Forces:
1. Are a Push or a Pull
2. Are a Vector having a magnitude and direction
3. Have units of Newtons “N” \( N = \frac{kgm}{s^2} \)

**Newton and his deceptively simple laws:**

Newton gives us 3 laws that concern forces of any kind. They tell us how forces behave and their effect on the motion of objects. They are listed here a little differently than what you see them in your book:

**Law #1:** If there aren’t any forces acting on an object it will do one or two things:
1. Sit still and remain sitting still (Velocity = 0)
2. Move in a straight line at a uniform rate (Velocity = Constant)

This is also true if there are outside forces on the object that all cancel out! \( \sum F = 0 \)

Here is the bottom line for Law #1:
- If \( \sum F = 0 \) then \( a = 0 \) and the object is sitting still or moving at a constant velocity.
- Conversely, if an object is sitting still or moving at a constant velocity then \( a = 0 \) and \( \sum F = 0 \)

**Law #2:** The vector sum of the external forces on an object will cause the object to accelerate in the same direction as the net force. Objects with less mass are more easily accelerated. Objects with more mass are harder to accelerate. \( \sum F = ma \)

Note: Law #1 is a special case of Law #2 when acceleration is zero!

Here is the bottom line for Law #2:
- If there is a net force on an object it will accelerate in the direction of that net force.
- The equation: \( \sum F = ma \) only relates forces to mass and acceleration. If you want to know the velocity or displacement of an object you will need to use kinematics or something else.

**Law #3:** When one objects exerts a force on another the second objects always replies with a duplicate force in the opposite direction.

3\(^{rd}\) Law Example: Lets say that you get into a fight with a friend over who is the better physics student. They get mad and hit you in the face with their fist. You have the satisfaction of knowing that your face exerted just as big a force back on their fist. The force from your face will cause their hand to slow down and possibly break their knuckle. Unfortunately, the force from their fist will make your head move backward and probably do serious damage because knuckle bones are stronger than face bones.

3\(^{rd}\) Law Reality Check: In movie fights it is not uncommon to see the “hero” head-butt the “bad guy”. According to the 3\(^{rd}\) Law, is this a good fighting strategy?
What you absolutely have to know about Forces to pass the AP Physics B test!

Newton’s Laws seem simple enough until we realize that there are lots of forces in the world and usually more than one acts on an object at the same time. The equation $\sum F = ma$ tells us to “sum up” all the forces acting on the object. So, first we have to know what kind of forces there are.

Here’s a list of common forces found in Mechanics on the AP Physics B test:

<table>
<thead>
<tr>
<th>Force</th>
<th>Symbol</th>
<th>Comment / Equation</th>
</tr>
</thead>
</table>
| Weight | $F_g, W$ | $F_g = mg$
| | | Always acts toward the center of the Earth.
| | | This is a simplified equation for gravity that is only good near the surface of a planet. |
| Gravity | $F_g$ | $F_g = G \frac{m_1 m_2}{r^2}$
| | | Always attracts one planet toward the center of mass of the other. |
| Normal | $F_N, N$ | A contact force between objects.
| | | Objects must touch for there to be a normal force.
| | | The $F_N$ always pushes perpendicular to the surface.
| | | CAUTION! $F_N$ is a “Lazy Force”. (Lazy Forces will be discussed in detail later.) |
| Friction | $F_f, f$ | $F_f \leq \mu F_N$
| | | $F_f$ is always parallel to the surface.
| | | Static Friction opposes the intended direction of relative sliding.
| | | Dynamic Friction (Also called Kinetic Friction or Sliding Friction) acts in the direction to oppose the relative sliding of objects.
| | | CAUTION! Static Friction is a “Lazy Force”. |
| Tension | $F_T, T$ | $F_T$ is a force that pulls through strings, ropes, cables, etc…
| | | $F_T$ is distributed throughout the string.
| | | CAUTION! Tension is a “Lazy Force”. |
| Spring | $F_S$ | $F_S = -kx$
| | | $F_S$ always acts opposite in direction to the way the spring is stretched. |

So… the real difficulty is building the “$\sum F$” side of the $\sum F = ma$ equation. What we need is a system to help us assemble $\sum F = ma$.

“**The System**” for solving $\sum F = ma$ problems.

1. Draw a Free Body Diagram (FBD).
2. Determine if the object is accelerating.
3. Set up your coordinate system.
4. Build $\sum F = ma$ for the two directions of your coordinate system.
5. Solve!
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**Step #1 Draw FBD**

How to draw a Free Body Diagram (FBD).

1. Draw a simple picture of the object that you are concerned with.
2. Draw an arrow for each force vector that acts on the object. These arrows should:
   - Be attached/connected to the object.
   - Point in the direction of the force.
   - Have a length appropriate to their magnitude.
     - Small forces should have short vectors.
     - Large forces should have long vectors.
     - Equal forces should have arrows of the same length.
3. Never, never, ever draw any other vector arrows attached to the object unless the problem specifically asks for them.
   
   For example: Never draw displacement, velocity, or acceleration vectors attached to your FBD. You may draw these vectors off away from your FBD as reference but never attached to it.

   WHY?  
   A) Extra vectors tend to confuse students when they build the $\sum F$ side of the equation.
   B) You will lose points on the AP test for having extra vectors on your FBD.

**Examples of FBD’s**

- **Example #1** Girl pulling a box at constant speed
  
  ![FBD for the box](image1)

- **Example #2** Cow on skateboard rolling down a hill
  
  ![FBD of cow on skateboard rolling down a hill](image2)

- **Example #3** Rocket accelerating off the launch pad
  
  ![FBD of rocket](image3)
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**Step #2 Determine if the object is accelerating**

A few key words in the problem can tell you if there is any acceleration or not. Here are the key words to look for:
- Rest -or- velocity equals zero
- constant velocity -or- velocity is a constant
- acceleration is zero -or- not accelerating

Each statement means that \( a = 0 \). Therefore either \( v = 0 \) -or- \( v = \) constant and that means that \( \sum F = 0 \! \)!

If the object is accelerating it is very important to determine which direction it is accelerating. Is it accelerating in the x direction, y direction, or some other direction?

For example:
- A cannon ball shot through the air is accelerating downward at \( a = g = 9.8 \frac{m}{s^2} \)
- A block on a frictionless incline accelerates down the incline parallel to the surface.

**Step #3 Set up the coordinate system**

Set up the coordinate system so that one axis is in the direction of the acceleration if there is any and the other perpendicular to it. This way you will always get \( \sum F = ma \) in one direction and \( \sum F = 0 \) in the other direction. This will simplify your calculations!

Example #1 FBD for the box

Example #2 FBD of cow on skateboard rolling down a hill

Example #3 FBD of rocket
What you absolutely have to know about Forces to pass the AP Physics B test!

**Step #4 Build** \( \sum F = ma \) **for the two directions of your coordinate system.**

**Step #5 Solve**

Look at each force in your FBD and compare it to your coordinate system. Are your forces in the same directions as your coordinates? If so you can go ahead and build your \( \sum F = ma \) equations. If a force is at an angle to the coordinate system you will need to break it into components before building \( \sum F = ma \).

This is demonstrated in the three examples below:
- Example #1: Notice that the pulling force from the girl is at an angle to the coordinate system. It must be broken into x and y components.
- Example #2: The weight of the cow must be broken into vectors parallel and perpendicular to the incline.
- Example #3: All the forces are in the y direction and nothing more needs to be done.

After all the force vectors have been broken down all that is left to do is build \( \sum F = ma \) and solve! This is demonstrated in each of the examples below.

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**Example #1 FBD for the box**

**\( \sum F = ma \) for the box**

**Example #2 FBD of cow on skateboard rolling down a hill**

**\( \sum F = ma \) for cow**

**Example #3 FBD of rocket**

**\( \sum F = ma \) for rocket**

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What you absolutely have to know about Forces to pass the AP Physics B test!

Beware the “Lazy Forces”

As mentioned earlier Normal, Static Friction, and Tension \((F_N, F_f, F_T)\) are all lazy forces. They only do what they absolutely have to do and nothing more or less. They are not like Weight, which can be calculated knowing \(m\) and \(g\). Lazy forces are never a set value. They change depending on the situation.

**Normal Force:** It is a common misconception that \(F_N = mg\). This is not always true!

Look again at examples #1 & #2 above for the wagon and the cow. Notice that \(F_N \neq mg\) in either case! The normal force is less than the weight! In fact, if the girl had been pushing down on the wagon in example #1 the normal force would be more than the weight.

**Tension:** Tension is similar to Normal Force. It will vary depending on the situation as shown in the following examples of a yo-yo on a string.

**Static Friction (The laziest of the lazy forces):** While \(F_N\) and \(F_T\) may sometimes be larger than we might expect, Static Friction is always less than an absolute maximum value \((F_f \leq \mu_{\text{static}} F_N)\). Here is an example:

A 20-kg box is pulled to the right by a force of 10 N. The static coefficient of friction between the box and floor is \(\mu = 0.50\). If the box remains stationary, what is the frictional force acting on the box?

Note: Sliding Friction is not a Lazy Force! Sliding Friction is always equal to \(\mu_{\text{kinetic}} F_N\).
Inclines: The most troublesome thing about these problems is that objects naturally want to accelerate down the incline. Since objects can accelerate down the incline, the coordinate system is also inclined. See the diagrams below:

Here is a good Incline/Friction problem. If you understand this one then you really know your stuff!

What is the maximum angle for which a box will not slide down an incline?

Assume $\mu_{\text{static}} = 0.4$ and $\mu_{\text{kinetic}} = 0.25$

If the box is not sliding: $v = 0$, $\alpha = 0$, $\Sigma F = 0$

If we are at the max angle $\theta$, we must be at the max $F_f$ value.

$\Sigma F_i = 0$

$mg \sin \theta = F_{\text{static}}$

$mg \sin \theta = \mu_{\text{static}} F_n$

Substitute

$mg \sin \theta = \mu_{\text{static}} mg \cos \theta$

$\mu = \sin \theta = \tan \theta$

$\cos \theta = \frac{1}{\sqrt{1 + \tan^2 \theta}}$

$\theta = \tan^{-1} 0.4 = 21.8^\circ$
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**Coupled Motion:** These are problems in which two or more objects are tied together by a string. Sometimes pulleys are involved. Remember that in AP Phys B the pulleys only change the direction of the string and thus the Tension in the string – Nothing more! In these problems it is usually necessary to draw several different FBD’s for different parts of the object.

Here are three common coupled motion problems:

- **Horizontal force pulling 2 blocks to the right at a constant speed**

- **Atwood Machine with two different masses**

- **Accelerating off a table with friction**
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Statics:
The important thing to remember about statics is that since the velocity is zero all the forces cancel!

\[ \sum F_{x-direction} = 0 \quad \text{and} \quad \sum F_{y-direction} = 0 \]

Here are the two most common types of problems you are likely to encounter on the AP Physics B test.

Here are two final examples for practice:

Example #1 A 6000-kg helicopter lifts a 500 kg package off the ground. The helicopter accelerates up at 3 m/s². 
   a) How much thrust must the rotor blades generate to accomplish this?
   b) What is the tension in the cable between the helicopter and the package?
What you absolutely have to know about
Forces to pass the AP Physics B test!

Example #2 Two blocks are attached by a string as shown below. Each block has a mass of 10 kg. The coefficients of friction between the block and the incline are $\mu_{\text{static}} = 0.3$ and $\mu_{\text{kinetic}} = 0.2$

a) Will the block A move? If so, in which direction will it move?
b) What is the minimum $\mu_{\text{static}}$ so that the blocks remain stationary?
c) The mass of block A is tripled to 40 kg. What is the acceleration of block A?