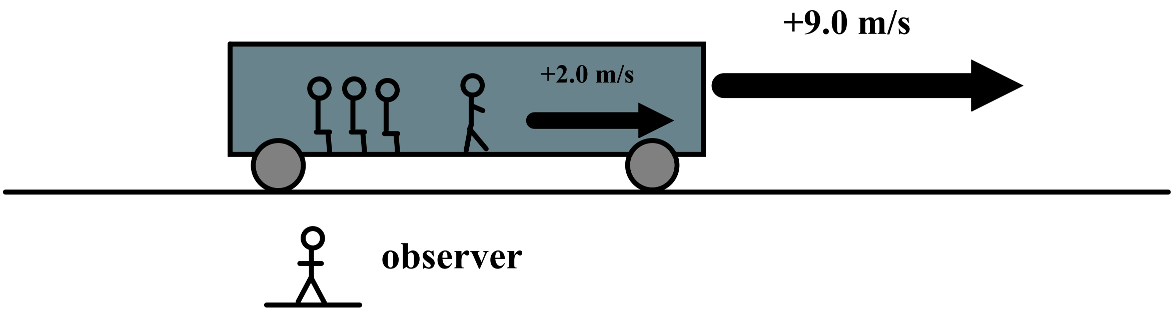
Relative Velocity

The velocity of an object is relative to the observer who is making the measurement.

Velocities Along The Same Line

When velocities are along the same line, simple addition or subtraction is sufficient to obtain relative velocity.

Example: A passenger walks to the front of a moving train. People on the train see the passenger walking with a velocity of +2.0 m/s. Suppose the train is moving with a velocity of +9.0 m/s relative to an observer standing on the ground. What would be the velocity of the passenger as observed by a ground-based observer?



The ground-based observer would see the passenger moving with a velocity of +11 m/s.

If the passenger had been walking toward the rear of the train, the velocity relative to the ground-based observer would have been +7.0 m/s.

☆

It is easy to make a mistake by adding or subtracting the wrong velocities.

Along with a diagram, try using the following labelling system.

Label each velocity using two subscripts:

- the first refers to the object
- the second refers to the reference frame in which the object has this velocity.

$\vec{V}_{pt}$ -> the velocity of the passenger relative to the train = +2.0 m/s

$\vec{V}_{tg}$ -> the velocity of the train relative to the ground = +9.0 m/s

$\vec{V}_{pg}$ -> the velocity of the passenger relative to the ground

$$V_{pg} = V_{pt} + V_{tg}$$

first last

$$V_{pg} = 2.0\text{ m/s} + 9.0\text{ m/s}$$

$$V_{pg} = 11.0\text{ m/s}$$

For any two objects or reference frames, A and B, the velocity of A relative to B has the same magnitude but opposite direction as the velocity of B relative to A.

$$\vec{V}_{BA} = -\vec{V}_{AB}$$

IF: $\vec{v}_{AC} = \vec{v}_{AB} + \vec{v}_{BC}$

THEN: $\vec{v}_{AC} = \vec{v}_{AB} - \vec{v}_{CB}$

Vectors Not Along The Same Line

If the velocities are not along the same line, vector addition must be used.

I. BOAT PROBLEMS

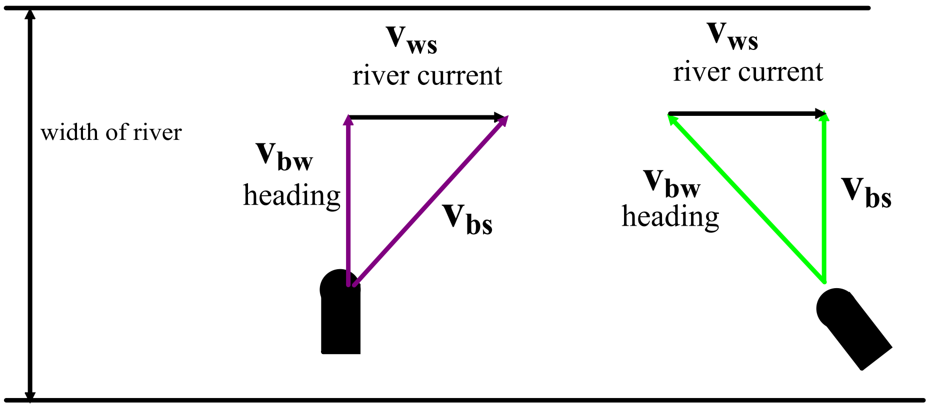
Example: Imagine a boat crossing a river. Consider the following velocities:

$\vec{V}_{bw}$ -> the velocity of the boat with respect to the water (heading/still water)

$\vec{V}_{ws}$ -> the velocity of the water with respect to the shore (current)

$\vec{V}_{bs}$ -> the velocity of the boat relative to the shore (resultant)

components



$$\vec{V}_{bs} = \vec{V}_{bw} + \vec{V}_{ws}$$

first last

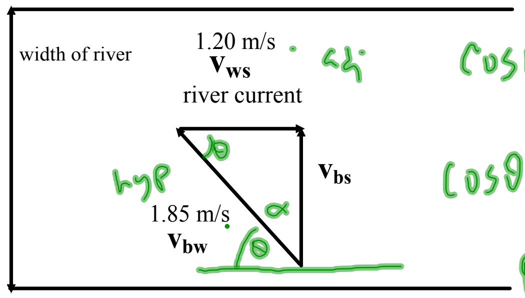
Do NOT just add the terms on the right. You need to find the resultant of the two vectors.

Law of Pythagoras.

Boat Simulation

TRY

1. A boat's speed in still water is 1.85 m/s. If the boat is to travel directly across a river whose current has a speed of 1.20 m/s, at what angle must the boat head relative to the shore? (49.6° N of W)



$\cos\theta = \frac{V_{ws}}{V_{bw}}$

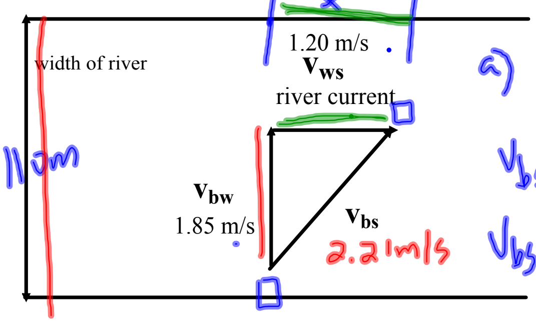
$\cos\theta = \frac{1.20}{1.85}$

$\theta = 49.6°$ N of W

2. The same boat now heads directly across the river.

a) What is the magnitude of $\mathbf{v_{bs}}$? (2.21 m/s)

b) If the river is 110 m wide, how long will it take to cross the river and how far downstream will the boat be then? (59.5 s, 71.4 m)



a) $V_{bs} = \sqrt{V_{bw}^2 + V_{ws}^2}$

$V_{bs} = \sqrt{(1.85)^2 + (1.20)^2}$

$V_{bs} = 2.21$ m/s

b) $\vec{v} = \frac{\vec{d}}{t}$

$V_{bw} = \frac{d}{t}$

$t = \frac{d}{V_{bw}}$

$t = \frac{110\text{ m}}{1.85\text{ m/s}}$

$t = 59.5$ s

$v = \frac{d}{t} = \frac{x}{t}$

$x = V_{ws} t$

$x = (1.20\text{ m/s})(59.5\text{ s})$

$x = 71.4$ m

NOTE: For plane problems:

$\vec{c}$ $\vec{v}_{pa}$ = velocity of plane relative to the air (airspeed)

$\vec{c}$ $\vec{v}_{ag}$ = velocity of air relative to ground (wind)

$\vec{R}$ $\vec{v}_{pg}$ = velocity of plane relative to ground (resultant)

$$\vec{V}_{pg} = \vec{V}_{pa} + \vec{V}_{ag}$$

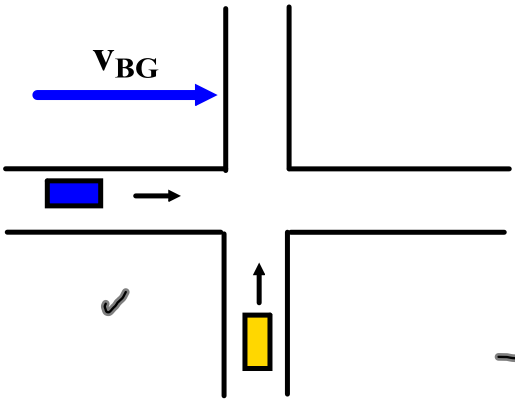
Textbook

Page 110 - #21, 22, 25, 27(a)
Page 117 - #23, 24, 29

#25 (Level 1)

II. INTERSECTION PROBLEMS

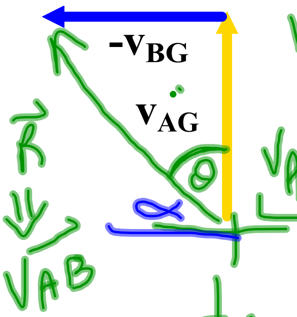
Example: The diagram shows two cars approaching an intersection along perpendicular roads. The velocity of **A** relative to the ground is 12.0 m/s, N and the velocity of **B** relative to the ground is 8.25 m/s, E. Find the velocity of **A** relative to **B**. (14.6 m/s, 34.5° W of N)



$$\vec{V}_{AB} = \vec{V}_{AG} + \vec{V}_{GB}$$

$$\vec{V}_{AB} = \vec{V}_{AG} - \vec{V}_{BG}$$

$$\vec{V}_{AB} = \vec{V}_{AG} + (-\vec{V}_{BG})$$

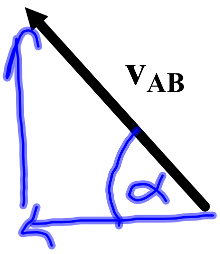


$$V_{AB} = \sqrt{V_{AG}^2 + V_{BG}^2}$$

$$V_{AB} = 14.6\ m/s$$

$$\tan\theta = \frac{8.25}{12.0}$$

$$\theta = 34.5^\circ$$



$$\vec{V}_{AB} = 14.6\ m/s,\ 34.5^\circ \text{ W of N}$$

Handouts (3)

Center of Mass

In Grade 11, we considered objects to be point masses and we observed the motion of the points. Real objects have dimensions.

We will need to determine the center of mass of objects for upcoming problems. The center of mass is a point in an object where the mass seems to be concentrated.

Types of Motion - Large Objects

The motion of large objects can be divided into two types, ***translational*** and ***rotational***.

translational motion - the motion of an object from one point to another

rotational motion - the motion of an object about one point (pivot point or fulcrum)

Figure 10.15 The wrench is rotating around the mark on the wrench while the mark is moving in a straight line.

Physics - McGraw-Hill Ryerson, Page 491

☆

Torque (MHR - Page 490)

Torque occurs when a force is applied to an object and that force causes the object to rotate.

"Seesaw" Demonstration

1. Balance the rod on the coffe can.

2. a) What happens if a 20 g mass is placed at the center of the seesaw (the pivot point)?

Even though a force has been applied to the rod, the rod does not rotate.

   b) What happens if a 20g mass is placed to the right of the pivot point?

The rod rotates, therefore torque has been produced.

   c) What was different about the two trials?

A force must be applied at some distance from the pivot point.

3. Place a 20 g mass on one side of the pivot point. Where would another 20 g mass have to be placed in order to keep the rod balanced?

The second mass must be placed at the same distance from the pivot point as the first, but on the other side of the pivot point.

4. Place a 50 g mass on one side of the pivot point. Where would a 100 g mass have to be placed in order for the masses to be in a state of equilibrium?

The 100 g has to be placed at half the distance from the pivot point as the 50 g mass.

☆

Torque can be defined as:

$$\tau = rF\sin\theta$$

τ * -> magnitude of torque (Nm)

* this symbol represents the Greek letter *tau*

r -> distance from pivot point to the application of the force (m)

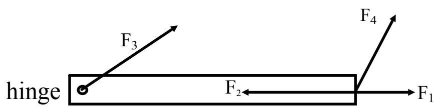
F -> magnitude of force applied (N)

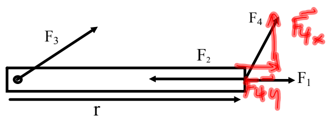
θ -> angle between r and F when they start at the same point (degrees)

Torque is a ***vector***. The direction of torque is based on the direction in which the force would cause the object to rotate if it were acting alone.

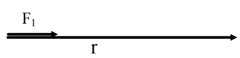
CW: clockwise (-)
CCW: counter-clockwise (+)

The diagram below shows four forces acting on a door. Which forces will cause the door to rotate?

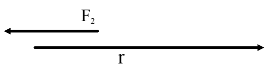




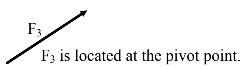
We can verify our previous answers by examining the equation.



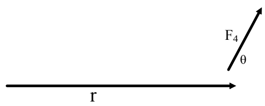
F1: $\theta = 0^o$
$\sin 0^o = 0$
$\tau = 0$ Nm



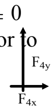
F2: $\theta = 180^o$
$\sin 180^o = 0$
$\tau = 0$ Nm



F3: $r = 0$ m
$\tau = 0$ Nm



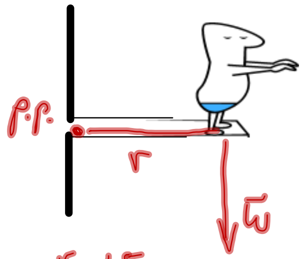
F4: $r \neq 0$ m and $\sin\theta \neq 0$
F_{4x} will cause the door to rotate!



WEB - Simulation "Wrench"

Label the Pivot Point

Example: A 490 N man stands at the end of a diving board at a distance of 1.5 m from the point at which it is attached to the tower. What is the torque the man exerts on the board?
(735 Nm, CW or -735 Nm)

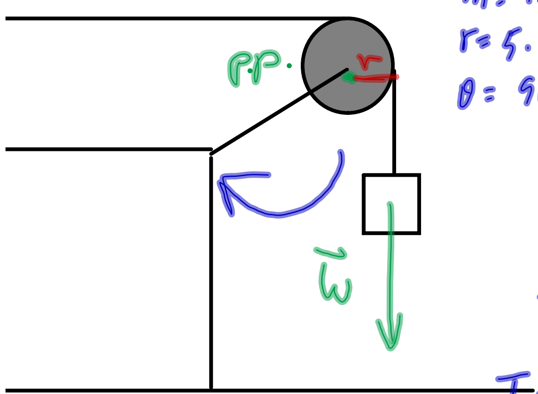


$r = 1.5\,m$
$W = 490\,N$
$\theta = 90^\circ$

$\tau = rF\sin\theta$
$\tau = rW\sin 90^\circ$
$\tau = rW$
$\tau = (1.5\,m)(490\,N)$
$\tau = 735\,Nm$

$\vec{\tau} = -735\,Nm$
$\vec{\tau} = 735\,Nm, CW$

Example: A 5.0 kg mass is attached as shown to a pulley of radius 5.0 cm. What torque is produced by the mass?
(2.5 Nm, CW or -2.5 Nm)



$m = 5.0\,kg$
$r = 5.0\,cm \rightarrow 0.050\,m$
$\theta = 90^\circ$

$\tau = rF\sin\theta$
$\tau = rW\sin 90^\circ$
$\tau = rmg$
$\tau = (0.050\,m)(5.0\,kg)(9.80\,\frac{m}{s^2})$
$\tau = 2.5\,Nm$

$\vec{\tau} = 2.5\,Nm, CW$

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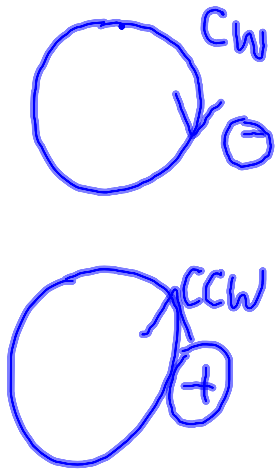
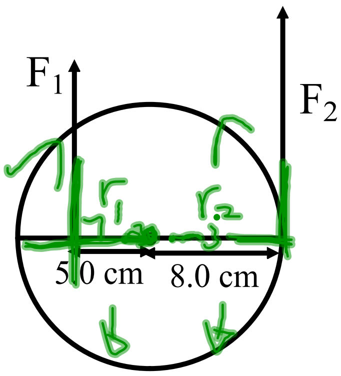
Net Torque

Just as net force sometimes plays a part in a problem, so does net torque. Net torque is the vector sum of all torques.



$$\vec{\tau}_{net} = \vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 + \ldots$$

Example: Two forces act on the cylinder as shown in the diagram below. If $F_1 = 10$ N and $F_2 = 15$ N, what is the net torque on the cylinder? (0.70 Nm, CCW)



$\vec{\tau}_{net} = -\tau_{F_1} + \tau_{F_2}$

$\vec{\tau}_{net} = -r_1 F_1 \sin\theta + r_2 F_2 \sin\theta$

$\vec{\tau}_{net} = -(0.050)(10)\sin 90^\circ + (0.080)(15)\sin 90^\circ$

$\vec{\tau}_{net} = +0.70\,\text{Nm}$

WS

Static Equilibrium - Revisited

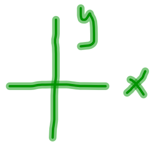
An object is in static equilibrium if:

1. $\mathbf{v} = 0$ m/s
2. $\mathbf{F}_{\mathbf{net}} = 0$ N
3. $\boldsymbol{\tau}_{\mathbf{net}} = 0$ Nm

Conditions

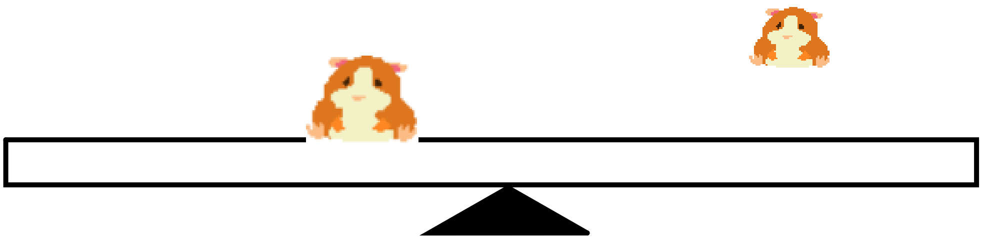
Steps for Solving Static Equilibrium Problems

1. Study the diagram provided or draw a diagram.
2. Label all forces acting on the board, beam, etc.
3. Choose a pivot point. It is helpful to place the pivot point where an unknown force exists. Label the pivot point.
4. Label distances from the pivot point to the forces. (r values)
5. Choose a coordinate system.



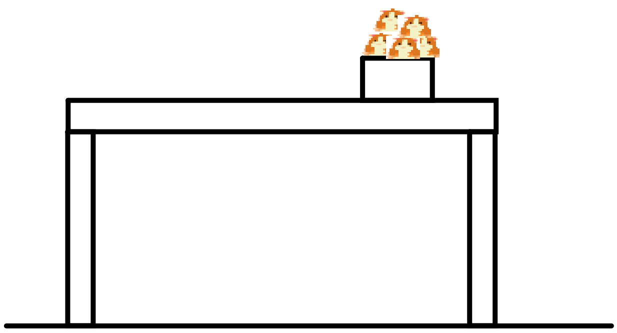
6. Resolve a force into its perpendicular components if the force doesn't fit into the chosen coordinate system.
7. Write F_{netx} and F_{nety} equations.
8. Write a τ_{net} equation.
9. Solve the equation(s) for the unknown(s).

Example: A massless board serves as a seesaw for two giant hamsters as shown below. One hamster has a mass of 30 kg and sits 2.5 m from the pivot point. At what distance from the pivot point must a 25 kg hamster place himself to balance the seesaw? (3.0 m)



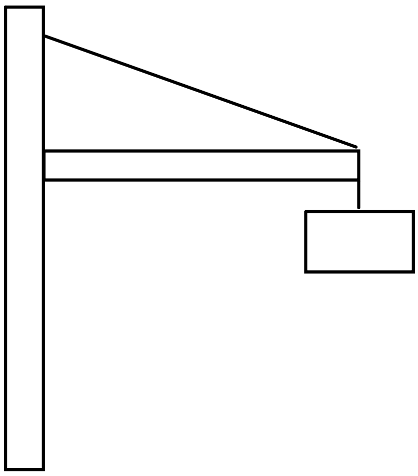
* If a solid object has mass, treat the object as if all its mass were concentrated at a point - the center of mass.

Example: A uniform 1500 kg beam, 20.0 m long, supports a 15000 kg box of hamsters 5.0 m from the right support column. Calculate the magnitude of the forces on the beam exerted by each of the vertical support columns. (1.2×10^5 N, 4.2×10^4 N)



Textbook - Page 501 #31
Page 529 #27

Example: A uniform beam of mass 50.0 kg and length 3.00 m is attached to a wall with a hinge. The beam supports a sign of mass 300 kg which is suspended from its end. The beam is also supported by a wire that makes an angle of 25^{o} with the beam. Determine the components of the force that the hinge exerts and the tension in the wire. (6.8 x 10^3 N, 2.5 x 10^2 N, 7.5 x10^3 N)



Textbook - Page 501 #33 (a)
Page 529 #28 (a)

Attachments

Physics 122 - Review Exercise.doc

Physics 121 - Type II Force Problems.doc