Year 12 Science: Momentum, energy and springs

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. What is the momentum of a 1200 kg car travelling at 15.0 m s^{-1}?

2. A 0.0600 kg tennis ball hits a wall at 20.0 m s^{-1} and bounces straight back at 15.0 m s^{-1}. What is its change in momentum?

3. A 60.0 kg skater and a 40.0 kg skater stand still on ice and push each other apart. The 60.0 kg skater moves off at 2.00 m s^{-1}. What is the other skater's velocity?

4. A 60.0 kg student runs up stairs 3.50 m high in 4.00 s. What power does she develop lifting herself?

5. A spring with k = 50.0 N m^{-1} is stretched by 0.120 m. How much elastic potential energy does it store?

Exam-style question: coupling rail wagons

In a rail yard, a 1500 kg wagon rolls at 2.00 m s^{-1} towards a stationary 1000 kg wagon on a level track. They couple together and move off as one. Ignore friction.

6. Calculate the momentum of the moving wagon, with its unit.

7. Calculate the speed of the coupled wagons.

8. Show that kinetic energy is not conserved in the coupling, and say where it goes.

9. The coupled wagons then run into a spring buffer with k = 2.40 × 10^{5} N m^{-1}. Calculate how far the buffer compresses as it stops them.

10. Discuss whether a stiffer buffer (bigger k) would be better for the wagons and their load.

Fix the mistake

11. Correct this statement: "A ball hits the wall at 20 m s^{-1} and bounces back at 15 m s^{-1}, so Δv = 20 − 15 = 5 m s^{-1}."

12. Correct this statement: "Momentum was conserved in the collision, so the kinetic energy must have been conserved too."

13. Correct this statement: "Doubling the compression of a spring doubles the energy it stores."

14. Correct this statement: "Work to climb stairs = 60 kg × 3.5 m = 210 J."

Answer key (for parents and tutors)

1. What is the momentum of a 1200 kg car travelling at 15.0 m s^{-1}?
   $p = mv = 1200 \times 15.0 = 18\,000$ kg m s^{-1} in the car's direction.

2. A 0.0600 kg tennis ball hits a wall at 20.0 m s^{-1} and bounces straight back at 15.0 m s^{-1}. What is its change in momentum?
   Away from the wall is positive: $\Delta p = 0.0600 \times (15.0 - (-20.0)) = 0.0600 \times 35.0 = 2.10$ kg m s^{-1} away from the wall.

3. A 60.0 kg skater and a 40.0 kg skater stand still on ice and push each other apart. The 60.0 kg skater moves off at 2.00 m s^{-1}. What is the other skater's velocity?
   Total momentum is 0 before, so $60.0 \times 2.00 + 40.0 \times v = 0$, $v = -120 \div 40.0 = -3.00$ m s^{-1}: 3.00 m s^{-1} in the opposite direction.

4. A 60.0 kg student runs up stairs 3.50 m high in 4.00 s. What power does she develop lifting herself?
   $W = mgh = 60.0 \times 9.8 \times 3.50 = 2058$ J; $P = W \div t = 2058 \div 4.00 = 514.5$ W, about 515 W.

5. A spring with k = 50.0 N m^{-1} is stretched by 0.120 m. How much elastic potential energy does it store?
   $E_p = \frac{1}{2}kx^2 = \frac{1}{2} \times 50.0 \times 0.120^2 = 0.360$ J.

6. Calculate the momentum of the moving wagon, with its unit.
   $p = mv = 1500 \times 2.00 = 3000$ kg m s^{-1} along the track (Achieved).

7. Calculate the speed of the coupled wagons.
   Momentum is conserved: $3000 = (1500 + 1000) \times v$, $v = 3000 \div 2500 = 1.20$ m s^{-1} in the same direction (Merit).

8. Show that kinetic energy is not conserved in the coupling, and say where it goes.
   Ek before = $\frac{1}{2} \times 1500 \times 2.00^2 = 3000$ J; Ek after = $\frac{1}{2} \times 2500 \times 1.20^2 = 1800$ J; 1200 J has become heat and sound in the coupling, so the collision is inelastic (Merit).

9. The coupled wagons then run into a spring buffer with $k = 2.40 \times 10^5$ N m^{-1}. Calculate how far the buffer compresses as it stops them.
   All 1800 J is stored in the spring: $\frac{1}{2}kx^2 = 1800$, $x^2 = 2 \times 1800 \div 240\,000 = 0.0150$ m^2, $x = 0.122$ m (Excellence).

10. Discuss whether a stiffer buffer (bigger k) would be better for the wagons and their load.
    The wagons' change in momentum is the same, $2500 \times 1.20 = 3000$ kg m s^{-1}, whatever the buffer. A stiffer spring stores the same 1800 J in a smaller compression ($x = \sqrt{(2Ek \div k)}$), so it stops them over a shorter distance and in a shorter time, and by $F = \Delta p \div \Delta t$ the force on the wagons and load is bigger. A softer buffer is gentler, as long as it is long enough to compress the extra distance (Excellence links Δp, time, force and the energy stored).

11. Correct this statement: "A ball hits the wall at 20 m s^{-1} and bounces back at 15 m s^{-1}, so $\Delta v = 20 - 15 = 5$ m s^{-1}."
    Directions matter: $\Delta v = -15 - 20 = -35$ m s^{-1}, a change of 35 m s^{-1} away from the wall.

12. Correct this statement: "Momentum was conserved in the collision, so the kinetic energy must have been conserved too."
    Momentum is conserved in every collision with no outside force; kinetic energy is conserved only in elastic ones.

13. Correct this statement: "Doubling the compression of a spring doubles the energy it stores."
    $E_p = \frac{1}{2}kx^2$, so doubling x makes the energy four times as big.

14. Correct this statement: "Work to climb stairs = 60 kg × 3.5 m = 210 J."
    The force is the weight, mg: $W = 60 \times 9.8 \times 3.5 = 2058$ J.