1 Motion and energy

Answers to Exam practice questions

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1 Answer D

[Total 1 mark]

2 No kinetic energy is lost in elastic collisions.

In inelastic collisions some kinetic energy is lost, usually to internal energy.

In both types of collision total energy is conserved.

[Total 3 marks]

3 a) As linear momentum is conserved:

\[
(21000 \text{ kg}) \times v = (28000 \text{ kg}) \times 3.5 \text{ m s}^{-1}
\]

\[\Rightarrow u = 4.66 \text{ m s}^{-1} = 4.7 \text{ m s}^{-1} \text{ (to 2 s.f.)} \]

[1]

b) \[\Delta KE = \frac{1}{2}(21000 \text{ kg})(4.7 \text{ m s}^{-1})^2 - \frac{1}{2}(28000 \text{ kg})(3.5 \text{ m s}^{-1})^2\]

\[= (232 - 172) \text{ kJ} = 60 \text{ kJ}\]

∴ Percentage loss of KE = \[\frac{60 \text{ kJ}}{232 \text{ kJ}} \times 100 \%\]

\[= 26 \%\]

[Total 6 marks]

4 Answer A

[Total 1 mark]

5 When the trolleys are released (in order to conserve momentum) the lighter trolley will move away at 4 × the speed of the heavier trolley.

Both trolleys gain kinetic energy, all of which comes from the elastic potential energy stored in the compressed spring.

[Total 3 marks]

6 Suppose the woman’s velocity after separation is \(v\). Applying the principle of conservation of momentum:

\[\begin{align*}
(65 + 75) \text{ kg} \times 5.8 \text{ m s}^{-1} &= 75 \text{ kg} \times 3.8 \text{ m s}^{-1} + 65 \text{ kg} \times v \\
\Rightarrow v &= 8.1 \text{ m s}^{-1} \quad [2]
\end{align*}\]

Initial KE = \[\frac{1}{2}(65 + 75) \text{ kg} \times (5.8 \text{ m s}^{-1})^2 \approx 2355 \text{ J}\]

Final KE = \[\frac{1}{2} \times 75 \text{ kg} \times (3.8 \text{ m s}^{-1})^2 + \frac{1}{2} \times 65 \text{ kg} \times (8.1 \text{ m s}^{-1})^2 \approx 2674 \text{ J}\]

∴ There is a gain in KE of 320 J

This comes from the work done by the skaters in pushing each other apart.

[Total marks 7]
7 Total KE before collision = \( \frac{1}{2} \times (6.65 \times 10^{-27} \text{ kg}) \times (1.50 \times 10^7 \text{ m s}^{-1})^2 \)
\[ = 7.48 \times 10^{-13} \text{ J} \quad [1] \]

Total KE after collision
\[ = \frac{1}{2} \times (6.65 \times 10^{-27} \text{ kg}) \times (1.23 \times 10^7 \text{ m s}^{-1})^2 + \frac{1}{2} \times (6.65 \times 10^{-27} \text{ kg}) \times (0.86 \times 10^7 \text{ m s}^{-1})^2 \]
\[ = 5.03 \times 10^{-13} \text{ J} + 2.46 \times 10^{-13} \text{ J} = 7.49 \times 10^{-13} \text{ J} \quad [2] \]
Therefore kinetic energy is conserved. [Total 4 marks]
(The difference of 0.01 \times 10^{-13} \text{ J} comes from the fact that the speed of the helium nucleus after the collision was only given to 2 s.f. As the masses were both the same, \( u_{\alpha}^2 = u_{\alpha}^2 + u_{\text{He}}^2 \) would be enough – and easier!)

8 Rockets ‘work’ by ejecting material (hot gases) backwards. [1]
Suppose the force needed to do this is \( F \).
By Newton’s third law the ejected material will exert a force \( F \) on the rocket car in the forward direction. [1]
The force \( F \) is equal to the rate of change of momentum of the ejected material, Newton’s second law. [1]
[Total 3 marks]
(Notice here that a rocket car is not driven forward by the push of the road on the car.)

9 a) A speed of 180 km h\(^{-1}\) = 180 000 m / 3 600 s = 50 m s\(^{-1}\) [1]
Therefore the ball leaves the racket with a momentum of
\[ mv = 57 \times 10^{-3} \text{ kg} \times 50 \text{ m s}^{-1} = 2.85 \text{ kg m s}^{-1} \quad [1] \]
So the change of momentum \( \Delta p \) = \( 2.85 \text{ N s} = \text{ impulse} \) [1]
From impulse = \( F \Delta t \) \( \Rightarrow F = \text{ impulse}/\Delta t \)
From Figure 1.24 we can estimate the contact time to be 4 ms giving:
\[ F = 2.85 \text{ N s} / 4.0 \times 10^{-3} \text{ s} = 700 \text{ N} \quad [2] \]

b) The force on the ball will not be constant – it will gradually increase as the ball deforms, reach a maximum and then decrease again as the ball recovers its shape, rather like Figure 1.1b of the Student Book. The maximum force will therefore be considerably more than the calculated force of 700 N – probably about twice as much. [2]
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c) ‘Elastic’ for a material means that the material will return to its original dimensions when the deforming force is removed. Clearly, we want both the ball and strings to do this after each shot and so they should be made of elastic materials. [1]

We also want the collision to be as ‘elastic’ as possible – we want as much kinetic energy to be conserved as possible. The elastic materials used for the ball and strings help to do this too. [1]

[Total 10 marks]

10 KE before the explosion = ½ × 2m × ʋ^2 = mu^2 [1]

KE after the explosion = 2 × mu^2 which can be written as ½m(2ʋ)^2 [1]

∴ If one part had a velocity of 2ʋ after the explosion and the other part had a velocity 0, then the principle of conservation of energy would be satisfied. [1]

But these numbers also have to meet the need to satisfy the principle of conservation of linear momentum. [1]

As the original momentum was 2m × ʋ, and the final momentum is m × 2ʋ, linear momentum is also conserved. [1]

[Total 5 marks]

11 The rotation of the helicopter’s blades, e.g. clockwise as seen from below, will tend to make the body of the helicopter rotate in an anticlockwise direction. [1]

(In physics this is described in a law called the conservation of angular momentum, which is not discussed in this book as it is not an A-Level requirement.)

To counter or balance this rotation, the helicopter has a set of small blades rotating in a vertical plane. [1]

These blades exert a horizontal force on the air. [1]

By Newton’s third law, the air exerts an equal and opposite horizontal force on the small blade that prevents the helicopter body rotating. [1]

[Total 4 marks]

(Some helicopters now have two supporting blades that operate in different directions, so doing away with the need to exert a horizontal force using a small rear rotor.)
12 a) \( p_{\text{shell}} = 12 \text{ kg} \times 320 \text{ m s}^{-1} = 3840 \text{ kg m s}^{-1} \) horizontally
\( p_A = 2.0 \text{ kg} \times 450 \text{ m s}^{-1} = 900 \text{ kg m s}^{-1} \) at 45\(^\circ\) above the horizontal
\( p_B = 6.0 \text{ kg} \times 400 \text{ m s}^{-1} = 2400 \text{ kg m s}^{-1} \) horizontally [3]
Note that, as momentum is a vector quantity, its direction must be stated in each case

b) \( p_C \) has a mass \( m = 12 \text{ kg} - 8.0 \text{ kg} = 4.0 \text{ kg} \) and a velocity \( v \) at an angle \( \theta \)

From this figure:
- PR measures 21 mm and thus represents 1050 kg m s\(^{-1}\)
- \( \theta = 38 \^\circ \)
\[ v_C = \frac{1050 \text{ kg m s}^{-1}}{4.0 \text{ kg}} = 260 \text{ m s}^{-1} \] at an angle of 38\(^\circ\) below the horizontal [5]

[Total 8 marks]

13 a) Conservation of linear momentum gives:
\[ 4m \times 5v = 4m \times Nv + 16m \times 2v \]
\[ 20mv = 4Nmv + 32mv \]
which gives \( N = -3 \) [1]
\[ \therefore \text{ The velocity of the helium nucleus after the collision is } 3v \text{ backwards.} \] [1]

b) Calculating the KE before and after the collision gives:
\[ \text{KE before collision} = \frac{1}{2} \times 4m \times (5v)^2 = 50mu^2 \] [1]
\[ \text{KE after collision} = \frac{1}{2} \times 4m \times (-3v)^2 + \frac{1}{2} \times 16m \times (2v)^2 \]
\[ = 18mu^2 + 32mu^2 = 50mu^2 \] [1]
The collision is thus an elastic collision, as kinetic energy is conserved. [1]

[Total 7 marks]
14 a) Referring to Figure 1.26 in the question: suppose the molecule’s velocity after absorbing the photon is $v_2$ to the right so that

\[ \Delta u = v_1 - v_2. \]  

Applying the principle of conservation of momentum to this interaction gives

\[ m v_1 + \frac{\hbar}{\lambda} = m v_2 \]  

\[ \therefore \; m \Delta u = \frac{\hbar}{\lambda} \; \text{or} \; \Delta u = \frac{\hbar}{m \lambda}. \]  

b) Here $\Delta u = \frac{\hbar}{m \lambda} = \frac{6.6 \times 10^{-34} \text{ J s}}{3.8 \times 10^{-26} \text{ kg x 0.025 m}} = 6.9 \times 10^{-7} \text{ m s}^{-1}$

\[ \text{(1)} \]

\[ \text{[Total 7 marks]} \]

15 Assume the two particles after the explosion have velocities $v_1$ and $v_2$.

Conservation of linear momentum gives:

\[ 2m v = m v_1 + m v_2 \]

\[ \therefore \; 2v = v_1 + v_2 \; \text{.................................}(1) \]  

As KE is doubled, this gives:

\[ 2 \times \frac{1}{2} m v^2 = \frac{1}{2} m v_1^2 + \frac{1}{2} m v_2^2 \]

\[ \Rightarrow 4v^2 = v_1^2 + v_2^2 \; \text{.................................}(2) \]  

Squaring equation (1) gives:

\[ 4v^2 = v_1^2 + 2v_1 v_2 + v_2^2 \; \text{.................................}(3) \]  

Equations (2) and (3) yield that $2v_1 v_2 = 0$, so either $v_1$ or $v_2$ must be 0.

Equation (1) means that the other particle must be moving at $2v$.

\[ \text{[Total 6 marks]} \]