

Momentum conservation, impulse and collision types

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Each answer states the principle, then the substitution and the result with its unit. Check the signs of velocities carefully, because a lost minus sign is the most common error in momentum problems. Keep extra digits until the final step.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB A.2

Problem 1 Key relationships

1. $p = m v$, in kg m/s.
2. Impulse = $F \Delta t = \Delta p = m v - m u$, in N s.
3. No external resultant force acts on the system.
4. Kinetic energy is conserved in an elastic collision and not in an inelastic one; momentum is conserved in both.

$$\mathbf{p = m v; J = F \Delta t = \Delta p.}$$

Problem 2 Motorbike momentum

1. $54 \text{ km/h} = 54\,000 \div 3600 = 15 \text{ m/s}$.
2. $p = m v = 210 \times 15 = 3150 \text{ kg m/s}$.
3. Momentum is proportional to speed, so the value doubles: $2 \times 3150 = 6300 \text{ kg m/s}$.

$$\mathbf{p = 3150 \text{ kg m/s; } 6300 \text{ kg m/s.}}$$

Problem 3 Pushing a cart

1. $J = F \Delta t = 70 \times 6.0 = 420 \text{ N s}$.
2. $\Delta p = J = 420 \text{ kg m/s}$.
3. $v = \Delta p \div m = 420 \div 85 = 4.9 \text{ m/s}$.

$$\mathbf{J = 420 \text{ N s; } v = 4.9 \text{ m/s.}}$$

Problem 4 Same unit, two names

1. $1 \text{ N} = 1 \text{ kg m/s}^2$, so $1 \text{ N s} = 1 \text{ kg m/s}^2 \times \text{s} = 1 \text{ kg m/s}$.
2. $m = 2500 \text{ kg}$ and $v = 10 \text{ m/s}$, so $p = 2500 \times 10 = 25\,000 \text{ kg m/s}$.

$$\mathbf{p = 2.5 \times 10^4 \text{ kg m/s.}}$$

Problem 5 Catching a volleyball

1. $\Delta p = 0 - 0.27 \times 6.0 = -1.62 \text{ kg m/s}$, a loss of 1.62 kg m/s .

2. $F = \Delta p \div \Delta t = 1.62 \div 0.15 = 10.8 \text{ N}$.

$\Delta p = 1.62 \text{ kg m/s}$; $F = 11 \text{ N}$.

Problem 6 Jumping off a raft

1. $p = 60 \times 2.5 = 150 \text{ kg m/s}$.

2. Total momentum stays zero, so the raft has 150 kg m/s the opposite way: $v = 150 \div 90 = 1.7 \text{ m/s}$.

$v = 1.7 \text{ m/s backwards}$.

Problem 7 Railway wagons

1. $12\,000 \times 2.0 = 20\,000 \text{ v}$, so $v = 24\,000 \div 20\,000 = 1.2 \text{ m/s}$.

2. Before: $\frac{1}{2} \times 12\,000 \times 2.0^2 = 24\,000 \text{ J}$. After: $\frac{1}{2} \times 20\,000 \times 1.2^2 = 14\,400 \text{ J}$.

3. Lost = $24\,000 - 14\,400 = 9600 \text{ J}$.

$v = 1.2 \text{ m/s}$; 9.6 kJ lost .

Problem 8 Basketball bounce

1. Area = $\frac{1}{2} \times 0.020 \times 260 = 2.6 \text{ N s}$.

2. $F = J \div \Delta t = 2.6 \div 0.020 = 130 \text{ N}$.

3. $J = m v - m u$: $2.6 = 0.40 v - 0.40 \times (-5.0)$, so $0.40 v = 0.60$ and $v = 1.5 \text{ m/s upwards}$.

$J = 2.6 \text{ N s}$; average $F = 130 \text{ N}$; $v = 1.5 \text{ m/s}$.

Problem 9 Cycling into soft sand

1. $F = \Delta p \div \Delta t = 75 \times 6.0 \div 0.80 = 562.5 \text{ N}$.

2. $F = 450 \div 0.050 = 9000 \text{ N}$.

3. The change in momentum is identical, so a longer stopping time gives a smaller average force and less injury.

560 N ; $9.0 \times 10^3 \text{ N}$.

Problem 10 Rain on a shed

1. Volume per hour = $0.025 \times 40 = 1.0 \text{ m}^3$, so mass = $1000 \text{ kg per } 3600 \text{ s} = 0.278 \text{ kg/s}$.

2. $F = (\Delta m / \Delta t) v = 0.278 \times 12 = 3.3 \text{ N}$.

0.28 kg/s ; $F = 3.3 \text{ N}$.

Problem 11 Gliders on an air track

1. $v_1 = (0.60 - 0.20) \times 5.0 \div 0.80 = 2.5 \text{ m/s}$ and $v_2 = 2 \times 0.60 \times 5.0 \div 0.80 = 7.5 \text{ m/s}$.

2. Before: $0.60 \times 5.0 = 3.0 \text{ kg m/s}$. After: $0.60 \times 2.5 + 0.20 \times 7.5 = 1.5 + 1.5 = 3.0 \text{ kg m/s}$.

3. Approach 5.0 m/s ; separation $7.5 - 2.5 = 5.0 \text{ m/s}$.

$v_1 = 2.5 \text{ m/s}$; $v_2 = 7.5 \text{ m/s}$.

Problem 12 Model rocket

1. $p = 0.050 \times 120 = 6.0 \text{ kg m/s}$ downwards.
 2. The rocket and its remaining fuel (0.75 kg) gain 6.0 kg m/s upwards: $v = 6.0 \div 0.75 = 8.0 \text{ m/s}$.
- $v = 8.0 \text{ m/s}$ upwards.**

Problem 13 Bullet and ball

1. Bullet: $0.0040 \times 500 = 2.0 \text{ kg m/s}$. Ball: $0.50 \times 4.0 = 2.0 \text{ kg m/s}$.
 2. Bullet: $\frac{1}{2} \times 0.0040 \times 500^2 = 500 \text{ J}$. Ball: $\frac{1}{2} \times 0.50 \times 4.0^2 = 4.0 \text{ J}$.
 3. Both need the same impulse (2.0 N s) to stop, but the bullet carries 125 times the kinetic energy, so it does more damage.
- Equal momentum 2.0 kg m/s; KE 500 J and 4.0 J.**

Problem 14 Checking glider data

1. Before: $0.30 \times 0.80 + 0.20 \times (-0.60) = 0.24 - 0.12 = 0.12 \text{ kg m/s}$. After: $0.30 \times (-0.32) + 0.20 \times 1.08 = -0.096 + 0.216 = 0.12 \text{ kg m/s}$.
2. Before: $\frac{1}{2} \times 0.30 \times 0.64 + \frac{1}{2} \times 0.20 \times 0.36 = 0.096 + 0.036 = 0.132 \text{ J}$. After: $\frac{1}{2} \times 0.30 \times 0.1024 + \frac{1}{2} \times 0.20 \times 1.1664 = 0.01536 + 0.11664 = 0.132 \text{ J}$.
3. Both are conserved, so the collision was **elastic**.

Problem 15 Catching a fast ball

1. $F = 0.16 \times 25 \div 0.010 = 400 \text{ N}$.
 2. $F = 4.0 \div 0.060 = 66.7 \text{ N}$.
 3. The impulse (4.0 N s) is the same, so six times the time gives one sixth of the force.
- 400 N and 67 N.**

Problem 16 Crossroads collision

1. Car: $1000 \times 20 = 20\,000 \text{ kg m/s}$ east. Van: $2000 \times 10 = 20\,000 \text{ kg m/s}$ north.
 2. Total momentum = $\sqrt{(20\,000^2 + 20\,000^2)} = 28\,284 \text{ kg m/s}$. $v = 28\,284 \div 3000 = 9.4 \text{ m/s}$.
 3. $\tan \theta = 20\,000 \div 20\,000 = 1$, so $\theta = 45^\circ$ north of east.
 4. Before: $\frac{1}{2} \times 1000 \times 400 + \frac{1}{2} \times 2000 \times 100 = 300\,000 \text{ J}$. After: $\frac{1}{2} \times 3000 \times 9.43^2 = 133\,333 \text{ J}$. Lost = $1.7 \times 10^5 \text{ J}$.
- $v = 9.4 \text{ m/s}$ at 45° north of east; $1.7 \times 10^5 \text{ J}$ lost.**

Problem 17 Ballistic pendulum

1. After the impact, $\frac{1}{2} M V^2 = M g h$, so $V = \sqrt{2 \times 9.81 \times 0.20} = 1.98 \text{ m/s}$.
2. Momentum: $0.015 v = 2.5 \times 1.98$, so $v = 4.95 \div 0.015 = 330 \text{ m/s}$.
3. KE before = $\frac{1}{2} \times 0.015 \times 330^2 = 817 \text{ J}$. KE after = $\frac{1}{2} \times 2.5 \times 1.98^2 = 4.9 \text{ J}$. Fraction lost = $(817 - 4.9) \div 817 = 0.994$.

$V = 1.98 \text{ m/s}$; $v = 330 \text{ m/s}$; 99 % lost.

Problem 18 Grain on a conveyor

1. Δp per second $= 40 \times 2.0 = 80 \text{ kg m/s per second}$.
2. $F = 80 \text{ N}$.
3. $P = F v = 80 \times 2.0 = 160 \text{ W}$.
4. KE per second $= \frac{1}{2} \times 40 \times 2.0^2 = 80 \text{ W}$. The other 80 W is lost as thermal energy because the grain slips on the belt before it reaches belt speed.

$F = 80 \text{ N}$; $P = 160 \text{ W}$; 80 W wasted.

Problem 19 Force readings in a kick

1. Each 2.0 ms strip has area $\frac{1}{2} (F_1 + F_2) \times 0.0020$: $(250 + 750 + 1250 + 1250 + 750 + 250) \times 0.0020 = 4500 \times 0.0020 = 9.0 \text{ N s}$.
2. $v = J \div m = 9.0 \div 0.45 = 20 \text{ m/s}$.
3. F average $= 9.0 \div 0.012 = 750 \text{ N}$.
4. The peak force of 1500 N is twice the average of 750 N.

$J = 9.0 \text{ N s}$; $v = 20 \text{ m/s}$; average $F = 750 \text{ N}$.

Problem 20 Elastic collision proof

1. Momentum: $m_1(u_1 - v_1) = m_2(v_2 - u_2)$. Energy: $m_1(u_1^2 - v_1^2) = m_2(v_2^2 - u_2^2)$. Dividing the second by the first gives $u_1 + v_1 = v_2 + u_2$, so $u_1 - u_2 = v_2 - v_1$.
 2. $v_2 = v_1 + 8.0$. Momentum: $0.20 \times 6.0 + 1.0 \times (-2.0) = -0.80 = 0.20 v_1 + 1.0 (v_1 + 8.0)$, so $1.2 v_1 = -8.8$ and $v_1 = -7.33 \text{ m/s}$, $v_2 = 0.67 \text{ m/s}$.
 3. Before: $\frac{1}{2} \times 0.20 \times 36 + \frac{1}{2} \times 1.0 \times 4 = 3.6 + 2.0 = 5.6 \text{ J}$. After: $\frac{1}{2} \times 0.20 \times 53.8 + \frac{1}{2} \times 1.0 \times 0.444 = 5.38 + 0.22 = 5.6 \text{ J}$.
- $v_1 = -7.3 \text{ m/s}$; $v_2 = +0.67 \text{ m/s}$.**