CHAPTER 4

The Laws of Motion

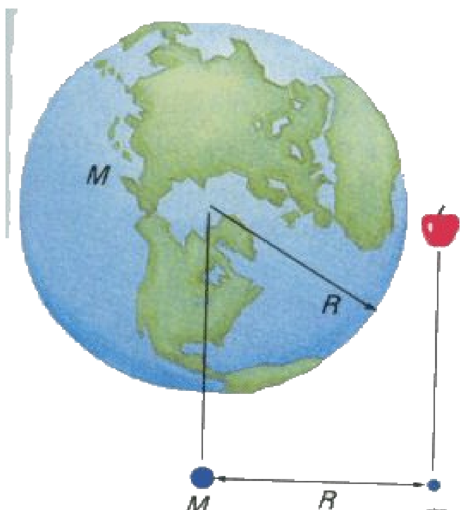
OUTLINE

4.1-Forces

4.2-Newtons First Law

4.3-Newtons Second Law

4.4-Newtons Third Law

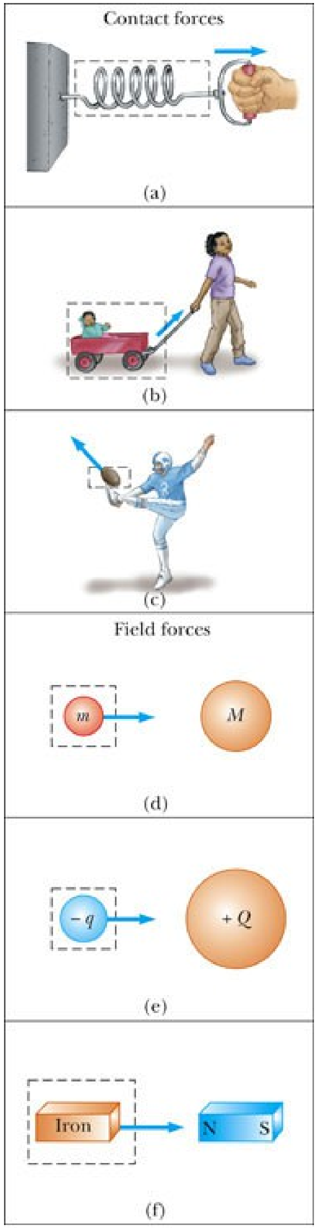


Force

- Forces are what cause any change in the velocity of an object
  - Newton's definition
  - A force is that which causes an acceleration

Classes of Forces

- Contact forces involve physical contact between two objects
  - Examples a, b, c
- Field forces act through empty space
  - No physical contact is required
  - Examples d, e, f



Fundamental Forces

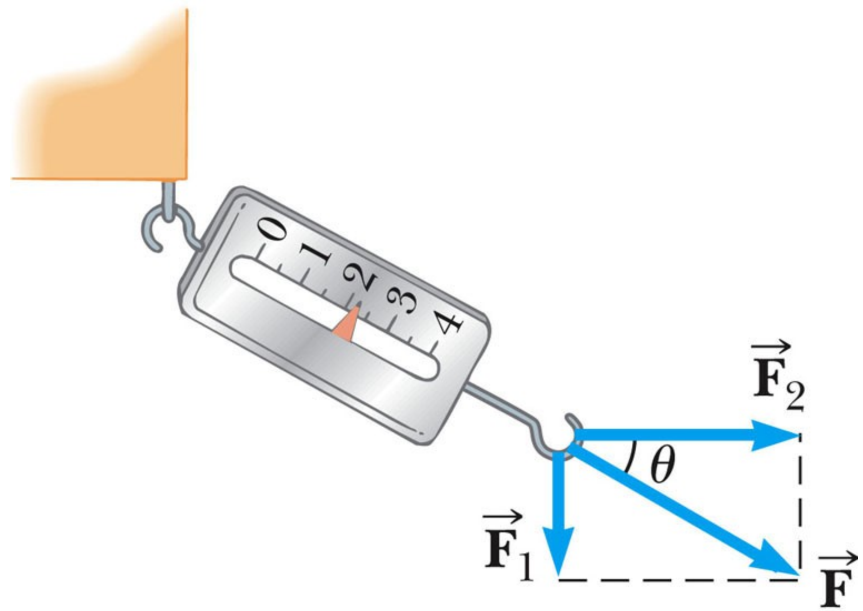
- Gravitational force
  - Between objects
- Electromagnetic forces
  - Between electric charges
- Nuclear force
  - Between subatomic particles
- Weak forces
  - Arise in certain radioactive decay processes
- Note: These are all field forces

Fundamental Forces

Fundamental Force	Example	Particles Affected
Strong nuclear	Nucleus	Nuclear
Electromagnetic	+, - Charges	Charged
Weak nuclear	Radioactivity	Nuclear
Gravitational	Your weight	All

Vector Nature of Forces

- The forces are applied perpendicularly to each other
- The resultant (or net) force is the hypotenuse
- Forces are vectors, so you must use the rules for vector addition to find the net force acting on an object



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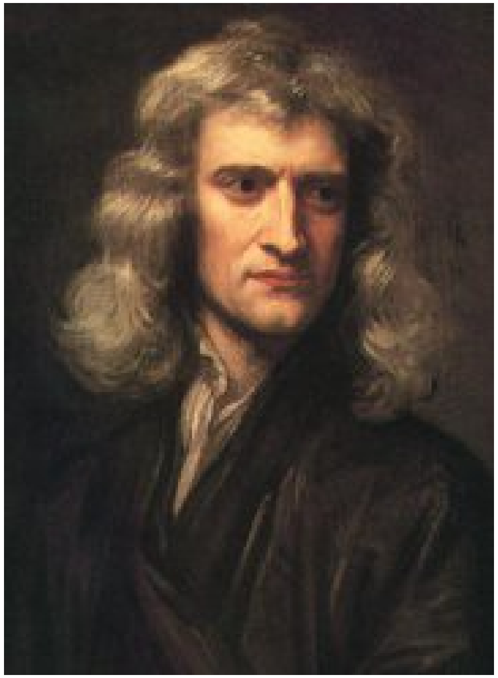


“If I have ever made any valuable discoveries, it has been owing more to patient attention, than to any other talent.”

-Sir Isaac Newton

Newton’s Laws of Motion

1. An object in motion tends to stay in motion and an object at rest tends to stay at rest unless acted upon by an unbalanced force.
2. Force equals mass times acceleration ($F = ma$).
3. For every action there is an equal and opposite reaction.

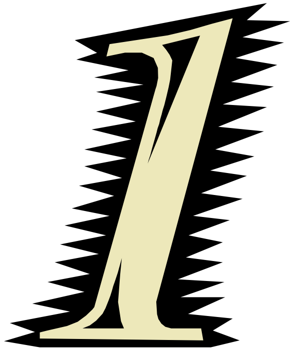
What does this mean?

Basically, an object will “keep doing what it was doing” unless acted on by an unbalanced force.

If the object was sitting still, it will *remain stationary*. If it was moving at a constant velocity, it will *keep moving*.

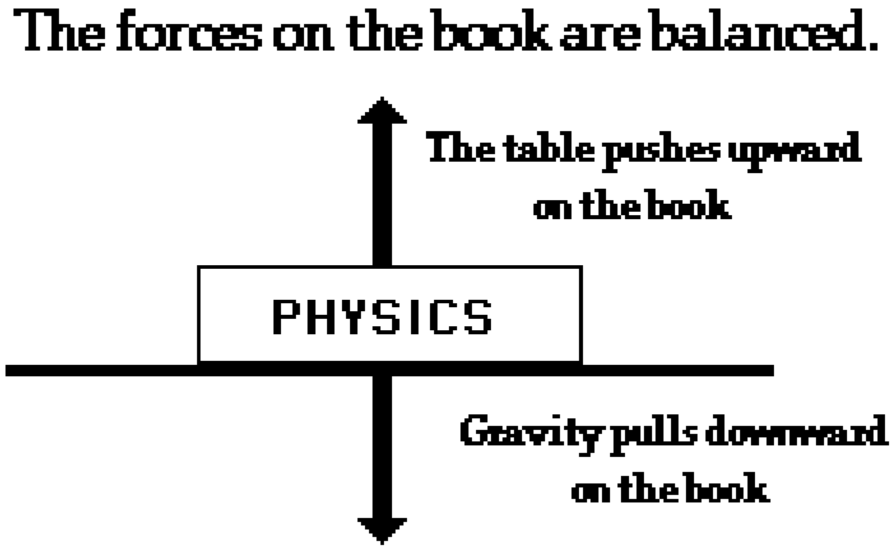
It takes *force* to change the motion of an object.

Newton’s First Law



An object at rest tends to stay at rest and an object in motion tends to stay in motion unless acted upon by an unbalanced force.

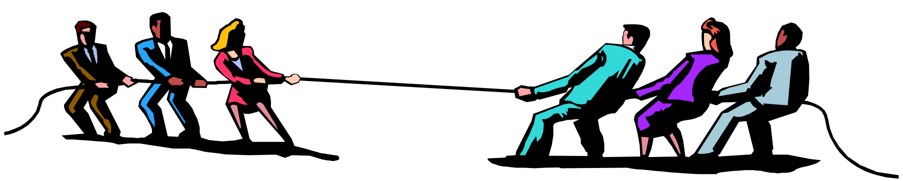
What is meant by *unbalanced force?*



If the forces on an object are equal and opposite, they are said to be balanced, and the object experiences no change in motion. If they are not equal and opposite, then the forces are unbalanced and the motion of the object changes.

Some Examples from Real Life

A soccer ball is sitting at rest. It takes an unbalanced force of a kick to change its motion.



Two teams are playing tug of war. They are both exerting equal force on the rope in opposite directions. This balanced force results in no change of motion.

Newton's First Law is also called the *Law of Inertia*

Inertia: the tendency of an object to resist changes in its state of motion

The First Law states that *all objects have inertia*. The more mass an object has, the more inertia it has (and the harder it is to change its motion).

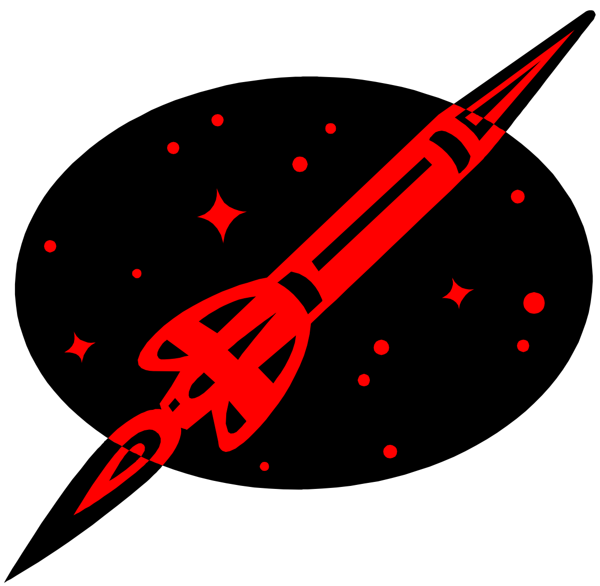
If objects in motion tend to stay in motion, why don’t moving objects keep moving forever?

Things don’t keep moving forever because there’s almost always an unbalanced force acting upon it.

A book sliding across a table slows down and stops because of the force of *friction*.

If you throw a ball upwards it will eventually slow down and fall because of the force of *gravity*.

In outer space, away from gravity and any sources of friction, a rocket ship launched with a certain speed and direction would *keep going in that same direction and at that same speed forever*.



Newton’s Second Law

- The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass
  - Force is the cause of change in motion, as measured by the acceleration
- Algebraically,

$$\vec{\mathbf{a}} \propto \frac{\sum \vec{\mathbf{F}}}{m} \rightarrow \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

<u>Acceleration</u>: a measurement of how quickly an object is changing speed.

More About Newton's Second Law

- $\sum \vec{\mathbf{F}}$ is the net force
  - This is the vector sum of all the forces acting on the object
- Newton's Second Law can be expressed in terms of components:
  - $\Sigma F_x = m\, a_x$
  - $\Sigma F_y = m\, a_y$
  - $\Sigma F_z = m\, a_z$

More about F = ma

If you *double* the mass, you *double* the force. If you *double* the acceleration, you *double* the force.

What if you double the mass *and* the acceleration?

$(2m)(2a) = 4F$

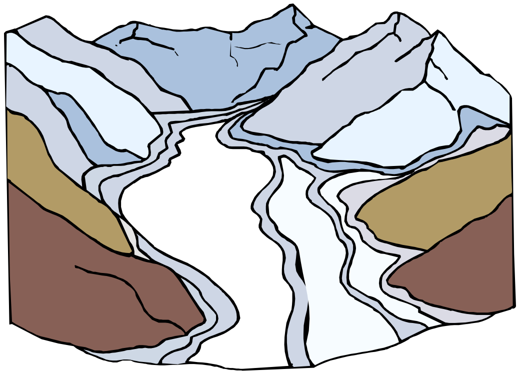
Doubling the mass *and* the acceleration *quadruples* the force.

So . . . what if you *decrease the mass by half*? How much force would the object have now?

What does F = ma say?

F = ma basically means that the force of an object comes from its mass and its acceleration.

Something very massive (high mass) that's changing speed very slowly (low acceleration), like a glacier, can still have great force.



Something very small (low mass) that's changing speed very quickly (high acceleration), like a bullet, can still have a great force. Something very small changing speed very slowly will have a very weak force.

Units of Mass and Force

The units of mass are **kilograms**. This is the third fundamental unit (along with meters and seconds) in the SI of units.

The units of force in the SI are **Newtons**, where a force of 1 N will give a mass of 1 kg an acceleration of 1 m/s^2 .

Newton’s First Law – Alternative Statement

- An object at rest remains at rest and an object in motion continues in motion with a constant velocity
  - Newton’s First Law describes what happens in the absence of a force
    - Does not describe zero net force
  - Also tells us that when no force acts on an object, the acceleration of the object is zero

Inertia and Mass

- The tendency of an object to resist any attempt to change its velocity is called ***inertia***
- ***Mass*** is that property of an object that specifies how much resistance an object exhibits to changes in its velocity
- Masses can be defined in terms of the accelerations produced by a given force acting on them:

$$m_1 / m_2 \equiv a_2 / a_1$$

  – The magnitude of the acceleration acting on an object is inversely proportional to its mass

More About Mass

- Mass is an inherent property of an object
- Mass is independent of the object's surroundings
- Mass is independent of the method used to measure it
- Mass is a scalar quantity
- The SI unit of mass is kg

Mass vs. Weight

- Mass and weight are two different quantities
- Weight is equal to the magnitude of the gravitational force exerted on the object
  - Weight will vary with location
- Weight

  Definition: The force with which an object is attracted by the earth's gravitational pull

  - Near the earth's surface, weight and mass are essentially the same

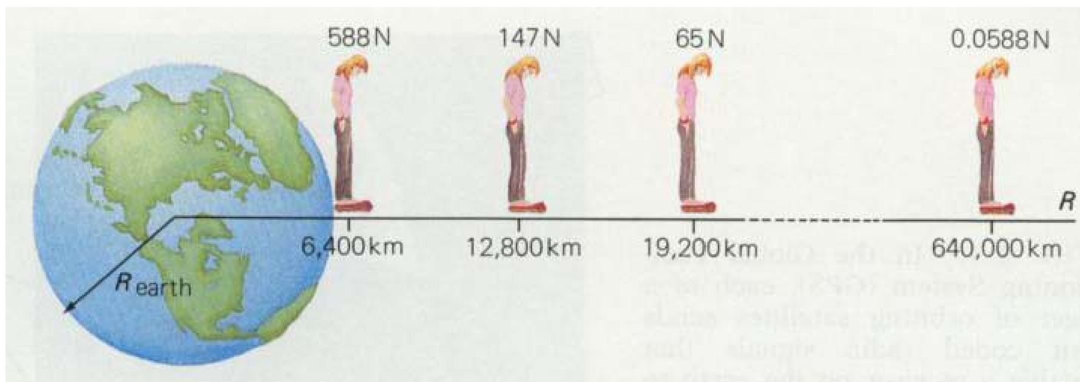
Newton's Law of Gravity

States That:

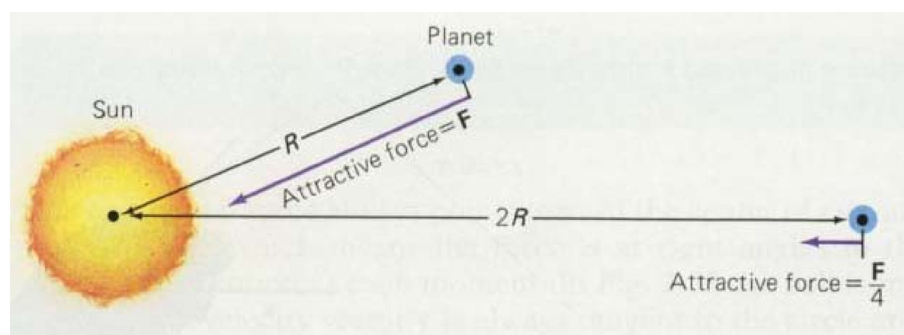
Every particle in the Universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Newton's Law of Gravity

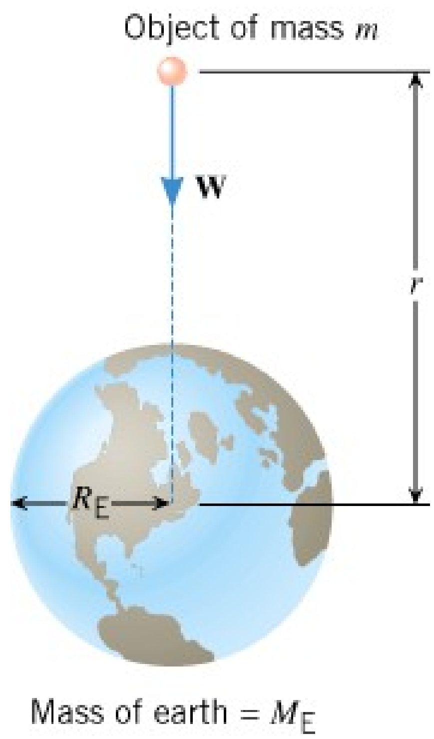
$$\text{Gravitational force} = F = \frac{Gm_1m_2}{R^2}$$



G = 6.67 x 10^{-11} N•m/kg^2



Acceleration Due to Gravity



$$W = \boxed{G\frac{M_E}{r^2}}\,m$$

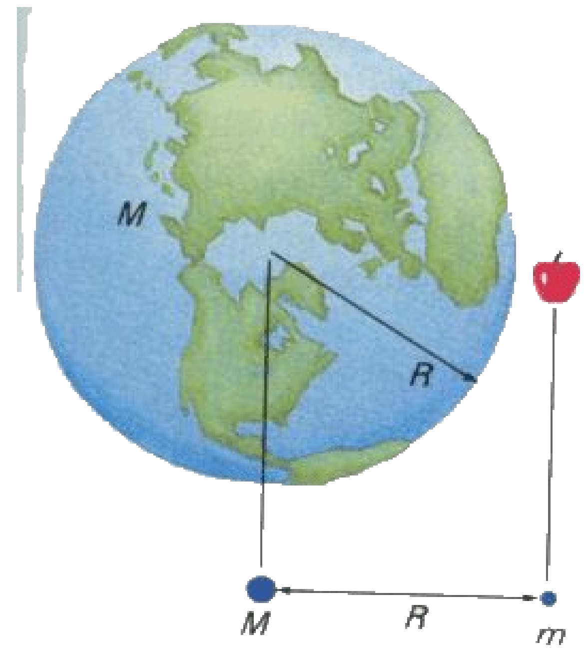
$$\downarrow$$

$$W = m\,\boxed{g}$$

Newton's Law of Gravity

How can we determine the mass of the earth using an apple?

– This illustrates the way scientists can use indirect methods to perform seemingly “impossible tasks”



Newton's Law of Gravity

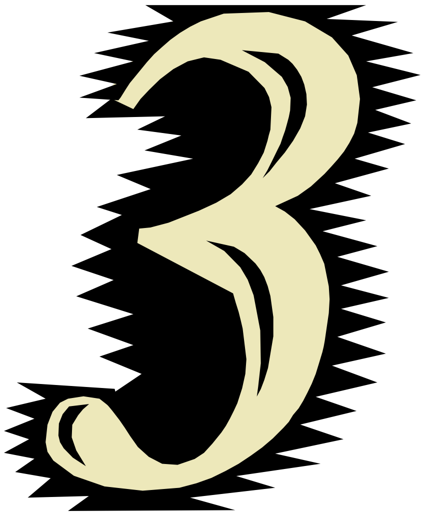
How can we determine the mass of the earth using an apple?

– This illustrates the way scientists can use indirect methods to perform seemingly “impossible tasks”

$$\text{Gravitational force on apple} = \text{F} = \left(\frac{GmM}{R^2}\right) = \text{mg}$$

$$M = \left(\frac{gR^2}{G}\right) = \frac{(9.8m/s^2)(6.4\times10^6 m)^2}{6.67\times10^{-11} N\times m^2/kg^2} = 6\times10^{24} kg$$

Newton’s Third Law



For every action there is an equal and opposite reaction.

Newton's Third Law

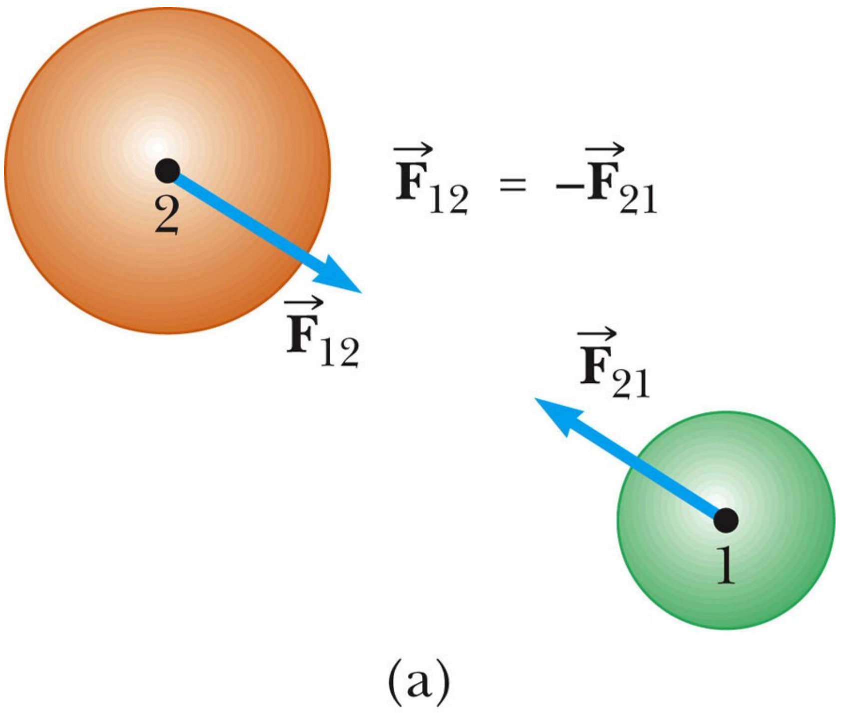
- If two objects interact, the force $\vec{\mathbf{F}}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{\mathbf{F}}_{21}$ exerted by object 2 on object 1
- $\vec{\mathbf{F}}_{12} = -\vec{\mathbf{F}}_{21}$
  – Note on notation: $\vec{\mathbf{F}}_{AB}$ is the force exerted *by* A *on* B

Newton’s Third Law, Alternative Statements

- Forces always occur in pairs
- A single isolated force cannot exist
- The action force is equal in magnitude to the reaction force and opposite in direction
  - One of the forces is the action force, the other is the reaction force
  - It doesn’t matter which is considered the action and which the reaction
  - The action and reaction forces must act on different objects and be of the same type

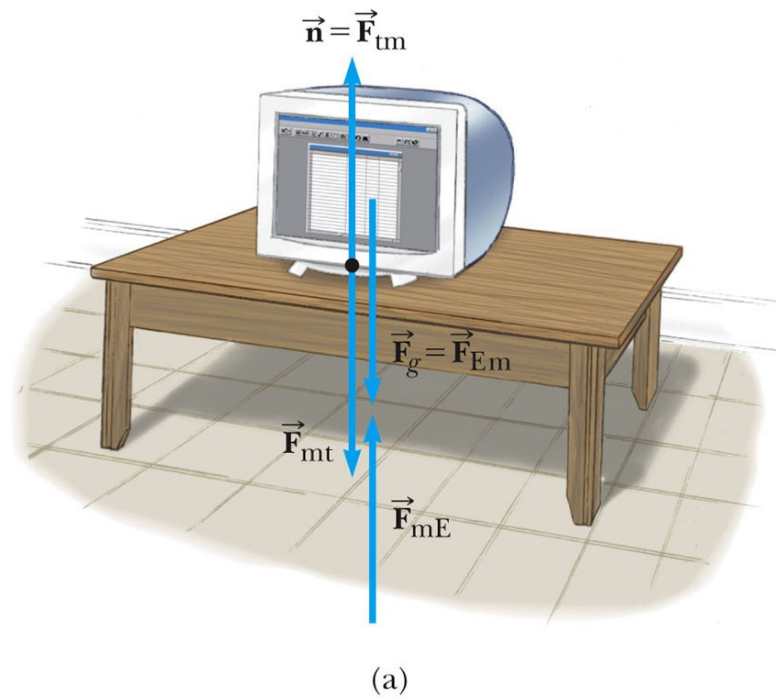
Action-Reaction Examples, 1

- The force $\vec{\mathbf{F}}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to $\vec{\mathbf{F}}_{21}$ exerted by object 2 on object 1
- $\vec{\mathbf{F}}_{12} = -\vec{\mathbf{F}}_{21}$



Action-Reaction Examples, 2

- The normal force (table on monitor) is the reaction of the force the monitor exerts on the table
  - Normal means perpendicular, in this case
- The action (Earth on monitor) force is equal in magnitude and opposite in direction to the reaction force, the force the monitor exerts on the Earth



Free Body Diagram

- In a free body diagram, you want the forces acting on a particular object
  - Model the object as a particle
- The normal force and the force of gravity are the forces that act on the monitor

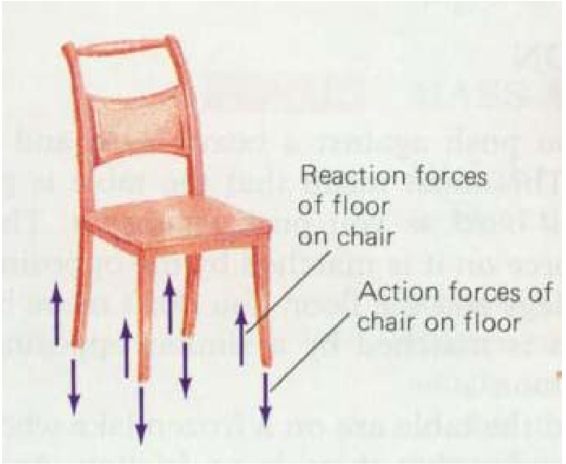
(b)

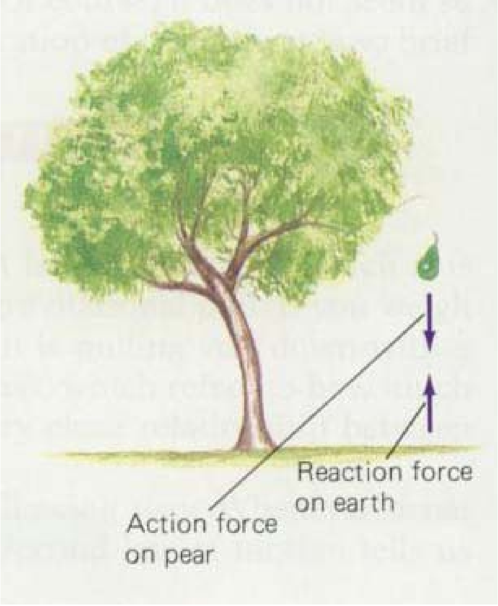
What does this mean?

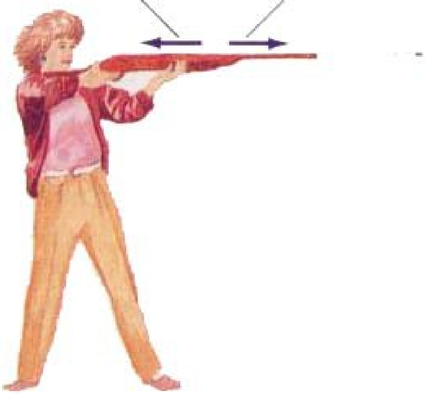
For every force acting on an object, there is an equal force acting in the opposite direction. Right now, gravity is pulling you *down* in your seat, but Newton's Third Law says your seat is pushing *up* against you with *equal force*. This is why you are not moving. There is a *balanced force* acting on you– gravity pulling down, your seat pushing up.

Third Law of Motion

Examples of the 3rd Law







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