Access Tuition

A-Level Physics

Momentum

Question Paper

Time available: 67 minutes
Marks available: 52 marks

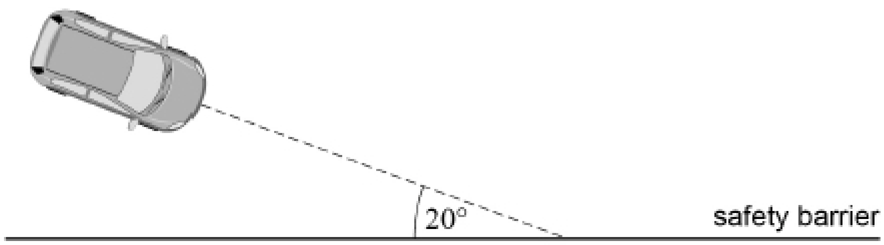
1. Safety barriers are used on UK motorways to prevent vehicles crossing from one carriageway to the other carriageway. The barriers also absorb some of the kinetic energy of a vehicle and deflect vehicles along the barrier.

The standard test of a safety barrier uses a vehicle that contains dummies. The total mass of the vehicle and its contents is 1.5×10^3 kg and its initial speed is 110 km h^{-1}.

(a) Show that the initial kinetic energy of the test vehicle is 700 kJ.

(2)

(b) The test vehicle hits a steel safety barrier at an angle of 20°, as shown in the diagram.



Calculate the component of the momentum of the test vehicle in a direction along the line of the safety barrier.
Give an appropriate unit for your answer.

momentum = ____________________ unit _________

(3)

(c) Immediately after the collision, the test vehicle moves along the safety barrier with no change in its momentum in this direction.

Show that the kinetic energy lost in the collision is about 80 kJ.

(3)

(d) The steel safety barrier deforms during the collision. For the barrier to pass the test, the test vehicle should not move more than 1.5 m towards the other carriageway.

The barrier can apply an average force of 60 kN at right angles to the carriageway.

Deduce whether the safety barrier will pass the test.

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(3)

(e) A different safety barrier uses a solid concrete wall which does not deform. The same standard test is carried out on a concrete wall.

Discuss which type of barrier would cause less damage to the dummies in the test.

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(2)

(Total 13 marks)

2. The diagram shows two railway trucks **A** and **B** travelling towards each other on the same railway line which is straight and horizontal.

The trucks are involved in an inelastic collision. They join when they collide and then move together.

The trucks move a distance of 15 m before coming to rest.

Truck **A** has a total mass of 16 000 kg and truck **B** has a total mass of 12 000 kg

Just before the collision, truck **A** was moving at a speed of 2.8 m s^{-1} and truck **B** was moving at a speed of 3.1 m s^{-1}

(a) State the quantity that is **not** conserved in an inelastic collision.

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(1)

(b) Show that the speed of the joined trucks immediately after the collision is about 0.3 m s^{-1}

(3)

(c) Calculate the impulse that acts on each truck during the collision.
Give an appropriate unit for your answer.

impulse = ____________________ unit ___________

(2)

(d) Explain, without doing a calculation, how the motion of the trucks immediately after the collision would be different for a collision that is perfectly elastic.

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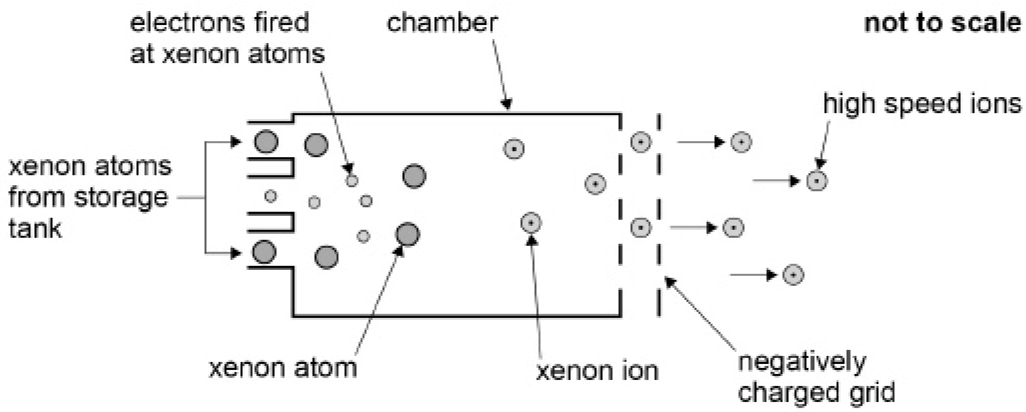
(2)
(Total 8 marks)

3. **Figure 1** represents an ion propulsion unit used on a spacecraft launched in 1998.

Atoms of xenon-131 ($^{131}_{54}Xe$) were injected from a storage tank into a chamber where they became ionised due to collisions with electrons.

A negatively charged grid attracted the xenon ions, accelerating them out of the back of the ion propulsion unit and causing the spacecraft to be propelled forward.

Figure 1



(a) The mass of a Xe^+ ion is 2.18×10^{-25} kg.

Calculate the specific charge of a Xe^+ ion.

Give an appropriate unit for your answer.

specific charge = ______________________________ unit ______________

(2)

(b) The storage tank contained 79 kg of xenon. When the ion propulsion unit was switched on it had an average power output of 2.1 kW.

Each xenon ion gained 1300 eV of energy as it was accelerated and ejected out of the propulsion unit.

Calculate the energy, in J, gained by each xenon ion.

energy = ____________________________ J

(1)

(c) Determine the length of time the ion propulsion unit operated before all of the 79 kg of xenon was used up.

mass of xenon atom = 2.18×10^{-25} kg

time = ____________________________ s

(3)

(d) Ion propulsion units could use helium ions instead of xenon ions.

An ion of helium-4 (He^+) has a much higher specific charge than an ion of xenon-131 (Xe^+). Both ions would gain 1300 eV of kinetic energy in being accelerated and ejected from an ion propulsion unit.

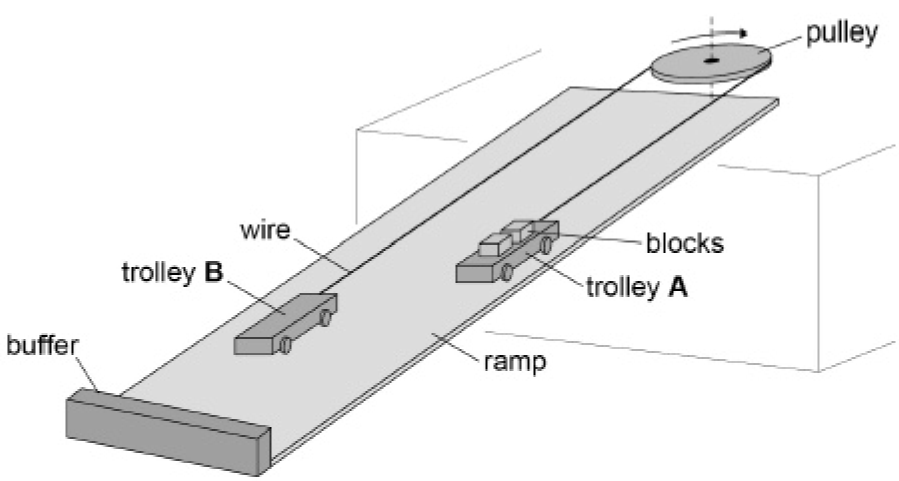
Suggest whether helium ions or xenon ions are better to use as a propellant in future space programmes. In your answer you should compare the relative speeds and momentum changes of the ions.

(3)

(Total 9 marks)

4. **Figure 1** shows a model of a system being designed to move concrete building blocks from an upper to a lower level.

Figure 1



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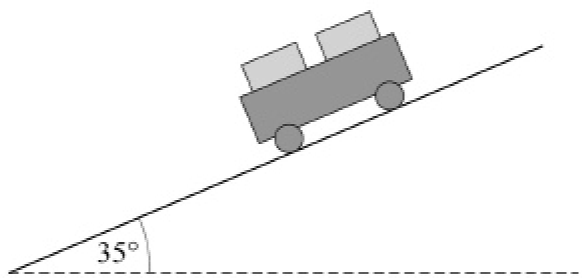
The model consists of two identical trolleys of mass M on a ramp which is at 35° to the horizontal. The trolleys are connected by a wire that passes around a pulley of negligible mass at the top of the ramp.

Two concrete blocks each of mass m are loaded onto trolley **A** at the top of the ramp. The trolley is released and accelerates to the bottom of the ramp where it is stopped by a flexible buffer. The blocks are unloaded from trolley **A** and two blocks are loaded onto trolley **B** that is now at the top of the ramp. The trolleys are released and the process is repeated.

Figure 2 shows the side view of trolley **A** when it is moving **down** the ramp.

Figure 2



(a) The tension in the wire when the trolleys are moving is T.

Draw and label arrows on **Figure 2** to represent the magnitudes and directions of any forces and components of forces that act on trolley **A** parallel to the ramp as it travels down the ramp.

(1)

(b) Assume that no friction acts at the axle of the pulley or at the axles of the trolleys and that air resistance is negligible.

Show that the acceleration a of trolley **B** along the ramp is given by

$$a = \frac{mg \sin 35^\circ}{M + m}$$

(2)

(c) Compare the momentum of loaded trolley **A** as it moves downwards with the momentum of loaded trolley **B**.

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(2)

(d) In practice, for safety reasons there is a friction brake in the pulley that provides a resistive force to reduce the acceleration to 25% of the maximum possible acceleration.

The distance travelled for each journey down the ramp is 9.0 m.

The following data apply to the arrangement.

Mass of a trolley M = 95 kg

Mass of a concrete block m = 30 kg

Calculate the time taken for a loaded trolley to travel down the ramp.

time = ____________________ s

(3)

(e) It takes 12 s to remove the blocks from the lower trolley and reload the upper trolley.

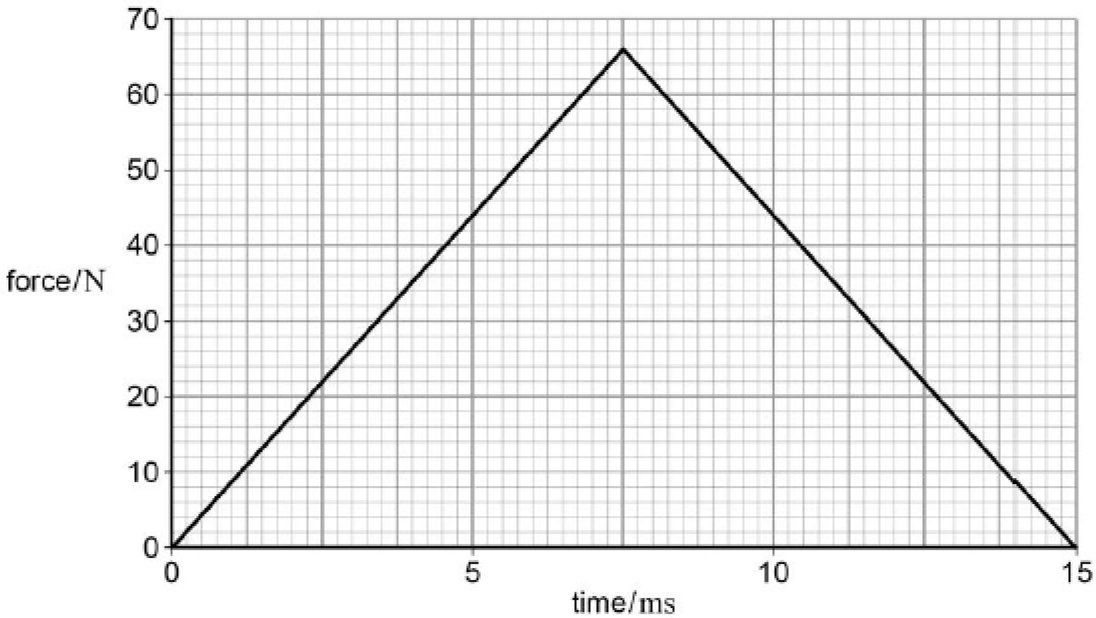
Calculate the number of blocks that can be transferred to the lower level in 30 minutes.

number = ____________________

(2)

(Total 10 marks)

5. A golf ball is raised from the ground and dropped onto a hard plate to test the properties of the ball. A sensor measures the force exerted by the plate on the ball during its collision with the plate. The graph below shows the variation of force exerted on the golf ball with time.



(a) Show that the change in momentum of the golf ball during the collision is about 0.5 N s.

(2)

(b) The ball strikes the plate with a speed of 7.1 m s^{-1} and has a mass of 45 g. It leaves the plate with a speed of 3.9 m s^{-1}.

Show that this is consistent with a change in momentum of about 0.5 N s.

(3)

(c) The ball continues to bounce, each time losing the same fraction of its energy when it strikes the plate. Air resistance is negligible.

Determine the percentage of the original gravitational potential energy of the ball that remains when it reaches its maximum height after bouncing three times.

gravitational potential energy remaining = ______________________ %

(4)

(d) Explain, with reference to the conservation of momentum, the effect that the motion of the golf ball has on the motion of the Earth from the instant it is released until it bounces at the plate.

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(3)

(Total 12 marks)