A2 Level Physics

Chapter 13 – Circular Motion

13.2.2 Centripetal Force

Worked Examples

Centripetal Force

Exam Style Question 1

(a) (i) State Newton's first law of motion.

(ii) Define the newton.

(b) A jet plane on the deck of an aircraft carrier is accelerated before take-off using a catapult. The mass of the plane is $3.2 \times 10^4\ kg$ and it is accelerated from rest to a velocity of $55\ m\ s^{-1}$ in a time of $2.2\ s$. Calculate

(i) the mean acceleration of the plane

(ii) the distance over which the acceleration takes place

(iii) the mean force producing the acceleration.

(c) The jet plane describes a horizontal circle of radius $870\ m$ flying at a constant speed of $120\ m\ s^{-1}$.

(i) State the direction of the resultant horizontal force acting on the plane.

(ii) Calculate the magnitude of this horizontal force.

(d) By changing the velocity of the plane it can be made to fly in a vertical circle of radius $1500\ m$. At a particular point in the vertical circle, the contact force between the pilot and his seat may be zero and the pilot experiences "weightlessness".

(i) State and explain at what point in the circle this weightlessness may occur.

(ii) Calculate the speed of the plane at which weightlessness occurs.

Centripetal Force

Exam Style Question 1

(a)(i) State Newton's first law of motion.
A body will remain at rest or continue to move with constant velocity unless acted upon by a force.

(ii) Define the newton.
The force which gives a mass of $1\ kg$ an acceleration of $1\ m\ s^{-2}$.

(b) Calculate
(i) the mean acceleration of the plane
Use $v = u + at$ and rearrange it for a

$$a = \frac{v - u}{t} = \frac{(55\ m\ s^{-1} - 0\ m\ s^{-1})}{2.2\ s}$$
$$a = 25\ m\ s^{-2}$$

(ii) the distance over which the acceleration takes place
Use $s = ut + \frac{1}{2}at^2$

$$s = (0)(2.2\ s) + \frac{1}{2}(25\ m\ s^{-2})(2.2\ s)^2$$
$$s = 60.5\ m$$

(iii) the mean force producing the acceleration.
Use $F = ma$

$$F = (3.2 \times 10^4\ kg)(25\ m\ s^{-2})$$
$$F = 8 \times 10^5\ N$$

(c) (i) State the direction of the resultant horizontal force acting on the plane.
Towards the centre of the circle.

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Centripetal Force

Exam Style Question 1

(a) (i) State Newton's first law of motion.

(ii) Define the newton.

(b) A jet plane on the deck of an aircraft carrier is accelerated before take-off using a catapult. The mass of the plane is $3.2 \times 10^4\ kg$ and it is accelerated from rest to a velocity of $55\ m\ s^{-1}$ in a time of $2.2\ s$. Calculate

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(i) State the direction of the resultant horizontal force acting on the plane.

(ii) Calculate the magnitude of this horizontal force.

(d) By changing the velocity of the plane it can be made to fly in a vertical circle of radius $1500\ m$. At a particular point in the vertical circle, the contact force between the pilot and his seat may be zero and the pilot experiences "weightlessness".

(i) State and explain at what point in the circle this weightlessness may occur.

(ii) Calculate the speed of the plane at which weightlessness occurs.

Centripetal Force

Exam Style Question 1

(c) (ii) Calculate the magnitude of this horizontal force.

Use $F = \frac{mv^2}{r}$

$$F = \frac{(3.2 \times 10^4\ kg)(120\ m\ s^{-1})^2}{(870\ m)}$$

$$F = 5.3 \times 10^5\ N$$

(d) (i) State and explain at what point in the circle this weightlessness may occur.

At the top of the circle when the weight provides the required centripetal force.

(d) (ii) Calculate the speed of the plane at which weightlessness occurs.

Use $a = \frac{v^2}{r}$ but remember when weightlessness occurs $a = g$ therefore: $g = \frac{v^2}{r}$ and rearrange for v:

$$v = \sqrt{gr} = \sqrt{(9.81\ m\ s^{-2})(1500\ m)}$$

$$v = 121.3\ m\ s^{-1}$$

Centripetal Force

Exam Style Question 2

(a) The Earth rotates about its axis. Show that its angular speed is approximately $7 \times 10^{-5}\ rad\ s^{-1}$.

(b) A stone is resting on the ground at a point on the equator.

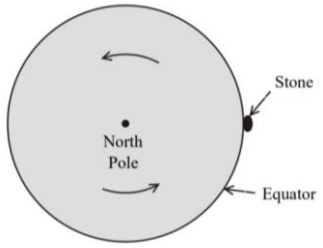

Figure 1

(i) The radius of the Earth is $6400\ km$. Calculate the acceleration of the stone as it follows its circular path.

(ii) Draw an arrow on Figure 1 to show the direction of the stone's acceleration.

(iii) In the space below, draw a labelled free-body force diagram for the stone when it is at the point shown in Figure 1.

(iv) With reference to your free-body force diagram, explain how the stone's acceleration is produced.

Centripetal Force

Exam Style Question 2

(a)Show that its angular speed is approximately $7 \times 10^{-5}\ rad\ s^{-1}$.

Use $\omega = \frac{2\pi}{T}$

Remember the time the Earth takes to rotate about its axis is 24 hours therefore:

$$\omega = \frac{2\pi}{(24\ h \times 3600)} = 7.27 \times 10^{5}\ rad\ s^{-1}$$

(b) (i) The radius of the Earth is $6400\ km$. Calculate the acceleration of the stone as it follows its circular path.

Use $a = r\omega^2$

$$a = (6400 \times 10^{3}\ m)(7.27 \times 10^{5}\ rad\ s^{-1})$$

$$a = 0.034\ m\ s^{-2}$$

(b) (ii) Draw an arrow on Figure 1 to show the direction of the stone's acceleration.

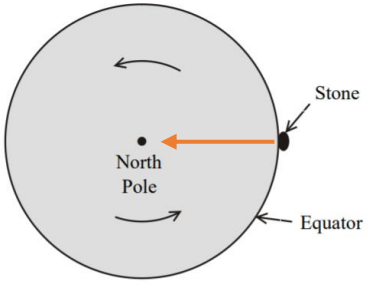

Figure 1

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Centripetal Force

Exam Style Question 2

(a) The Earth rotates about its axis. Show that its angular speed is approximately $7 \times 10^{-5}\ rad\ s^{-1}$.

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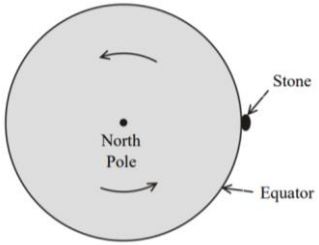

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(iv) With reference to your free-body force diagram, explain how the stone's acceleration is produced.

Centripetal Force

Exam Style Question 2

(b) (iii) In the space below, draw a labelled free-body force diagram for the stone when it is at the point shown in Figure 1.

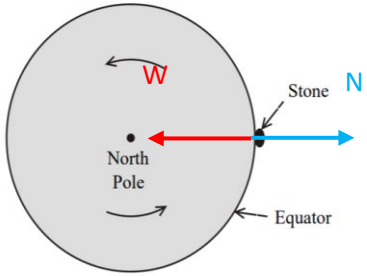

Figure 1

(b) (iv) With reference to your free-body force diagram, explain how the stone's acceleration is produced.

N is less than W therefore resultant force towards the centre which produces the acceleration.

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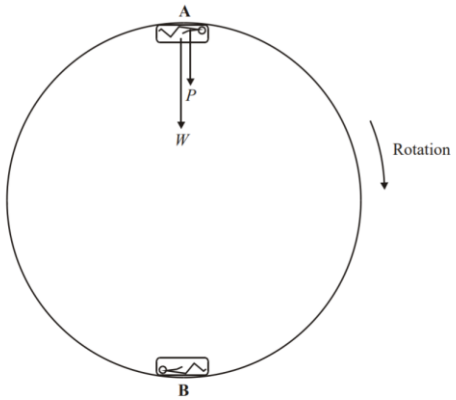
Centripetal Force

Exam Style Question 3

Riders on a theme park ride lie back in capsules round the rim of a large wheel. Initially the wheel is horizontal but it then moves into a vertical plane in which it rotates. The diagram shows the wheel when it is rotating in a vertical plane.



(a) State the direction of the centripetal acceleration of the rider at A.

(b) Explain why the resultant force on the rider at A has to be in this same direction.

(c) The radius of the wheel is $8.0\ m$ and the time for $1\ revolution$ at maximum speed is $4.5\ s$. Show that at this speed the resultant force acting on a rider of mass $60\ kg$ is about $900\ N$.

(d) Calculate the weight W of the rider.

(e) Calculate P, the magnitude of the push from the capsule on the rider, when he is at point A.

(f) Draw labelled arrows on the diagram to show the two principal forces acting on the rider when he is at point B.

Centripetal Force

Exam Style Question 3

(a) State the direction of the centripetal acceleration of the rider at A.

Towards the centre.

(b) Explain why the resultant force on the rider at A has to be in this same direction.

$$F = ma$$

Therefore acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force and so a and F are in the same direction.

(c) The radius of the wheel is $8.0\ m$ and the time for $1\ revolution$ at maximum speed is $4.5\ s$. Show that at this speed the resultant force acting on a rider of mass $60\ kg$ is about $900\ N$.

We need to use $F = \frac{mv^2}{r}$ but we don't have v so:

$$v = \frac{2\pi r}{T} = \frac{2\pi \times 8}{4.5\ s} = 11.170\ldots\ m\ s^{-1}$$

Now use:

$$F = \frac{mv^2}{r} = \frac{(60\ kg)(11.170\ldots\ m\ s^{-1})^2}{8\ m} = 935.78\ldots\ N$$

$$\therefore F = 936\ N$$

(d) Calculate the weight W of the rider.

Use $W = mg$

$$W = (60\ kg)(9.81\ m\ s^{-2})$$

$$W = 589\ N$$

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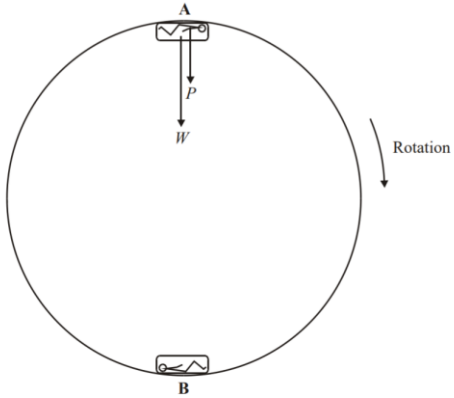
Centripetal Force

Exam Style Question 3

Riders on a theme park ride lie back in capsules round the rim of a large wheel. Initially the wheel is horizontal but it then moves into a vertical plane in which it rotates. The diagram shows the wheel when it is rotating in a vertical plane.



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(e) Calculate P, the magnitude of the push from the capsule on the rider, when he is at point A.

(f) Draw labelled arrows on the diagram to show the two principal forces acting on the rider when he is at point B.

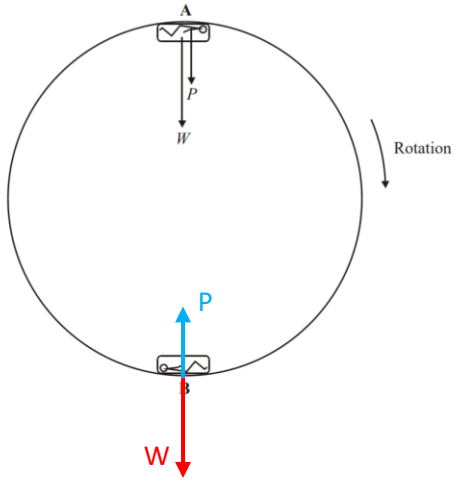
Centripetal Force

Exam Style Question 3

(e) Calculate P, the magnitude of the push from the capsule on the rider, when he is at point A.

$$F_{net} = W + P$$
$$P = F - W = 936\ N - 589\ N$$
$$P = 347\ N$$

(f) Draw labelled arrows on the diagram to show the two principal forces acting on the rider when he is at point B.



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Please see '13.2.1 Centripetal Force notes' pack for exam style questions.

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