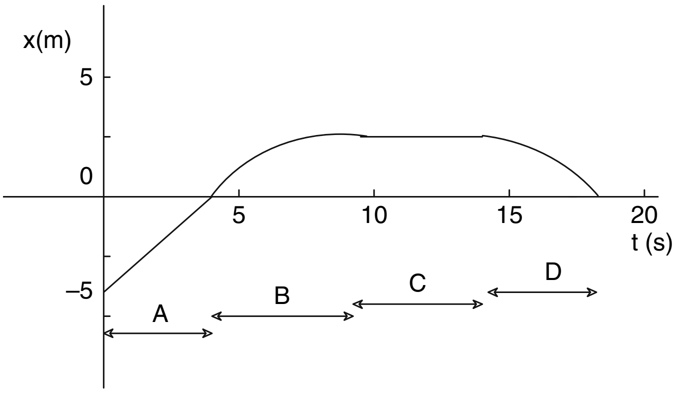
PHYS-183 : Day #2

Review Day #1:

- Last time we looked at the basic quantities of motion: position, velocity, and acceleration.

Example Problem #1:



In the figure, the position of the location of the center of mass of an object is shown as a function of time. Indicate whether the velocity and acceleration is each labeled interval are positive, negative or zero.

A: velocity is positive, acceleration is zero

B: velocity is positive, acceleration is negative

C: velocity is zero, acceleration is zero

D: velocity is negative, acceleration is negative

Example Problem #2:

The x-position of an object is taken every 0.5 seconds, as given in the following table:

Time (s)	*x-Position (m)*
0.0	+3.0
0.5	+2.2
1.0	+3.0
1.5	+1.0
2.0	−0.5

Which one of the following must be true?

a) The average velocity in the time interval 0.0 sec to 1.0 sec is 0.0 m/s.

b) The average speed in the time interval 0.0 sec to 1.0 sec is 0.0 m/s.

c) The instantaneous velocity at 1.0 sec is +3.0 m/s.

d) The instantaneous velocity in the entire interval 1.0 sec to 2.0 sec is always negative.

Newton's Laws of Motion:

- The message from last time is that there is an intimate mathematical connection between position, velocity and acceleration.

- If we know an objects position, we can calculate the acceleration.

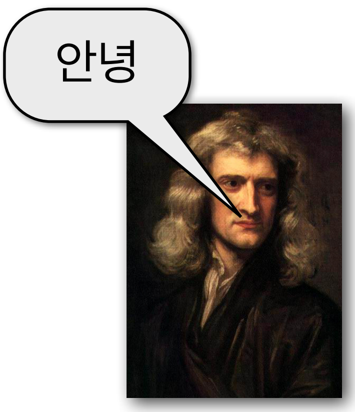
- If we know the acceleration of an object, we can work out what its position should be.

- These are just mathematical statements, but we are doing physics!

    - Physics and mathematics are not the same

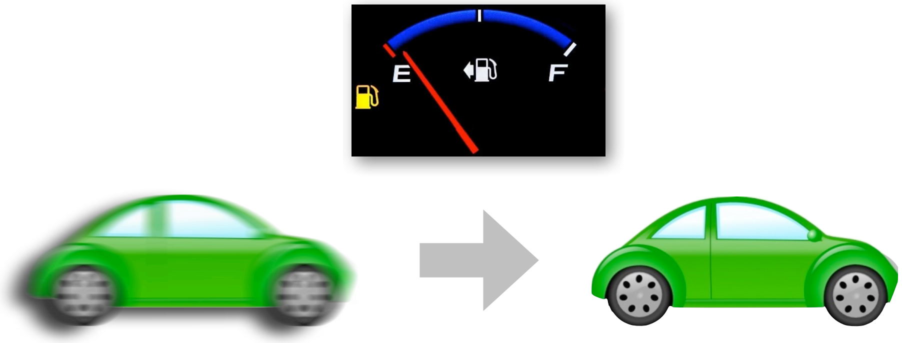
- Example: You can feel accelerations but <u>not</u> constant velocity motion.

    - Why?
    - Mathematics does not tell us why
    - What you feel when you accelerate is physics
    - Explaining acceleration requires physical laws



Newton's Laws

- **Wait a second!** Why are we focusing only on acceleration?
    - Almost nothing I see moves at a constant velocity.
    - Unless something is pushing, things always come to a stop.



- If I hold something above the ground it always falls down.
- It seems that velocity is more important than acceleration.
- We should explain why constant velocity is so special, not acceleration.

- Wrong! Your common experiences are dominated by two phenomena that hide the truth about motion

Gravity always pulls things down

Friction always makes things stop

<u>Newton's 1st Law (1867):</u>

It is possible to find laboratories ("frames of reference") in which an objects acceleration is due only to interactions between that object and other bodies.

- In these reference frames, every acceleration is caused by an interaction
    - Objects do not accelerate on their own.
- An interaction is a push or a pull between two or more objects.
- What kind of laboratories ("frames") are these?
    - These are laboratories that move at a <u>constant velocity</u>

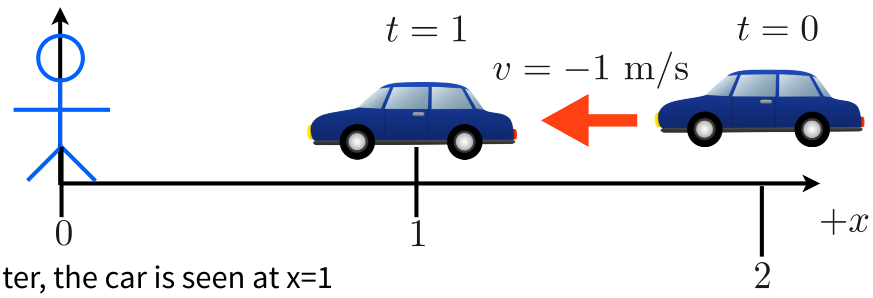
Person standing still

Person moving at a constant velocity in a car

- The rules of physics are the same when moving at a constant velocity or standing still

Ex. Person is the laboratory at V=0:

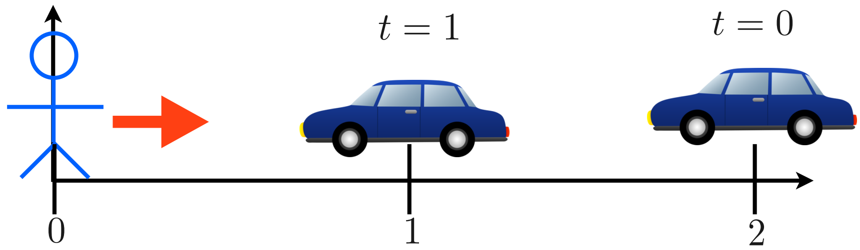
- Since the person is the laboratory, she is at x=0.



- One second later, the car is seen at x=1

Ex. Person is the laboratory at $v = +1\ \mathrm{m/s}$:

- Since the person is the laboratory, the person is always at x=0, even when moving!
- According to the person, the car is still coming closer, but she is always at x=0



- Same answer! One second later the car is still at x=1.

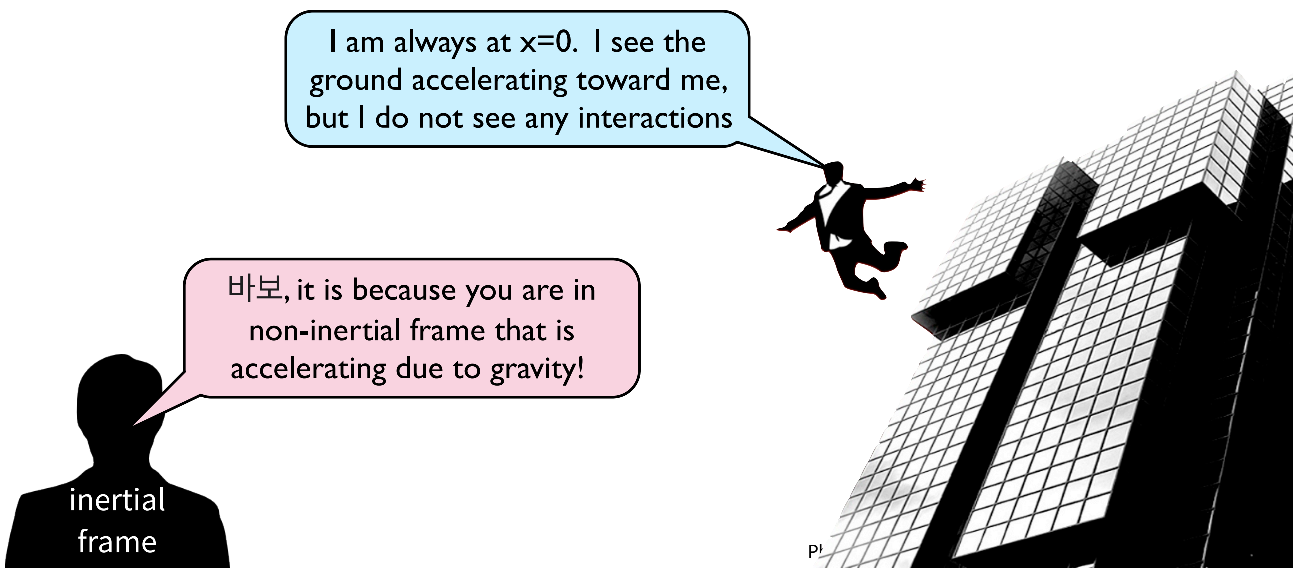
- Laboratories that move at a constant velocity (including V=0) are important so they have a special name: **Inertial Frames**

- Inertial frames make explaining physics easy

- Since inertial frames have constant velocity, non-inertial frames are accelerating

- In non-inertial frames, objects look like they are accelerating without any interactions

- The laws of physics in non-inertial frames does not agree with physics in inertial frames



- Any reference frame (laboratory) in which accelerations occur for no reason is itself accelerating.

Newton's 1st Law (revised):

In inertial reference frames, objects traveling at constant velocity (including zero velocity) will maintain that velocity unless influenced by an interaction with another object

Forces in One Dimension:

- Acceleration of any body is caused by interactions with other objects.

- Interactions are pushes and pulls; they have a magnitude (size) and a direction.

    - Things with both a magnitude and a direction are called **vectors**

- In one-dimension, the direction, right or left, is given by a + or a - sign

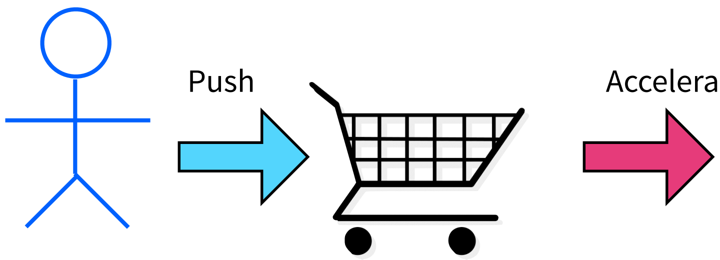
- Things that are vectors: position, velocity, and acceleration, are labeled with arrows on top:

$$\vec{x}, \vec{v}, \vec{a}$$

- Distance and speed do not have a direction, so they are not vectors

- Forces are also vectors with a magnitude and a direction

- How does force relate to acceleration?



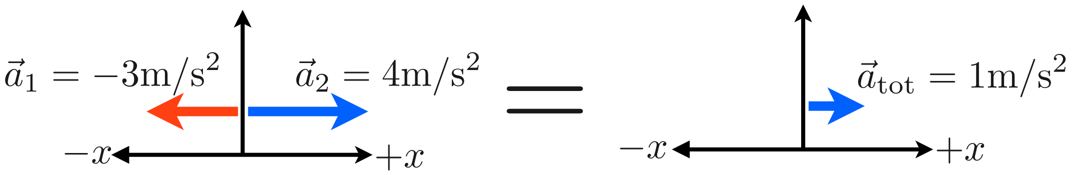
- Forces are in the same direction as accelerations

- Force and acceleration are not the same thing, but should be related by a single parameter "m" with units.

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

- If there are more than one force (interaction) on an object, then the total force is just the sum of the individual forces

    - In one-dimension, this vector addition is just addition and subtraction

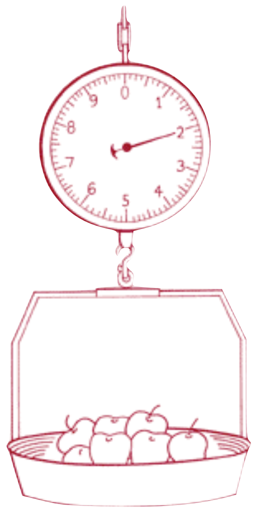


- The sum of all the forces on an object is called the **Net Force**:

$$\sum_{i=1}^{N} \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \cdots + \vec{F}_N = \vec{F}_{\text{net}}$$

- If an object is at rest, or moving with a constant velocity, then the net force is zero
    - If the net force is zero, then the object is said to be in **equilibrium**.

<u>Gravitational Forces:</u>

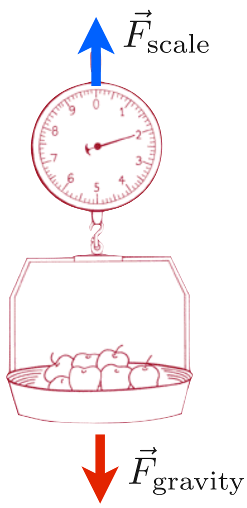


- We all know that objects that are not on the ground will fall unless they are supported.

- We say that the earth exerts a **gravitational force** (pull) on all objects nearby.

- The force of gravity on an object is called the objects **weight**

- Gravity is a special force because it can pull objects without the Earth actually touching them



- Here, the apples are not moving, therefore they must be in equilibrium with no net force

- The scale provides an upward force that is exactly the same size, but opposite direction, as the gravitational force from Earth.

<u>Mass and Newton's Law of Gravity:</u>

- Earth is not the only object that has gravity.

- Every object with mass has a gravitational pull on every other object with mass.

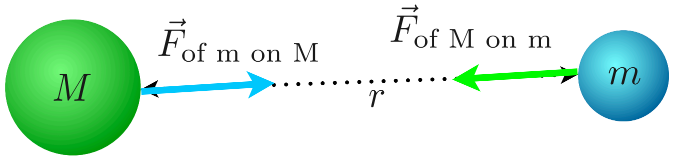
- I pull on you, you pull on me, you pull on the moon,....

- Since gravity always pulls, the force of gravity always points toward the object that makes it

- Since force is a vector, it also has magnitude (size).

- Let us consider an object with mass M. Then the magnitude of the gravitational acceleration is labeled as g_M

- Suppose I put another object a distance r away from the first one.



- The magnitude of the force on m from M is defined to be:

$$F_{\text{of M on m}} = m g_M$$

mass of m

gravitational acceleration of M

- Since acceleration has units of $\mathrm{m/s^2}$ and mass has units of kg

Force has units of $\mathrm{kg \cdot m/s^2 = N}$ (**Newton**)

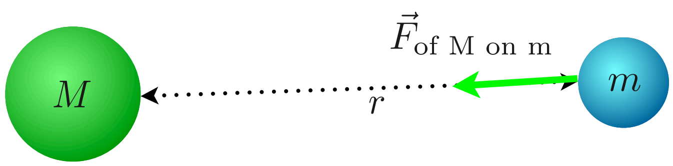
- Mass m also pulls on M

- The magnitude of the gravitational accel. of Earth, for any mass is: $\boxed{g_{\text{Earth}} = 9.8\ \mathrm{m/s^2}}$

- Thus the weight of an object (force of gravity) with mass m <u>near</u> Earth is:

$$W_{\text{mass m}} = F_{\text{Earth on m}} = m g_{\text{Earth}}$$

- Why is “near” Earth so important?



- For any two objects, the magnitude of gravitational force of M on m, depends on the distance between them:

$$\boxed{F_{\text{of M on m}} = G\frac{Mm}{r^2}}$$

$$G = 6.67 \times 10^{-11}\ \mathrm{N - m^2/kg^2}$$ (Gravitational Constant)

- If you double the distance between two objects, the gravitational force is four times weaker

- Now since $F_{\text{of M on m}} = m g_M$, we can divide both side of the above equation by m to to get the gravitational acceleration

$$g_M = G\frac{M}{r^2}$$

- The gravitational acceleration depends only on the mass of the object creating it

- Newton's 1st law said that accelerations requires forces

- For gravity, we saw that the force and acceleration are related by the objects mass

- Newton's second law tells us that this is true for **<u>any</u>** force:

In an inertial reference frame, the acceleration of a body with mass m, is given by

$$\vec{a} = \frac{\vec{F}_{\text{net on m}}}{m}$$

where $\vec{F}_{\text{net on m}}$ is the net external force acting on the body (i.e. the sum of all the forces due to all the other objects that push and pull on it

<u>Key Ideas:</u>

1) Accelerations are caused by forces from other objects. An object cannot accelerate itself

2) The acceleration of an object is determined by the <u>net force</u> on the object from other objects.

3) For the same amount of force, the more mass an object has, the smaller its acceleration

<u>Ex. Shopping cart:</u>

- Suppose I push both carts with the same force equal to 1N. What is the acceleration?

$\vec{F} = 1\ \mathrm{N}$ $\quad M = 10\ \mathrm{kg}$ $\quad \vec{a} = 0.1\ \mathrm{m/s^2}$

$$\vec{a} = \frac{\vec{F}}{M}$$

$\vec{F} = 1\ \mathrm{N}$ $\quad m = 1\ \mathrm{kg}$ $\quad \vec{a} = 1.0\ \mathrm{m/s^2}$

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

- From Newton's 2nd Law: For any two objects, object 1 and object 2, with the same force acting on them:

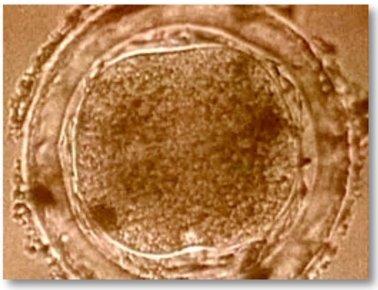
$$m_1\vec{a}_1 = \vec{F} = m_2\vec{a}_2$$

$$\boxed{\frac{m_2}{m_1} = \frac{a_1}{a_2}}$$

(True for <u>any</u> force, and <u>any</u> two objects)

- If I know any three of these parameters, I can find the fourth.

- Newton's second law works for <u>everything:</u>



Cellular division

<u>Newton's Third Law:</u>

- According to Newton's 2nd law, objects accelerate only because of <u>external</u> forces

→ People run, birds fly, and fish swim all because something is pushing on them

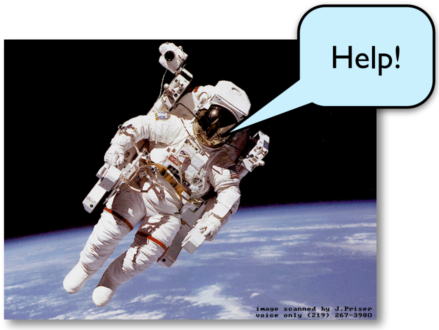
- What is doing the pushing? If I go running, don't my legs push me (self accelerate)?

<u>Ex. Running:</u>

- Suppose I run using the <u>same amount of force</u> in my legs on dirt, ice, and in space. What happens?

Easy to run

Difficult to run



Impossible to run

- This tells us that not only is moving your legs important for running, but also what you run on!

- You must have something to push on in order to run

- Therefore, in order to run, or have any force, something must be pushing back on you

- This leads us to Newton's Third Law

Newton's Third Law:

When one object exerts a force on a second object, the second object exerts a force in the opposite direction and with equal magnitude on the first. That is:

$$\vec{F}_{2\text{ on }1} = -\vec{F}_{1\text{ on }2}$$

- Also known as "Action-Reaction": For every action (force), there is an equal, but opposite, reaction (force).

Key Idea: **Forces always come in pairs**, each with the same magnitude, but pointed in opposite direction

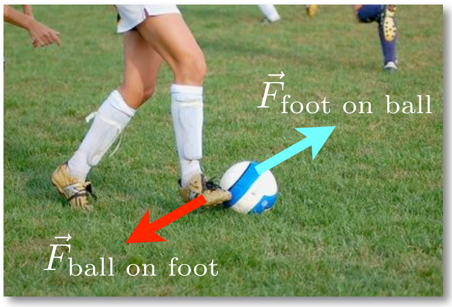
- Action-reaction forces are equal, not the accelerations that they produce.

- Be careful how you use Newton's laws, especially third law!

Ex. Soccer ball and foot:

Question: A young woman kicks a soccer ball 30m downfield. How does she do this?

Wrong Answer: Newton's third law says that the force of her foot on the ball is balanced by the force of the ball on her foot. The net force is then zero, so the ball does not accelerate.



- We used the wrong Newton's law!

- If we are interested in the motion of only one of the objects (soccer ball), then we only need to worry about the forces on that object.

- Looking only at the forces on the soccer ball, we can use Newton's 2nd law (F=ma) to tell us why the ball moves downfield.

- Newton's 3rd law doesn't give us any information.

- Do not say “The ball moves because the woman has more mass or is more powerful”

- This is wrong thinking!!!

- Objects with less mass, can pull extremely heavy objects

Ex. Two Ice skaters:

Suppose two ice skaters, a 90kg father, and 40kg daughter, push each other with a force of 20N. What is the acceleration of both people?

- Magnitude of force (20N) is the same on both, no matter who pushes

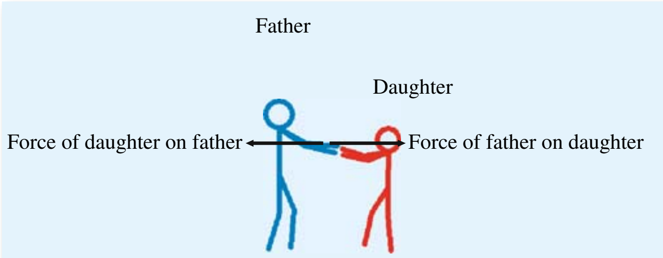


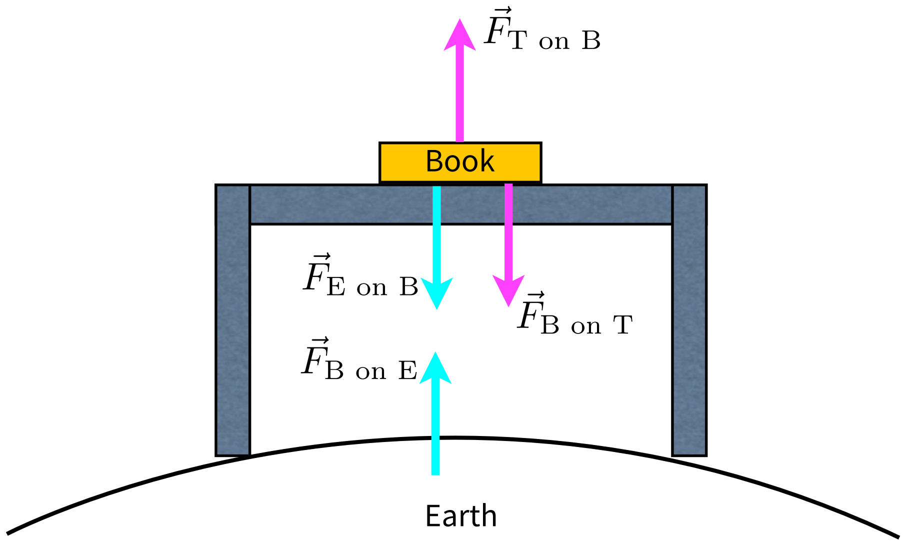
FIGURE 2.13 *Two ice skaters pushing off from each other.*

$$a_{\text{father}} = \frac{F_{\text{father}}}{m_{\text{father}}} = \frac{20\ \text{N}}{90\ \text{kg}} = 0.22\ \text{m/s}^2 \qquad a_{\text{daughter}} = \frac{F_{\text{daughter}}}{m_{\text{daughter}}} = \frac{20\ \text{N}}{40\ \text{kg}} = 0.5\ \text{m/s}^2$$

Ex. Action-Reaction pairs:

Draw all of the forces acting on the book, and draw the appropriate reaction force.

- I asked for forces, which are vectors. Therefore, we better draw arrows to show direction



If book has 1kg mass then: $a_{\text{book}} = 9.8\ \text{m/s}^2$

$$a_{\text{earth}} = 0.0000000000000000000000098\ \text{m/s}^2$$