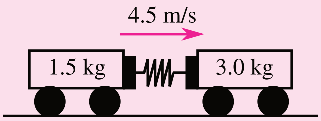
20 Momentum Conservation

momentum (kg m/s) = mass (kg) × velocity (m/s) $p = mv$

change in momentum (kg m/s) = force (N) × time (s) $p_{\text{after}} - p_{\text{before}} = Ft$

The sign of the momentum (plus or minus) tells you the direction.
In these one dimensional problems, positive momentum means 'travelling East' and negative momentum means 'travelling West'.

Example 1



Two motion trolleys are moving East. The spring expands, and pushes the trolleys apart. It pushes the 3.0 kg trolley forwards with a 2.5 N force for 1.2 s. What is the change in momentum change of each trolley?

Momentum change of 3.0 kg trolley = Ft = 2.5 N × 1.2 s = 3.0 kg m/s

By Newton's 3rd Law, force on 1.5 kg trolley must be 2.5 N West (−2.5 N).

Momentum change of 1.5 kg trolley = Ft = −2.5 N × 1.2 s = −3.0 kg m/s.

The momentum gained by the 3.0 kg trolley is equal to the momentum lost by the 1.5 kg trolley. So the total momentum stays the same.

So, when forces act between objects, their total momentum is conserved.

Example 2 – Calculate the new velocity of the 1.5 kg trolley.
Momentum = old momentum + change = 1.5 × 4.5 − 3 = 3.75 kg m/s
New velocity = momentum / mass = 3.75 / 1.5 = 2.5 m/s (2.5 m/s East)

Example 3 – A 2.5 kg mass travelling at 2.5 m/s collides with and sticks to a 7.5 kg mass which is stationary. Calculate the velocity afterwards.
Total initial momentum: 2.5 kg × 2.5 m/s + 7.5 kg × 0 m/s = 6.25 kg m/s
Total final momentum must be the same = 6.25 kg m/s
Final velocity = momentum / mass = 6.25 / 10.0 = 0.63 m/s (2 sf)

20.1 Calculate the momentum of:

(a) a 3.0 kg trolley moving at 2.0 m/s to the East;

(b) a 700 kg car moving at 6.0 m/s to the West;

(c) a 50 g mass moving at 50 cm/s to the East;

(d) a 10 000 kg bus moving Eastwards at 3.0 m/s.

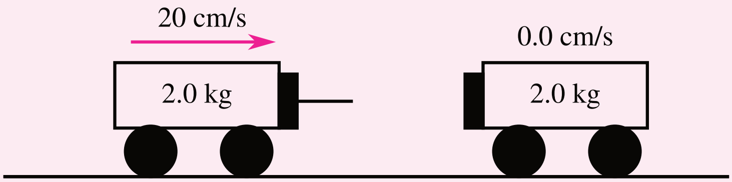
(e) What is the total momentum of the car in (b) and the bus in (d)?

(f) If the car and the bus were to collide and stick together in a crumpled mess, what would the total mass of the wreckage be just after the impact?

(g) What would the total momentum of the crumpled mass be?

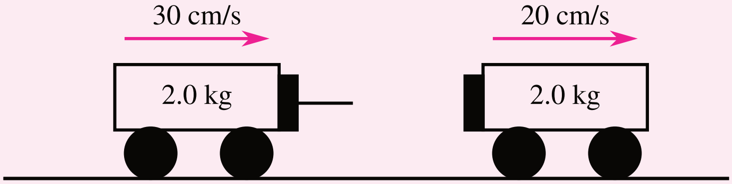
(h) Calculate the initial velocity of the wreckage.

20.2 Two 2.0 kg trolleys collide and stick together on a smooth, horizontal surface. One trolley is at rest before the collision.



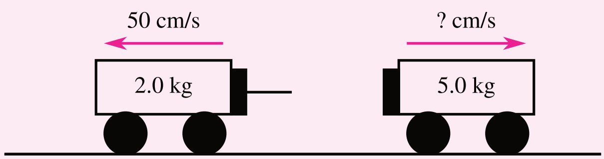
Calculate the combined velocity of the trolleys after the collision.

20.3 Two trolleys are moving in the same direction along a smooth surface. One is moving faster and catches up on the other. The trolleys collide and stick together.



Calculate the combined velocity of the trolleys after the collision.

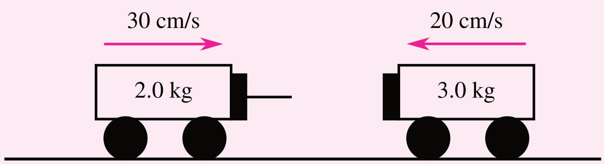
20.4 Two trolleys are at rest and in contact on a smooth, level surface. A coiled spring in one trolley is released so that they 'explode' apart. The lighter trolley moves off at 50 cm/s.



(a) Calculate the speed of the other trolley.

(b) Calculate the minimum energy which was stored in the coiled spring before the release. *[Hint: see Kinetic Energy P34]*

20.5 Two trolleys are moving in opposite directions along a smooth surface. The trolleys collide and stick together.



(a) What is the total momentum of the trolleys before and after the collision?

(b) What is the trolleys' combined velocity after the collision?

20.6 Complete the following table for two objects A and B, travelling together until pushed apart by explosions. 'm_A' means 'mass of A'.

m_A (kg)	m_B (kg)	Initial combined velocity (m/s)	Final v_A (m/s)	Final v_B (m/s)
2.5	2.5	0.0	(a)	+2.0
2.5	5.0	0.0	−6.8	(b)
2.5	7.5	5.0	−4.0	(c)
9.0	(d)	−4.0	−5.0	+6.0

20.7 A 10 g bullet (0.010 kg) is fired at 250 m/s Eastwards towards a 10 kg sandbag.

(a) Calculate the momentum of the bullet.

(b) What is the total momentum before the collision?

The bullet enters the sandbag and stops inside it:

(c) What is the total momentum now?

(d) Calculate the speed of the sandbag.

20.8 A 70 kg astronaut has a 20 kg backpack, and is stranded, stationary, in space 30 m to the West of her spacecraft. To get back to safety, she hurls the backpack at a speed of 4.2 m/s.

(a) Which way does she need to throw the backpack?

(b) What is the total momentum before she throws it?

(c) What is the momentum of the backpack after throwing?

(d) What will the astronaut's momentum be after she has thrown the backpack?

(e) What is the astronaut's velocity after she has thrown the backpack?

(f) How much time does it take her to get back to the spacecraft?

20.9 The exhaust from a rocket on a test rig leaves the engine at $2\,800$ m/s. How many kilograms of propellant (fuel and oxidizer) need to be burnt every second to provide a force of 3.5×10^8 N?

20.10 A conveyor belt is used to move coal along a horizontal shaft in a coal mine. How much force needs to be applied horizontally to the belt to keep it moving at 1.2 m/s if 40 kg of coal is dropped onto it every second? Assume that the coal has no horizontal velocity before it touches the belt and the belt's turning mechanism is well lubricated.