

How momentum is conserved in collisions

Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Worksheet answers

Check your working against these answers: the formula, the substitution and the result with its unit. If a sign or a unit differs from yours, find the step where it changed, because that is usually where the mistake began.

Level: Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** HS-PS2-2, HS-PS2-3

Problem 1 Units and direction

1. The unit is **kg m/s** (equivalent to N s).
2. Momentum is a **vector**, because it has size and direction.
3. It points **in the same direction as the velocity**.

Problem 2 Momentum of two movers

1. $p = mv = 65 \times 4.0 = \mathbf{260 \text{ kg m/s}}$.
2. $p = 0.045 \times 40 = \mathbf{1.8 \text{ kg m/s}}$.

Problem 3 Rearranging $p = mv$

1. $v = p \div m = 9000 \div 1500 = \mathbf{6.0 \text{ m/s}}$.
2. $m = p \div v = 36 \div 12 = \mathbf{3.0 \text{ kg}}$.

Problem 4 Convert then calculate

1. $250 \text{ g} = 0.250 \text{ kg}$ and $72 \text{ km/h} \div 3.6 = 20 \text{ m/s}$. $p = 0.250 \times 20 = \mathbf{5.0 \text{ kg m/s}}$.
2. $3.0 \text{ tonnes} = 3000 \text{ kg}$. $p = 3000 \times 10 = \mathbf{30\,000 \text{ kg m/s}}$ ($3.0 \times 10^4 \text{ kg m/s}$).

Problem 5 Light and fast or heavy and slow

1. Ball: $0.15 \times 40 = 6.0 \text{ kg m/s}$. Person: $60 \times 0.50 = 30 \text{ kg m/s}$.
2. The **person has 5.0 times more momentum** ($30 \div 6.0 = 5.0$).

Problem 6 Force for a time

1. Impulse = $Ft = 20 \times 0.50 = \mathbf{10 \text{ N s}}$.

2. Δp equals the impulse: **10 kg m/s**.

3. $v = \Delta p \div m = 10 \div 2.0 = \mathbf{5.0 \text{ m/s}}$.

Problem 7 Coupling trolleys

1. $1.5 \times 4.0 + 0 = \mathbf{6.0 \text{ kg m/s}}$.

2. $6.0 = 2.0 \times v$, so $v = \mathbf{3.0 \text{ m/s}}$.

3. Before: $\frac{1}{2} \times 1.5 \times 4.0^2 = 12 \text{ J}$. After: $\frac{1}{2} \times 2.0 \times 3.0^2 = 9.0 \text{ J}$. Lost: **3.0 J**.

Problem 8 Kicking a football

1. $\Delta p = 0.43 \times 22 - 0 = 9.46$, so **9.5 kg m/s**.

2. $F = \Delta p \div t = 9.46 \div 0.010 = 946$, so **950 N**.

Problem 9 Throwing from skates

1. $p = 3.0 \times 8.0 = \mathbf{24 \text{ kg m/s}}$ forward.

2. Total momentum stays zero, so $48 \times v = 24$ and $v = \mathbf{0.50 \text{ m/s}}$.

3. She moves **backwards**, opposite to the ball.

Problem 10 Bouncing off a wall

1. $+0.40 \times 6.0 = +2.4 \text{ kg m/s}$.

2. $0.40 \times (-4.0) = -1.6 \text{ kg m/s}$.

3. $\Delta p = -1.6 - 2.4 = \mathbf{-4.0 \text{ kg m/s}}$, so 4.0 kg m/s away from the wall.

4. $F = 4.0 \div 0.050 = \mathbf{80 \text{ N}}$ away from the wall.

Problem 11 Seat belts

1. $\Delta p = 70 \times 15 = \mathbf{1050 \text{ kg m/s}}$.

2. $F = 1050 \div 0.10 = \mathbf{10\,500 \text{ N}}$.

3. $F = 1050 \div 0.50 = \mathbf{2100 \text{ N}}$.

4. The momentum change is the same, but the longer time makes the force five times smaller, so there is less risk of injury.

Problem 12 Area under a force-time graph

1. The peak force is **600 N**.

2. $\text{Area} = \frac{1}{2} \times 0.020 \times 600 = \mathbf{6.0 \text{ N s}}$.
3. $v = 6.0 \div 0.30 = \mathbf{20 \text{ m/s}}$.
4. $F = 6.0 \div 0.020 = \mathbf{300 \text{ N}}$, half of the peak.

Problem 13 Spring-loaded trolleys

1. It equals the total before: **zero**.
2. $3.0 \times v = 2.0 \times 6.0 = 12$, so $v = \mathbf{4.0 \text{ m/s}}$ to the right.
3. $\frac{1}{2} \times 2.0 \times 6.0^2 + \frac{1}{2} \times 3.0 \times 4.0^2 = 36 + 24 = \mathbf{60 \text{ J}}$, supplied by the spring.

Problem 14 Truck and car

1. Truck: $4000 \times 5.0 = 20\,000 \text{ kg m/s}$. Car: $1000 \times 20 = 20\,000 \text{ kg m/s}$. They are **equal**.
2. Truck: $\frac{1}{2} \times 4000 \times 5.0^2 = 50\,000 \text{ J}$. Car: $\frac{1}{2} \times 1000 \times 20^2 = 200\,000 \text{ J}$.
3. Equal momentum change over equal time gives **equal forces**.
4. The car has four times more kinetic energy, so it needs four times more work from the brakes and is harder to stop in a short distance.

Problem 15 Checking a collision record

1. $0.80 \times 1.50 + 0 = \mathbf{1.20 \text{ kg m/s}}$.
2. $0.80 \times 0.50 + 0.40 \times 1.9 = 0.40 + 0.76 = \mathbf{1.16 \text{ kg m/s}}$.
3. $(1.20 - 1.16) \div 1.20 \times 100 = \mathbf{3.3 \%}$.
4. The totals agree within normal experimental error such as timing and friction, so the data **support conservation of momentum**.

Problem 16 Head-on carts

1. $3.0 \times 2.0 + 1.0 \times (-4.0) = 6.0 - 4.0 = \mathbf{+2.0 \text{ kg m/s}}$.
2. $v = 2.0 \div 4.0 = \mathbf{+0.50 \text{ m/s}}$, in the direction of the heavier cart.
3. Before: $\frac{1}{2} \times 3.0 \times 2.0^2 + \frac{1}{2} \times 1.0 \times 4.0^2 = 6.0 + 8.0 = 14 \text{ J}$. After: $\frac{1}{2} \times 4.0 \times 0.50^2 = 0.50 \text{ J}$. Lost: **13.5 J**.

Problem 17 Find the missing mass

1. $p = 4.0 \times 1.5 = \mathbf{6.0 \text{ kg m/s}}$ to the left.
2. The right-hand cart has equal momentum: $m \times 2.0 = 6.0$, so $m = \mathbf{3.0 \text{ kg}}$.
3. $\frac{1}{2} \times 4.0 \times 1.5^2 + \frac{1}{2} \times 3.0 \times 2.0^2 = 4.5 + 6.0 = \mathbf{10.5 \text{ J}}$.

Problem 18 Does the energy match?

1. $0.60 \times 5.0 = 0.60 \times 1.0 + 0.40 \times v$, so $3.0 = 0.60 + 0.40v$ and $v = \mathbf{6.0 \text{ m/s}}$.
2. Before: $\frac{1}{2} \times 0.60 \times 5.0^2 = 7.5 \text{ J}$. After: $\frac{1}{2} \times 0.60 \times 1.0^2 + \frac{1}{2} \times 0.40 \times 6.0^2 = 0.30 + 7.2 = \mathbf{7.5 \text{ J}}$.
3. The kinetic energy is unchanged, so the collision is **elastic**.

Problem 19 Landing from a vault

1. $v^2 = 2gh = 2 \times 9.8 \times 1.8 = 35.28$, so $v = \mathbf{5.9 \text{ m/s}}$.
2. $p = 45 \times 5.94 = \mathbf{270 \text{ kg m/s}}$ (267 before rounding).
3. $F = 267 \div 0.050 = \mathbf{5300 \text{ N}}$.
4. $F = 267 \div 0.40 = \mathbf{670 \text{ N}}$, eight times smaller.

Problem 20 Spot the error

1. The student treated both momenta as positive, but the trolleys move in opposite directions, so one momentum must be negative.
2. $(2.0 \times 3.0 - 1.0 \times 3.0) \div 3.0 = 3.0 \div 3.0 = \mathbf{1.0 \text{ m/s}}$ in the direction of the 2.0 kg trolley.
3. The momenta partly cancel while the mass moved doubles up, so the speed drops: the result is **less than 3.0 m/s**.