

## PHYSICS 151 – Notes for Online Lecture #10

### Kinematics – describes the motion

### Dynamics – describes the cause of the motion

**Force** - Up to now, we've been analyzing motion, but not considering how motion occurs. Now we're ready to take into consideration the causes of motion - forces.

The early Greeks – specifically Aristotle – believed that the natural state of all things was to be at rest. If you drop a ball, it eventually comes to a stop. Galileo was the person who realized that objects were as equally likely to be in motion as they are to be at rest. Part of the problem Aristotle has was that when the cart was in motion, he would say that there are no forces acting on the cart – they didn't understand the idea of friction.

The person who summed up the laws of motion and forces was Sir Isaac Newton. You've all probably heard the story of Sir Isaac Newton, who was sitting under an apple tree one day and an apple fell on his head and he discovered gravity. The tale is probably a little exaggerated, but it was well known that Sir Isaac spent a lot of time sitting underneath a particular apple tree.

*A body at rest will remain at rest unless acted upon by a net force*

*A body in motion will continue moving at constant velocity unless acted upon by a net force*

This is a common statement of **Newton's First Law of Motion**, which is also called the law of inertia. Before we can understand what this law means, we have to understand the terms that we're using.

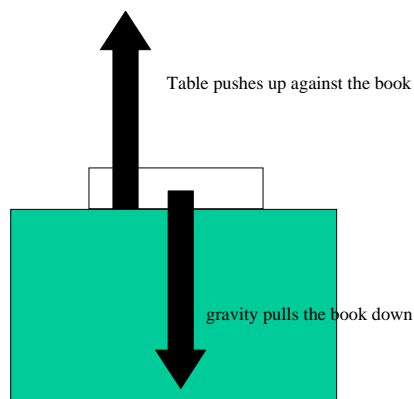
**Force** - Simply, a force is a push or a pull. An example of a force would be pushing a lawnmower, lifting a box, etc. What types of forces can you identify?  
gravity - the gravitational force  
friction –  
contact – the normal force

**Net Force** - We will talk a lot about the **net** force. Very rarely does an object have no forces at all acting on it. More usually, an object has lots of forces acting on it, but many of them act in different directions.

For example, let's look at a book on the table. What forces act on it? We can identify here both gravity and the force of the table pushing up on the book. However the book is not accelerating.

$$F_{\text{table (up)}} = F_{\text{gravity (down)}}$$

The **net force** is the sum of all the forces acting on a body.



For example, In a tug-of-war, one side is pulling to the left with a force of 15 N. The other side is pulling to the right with a force of 10N. The net force on the rope is:

$$\mathbf{F}_{\text{net}} = -15 \text{ N} + 10 \text{ N} = -5 \text{ N}$$

Where the negative sign means that the force is to the left. This example didn't need vectors, but many of the more complicated examples will.

## Mass and Inertia

Inertia is a word that is used inside and outside of physics, but it usually means the same thing: resistance to change.

Mass is a way to measure inertia. Mass is measured in kg in the SI system and in a unit called a slug in the English system. Weight depends on gravity. Since gravity can be different in different places, we like to use a more independent measure of inertia, called mass.

Let's return to the statement of the first law

*A body at rest will remain at rest unless acted upon by a net force*

*A body in motion will continue moving at constant velocity unless acted upon by a net force*

The first part of the law you probably believe. Things don't spontaneously move without someone (or something) moving them.

The second part is a more subtle, however. Not only does the object in motion continue moving when there are no forces applied to it, but also it moves **at constant velocity**. We know that when something is moving at constant velocity, the acceleration is zero. This is an important point.

**This means that in order to have acceleration, you have to have a force!**

## Newton's Second Law

$$\Sigma \vec{F} = m\vec{a}$$

The greek letter sigma means sum, so  $\Sigma \mathbf{F}$  represents the net force. A net force  $\Sigma \mathbf{F}$  on an object of mass  $m$  will thus cause an acceleration  $\mathbf{a}$ . Remember that this is a vector equation. From this law, we can obtain the units for force:

$$ma = (\text{kg}) \left( \frac{\text{m}}{\text{s}^2} \right) = \text{N}$$

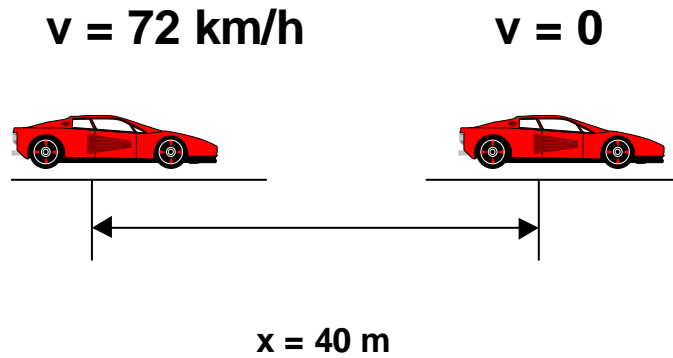
In the British system, the pound is actually the unit of force and not the unit of mass. The mass is measured in something called a slug.

$$ma = (\text{slug}) \left( \frac{\text{ft}}{\text{s}^2} \right) = \text{lb}$$

In words:

*The acceleration of an object will be directly proportional to the net force acting on the object and inversely proportional to the mass of the object*

**Ex. 11-1:** A car traveling at 72.0 km/hr along a straight, level road is brought uniformly to a stop in a distance of 40.0 m. If the car has a mass of  $8.80 \times 10^2$  kg, what is the braking force?



We know  $\Sigma \mathbf{F} = m\mathbf{a}$ , so we need to get  $a$ . This means that we have to use kinematics. Since there are no times given in this question, we have to use the  $v^2$  equation. Before starting, though, notice that the numbers have different units. Let's convert to mks

$$72.0 \frac{\text{km}}{\text{h}} \left( \frac{1000 \text{ m}}{1 \text{ km}} \right) \left( \frac{1 \text{ h}}{3600 \text{ s}} \right) = 20.0 \frac{\text{m}}{\text{s}}$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$0 = v_0^2 + 2a(x - x_0)$$

$$\frac{-v_0^2}{2(x - x_0)} = a = \frac{-(20.0 \frac{\text{m}}{\text{s}})^2}{2(40.0 \text{ m})}$$

$$a = -5 \frac{\text{m}}{\text{s}^2}$$

The sign makes sense, because we know the car is decelerating.

$$\Sigma \vec{F} = m\vec{a} = 8.80 \text{ kg} \left( -5 \frac{\text{m}}{\text{s}^2} \right) = 4.40 \times 10^3 \text{ N}$$

### Mass, Weight and Normal Forces

We've already learned about the acceleration due to gravity,  $g$ . From

$$\mathbf{F} = m\mathbf{a}$$

we see that gravity is responsible for a force, which acts to pull things downward. We call this force the weight:

$$\mathbf{W} = m\mathbf{g}$$

where the direction of the weight is in the same direction as gravity.

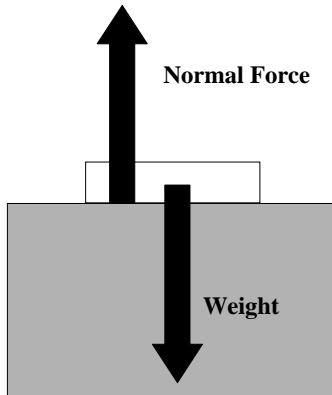
In British units: weight is in lbs, so

$$m = \frac{W}{g} = \frac{\text{lb}}{\frac{\text{ft}}{\text{s}^2}} = \frac{\text{lb} \cdot \text{s}^2}{\text{ft}} = \text{slug}$$

Remember that, unless you're specifically told to ignore gravity, gravity will always be included in the sum of forces.

So if there is a force that wants to cause acceleration downward, why don't we all accelerate down?

Actually, we do, to some extent; however, the fact that there is a hard surface beneath us keeps us from being pulled constantly downward. Objects on which we stand or sit exert a force upward. We call this a **contact** force or a **normal** force (normal means perpendicular) because the force always acts perpendicular to the surface.



Any time there is a surface involved, there will be a normal force.

Let's apply Newton's second law to this situation.

$$\sum \vec{F} = m\vec{a}$$

Here, the acceleration is zero, so

$$\sum \vec{F} = 0$$

Since we're dealing with vectors, we have to establish a coordinate system. I'll take the system to be with positive y upward.

$$\sum \vec{F} = 0$$

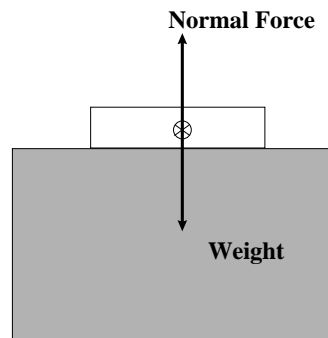
$$\sum \vec{F} = N - mg = 0$$

$$N = mg$$

The two forces thus exactly balance each other so that there is no net force and thus no acceleration.

**IMPORTANT:** N is not always equal to mg!

When we draw diagrams for using Newton's Laws, we draw them in a special way and call the resulting picture a **free-body diagram**. To draw a free body diagram, you assume that all forces acting on the object act at its center. This is sometimes confusing – I just told you that the normal force is a contact force and here we're drawing it so that it doesn't emphasize the contact of the surfaces.

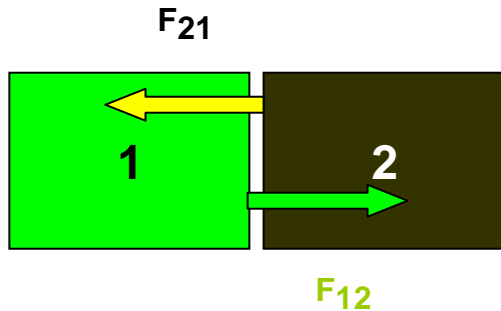


## Newton's Third Law

*For every action, there is an equal and opposite reaction*

For example, if two people on rollerblades stand facing each other and push off from one another, person 1 exerts a force on person 2. Newton's third law tells us that person two exerts a force on person 1 that is of the same magnitude, but opposite in direction.

If we represent the skaters as blocks, and draw the forces acting on the skaters due to their pushing off each other, skater 1 exerts a force  $F_{12}$  on skater 2. Skater 2 exerts a force  $F_{21}$  on skater 1. The third law tell us that



$$F_{12} = -F_{21}$$

This will be an important thing to know as we apply Newton's Laws, because it occasionally it gives us information we might not be given explicitly in the problem.

We call  $F_{12}$  and  $F_{21}$  an action-reaction pair.

To recap, Newton's three laws are:

- 1) an object at rest will remain at rest until acted upon by a net force and an object in motion will remain in motion at constant velocity unless acted upon by a net force
- 2)  $\Sigma F = ma$
- 3) for every action, there is an equal and opposite reaction

## Applying Newton's Laws

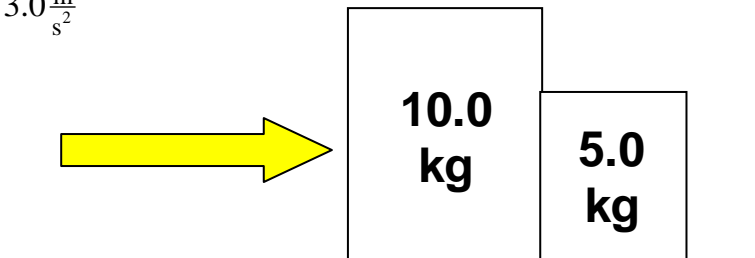
**Ex. 11-2:** A box of mass 10.0 kg and a box of 5.0 kg are pushed by an applied force of 45.0 N in the horizontal direction as shown. a) What is the acceleration of each box? b) What is the net force exerted on each box? c) what is the magnitude of the force exerted by one box on the other?

a)

$$\Sigma \vec{F} = ma$$

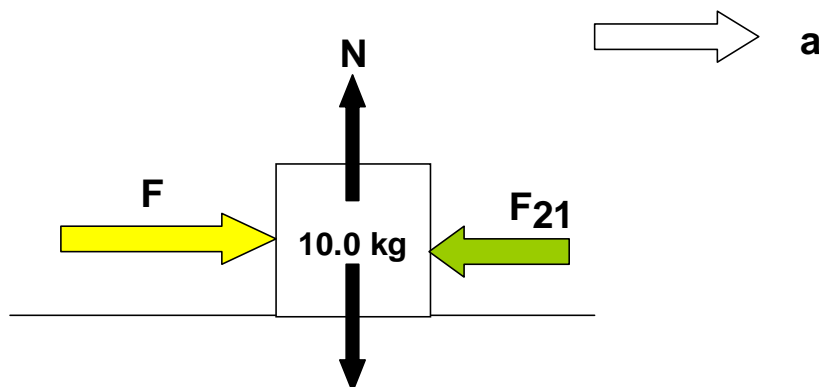
$$\Sigma \vec{F} = (m_1 + m_2)a$$

$$a = \frac{\Sigma \vec{F}}{(m_1 + m_2)} = \frac{45.0 \text{ N}}{(10.0 \text{ kg} + 5.0 \text{ kg})} = 3.0 \frac{\text{m}}{\text{s}^2}$$



b) Draw separate pictures to analyze the motion of each block. Call the 10.0 kg mass  $m_1$  and the 5.00 kg mass  $m_2$ . The acceleration is  $a_1 = 3.0 \text{ m/s}^2$  right, as found in part a.

$$\begin{aligned}\sum F_{\text{on } m_1} &= m_1 a_1 \\ \sum F_{\text{on } m_1} &= (10.0 \text{ kg})(3.0 \frac{\text{m}}{\text{s}^2}) \\ \sum F_{\text{on } m_1} &= 30 \text{ N}\end{aligned}$$

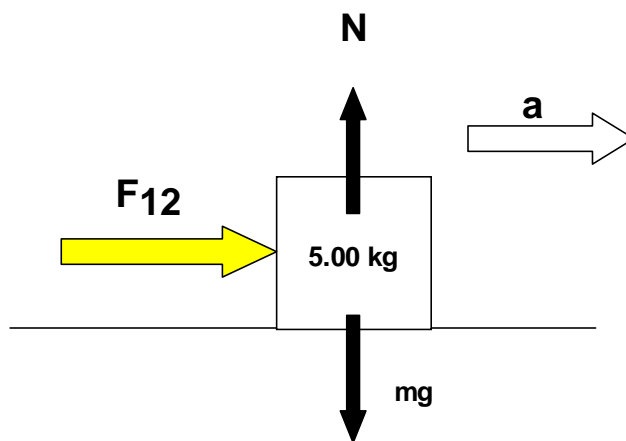


Draw a separate diagram for mass 2 (5.00 kg)

$$\begin{aligned}\sum F_{\text{on } m_2} &= m_2 a_2 \\ \sum F_{\text{on } m_2} &= (5.0 \text{ kg})(3.0 \frac{\text{m}}{\text{s}^2}) \\ \sum F_{\text{on } m_2} &= 15 \text{ N}\end{aligned}$$

Note that the net force on  $m_1$  and the net force on  $m_2$  add up to the total applied force

$$30 \text{ N} + 15 \text{ N} = 45 \text{ N}$$



c) The force between the two blocks is  $F_{12}$ , which has the same magnitude as  $F_{21}$ . From the diagram above,  $F_{12}$  is the net force on block 2

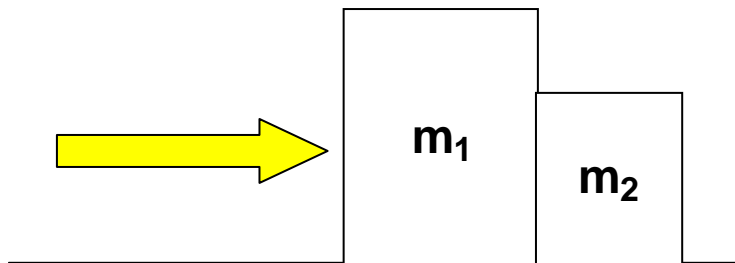
$$\begin{aligned}\sum F_{\text{on } m_2} &= m_2 a_2 \\ F_{12} &= m_2 a_2 \\ F_{12} &= 15 \text{ N}\end{aligned}$$

You can find the same answer from looking at the equations for block #1

$$\begin{aligned}\sum F_{\text{on } m_1} &= m_1 a_1 \\ F_A - F_{21} &= m_1 a_1 \\ F_A - m_1 a_1 &= F_{21} \\ 45.0 \text{ N} - 30 \text{ N} &= F_{21} \\ 15 \text{ N} &= F_{21}\end{aligned}$$

**Ex. 11-3:** 67 N are being used to push  $m_1$  and  $m_2$  as shown. If  $m_1 = 7.0$  kg and the boxes accelerate at  $3.9 \text{ m/s}^2$ , what is the mass of  $m_2$ ?

From the drawings in example 11-2, we have two equations for  $m_1$  and  $m_2$



$$F_A - F_{21} = m_1 a \qquad F_{12} = m_2 a$$

It looks as though there are three unknowns:  $m_2$ ,  $F_{12}$  and  $F_{21}$ ;

however, we know that the magnitude of  $F_{12}$  equals the magnitude of  $F_{21}$ , so we can combine these equations to:

$$F_A - m_2 a = m_1 a$$

$$F_A - m_1 a = m_2 a$$

$$\frac{F_A - m_1 a}{a} = m_2$$

$$\frac{67 \text{ N} - 7.0 \text{ kg} \left( 3.9 \frac{\text{m}}{\text{s}^2} \right)}{\left( 3.9 \frac{\text{m}}{\text{s}^2} \right)} = m_2$$

$$10 \text{ kg} = m_2$$

Note: You know that  $F_{12} = -F_{21}$ , so why did we replace  $F_{21}$  with  $+F_{12}$ ? The answer is that the signs have already been taken into account in our drawings. When we wrote  $F_{21}$ , we wrote it as a force acting toward the left. When we wrote  $F_{12}$ , we wrote it as a force acting toward the right. This is why the substitution is only in the magnitude of the forces.