AP Physics 1 & C

Momentum & Impulse

Spring 2020

Linear Momentum

Key words
equations

Notes

$p = m \cdot v$

mass

velocity

p: momentum

m: mass

v: velocity

UNITS: $kg \frac{m}{s}$

The importance of momentum, unlike the importance of energy, was recognized early in the development of classical physics. Momentum was deemed so important that it was called the “quantity of motion.” Newton actually stated his second law of motion in terms of momentum: The net external force equals the change in momentum of a system divided by the time over which it changes. Using symbols, this law is

$\mathbf{F}\text{net}=\Delta\mathbf{p}\Delta t$,

(a) Calculate the momentum of a 110-kg football player running at 8.00 m/s. (b) Compare the player’s momentum with the momentum of a hard-thrown 0.410-kg football that has a speed of 25.0 m/s.

Momentum

Equations & Key Words

scalar ↓ $p = m \cdot V$ dir $kg \cdot \frac{m}{s}$	p: momentum m: mass V: velocity
p is always same dir. as velocity	Scalar: magnitude Vector: mag & dir

$F = m \cdot a$

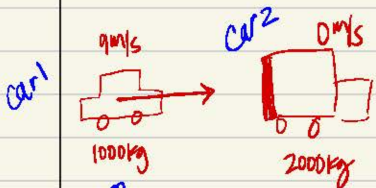
$= m \cdot \frac{\Delta V}{\Delta t}$

$= \frac{\Delta(m \cdot V)}{\Delta t} = \frac{\Delta p}{\Delta t} = F$

impulse — same units as p

$p = m \cdot v$

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



$p_2 = (2000kg)(0 m/s)$

$p_2 = 0$

$p_1 = m_1 v_1 = (9 m/s)(1000 kg)$

$p_1 = 9000 \, kg\,m/s$

$p_1 + p_2 = p_1' + p_2'$

$9000 \, kg\,m/s + 0 = m_T \cdot v_T$

velocity both cars stuck

$9000 \, kg\,m/s = (3000kg)(v_T)$

$v_T = \frac{9000}{3000} = \boxed{3 m/s}$ East

$p_i = p_f$

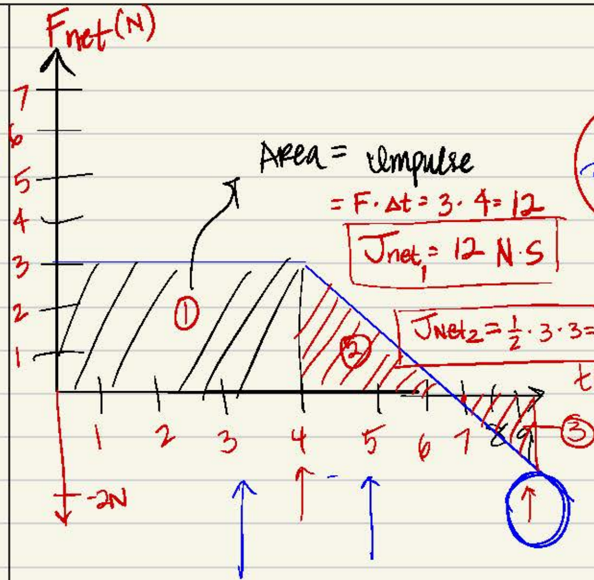
$p_i = p_1 + p_2$

$p_f = p_1' + p_2'$

Force vs. Time Graph

(momentum)
$p = m \cdot v$

Δp (impulse) $= F \cdot \Delta t$
J; (N) (s)



Area = impulse
$= F \cdot \Delta t = 3 \cdot 4 = 12$

$\boxed{J_{net_1} = 12\ N \cdot S}$

$\boxed{J_{net_2} = \frac{1}{2} \cdot 3 \cdot 3 = 4.5\ N \cdot S}$

$J_{net_3} = \frac{1}{2}(2)(-2N)$

$\boxed{J_{net_3} = -2NS}$

$J_{net} = J_{net_1} + J_{net_2} + J_{net_3} = 12 + 4.5 - 2$

$J_{net} = 14.5\ NS$

$J_{net} = \Delta p = m_f v_f - m_i v_i$

$14.5\ NS = (2.9kg)(v_f) - (2.9kg)(4m/s)$

Solve for $v_f > 0$

$14.5 + (2.9 \cdot 4) = 2.9 v_f$

$v_f = \frac{14.5 + 2.9 \cdot 4}{2.9} = 9m/s$

Example Question:

Question: Two blocks of mass 3M and M head toward each other sliding over a frictionless surface with speeds 2v and 5v respectively and stick together. In which direction will the two masses slide across the frictionless floor after the collision?

P: power

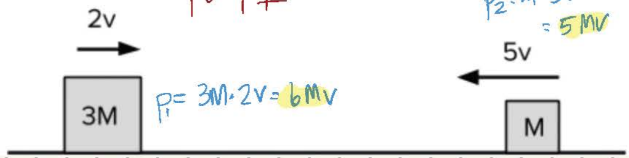
p: mom.

$p = m \cdot v$

A. Left
B. Right
C. They stop upon collision
D. Not enough info

$p_i = p_f$

$p_2 = M \cdot 5v = 5Mv$



$p_1 = 3M \cdot 2v = 6Mv$

Example Question:

Question: A bouncy ball of mass M is is initially moving to the right toward a wall with a speed 2v as seen below. The ball recoils off the wall with a speed v. What is the magnitude of the impulse on the ball from the wall?

Wall

A. Mv
B. 2Mv
C. 3Mv
D. 4Mv

$p = m \cdot v$ $\qquad J = \frac{dp}{dt}$

$\Delta p = J$ (impulse)

$= m_f v_f - m_i v_i$

$J = m_f v_f - m_i v_i$

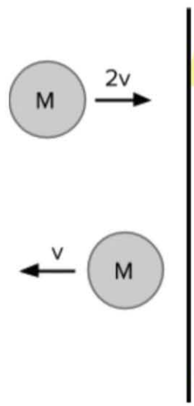
$= M(-v) - M(2v)$

$J = -Mv - 2Mv$

$= -3Mv$

[redacted]

$J_{wall} = 3Mv$



Example Question:

Question: A toy rocket of mass 2kg is initially heading to the right with a speed of 10m/s. A force in the horizontal direction is exerted on the rocket as shown in the graph below. What is the velocity of the rocket at time t=10s?

$Ns = kg\frac{m}{s}$

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

A. 20m/s
B. 40m/s
C. -20m/s
D. -40m/s

$J_1 = -J_2$

$J_{net} = J_3$

$= -60\,N{\cdot}s$

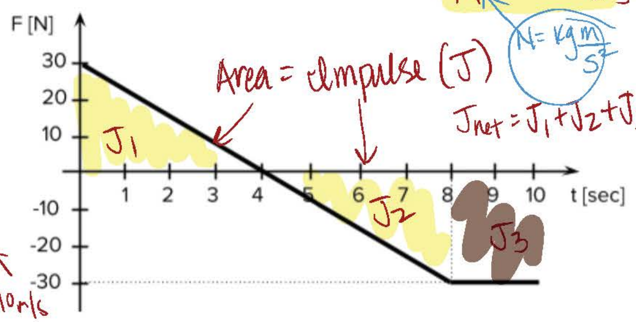
Area = Impulse (J)

$J_{net} = J_1 + J_2 + J_3$

[redacted]

$\Delta p = -60Ns = m_f v_f - m_i v_i$

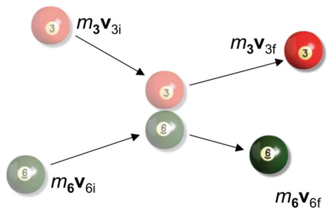
2kg $\quad$ 2kg $\quad$ 10m/s



Conservation of Momentum

Conservation?

Two particles that are interacting with each other via some force apply equal and opposite forces to each other (Newton's 3rd Law), for some amount of time *t*.



$$F_{36} = -F_{63}$$

$$\frac{dp_3}{dt} = \frac{-dp_6}{dt}$$

$$\frac{d(p_3 + p_6)}{dt} = 0$$

$$p_3 + p_6 = \text{constant}$$

$$p_3 + p_6 = p_3' + p_6'$$

Law of Conservation of Momentum (isolated sys)

Whenever two or more particles in an *isolated* system interact, their total momentum remains constant.

$$p_1 + p_2 = p_1' + p_2'$$

$$m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$$

Example 1

Alex (*m*=75 kg) sits on a 5kg cart with no-friction wheels, and gets hit by a 7.0 kg bowling ball with a velocity of 5.0 m/s.

a) What is Alex's velocity after catching the ball?

$$m_1v_1 + m_2v_2 = (m_1 + m_2)v_{final}$$

$$(7.0kg)(5.0m/s) + (80kg)(0) = (7+80)v_{final}$$

$$v_{final} = \frac{35kg \bullet m/s}{87kg} = 0.40m/s$$

b) What is Alex's velocity after the collision if the bowling ball bounces off with a velocity of -0.50 m/s?

$$m_1v_1 + m_2v_2 = m_1v_{1-final} + m_2v_{2-final}$$

$$(7.0kg)(5.0m/s) + (80kg)(0) = (7)(-0.5) + (80)v_{final}$$

$$v_{final} = \frac{35 + 3.5}{80} = 0.48m/s$$

Example 2

Alex (still 75 kg) sits on the 5 kg cart and slams into the wall with an initial velocity of 90 km/h. The collision lasts 0.257 seconds.

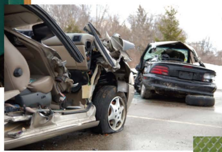
a)What was the impulse in this collision?

b) What *average* force is exerted on Alex during the collision?

Collisions

Elastic

Inelastic



Perfectly inelastic

Collisions

$KE = \frac{1}{2}mv^2$

- *Elastic collisions:* $K_1 + K_2 = K_1' + K_2'$ & $\mathbf{p}_1 + \mathbf{p}_2 = \mathbf{p}_1' + \mathbf{p}_2'$

$$\frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2 = \frac{1}{2}m_1 v_1'^2 + \frac{1}{2}m_2 v_2'^2$$

$$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v}_1' + m_2\mathbf{v}_2'$$

Bounce & momentum

- *Inelastic collisions:*

$$\mathbf{p}_1 + \mathbf{p}_2 = \mathbf{p}_1' + \mathbf{p}_2' \quad \text{or}$$
$$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v}_1' + m_2\mathbf{v}_2'$$

Momentum conserved

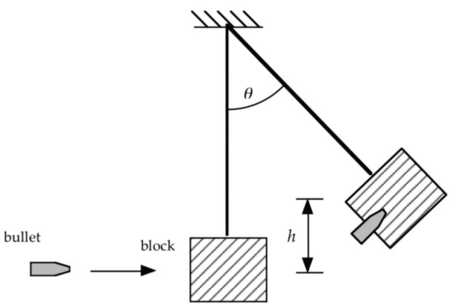
- ***Perfectly** inelastic collisions:*

$$\mathbf{p}_1 + \mathbf{p}_2 = \mathbf{p}_1' + \mathbf{p}_2' \quad \text{or}$$
$$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = (m_1 + m_2)\mathbf{v}_2'$$

Stick

Example 4

A ballistic pendulum is used to measure the speed of a projectile: a 5-gram bullet is fired into a 1-kg block of wood, which swings up to a height of 5-cm.



Find the initial speed of the projectile, and the energy lost in the collision.

For pendulum swinging up, use Cons. of Energy:

$$K_i = U_f$$

$$\frac{1}{2}mv_{bottom}^2 = mgh$$

$$v_{bottom} = \sqrt{2gh} = \sqrt{2(9.8m/s^2)(0.05m)}$$

$$v_{bottom} = 0.99m/s$$

For collision, use Cons. of Momentum:

$$m_{bullet}v_{bullet} + m_{block}v_{block} = \left(m_{bullet} + m_{block}\right)v'$$

$$(0.005kg)v_{bullet} + 0 = (1.005kg)(0.99m/s)$$

$$v_{bullet} = 199m/s$$

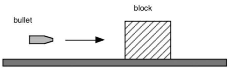
Example 5

Tarzan (69kg) is on the ground, about to be eaten by a tiger. Jane (62 kg) climbs 14 meters up a nearby tree and swings down towards the ground on a vine. She swings past Tarzan, grabbing him as she passes by, and they swing together up into another tree.

What is the maximum height that Jane and Tarzan can reach on their upswing?

Example 6

A 100 gram rubber bullet is fired horizontally at an 800 gram block of wood which is sitting on top of a flat surface. The coefficient of kinetic friction between the block of wood and the surface is 0.70., and the block slides 50 cm before coming to rest.



If the bullet collided *elastically* with the block, what were its initial and final velocities?

Example 6

$$\tfrac{1}{2}m_1 v_{1i}^2 + \tfrac{1}{2}m_2 v_{2i}^2 = \tfrac{1}{2}m_1 v_{1f}^2 + \tfrac{1}{2}m_2 v_{2f}^2$$ KE Conservation

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$ Mom. Conservation

$$m_1(v_{1i}^2 - v_{1f}^2) = m_2(v_{2f}^2 - v_{2i}^2)$$

$$m_1(v_{1i} - v_{1f})(v_{1i} + v_{1f}) = m_2(v_{2f} - v_{2i})(v_{2f} + v_{2i})$$

$$m_1(v_{1i} - v_{1f}) = m_2(v_{2f} - v_{2i})$$

Divide eqns to get :

$$\boxed{(v_{1i} + v_{1f}) = (v_{2f} + v_{2i})}$$

Useful relationship for 1-d elastic collision problems

$$F_{net} = ma,\ F_f = ma,\ \mu mg = ma,\ a = (0.7)(9.80) = 6.86 m/s^2 (a\ \ of\ \ block)$$

$$v_f^2 = v_i^2 + 2a\Delta x,\ v_i = \sqrt{2a\Delta x} = \sqrt{2(6.86)(.50)} = 2.62 m/s\ (v_i\ \ of\ \ block)$$

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

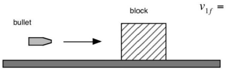
$$0.1 v_{1i} + 0 = 0.1 v_{1f} + (0.8)(2.62) \rightarrow v_{1i} = v_{1f} + 20.96$$

$$(v_{1i} + v_{1f}) = (v_{2f} + v_{2i})$$

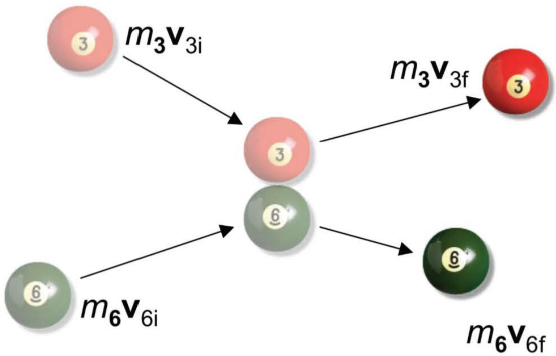
$$v_{1i} + v_{1f} = (2.62 + 0)$$

Combine eqns to get

$$v_{1f} = -9.17 m/s,\ v_{1i} = 11.79 m/s$$



2-D Collisions



$$\mathbf{p}_{1i} + \mathbf{p}_{2i} = \mathbf{p}_{1f} + \mathbf{p}_{2f}$$

$$x: \quad m_1\mathbf{v}_{1ix} + m_2\mathbf{v}_{2ix} = m_1\mathbf{v}_{1fx} + m_2\mathbf{v}_{2fx}$$

$$y: \quad m_1\mathbf{v}_{1iy} + m_2\mathbf{v}_{2iy} = m_1\mathbf{v}_{1fy} + m_2\mathbf{v}_{2fy}$$

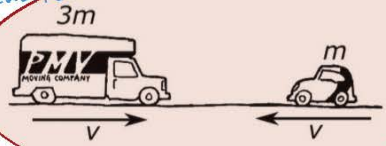
$$\tfrac{1}{2}m_1{v_{1i}}^2 + \tfrac{1}{2}m_2{v_{2i}}^2 = \tfrac{1}{2}m_1{v_{1f}}^2 + \tfrac{1}{2}m_2{v_{2f}}^2$$

Scenario

A toy car of mass m and a toy truck with a mass 3m travel in opposite directions at identical speeds. The truck moves to the right and the car moves to the left. The two toys collide and stick together.

So the masses add

Inelastic



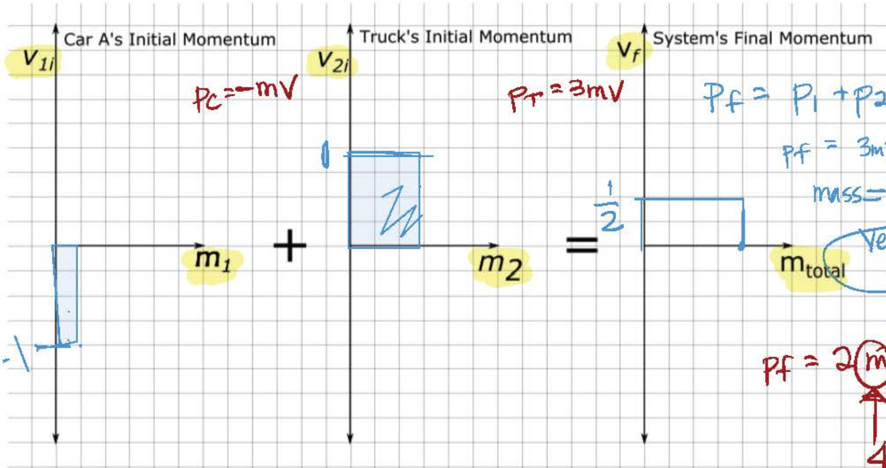
$P_T = 3mV$ $\quad P_C = m(-v)$

$P_C = -mV$

Using Representations

PART A: Identify the system by drawing a dotted circle around the truck and the car.

PART B: Diagram the situation.



$P_f = P_1 + P_2$

$P_f = 3mV + (-mV)$

mass $= 4m$

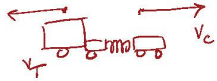
Velocity $= \frac{1}{2}$

$P_f = 2(m)V_f$

$4m \quad \frac{1}{2}V$

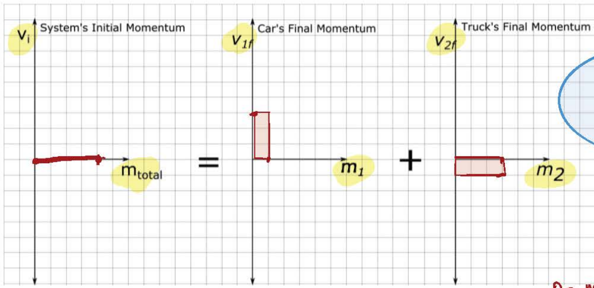
In which direction will they be traveling after the they collide? Explain and justify your answer.

To the right because the truck has more momentum ∴ the final momentum must move to the right.



PART C: The toy car and truck are now pressed together with an ideal spring compressed between them. They are then released from rest. Diagram the momentum before and after the explosion as well as the energy before and after the explosion.

3kg
1kg



$p_C = m_C v_C$

$p_T = m_T v_T$

Final mom

initial mom

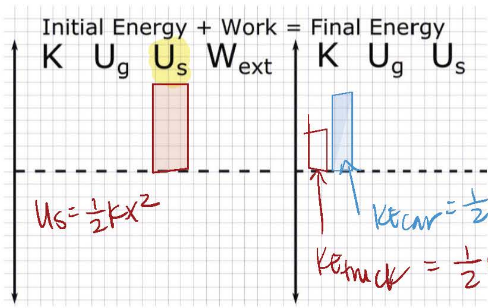
$p_i = 0$

$0 = m_c v_c + m_T v_T$

$0 = 1M\, v_c + 3M\, v_T$

$1M\, v_c = -3M\, v_T$

$\boxed{v_T = -\frac{1}{3} v_c}$



$U_s = \frac{1}{2}kx^2$

$KE_{car} = \frac{1}{2}m_c v_c^2$

$KE_{truck} = \frac{1}{2}m_T v_T^2$

$U_s = KE_c + KE_T$

$\frac{1}{2}kx^2 = \frac{1}{2}m_c v_c^2 + \frac{1}{2}m_T v_T^2$

$(-v_T)$

Energy : Scalar

Momentum : Vector

P : momentum = kg m/s

P : power = W/s

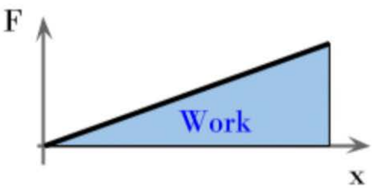
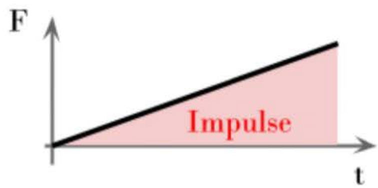
HW: Calc: ch.9

alg: ch 7

Work/Energy is analogous to Impulse/Momentum

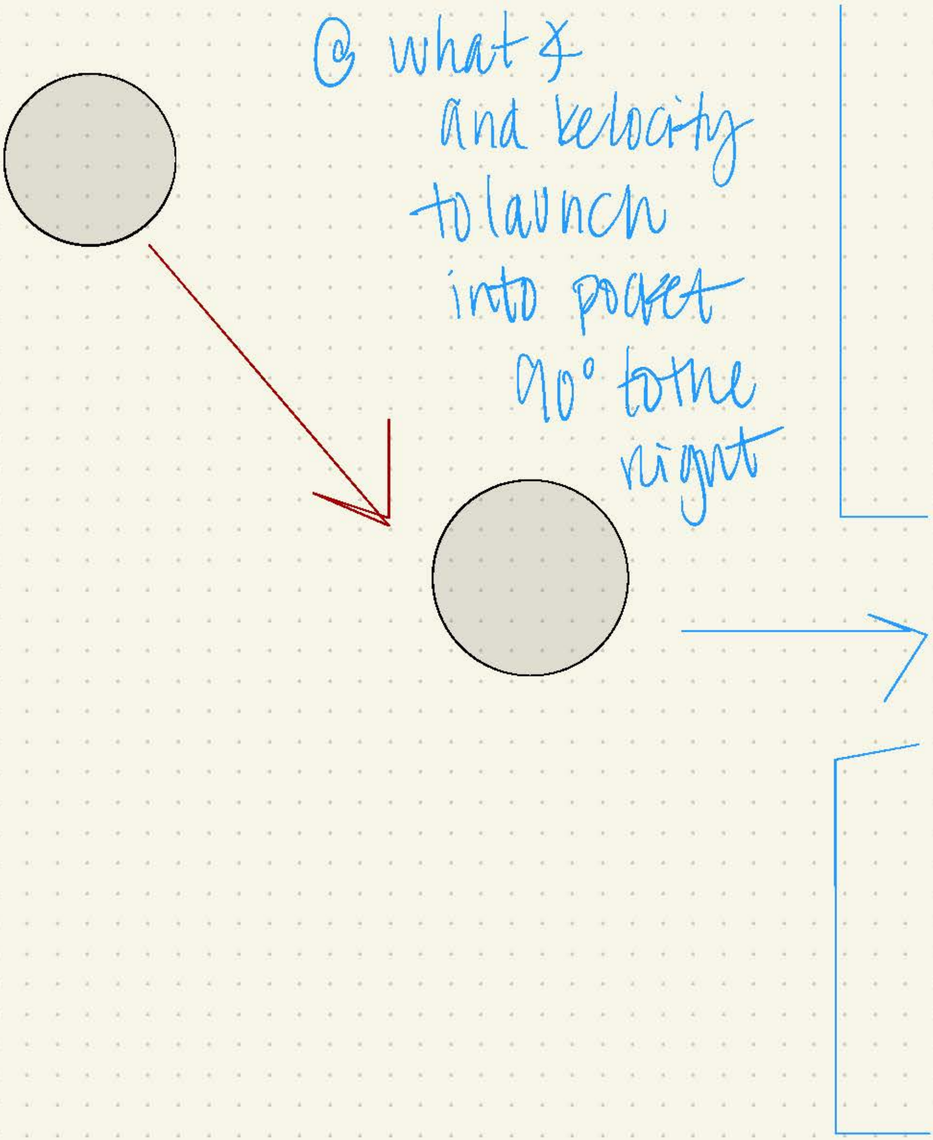
What does the Work/Energy and Impulse/Momentum analogy mean?

There is a strong analogy between the ideas of Work/Energy and Impulse/Momentum.

Work W is the amount of **energy** transferred to a system	**Impulse J** is the amount of **momentum** transferred to a system
$W = Fd\cos\theta$	$J = F\Delta t$
$W_{net} = F_{net} d\cos\theta = \Delta K$	$J_{net} = F_{net}\Delta t = \Delta p$
$E_i + W_{ext} = E_f$	$p_i + J_{ext} = p_f$
Work is area under F vs. x	**Impulse** is area under F vs. t
	

Hover Air Hockey Battle

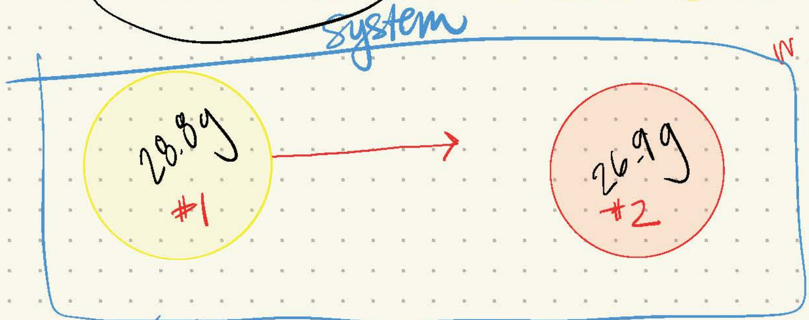
Partner with another team

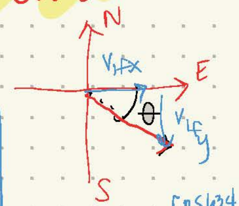


A 28.8 g yellow air hockey disc elastically strikes a 26.9 g stationary red air hockey disc. If the velocity of the yellow disc before the collision is 33.6 cm/s in the x direction and after the collision it is 10.7 cm/s at an angle 63.4° S of E, what is the velocity of the red disc after the collision?

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

$V_{1ix} = 33.6 \frac{cm}{s}$ $V_{1f} = 10.7 \frac{cm}{s}$ @ 63.4° S of E





$V_{1fx} = 10.7 \frac{cm}{s}$ cos 63.4

$V_{1fy} = 10.7 \frac{cm}{s}$ sin 63.4°

$\Sigma p_i = \Sigma P_f \longrightarrow$ momentum must be conserved

$\Sigma p_i = p_{1i} + p_{2i} = p_{1f} + p_{2f}$

x-dir

$\Sigma p_{xi} = m_{1ix} \cdot V_{1ix} + m_{2ix} \cdot \cancel{V_{2ix}}^{\,0\, m/s}$

$28.8g = 0.0288 kg$

$33.6 \frac{cm}{s} = 0.336 \frac{m}{s}$

$m_{1ix} \cdot V_{1ix} = (28.8g)(33.6 cm/s) = 0.00968 \ kg\frac{m}{s}$ or N·S

$\Sigma p_{xf} = m_{1fx} \cdot V_{1fx} + m_{2fx} \cdot V_{2fx}$

$\Sigma p_{xi} = \Sigma p_{xf}$

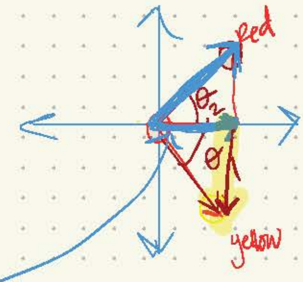
$(0.0288 kg)(0.0479 \frac{m}{s}) + (0.0269 kg) V_{2fx}$

$V_{1fx} = 10.7 \frac{cm}{s} \cdot \cos 63.4$

$0.107 \frac{m}{s} \cdot \cos 63.4$

$$\Sigma p_{ix} = \Sigma p_{fx}$$

$$0.00968\,\frac{kgm}{s} = 0.0014\,\frac{kgm}{s} + \underset{26.9g}{m_2} \cdot V_{2fx}$$



$$V_{2fx} = \frac{0.00968 - 0.0014}{0.0269}$$

$$V_{2fx} = 0.308438\ m/s$$

$$\Sigma p_{iy} = \Sigma p_{fy}$$

$$m_{1iy}\cancelto{0}{V_{1iy}} + m_{2iy}\cancelto{0}{V_{2iy}} = m_{1fy}V_{1fy} + m_{2fy}V_{2fy}$$

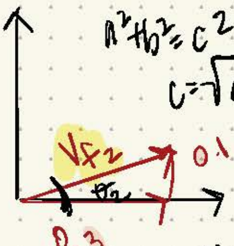
$$0 = m_{1fy}V_{1fy} + m_{2fy}V_{2fy}$$

$$0 = (28.8g)\left(10.7\frac{cm}{s}\sin 63.4\right) + (0.0269)(V_{2fy})$$

$$0 = (0.0288)\left(0.107\frac{m}{s}\sin 63.4\right) + (0.0269)(V_{2fy})$$

$$0 = (0.0288)(-0.0957) + (0.0269)(V_{2fy})$$

$$V_{2fy} = 0.102432\ m/s$$



$$a^2 + b^2 = c^2$$

$$c = \sqrt{a^2 + b^2}$$

$$c = .32$$

$$V_{f2} = 0.32\ m/s$$

$$\tan\theta = \frac{0.1}{0.3} \quad \theta = 18^\circ$$

$$V_{f2} = 0.32\ m/s\ @\ 18^\circ\ N\ of\ E$$

predicted

$$V_{f2} = 0.325\ m/s\ @\ 13^\circ\ N\ of\ E$$

measured

Is this collision elastic?

$$\Sigma p_i = \Sigma p_f$$

$$\Sigma KE_i = \Sigma KE_f$$

$$\underbrace{\frac{1}{2} m_{1i} v_{1i}^2 + \frac{1}{2} m_{2i} \cancel{v_{2i}}^2}_{} \overset{0}{} = \underbrace{\frac{1}{2} m_{1f} v_{1f}^2 + \frac{1}{2} m_{2f} v_{2f}^2}_{}$$

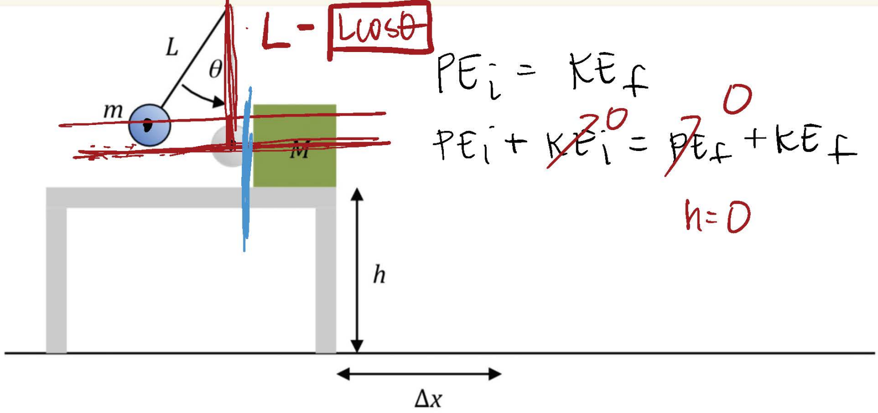
$$\frac{1}{2}(0.0288)(0.336)^2 + 0$$

$$KE_i = 0.0016257\,J$$

$$\Rightarrow \frac{1}{2}(0.0288)(0.107)^2 + \frac{1}{2}(0.0269)(0.32)^2$$

$$KE_f = 0.0015421\,J$$

$$E_R = \frac{1.54 - 1.62}{1.62} \times 100 = 5.14\%$$



$PE_i = KE_f$

$PE_i + \cancel{KE_i}^{0} = \cancel{PE_f}^{0} + KE_f$

$h = 0$

A pendulum of length $L = 1.0$ meter and bob with mass $m = 1.0$ kg is released from rest at an angle $\theta = 30°$ from the vertical. When the pendulum reaches the vertical position, the bob strikes a mass $M = 3.0$ kg that is resting on a frictionless table that has a height $h = 0.85$m.

a. When the pendulum reaches the vertical position, calculate the speed of the bob just before it strikes the box.

$PE_i = m \cdot g \cdot h$ $\quad KE_f = \frac{1}{2} m v^2$ $\quad h = ?$

$h = L - L\cos\theta$

$PE_i = KE_f$ $\quad \cancel{m} g h = \frac{1}{2} \cancel{m} v^2$ $\quad v^2 = 2gh$

$v = \sqrt{2gh}$

$v = \sqrt{2(9.8 m/s^2)(1 - 1\cos 30)}$

$V_i = 1.62$ m/s

b. Calculate the speed of the bob and the box just after they collide elastically.

1: Bob

2: Block

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

Cons of mom. $\quad P_{1i} + P_{2i} = P_{1f} + P_{2f}$

Cons. of energy

$\Sigma KE_i = \Sigma KE_f$

$\underbrace{\frac{1}{2} m v^2}_{Bob} + \underbrace{\frac{1}{2} \cancel{m v^2}^{0}}_{Block} = \underbrace{\frac{1}{2} m v^2}_{Bob'} + \underbrace{\frac{1}{2} m v^2}_{Block'}$

$\underbrace{\frac{1}{2} m_{1i} v_{1i}^2}$ $= \frac{1}{2} m_{1f} v_{1f}^2 + \frac{1}{2} m_{2f} v_{2f}^2$

$m_{1i} v_{1i} + \cancel{m_{2i}}^{0} v_{2i} = m_{1f} v_{1f} + m_{2f} v_{2f}$

$(1)(1.62) = (1) v_{1f} + (3) v_{2f}$

$\frac{(1.62)^2 \cdot (1)}{2} = \frac{1}{2}(1) v_{1f}^2 + \frac{1}{2}(3) v_{2f}^2$ need to find both

$\underbrace{① \; 1.62 = v_{1f} + 3 v_{2f}}_{\text{conser. mom}}$ $\quad \underbrace{② \; 1.33 = \frac{1}{2} v_{1f}^2 + \frac{3}{2} v_{2f}^2}_{\text{cons energy}}$

$v_{1f} = 1.62 - 3 v_{2f}$

$$\boxed{\begin{aligned} v_{1f} &= -0.81 \text{ m/s} \\ v_{2f} &= +0.81 \text{ m/s} \end{aligned}}$$

c. Determine the impulse acting on the box during the collision.

$$J = \Delta p = F\cdot\Delta t = m_2 v_2 - m_1 \cancel{v_1}^{\,0}$$

$$= (3\,kg)(0.8\,m/s) = \boxed{2.43\,kg\,m/s \text{ or } 2.43\,N\cdot S}$$

d. Determine how far away from the bottom edge of the table, Δx, the box will the box strike the floor.

$\Delta y = -0.85$ Δx

$\Delta y = 0.85\,m$

$$\Delta y = v_{iy} t + \frac{1}{2} a_y t^2$$

$v_{iy} = 0$, $a_y = (-9.8\,m/s^2)$

$$\Delta y = \frac{1}{2}(9.8)(t)^2$$

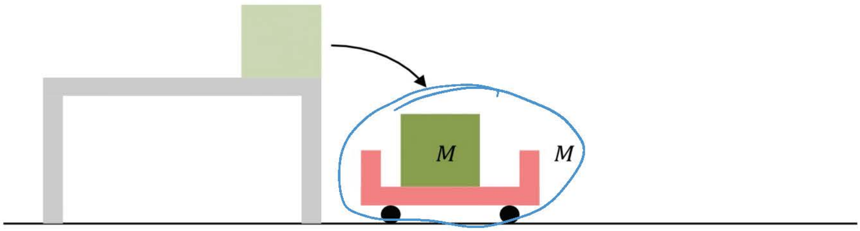
$$t = \sqrt{\frac{2(0.85)}{9.8}} = \boxed{0.416\,s}$$

scalar

$$\Delta x = v_x \cdot t$$

$$\Delta x = (0.8\,m/s)(0.416\,s)$$

$$\boxed{\Delta x = 0.33\,m}$$



At the location where the box would have struck the floor, now a small cart of mass $M = 3.0$ kg and negligible height is placed. The box lands in the cart and sticks to the cart in a perfectly inelastic collision.

e. Calculate the horizontal velocity of the cart just after the box lands in it.

Cons. of mom

$$m_{1B} v_{1B} + \cancel{m_{1C} v_{1C}}^{\,0} = \boxed{m_{2B} v_{2B} + m_{2C} v_{2C}}$$

$$m_{1B} v_{1B} = (m_{2B} + m_{2C}) v_3$$

v_3 : combine cart & block

$$(3)(0.81\ m/s) = (6) v_3$$

$$\boxed{v_3 = 0.41\ m/s}$$

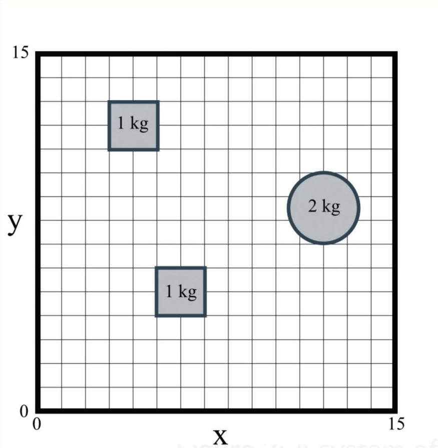
Center of Mass or Center of gravity

$$x_{cm} = \frac{\sum x_i m_i}{\sum m_i}$$

$$x_{cm} = \frac{\sum x_i m_i}{\sum m_i} = \frac{(2kg)(0) + (6kg)(10m)}{2kg + 6kg}$$

$$x_{cm} = \frac{60\,kg \cdot m}{8\,kg} = \frac{60}{8}\,m =$$

Center of mass = center of gravity in a UNIFORM gravitational field

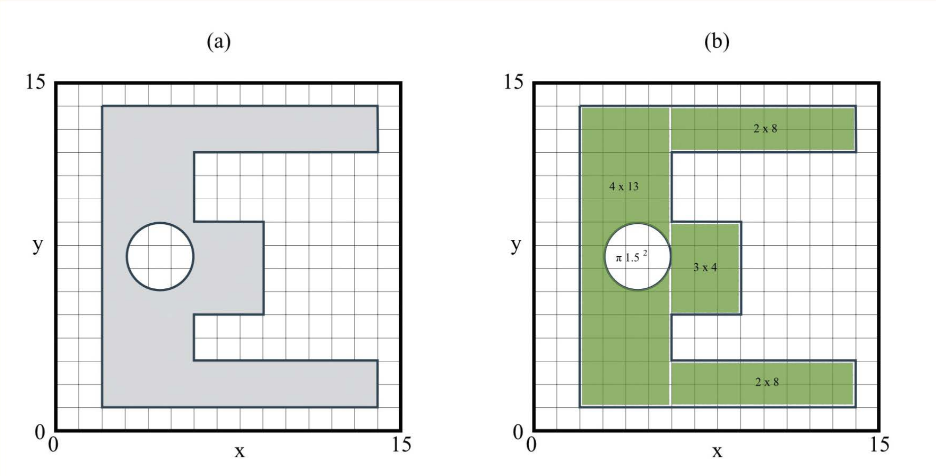


X-direction:

$$x_{cm} = \frac{\sum x_i m_i}{\sum m_i}$$

y-direction:

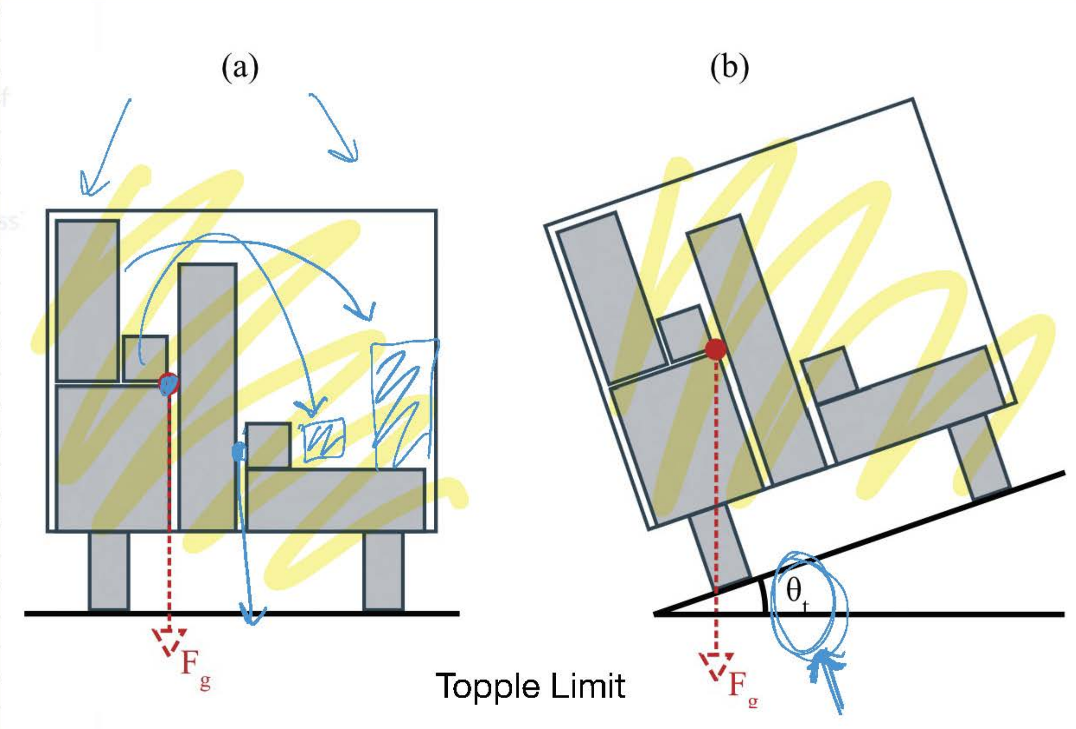
$$y_{cm} = \frac{\sum y_i m_i}{\sum m_i}$$



Let's find the center of Mass

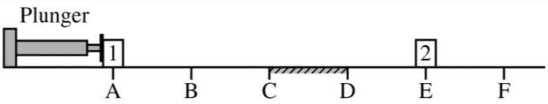
x-direction

y-direction



Why do we care about the center of mass?

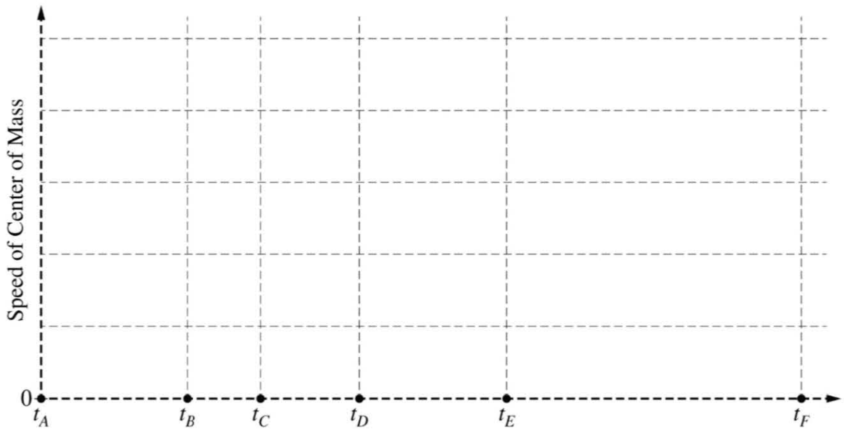
Video on semi truck tipping



1. (7 points, suggested time 13 minutes)

Identical blocks 1 and 2 are placed on a horizontal surface at points A and E, respectively, as shown. The surface is frictionless except for the region between points C and D, where the surface is rough. Beginning at time t_A, block 1 is pushed with a constant horizontal force from point A to point B by a mechanical plunger. Upon reaching point B, block 1 loses contact with the plunger and continues moving to the right along the horizontal surface toward block 2. Block 1 collides with and sticks to block 2 at point E, after which the two-block system continues moving across the surface, eventually passing point F.

(a) On the axes below, sketch the speed of the center of mass of the two-block system as a function of time, from time t_A until the blocks pass point F at time t_F. The times at which block 1 reaches points A through F are indicated on the time axis.



Momentum, Impulse, Center of Mass

Review