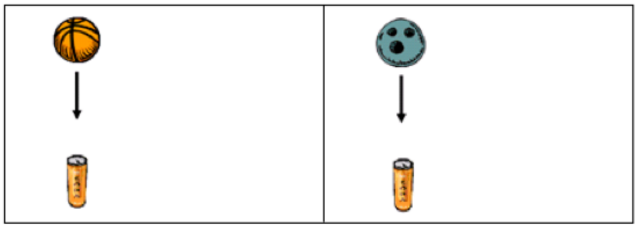
Momentum

Demonstration 1 | Demonstration 2



Is there a way the results could have been identical?

have basketball move very fast
or
bowling ball very slowly

Mass: amount of matter in an object

Inertia: resistance to change in motion

Kinetic energy: energy of motion

Momentum: product of mass and velocity

Formula: $\vec{p} = m\vec{v}$

Direction: same as $\vec{v}$

Symbol	$\vec{p}$	m	$\vec{v}$
Quantity	momentum	mass	velocity
Units	[kg·m/s]	[kg]	[m/s]
Type	vector	scalar	vector

1. What is the momentum of a 1500 kg car traveling east at 20. m/s?

$\vec{p} = m\vec{v}$
$= 1500\,kg \cdot 20\,m/s = 3 \times 10^4\,kg\,m/s$ East

Did you know?

Momentum is so fundamental in Newton's mechanics that Newton called it simply "quantity of motion." The symbol for momentum, **p**, comes from Leibniz's use of the term *progress*, defined as "the quantity of motion with which a body proceeds in a certain direction."

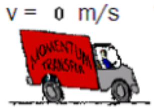
2. Compare the inertia, momentum, and kinetic energy of a 100. kg football player running at 2.0 m/s and a 50. kg field hockey player running at 3.0 m/s.

Inertia	Momentum	Kinetic energy
F: 100kg ✓	$m\vec{v} = 200\,kg\,m/s$ ✓	$\frac{1}{2}mv^2 = 200\,J$
H: 50kg	$m\vec{v} = 150\,kg\,m/s$	$\frac{1}{2}mv^2 = 225\,J$ ✓

Compare the quantities listed below for each pair of objects.

v = 25 m/s v = 25 m/s

v = 0 m/s v = 25 m/s



v = 7 m/s v = 3 m/s

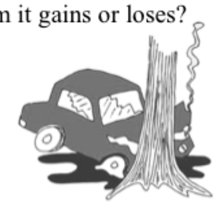
Inertia	✓	
Momentum	✓	
Kinetic Energy	✓	

Inertia	✓	
Momentum		✓
Kinetic Energy		✓

Inertia	mass	
Momentum	✓	
Kinetic Energy	✓	

How does an object gain or lose momentum? What determines how much momentum it gains or loses?

A force is applied for a certain amount of time.



Impulse

1. a change in momentum
2. the product of force and the amount of time the force acts

Formula: $\vec{a} = \frac{\Sigma \vec{F}}{m}$ $\vec{a} = \frac{\Delta \vec{V}}{t}$

$\vec{J} = \vec{F} \cdot t = m \Delta \vec{V} = \Delta \vec{p}$

impulse = change in momentum

Symbol	$\vec{J}$ (or $\vec{I}$)	$\Delta \vec{p}$
Quantity	impulse	change in momentum
Units	[N·s]	[kg m/s]
Type	vector	vector

1. A 50. kg runner accelerates from 2.0 m/s to 3.0 m/s. What is her:
   a) initial momentum?
   b) final momentum?
   c) change in momentum?
   d) What impulse did she apply?

a) $\vec{p} = m\vec{v} = 50kg \cdot 2.0 m/s = 100 \, kg\,m/s$

b) $\vec{p} = m\vec{v} = 50kg \cdot 3 m/s = 150 \, kg\,m/s$

c) $\Delta\vec{p} = \vec{p}_f - \vec{p}_i = 50 \, kg\,m/s$

d) $\vec{J} = \Delta\vec{p} = 50 \, N \cdot s$

2. A player kicks a 0.50 kg soccer ball with an average force of 10. N. His foot is in contact with the ball for 0.40 s.

a) What impulse does he apply to the ball?

$\vec{J} = \vec{F}_{avg} \cdot t = 10N \cdot .4s = 4 \, N \cdot s$

b) How much does the momentum of the ball change as a result?

$\Delta\vec{p} = \vec{J} = 4 \, kg\,m/s$

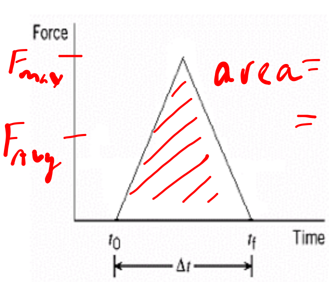
c) What is the final velocity of the soccer ball?

$\Delta\vec{p} = m\Delta\vec{v} \rightarrow \Delta\vec{v} = \Delta\vec{p}/m = \frac{4 \, kg\,m/s}{.5 \, kg} = 8 \, m/s$

Notice that the force

a) not instantaneous

b) not constant



F_{max}, F_{avg}

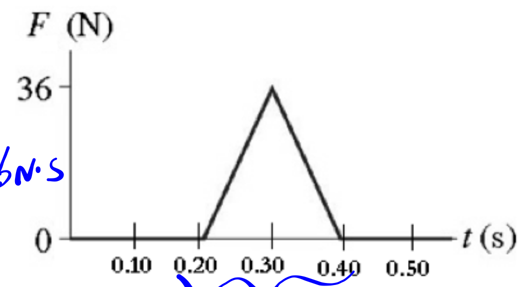
area $= \Delta\vec{p} = \vec{J}$

3. How can an impulse be determined from a force-time graph?

$area = F_{avg} \cdot t$

$= \left(\frac{1}{2} F_{max}\right) t$

4. A player kicks a 0.50 kg football and the force versus time graph is shown at right.



a) What impulse does he apply to the ball?

$F_{Avg} = 18N \qquad F_{avg}\cdot t = 18N\cdot .2s = 3.6 N\cdot s$

b) How much does the momentum of the ball change as a result?

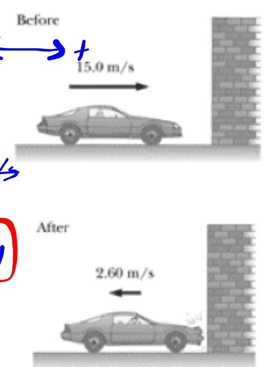
$\Delta\vec{p} = \vec{J} = 3.6 kg\,m/s$

$.2s$

c) How fast is the football going after the kickoff?

$m\Delta\vec{v} = \Delta\vec{p} \rightarrow \Delta\vec{v} = \frac{\Delta\vec{p}}{m} = \frac{3.6\,kg\,m/s}{.5\,kg}$ **7.2 m/s**

5. A 1500. kg car is in contact with a wall for 0.15 seconds. Calculate:



a) its change in momentum

$\vec{p}_i = m\vec{v} = 1500kg\cdot 15m/s$

$= 22,500\,kg\,m/s$

$\vec{p}_f = m\vec{v} = 1500kg\cdot -2.6m/s$

$= -3900\,kg\,m/s$

$\Delta\vec{p} = \vec{p}_f - \vec{p}_i = -3900\,kg\,m/s - 22,500\,kg\,m/s$

$= -26,400\,m/s\cdot kg$

b) the impact force

$- \leftrightarrow +$

$\vec{J} = \vec{F}\cdot t = \Delta\vec{p}$

$\vec{F} = \frac{\Delta\vec{p}}{t} = \frac{-26,400\,kg\,m/s}{.15\,s}$

$= -1.8\times 10^5\,N$

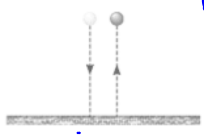
6. Why do coaches always tell you to "follow through" on the ball?

increase contact time for *same force*, increase momentum, for a given mass, increase velocity

7. Which cannon will shoot the cannonball further? Why?

longer barrel, longer contact time, greater impulse (greater change in momentum)

8. Compare the impulse when a 1.0 kg ball bounces off the floor to when it doesn't.

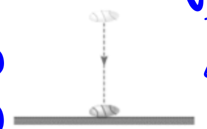


$\vec{v}_f = -\vec{v}_i$

$\Delta\vec{p} = \vec{p}_f - \vec{p}_i = m(\vec{v}_f - \vec{v}_i)$

$m(-\vec{v}_i - \vec{v}_i)$

$= 2(-m\vec{v}_i)$



$\vec{v}_f = 0$

$\Delta\vec{p} = m\Delta\vec{v} = m(\vec{v}_f - \vec{v}_i)$

$= -m\vec{v}_i$

In general, bouncing requires more impulse than crashing (bumper cars = dangerous)

Impact Force

Demonstration 1	Demonstration 2

1. Compare the change in momentum of the egg in each case.

same

2. Compare the impulse exerted on each egg.

same

3. Explain the differences in results.

$F \cdot t = F \cdot t$

4. If your brakes fail in your car, would you rather drive into a brick wall or a haystack? Why?

haystack - increase contact time,
reduce average, peak impact force

5. Why are airbags used in cars? What are some other safety devices that operate on the same principle?

increase contact time, reduce impact force = safer

crumple zones, bumpers, etc

6. What are some other examples of this principle?

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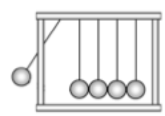
7. Compare the impact force, contact time, impulse, acceleration, and change in momentum for each vehicle in the impending collision.

Principle of Conservation of Momentum



Isolated system:

Meaning of principle:

Formula:

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1)