Lesson 3.3: Momentum and Impulse

Unit 3: Momentum and Energy

Momentum:

* the product of mass × velocity
* Vector quantity (in direction of $\vec{v}$)

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

p = momentum * ($kg \cdot m/s = N \cdot s$)
m = mass (kg)
v = velocity (m/s)

Example 1 – Momentum of a single object: Find the momentum of an 1800 kg car travelling at 60 km/h.

$\frac{60 km}{h} \times \frac{1 h}{3600 s} \times \frac{1000 m}{1 km} = 16.\bar{6} m/s$

$\vec{p} = m\vec{v}$
$\vec{p} = (1800 kg)(16.\bar{6} m/s)$
$\vec{p} = 3.0 \times 10^4 N \cdot s$

Concept: Mass and Velocity are directly proportional to momentum	
What happens to momentum when… (p = mv)	
Mass is tripled	3p
Velocity is quadrupled	4p
Mass is doubled and velocity is halved	Moment stays the same

A force acting over a period of time — **Impulse** — Δ in momentum

Amount of momentum transfered to an object

$\vec{J} = \vec{F}_{net} \cdot \Delta t$ ($\vec{F}_{net}$: Avg Force (N); Δt: change in time (s))

Impulse

Units: $N \cdot s = kg \cdot \frac{m}{s^2} \cdot s = kg \cdot \frac{m}{s}$

* Remember the units for momentum → $\vec{p} = m \cdot \vec{v}$

Deriving Impulse from Newton's 2nd Law

$\vec{F}_{net} = m\vec{a}$

$\vec{F}_{net} = m\left(\frac{\Delta \vec{v}}{\Delta t}\right)$

$\vec{F}_{net} = m\left(\frac{\vec{v} - \vec{v}_o}{\Delta t}\right)$

$\vec{F}_{net} = \frac{m\vec{v} - m\vec{v}_o}{\Delta t}$

$\vec{F}_{net}\Delta t = m\vec{v} - m\vec{v}_o$

$\vec{J} = \vec{p} - \vec{p}_o = \Delta \vec{p}$

Concept: *Imagine dropping onto a trampoline vs. a hard floor, or catching a baseball with your bare hand vs a padded glove.*

The impulse – total momentum change – is the same in each case.
How can this be? What happens to force and time?

Example 2: A 0.5 kg baseball is falling at 20 m/s. A player catches it:

1. **Case A:** catches it with bare hands, stopping it in 0.05 s.
2. **Case B:** catches it in a padded glove, stopping it in 0.20 s.

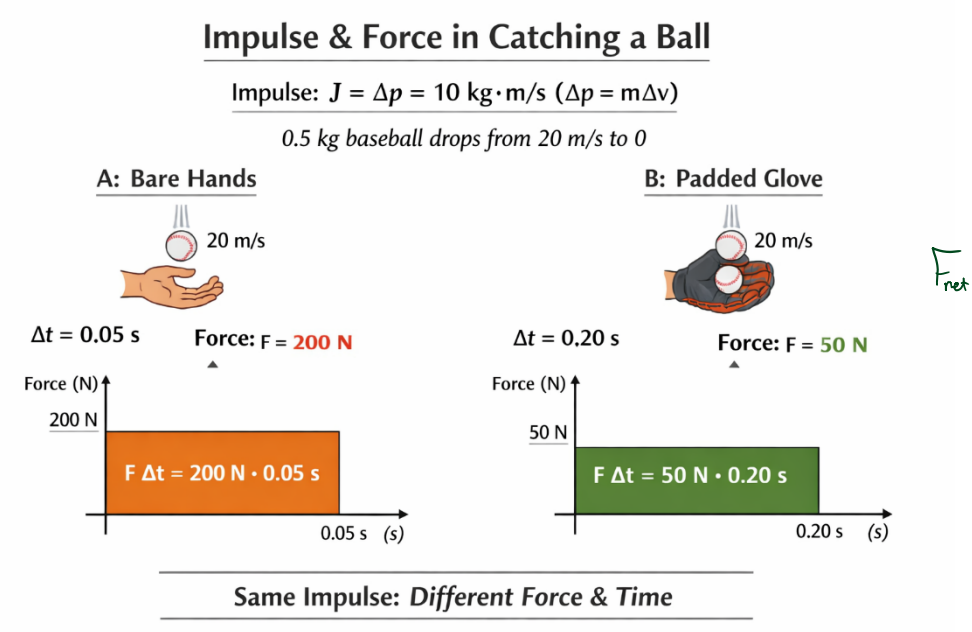
Question: How does the force on the ball differ? What is the impulse?

$J = F_{net}\,\Delta t$

$F_{net} = \frac{J}{\Delta t}$

$= \frac{10\,N\cdot s}{0.05s}$

$= 200N$



$F_{net} = \frac{J}{\Delta t}$

$= \frac{10\,N\cdot s}{0.2s}$

$= 50N$

Example 4 – Impulse with angles: A 2000 kg car changes velocity from 16.7 m/s North to 8.3 m/s East. Find the impulse.

$m = 2000kg$

$V_o = 16.7m/s\ [N]$

$V_f = 8.3m/s\ [E]$

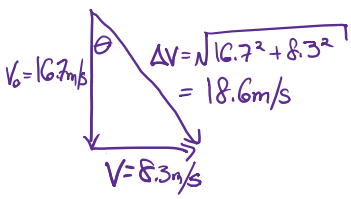
$\vec{J} = \Delta\vec{p} = m\Delta\vec{v}$ ← we have 2-D for velocity so lets use vector addition/subtraction

$\Delta\vec{p} = 2000(18.6)$

$\Delta\vec{p} = 3.7\times10^4\,N\cdot s,\ 26°\ E\ of\ S.$

$\Delta\vec{V} = V - V_o$

$= V + (-V_o)$



$\tan^{-1}\left(\frac{8.3}{16.7}\right) = 26°$

Example 5 – A conservation of momentum problem where one object becomes two: An 1800 kg car is traveling at 6.0 m/s when a 250 kg moose jumps on top of the hood.

$m_c = 1800\,kg$

$m_m = 250\,kg$

$V_{co} = 6.0\,m/s$

$V_{mo} = 0\,m/s$

Momentum is Conserved $\Rightarrow$

$p_{mo} + p_{co} = p_{m+cf}$

$m_m v_{mo} + m_c v_{co} = (m_m + m_c) v$

$1800(6) = (250 + 1800) v$

$V_f = 5.3\,m/s$

$F_{A\,on\,B} = -F_{B\,on\,A}$

$\frac{\Delta(m_A v_A)}{\Delta t} = -\frac{\Delta(m_B v_B)}{\Delta t}$

$\Delta p_A = -\Delta p_B$

$\Delta p_A + \Delta p_B = 0$

Example 6 – A conservation of momentum problem where 2 objects collide and stay 2: A 1200 kg car is travelling 30 km/h west and collides with a 300 kg car traveling 40 km/h east. Afterwards the first car is travelling 5.0 km/h east. What is the resulting velocity of the second car?

$m_1 = 1200\,kg$

$V_{1o} = -30\,km/h\ [W]$

$m_2 = 300\,kg$

$V_{2o} = 40\,km/h\ [E]$

$V_1 = 5.0\,km/h\ [E]$

*Conserved Momentum

$m_1 V_{1o} + m_2 V_{2o} = m_1 V_1 + m_2 V_2$

$V_2 = \frac{m_1 V_{1o} + m_2 V_{2o} - m_1 V_1}{m_2}$

$V_2 = \frac{1200(-30) + 300(40) - 1200(5)}{300}$

$V_2 = -100\,km/h = 100\,km/h\ West$

Assignment: Sander-Gore Pgs. 72-63 #1-10 | Extra Practice Pg. 61 #1-3