

Chapter 5: Forces: Basic Concepts

In the first four chapters, we have concentrated on answering the question:

How do things move? **Answer: Kinematics** $\vec{v} = \frac{d\vec{r}}{dt}$ $\vec{a} = \frac{d\vec{v}}{dt}$

Now, we want to begin to address the question:

Why do things move? **Answer: Dynamics**

First, in Chapter 5, we'll develop some basic concepts, then in Chapters 6 & 7, we'll take up the details in 1D (mostly), and then finally in full 2D in Chapter 8.

What is a Force?

Very Loosely: a force is a push or a pull that can produce motion.

What kind of mathematical animal is force? **It has magnitude and direction.**
So Force is a Vector.

We will work with **two basic types of forces**:

1. **Contact forces**: between objects that touch; e.g. pushing on a chair
2. **Long Range Forces**: there is no contact between the bodies, e.g. gravity.

Do long range forces bother you? By what mechanism does the Earth communicate the gravitational force? They bothered Newton, Maxwell, and Einstein a lot! We'll keep coming back to this question.

Your author points out that all of the familiar contact forces that we'll encounter in PHY181, e.g. normal, spring, tension, friction, drag, are actually caused by the long range electromagnetic force at the atomic and molecular level.

What about the four fundamental forces?

Force Identification Diagram

TACTICS BOX 5.2



Identifying forces

- ➡ **1 Identify the object of interest.** This is the object you wish to study.
- ➡ **2 Draw a picture of the situation.** Show the object of interest and all other objects—such as ropes, springs, or surfaces—that touch it.
- ➡ **3 Draw a closed curve around the object.** Only the object of interest is inside the curve; everything else is outside.
- ➡ **4 Locate every point on the boundary of this curve where other objects touch the object of interest.** These are the points where *contact forces* are exerted on the object.
- ➡ **5 Name and label each contact force acting on the object.** There is at least one force at each point of contact; there may be more than one. When necessary, use subscripts to distinguish forces of the same type. **You don't have use the symbol F for all forces!**
- ➡ **6 Name and label each long-range force acting on the object.** For now, the only long-range force is the gravitational force.

Exercises 3–8



As we become experienced at this, we won't have to do a detailed identification diagram for every problem.

Whiteboard Problem 5-1

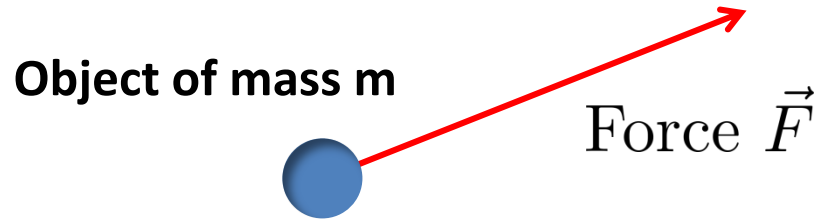
(we'll do this one together)

A baseball player is sliding into second base. **Draw a Force Identification Diagram**, and identify the forces on the baseball player.



Shohei Ohtani of the Angels (now a Dodger) sliding into 2nd Base

What does a Force do?

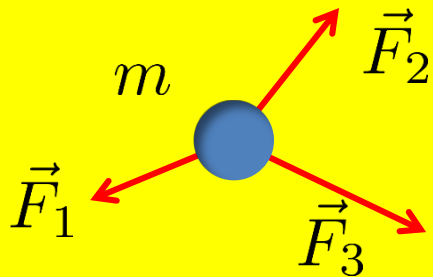


The force can cause the mass to move, but how?

In section 5.4, your author describes a simple set of experiments that would lead you to the conclusion that a **force produces an acceleration in the same direction as the force and with magnitude inversely proportional to the mass.**

We call this:

Newton's Second Law:



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

The acceleration of the body is:

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

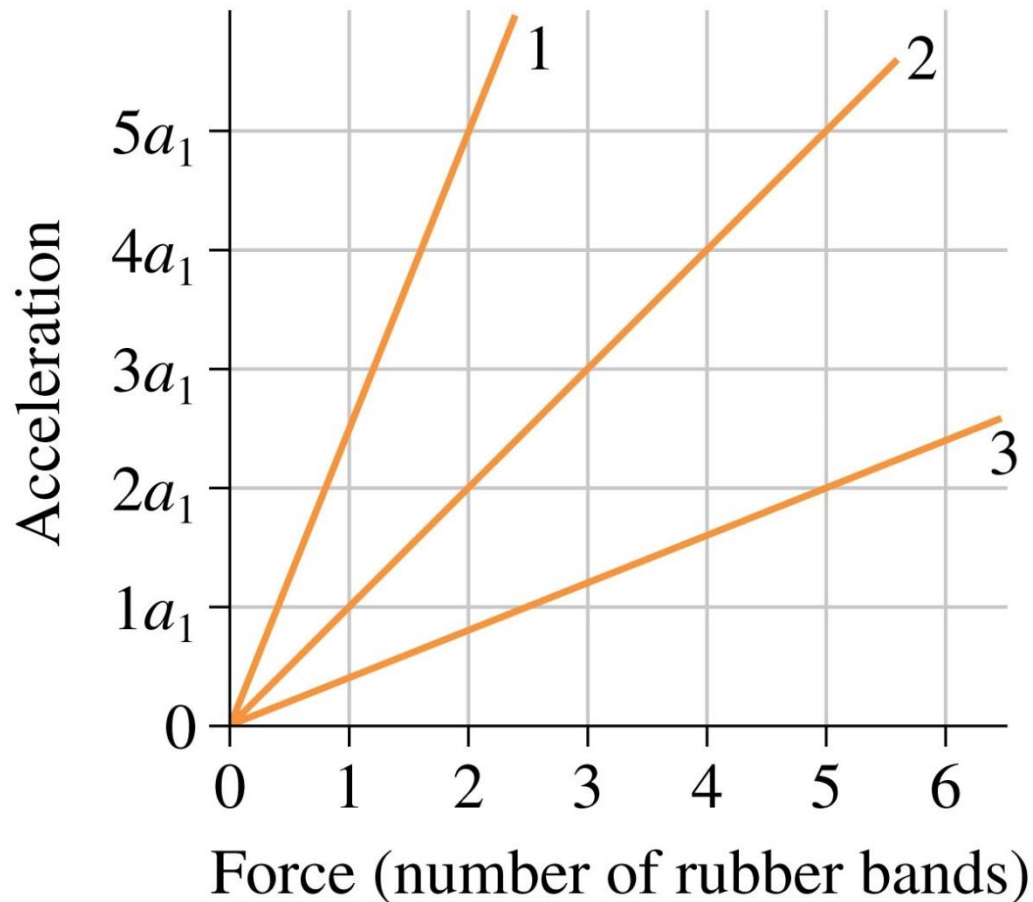
Once we know the acceleration, kinematics tells us how the object moves.

$$\vec{F} = m\vec{a} \text{ also gives us the units of force:}$$
$$[\text{units of } \vec{F}] = 1 \text{ kg } \frac{\text{m}}{\text{s}^2} \equiv 1 \text{ Newton (N)}$$

Whiteboard Problem 5-2

The figure below shows an acceleration vs. force graph for three objects pulled by rubber bands. The mass of object 2 is 0.20 kg.

What are the masses of objects 1 and 3 (LC)?



Newton's First Law

Your author's version:

Newton's first law An object that is at rest will remain at rest, or an object that is moving will continue to move in a straight line with constant velocity, if and only if the net force acting on the object is zero.

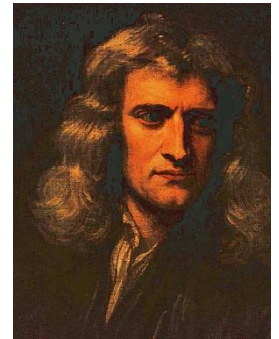
In Newton's own words (quoted from the Principia):

“Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon.”

Note: the second law in vector form, with kinematics and, specifying the initial conditions says the same thing.

Is this intuitive? Does it make common sense?

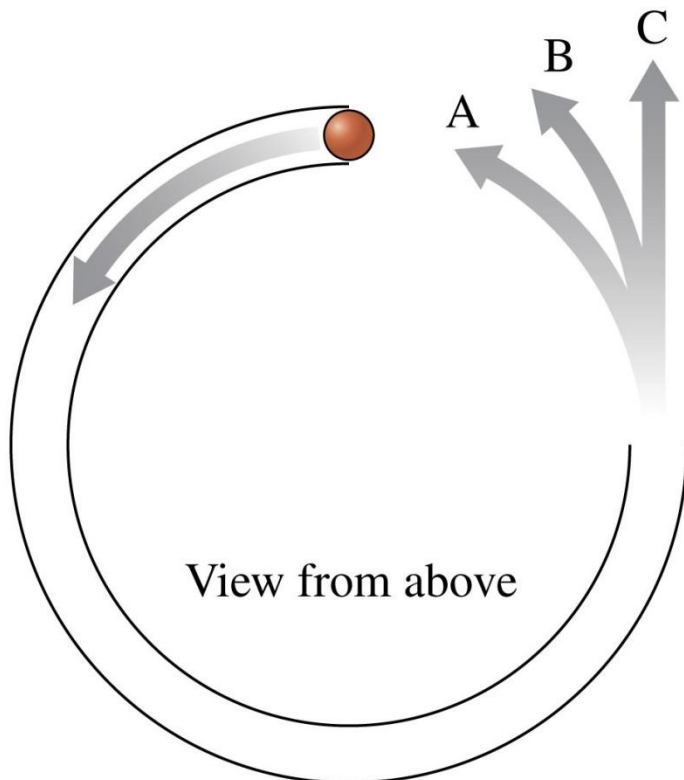
Not really, Aristotle took the common sense view that “the natural state of an Earthly object is a state of rest.” But what didn't Aristotle understand ?



After the exam, we'll see an excellent video on the life and science of Isaac Newton.

A little experiment with Newton's First Law

The figure below shows a hollow tube forming three quarters of a circle. It is lying flat on a table. A ball is shot through the tube at high speed. As the ball emerges from the other end, **does it follow Path A, Path B, or path C? Everyone make a prediction. (LC)**



The ball follows path C since the tube is no longer providing a centripetal force, and thus the ball continues on a straight line according to Newton's 1st Law.

Here's another example of this:
[Turning off the force of gravity from the Sun on the Earth from PheT.](#)

Free Body Diagrams

(as important as vectors*)

TACTICS BOX 5.3



Drawing a free-body diagram

- 1 Identify all forces acting on the object. This step was described in Tactics Box 5.2. **Choose and draw (there is no incorrect choice, but there are inconvenient ones)**
- 2 Draw a coordinate system. Use the axes defined in your pictorial representation.
- 3 Represent the object as a dot at the origin of the coordinate axes. This is the particle model. **The tail of the force vectors go on the body, i.e. the dot.**
- 4 Draw vectors representing each of the identified forces. This was described in Tactics Box 5.1. Be sure to label each force vector.
- 5 Draw and label the net force vector \vec{F}_{net} . Draw this vector beside the diagram, not on the particle. Or, if appropriate, write $\vec{F}_{\text{net}} = \vec{0}$. Then check that \vec{F}_{net} points in the same direction as the acceleration vector \vec{a} on your motion diagram.

Exercises 24–29

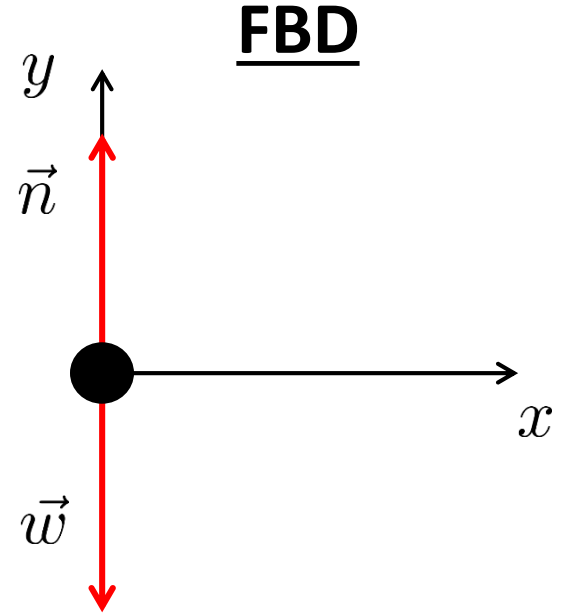
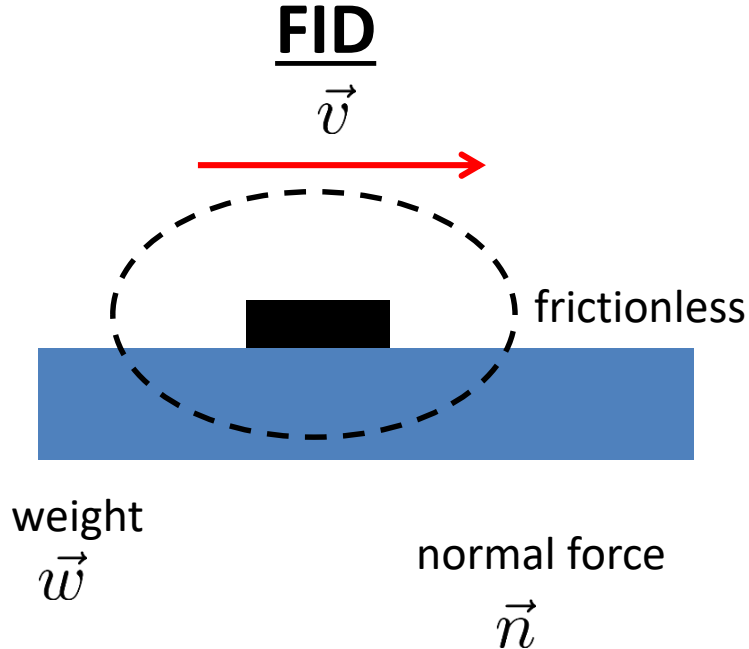


***In any dynamics problem, if the free body diagram is incorrect, then everything done after that will be incorrect as well!**

Whiteboard Problem 5-3

An ice hockey puck glides across frictionless ice at Goggin.

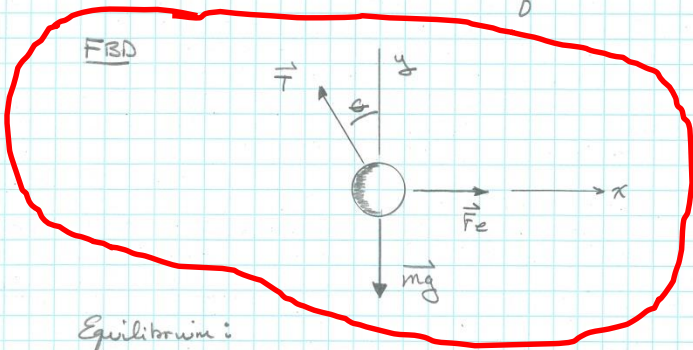
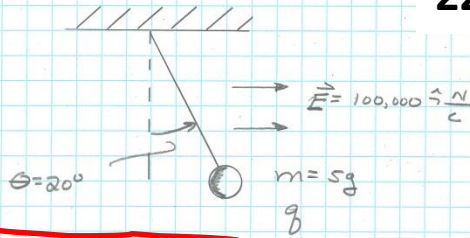
Mentally, draw a Force Identification Diagram and actually draw a Free Body Diagram of the puck (LC).



Assuming no air drag.

We'll be using Free Body Diagrams (FBD's) for a long time

22-67



Equilibrium:

$$\sum F_x = -T \sin \theta + F_e = 0$$

$$\sum F_y = T \cos \theta - mg = 0$$

Now, $\vec{F}_e = q\vec{E} \Rightarrow F_e = qE$

So

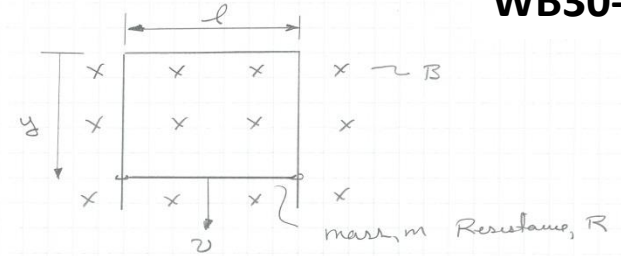
$$T \sin \theta = qE \quad (1)$$

$$T \cos \theta = mg \quad (2)$$

Divide (1)/(2):

$$\tan \theta = \frac{qE}{mg} \Rightarrow q = \frac{mg \tan \theta}{E} = \frac{1.763 \times 10^{-7} \text{ C}}{178.3 \text{ nC}}$$

WB30-7

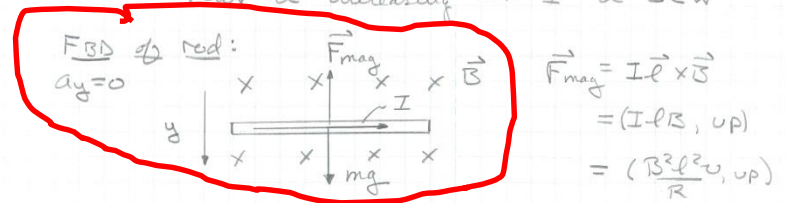


a.) As the rod slides down under gravity, the flux is increasing which induces a current in the rod. The rod will reach a terminal velocity (constant) when the gravitational force on it balances the magnetic force.

$$\text{Induced EMF: } \mathcal{E} = \left| \frac{d\Phi_m}{dt} \right| = \frac{d}{dt} (Blv) = Blv$$

$$\text{Induced Current: } I = \frac{\mathcal{E}}{R} = \frac{Blv}{R}$$

Flux is increasing $\Rightarrow I$ is ccw



$$\vec{F}_{\text{mag}} = I\vec{l} \times \vec{B} = (I\vec{l} \times \vec{B}, \text{up}) = \left(\frac{B^2 l^2 v}{R}, \text{up} \right)$$

$$\sum F_y = -F_{\text{mag}} + mg = 0$$

$$-\frac{B^2 l^2 v}{R} + mg = 0 \Rightarrow v = \frac{mgR}{B^2 l^2}$$

b.) $m = 10 \text{ g}$
 $l = 20 \text{ cm}$
 $B = 0.5 \text{ T}, R = 0.10 \Omega$

$$v = 0.98 \text{ m/s}$$

Whiteboard Problem 5-4

You've slammed on the brakes and your car is skidding to a stop while going down a 20° hill.

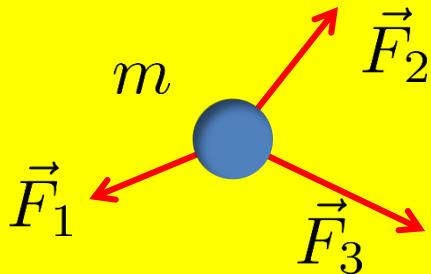
Draw a Free Body Diagram of the car (LC) .

Chapter 6 Dynamics I

In Chapter 6, we begin to look at actual dynamics problems – mostly in 1D, but some in 2D.

Everything that we'll do is based on Newton's Second Law (from previous slide):

Newton's Second Law:



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

The acceleration of the body is:

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

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

In 1D, we'll work with the component equation: $F_x = ma_x$

And the 1D kinematics equations: $v_x = \frac{dx}{dt}$ and $a_x = \frac{dv_x}{dt}$

For 2D problems, we'll have a set of equations for the y-component too.

Newtonian mechanics

MODEL Model the object as a particle. Make other simplifications depending on what kinds of forces are acting. **(will always be the case until we get to chapter 12)**

VISUALIZE Draw a pictorial representation. **(Draw, draw, draw . . .)**

- Show important points in the motion with a sketch, establish a coordinate system, define symbols, and identify what the problem is trying to find.
- Use a motion diagram to determine the object's acceleration vector \vec{a} . The acceleration is zero for an object in equilibrium.
- Identify all forces acting on the object at this instant and show them on a free-body diagram. **(Tails of forces go on the object. The FBD must be correct!)**
- It's OK to go back and forth between these steps as you visualize the situation.

SOLVE The mathematical representation is based on Newton's second law:

Use in component form:

$$\vec{F}_{\text{net}} = \sum_i \vec{F}_i = m\vec{a} \quad \left\{ \begin{array}{l} \sum F_x = ma_x \\ \sum F_y = ma_y \end{array} \right.$$

The forces are “read” directly from the free-body diagram. Depending on the problem, either **(We'll see both types of problems.)**

- Solve for the acceleration, then use kinematics to find velocities and positions; or
- Use kinematics to determine the acceleration, then solve for unknown forces.

ASSESS Check that your result has correct units and significant figures, is reasonable, and answers the question.



Equilibrium Problems

There are two types of equilibrium problems that we'll see:

Static Equilibrium $\Rightarrow \vec{v} = 0 = \text{constant}$ and $\vec{a} = 0$

Dynamic Equilibrium $\Rightarrow \vec{v} = \text{constant}$ and $\vec{a} = 0$

For particles, both types of equilibrium mean: $\vec{F}_{net} = m\vec{a} = 0$

And, in 2D, we'll always apply this in component form:

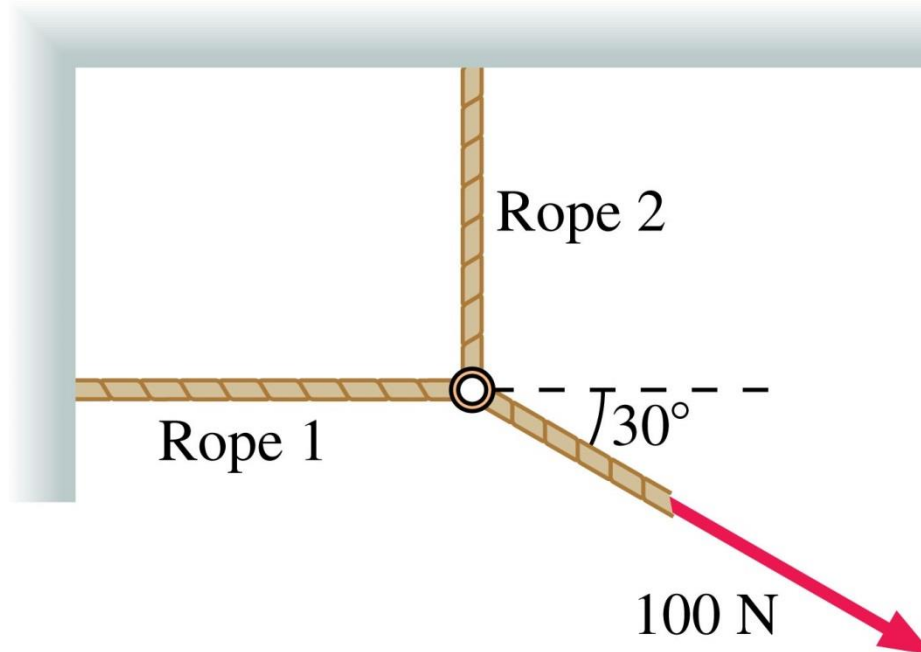
The Sum of the x-components, $\sum F_x = 0$

The Sum of the y-components, $\sum F_y = 0$

Whiteboard Problem 6-1

The three ropes in the figure below are tied to a small, very light ring. Two of the ropes are anchored to the walls at right angles, and the third rope pulls as shown.

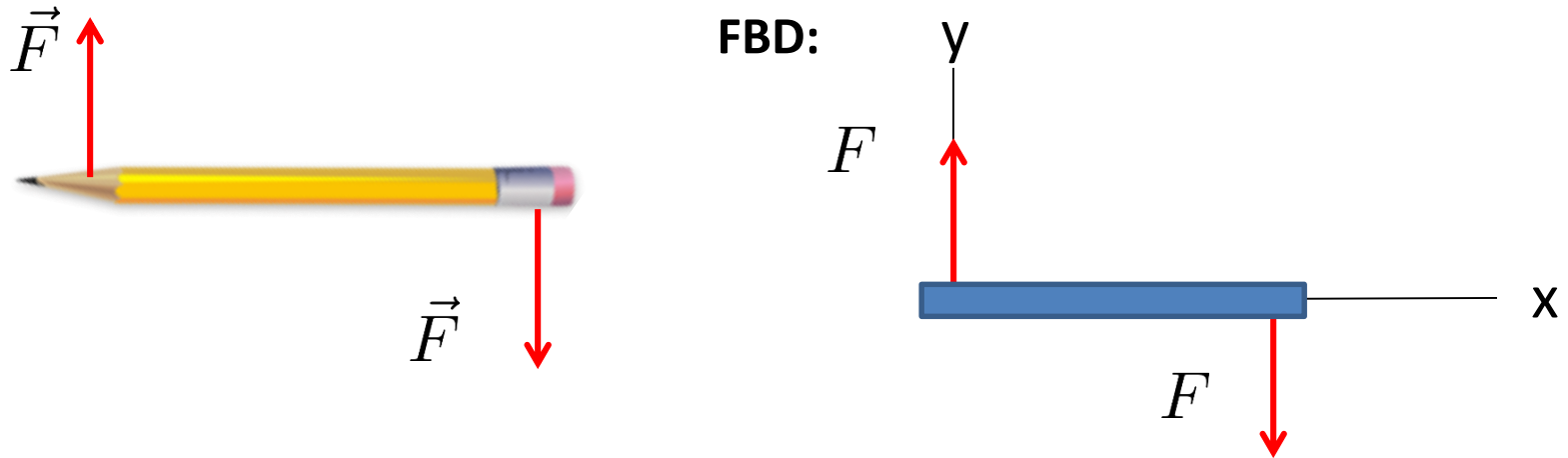
- Draw a complete Free Body Diagram of the ring
(assume the ring is massless).
- What are T_1 (LC) and T_2 , the magnitudes of the tension forces in Ropes 1 and 2?



Real Static Equilibrium

(For real objects)

Static Equilibrium for objects that can't be represented as a particle is somewhat different: consider a pencil subject to the two forces:

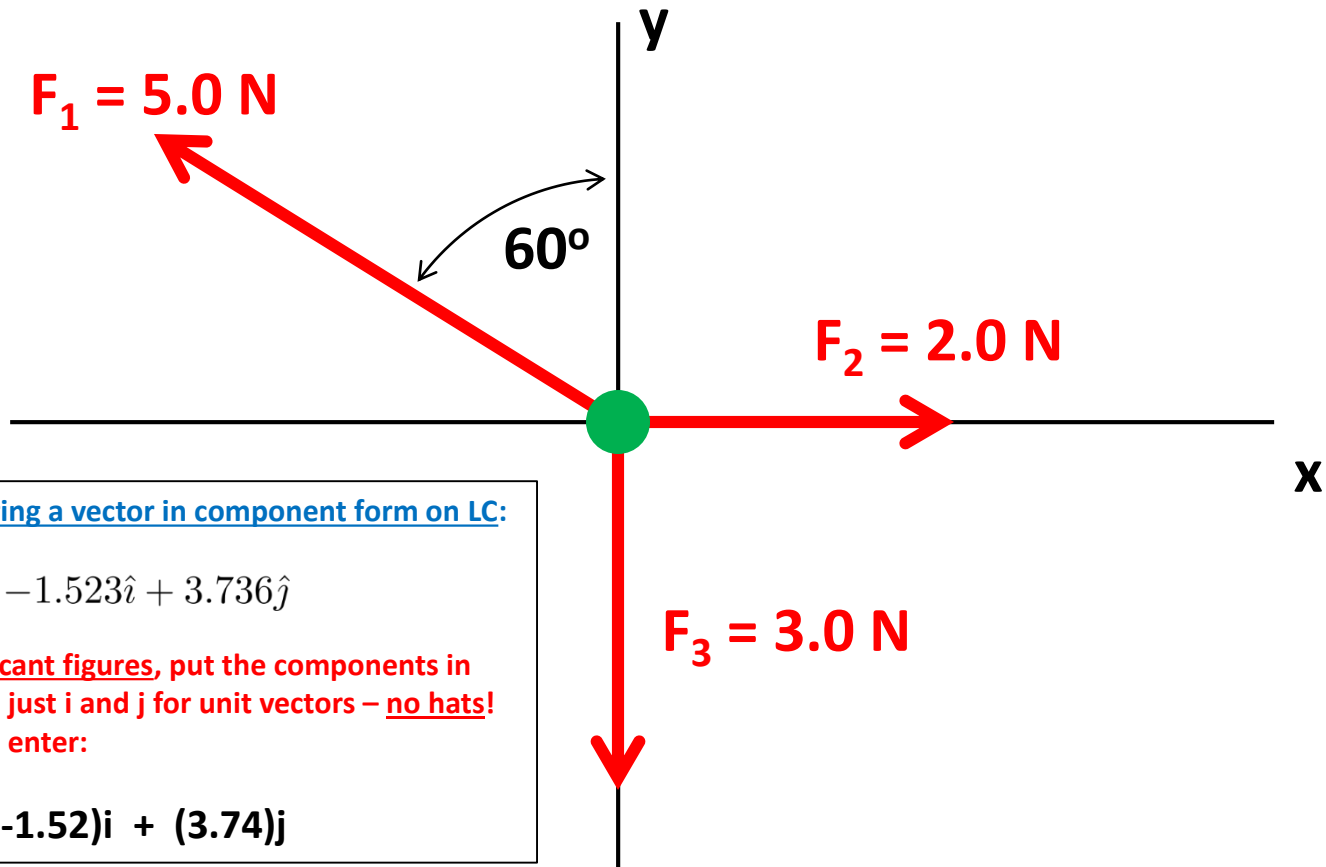


$\sum F_x = 0$ and $\sum F_y = 0$, but is the pencil in equilibrium?

No, it will rotate with an angular acceleration. For real objects in equilibrium, you need the force components to be zero and the sum of the torques about any point to also be zero - **don't worry now, we'll do this in Chapter 12.**

Whiteboard Prob. 6-2

The forces shown in the FBD below act on a 2.0 kg object.
Find the object's acceleration vector in component form (LC).



Types of forces that we'll encounter in problems

1. **Weight**, the long range force of gravity on an object.

$$\vec{w} = (mg, \text{toward the center of the Earth})$$

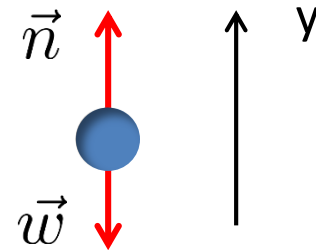
(sometimes I just write $m\vec{g}$ instead of \vec{w})

2. **Normal Force**, \vec{n} : Contact force between objects that touch; direction is **perpendicular (i.e. normal)** to the surface at the point of contact.

Note: read section 6.3 carefully and make sure that you understand the difference between mass and weight. **Also, what force does a bathroom scale measure?** (Note: I disagree with your author here, weight is always just the gravitational force on an object)



FBD of the person:



The scale measures the force of contact between the person and the scale, **i.e. the normal force**. *If there is an acceleration or the surface is tilted, the normal force won't equal the weight.*

Whiteboard Problem: 6-3

Zach, whose mass is 80 kg, is standing on a scale in an elevator descending at 10 m/s. The elevator takes 3.0 s to brake to a stop at the first floor.

- a. **Sketch the problem and draw a free body diagram of Zach; what is the reading on the scale before the elevator starts braking? (LC)**

- b. **Using the same free body diagram; what is the reading on the scale while the elevator is braking? (LC)**