2002/2

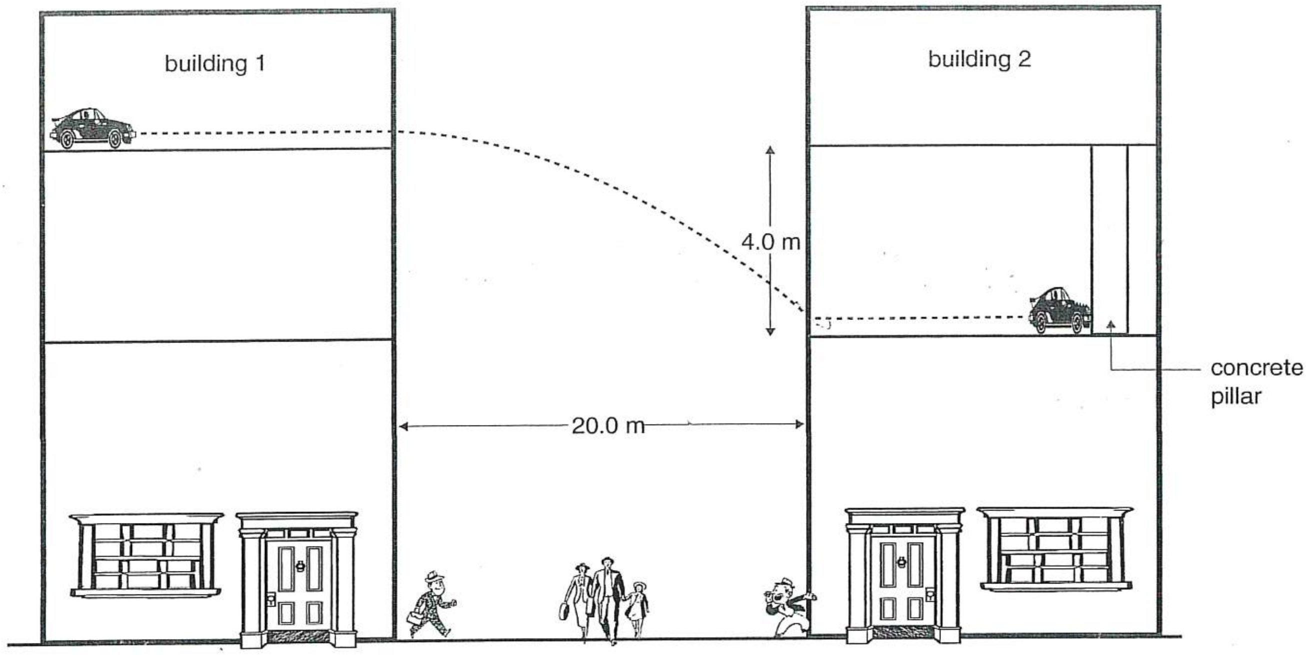


Figure 1

In the movie, *Car Escape*, Taylor and Jones drove their sportscar across a horizontal car park in building 1 and landed it in the car park of building 2, landing one floor lower. Building 2 is 20 metres from building 1, as shown in Figure 1. The floor where the car lands in building 2 is 4.0 m below the floor from which it started in building 1. In Questions 5 and 6, treat the car as a point particle and assume air resistance is negligible.

Question 5 43% Average mark 1.4

Calculate the minimum speed at which the car should leave building 1 in order to land in the car park of building 2.

$x = ut$

$y = 4 - \frac{gt^2}{2}$ $\quad \frac{gt^2}{2} = 4$

$y = 0$ $\quad t = \sqrt{\frac{8}{g}} = 0.9\,s$

$20 = u \times 0.9$

$u = \frac{20}{0.9}$

22 m s^{-1}

3 marks

In order to be sure of landing in the car park of building 2, Taylor and Jones in fact left building 1 at a speed of 25 m s^{-1}.

Question 6

Calculate the magnitude of the **velocity** of the car just prior to landing in the car park of building 2.

$V_x \simeq 25 \text{ m s}^{-1}$

$V_y = gt = 9 \text{ ms}^{-1}$ $\quad V = \sqrt{V_x^2 + V_y^2} = 26.57 \text{ ms}^{-1}$

$t = 0.9 \text{ s}$

26.5 m s^{-1}

2 marks

After landing, Taylor applies the brakes and the car slows down until its speed is 11.0 m s^{-1}. The car then collides head-on with a concrete pillar. The car comes to rest in a time of 0.10 s. The car comes to rest against the pillar. The mass of the car and occupants is 1.30 tonne.

Question 7

Determine the average force on the car during the impact with the pillar.

$\Delta p = 1300 \times 11 - 0 = 14300 \text{ Ns}$

$F \times 0.1 = 14300$

$F = 1.4 \times 10^5 \text{ N}$

1.4×10^5 N

2 marks

Question 8 24%

Explain how the crumple zone of the car can minimise the extent of injuries experienced by the occupants of the car. (Assume that the occupants are wearing seatbelts.)

Crumple zone extends time of the collision.

Change in the momentum is fixed quantity determined by initial velocity.

Increase in time decrease the force on the occupants of the car.

3 marks

AREA 2 – Gravity

The Mars Odyssey spacecraft was launched from Earth on 7 April 2001 and arrived at Mars on 23 October 2001. Figure 1 is a graph of the gravitational force acting on the 700 kg Mars Odyssey spacecraft plotted against height above Earth's surface.

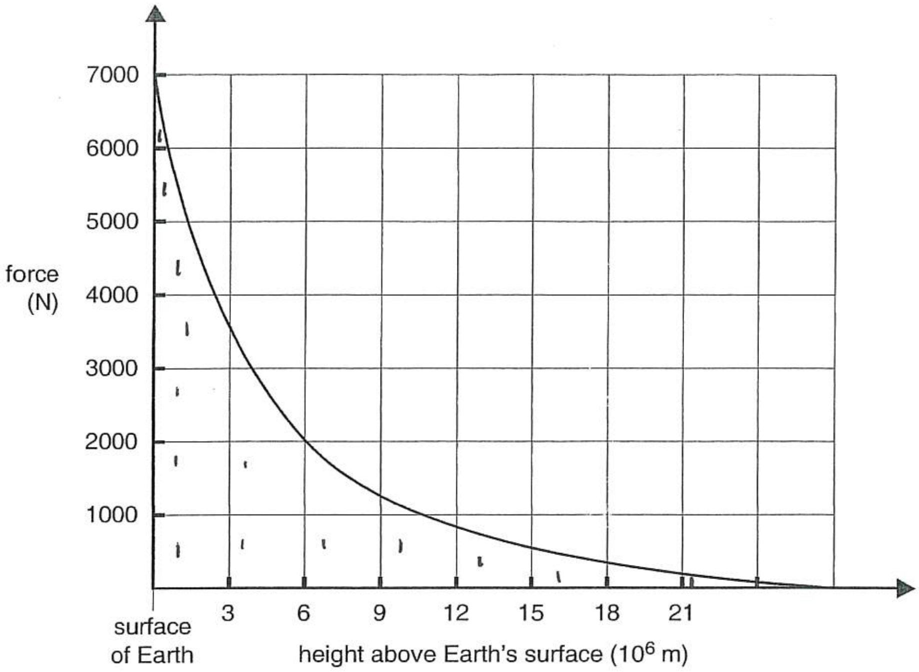


Figure 1

Question 1 42 % Average mark 1.58

Estimate the minimum launch energy needed for Mars Odyssey to escape Earth's gravitational attraction.

1 sq. = 1000 N × 3 × 10^6 m = 3 × 10^9 J

≈ ~~10.25 sq.~~

12 sq

12 × 3 · 10^9

Accepted range 3.3 – 4.4 × 10^{10} J

$\boxed{3.6 \times 10^{10} \text{ J}}$

3 marks

While in deep space, on the way to Mars, Odyssey was travelling at a constant velocity of 23 000 m s^{-1} and the spacecraft and all its contents were weightless.

Question 2 29% Average mark 0.7/

Explain why an object inside the spacecraft could be described as weightless.

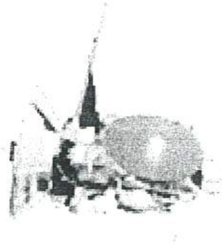
No gravity ($\Sigma \vec{F}_{g} = 0$)

2 marks

CONTINUED OVER PAGE

 2002/2

Currently, the space probe, Cassini, is **between** Jupiter and Saturn (see Figure 2 opposite). Cassini's mission is to deliver a probe to one of Saturn's moons, Titan, and then orbit Saturn collecting data. Below is astronomical data that you may find useful when answering the following questions.



mass of Cassini	2.2×10^3 kg
mass of Jupiter	1.9×10^{27} kg
mass of Saturn	5.7×10^{26} kg
Saturn day	10.7 hours

Question 3 32% Average mark 2.05

Calculate the magnitude of the total gravitational field experienced by Cassini when it is 4.2×10^{11} m from Jupiter and 3.9×10^{11} m from Saturn. g

($G = 6.67 \times 10^{-11}$ N m^2 kg^{-2})

$$\frac{F}{m} = \frac{F_1 - F_2}{m} = G\cancel{m}\left(\frac{M_J}{r_J^2} - \frac{M_S}{r_S^2}\right)$$

$$g = 6.67\times10^{-11}\left(\frac{1.9\times10^{27}}{(4.2\times10^{11})^2} - \frac{5.7\times10^{26}}{(3.9\times10^{11})^2}\right)$$

$\cancel{2\times10^{-4}}$ N kg^{-1}

4.7×10^{-7}

4 marks

Question 4

Indicate the direction of the gravitational field at Cassini (determined in Question 3) on **Figure 2** below.

not to scale

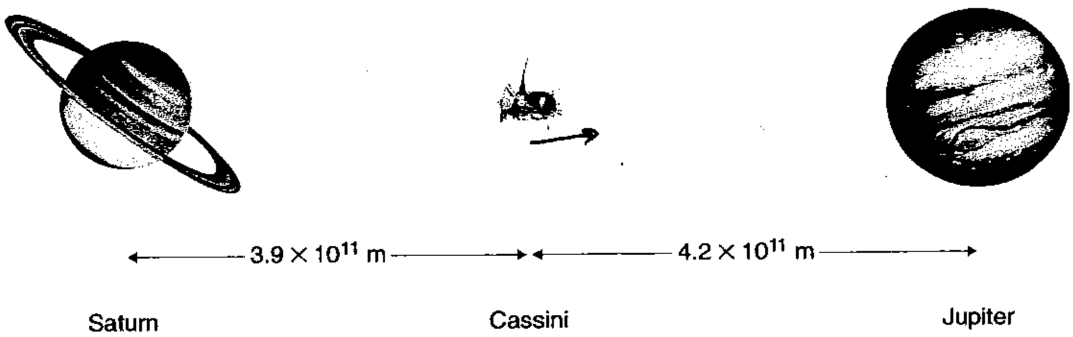


Figure 2. Cassini between Saturn and Jupiter (not drawn to scale)

1 mark

When Cassini arrives in the vicinity of Saturn this year, scientists want it to remain above the same point on Saturn's equator throughout one complete Saturn day. This is called a 'stationary' orbit.

Question 5

What is the period in seconds of this 'stationary' orbit?

10.7 h

| 3.85×10^4 | s |

1 mark

Question 6 31% Average mark 1.23

Calculate the radius of this 'stationary' orbit.

($G = 6.67 \times 10^{-11}$ N m^2 kg^{-2})

$$\frac{mv^2}{r} = G\frac{mM_s}{r^2} \qquad \cancel{r = \frac{GM_s}{v^2}}$$

$$v = \frac{2\pi r}{T} \qquad \frac{4\pi^2 r^2}{T^2} = G\frac{M_s}{r} \qquad r^3 = \frac{GM_sT^2}{4\pi^2}$$

$$r = \sqrt[3]{\frac{6.67\times10^{-11} \times 5.7\times10^{26} \times 3.85^2\times10^8}{4\pi^2}}$$

| 1.1×10^8 | m |

3 marks

2003/2

The law of conservation of momentum (for an isolated system) is a fundamental law of physics that applies to all collisions.

Question 7 4%

Describe how you would show that the collision between the dodgem car and the guardrail satisfies the law of conservation of momentum. In particular, address these three aspects.

Initial momentum of dodgem car

$\leftarrow 400$

Final momentum of dodgem car

$400 \rightarrow$

Given the previous answers, explain how momentum is conserved.

Change in momentum 800 Ns. This momentum was transfered to guardrail/earth.

4 marks

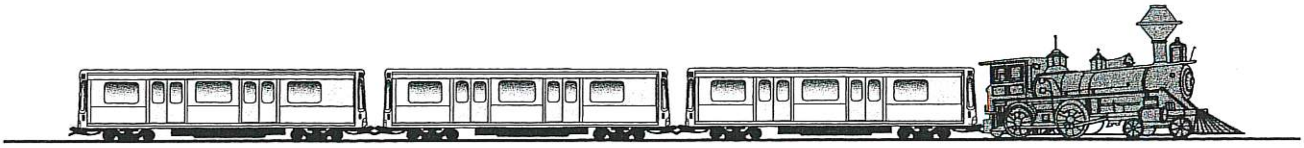


Figure 4

Figure 4 shows a train with an engine and three carriages travelling at constant velocity along a straight, level section of track. The mass of the engine is 40.0 tonnes and the mass of each of the carriages is 20.0 tonnes.

At this constant velocity the resistance forces on the engine (due to frictional forces and air resistance) total 5000 N and each carriage experiences a resistance force of 2000 N.

Question 8

What is the magnitude of the driving force provided by the engine?

$v = const$

$F_{dr} = F_{res\ total}$

11 000	N

2 marks

While still on the same section of track, the train is required to speed up and so the engine driving force is increased to 4.6×10^4 N.

Question 9

Calculate the acceleration of the train.

$$a = \frac{4.6 \times 10^4 - 11000}{100\,000}$$

0.35	m s^{-2}

2 marks

During another part of the journey the train is accelerating at 0.20 m s^{-2} along a straight, level section of track.

Question 10

Calculate the magnitude of the tension in the coupling between the final two carriages during this acceleration. (Assume that the resistance forces remain unchanged.)

$T - F_{res} = ma$

$T - 2000 = 20000a$

$T = 2000 + 4000$

6000	N

4 marks

A small car travels in a circle of radius 10.0 m at a constant speed. Figure 5a shows the car from **above** and Figure 5b shows the car from **behind**.

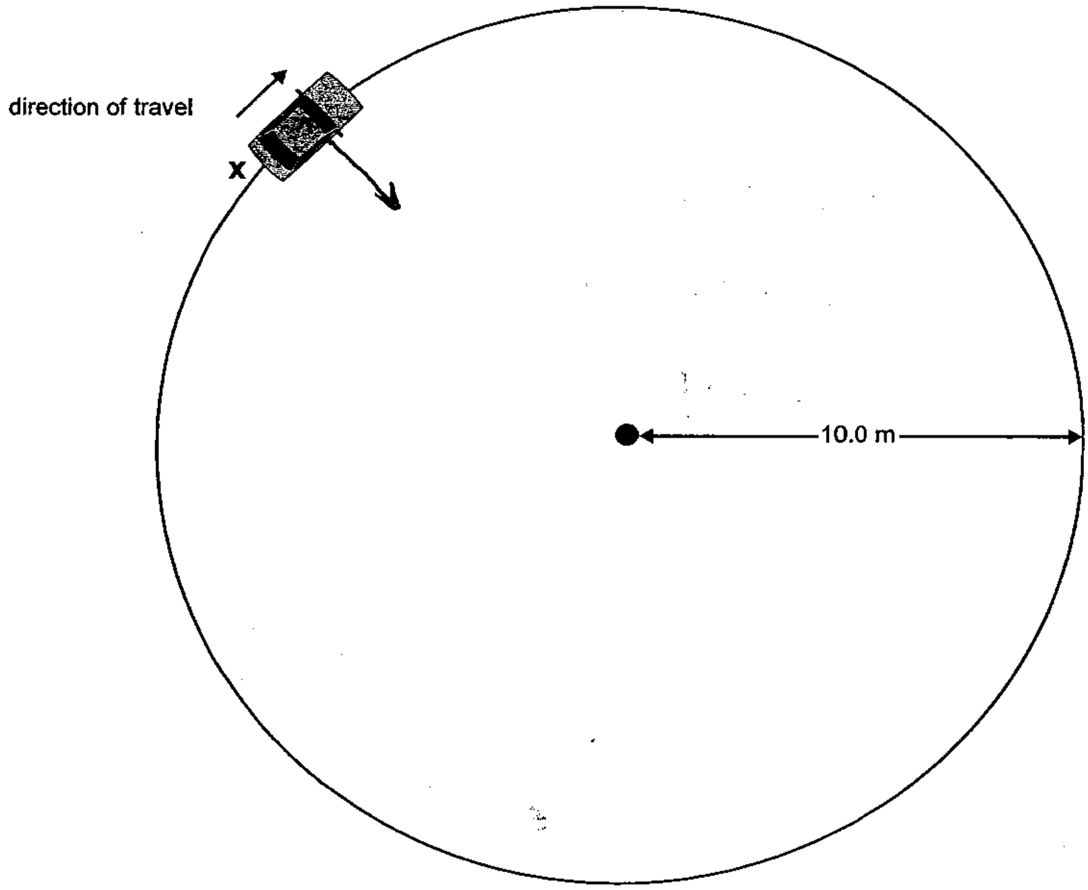


Figure 5a

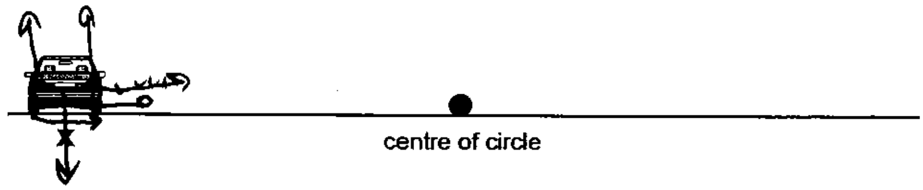


Figure 5b

Figure 1 is a graph of the force of gravitational attraction between the 400 kg spacecraft Odyssey and the planet Mars versus distance above the surface of Mars.

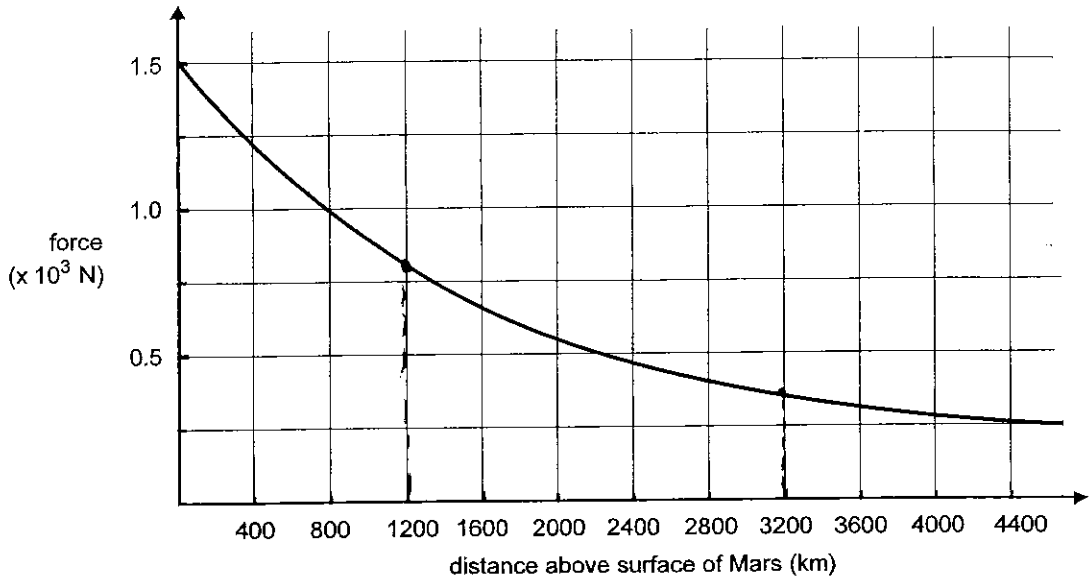


Figure 1

Before its orbit around Mars, Odyssey was originally launched from Earth and took 200 days to reach Mars. At a distance of 3200 km away from the surface of Mars it was travelling at approximately 24 000 m s^{-1}. At this point it was speeding up due to the gravitational attraction of Mars.

Question 2 13 %

Describe, **but do not calculate**, the method you would use to determine the speed of Odyssey at a distance of 1200 km above the surface of Mars.

$E_{K_0} = \frac{Mu^2}{2}$ $E_{K_f} = E_{K_0} + A = \frac{Mv_f^2}{2}$

A - area under the graph

4 marks

Last year astronomers discovered a new body, Quaoar, in our solar system just beyond Pluto. This very large asteroid orbits our Sun in a near perfect circle of radius 6.5×10^{12} m.

Question 3 62 %

Calculate the speed of Quaoar in its orbit around the Sun.

($G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, $M_{Sun} = 2.0 \times 10^{30}$ kg)

$$v = \frac{2\pi r}{T} \qquad \frac{mv^2}{r} = G\frac{mM_s}{r^2}$$

$$v = \sqrt{\frac{GM}{r}}$$

4.5×10^3 m s^{-1}

3 marks

Two enthusiastic astronomy students, Kiera and Darla, were talking about what it would be like to travel and land on Quaoar. Both agreed that they would feel a very small gravitational effect if they were on the surface of Quaoar. However, Darla did not agree with Kiera's reason for the small gravitational effect.

Darla explained that a very small gravitational effect would be felt because Quaoar has such a small mass and that the gravitational force between the asteroid and himself would be very small.

Kiera explained that because Quaoar was in orbit around the Sun they would experience apparent weightlessness because both they and Quaoar would be accelerating towards the Sun at the same rate.

Question 4 15 %

Was Kiera correct or incorrect? Explain your answer.

No, Kiera incorrect.

On the surface of Quaoar a person would be subject to the combined gravity of the sun and Quaoar

Because both the person and Quaoar in the orbit around the sun - this part of Kiera's explanation is correct but she has neglected the gravity of Quaoar.

A person on the surface of Quaoar would feel a normal reaction force and so would not feel weightless.

4 marks

END OF AREA 2

2004/2

1

AREA 1 – Motion

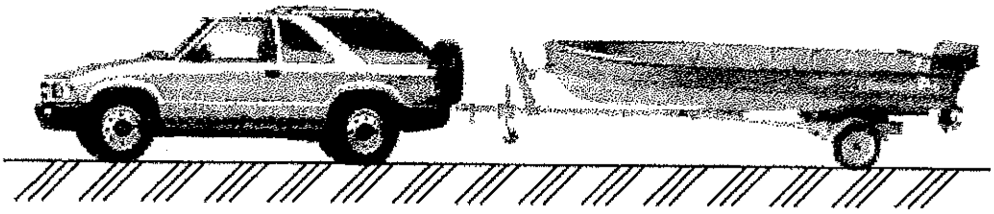


Figure 1

Figure 1 shows a car of mass 1600 kg towing a boat and trailer of mass 1200 kg.

The driver changes the engine power to maintain a constant speed of 72 km h^{-1} on a straight road.
The total retarding force on the car is 1400 N and on the boat and trailer 1200 N.

Question 1 65% Average mark 1.4

Calculate the driving force exerted by the car at this speed.

$V = \text{const} \quad a = 0$

$F_{dr} - F_{fr} = 0$

$F_{dr} = F_{fr} = 1400 + 1200$

$\boxed{2600 \text{ N}}$

2 marks

To overtake another car the driver accelerates at a constant rate of 1.20 m s^{-2} from 72 km h^{-1} until reaching 108 km h^{-1}.

Question 2 62% Average 2.2

Calculate the distance covered during this acceleration.

$72 \text{ km h}^{-1} = 20 \text{ m s}^{-1} = u \qquad v^2 = u^2 + 2as$

$108 \text{ km h}^{-1} = 30 \text{ m s}^{-1} = v \qquad S = \frac{30^2 - 20^2}{2 \times 1.2}$

$\boxed{208 \text{ m}}$

3 marks

2004/2

moderate

Question 3 33 % Average mark 1.1

Calculate the tension in the coupling between the car and trailer during the acceleration. (Assume the same retarding forces of 1400 N and 1200 N respectively.)

$T - F_{fr} = ma$

$T - 1200 = 1200 \times 1.2$

2640 N

3 marks

A delivery van of mass 1200 kg, travelling south at 20 m s^{-1}, collides head-on with a power pole. The impact crushes the crumple zone of the van by 0.60 m bringing the van to rest against the pole.

Question 4 50 % Average 1.7

Calculate the average force that the pole exerts on the van.

$v = 0$
$u = 20 \text{ m s}^{-1}$
$s = 0.6 \text{ m}$

$v^2 = u^2 + 2as$
$0 = 20^2 - 2a \times 0.6$

$a = \frac{400}{1.2}$

$F = ma$
$F = 1200 \times \frac{400}{1.2}$

4.0×10^5	N

3 marks

Question 5 63 % average 1.4

Calculate the time for the impact.

$Ft = \Delta p$

$t = \frac{\Delta p}{F} = \frac{1200 \times 20}{4 \times 10^5}$

0.06 s	s

2 marks

Question 6 12 % Average 1.3

Calculate the initial momentum and final momentum of the van and explain how momentum has been conserved in this collision.

24000 Ns south - initial momentum

final momentum = 0

24000 Ns was transfered to the system of the pole and Earth.

3 marks

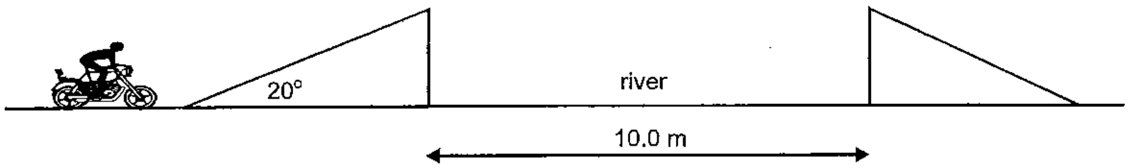


Figure 2

Figure 2 shows a motorcycle rider using a 20° ramp to jump her motorcyle across a river that is 10.0 m wide.

Question 7 29 %. Average 1.5

Calculate the minimum speed that the motorcycle and rider must leave the top of the first ramp to cross safely to the second ramp that is at the same height. (The motorcycle and rider can be treated as a point-particle.)

($g = 9.8$ m s^{-2})

$$\text{Range} = \frac{2u^2 \sin\theta\cos\theta}{2g}$$

$$\cancel{u \sin 20 = 5t}$$

$$\cancel{t = \frac{u \sin 20}{5 \quad 4.9}}$$

$$10 = \frac{u^2 \sin 20 \cos 20}{5}$$

$$u = \sqrt{\frac{50 \; (49)}{\sin 20 \cos 20}}$$

$$u = \sqrt{\frac{100}{\sin 40}}$$

12.35 m s^{-1}

($g = 9.8$)

12.47 · ($g = 10$)

4 marks

Two students are discussing the forces on the tyres of a car. Both agree that there must be a friction force acting on the tyres of a car. The first student claims that the friction force acts to oppose the motion of the car and slow it down, for example, when braking. The second student claims that friction acts in the direction of motion as a driving force to speed the car up when accelerating.

Question 8 17% Average 1.1

On the diagram of the front-wheel drive car in Figure 3 clearly show all the forces acting **on the tyres** of the car **when it is accelerating** forwards in a straight line. Use arrows for the force vectors to show both the **magnitude** and **point of action** of the different forces.

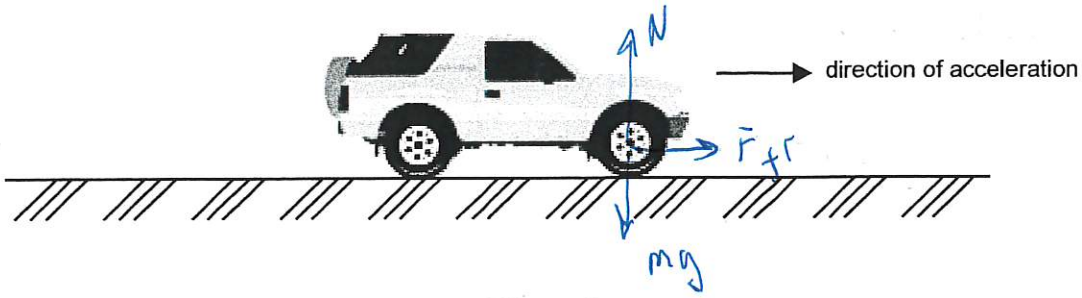


Figure 3

3 marks

Question 9 23% Average 0.9

On the diagram of the same car in Figure 4 clearly show all the forces acting **on the tyres** of the car **when it is braking** in a straight line. Use arrows for the force vectors to show both the **magnitude** and **point of action** of the different forces.

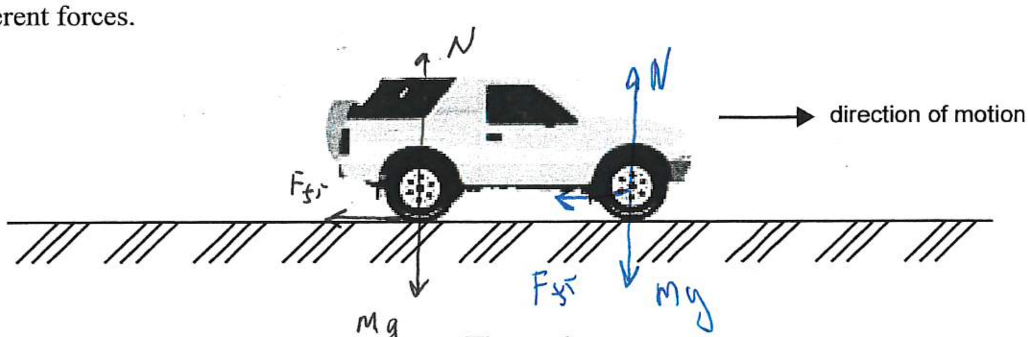


Figure 4

2 marks

Figure 1 shows the variation of gravitational field with height above Earth's surface.

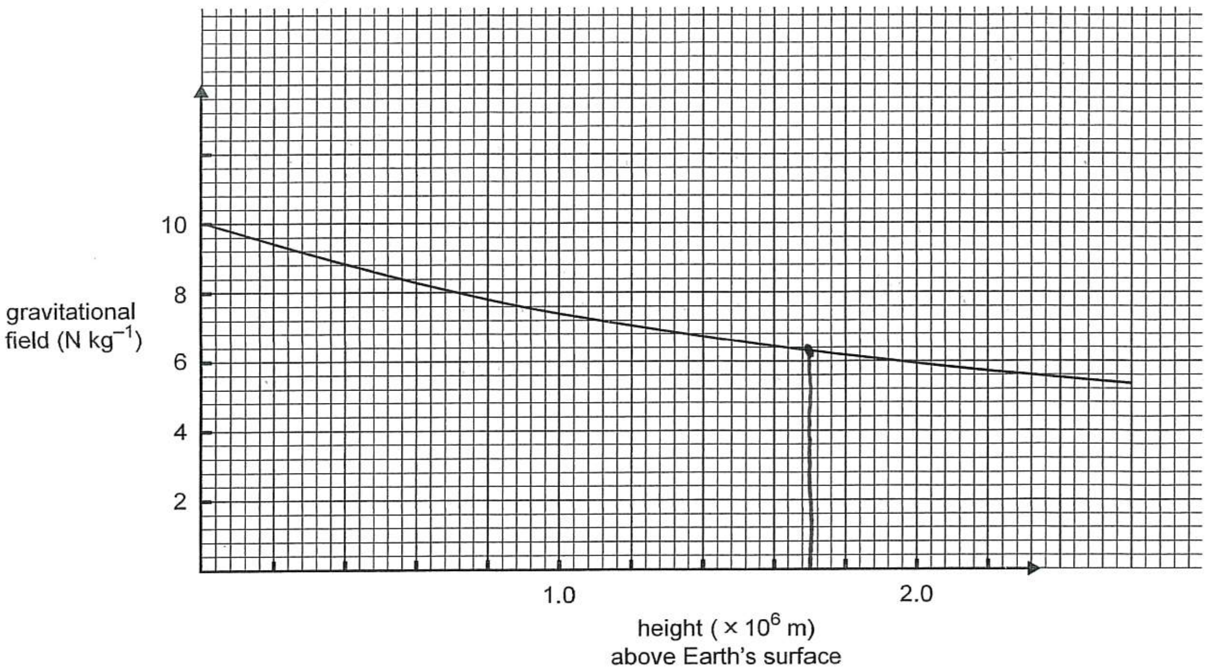


Figure 1

Question 3 1% Average 1.7

Calculate the energy needed to take the 400 kg spacecraft from rest at the surface of Earth and place it in a stable circular orbit of height 1.70×10^6 m. You must show your working.

Area under the graph (approximate as trapezium)

$A = \frac{10 + 6.5}{2} \times 1.7 \times 10^6 = 1.4 \times 10^7$ Work done = m × Area

$W = 400 \times 1.4 \times 10^7 = 5.6 \times 10^9$ J

To stay in the orbit also need kinetic energy.

$v = \sqrt{\frac{GM}{r}}$ $E_K = \frac{mv^2}{2}$ $E_K = \frac{GmM}{2r}$

$E_K = \frac{6.67 \times 10^{-11} \times 400 \times 6 \times 10^{24}}{2(6.4 + 1.7) \times 10^6} = 9.9 \times 10^9$ J

Total energy $= 5.6 \times 10^9 + 9.9 \times 10^9$

$= 1.5 \times 10^{10}$ J

$\boxed{1.5 - 1.6 \times 10^{10}}$ J

accepted range

5 marks

Pictures of astronauts in the orbiting spacecraft are 'beamed' back to Earth. In these pictures the astronauts appear to be 'floating' around inside the spacecraft.

Question 4 24% Average 1.4

Explain why the astronauts appear to be floating around inside the orbiting spacecraft.

They are in the state of apparent weightlessness.
Astronauts and spacecraft are in a free fall, they
both accelerating towards Earth at g.
So there is no normal reaction force.

3 marks

END OF AREA 2

2004/1p

SECTION A – Core

Instructions for Section A

Answer **all** questions **for both** Areas of study in this section of the paper.

Area of study 1 – Motion in one and two dimensions

In the following questions you should take the value of g to be 10 m s^{-2}

A bushwalker is stranded while walking. Search and rescue officers drop an emergency package from a helicopter to the bushwalker. They release the package when the helicopter is a height (h) above the ground, and directly above the bushwalker. The helicopter is moving with a velocity of 10 m s^{-1} at an angle of 30° to the horizontal, as shown in Figure 1. The package lands on the ground 3.0 s after its release. Ignore air resistance in your calculations.

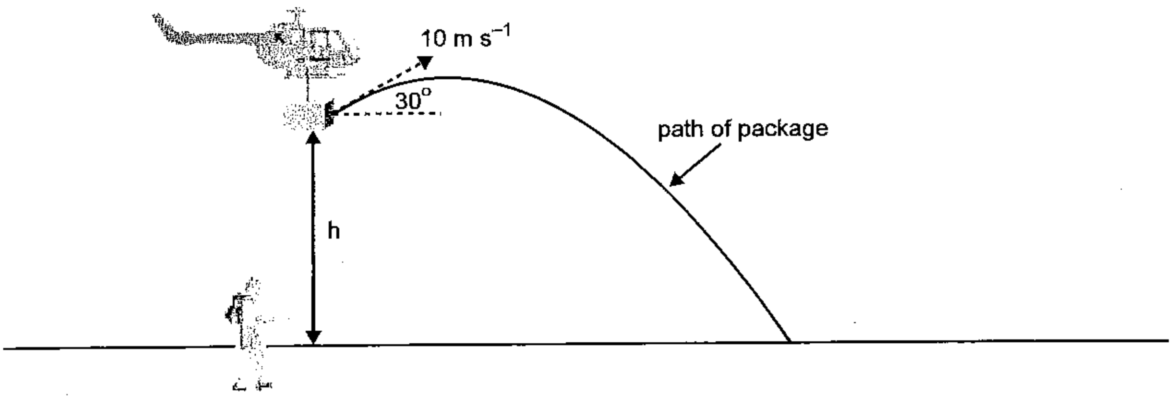


Figure 1

Question 1

What is the value of h in Figure 1?

$$y = h + 10\sin 30^\circ t - \frac{gt^2}{2}$$

$$0 = h + 10\sin 30^\circ \times 3 - \frac{10 \times 3^2}{2}$$

$$h = 30 \text{ m}$$

30 m

3 marks

Question 2

Assuming that the helicopter continues to fly with its initial velocity, where is it when the package lands? Which one of the statements below is most correct?

A. It is directly above the package.

B. It is directly above a point that is 15 m beyond the package.

C. It is directly above a point that is 26 m beyond the package.

D. It is directly above a point that is 30 m from the bushwalker.

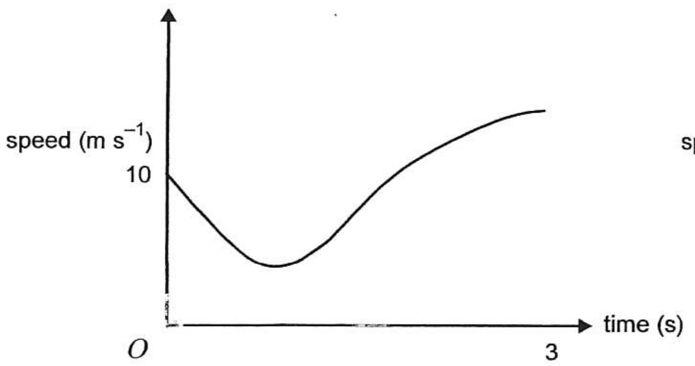
A

2 marks

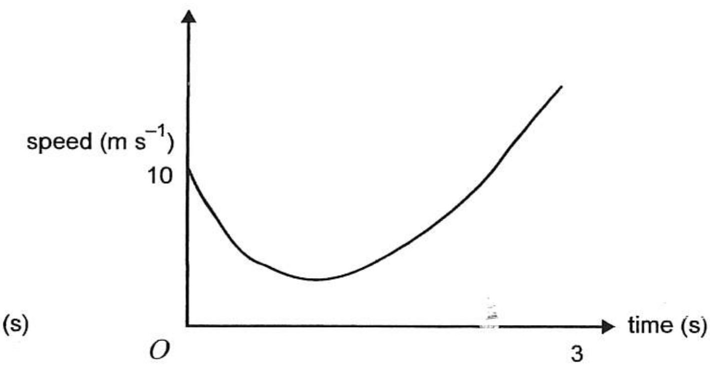
Question 3

Which of the graphs below best represents the **speed** of the package as a function of time?

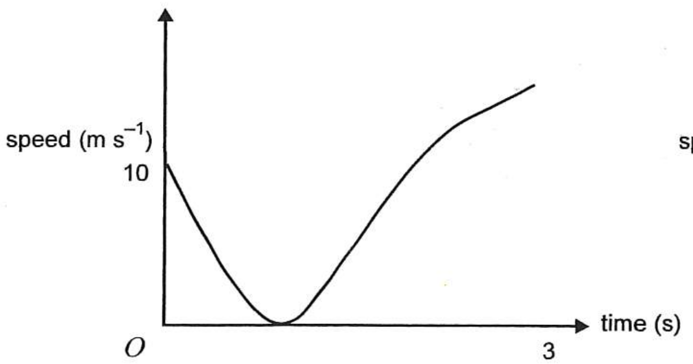
A.



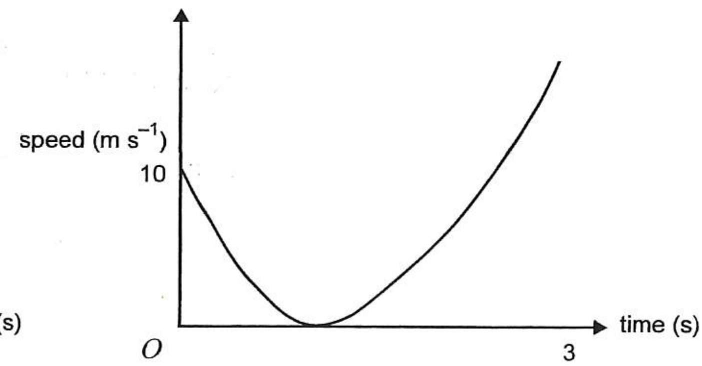
B.



C.



D.



B

2 marks

The radius of the orbit of Earth in its circular motion around the Sun is 1.5×10^{11} m (Figure 3).

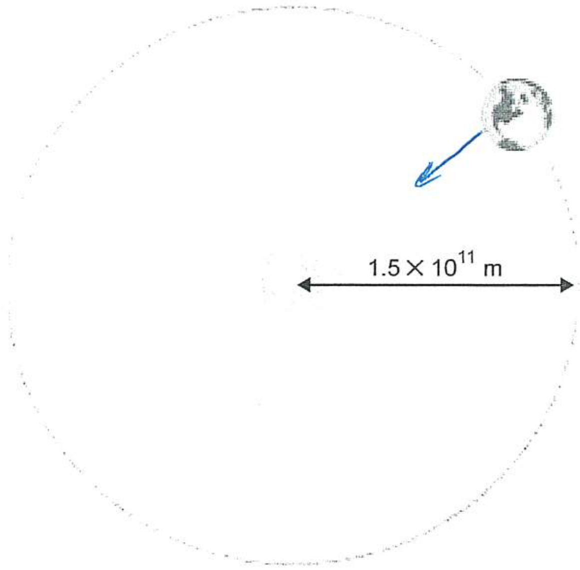


Figure 3

Question 12

Indicate on the diagram, with an arrow, the direction of the acceleration of Earth.

1 mark

Question 13 20% Average 0.8

Calculate the mass of the Sun. Take the value of the gravitational constant $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}.

$$\frac{r^3}{T^2} = \frac{GM}{4\pi^2} \qquad M = \frac{4\pi^2 r^3}{G T^2}$$

$$T = 365 \times 24 \times 3600$$

$\boxed{2.0 \times 10^{30}}$ kg

3 marks

In a storeroom a small box of mass 30.0 kg is loaded onto a slide from the second floor, and slides from rest to the ground floor below, as shown in Figure 4. The slide has a **linear length of 6.0 m**, and is designed to **provide a constant friction force** of 50 N on the box. The box reaches the end of the slide with a speed of 8.0 m s^{-1}.

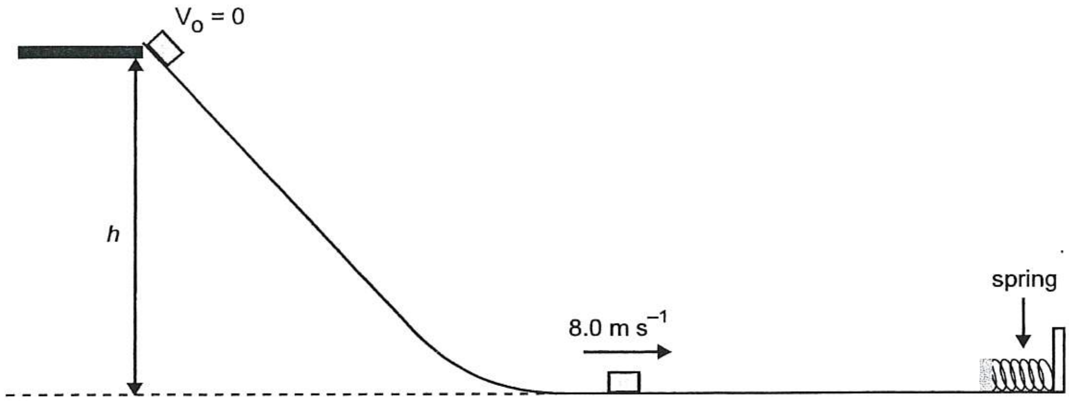


Figure 4

Question 14 Average 0.9

What is the height, h, between the floors?

$mgh = \frac{mv^2}{2} + W$ $\quad W = 6 \times 50 = 300\text{ J}$

work against friction

$300h = \frac{30 \times 8^2}{2} + 300$

$h = 4.2\text{ m}$

4.2	m

4 marks

The box then slides along the **frictionless floor**, and is momentarily stopped by a spring of stiffness 30 000 N m^{-1}.

Question 15 Average 1.6

How far has the spring compressed when the box has come to rest?

$\frac{mv^2}{2} = \frac{Kx^2}{2}$ $\quad x = \sqrt{\frac{M}{K}}\, v$

$x = \sqrt{\frac{30}{30000}} \times 8$

0.25	m

3 marks

END OF AREA OF STUDY 1

2005/1

The safe speed for a train taking a curve on level ground is determined by the force that the rails can take before they move sideways relative to the ground. From time to time trains derail because they take curves at speeds greater than that recommended for safe travel.

Figure 5 shows a train at position P taking a curve on horizontal ground, at a constant speed, in the direction shown by the arrow.

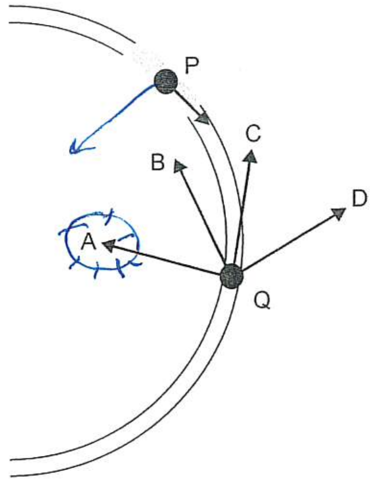


Figure 5

Question 5

At point P shown on the figure, draw an arrow that shows the direction of the force exerted by the rails **on the wheels** of the train.

2 marks

The radius of curvature of a track that is safe at 60 km/h is approximately 200 m.

Question 6 Average 34%

What is the radius of curvature of a track that would be safe at a speed of 120 km/h, assuming that the track is constructed to the same strength as for a 60 km/h curve?

$$\frac{v_1^2}{r_1} = \frac{v_2^2}{r_2} \quad r_2 = \frac{v_2^2}{v_1^2} r_1 \quad r_2 = \left(\frac{120}{60}\right)^2 \times 200$$

800 m

3 marks

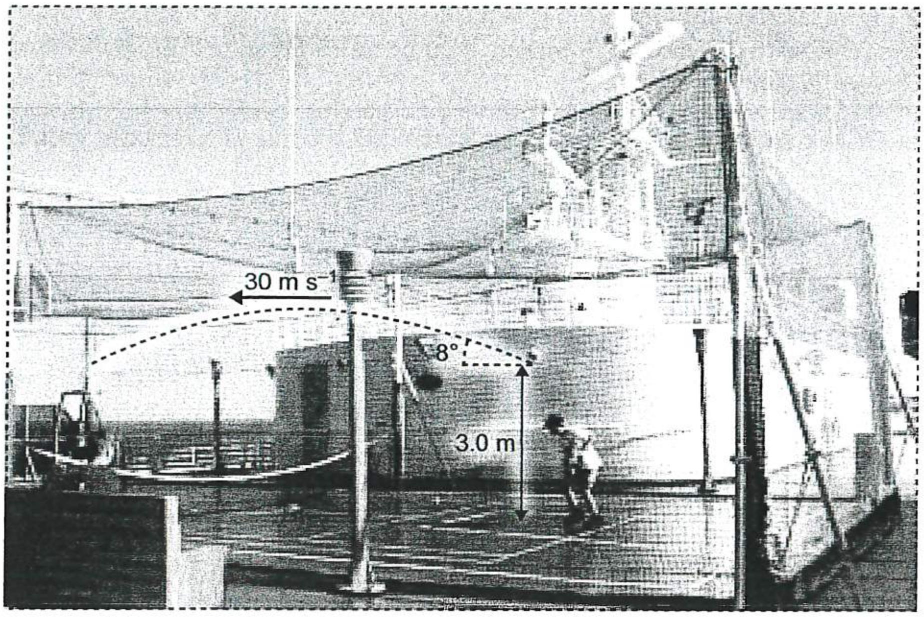
Question 7 33% Average 0.7

At point Q the driver applies the brakes to slow down the train on the curve.

Which of the arrows **(A–D)** indicates the direction of the **net** force exerted **on the wheels** by the rails?

B

2 marks



Fred is playing tennis on the deck of a moving ship. He serves the ball so that it leaves the racket 3.0 m above the deck and travels perpendicular to the direction of motion of the ship. The ball leaves the racket at an angle of 8° to the horizontal. **At its maximum height** it has a speed of 30.0 m s^{-1}. You may ignore air resistance in the following questions.

Question 11

With what speed, relative to the deck, did the ball leave Fred's racket? Give your answer to three significant figures.

At maximum height $v_y = 0$, so

$v_x = 30.0$ $\quad v_x = u\cos\theta$

$$u = \frac{v_x}{\cos\theta}$$

$$u = \frac{30}{\cos(8°)}$$

30.3 m s^{-1}

3 marks

Question 12

At its highest point, how far was the ball **above the deck**?

$x = 30.0t \ (1)$

$y = 3 + 30.3\sin 8^\circ t - 5t^2 \ (2)$

$V_y = 30.3 \sin 8^\circ - 10t$

At highest point $V_y = 0$

$t = \dfrac{30.3 \sin 8^\circ}{10} = 0.42\,s$

Sub in (2)

3.89	m

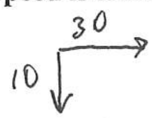
3 marks

The ship is travelling straight ahead at a velocity of 10 m s^{-1}.

Question 13

When the ball is at its highest point

a. at what **speed** is it moving **relative to the ocean**?



$V = \sqrt{30^2 + 10^2} = 31.6$

speed	31.6	m s^{-1}

b. at what **angle** is the ball travelling **relative to the direction** of the ship's travel?

$\theta = \tan^{-1}\left(\frac{30}{10}\right)$

angle	71.6	°

3 marks

Newton was the first person to quantify the gravitational force between two masses M and m, with their centres-of-mass separated by a distance R as

$F = G\frac{Mm}{R^2}$ where G is the universal gravitational constant, and has a value of 6.67×10^{-11} N m^2 kg^{-2}.

For a mass m **on the surface of Earth** (mass M) this becomes $F = gm$, where $g = G\frac{M}{R^2}$

Question 14 38%

Which one of the expressions **(A–D) does not** describe the term g?

A. g is the gravitational field at the surface of Earth.

B. g is the force that a mass m feels at the surface of Earth.

C. g is the force experienced by a mass of 1 kg at the surface of Earth.

D. g is the acceleration of a free body at the surface of Earth.

B

2 marks

Question 15

What is the magnitude of the force exerted by Earth on a water molecule of mass 3.0×10^{-26} kg at the surface of Earth?

~~FG~~ $F = mg$

3.0×10^{-25} N

2 marks

A satellite in a circular orbit of radius 3.8×10^8 m around Earth has a period of 2.36×10^6 s.

Question 16

Calculate the mass of Earth. You **must** show your working.

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM_e}$$

$$M_e = \frac{4\pi^2 r^3}{GT^2} \qquad M_e = \frac{4\pi^2 \times (3.8\times10^8)^3}{6.67\times10^{-11} \times (2.36\times10^6)^2}$$

5.83×10^{24} kg

3 marks