IGC HK EXAM

Eduqas - Physics

Circular Motion

2017

3. *(a)* The magnitude of the acceleration of a body travelling at speed v in a circle of radius r is given by:

$$a = \frac{v^2}{r}$$

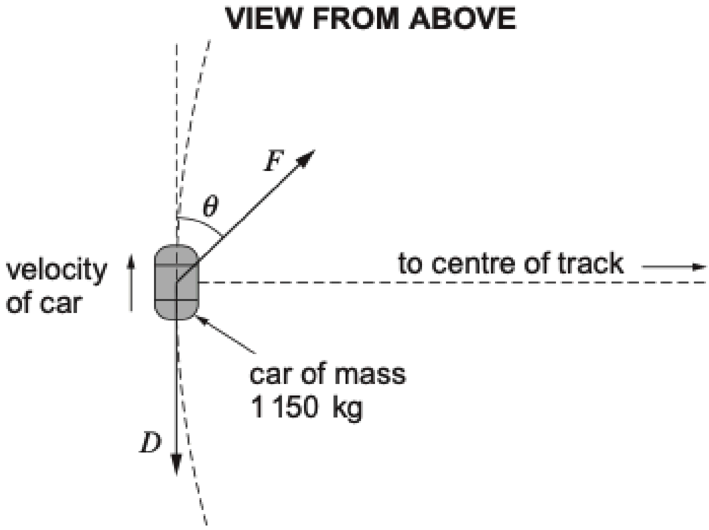
(i) Show clearly that this equation is homogeneous in terms of units. [2]

(ii) A teacher claims that the equation gives a 'sensible' value for the centripetal acceleration as r becomes extremely large. Justify her claim. [2]

(b) A car of mass 1 150 kg moving at constant speed takes 52 s to complete a lap of a flat circular track of radius 200 m.

(i) Show that the magnitude of the centripetal force on the car is approximately 3400 N. [3]

(ii) The diagram shows the car at one point on its journey (clockwise) around the track. D is the force of air resistance on the car, and F is the horizontal component of the force on the car's tyres from the road. F = 5 500 N.



I. Calculate the angle, θ, at which F must act in order to provide the centripetal force calculated in *(b)*(i). [2]

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II. Calculate D, giving your reasoning. [3]

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Question				Marking details	Marks available					
					AO1	AO2	AO3	Total	Maths	Prac
3	*(a)*	(i)		Units of a, v, r given as m s^{-2}, m s^{-1}, m (1) Convincing algebra **must see** $m^2 s^{-2}$ (1)	1	1		2	1	
		(ii)		[According to equation] a becomes smaller **or** zero (1) [Sensible because] body's path [almost] straight **or** equivalent (1)			2	2		
	(b)	(i)		$v = \frac{2\pi \times 200}{52}$ [= 24.2 m s^{-1}] or ω = 0.121 [rad s^{-1}](1) $F_{centrip}$ = 1 150 × ($\frac{2\pi \times 200}{52}$)^2 ÷ 200 [N] or equivalent or by implic(1) $F_{centrip}$ = 3 360 [N] **or** 3 400 [N] **Accept** 3 358 [N] or 3 300 [N] (1)		3		3	3	
		(ii)	I	$F_{centrip} = F \sin\theta$ **or** 3 360 (or 3 000) = 5 500 $\sin\theta$ **or** equiv **or** by implic **ecf** on $F_{centrip}$ (1) θ = 37.6°(or 38°) (1)		2		2	2	
			II	Forward component of F must balance D (**or** must be equal and opposite to D) **or** since car is travelling at constant speed (1) $D = F\cos\theta$ or equiv **ecf on θ** (1) D = 4 360 [N] (1)	1	1 1		3	2	
				Question 3 total	**2**	**8**	**2**	**12**	**8**	**0**

2018

2. *(a)* (i) Define the angular velocity, ω, for a body moving in a circle. [1]

(ii) Two equations giving the acceleration of a body moving at constant speed in a circle are:

$$a = \frac{v^2}{r} \quad \text{and} \quad a = r\omega^2.$$

Show clearly that the equations are equivalent. [2]

(b) A moon called *Deimos* orbits Mars in a circular path of radius 23 500 km. Astronomers have calculated the mass of Deimos to be 1.48×10^{15} kg, and the force exerted on it by Mars to be 1.15×10^{14} N.

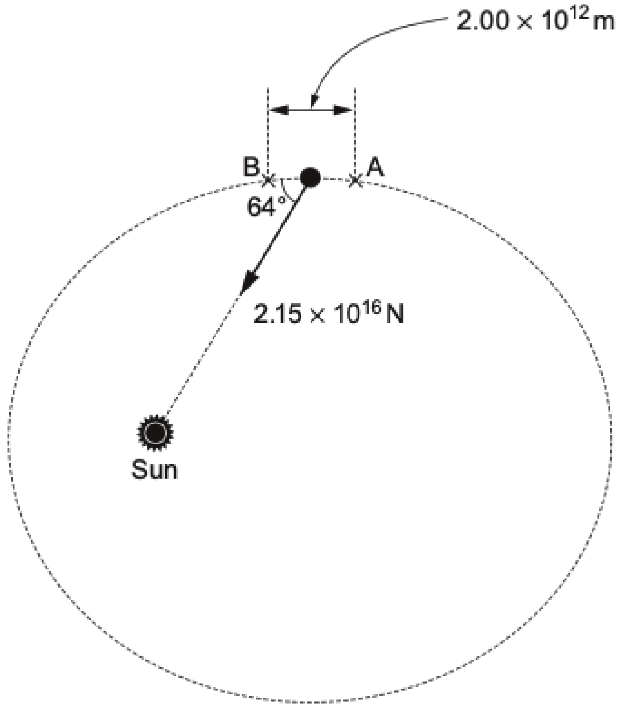
(i) Calculate the speed of Deimos around Mars. [2]

(ii) Explain whether or not a moon of twice the mass of Deimos, but in a circular orbit of the same radius about Mars, would have the same speed as Deimos. [2]

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
2	*(a)*	(i)	$\omega = \frac{\text{angle swept out}}{\text{time taken}}$ [or in words] **Or** angle [accept: number of radians] swept out per unit time [or per second]	1			1		
		(ii)	Clear use of $\omega = \frac{v}{r}$ or equivalent (1) Convincing algebra (1)	1	1		2	1	
	(b)	(i)	Substitution into: $F = m\frac{v^2}{r}$ or equivalent either before or after rearrangement (1) v = 1.35 km s^{-1} (1)	1	1		2	1	
		(ii)	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ or equivalent with M and m correctly identified (1) m cancels so speed of moon of twice the mass would be the same as that of Deimos. [Must be supported by argument even if argument not clear enough to give first mark.] (1) **or** in words, e.g. Equivalence of gravitational and inertial mass however expressed, [e.g. the force would be double and the mass is doubled] (1) Hence speed the same (1) **or** Another identical moon next to the existing one will orbit at the same speed (1), so the composite moon [of double the mass] will orbit at that speed (1).		2		2		
			Question 2 total	**3**	**4**	**0**	**7**	**2**	**0**

2019

2. The diagram shows the dwarf planet, Eris, at one point in its orbit.



(a) Explain why the *moment* (about the centre of the Sun) of the Sun's force on Eris is zero. [1]

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(b) Calculate the *work* done by the Sun's gravitational force on Eris as Eris moves from A to B. The mean values of the force and the angle at which it acts are shown on the diagram. [2]

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(c) Showing your reasoning clearly, determine whether your answer to *(b)* is consistent with these data:

$$\text{Mass of Eris} = 1.66 \times 10^{22}\,\text{kg}$$

$$\text{Speed of Eris at A} = 3460\,\text{m s}^{-1}$$

$$\text{Speed of Eris at B} = 3770\,\text{m s}^{-1}$$

[3]

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Question				Marking details	Marks available					
					AO1	AO2	AO3	Total	Maths	Prac
2	*(a)*			Zero distance from Sun to line of action of force **accept** zero perpendicular distance **or** [line of action of] force is straight through [centre of] Sun		1		1		
	(b)			Work $= 2.15 \times 10^{16} \times 2.0 \times 10^{12} \times \cos 64°$ [1] $= 1.88 \times 10^{28}$ J **unit mark** [1]	1	1		2	2	
	(c)			Work = ΔE_k declared as strategy **or** implied by conclusion **ecf** from (b) provided comment made [1] Intermediate step: $E_{kA} = 9.94 \times 10^{28}$ [J] **or** $E_{kB} = 1.18 \times 10^{29}$ [J] **or** $v_B^2 - v_A^2 = 2.24 \times 10^6$ [m^2 s^{-2}] or correct substitution into $\frac{1}{2}mv_B^2 - \frac{1}{2}mv_A^2$ [1] $E_{kB} - E_{kA} = 1.86 \times 10^{28}$ [J] **clearly arrived at** [1]			3	3	2	
				Question 2 total	**1**	**2**	**3**	**6**	**4**	**0**

4. *(a)* A fairground ride rotates at a rate of 8.20 revolutions per **minute**.

(i) Calculate:

I. the angular velocity in radians per second; [2]

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II. the time taken to travel an arc of length 10.0 m for a point P on the ride at 3.80 m from the central axis around which the ride is rotating; [2]

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III. the acceleration of point P. [2]

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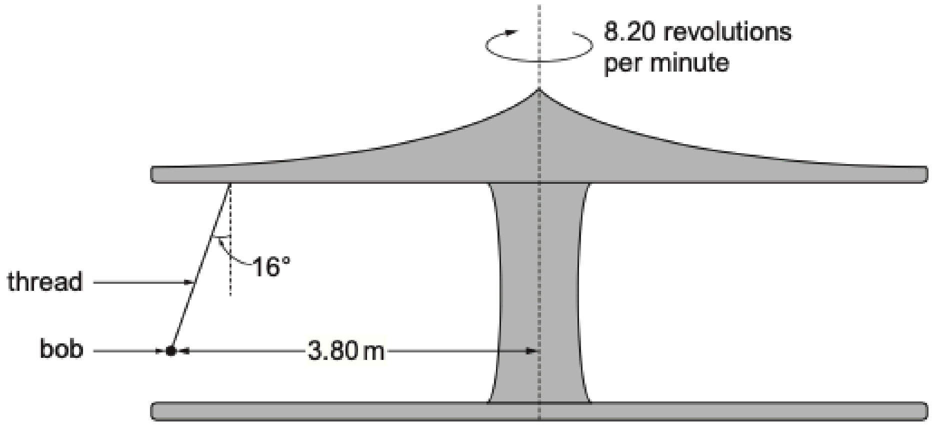
(ii) Annushka has been given permission to tie a simple pendulum from the ceiling of the rotating ride. She finds that, when the pendulum has stabilised, it hangs at 16° to the vertical, with its bob at 3.80 m from the central axis (see diagram).



I. The mass of the bob is 0.270 kg. By considering the **vertical** force components on the bob, calculate the tension in the thread. [2]

II. State what provides the centripetal force on the bob and show clearly whether or not this is consistent with the acceleration calculated in *(a)*(i)III. [3]

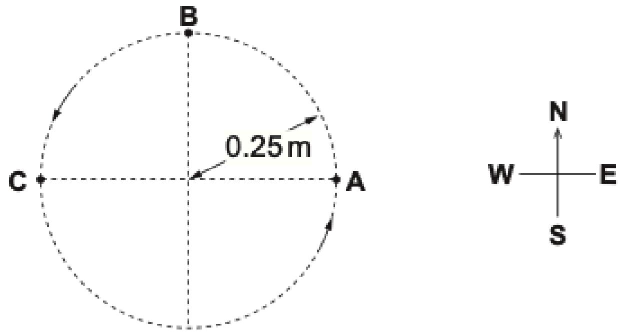
(b) Discuss **one** way in which our knowledge of the magnitude of centripetal force has been applied in the design of roads **or** railways **or** a domestic appliance. [3]

Question				Marking details	Marks available					
					AO1	AO2	AO3	Total	Maths	Prac
4	*(a)*	(i)	I	Use of $\omega = 2\pi f$ even if f is still in revs per minute **or by impl** [1] ω = 0.859 [rad s^{-1}] [1]	1	1		2	1	
			II	Use of $v = r\omega$ [= 3.26 m s^{-1}] **or equiv or by impl.** [1] Time = 3.06 [s] [1] **ecf**	1	1		2	1	
			III	Use of $a = \frac{v^2}{r}$ or $a = r\omega^2$ **or by implication** [1] a = 2.80 [m s^{-2}] [1] **ecf**	1	1		2	1	
		(ii)	I	Correct substitutions in $mg = T\cos\theta$ (or after transposition) or by implication [1] 2.76 [N] [1] [2.55 N indicates error of principle]		2		2	1	
			II	[Horizontal component of] tension provides centripetal force [1] $T\sin 16°$ evaluated [0.761 N **ecf on T**] or used in calculation [1] Conclusion clearly based on calculation e.g. Either $\frac{2.76 \sin 16°}{0.270}$ = 2.82 [m s^{-2}] **or** 2.80 **ecf** from (a)(i)III × 0.270 kg = 0.756 [N] **and** agreement noted **ecf** [1]			3	3	2	
	(b)			Example defined e.g. bends in roads or rail lines, spin-drier... [1] One factor affecting centripetal acceleration considered in context e.g. bends in roads or tracks must not be too sharp, or spin speed must be high enough... [1] Another factor considered e.g. vehicle speed warnings, drum size limited **or** more intricate measures e.g. banking of tracks [1]			3	3		
				Question 4 total	**3**	**5**	**6**	**14**	**6**	**0**

2020

2. *(a)* State what is meant by a body's *mean acceleration* over a period of time. [1]

(b) Protons are 'stored' by being made to go round and round a circular path of radius 0.25 m at constant speed. They perform 5.2×10^6 revolutions per second.



(i) Show clearly that the protons' speed is approximately $8 \times 10^6\ \text{m s}^{-1}$. [2]

(ii) Determine the magnitude and direction of a proton's acceleration at point **B**. [3]

(iii) Calculate a proton's mean acceleration over the semicircle **ABC**. [3]

(c) Two students discuss the mean force on a proton over one revolution **ABCA**. Adam says that the mean force is the same as the force at B, because the force is the same all the way round. Brian says that the mean force is zero. Evaluate these opinions. [2]

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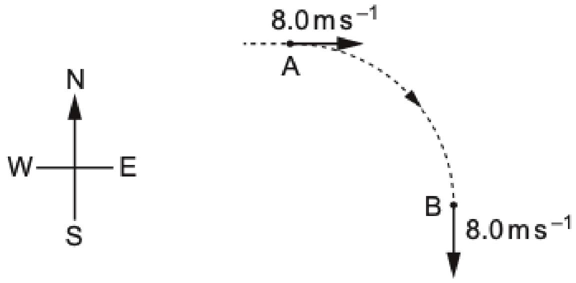
Question				**Marking details**	**Marks available**					
					AO1	**AO2**	**AO3**	**Total**	**Maths**	**Prac**
2	(a)			$\frac{\text{final velocity - initial velocity}}{\text{time [taken to change]}}$ or equivalent [1]	1			1		
	(b)	(i)		[Distance gone per second] = $2\pi \times 0.25$ [m] $\times$ 5.2×10^6 [s^{-1}] [1] = 8.2×10^6 [m s^{-1}] [1]	1	1		2	2	
		(ii)		acc = $\frac{(8.0\times10^6)^2}{0.25}$ [m s^{-2}] **or** $\frac{(8.17\times10^6)^2}{0.25}$ [m s^{-2}] [1] = 2.6 (or 2.7) $\times$ 10^{14} m s^{-2} **unit mark** [1] South or towards circle centre. Accept downwards. [1]	1 1	1		3	1	
		(iii)		Time for half revolution = $\frac{1}{2} \times \frac{1}{5.2 \times 10^6}$ s [= 9.62×10^{-8} s] [1] Final velocity – initial velocity = 1.63×10^7 [m s^{-1}] [South] [1] Mean acc = 1.7×10^{14} [m s^{-2}] **South** [Accept South for Δv] [1]		3		3	2	
	(c)			Adam is wrong because acc's (or force) *direction* keeps changing [1] Brian is right because final vel – initial vel = 0 or equiv [1]			2	2		
				Question 2 total	**4**	**5**	**2**	**11**	**5**	**0**

20210

4. *(a)* A car travels around a bend in a road at a constant speed of $8.0\,\mathrm{m\,s^{-1}}$. It takes 2.5 s to go from A to B. The diagram shows the car's velocities at A and B.



Determine the magnitude and **compass direction** of the car's **mean** acceleration as it goes from A to B. [3]

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(b) In special circumstances an electron has been made to orbit a nucleus in a circular orbit of radius 0.37 mm.

(i) Comment on the radius of this atomic orbit. [1]

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(ii) Assuming the charge on the nucleus to be $+e$, show that the speed of the electron is approximately $800\,\mathrm{m\,s^{-1}}$. [3]

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(iii) Calculate the frequency at which the electron orbits. [2]

Question				Marking details	Marks available					
					AO1	AO2	AO3	Total	Maths	Prac
4	*(a)*			$\Delta v = 8.0\sqrt{2}\,[\mathrm{m\,s^{-1}}]\ [= 11.3\ \mathrm{m\,s^{-1}}]$ or by implic [1] a = 4.5 [m s^{-2}] [1] South West **or** bearing of 225° [1]		3		3	2	
	(b)	(i)		Very large [for an atom]. Accept definite orbit not possible	1			1		
		(ii)		$\frac{m_e v^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$ or by implic [1] $v = \sqrt{\frac{1}{4\pi\varepsilon_0}\frac{e^2}{m_e r}}$ **or** $v = \sqrt{9.0\times10^9\,\frac{(1.60\times10^{-19})^2}{9.11\times10^{-31}\times0.37\times10^{-3}}}\ \mathrm{m\,s^{-1}}$ or by implic [1] v = 827 [m s^{-1}] [1]		3		3	2	
		(iii)		$f = \frac{827}{2\pi\times0.37\times10^{-3}}$ [Hz] or equiv or by implic [1] f = 3.6 [or 3.4] × 10^5 Hz [**or** s^{-1}] **unit mark** [1]	1	1		2	1	
				Question 4 total	**2**	**7**	**0**	**9**	**5**	**0**

2022

4. (a) Explain why an object moving in a circular path requires a resultant force to act on it, even when it is travelling at constant speed. [2]

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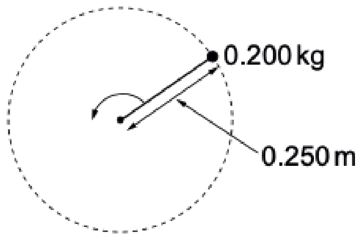
(b) Behind a safety screen in an engineering laboratory, a metal sphere of mass 0.200 kg is whirled in a horizontal circle on the end of a thin steel rod.



View from above

(i) The breaking stress of the steel under tension is 450 MPa and the **rod's diameter** is 1.2 mm. Show that the greatest force that the rod can exert is roughly 500 N. [2]

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(ii) Calculate the greatest rotation frequency (number of revolutions per second) at which the sphere can be whirled before the rod breaks. [3]

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(iii) I. State an assumption that you have made (or factor that you have ignored) in your calculation for part (b)(ii). [1]

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II. Bearing in mind your previous answer, will the greatest rotation frequency before the rod breaks be larger or smaller than your calculated value? Justify your answer briefly. [1]

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Question				Marking details	Marks available					
					AO1	AO2	AO3	Total	Maths	Prac
4	(a)			Object is accelerating [or velocity changing] because direction [of travel] [continuously] changing (1) [Resultant] force needed to give object an acceleration **or** a velocity change [or $F = ma$ cited] (1)	2			2		
	(b)	(i)		Force = 450 × 10^6 × π × 0.0006^2 [N] (1) [Tolerate slips in powers of 10 or factors of 2 or 4 for this mark only] = 509 N or 510 N [N] (1)	1	1		2	1	
		(ii)		Insertion of values for F, m, and r into $F = \frac{mv^2}{r}$ or $F = mr\omega^2$ or by implication (1) $v = \sqrt{\frac{509 \times 0.250}{0.200}}$ [= 25.2 m s^{-1}] **or** $\omega = \sqrt{\frac{509}{0.200 \times 0.250}}$ [= 101 rad s^{-1}] or by implication (1) f = 16 [Hz] **ecf** on v or ω (1)	1 1	1		3	2	
		(iii)	I	Mass of rod ignored **or** stretching of rod ignored [or any other significant assumption or factor ignored]		1		1		
			II	Mass of rod makes greatest rotation rate smaller **or** more stress on [inner part] of rod [for a given rotation rate] **or** stretching makes greatest rotation rate smaller **or** more stress for a given rotation rate.			1	1		
				Question 4 total	**5**	**3**	**1**	**9**	**3**	**0**