12. Motion in a Circle

12.2 Centripetal acceleration

Paper 4

Question Paper

1 **(b)** A circular metal disc spins horizontally about a vertical axis, as shown in Fig. 1.1.

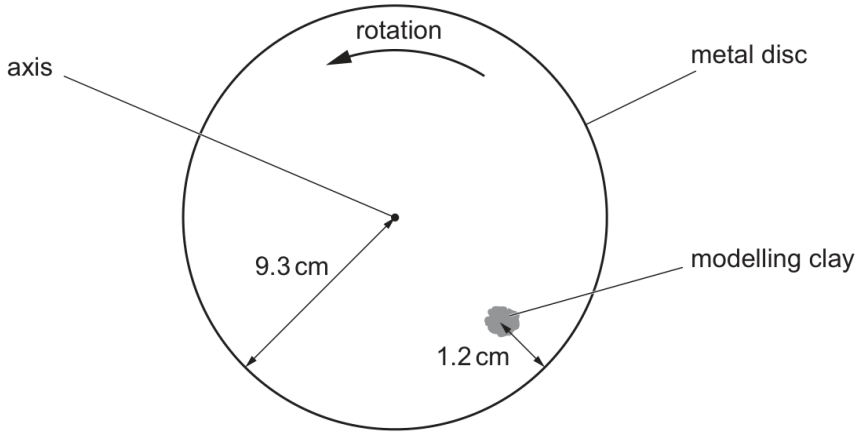


Fig. 1.1 (not to scale)

A piece of modelling clay is attached to the disc.

For the instant when the piece of modelling clay is in the position shown, draw on Fig. 1.1:

(ii) an arrow, labelled A, showing the direction of the acceleration of the modelling clay. [1]

(c) The metal disc in Fig. 1.1 has a radius of 9.3 cm.
The centre of gravity of the modelling clay is 1.2 cm from the rim of the disc and moves with a speed of 0.68 m s^{-1}.

(ii) Calculate the acceleration *a* of the centre of gravity of the modelling clay.

a = ... m s^{-2} [2]

2 A metal wheel consists of an axle A, eight spokes and a rim, as shown in Fig. 1.1.

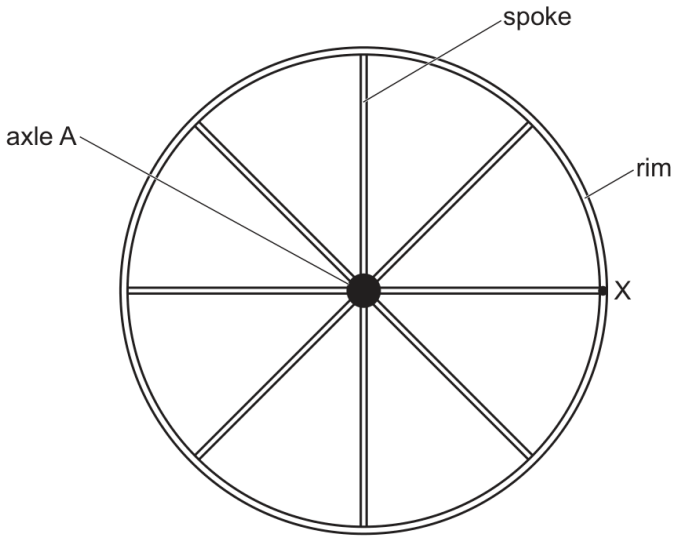


Fig. 1.1

Point X is on the rim at the end of one of the spokes.

The rim has a radius of 0.85 m.
The wheel is rotating clockwise with an angular speed of 140 rad s^{-1}.

(a) For point X, determine:

(ii) the centripetal acceleration.

acceleration = ... $m\,s^{-2}$ [2]

3 A steel sphere of mass 0.29 kg is suspended in equilibrium from a vertical spring. The centre of the sphere is 8.5 cm from the top of the spring, as shown in Fig. 2.1.

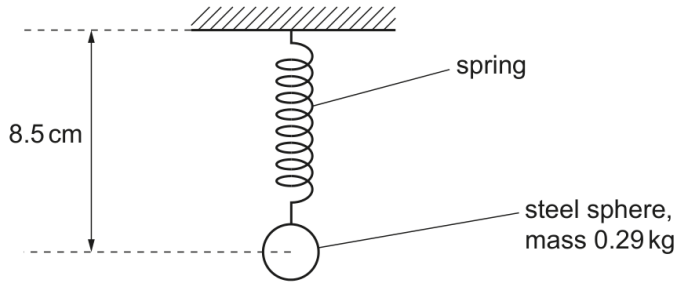


Fig. 2.1

The sphere is now set in motion so that it is moving in a horizontal circle at constant speed, as shown in Fig. 2.2.

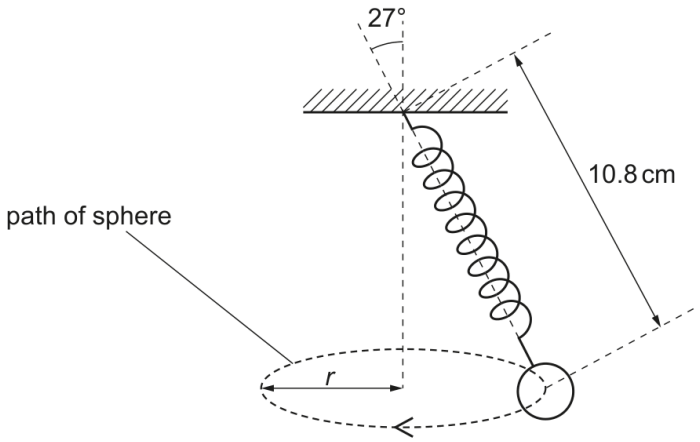


Fig. 2.2

The distance from the centre of the sphere to the top of the spring is now 10.8 cm.

(a) Explain, with reference to the forces acting on the sphere, why the length of the spring in Fig. 2.2 is greater than in Fig. 2.1.

.....

.....

.....

.....

..... [3]

(b) The angle between the linear axis of the spring and the vertical is 27°.

(i) Show that the radius r of the circle is 4.9 cm.

[1]

(ii) Show that the tension in the spring is 3.2 N.

[2]

(iii) The spring obeys Hooke's law.

Calculate the spring constant, in $N\,cm^{-1}$, of the spring.

spring constant = ... $N\,cm^{-1}$ [2]

(c) **(i)** Use the information in **(b)** to determine the centripetal acceleration of the sphere.

centripetal acceleration = ... $m\,s^{-2}$ [2]

(ii) Calculate the period of the circular motion of the sphere.

period = ... s [2]

4 **(b)** The minute hand of a clock revolves at constant angular speed around the face of the clock, completing one revolution every hour. A small piece of modelling clay is attached to the hand with its centre of gravity at a distance *L* from the fixed end of the hand, as shown in Fig. 1.1.

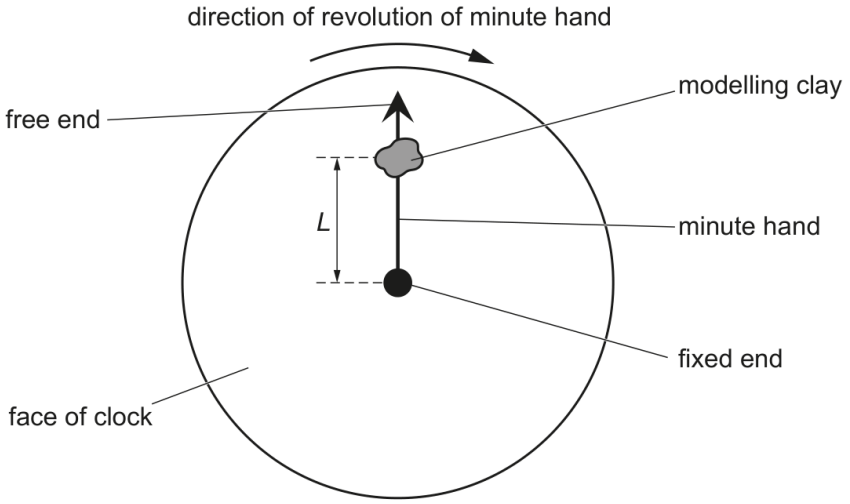


Fig. 1.1

(c) During a time interval of 1400 s, the centre of gravity of the piece of modelling clay in Fig. 1.1 moves through a total distance of 0.44 m.

(iii) Calculate the magnitude of the centripetal acceleration of the piece of modelling clay.

centripetal acceleration = ... $m\,s^{-2}$ [2]

(d) Use your answer in **(c)(iii)** to explain why the variation with time of the magnitude of the force exerted by the minute hand on the piece of modelling clay is negligible as the minute hand undergoes one full revolution.

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..... [2]

5 **(b)** Positronium is a system in which an electron and a positron orbit, with the same period, around their common centre of mass, as shown in Fig. 2.1.

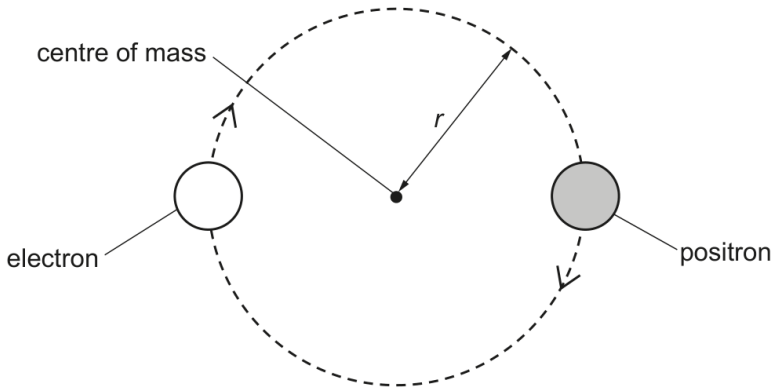


Fig. 2.1 (not to scale)

The radius r of the orbit of both particles is 1.59×10^{-10} m.

(i) Explain how the electric force between the electron and the positron causes the path of the moving particles to be circular.

.....

.....

..... [2]

(iii) Use the information in **(b)(ii)** to determine the period of the circular orbit of the two particles.

period = ... s [3]

6 **(c)** An object rests on the surface of the Earth at the Equator.
The radius of the Earth is 6.4×10^6 m.

(i) Determine the centripetal acceleration of the object.

centripetal acceleration = ... $m\,s^{-2}$ [3]

(ii) Describe how the two forces acting on the object give rise to this centripetal acceleration.
You may draw a diagram if you wish.

.....

.....

..... [2]

7 **(b)** An isolated planet is a uniform sphere of radius 3.39×10^6 m. Its mass of 6.42×10^{23} kg may be considered to be a point mass concentrated at its centre. The planet rotates about its axis with a period of 24.6 hours.

For an object resting on the surface of the planet at the equator, calculate, to three significant figures:

(ii) the centripetal acceleration

acceleration = ... $m\,s^{-2}$ [2]

8 **(a)** With reference to velocity and acceleration, describe uniform circular motion.

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..... [2]

(b) Two cars are moving around a horizontal circular track. One car follows path X and the other follows path Y, as shown in Fig. 1.1.

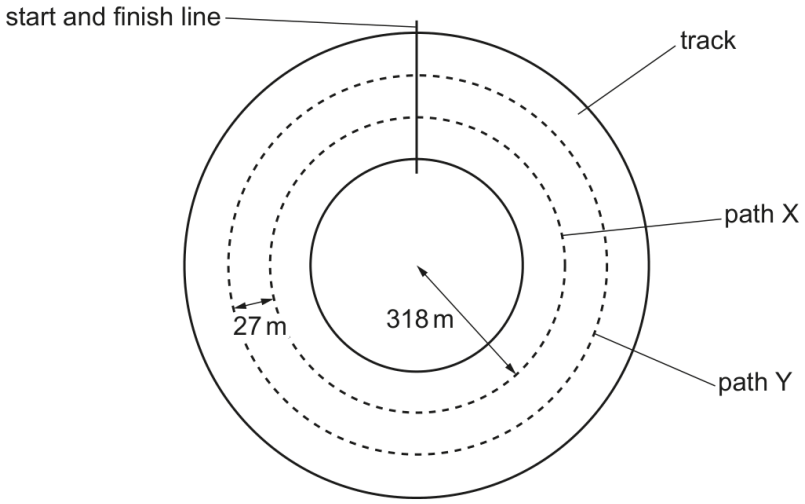


Fig. 1.1 (not to scale)

The radius of path X is 318 m. Path Y is parallel to, and 27 m outside, path X. Both cars have mass 790 kg. The maximum lateral (sideways) friction force F that the cars can experience without sliding is the same for both cars.

(i) The maximum speed at which the car on path X can move around the track without sliding is 94 m s^{-1}.

Calculate F.

F = ... N [2]

(ii) Both cars move around the track. Each car has the maximum speed at which it can move without sliding.

Complete Table 1.1, by placing one tick in each row, to indicate how the quantities indicated for the car on path Y compare with the car on path X.

Table 1.1

	Y less than X	Y same as X	Y greater than X
centripetal acceleration			
maximum speed			
time taken for one lap of the track			

[3]

9 **(a)** State what is meant by *centripetal* acceleration.

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.....

..... [1]

(b) An unpowered toy car moves freely along a smooth track that is initially horizontal. The track contains a vertical circular loop around which the car travels, as shown in Fig. 1.1.

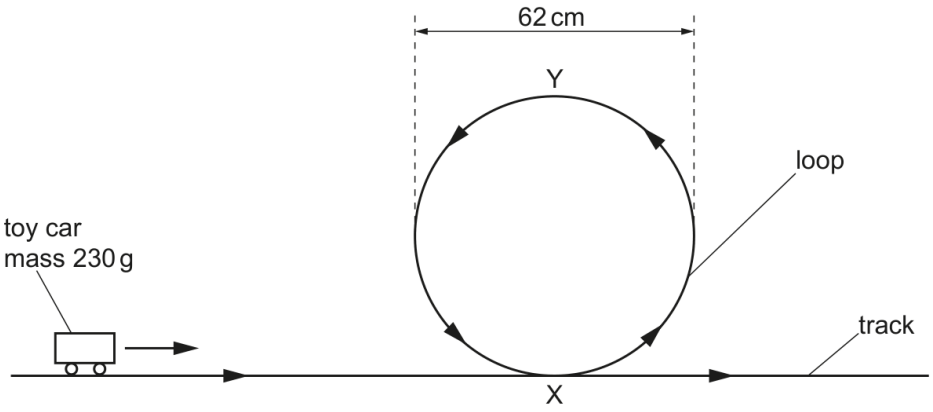


Fig. 1.1

The mass of the car is 230 g and the diameter of the loop is 62 cm. Assume that the resistive forces acting on the car are negligible.

(i) State what happens to the magnitude of the centripetal acceleration of the car as it moves around the loop from X to Y.

..... [1]

(ii) Explain, if the car remains in contact with the track, why the centripetal acceleration of the car at point Y must be greater than 9.8 m s^{-2}.

.....

.....

..... [2]

(c) The initial speed at which the car in **(b)** moves along the track is $3.8\,m\,s^{-1}$.

Determine whether the car is in contact with the track at point Y. Show your working.

[3]

(d) Suggest, with a reason but without calculation, whether your conclusion in **(c)** would be different for a car of mass 460 g moving with the same initial speed.

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..... [1]

10 **(c)** The stars S_1 and S_2 rotate with the same angular velocity ω about a point P, as illustrated in Fig. 1.2.

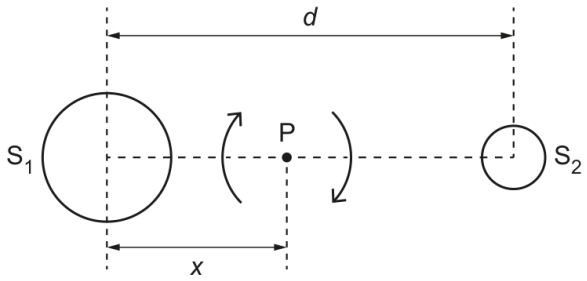


Fig. 1.2 (not to scale)

Point P is at a distance x from the centre of star S_1.
The period of rotation of the stars is 44.2 years.

(ii) By considering the forces acting on the two stars, show that the ratio of the masses of the stars is given by

$$\frac{\text{mass of } S_1}{\text{mass of } S_2} = \frac{d - x}{x}.$$

[2]

11 **(b)** A distant star is orbited by several planets. Each planet has a circular orbit with a different radius.

(i) Each planet orbits at constant speed.
Explain whether the planets are in equilibrium.

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.....[1]