AP Physics – Applying Forces

This section of your text will be very tedious, very tedious indeed. It's mostly just a bunch of complicated problems and how to solve them. Don't be discouraged by how dry it is – sometimes things that are useful don't come in exciting packages. Life cannot always be MTV and video game quality. This section is actually one of the most important parts of the course.

Key Concept: Of enormous importance in solving kinematic problems is this concept.

The sum of the forces acting on objects at rest or moving with constant velocity is always zero.

$$\sum \boldsymbol{F} = \mathbf{0}$$

This is a special case of Newton's second law; the special case where the net force acting on the system is zero.

We can further simplify the situation! We can analyze the forces in both the ***x*** and ***y*** directions. For an object in equilibrium (at rest or moving with constant velocity) the sum of the forces in the ***x*** and ***y*** directions must also equal zero.

$$\sum \boldsymbol{F_X} = \mathbf{0} \quad \text{and} \quad \sum \boldsymbol{F_Y} = \mathbf{0}$$

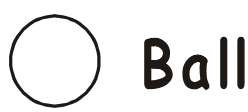
Next Key Concept: Yet another key concept is that when a system is not in equilibrium, the sum of all forces acting must equal the mass times the acceleration that is acting on it, i.e., good old Newton's second law.

$$\sum \boldsymbol{F} = \boldsymbol{ma}$$

Free Body Diagrams: When analyzing forces acting on an object, a most useful thing to do is to draw a ***free body diagram*** or ***FBD***. You draw all the force vectors acting on the system as if they were acting on a single point within the body.

You do not draw the reaction forces.

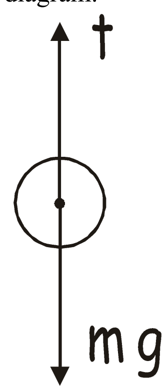
A ball hangs suspended from a string. Let's draw a FBD of the thing. First, draw the ball.



What are the forces acting on it? In this simple case, there are only two forces, the weight of the ball, ***mg***, and the upward force, ***t***, exerted by the string. We call forces that act along strings and chains and such things ***tensions***.

So there are two forces. The weight is directed downward and the tension is directed upward.

Draw the vectors from the center of the ball and label them. You have now made your first free body diagram.



Tension ≡ a pull tangent to a string or rope.

What can we say about the tension and the weight? Well, is the ball moving?

No, it's just hanging. So no motion; that means it is at rest.

What do we know about the sum of the forces acting on it?

If a body is at rest, then the sum of the forces is zero. There are only two forces, the tension and the weight.

$$\sum F = 0$$

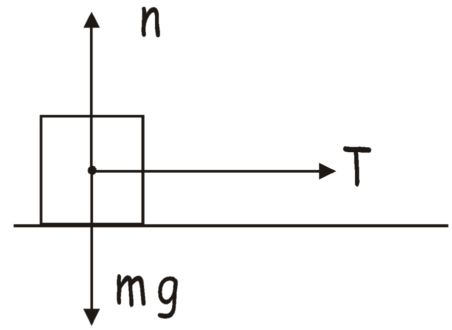
Therefore:

$$t - mg = 0 \qquad so \qquad t = mg$$

Thus, behold! The two forces are equal in magnitude, but opposite in direction (one is up and the other is down).

Problems that involve objects at rest (so the sum of the forces is zero) are called ***static problems***.

Let's look at a typical static problem. We have a crate resting on a frictionless horizontal surface. A force ***T*** is applied to it in the horizontal direction by pulling on a rope - another tension. Let's draw a free body diagram of the system.



There are three forces acting on the crate: the tension from the rope (***T***), the normal force exerted by the surface (***n***), and the weight of the crate (***mg***).

A normal force is a force exerted perpendicular to a surface onto an object that is on the surface.

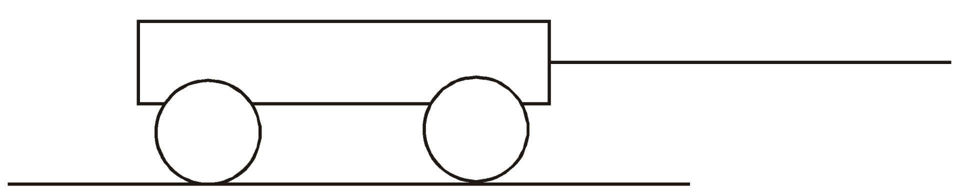
It is important to realize that the normal force is not the reaction force to the object's weight. The reaction force to the object's weight is the force that the object exerts on the earth – recall that the object pulls the earth up just as the earth pulls the object down. The normal force is the table pushing the object up, the reaction force is the object pushing the table down. These action reaction pairs are separate things.

Again, we do not draw the reaction forces on the FBD.

Useful Problem Solving Strategy: Here is a handy set of steps to follow when solving static problems.

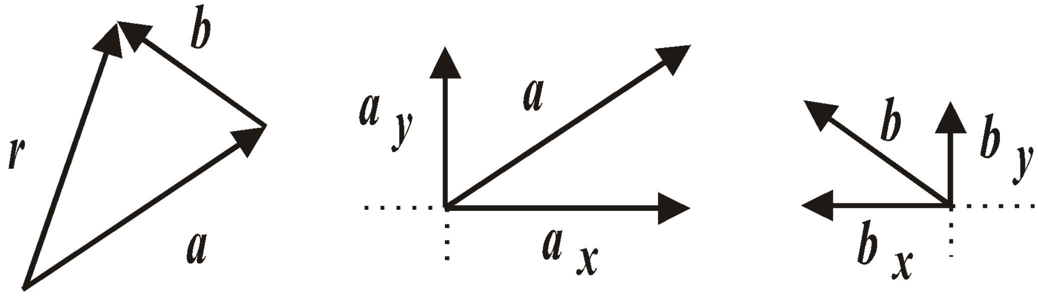
1. Make a sketch.
2. Draw a FBD for each object in the system - label all the forces.
3. Resolve forces into ***x*** and ***y*** components.
4. Use $\sum \boldsymbol{F_X} = \mathbf{0}$ and $\sum \boldsymbol{F_Y} = \mathbf{0}$
5. Keep track of the force directions and decide on a coordinate system so you can determine the sign (neg or pos) of the forces.
6. Develop equations using the second law for the ***x*** and ***y*** directions.
7. Solve the equations.

- A crate rests on very low friction wheels. The crate and the wheels and stuff have a weight of 785 N. You pull horizontally on a rope attached to the crate with a force of 135 N. (a) What is the acceleration of the system? (b) How far will it move in 2.00 s?

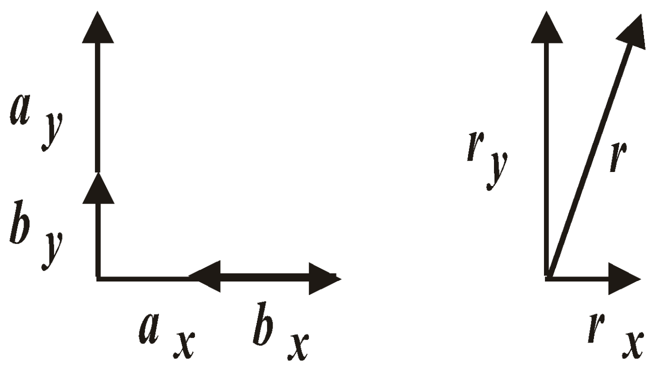


Adding Forces: When adding two or more vectors, you find the components of the vectors, then add the components. So you would add the x components together which gives you the resultant x component. Then add the y components obtaining the resultant y component. Then you can find the magnitude and direction of the resultant vector.

You want to add two forces, ***a*** and ***b***. They are shown in the drawing. The resultant force, ***r***, is also shown. To the right you see the component vectors for ***a*** and ***b***.



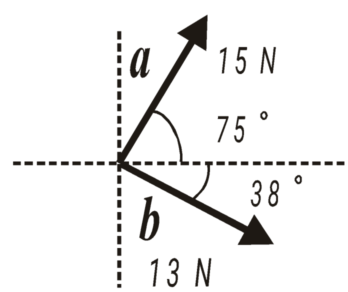
We add the component vectors – it looks like this:



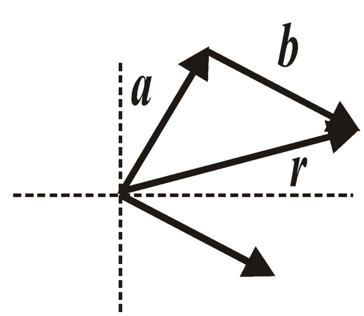
See how you end up with the resultant vector after you've added up the components?

Now let's do a problem where we have to add two forces.

Here is a drawing showing the two vectors:

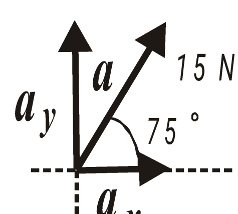


We do a quick sketch showing how the forces add up:



Okay, here's how to add them up.

1. Resolve each vector into its ***x*** and ***y*** components.
2. Add all the ***x*** components to each other and the ***y*** components to each other. This gives you the ***x*** and ***y*** components of the resultant vector.
3. Use the Pythagorean theorem to find the magnitude of the resultant vector.
4. Use the tangent function to find the direction of the resultant.

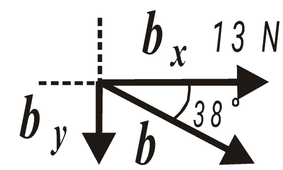


1. Find the ***x*** and ***y*** components for force ***a***:

$$a_x = a\cos\theta \quad = 15\ N \cos 75^{\circ} \quad = \quad 3.88\ N$$

$$a_y = a\sin\theta \quad = 15\ N \sin 75^{\circ} \quad = \quad 14.5\ N$$

2. Find ***x*** and ***y*** components for force ***b***



$$b_x = a\cos\theta \quad = 13\ N \cos 38^{\circ} \quad = \quad 10.2\ N$$

$$b_y = a\sin\theta \quad = 13\ N \sin 38^{\circ} \quad = \quad -8.00\ N$$

2. Add the components:

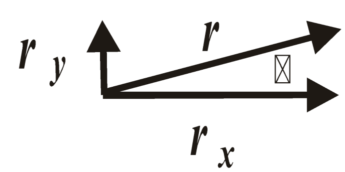
$$r_x = a_x + b_x \quad = 3.88\ N + 10.2\ N \quad = \quad 14.08\ N$$

$$r_y = a_y + b_y \quad = 14.5\ N + (-8.00\ N) \quad = \quad 6.50\ N$$

3. Find the magnitude of the resultant vector (which we shall call r):

$$r^2 = r_x{}^2 + r_y{}^2 \quad r = \sqrt{r_x{}^2 + r_y{}^2} \quad = \sqrt{(14.08\ N)^2 + (6.50\ N)^2} \quad = \quad \boxed{15.5\ N}$$

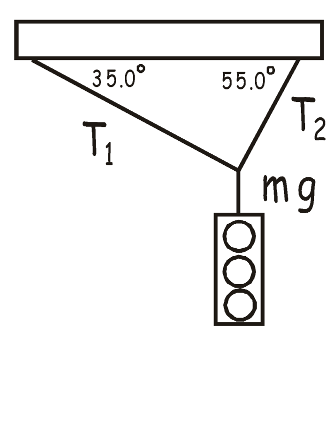
4. Find the direction of the resultant force:



$$\theta = \tan^{-1}\left(\frac{r_Y}{r_X}\right)$$

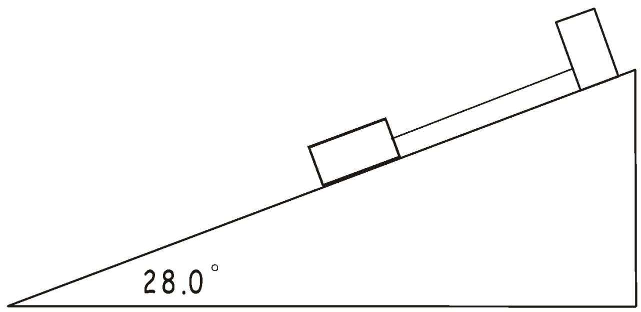
$$\theta = \tan^{-1}\left(\frac{6.50\ \cancel{N}}{14.08\ \cancel{N}}\right) \quad = \quad \boxed{24.8^{\circ}}$$

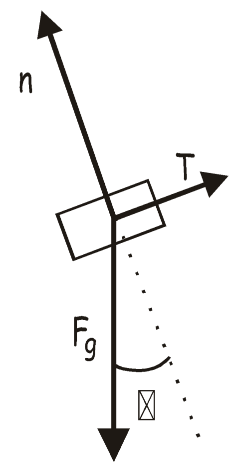
- A 85.0 kg traffic light is supported as shown. Find the tension in each cable.



Lovely Ramp Problems: A common type of kinematic problem involves an object at rest upon or moving along the surface of an elevated ramp.

Here's a simple problem. A frictionless ramp is elevated at a 28.0° angle. A block rests on the surface and is kept from sliding down by a rope tied to a secure block as shown

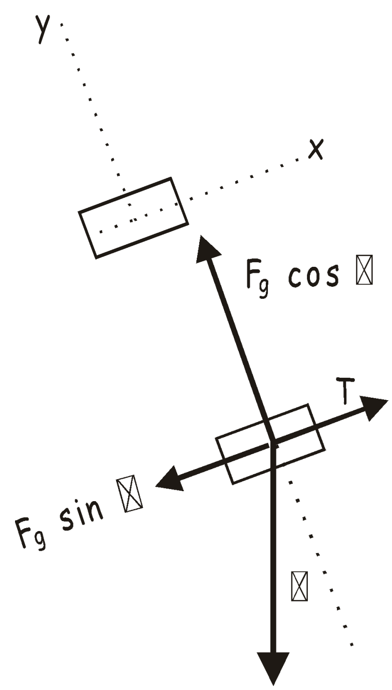




If the block has a weight of 225 N, what is the force on the rope holding it up?

First, let's draw a FBD:

Next we have to choose ***x*** and ***y*** coordinates:



The positive ***x*** direction is up the surface of the ramp – parallel to the surface.

The positive ***y*** direction is perpendicular to the surface of the ramp.

There is a component of the block's weight, F_g, that is directed down the surface of the ramp, which would be along the ***x*** axis. This force is $F_g \sin\theta$. The normal force will be $F_g \cos\theta$.

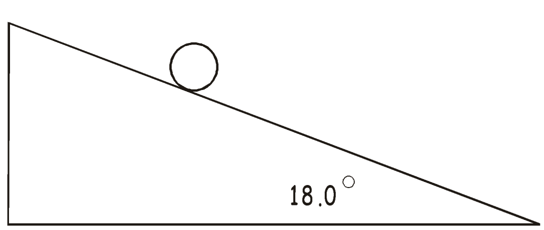
$\sum F_x = 0$ and $\sum F_y = 0$

x direction: ***T*** is balanced by a force down the ramp

$$T - F_g \sin\theta = 0 \qquad T = F_g \sin\theta$$

$$T = (225\ N)\sin 28^o \quad = \quad \boxed{106\ N}$$

- A 5.00 kg ball slides down a 18.0° ramp. (a) What is the acceleration of the ball? Ignore friction. (b) If the ramp is 2.00 m long, how much time to reach the bottom?



The Origin of the term "Nerd":

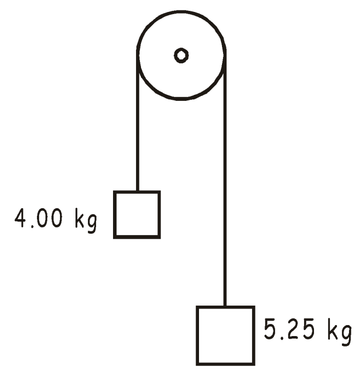
The Nerd word has two popular stories toward its origin. One is that it comes from Dr. Seuss's *If I Ran the Zoo*, in which appears a creature called a "nerd." This book was published in 1950. The second is that it is a variation on the name of ventriloquist Edgar Bergen's (Candace's father) dummy, Mortimer Snerd.

Both stories could be correct. There is no cite of the term prior to its 1950 appearance in the Dr. Seuss book. The earliest cite of the current usage is from 1951. Lighter, however, cites a 1941 use of the nickname Mortimer Snerd to refer to a technical, brainy type of guy.

http://www.idiomsite.com/nerd.htm

Two Body Problems: So far we've dealt with only one body. Let's expand the use of Newton's laws to deal with multiple body situations. To solve these problems, each body is treated separately. You draw a FBD for each object an then analyze the forces that are acting. This will give you several equations that can be used to solve the problem.

- Two masses, 4.00 kg and 5.25 kg are connected by a light string to a frictionless pulley as shown. Find the tension in the string, and the acceleration on the system.

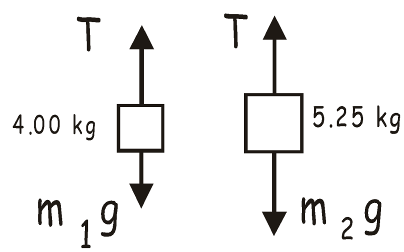


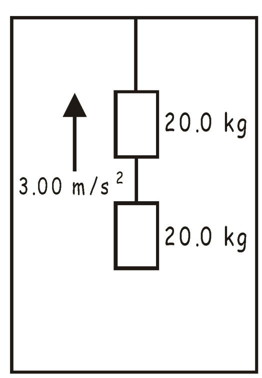
A single pulley as we have here simply changes the direction of the forces. With the weights arranged as they are, we can see that the heavy weight will move downward and the lighter mass will move up. We will treat the as if they are in one dimension, however.

As we have two bodies, we must draw a FBD for each of them.

Each body experiences two forces; the tension in the string (***T***) which has the same magnitude for each of them (although it is directed in opposite directions), and their weight (m_1g and m_2g).

HINT: Here are the FBD's for each:

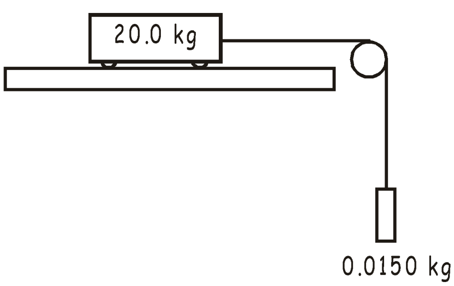




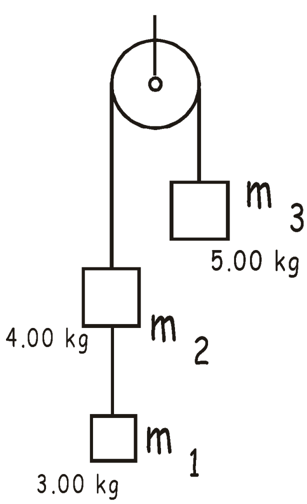
- 2 blocks hang in an elevator as shown. The elevator accelerates upward at 3.00 m/s^2. Find the tension in each rope.

> ***Trivial Stuff:***
>
> - Your statistical chance of being murdered is one in twenty thousand.
> - A Japanese company hired a soothsayer to throw dice to help determine on which floor of the two 110-story World Trade Center towers they should have their offices on. Their office survived the initial impact of the aircraft strikes.

- A 20.0 kg cart with very low friction wheels sits on a table. A light string is attached to it and runs over a low friction pulley to a 0.0150 kg mass. What is the acceleration experienced by the cart?



- 3 masses hang as shown, they are connected by light strings and your basic frictionless pulley. (a) Find the acceleration of each mass and (b) the tensions in the 2 strings.



FBD's: