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.

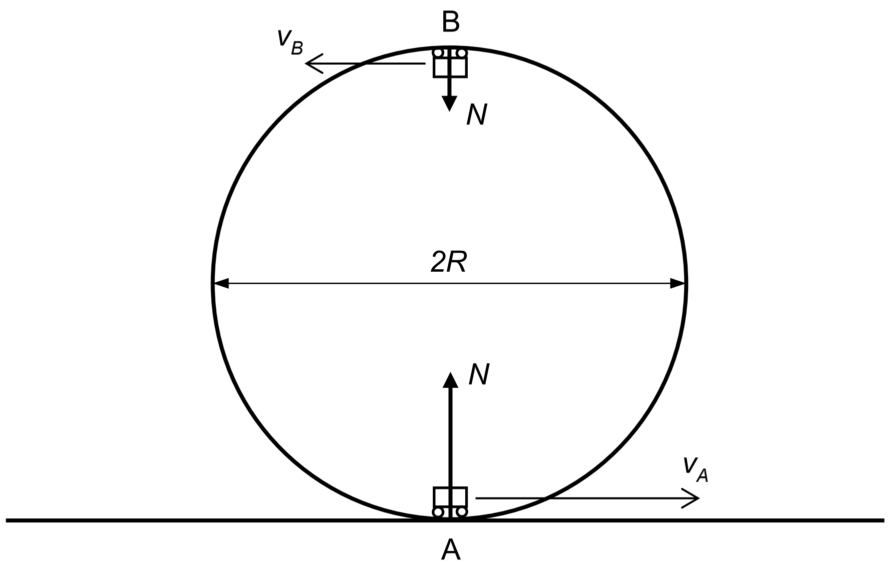

Fig. 2.1

(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]

(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 that is acting on him. A quantity known as the g-force compares N with his weight as follows:

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

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

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

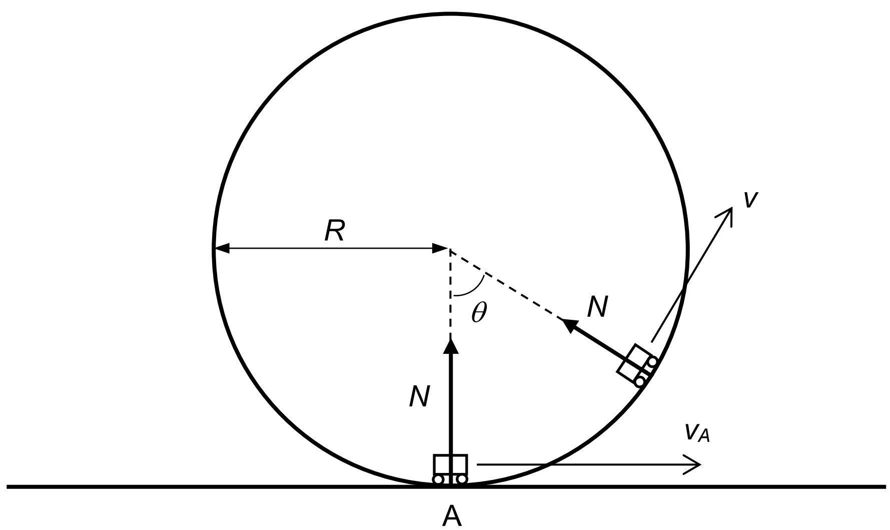

Fig. 2.2

(i) In order for the carriage to just reach the top of the loop ($\theta = 180°$), the g-force at A ($\theta = 0°$) 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'.

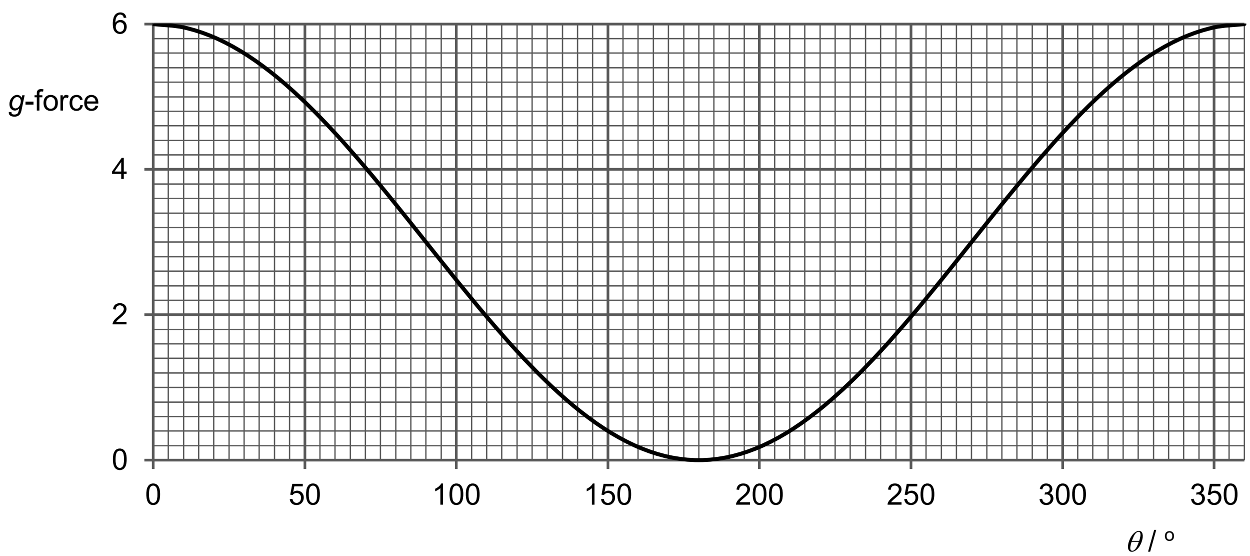

Fig. 2.3

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]

(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.

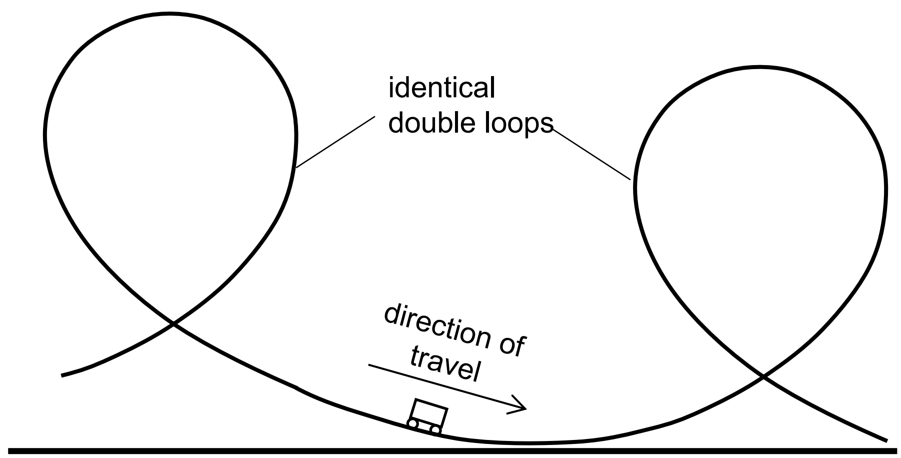

Fig. 2.5

(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]