

Exercise walk-through

4.1

Impulse and two-dimensional collisions (statements 81–86, CP9–10)

Scattering links observation to a model

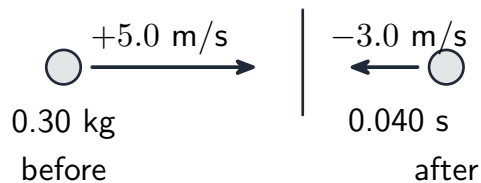
Observation / symbol	Supported conclusion
Most pass nearly straight	Most atomic volume is empty
Rare large deflections	Tiny, dense, positive nucleus
A_ZX	Proton number Z ; nucleon number A ; neutrons $A - Z$

The quark–lepton model organises particles

Family	Constituents / example
Baryon	Three quarks; proton uud
Meson	Quark + antiquark; pion
Lepton / antilepton	Electron / positron
Photon	Electromagnetic quantum

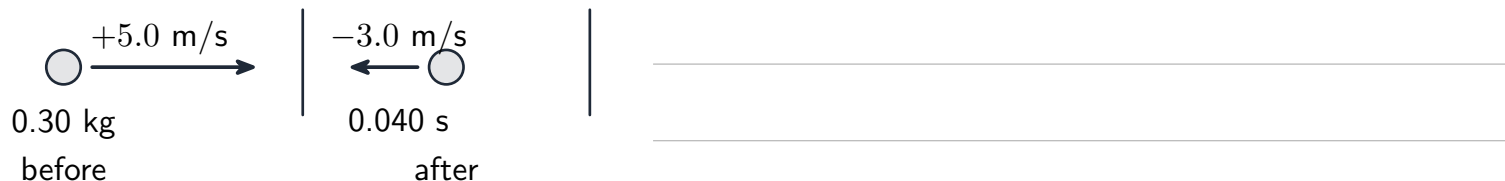
Exercise 2.1

2.1 A 0.30 kg ball moves at $+5.0 \text{ m s}^{-1}$ and rebounds at -3.0 m s^{-1} after 0.040 s of contact. Calculate its impulse and average force, stating directions. [4]



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2.1 Rebound reverses the velocity sign.

$$\Delta p = m(v - u) = 0.30 \text{ kg} \times (-3.0 - 5.0) \text{ m s}^{-1} = -2.4 \text{ kg m s}^{-1}$$

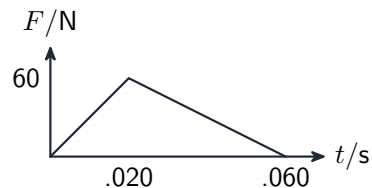
Impulse is negative, opposite the approach. Use impulse per contact time.

$$F_{\text{av}} = \frac{\Delta p}{\Delta t} = \frac{-2.4 \text{ kg m s}^{-1}}{0.040 \text{ s}} = -60 \text{ N}$$

Average force is 60 N opposite approach.

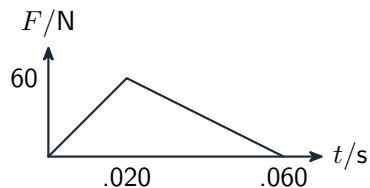
Exercise 2.2

2.2 A force pulse rises linearly from zero to 60 N in 0.020 s and falls linearly to zero at 0.060 s. It acts in the positive direction on a 0.40 kg trolley initially at rest. Find impulse and final speed. Explain why using 60 N as average force is wrong. [5]



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2.2 Integrate the triangular pulse.

$$J = \frac{1}{2} F_{\max} \Delta t = \frac{1}{2} \times 60 \text{ N} \times 0.060 \text{ s} = 1.8 \text{ N s}$$

Impulse +1.8 N s. Use $J = m(v - u)$ with $u = 0$.

$$v = \frac{J}{m} = \frac{1.8 \text{ N s}}{0.40 \text{ kg}} = 4.5 \text{ m s}^{-1}$$

Final speed. The force is below its maximum for almost all the interval; its average here is half the peak.

Exercise 2.3

2.3 Two non-relativistic particles have equal kinetic energy. Their masses are m and $4m$. Derive an expression for kinetic energy in terms of momentum and mass, then find the ratio of their momenta, heavier to lighter. [3]

 m $4m$ equal E_k

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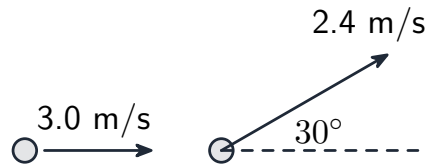
2.3 Rearrange momentum to eliminate velocity.

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2}m \left(\frac{p}{m} \right)^2 = \frac{p^2}{2m}$$

At equal energy, $p \propto \sqrt{m}$, so heavier:lighter is 2 : 1.

Exercise 3.1

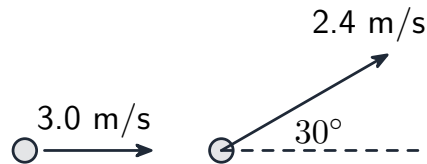
3.1 A 0.20 kg puck moving at 3.0 m s^{-1} along $+x$ strikes an identical stationary puck. Afterwards the first moves at 2.4 m s^{-1} at $+30.0^\circ$ to x . Find the second puck's two velocity components and its speed and direction. Test whether the collision is elastic. Assume negligible external impulse. [7]



equal masses 0.20 kg

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3.1 Resolve the momentum in both axes; equal masses cancel.

$$v_{2x} = u - v_1 \cos \theta = 3.0 \text{ m s}^{-1} - 2.4 \text{ m s}^{-1} \cos 30.0^\circ = 0.922 \text{ m s}^{-1}$$

x component.

Full solution 3.1

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$$v_{2y} = -v_1 \sin \theta = -2.4 \text{ m s}^{-1} \sin 30.0^\circ = -1.20 \text{ m s}^{-1}$$

y component. Recombine perpendicular components.

$$v_2 = \sqrt{v_{2x}^2 + v_{2y}^2} = \sqrt{0.922^2 + 1.20^2} \text{ m s}^{-1} = 1.51 \text{ m s}^{-1}$$

$$\beta = \tan^{-1} \left(\frac{|v_{2y}|}{v_{2x}} \right) = \tan^{-1} \left(\frac{1.20}{0.922} \right) = 52.5^\circ$$

Speed and direction 52.5° below $+x$. Compare total kinetic energies.

$$E_{k,b} = \frac{1}{2} m u^2 = \frac{1}{2} \times 0.20 \text{ kg} \times (3.0 \text{ m s}^{-1})^2 = 0.900 \text{ J}$$

Kinetic energy decreases: inelastic.

Exercise 3.2

3.2 Describe how a force sensor, light gates and data logger can test impulse equals momentum change for a trolley collision. Include processing, a sampling issue, a cause of systematic disagreement and one safety measure. [6]



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3.2 Measure trolley mass and use light gates with a measured interrupt length for velocities immediately before and after. Zero the force sensor and use consistent positive directions for force and velocity. Integrate the entire force–time pulse, including signed areas. Compare that impulse with $m(v - u)$ over repeated trials. Choose high enough sampling rate to resolve the short pulse; a missed peak, sensor offset or friction can cause systematic disagreement. Secure the track and catch the trolley to prevent falls.

Exercise 3.3

3.3 A student films two spheres colliding and finds momentum conserved to within 3% but kinetic energy apparently increases by 4%. Explain how to obtain the two velocity components from the film, identify two calibration or recording controls, and explain why the reported percentages alone cannot establish a real energy gain. [6]

overhead film



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3.3 Track sphere centres over several frames before and after contact and divide calibrated x and y displacements by the time interval. Put a length scale in the collision plane. Use a known frame rate and camera perpendicular to the plane to reduce perspective error. Calculate kinetic energies from both components and measured masses, propagating or estimating uncertainty. A 4% increase may lie within the combined energy uncertainty, especially because velocity is squared. For a passive collision, investigate calibration/tracking errors or an additional energy source before claiming a physical increase; agreement of momentum to 3% does not by itself validate energy to 4%.