19 Introducing Momentum and Impulse

Momentum measures how much 'motion' an object has, taking into account its mass and velocity.

$$\text{momentum} = \text{mass (kg)} \times \text{velocity (m/s)} \qquad p = mv$$

The unit of momentum is kilogram metres per second (kg m/s)

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'.

Momentum is a vector – it has a direction.

19.1 Complete the table. Each row represents a separate situation.

Mass	Velocity (m/s)	Momentum (kg m/s)
2.0 kg	+4.5	(a)
1.6 kg	−3.4	(b)
50 g	2.5 East	(c)
60.3 kg	31 West	(d)
120 kg	Stationary	(e)
360 kg	(f)	1 200 East
2.0 g	(g)	2.0 West

Example 1 – A 3.0 kg motion trolley is moving at 2.0 m/s East. A force of 4.2 N acts on it for 6.0 s.
Acceleration = force / mass = $4.2\ \text{N} / 3.0\ \text{kg} = 1.4\ \text{m/s}^2$
Velocity change = acceleration × time = $1.4\ \text{m/s}^2 \times 6.0\ \text{s} = 8.4\ \text{m/s}$
New velocity = $2.0\ \text{m/s} + 8.4\ \text{m/s} = 10.4$ East m/s
Original momentum = mass × velocity = $3.0\ \text{kg} \times 2.0\ \text{m/s} = +6.0\ \text{kg m/s}$
New momentum = $3.0\ \text{kg} \times 10.4\ \text{m/s} = +31.2\ \text{kg m/s}$
Change in momentum = $31.2\ \text{kg m/s} - 6.0\ \text{kg m/s} = +25.2\ \text{kg m/s}$
Notice that force × time = $4.2\ \text{N} \times 6.0\ \text{s} = +25.2\ \text{Ns}$

The last line of the example suggests:

$$\text{change in momentum (kg m/s)} = \text{force (N)} \times \text{time (s)}$$

$$p_{\text{after}} - p_{\text{before}} = Ft$$

19.2 A 5.0 kg trolley is initially moving at 3.5 m/s West. A 12.4 N force (East) acts on it for 3.5 s. Take 'travelling East' as being positive, and 'travelling West' as being negative.

(a) Calculate the acceleration

(b) Calculate the velocity change

(c) Calculate the original momentum

(d) Calculate the new momentum

(e) Calculate the change in momentum

(f) Is the change in momentum equal to the product of the force and time?

19.3 Complete the table. Each row represents a separate situation. You should fill the different columns in the easiest order (which may not be left to right). The first row has been worked as an example.

m (kg)	v (m/s)		p (kg m/s)			F (N)	t (s)
	Before	After	Before	Change	After		
1.0	0.0	180	0.0	180	180	3.0	60
2.5	0.0	(a)	(b)	(c)	(d)	4.2	12
25	0.0	(e)	(f)	(g)	(h)	16.9	300
700	10	31	(i)	(j)	(k)	(l)	12
1 800	13	0.0	(m)	(n)	(o)	−12 000	(p)
15 g	0.0	250	(q)	(r)	(s)	(t)	2.0 ms

Example 2 - First row of table above
Momentum before $= mu = 1.0 \text{ kg} \times 0.0 = 0.0 \text{ kg m/s}$
Momentum change $= Ft = 3.0 \text{ N} \times 60 \text{ s} = 180 \text{ kg m/s}$
Momentum afterwards $= 0.0 + 180 = 180 \text{ kg m/s}$
Velocity afterwards $=$ momentum$/$mass $= 180/1.0 = 180 \text{ m/s}$

Impulse

We define impulse (Ns) = force (N) × time (s)

so impulse (Ns) = change in momentum (kg m/s)

So, a moving object with 400 kg m/s of momentum would need a 400 N force to stop it in one second.

Newton's 2nd Law: resultant force = rate of change of momentum.

19.4 What magnitude of force is needed to accelerate a 300 000 kg wide-body jet from 0.0 m/s to take off speed of 90 m/s in 50 s?

19.5 What will the momentum of a 200 kg rocket be after a 10 kN force has pushed it for four minutes?

19.6 At what speed is a 20 gram air rifle pellet moving if it has a momentum of 1.6 kg m/s?

19.7 A girl on a 10 kg bicycle is riding it at a speed of 6.0 m/s. If the momentum of the girl and bicycle is 360 kg m/s, what is the mass of the girl?

19.8 Your mass is 60.6 kg and you are about to land on your feet after a jump, falling at 0.85 m/s.
Calculate the force on each leg if:

(a) you bend your knees and stop in 0.75 s;

(b) you keep your knees locked and stop in 0.082 s.

19.9 An 800 kg car is travelling at 70 mph and overtaking a 15 000 kg truck travelling at 55 mph. Calculate the ratio of the momentum of the truck to the momentum of the car ($p_{\text{truck}} / p_{\text{car}}$).

19.10 Calculate the momentum of a 20 000 tonne ship moving through the water at a speed of 12 m/s. [Note: 1 tonne = 1000 kg]

Additional Introducing Momentum and Impulse Questions

19.11 A car is travelling at 15 m/s. It has 18 000 kg m/s of momentum. What is the car's mass?

19.12 Two cars are travelling in the same direction. One has a mass of 1 000 kg and is moving at 10 m/s, the other's mass is 1 200 kg and it is moving at 15 m/s. What is the total momentum of the cars?