) Show that the distance from the planet to the star is approximately 3.2×10^{11} m. The mass of the planet is very much smaller than the mass of the star.

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[4]

- (ii) Hence, estimate the mass of the planet.

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[2]

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(c) Suggest how the orbital speed of the star may have been measured.

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[2]

END OF QUESTION PACK

12 questions · 134 marks · ~3h 8m

Source: WJEC PH4 (2008 modular spec)

Curated for WJEC Physics 2015 spec A2 Unit 3 – Topic 1 (3.1)

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