Question 4 (9 marks)

Charon, a moon of Pluto, has a circular orbit.

Data

mass of Pluto	1.3×10^{22} kg
radius of Pluto	1.2×10^{6} m
mass of Charon	1.6×10^{21} kg
radius of orbit of Charon	1.8×10^{7} m
universal gravitational constant (G)	6.67×10^{-11} N m^2 kg^{-2}

Assume that Pluto is a uniform sphere.

a. Calculate the gravitational field strength at the surface of Pluto. Show your working and include an appropriate unit. 3 marks

61%

$$g = \frac{GM}{r^2} \qquad g = \frac{6.67\times10^{-11}\times1.3\times10^{22}}{(1.2\times10^{6})^{2}}$$

$$g = 0.60 \text{ N kg}^{-1}$$

$\boxed{0.60 \text{ N kg}^{-1}}$

b. Calculate the period of orbit of Charon. Show your working. 3 marks

30%

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

$$T = \sqrt{\frac{4\pi^2\times(1.8\times10^{7})^{3}}{6.67\times10^{-11}\times1.3\times10^{22}}}$$

$\boxed{5.2\times10^{5} \text{ s}}$

c. Scientists wish to place a spacecraft, of mass 1000 kg, in an orbit of the same radius as Charon. Three students, Rick, Melissa and Nam, are discussing the situation and have different opinions.

Rick says as the spacecraft is lighter, it will have to move at a greater speed than Charon to achieve the same orbit.

Melissa says the spacecraft would need to move at the same speed as Charon.

Nam says the spacecraft would need only to move at a lower speed as it is lighter than Charon.

Evaluate these three opinions. Detailed calculations are **not** necessary. 3 marks

23%.

Melissa is correct

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

The orbital characteristics (particularly velocity) of a satellite are independent of the mass of the satellite.

Question 7 (4 marks)

A bicycle and its rider have a total mass of 100 kg and travel around a circular banked track at a radius of 20 m and at a constant speed of 10 m s^{-1}, as shown in Figure 6. The track is banked so that there is no sideways friction force applied by the track on the wheels.

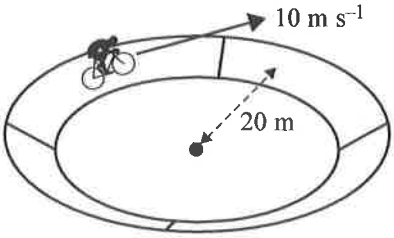
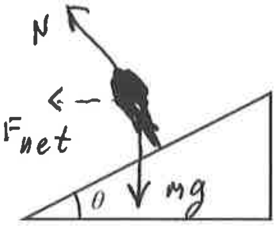


Figure 6

a. On the diagram below, draw all of the forces on the rider and the bicycle, considered as a single object, as arrows. Draw the net resultant force as a dashed arrow labelled F_{net}. 2 marks

55%



b. Calculate the correct angle of bank for there to be no sideways friction force applied by the track on the wheels. Show your working. 2 marks

67%

$\theta = \tan^{-1}\left(\frac{v^2}{gr}\right)$

$\theta = \tan^{-1}\left(\frac{10^2}{20 \times 9.8}\right)$

27 °

Question 8 (4 marks)

A roller-coaster is arranged so that the normal reaction force on a rider in a car at the top of the circular arc at point P, shown in Figure 7, is briefly zero. The section of track at point P has a radius of 6.4 m.

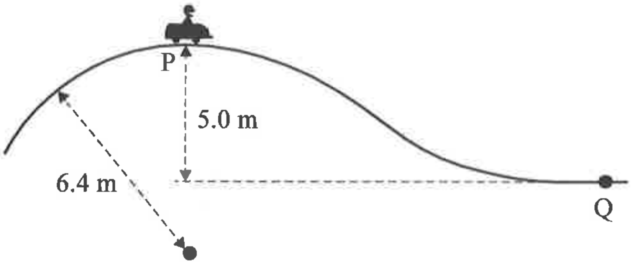


Figure 7

a. Calculate the speed that the car needs to have to achieve a zero normal reaction force on the rider at point P. 2 marks

64%

$mg = \frac{mv^2}{r}$

$v = \sqrt{gr}$

$v = \sqrt{6.4 \times 9.8}$

$\boxed{7.9 \text{ m s}^{-1}}$

b. The car is faulty and only achieves a speed of 4.0 m s^{-1} at the top of the arc at point P.

Calculate how fast this car would be moving when it reaches the bottom at point Q, 5.0 m below point P. Assume that there is no friction and no driving force on the car. 2 marks

35%

$\frac{mu^2}{2} + mgh = \frac{mv^2}{2}$

$0.5 \times 4^2 + 9.8 \times 5 = \frac{v^2}{2}$

$\boxed{10.7 \text{ m s}^{-1}}$

Question 9 (14 marks)

Students use a catapult to investigate projectile motion. In their first experiment, a ball of mass 0.10 kg is fired from the catapult at an angle of 30° to the horizontal. Ignore air resistance. In this first experiment, the ball leaves the catapult at ground level with a speed of 20 m s^{-1}.

However, instead of reaching the ground, the ball strikes a wall 26 m from the launching point, as shown in Figure 8a. Figure 8b shows an enlarged view of the catapult.

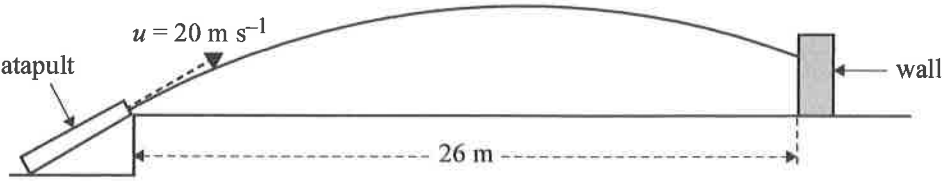


Figure 8a

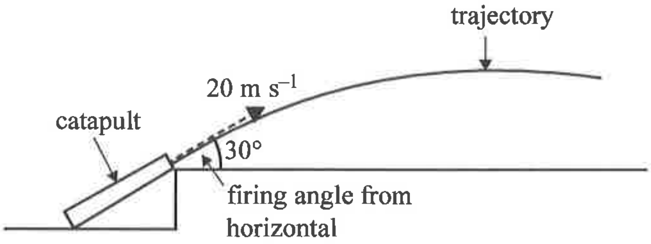


Figure 8b

a. Calculate the height of the ball above the ground when it strikes the wall. Show your working. 3 marks

40 %

$d = V_x t \quad t = \frac{d}{V\cos 30^\circ}$

$t = \frac{26}{20\cos(30^\circ)} = 1.5\,s$

$h = V\sin\theta t - \frac{gt^2}{2}$

$h = 20\sin 30^\circ \times 1.5 - \frac{9.8 \times 1.5^2}{2}$

$\boxed{3.98 \text{ m}}$

Question 12 (3 marks) 54%

Students are using two trolleys, Trolley A of mass 4.0 kg and Trolley B of mass 2.0 kg, to investigate kinetic energy and momentum in collisions.

Before the collision, Trolley A is moving to the right at 5.0 m s^{-1} and Trolley B is moving to the right at 2.0 m s^{-1}, as shown in Figure 10a. The trolleys collide and lock together, as shown in Figure 10b.

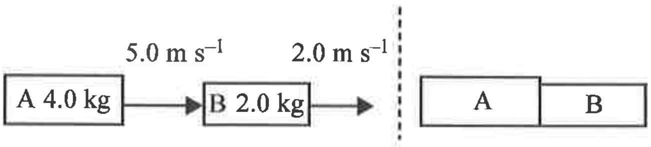


Figure 10a **Figure 10b**

Determine, using calculations, whether the collision is elastic or inelastic. Show your working and justify your answer.

$M_1 V_1 + M_2 V_2 = (M_1 + M_2) V$

$4 \times 5 + 2 \times 2 = 6V$

$V = 4 \text{ ms}^{-1}$

$E_{k_0} = \frac{4 \times 5^2}{2} + \frac{2 \times 2^2}{2} = 54 J \quad E_{k_f} = \frac{6 \times 4^2}{2} = 48 J$

$E_{k_f} < E_{k_0}$

Collision is inelastic

Question 13 (7 marks)

Pat and Robin hang a mass of 2.00 kg on the end of a spring with spring constant $k = 20.0\ \text{N m}^{-1}$.

They hold the mass at the unstretched length of the spring and release it, allowing it to fall, as shown in Figure 11.

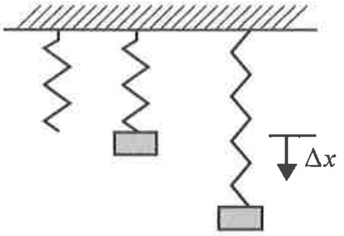


Figure 11

a. Determine how far the spring stretches until the mass comes momentarily to rest at the bottom. Show your working.

3 marks

30%

$$mgx = \frac{Kx^2}{2}$$

$$x = \frac{2mg}{K}$$

$$x = \frac{2\times2\times9.8}{20}$$

1.96 m

b. Explain how the three energies involved and the total energy of the mass vary as the mass falls from top to bottom. Calculations are **not** required.

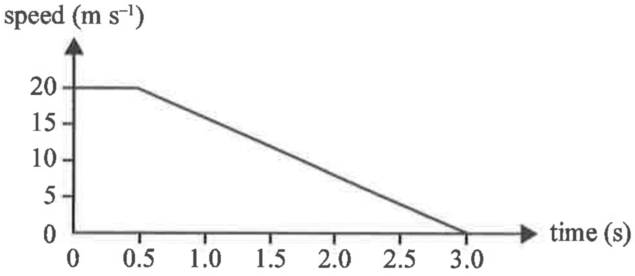
4 marks

16%

Gravitational potential energy max at the top and decreases as mass falls. Spring potential energy is min at the top and increases as mass falls. Kinetic energy is 0 at the top, increases to the middle where it is max, then decreases to 0 at the bottom. Total energy of the mass decreases as mass falls.

Question 6

Lisa is driving a car of mass 1000 kg at 20 m s^{-1} when she sees a dog in the middle of the road ahead of her. She takes 0.50 s to react and then brakes to a stop with a constant braking force. Her speed is shown in the graph below. Lisa stops before she hits the dog.



Which one of the following is closest to the magnitude of the braking force acting on Lisa's car during her braking time?

A. 6.7 N
B. 6.7 kN
[✓ **C.**] 8.0 kN
D. 20.0 kN

69%

$F = ma$

$a = \frac{v-u}{t}$

$F = 1000 \times \frac{20}{2.5}$

Question 7

At one point on Earth's surface at a distance *R* from the centre of Earth, the gravitational field strength is measured as 9.76 N kg^{-1}.

Which one of the following is closest to Earth's gravitational field strength at a distance 2*R* **above** the surface of Earth at that point?

[✓ **A.**] 1.08 N kg^{-1}
B. 2.44 N kg^{-1}
C. 3.25 N kg^{-1}
D. 4.88 N kg^{-1}

16%

$g = \frac{GM}{r^2}$

$g_1 = \frac{GM}{R^2}$

$\frac{g_2}{g_1} = \frac{R^2}{9R^2}$

$g_2 = \frac{GM}{(3R)^2}$

$g_2 = \frac{g_1}{9}$

Question 6 (7 marks)

A ball of mass 2.0 kg is dropped from a height of 2.0 m above a spring, as shown in Figure 8. The spring has an uncompressed length of 2.0 m. The ball and the spring come to rest when they are at a distance of 0.50 m below the uncompressed position of the spring.

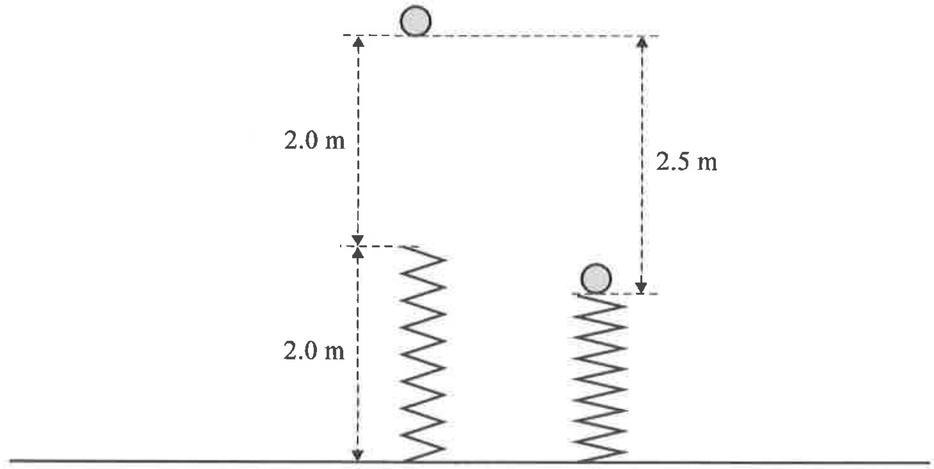


Figure 8

a. Using $g = 9.8$ N kg^{-1}, show that the spring constant, k, is equal to 392 N m^{-1}. Show your working. 3 marks

45%

$mgh = \frac{Kx^2}{2}$

$K = \frac{2mgh}{x^2}$ $K = \frac{2 \times 9.8 \times 2.5}{0.5^2} = 392$

b. Determine the acceleration of the ball when it reaches its maximum speed. Explain your answer. 2 marks

6%

0 m s^{-2}

Maximum velocity is ~~in the middle~~ where $mg = kx$ so $F_{net} = 0$.

Before this point $mg > kx$ and ball still accelerating

c. Calculate the compression of the spring when the ball reaches its maximum speed. Show your working. 2 marks

13%

$mg = kx$

$x = \frac{mg}{K}$ $x = \frac{2 \times 9.8}{392}$

0.05 m

Question 7 (6 marks)

A small ball of mass 0.20 kg rolls on a horizontal table at 3.0 m s^{-1}, as shown in Figure 9.

The ball hits the floor 0.40 s after rolling off the edge of the table. The radius of the ball may be ignored. In this question, take the value of g to be 10 m s^{-2}.

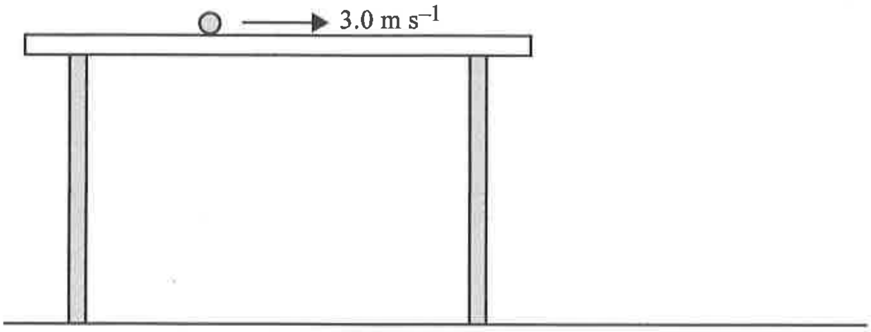


Figure 9

a. Calculate the horizontal distance from the right-hand edge of the table to the point where the ball hits the floor. 1 mark

79%

$d = vt = 3 \times 0.4$

$\boxed{1.2 \text{ m}}$

b. Calculate the height of the table. Show your working. 2 marks

66%

$h = \frac{gt^2}{2} = \cancel{\frac{9.8 \times 0.4^2}{2}}$ $\frac{10 \times 0.4^2}{2}$

$\boxed{0.8 \text{ m}}$

c. Calculate the speed at which the ball hits the floor. Show your working. 3 marks

41%

$v_x = \overset{3}{\text{[illegible]}}\ m\,s^{-1}$ $v_y = gt = \cancel{9.8 \times 0.4 = 3.92}$ $10 \times 0.4 = 4$

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

$\cancel{v = \sqrt{3^2 + 3.92^2}}$ $v = \sqrt{3^2 + 4^2}$

$\boxed{5 \text{ m s}^{-1}}$

Question 8 (4 marks)

Two blocks, A of mass 4.0 kg and B of mass 1.0 kg, are being pushed to the right on a smooth, frictionless surface by a 40 N force, as shown in Figure 10.

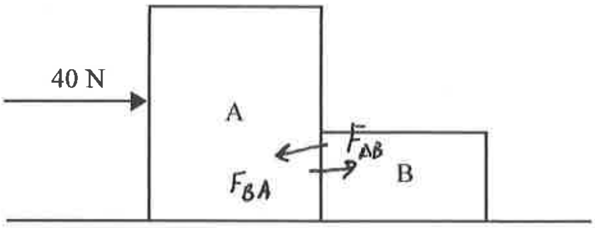


Figure 10

a. Calculate the magnitude of the force on block B by block A ($F_{\text{on B by A}}$). Show your working. 2 marks

27%

$F_{AB} = F_{BA}$ ~~$f = m_B a$~~ Block A : $40 - F_{BA} = 4a$

~~$F = f$~~ Block B : $F_{AB} = 1a$

$40 = 5a$ $a = 8 ms^{-2}$ $F_{AB} = 1 \times 8 = 8N$

8 N

b. State the magnitude and the direction of the force on block A by block B ($F_{\text{on A by B}}$). 2 marks

61%

8 N

to the left

Question 9 (8 marks)

The spacecraft *Juno* has been put into orbit around Jupiter. The table below contains information about the planet Jupiter and the spacecraft *Juno*. Figure 11 shows gravitational field strength (N kg^{-1}) as a function of distance from the centre of Jupiter.

Data

mass of Jupiter	1.90×10^{27} kg
radius of Jupiter	7.00×10^{7} m
mass of spacecraft *Juno*	1500 kg

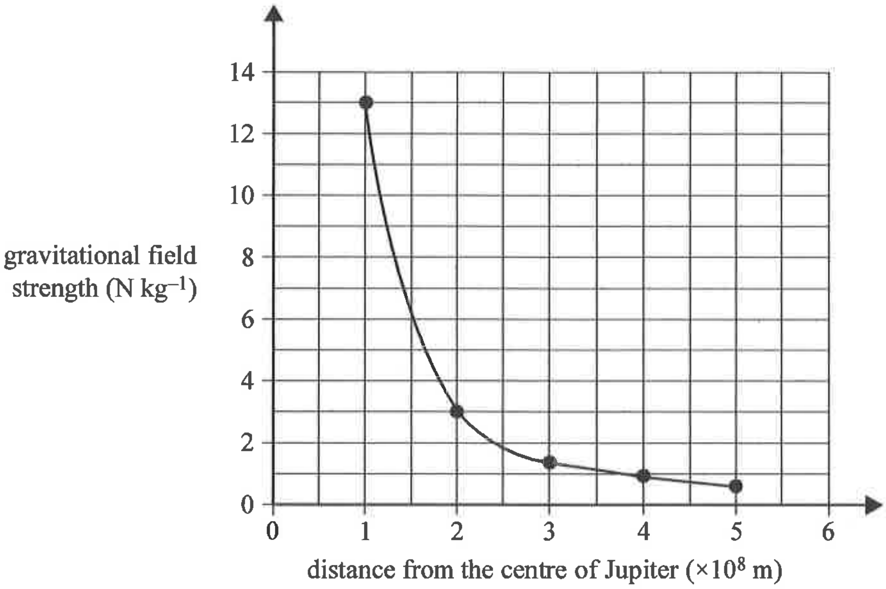


Figure 11

a. Calculate the gravitational force acting on *Juno* by Jupiter when *Juno* is at a distance of 2.0×10^{8} m from the centre of Jupiter. Show your working.

2 marks

57%

From the graph $g = 3$ N kg^{-1}

$F = ma = 1500 \times 3$

4500 N

b. Use the graph in Figure 11 to estimate the magnitude of the change in gravitational potential energy of the spacecraft *Juno* as it moves from a distance of 2.0 × 10^8 m to a distance of 1.0 × 10^8 m from the centre of Jupiter. Show your working.

3 marks

33%

14 squares   1 square $1 \times 0.5\times10^8 = 0.5\times10^8 \text{ J kg}^{-1}$

$\Delta E_{gp} = \text{mass} \times \text{Area}$

$= 1500 \times 14 \times 0.5\times10^8$

1.05×10^{12} J

c. Europa is a moon of Jupiter. It has a circular orbit of radius 6.70 × 10^8 m around Jupiter.

Calculate the period of Europa's orbit. Show your working.

3 marks

51%

$T = \sqrt{\frac{4\pi^2 r^3}{GM}}$ $T = \sqrt{\frac{4\pi^2 \times (6.7\times10^8)^3}{6.67\times10^{-11} \times 1.9\times10^{27}}}$

3.06×10^5 s

Question 10 (4 marks)

Members of the public can now pay to take zero gravity flights in specially modified jet aeroplanes that fly at an altitude of 8000 m above Earth's surface. A typical trajectory is shown in Figure 12. At the top of the flight, the trajectory can be modelled as an arc of a circle.

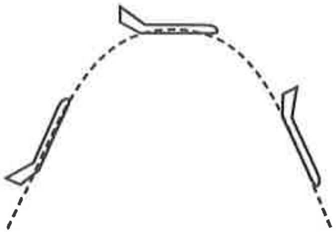


Figure 12

a. Calculate the radius of the arc that would give passengers zero gravity at the top of the flight if the jet is travelling at 180 m s^{-1}. Show your working. 2 marks

63%

$v^2 = gr \quad r = \frac{v^2}{g} = \frac{180^2}{9.8}$

3306 m

b. Is the force of gravity on a passenger zero at the top of the flight? Explain what 'zero gravity experience' means. 2 marks

42%

Force of gravity at the top doesn't = 0.

Zero gravity experience means normal reaction = 0.