Exercise 4.4 Kinetic energy and momentum

In this section of questions, you will bring together your understanding of kinetic energy (which you explored in Chapter 3) and momentum to solve problems about collisions, interactions and explosions.

1 **a** Show that the kinetic energy of a body of mass, *m*, and momentum, *p*, can be expressed as $E_K = \frac{p^2}{2m}$.

b Calculate the kinetic energy of

i a 3.0 kg mass with momentum 12.0 $kgms^{-1}$.

ii an electron of mass 9.11×10^{-31} kg with a momentum of 5.4×10^{-24} $kgms^{-1}$.

c Calculate the momentum of

i a mass of 0.60 kg with a E_K of 30.0 J. (Direction not required.)

ii a tennis ball of mass 58 g with a E_K of 26.1 J. (Direction not required.)

2 A body of mass 3 kg travelling horizontally at 4 ms^{-1} collides with, and sticks to, a stationary mass of 1 kg. Use the principle of conservation of momentum to calculate the speed of the combined masses after the collision.

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3 A falling ball of mass 0.4 kg and speed 8 ms^{-1} hits the ground and bounces back upwards with a speed of 5 ms^{-1}.

a Calculate the momentum of the ball *before* its collision with the ground.

b Calculate the momentum of the ball *after* its collision with the ground.

c How do you reconcile the principle of conservation of momentum?

TIP

Remember that 1 Pa ≡ 1 Nm^{-2}.

4 A typical molecule of gas in the air has a mass of 4.8×10^{-26} kg and moves at 500 ms^{-1}. If such a molecule collides with, and rebounds elastically from, a flat surface,

a calculate the impulse felt by the molecule.

b state the impulse felt by the flat surface.

c if 2.1×10^{27} molecules collide with, and bounce off, 1 m^2 of the surface every second, calculate the pressure that the air exerts on the surface.

5 Marcus is at a shooting range, firing bullets at bales of hay with targets on them. He uses bullets with a mass of 250 g. The bullets travel at 450 ms^{-1} when fired.

a Calculate the momentum of the bullet after it has been fired from the gun.

Marcus hits the target. The bullet lodges inside the bale of hay in a time of 0.1 s. The bale of hay has a mass of 70 kg.

b Calculate the speed of the bale of hay just after it has been hit.

c Now calculate the force that the bullet exerted on the bale of hay.

d What do your answers to **parts b** and **c** tell you about the subsequent motion of the bale of hay?

6 One of the most famous experiments in the history of physics is the Rutherford **α**-particle scattering experiment. In this experiment, which helped Rutherford to formulate a new model for the structure of an atom, **α**-particles of mass 6.64×10^{-27} kg and kinetic energy 8.0×10^{-13} **J** were fired at gold nuclei of mass 3.29×10^{-25} kg. Very occasionally, an **α**-particle bounced backwards from its interaction with a gold nucleus. Such collisions were thought to be elastic.

a Calculate the speed of an **α**-particle as it starts to approach a gold nucleus

b Hence, calculate the impulse felt by the *α*-particle during its interaction with the gold nucleus.

c Calculate the recoil speed of the gold nucleus.

d Hence, calculate the E_K of the gold nucleus after the collision.

e Comment on the validity of the assumption that the collisions between the **α**-particles and gold nuclei were elastic.

7 Consider a steel sphere, of mass, *m*, colliding elastically head-on at a speed, *u*, with a stationary identical steel sphere.

a Use conservation of linear momentum to write a general expression for the total momentum before and after the collision.

b If the collision is elastic, write a general expression for the total kinetic energy before and after the collision.

c Show that the initially stationary sphere moves off at speed, u, and the initially moving sphere stops.

8 On take-off, a space rocket expels gas of speed 3.0×10^4 ms^{-1} at a rate of 1250 kgs^{-1}. Calculate the force exerted on the rocket by the expelled gas.

TIP

Draw a vector diagram to help you visualise what is happening.

9 An eagle of mass 3.9 kg flying horizontally eastwards at a speed of 7.5 ms^{-1} collides with a seagull of mass 1.8 kg flying horizontally southwards at a speed of 3.0 ms^{-1}. On collision, the eagle holds the seagull firmly in its claws.

a Calculate the speed at which the two birds move after the collision.

b In which direction do the two birds move after the collision?

c Determine whether the collision was elastic or inelastic.

10 A rifle of mass 2.970 kg fires a cartridge of mass 32.0 g at a speed of 500 ms^{-1}.

a Calculate the recoil speed of the rifle when firing.

b What is the minimum amount of chemical energy that must be available from the cartridge during firing?