

**Question 5** (5 marks)

Navigation in vehicles or on mobile phones uses a network of global positioning system (GPS) satellites. The GPS consists of 31 satellites that orbit Earth.

In December 2018, one satellite of mass 2270 kg, from the GPS Block IIIA series, was launched into a circular orbit at an altitude of 20 000 km above Earth's surface.

- a. Identify the type(s) of force(s) acting on the satellite and the direction(s) in which the force(s) must act to keep the satellite orbiting Earth.

2 marks

Gravity towards the centre of the Earth.

38%

- b. Calculate the period of the satellite to three significant figures. You may use data from the table below in your calculations. Show your working.

3 marks

**Data**

33%

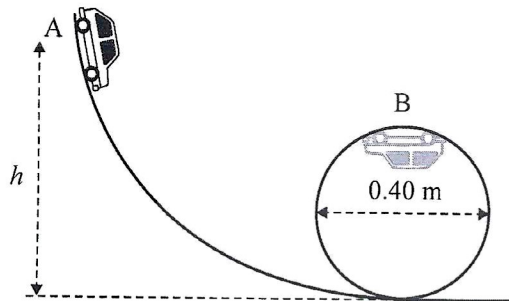
mass of satellite	$2.27 \times 10^3 \text{ kg}$
mass of Earth	$5.98 \times 10^{24} \text{ kg}$
radius of Earth	$6.37 \times 10^6 \text{ m}$
altitude of satellite above Earth's surface	$2.00 \times 10^7 \text{ m}$
gravitational constant	$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$

$$T = \sqrt{\frac{4\pi^2 R^3}{GM}} = \sqrt{\frac{4\pi^2 \times (2 \times 10^7 + 6.37 \times 10^6)^3}{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}}$$

$4.26 \times 10^4 \text{ s}$

**Question 8** (9 marks)

A 250 g toy car performs a loop in the apparatus shown in Figure 8.

**Figure 8**

The car starts from rest at point A and travels along the track without any air resistance or retarding frictional forces. The radius of the car's path in the loop is 0.20 m. When the car reaches point B it is travelling at a speed of  $3.0 \text{ m s}^{-1}$ .

- a. Calculate the value of  $h$ . Show your working.

3 marks

$$mgh_A = mgh_B + \frac{1}{2} mV^2$$

46%

$$0.25 \times 9.8 h_A = 0.25 \times 9.8 \times 0.4 + \frac{1}{2} \times 3^2$$

8.6	m
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- b. Calculate the magnitude of the normal reaction force on the car by the track when it is at point B. Show your working.

3 marks

$$N + mg = \frac{mV^2}{r} \quad N = \frac{mV^2}{r} - mg$$

48%

$$N = \frac{0.25 \times 3^2}{0.2} - 0.25 \times 9.8$$

8.8	N
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- c. Explain why the car does not fall from the track at point B, when it is upside down.

3 marks

Car stays on track when it is pushing on the track so due to 3rd Newtons Law  $N > 0$ .  
 In this case  $\frac{mv^2}{r} > mg$ , so  $N > 0$  6%

$$a = \frac{v^2}{r} = 15 \text{ m s}^{-2} > g (2 \text{ m})$$

$$\text{Minimum speed when } mg = \frac{mv^2}{r} \quad v = 1.4 \text{ m s}^{-1}$$

As  $v = 3 > 1.4 \text{ m s}^{-1}$  car stay on the track.

**Question 9** (3 marks) *46%*

A proton in an accelerator detector collides head-on with a stationary alpha particle, as shown in Figure 9a and Figure 9b. After the collision, the alpha particle travels at a speed of  $4.0 \times 10^6 \text{ m s}^{-1}$ . The proton rebounds at  $6.0 \times 10^6 \text{ m s}^{-1}$ .

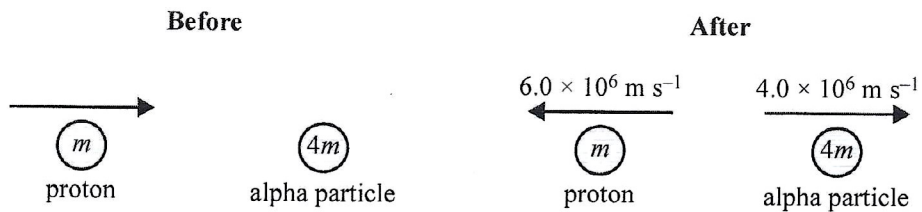


Figure 9a

Figure 9b

Find the speed of the proton before the collision, modelling the mass of the alpha particle,  $4m$ , to be equal to four times the mass of the proton,  $m$ . Show your working. Ignore relativistic effects.

$$p_0 = m u, \text{ ~~initial~~}$$

$$p = 4m \times 4 \times 10^6 - m \times 6 \times 10^6 = 10 \times 10^6 m$$

$$p = p_0$$

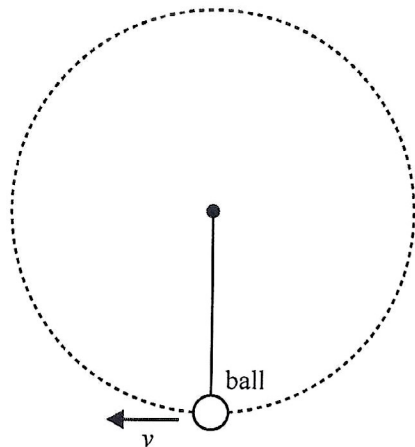
$$m u = 10 \times 10^6 m$$

$$u = 1 \times 10^7$$

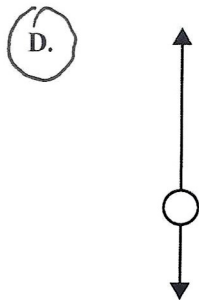
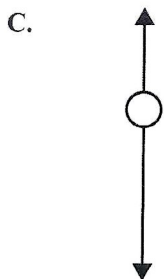
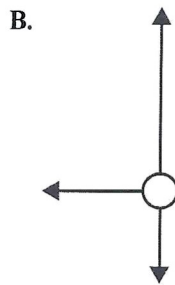
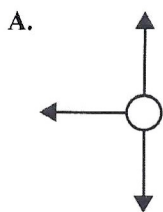
$$1 \times 10^7 \text{ m s}^{-1}$$

## Question 8 56%

A ball is attached to the end of a string and rotated in a circle at a constant speed in a vertical plane, as shown in the diagram below.



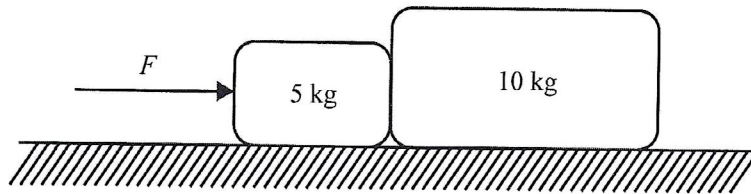
The arrows in options A. to D. below indicate the direction and the size of the forces acting on the ball. Ignoring air resistance, which one of the following best represents the forces acting on the ball when it is at the bottom of the circular path and moving to the left?



There are only 2 forces acting - tension and gravity and as ~~the~~ ball going in a circle net force towards the center so  $T > mg$

Use the following information to answer Questions 9 and 10.

Two blocks of mass 5 kg and 10 kg are placed in contact on a frictionless horizontal surface, as shown in the diagram below. A constant horizontal force,  $F$ , is applied to the 5 kg block.



Acceleration same  $F_{net} = ma$

Mass smaller  $\rightarrow$  force smaller

Question 9 49%.

Which one of the following statements is correct?

- A. The net force on each block is the same.
- B. The acceleration experienced by the 5 kg block is twice the acceleration experienced by the 10 kg block.
- C. The magnitude of the net force on the 5 kg block is half the magnitude of the net force on the 10 kg block.
- D. The magnitude of the net force on the 5 kg block is twice the magnitude of the net force on the 10 kg block.

Question 10 80%.

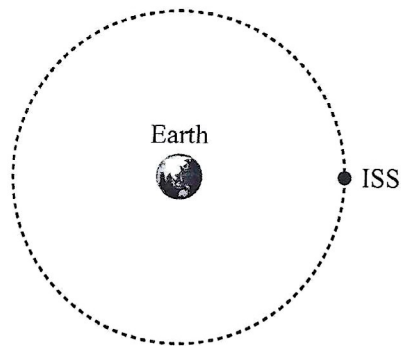
If the force  $F$  has a magnitude of 250 N, what is the work done by the force in moving the blocks in a straight line for a distance of 20 m?

- A. 5 kJ
- B. 25 kJ
- C. 50 kJ
- D. 500 kJ

$$W = FS = 250 \times 20 = 5000 \text{ J}$$

## Question 11 31%

The International Space Station (ISS) is travelling around Earth in a stable circular orbit, as shown in the diagram below.



Which one of the following statements concerning the momentum and the kinetic energy of the ISS is correct?

- A. Both the momentum and the kinetic energy vary along the orbital path.
- B. Both the momentum and the kinetic energy are constant along the orbital path.
- C. The momentum is constant, but the kinetic energy changes throughout the orbital path.
- D. The momentum changes, but the kinetic energy remains constant throughout the orbital path.

Speed constant (as orbit stable circular) so  $E_k$  - constant. Direction of the velocity changes so momentum changes.

**Question 4** (10 marks)

The Ionospheric Connection Explorer (ICON) space weather satellite, constructed to study Earth's ionosphere, was launched in October 2019. ICON will study the link between space weather and Earth's weather at its orbital altitude of 600 km above Earth's surface. Assume that ICON's orbit is a circular orbit. Use  $R_E = 6.37 \times 10^6$  m.

- a. Calculate the orbital radius of the ICON satellite.

1 mark

$$6.37 \times 10^6 + 6 \times 10^5$$

76%

$$6.97 \times 10^6 \text{ m}$$

- b. Calculate the orbital period of the ICON satellite correct to three significant figures. Show your working.

4 marks

$$T = \sqrt{\frac{4\pi^2 R^3}{GM}} = \sqrt{\frac{4\pi^2 \times (6.97 \times 10^6)^3}{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}}$$

38%

$$T = 5.79 \times 10^3$$

$$5.79 \times 10^3 \text{ s}$$

- c. Explain how the ICON satellite maintains a stable circular orbit without the use of propulsion engines. 2 marks

There is only one force acting - gravitational force towards Earth. This force is constant in magnitude and perpendicular to the velocity which results in a stable circular orbit.



- d. Figure 3 shows the strength of Earth's gravitational field,  $g$ , as a function of orbital altitude,  $h$ , above the surface of Earth.

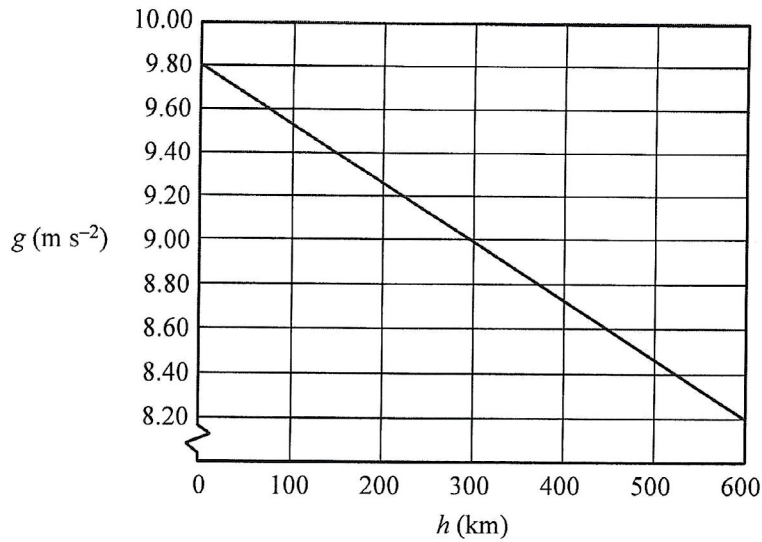


Figure 3

Determine the change in gravitational potential energy of the ICON satellite as it travels from Earth's surface to its orbital altitude of 600 km above Earth's surface. The mass of the ICON satellite is 288 kg.

3 marks

$$\Delta E_{gp} = \text{Area under the graph} \times \text{mass} \quad 21\%$$

$$\text{Area} = \frac{9.8 + 8.2}{2} \times 6 \times 10^5 = 5.4 \times 10^6$$

$$\Delta E_{gp} = 5.4 \times 10^6 \times 288$$

$$1.56 \times 10^9 \text{ J}$$

**Question 8** (6 marks)

Figure 8 shows a small ball of mass 1.8 kg travelling in a horizontal circular path at a constant speed while suspended from the ceiling by a 0.75 m long string.

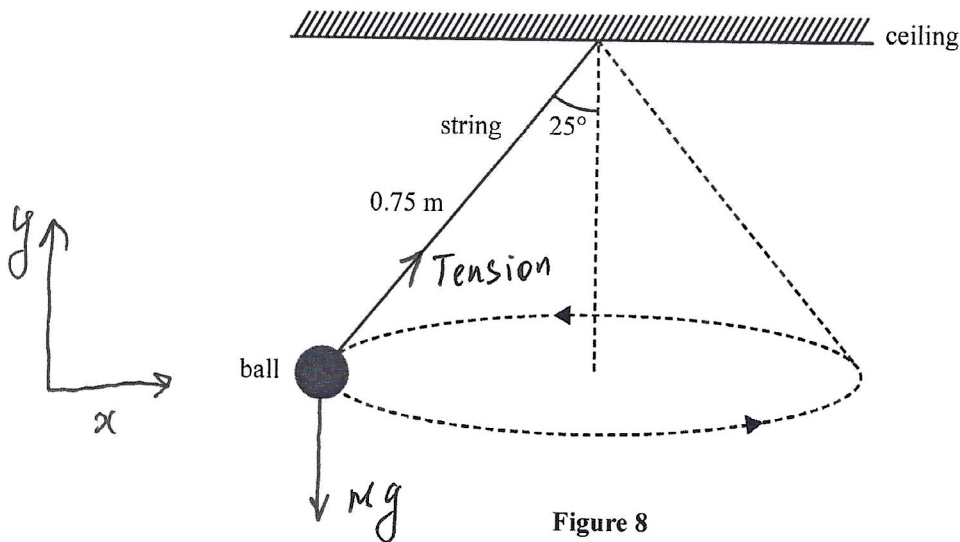


Figure 8

- a. Use labelled arrows to indicate on Figure 8 the two physical forces acting on the ball.

*See picture above*

54%

2 marks

- b. Calculate the speed of the ball. Show your working.

4 marks

39%

$$y: T \cos 25^\circ - mg = 0 \quad T \cos 25^\circ = mg$$

$$x: T \sin 25^\circ = \frac{mv^2}{r}$$

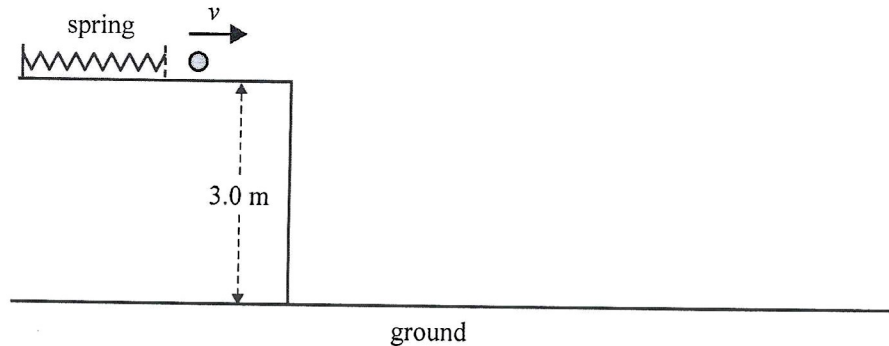
$$\text{Divide } \frac{x}{y}: \tan 25^\circ = \frac{v^2}{gr} \quad r = 0.75 \sin 25^\circ = 0.32 \text{ m}$$

$$v = \sqrt{gr \tan 25^\circ} = \sqrt{9.8 \times 0.32 \tan 25^\circ}$$

$1.2 \text{ m s}^{-1}$

**Question 9** (5 marks)

An ideal spring is compressed by 0.15 m. A ball of mass 0.20 kg is placed in contact with the compressed spring. The spring is then released, causing the ball to move horizontally, with a velocity of  $v$ , across a smooth surface, as shown in Figure 9.

**Figure 9**

- a. If the spring constant is  $1250 \text{ N m}^{-1}$ , show that the magnitude of the initial velocity,  $v$ , of the ball is  $12 \text{ m s}^{-1}$ , correct to two significant figures. Show your working.

2 marks

$$\frac{1}{2} k x^2 = \frac{m v^2}{2}$$

66 %

$$v = \sqrt{\frac{k}{m}} x = \sqrt{\frac{1250}{0.2}} \times 0.15 = 11.86 \text{ m s}^{-1}$$

$$v = 12 \text{ m s}^{-1}$$

- b. Calculate the speed of the ball after it has fallen a vertical distance of 2.5 m. Show your working.

3 marks

Horizontal velocity constant  $v_x = 12 \text{ m s}^{-1}$

43 %

Vertically  $v_y^2 = u^2 + 2gh$   $u = 0$

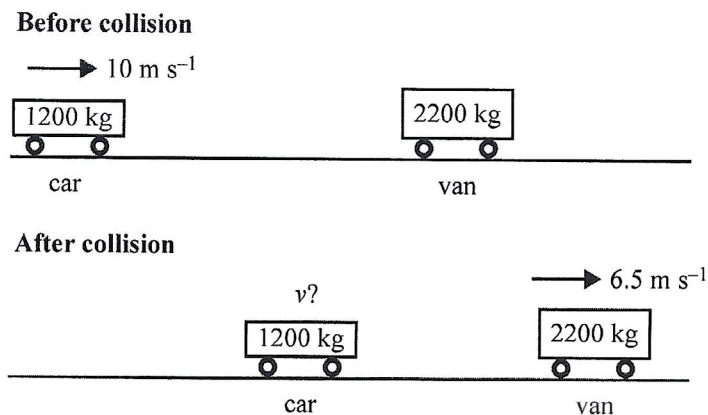
$$v_y = \sqrt{2gh} = \sqrt{2 \times 9.8 \times 2.5} = 7 \text{ m s}^{-1}$$

$$v = \sqrt{v_x^2 + v_y^2} = \sqrt{12^2 + 7^2}$$

14 $\text{m s}^{-1}$
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**Question 10** (12 marks)

Jacinda designs a computer simulation program as part of her practical investigation into the physics of vehicle collisions. She simulates colliding a car of mass 1200 kg, moving at  $10 \text{ m s}^{-1}$ , into a stationary van of mass 2200 kg. After the collision, the van moves to the right at  $6.5 \text{ m s}^{-1}$ . This situation is shown in Figure 10.



**Figure 10**

- a. Calculate the speed of the car after the collision and indicate the direction it would be travelling in. Show your working.

4 marks

$p_0 = 1200 \times 10 = 12000 \text{ N s}$

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$p_f = 1200v + 2200 \times 6.5 = 14300 + 1200v$

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$p_0 = p_f$

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$14300 + 1200v = 12000$

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$v = \frac{-2300}{1200}$

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77%

$1.9 \text{ m s}^{-1}$	Left
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- b. Explain, using appropriate physics, why this collision represents an example of either an elastic or an inelastic collision.

3 marks  
52%

$$E_{K_0} = \frac{1200 \times 10^2}{2} = 6 \times 10^4 \text{ J}$$

$$E_{K_f} = \frac{2200 \times 6.5^2}{2} + \frac{1200 \times 1.9^2}{2} = 4.9 \times 10^4 \text{ J}$$

$E_{K_f} < E_{K_0} \therefore$  collision inelastic

- c. The collision between the car and the van takes 40 ms.

- i. Calculate the magnitude and indicate the direction of the average force on the van by the car.

3 marks  
44%

$$Ft = \Delta p \quad \Delta p = 2200 \times 6.5 = 14300$$

$$F = \frac{\Delta p}{t} = \frac{14300}{0.04}$$

358 kN

To the right

- ii. Calculate the magnitude and indicate the direction of the average force on the car by the van.

2 marks  
55%

According to the 3<sup>rd</sup> Newton's law

358 kN

To the left