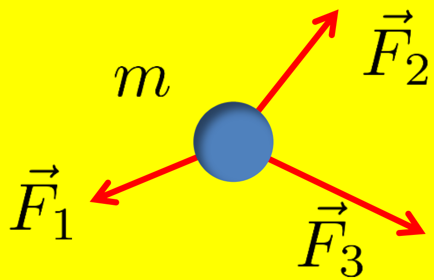
Chapter 6 Dynamics 2 – Quick Recap of Last Class

Everything that we'll do is based on Newton's Second Law:

Newton's Second Law:



$$\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$$

The **acceleration** of the body is:

$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m} \quad (\text{Why not } \vec{F}_{\text{net}} = m\vec{a}\ ?)$$

Once we know the acceleration, kinematics tells us how the object moves.

Every problem will have a Free Body Diagram (FBD) that must be correct.

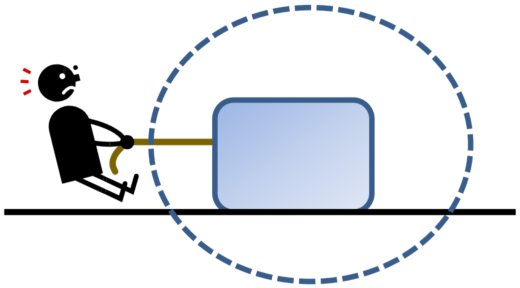
We will ALWAYS apply Newton's Second Law in Component Form by reading the force components directly from the FBD.

$$\sum F_x = ma_x \qquad \sum F_y = ma_y$$

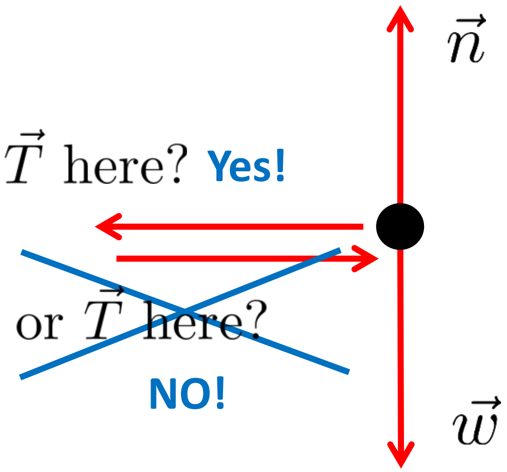
In some problems, we'll find the accelerations from Newton's 2nd and then use kinematics to find the motion. In others, we'll use kinematics to find the accelerations, and then use Newton's 2nd to find forces. All done in component form.

More types of forces

3. **Tension**: force of contact transmitted between a rope, string, or chain on an object.



FBD of the box:



The tension force is always away from the object.

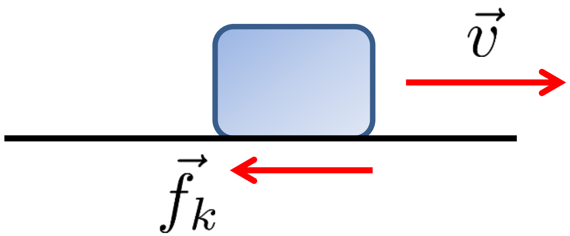
My Civil Engineering friends in college referred to this as:

Newton's Fourth Law: *"You can't push on a rope."*

Friction Forces

We will consider three types of friction forces between objects. All three are contact forces between objects. **Remember that what we are using are models based on experiments; i.e. friction coefficients are determined by experiments; they are not exact.**

Kinetic Friction: when there is motion.



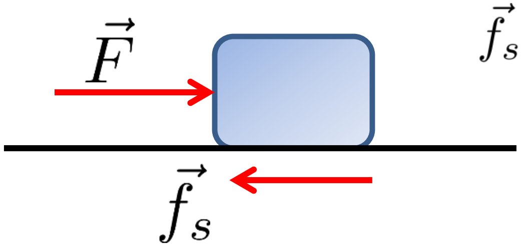
$$\vec{f}_k = (\mu_k n, \text{ opposite the direction of motion})$$

$$\mu_k = \text{coefficient of kinetic friction}$$

$$n = \text{magnitude of the normal force}$$

Static Friction: when there is **no motion**.

Note: static friction is a variable force



$$\vec{f}_s \leq (\mu_s n, \text{ opposite the direction of } \underline{\text{impending}} \text{ motion})$$

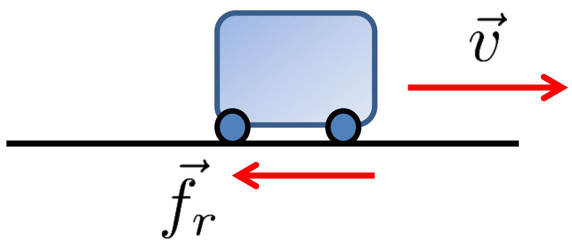
$$\mu_s = \text{coefficient of static friction}$$

$$n = \text{magnitude of the normal force}$$

Also Note: the direction of the **impending motion** is the direction that the object would move if there was no friction.

More Friction forces

Rolling Friction: when there is rolling motion, there is friction present, but it is different than for sliding. A rolling friction force is modeled like a kinetic friction force. The coefficient of rolling friction is always much less than that for sliding motion.



$$\vec{f}_r = (\mu_r n, \text{ opposite the direction of motion})$$
$$\mu_r = \text{coefficient of rolling friction}$$
$$n = \text{magnitude of the normal force}$$

We'll talk about fluid drag later in the class.

Whiteboard Problem: 6-4

Bonnie and Clyde are sliding a 300 kg bank safe across a rough floor to their getaway car. Clyde pushes from behind with 385 N of force while Bonnie pulls forward on a rope with 350 N of force.

a) **Sketch the problem and Draw a complete Free Body Diagram of the safe.**
b) **If the safe slides with a constant speed, determine the safe's coefficient of kinetic friction on the floor. (LC)**

Whiteboard Problem 6-5

A wooden block of mass 100 kg is at rest on a rough incline plane of angle θ = 20°. The coefficient of static friction of the wood on the incline is 0.8.

a) **Draw the problem and the free body diagram of the block.**

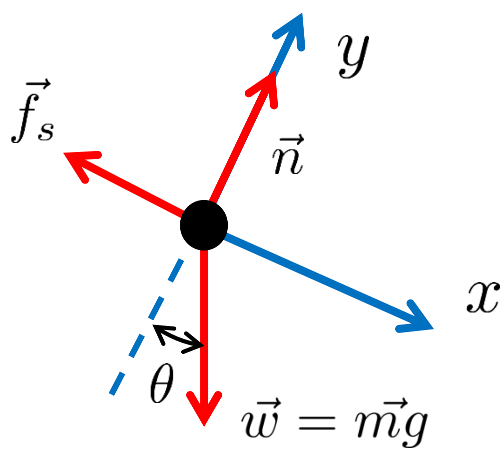
see incline plane geometry ➡

b) **What is the magnitude of the static friction force on the block? (LC)**

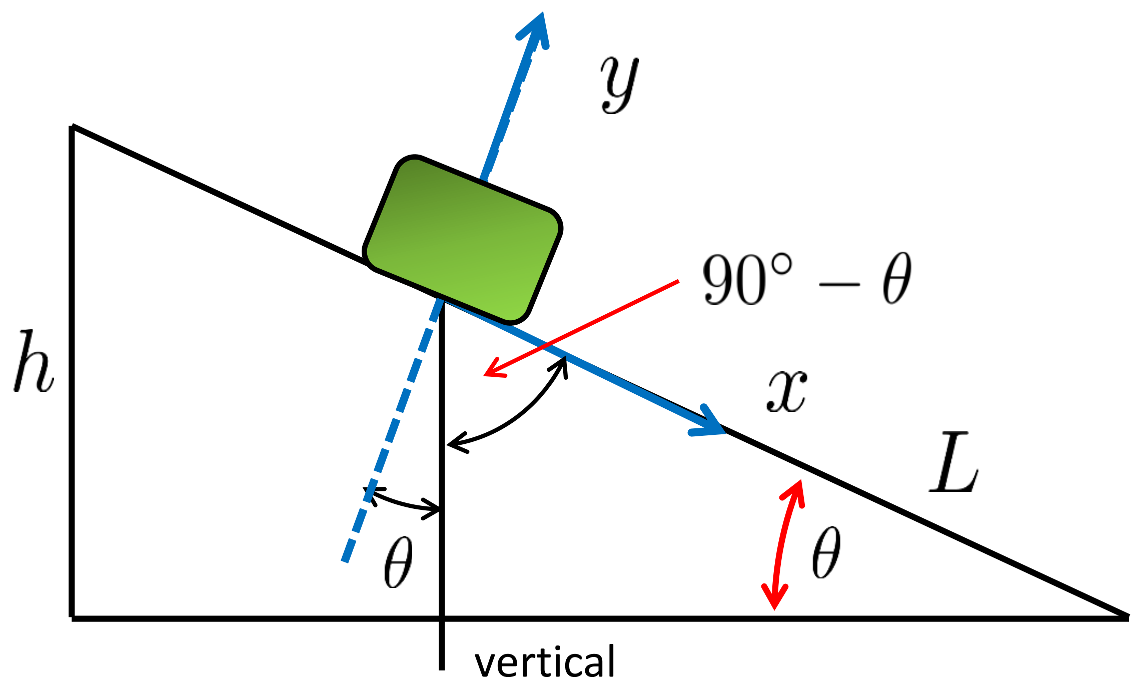
c) **What will happen if the angle is increased?**

Ans: At some angle, the static friction force will exceed it's maximum, and the block will begin to slide down the incline. Calculate this angle. (LC)

FBD:



Incline Plane Geometry



For incline plane problems, it's almost always a good idea to choose your coordinates so that one is parallel to the incline and the other perpendicular. **Why? The acceleration perpendicular to the incline, a_y, is zero.**

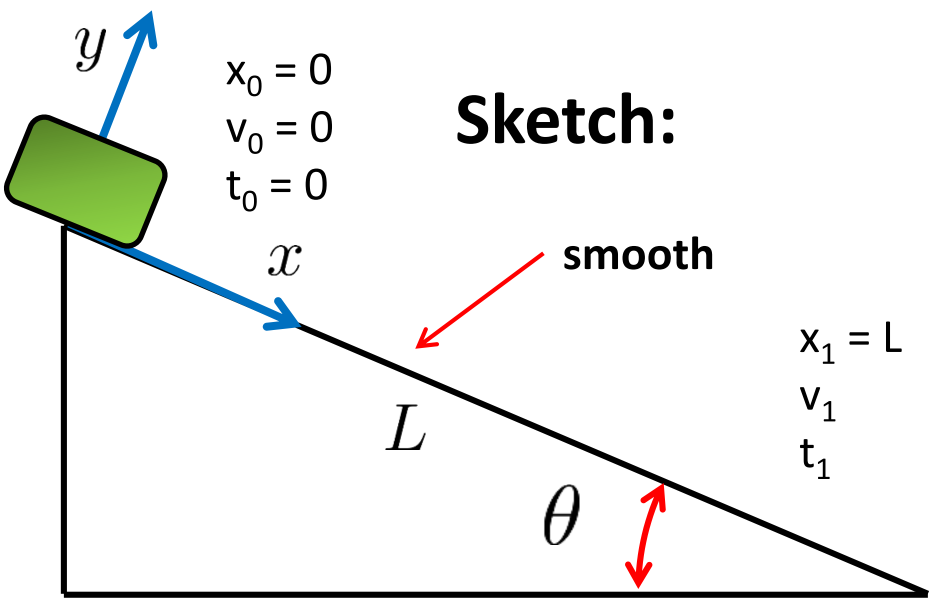
Whiteboard Problem: 6-6

A block of mass m slides from rest at the top of a **smooth** incline of length L and angle θ and slides to the bottom.

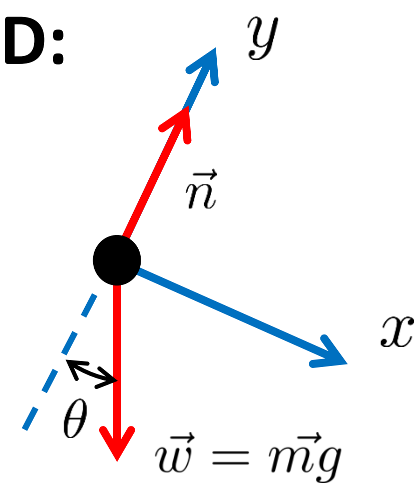
a) Draw the problem and draw a complete free body diagram for the block.

b) Find an expression for the speed of the block when it gets to the bottom of the incline. (LC) *(your expression should contain only the given quantities, but not necessarily all of them, and possibly numbers and physical constants.)*

Sketch:



FBD:



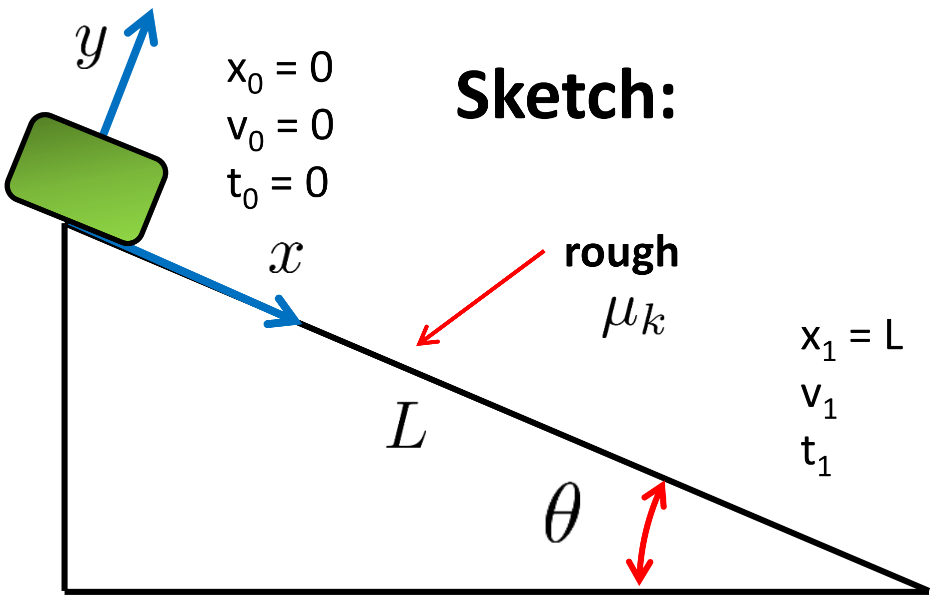
Whiteboard Problem: 6-7

A block of mass m starts from rest at the top of a **rough** incline of length L and angle θ and slides to the bottom. The coefficient of kinetic friction between the block and the incline is μ_k.

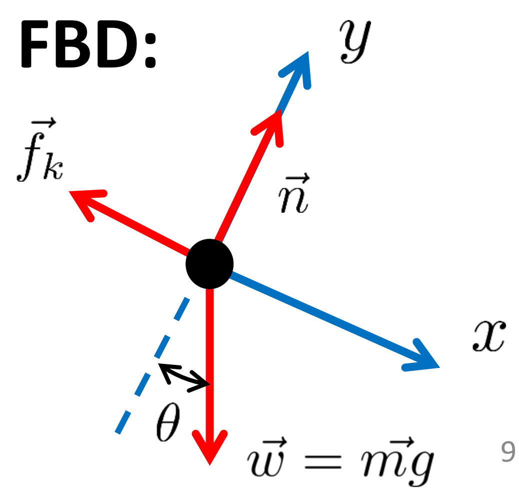
a) **Draw the problem and draw a complete free body diagram for the block –** easiest, just modify your sketch & FBD from WB 6-6!

b) **Find an expression for the speed of the block when it gets to the bottom of the incline.** (LC) *(your expression should contain only the given quantities, but not necessarily all of them, and possibly numbers and physical constants.)*

Sketch:



FBD:

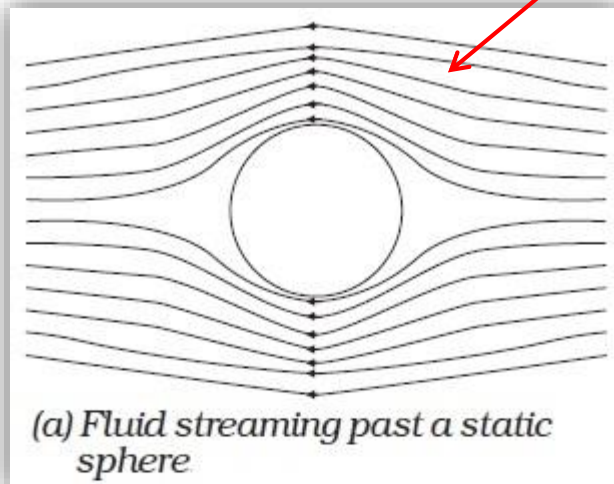


More on Types of Forces

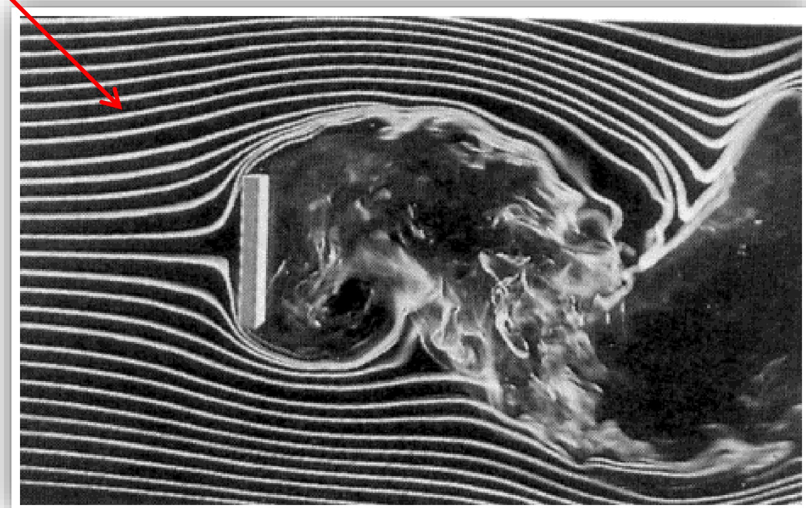
Aerodynamic Drag: Force on an object moving in a fluid (gas or liquid). This force can be very difficult to analyze since, in general, you have to know how the fluid moves:

Flow Streamlines

Fairly Simple Flow:



Complicated Flow:



[An example video of a simple object with complicated flow.]

The drag force has two sources:

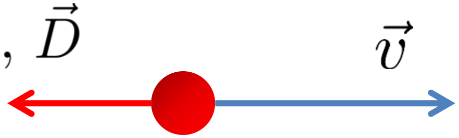
1. **Pressure drag** – integrate the pressure over the surface to find net force
2. **Viscous drag** - fluid friction force

A Simple Fluid Drag Model (remember this)

PhET Projectile

Your author gives an approximate formula for the drag force that is reasonably accurate for normal sized objects moving in air at slow speeds (~ 100's m/s or less).

Drag Force, $\vec{D}$



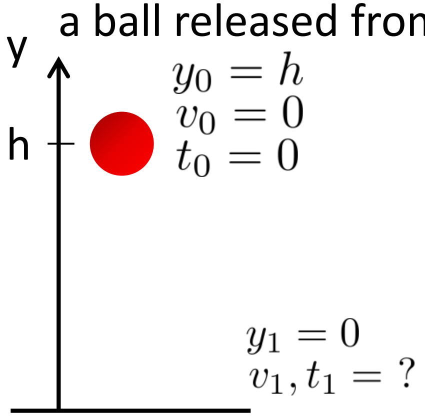
$$\vec{D} \approx (\tfrac{1}{2}C\rho A v^2, \text{ opposite } \vec{v})$$

$A =$ cross sectional area of the object $\perp \vec{v}$

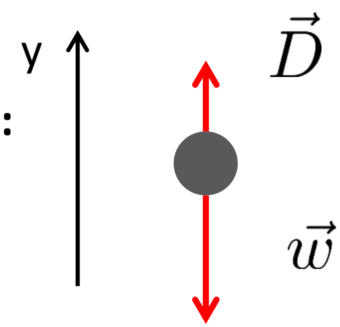
$C =$ drag coefficient

$\rho =$ fluid (air) density

Even with this simple model, problems with drag are very difficult, e.g. a ball released from rest at height h:



FBD:



$$\sum F_y = D - w = ma_y$$

$$\tfrac{1}{2}C\rho A v_y^2 - mg = ma_y$$

$$\frac{1}{2}C\rho A\left(\frac{dy}{dt}\right)^2 - mg = m\frac{d^2y}{dt^2}$$

-a fairly nasty differential equation!
(solve on a computer numerically)

In general, this is a tough problem, but we can answer some questions, e.g.

What is the object's Terminal Speed; i.e. constant speed when the drag force = weight ?

$$\sum F_y = D - w = ma_y = 0$$

$$\tfrac{1}{2}C\rho A v_y^2 - mg = 0 \quad \Rightarrow v_y = \sqrt{\frac{2mg}{C\rho A}}$$

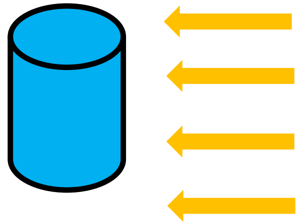
Terminal Speed,

but this is not a general equation, different problems will have different expressions.

Whiteboard Problem: 6-8

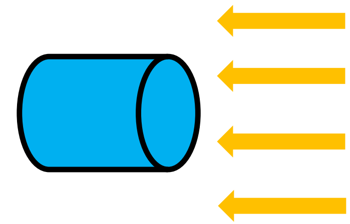
Why do Olympic downhill skiers tuck?

To reduce the aerodynamic drag and achieve a higher terminal velocity.



$C \approx 1.1$

Skier standing straight up:



$C \approx 0.8$

Skier in a racer's tuck:

Assume that a skier (standing straight up or tucking) is going straight down a race course of angle θ and that the coefficient of kinetic friction between her skis and the snow is μ_k. Also, use m as her mass, A as her cross sectional area, $\rho = \text{fluid (air) density}$, and C as her drag coefficient. (*Note, this is a different problem than the terminal speed on the previous slide – can't use that equation.)

a) Find an expression for her terminal speed. (LC)

Now, model the skier as an 80 kg cylinder that is 1.8 m tall and 0.4 m wide and that she is going down a 40° hill. The coefficient of kinetic friction between the skis and the snow is 0.06 and the density of air is 1.2 kg/m^3.

b) Using the drag coefficient above, calculate her terminal speed if she is standing straight up. (LC)

c) Using the drag coefficient above, calculate her terminal speed if she is in a racer's tuck. (LC)