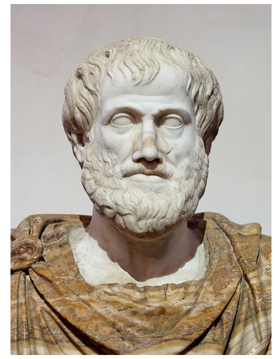
Newton's Laws of Motion

Aristotle

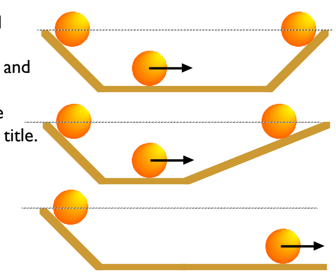
The Greek philosopher & metaphysicist Aristotle (384-322 B.C.) based his analysis of falling bodies on pure logic: "Heavier objects fall faster in proportion to their weight." This belief was *so* logical that it persisted for almost 2000 years.

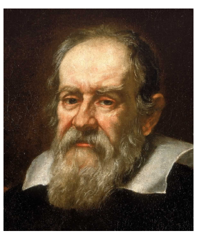
Aristotle also surmised that motion could be described as *violent* (a ball getting kicked, say) and *natural* (the ball rolling to a stop). The natural state of of a body, of course, is "at rest."



Galileo

Galileo (1564-1642) rebelled against blind acceptance of Aristotle's "logical" thinking, and encouraged repeatable experiments, earning him the "Father of Modern Science" title.



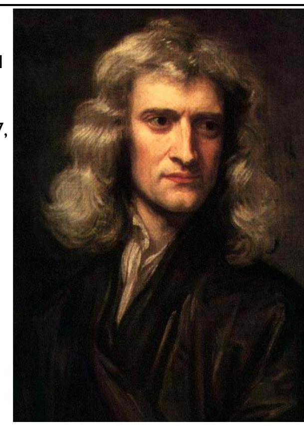


He also demonstrated, with a little logical thinking of his own, that Aristotle's ideas regarding "natural states of rest" were wrong.

Newton

Newton (1643-1727) continued Galileo's studies of motion. Newton wasn't known for publicizing his work, but in 1687, he published the *Philosophiae Naturalis Principia Mathematica*, which summarized his studies. This book was written in Latin, the language of scholars, and is considered by many to be the single greatest scientific book ever published.

Among other things, it included his analysis of motion, summarized in three laws.



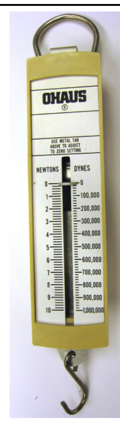
Force

Force = "a push or pull on an object". Doesn't always cause motion, but does cause deformation (change in shape).

Forces have a *magnitude* and a *direction*: they are vector quantities.

One of the most common ways of measuring force magnitude is with a *spring scale*.

The units of force are **kg•m/s²**, otherwise known as the **Newton**.



Mass

Mass is one of the single most misunderstood concepts in chemistry and physics. It is *not* the same as "weight," although the two measurements are related.

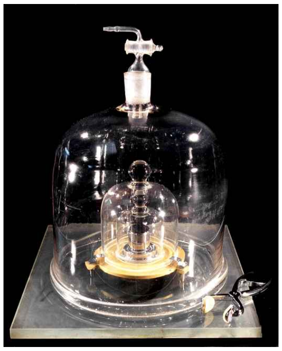
Mass is a measure of the amount of inertia that a body has—it's a measure of how hard it is to change an object's motion. The more mass you have, the more inertia you have, and the more inertia you have, the harder it is to get you moving (if you're motionless), or to stop your motion (if you're moving).

Mass

Mass is measured using a *balance*, and comparing the mass of an unknown object with the mass of a known object.

The official SI unit for mass is the *kilogram* = 2.20 pounds.

A *gram*, 0.001 kg, on earth is about the weight of a small paperclip.



Example 1

A spring scale is used to measure forces. Can you measure mass with a spring scale?

Well... sort of. Sometimes.

We can use a spring scale to measure the mass of an object on earth, because a given mass has a given weight on the earth. This won't work if we're out in space, though—earth's gravity won't pull the object down on the spring scale. Clearly, the "stuff" in an object doesn't just disappear when we go into space, so an object can still have mass, but be weightless. (In space, where a spring scale is useless, we have other ways of measuring an object's mass.)

Weight

Weight is a measure of how strongly earth's gravity pulls on a mass. It is a measure of Force, and written as $\mathbf{F}_g$, or sometimes as *W*, and as with all forces, its SI units are the kg•m/s² (Newton).

The weight of an object at the surface of the earth may be calculated as follows:

$$\mathbf{F}_g = m\mathbf{g} \ (= W)$$

Example 2

"I weigh 79.0 kilograms." Is this an acceptable statement? If true, is it true out in space as well?

No; *mass* ≠ *weight*, although in common usage, one may hear this. *Mass* is the same everywhere.

"I weigh 174 pounds." Is this an acceptable statement? Is this true out in space as well?
What's the relationship between a pound and a kilogram?

No; weight = force of earth's gravity, which varies with distance from Earth. 1.00kg at Earth's surface = 2.21pounds.

"I weigh 774 Newtons." Is this an acceptable statement? If true, is it true out in space as well? What is the relationship between a Newton and a kilogram?

Yes, this is acceptable, but weight varies with distance from Earth. 1.00 kg = 9.8 N (according to F_g=mg).

Inertia

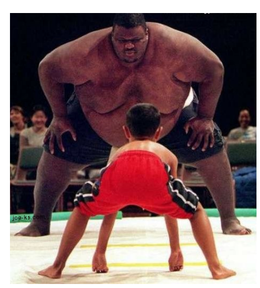
Another name for mass is "inertia." The more mass something has, the more *inertia* it has: the more it resists a change in its state of motion.

Example 3

Which sumo wrestler has more mass?

Which sumo wrestler is more difficult to move (accelerate)?

Which sumo wrestler has more inertia?



Newton's First Law of Motion

"Every body continues its state of rest or uniform speed *in a straight line*, unless it is compelled to change that state by a *net force* acting on it."

This tendency to maintain one's state of motion (whether actually moving or at rest) is called **inertia**; for this reason, the Newton's First Law of Motion is commonly called "The Law of Inertia."

Newton's First Law of Motion

"Every body continues its state of rest or uniform speed *in a straight line*, unless it is compelled to change that state by a *net force* acting on it."

You need to be able to use the key words and phrases above in describing the motion of objects:

- "at rest"
- "constant speed"
- "in a straight line"
- "net force"

Newton's Second Law of Motion

The *single most important thing* you will learn in here all year:

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

A *net Force* applied to a *mass* causes it to *accelerate*.

Example 4

A net force of 60 N causes the 15 kg girl to accelerate down the slide.

- What is her acceleration?
- If the force is applied over 3 seconds, what is her velocity at the bottom of the slide?

Example 5

A net force is applied to a 0.150kg baseball causing it to accelerate at 1000 m/s^2.

- How big a force was applied?
- If the ball was traveling toward the batter at 40m/s, and was hit for 0.1 seconds, what was its velocity after the hit?

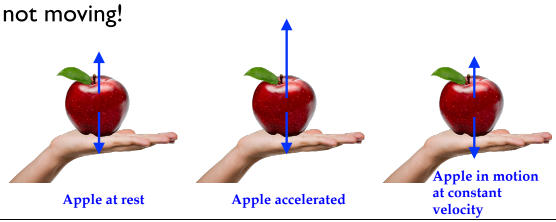
Free-body Diagrams

A *free-body diagram* shows all the important forces acting on an object, with labelled vectors drawn to indicate the magnitude and direction of those forces.

F_{net}

Net Force, or *resultant force*, or *sum of forces* refers to the overall force acting on a mass.

If the net force is zero, than there is 0 acceleration… but that doesn't necessarily mean that the object is not moving!



Static/Dynamic Equilibrium

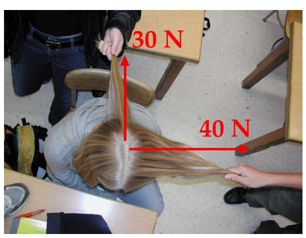
Static equilibrium = forces balanced, object not moving

Dynamic equilibrium = forces balanced, object moving

How does an object *start* moving? Being accelerated by a net (unbalanced) force!

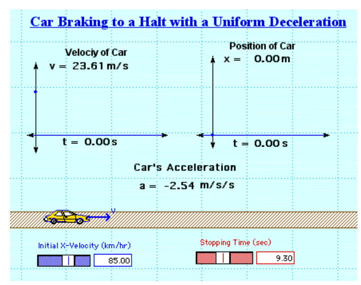
2 or more Forces produce F_{net}

What is the net Force due to the indicated forces acting on this girl's head?



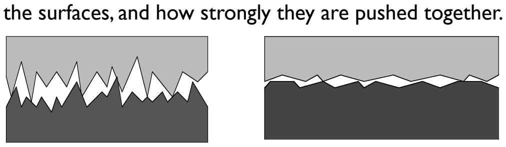
Friction

= *a force between two surfaces that acts in a direction to oppose motion.*



Types of Friction

- **Sliding friction**
  How big the force of friction is depends on the nature of the surfaces, and how strongly they are pushed together.



- **Fluid friction**
  Occurs when an object moves through a liquid or gas (such as water, or air). *Air resistance* is perhaps the most familiar example of this type of friction.

Demo–Sliding Friction

- **How big is the force of friction in this situation?** Draw a free-body diagram with appropriate arrows.
- **How big is the force of friction in this situation?** Draw a free-body diagram with appropriate arrows.

How does Free Fall work?

A hammer and a feather are dropped. Which hits the ground first? Why?

Falling & Air Resistance

When air resistance is strong enough to significantly affect a falling object, we need to take it into account.

At the beginning of the object's fall, it's not quite moving yet, so there's no motion, so no air resistance.

When Force of air resistance = Force of gravity, object has reached *terminal velocity*: it can't fall any faster.

Free-Body Diagrams of Air Resistance

Draw a free-body diagram for each of these situations regarding a skydiver jumping from a hovering helicopter.

Just as diver is released	A little later	Later still	Terminal velocity	When chute opens	Terminal velocity	Hitting ground	Standing on ground

Demo–Falling Objects

"A 1.00 kg book, and 2.00 kg brick, are both held 1.00 meter above the surface of the moon, where there is no air friction. Which of the following is *true*?

a. When released, the objects won' t fall because there is no gravity on the moon.
b. When released, the brick will land first a greater force is pulling on it.
c. When released, the brick will land at the same time as the book because the force of gravity is the same on both of them.
d. When released, the book will land first .
e. none of the above

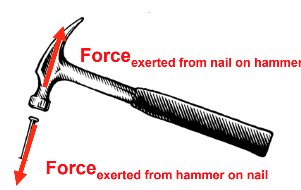
Newton's Third Law of Motion

"Whenever one object exerts a force on a second object, the second objects exerts a force (equal in magnitude, in the opposite direction) back on the first."

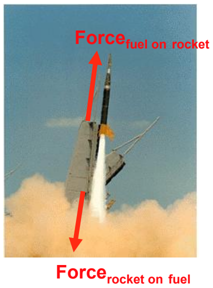
"Forces *always* occur in pairs." The Third Law of Motion is sometimes called *The Law of Force Pairs*.

You need to become really good at identifying Force Pairs.

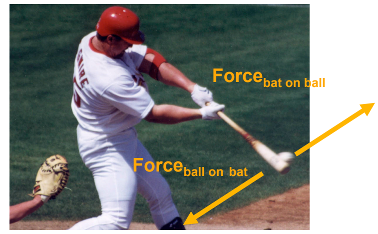
Newton's Third Law of Motion



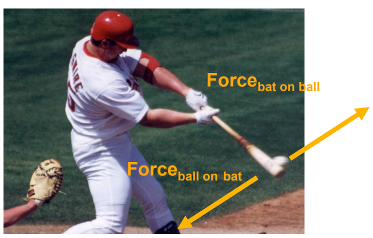
Newton's Third Law of Motion



Newton's Third Law of Motion

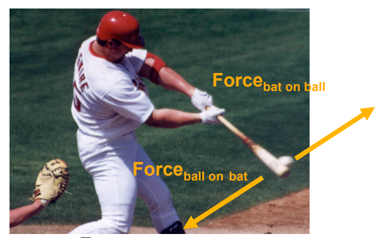


Newton's Third Law of Motion



If the Forces are "equal and opposite," why does the ball fly farther than the bat?

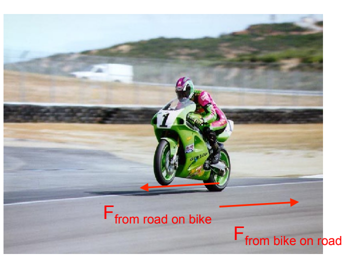
Newton's Third Law of Motion



$$F_{bat\ on\ ball} = -F_{ball\ on\ bat}$$

$$m_{ball} a_{ball} = -m_{bat} a_{bat}$$

Newton's Third Law of Motion



Example: Horse-Cart

A horse is attached to a cart. When the horse tries to move forward, the cart pulls back with an equal and oppostite force. How can the horse move forward?