Applying Newton’s Laws

Auburn Mountainview

Karl Steffin, 2006

8/5/2024

Quick or Slow

- Until now problems had continual forces which produced continual acceleration.
- What about in sports where a soccer ball is kicked, a baseball thrown or a volleyball hit?
  - – In these cases a brief contact is made which only allows for a brief acceleration (and force).

Impulse [v]

- Impulse is the application of a force during a set amount of time.

$$J = F\Delta t$$

Impulse = Force x Time (N·s)


What Does This Mean?

- A large impulse produces a large response and vice versa.
- It is normally thought that a large kick/hit will allow a ball to travel quickly.
  - What if a cannon ball is hit with a bat?
- From Newton’s first law Inertia showed the importance of mass in the ability to move an object.

Momentum [v]

- Momentum is a way to show the relationship of mass and velocity to eachother.

$$p = mv$$

Momentum = mass x velocity (SI: kg·m/s)

$$\Delta p = \Delta mv$$

$\Delta p = mv_f - mv_o$ or $\Delta p = m_f v - m_o v$

Bringing it Together

- From F_{NET} = ma, Impulse, and Momentum:

Impulse-Momentum Theory

$F = ma$

$$a = \frac{(v_f - v_o)}{\Delta t}$$

$$F = \frac{m(v_f - v_o)}{\Delta t}$$

$$F\Delta t = m(v_f - v_o)$$

$$J = \Delta p$$

Impulse = Change in Momentum

I-M Theory I

While teeing off Jordan Spieth drives the ball (45-g) from rest to 38-m/s in just 3-ms.

m/s is not ms! One is velocity the other time (m=10^{-3}).

A. What is the change in momentum of the ball?
B. What impulse is applied on the ball?
C. What force is applied to the ball?

I-M Theory I cont

A. What is the change in momentum of the ball?

Another solving method: Set up a table.

$p=m\mathcal{v}$	Initial (o)	Final (f)
m (kg)	.045	.045
$\mathcal{v}$ (m/s)	0	38

$$\Delta p = mv_f - mv_o$$

$$\Delta p = .045 - kg \cdot 38\frac{m}{s} - .045 - kg \cdot 0\frac{m}{s}$$

$$\Delta p = 1.71 - kg\frac{m}{s}$$

I-M Theory I cont

B. What impulse is applied on the ball?

We will use the 'formula' but really the only concern is changing the unit.

$$J = \Delta p$$

$$J = 1.71 - kg\frac{m}{s}$$

J = x

Δp = 1.71-kg·m/s

$$J = 1.71 - Ns$$

I-M Theory I cont

C. What force is applied to the ball?

$$J = F\Delta t$$

$$1.71 - kg\frac{m}{s} = F \cdot .003 - s$$

J = 1.71-N·s
F = x
t = 3.00 x 10^{-3}-s

$$F = 570.00 - N$$

I-M Theory II

A baseball (m=149-g) approaches a bat horizontally at a speed of 42-m/s and is hit straight back with a speed of 45-m/s. If the ball is in contact of the bat for a time of 1.10-ms, what is the average force exerted on the ball by the bat?

c/o 2013 #22 J. Cassano
vs. PHS GSHR (5/12/13)

I-M Theory II cont

Start by finding the change in momentum…

p=mv	Initial	Final
m (kg)	.149	.149
v (m/s)	-42.00	45.00

$$\Delta p = mv_f - mv_o$$

$$\Delta p = .149 - kg \cdot 45 - \frac{m}{s} - .149 - kg \cdot -42 - \frac{m}{s}$$

$$\Delta p = 12.96 - kg\frac{m}{s}$$

I-M Theory II cont

To find the Force use the I-M theory.

$$\mathbf{J = \Delta p}$$

$$\mathbf{J = F\Delta t}$$

$$\mathbf{\Delta p = F\Delta t}$$

$$\boldsymbol{12.96 - Ns = F \cdot .0011 - s}$$

$$\boldsymbol{11784 - N = F}$$

Δp = 12.96-kg·m/s
F = x
t = 1.10 x 10^{-3}-s

$$\boldsymbol{F = 1.18x10^{4} - N}$$

Conservation of Momentum

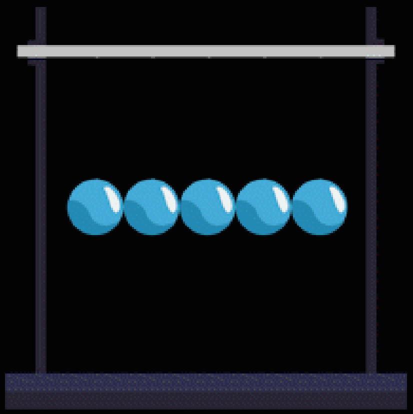
- In a closed system (no outside forces) it is assumed that there will be no change in momentum.

Conservation of Linear Momentum

$$\Sigma p_o = \Sigma p_f$$

$$m_1 v_{o1} + m_2 v_{o2} = m_1 v_{f1} + m_2 v_{f2} \text{ (Elastic)}$$

$$m_1 v_{o1} + m_2 v_{o2} = (m_1 + m_2) v_f \text{ (Inelastic)}$$



Con Mom Example I

- To make a 7-10 split a bowler must hit a pin at just the right angle. The ball (5.50-kg) traveling at 7.60-m/s hits the pin (1.55-kg). The ball continues traveling at 6.50-m/s. What is the speed of the pin (assume no energy is lost)?
  - Since no Energy is lost this will be an elastic collision.

Con Mom Example I cont

p=mv	Ball	Pin
m (kg)	5.50	1.55
v_o (m/s)	7.60	0.00
v_f (m/s)	6.50	x

$$p_o = p_f$$

$$5.5 - kg \cdot 7.6 - \frac{m}{s} + 0 - kg\frac{m}{s} = 5.5 - kg \cdot 6.5 - \frac{m}{s} + 1.55 - kg \cdot v_f$$

$$41.8 - kg - \frac{m}{s} = 35.75 - kg - \frac{m}{s} + 1.55 - kg \cdot v_f$$

$$v_f = 3.90 - \frac{m}{s}$$

Con Mom Example II

- A 2270.00-kg car going 28.00-m/s rear ends a 875.00-kg car going 16.00-m/s and their bumpers lock. What is the speed of the wreckage as soon as they lock up (assume no friction or loss of momentum) ?
  - Since the bumpers lock this will be an inelastic collision and since the final velocities must be same the final equation can be:

$$m_1 v_{o1} + m_2 v_{o2} = (m_1 + m_2) v_f$$

Con Mom Example II cont

p=mv	Car 1	Car 2	Wreckage
m (kg)	2270	875	3145
v (m/s)	v_o = 28.0	v_o =16.0	v_f

$$m_1 v_{o1} + m_2 v_{o2} = (m_1 + m_2) v_f$$

$$2270 - kg \cdot 28 - \frac{m}{s} + 875 - kg \cdot 16 \frac{m}{s} = 3145 - kg \cdot v_f$$

$$63560 - \frac{m}{s} + 14000 - \frac{m}{s} = 3145 \cdot v_f$$

$$v_f = 24.67 - \frac{m}{s}$$

Con Mom Example III

- At rest in space, Mike Massimino fires a thruster gun that expels 35.00-g of gas at 875.00-m/s. Assuming the mass of the astronaut and gun is 84.00-kg what is the recoil velocity of the astronaut?

Con Mom Example III cont

p=mv	Initial	Gas	Astronaut+Gun
m (kg)	84.04	.0350	84.0
v (m/s)	$v_o = 0$	$v_{fg} = 875$	v_{fa}

$$0 = m_1 v_{f1} + m_2 v_{f2}$$

$$0 = .035 - kg \cdot 875 - \frac{m}{s} + 84 - kg \cdot v_f$$

$$84 \cdot v_f = -30.625 - \frac{m}{s}$$

$$v_f = -3.65x10^{-1} - \frac{m}{s}$$

Center of Mass

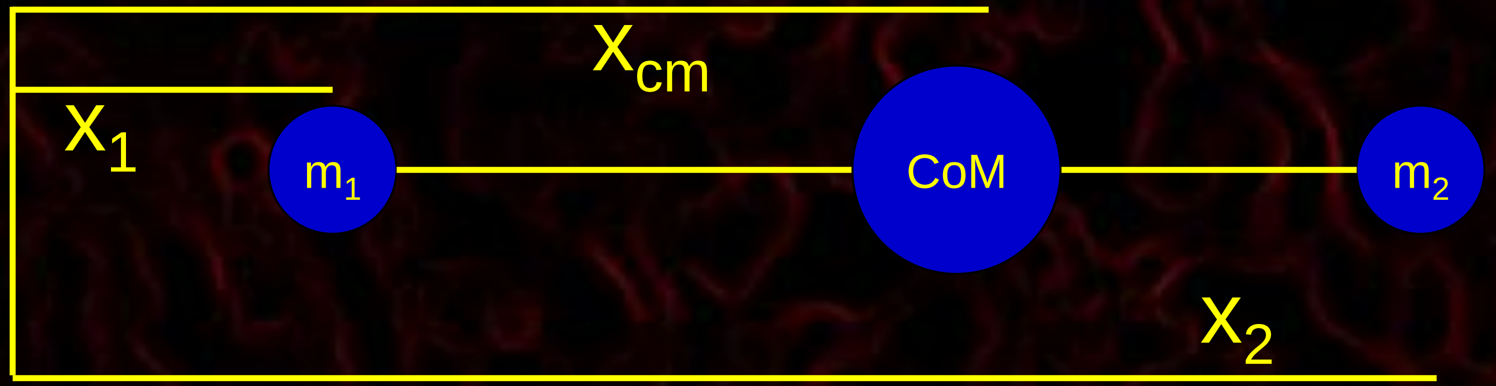
- Physics measures the masses of both large and small objects.
- For simplicity's sake when looking at an objects mass, it can be thought of as if it were at a singular point.
- Thinking of the mass of an object as a single point does not influence the mathematical outcome.
  - Another way to think about it: I can replace a group of objects with one object.
  - The one object must have a mass equal to all the others and placed somewhere between where the group of objects were.

Center of Mass

- Center of Mass (cm): To consider two (or more) objects as one:

$$x_{cm} = \frac{m_1x_1 + m_2x_2 + m_nx_n}{\Sigma m}$$

- The CoM will be closer to the more massive object.



CoM Example

- A server brings dinner on a 1-m tray: Fish and chips (850-g) sits on the far edge, dessert (400-g) sits on the other edge and the drink (350-g) sits .2 meters from the soda.
- What is the force needed to carry the tray? Where does the server place their hand to keep it balanced?



Reference Point

x_{fc} (1-m)

x_d (1.8-m)

x_s (2-m)

CoM Example cont.

- The force needed is nothing more than adding all the items together.

  F = (.85+.35+.4)-kg * 9.8-m/s2

  F = 15.68-N

- For the balancing point:

Ref.	F&C	Dessert	Soda
m (kg)	.85	.35	.4
d (m)	1	1.8	2

CoM Example cont.

Ref.	F&C	Dessert	Soda
m (kg)	.85	.35	.4
d (m)	1	1.8	2



Reference Point

x_{fc} (1-m)

x_d (1.8-m)

x_s (2-m)

$$cm = \frac{m_{fc}x_{fc} + m_d x_d + m_s x_s}{m_{fc} + m_d + m_s}$$

CoM Example cont.

$$\text{CoM} = \frac{.85\text{-kg}\cdot 1\text{-m} + .35\text{-kg}\cdot 1.8\text{-m} + .4\text{-kg}\cdot 2\text{-m}}{(.85 + .35 + .4)\text{-kg}}$$

$$\text{CoM} = \frac{2.28\text{-kg}\cdot\text{m}}{1.6\text{-kg}}$$

CoM = 1.425-m

Remember to take away the reference distance (1-m).

CoM = .425-m or 4.25×10^{-1}-m from the left side.

The server can put all three items .43-m from the left edge and feel the same (force/balance).