H2 Physics Revision Topic : Motion in a Circle

Structured Questions Name: ______________________

1 An elastic cord has an unextended length of 13.0 cm. One end of the cord is attached to a fixed point C. A small mass of weight 5.0 N is hung from the free end of the cord. The cord extends to a length of 14.8 cm, as shown in Fig. 5.1.

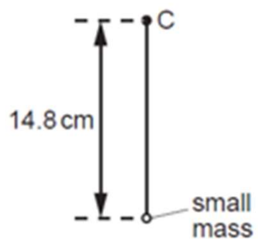

Fig. 5.1

The cord and mass are now made to rotate at constant angular speed ω in a vertical plane about point C. When the cord is vertical and above C, its length is the unextended length of 13.0 cm, as shown in Fig. 5.2.

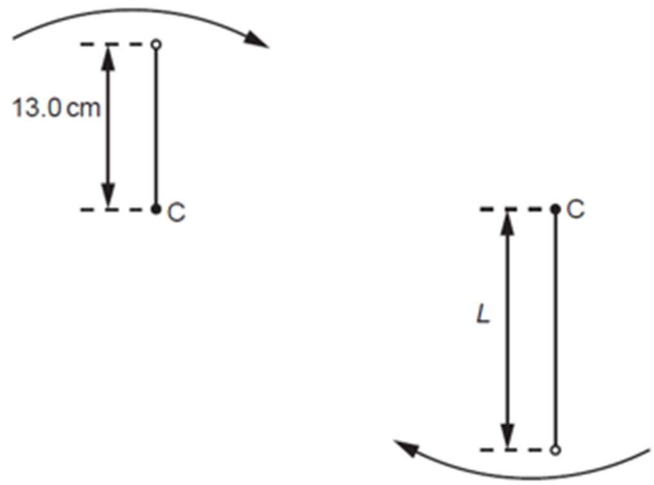

Fig. 5.2 **Fig 5.3**

(a) Show that the angular speed ω of the cord and mass is 8.7 rad s^{-1}.

[2]

1

(b) The cord and mass rotate so that the cord is vertically below C, as shown in Fig. 5.3.

Calculate the length L of the cord, assuming it obeys Hooke's law.

L = ………………………………cm [3]

[Total: 5]

2 A roller coaster carriage of mass m enters a circular loop-the-loop at point A with speed v_A, reaches the top of the loop at B with speed v_B and exits the loop with the same speed v_A as shown in Fig. 2.1.

The radius of the loop is R. The magnitudes of the normal contact forces acting on the carriage at A and B are N_A and N_B respectively.

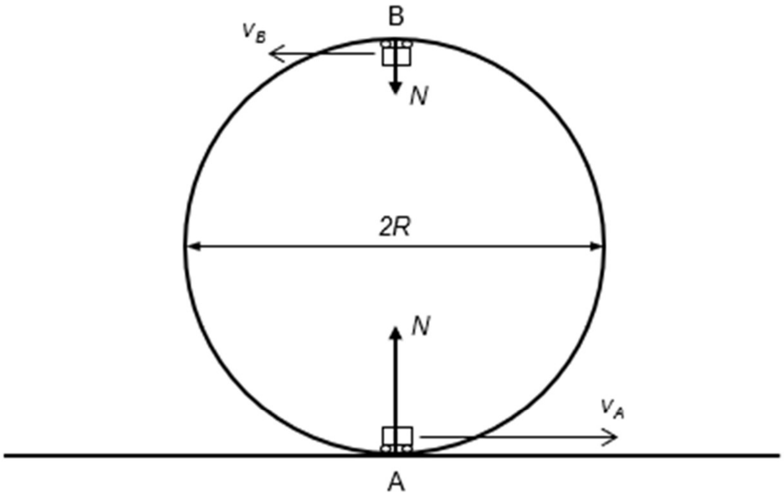

Fig. 2.1

(a) **(i)** State an expression for the loss in kinetic energy from A to B in terms of m, g and R, where g is the gravitational acceleration.

.... [1]

(ii) The track is smooth and there is no other resistive force present. Using your answer in **(a)(i)**, show that

$$N_A - N_B = 6mg\ .$$

[3]

2 **(b)** A rider may feel that he is heavier or lighter during a roller coaster ride depending on the normal contact force N from the seat th[illegible]antity known as the g-force compares N with his weight as fol[illegible]

$$g\text{-force} = \frac{N}{\text{weight}}.$$

A g-force of 2.0 means that the rider feels twice as heavy as his normal weight.

As the carriage moves through the loop, the g-force varies with the angle θ with the vertical as shown in Fig. 2.2, according to the relation

$$g\text{-force} = \frac{v_A^{\,2}}{gR} + 3\cos\theta - 2$$

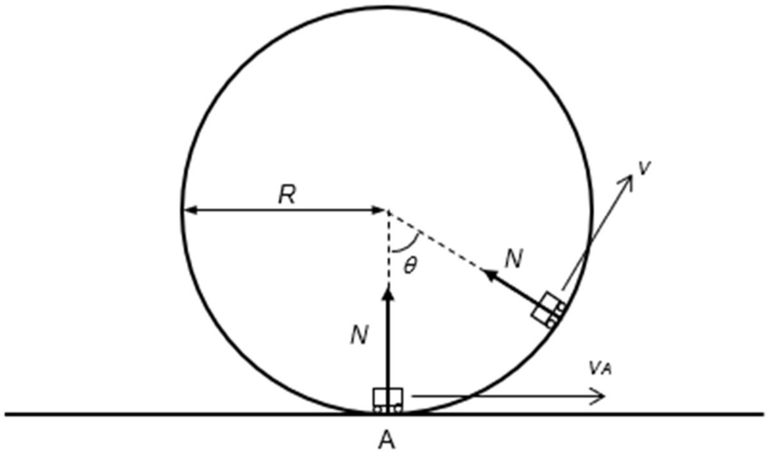

Fig. 2.2

(i) In order for the carriage to just reach the top of the loop (θ = 180°), the g-force at A (θ = 0°) would have to be 6.0, as shown in Fig. 2.3. The contact force at the top of the loop is then zero, and the rider would feel 'weightless'.

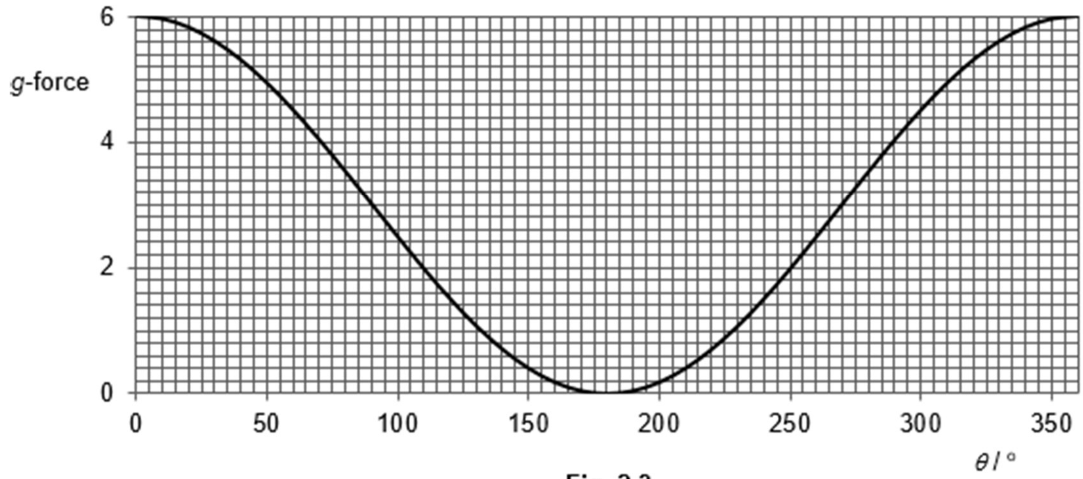

Fig. 2.3

2

1. Use information from Fig. 2.3 or otherwise to complete Fig. 2.4. Show your workings clearly. a_c refers to the centripetal acceleration.

θ / °	$\frac{a_c}{g}$
0	....
90	....
180	1.0

Fig. 2.4

[2]

2. Show that the speed of the carriage at A is equal to $\sqrt{5gR}$.

[1]

(ii) If the carriage enters the loop with a speed slower than $\sqrt{5gR}$ such that the g-force at A is 5.0, the carriage would lose contact with the track before it reaches the top of the loop.

Use Fig. 2.3 to deduce a value for θ at which the carriage first loses contact with the track.

θ = ... ° [1]

2

(c) A major disadvantage of circular loop-the-loop is that the circular track generates intense *g*-force, which makes it very uncomfortable for riders. A modern loop-the-loop is carefully designed with non-constant radius to overcome such limitations.

Fig. 2.5 shows two identical loop-the-loops at the Carolina Cyclone roller coaster located at Carowinds in North Carolina.

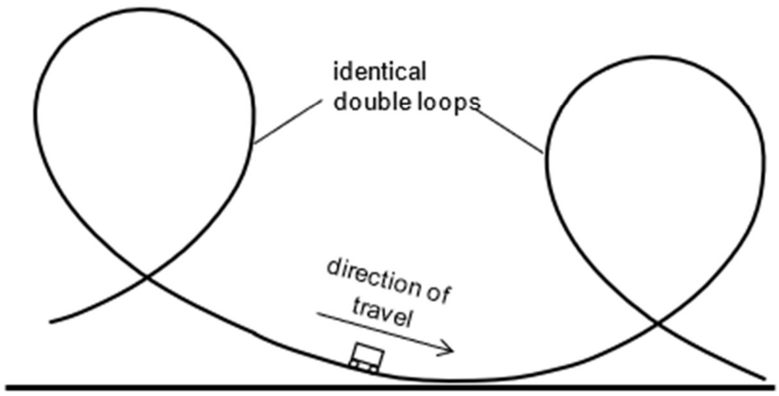

Fig. 2.5

(i) State and explain one advantage of the non-circular loop over the circular loop in **(a)** and **(b)**.

....

....

....

....[1]

(ii) Explain why the second loop in Fig. 2.5 is lower in height compared to the first loop.

....

....

....

....[1]

[Total: 10]

3 **(a)** A body moving with uniform speed v in a circle of radius r experience an acceleration a.

(i) Explain why the acceleration is directed towards the centre of the circle.

....

....

....

.... [2]

(ii) Write the expression of the acceleration a in terms of v and r.

.... [1]

(b) The Mars helicopter, Ingenuity, completed its first flight outside Earth on 19 April 2021.

To understand the difficulty of this flight, we will consider a simple model of Ingenuity comprising of a pair of rotating blades and a body, as shown in Fig. 3.1.

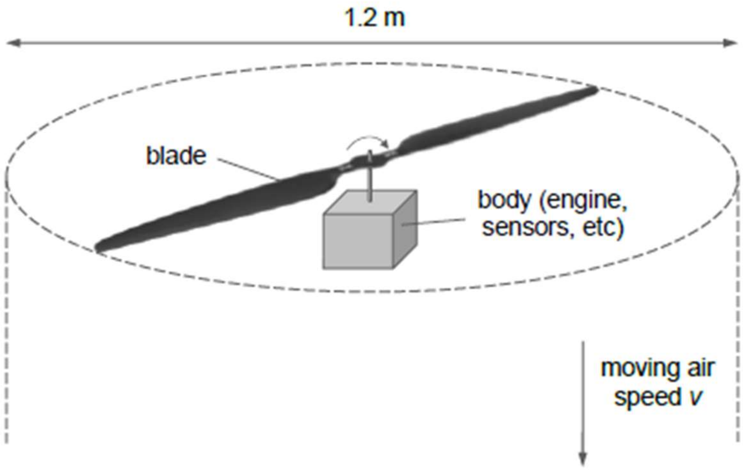

Fig. 3.1

The mass of the model is 1.8 kg.

When the motor is switched on, the air moves with a speed v in a uniform cylinder of diameter 1.2 m.

3

(i) The density of air on Earth is 1.2 kg m^{-3}.
Determine the speed v of the air when the model is hovering at a constant height from the surface of the Earth.

v = ... m s^{-1} [3]

(ii) The density of air on Mars is 0.020 kg m^{-3} and the gravitational field strength near the surface of Mars is 38% that of Earth.

When the model operates on Mars, the same blades will need to rotate at a much higher angular velocity than in **(b)(i)**. The blades are therefore subjected to a larger amount of stress.

Explain why the blades

1. need to rotate at a higher angular velocity,

....

.... [1]

2. experience a larger stress by referring to your answer in **(a)**.

....

....

....

.... [2]

[Total: 9]

4 **(a)** A pendulum with a bob of mass 10 g is suspended from a fixed point O by an inextensible string of length 30 cm. The bob is initially held at point A, at an angle of 25° to the vertical as shown in Fig. 4.1. It is released from rest and swings towards point B, which is vertically below O.

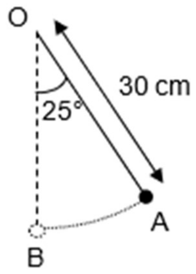

Fig. 4.1

(i) Show that the speed of the mass at point B is 0.74 m s^{-1}.

[2]

(ii) Hence, determine the tension in the string at point B.

tension = ... N [2]

4 **(iii)** A rod is placed above point B such that part of the string remains vertical as the mass swings past B as shown in Fig. 4.2.

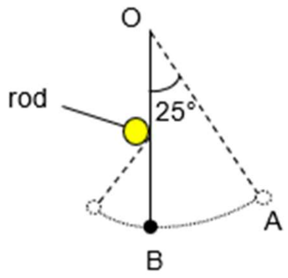

Fig. 4.2

Explain why the tension in the string just after the bob passes point B will be larger than the tension calculated in **(a)(ii)**.

....

....

....

.... [2]

(b) The bob is now set in uniform circular motion in a horizontal plane with the string making an angle θ to the vertical as shown in Fig. 4.3. The tension in the string is 0.20 N.

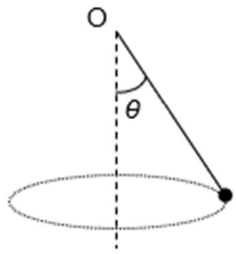

Fig. 4.3

(i) Calculate angle θ.

θ = ... ° [2]

4 **(ii)** Calculate the angular speed of the bob.

angular speed = ... rad s^{-1} [2]

5

In the design of space stations, one way to let the astronauts inside stand upright as if they are on Earth would be to spin a ring about an axis through its centre, as shown in **Fig. 2.1**.

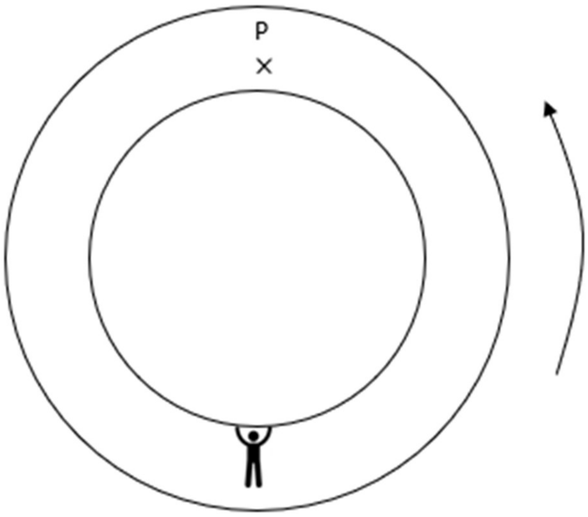

Fig. 2.1

An astronaut inside the station, who was initially floating weightlessly, grabs hold of the "ceiling" when the space station first starts to spin gradually from rest, as shown in **Fig. 2.1**. Assume that the space station is far away from any massive celestial bodies.

(a) Draw an arrow in **Fig. 2.1** to show the direction of the force that the astronaut experiences as the space station is *accelerating* to its final rotational speed. [1]

(b) Explain your answer to **(a)**.

....

....

....

.... [2]

After the station has reached a constant angular speed, the astronaut, who is at point P in **Fig. 2.1**, releases his hold on the "ceiling".

(c) On **Fig. 2.1**, draw the trajectory that the astronaut will follow at the instant he releases his hold at point P. [1]

5 The astronaut is now able to stand upright like on Earth (see **Fig. 2.3**). However, he feels that his weight is different from that on Earth. He proceeds to perform an experiment in which he swings a bob attached to a light inextensible string so that it performs uniform circular motion in a plane that appears horizontal to him (see **Fig. 2.2**).

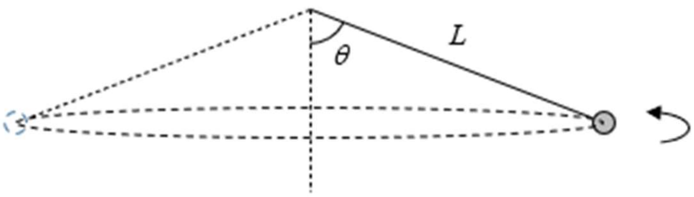

Fig. 2.2

The length L of the string is 95.8 cm and the period of the circular motion is 1.185 s. The angle θ between the string and the vertical is 65.2°.

The rotational motion of the station causes the astronaut to undergo an acceleration g towards the rotational axis of the station. This acceleration gives him the impression that he is experiencing weight.

(d) Determine the acceleration g experienced by the astronaut due to the station's rotation.

g = ... m s^{-2} [4]

5 By looking at the stars outside of the space station as it spins, the astronaut measures the period of rotation of the station to be 14.2 s.

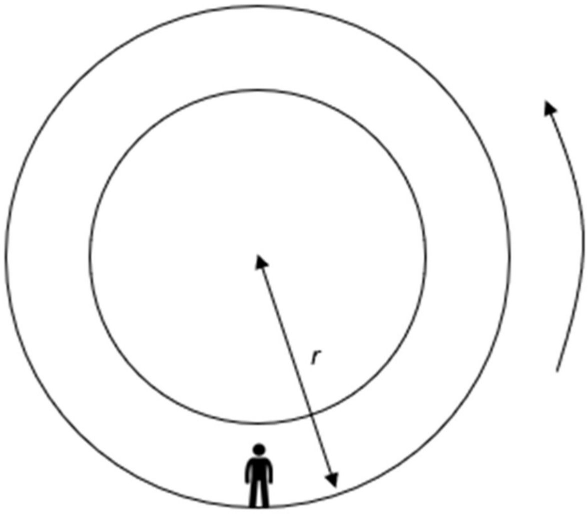

Fig. 2.3

(e) Determine the distance r between the axis of rotation of the station and the "floor" on which the astronaut stands, as shown in **Fig. 2.3**.

r = ……………….. m [2]