PHY 101 Lecture 4 - Force

A force is a push or a pull.
But that definition is not quantitative.
We need a more technical definition.

The technical definition of the concept of "Force" started with Isaac Newton, in the *Three Laws of Motion*.

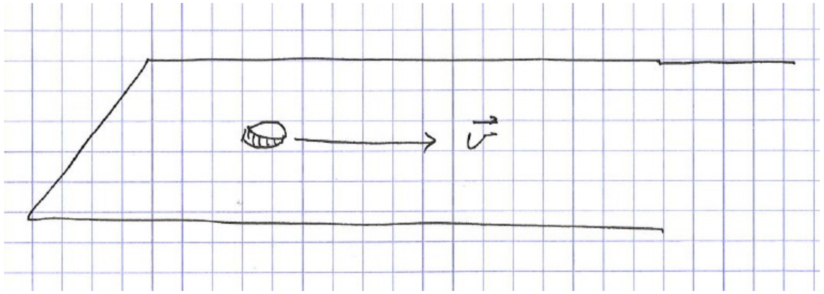
/1/ If the net force acting on an object is 0, then the object moves with constant velocity.

/2/ If the net force is **F,** then the object undergoes acceleration; **a** = **F** /m where m is the mass.

/3/ For every action there is an equal but opposite reaction.

Now, what do these statements mean?

Example. The first law of motion
Consider an object sliding without friction on a horizontal surface. The net force is zero.

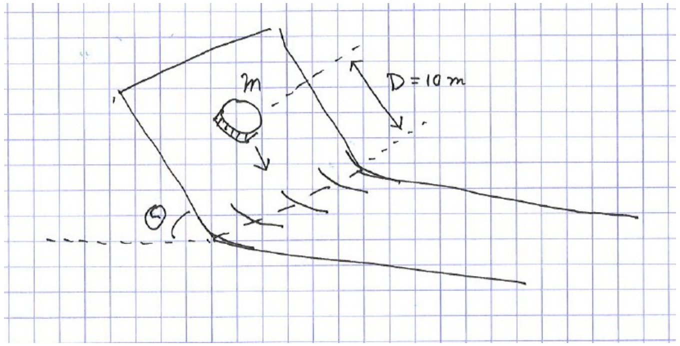


The object slides with constant velocity. It does not slow down nor speed up nor come to rest. As long as the net force is 0, it continues moving *in the same direction with the same speed.*

Inertia : the tendency of an object to continue its motion.

Example. The second law of motion

Consider an object sliding without friction on a surface with constant slope. Now there is a net force, due to gravity.



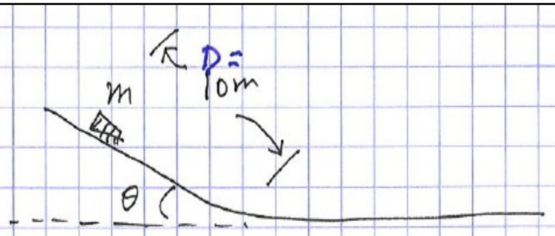
The object undergoes acceleration as it moves.

Review:

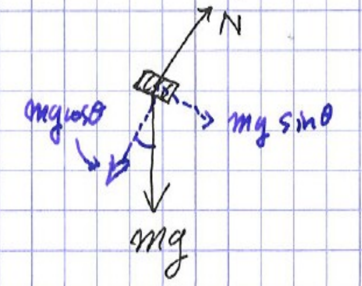
Acceleration is the rate of change of velocity. There are three kinds of acceleration:

- The object speeds up.
- The object slows down.
- The direction of motion changes (the speed may remain constant).

Calculate the time for the slider to go down 10 m on the slope, starting from rest.



Forces acting on m



$N = mg\cos\theta$

$a = \frac{mg\sin\theta}{m} = g\sin\theta$

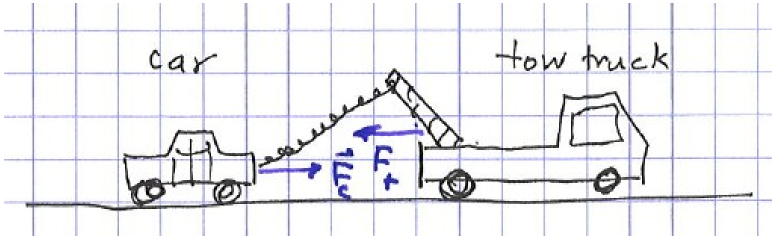
$D = \frac{1}{2}at^2$

$t = \sqrt{\frac{2D}{a}} = \sqrt{\frac{2D}{g\sin\theta}}$

$t = 1.43\,\text{sec}/\sqrt{\sin\theta}$

Example. The third law of motion

Many people won't understand this.
Consider a tow truck attached to a small car.

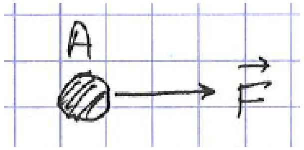


As the driver of the tow truck engages the engine, the truck pulls the car forward.
At the same time, the car pulls the truck backward.

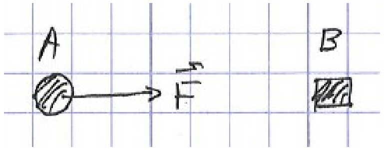
Which force is greater?

Newton's third law - in more modern terminology

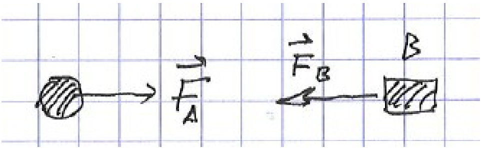
- A force acts on an object (A).



- There must be a second object (B) that exerts the force.

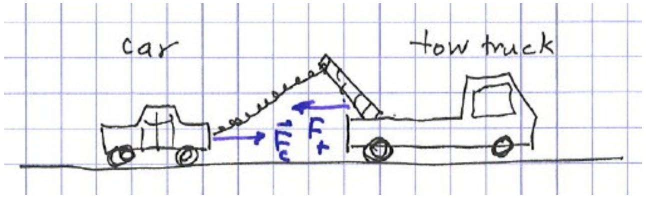


- The first object (A) also exerts a force on the second object (B).



- **F**$_A$ and **F**$_B$ are equal in strength but opposite in direction.

Example. The third law of motion

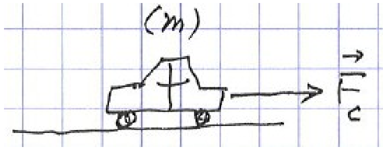


Which force is greater?

According to Newton’s third law, they are equal in strength, opposite in direction.

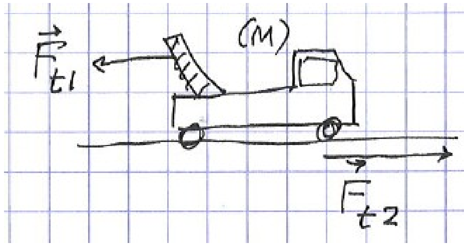
But if the forces are equal but opposite, *how can the vehicles accelerate?*

First analyze the net force on the car.



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

Now analyze the net force on the truck.



$$\vec{a}_t = \frac{\vec{F}_{t2} + \vec{F}_{t1}}{M}$$

They must accelerate together;

$$\mathbf{a}_{\text{truck}} = \mathbf{a}_{\text{car}} .$$

Do you see how to calculate the forces?

$$\vec{F}_c = m\vec{a} \; ; \; \vec{F}_{t1} = -\vec{F}_c \; ; \; \vec{F}_{t2} = M\vec{a} - \vec{F}_{t1}$$

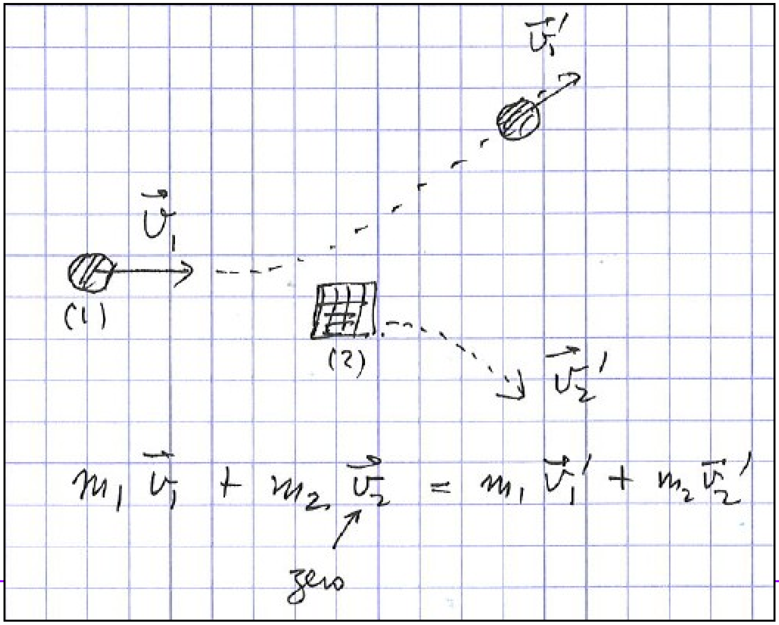
Momentum

$$\boxed{p = m\,v}$$

and the

Conservation of Momentum

$p_1 + p_2$ is constant in any isolated interaction between two objects.



$$m_1 \vec{v}_1 + m_2 \underset{\overset{\uparrow}{\text{zero}}}{\vec{v}_2} = m_1 \vec{v}_1{}' + m_2 \vec{v}_2{}'$$

Proof:

$$\vec{P} = m_1 \vec{v}_1 + m_2 \vec{v}_2$$

$$\delta\vec{P} = m_1\,\delta\vec{v}_1 + m_2\,\delta\vec{v}_2$$

$$= m_1 \vec{a}_1\,\delta t + m_2 \vec{a}_2\,\delta t$$

$$= \vec{F}_1\,\delta t + \vec{F}_2\,\delta t$$

$$= (\vec{F}_1 + \vec{F}_2)\,\delta t$$

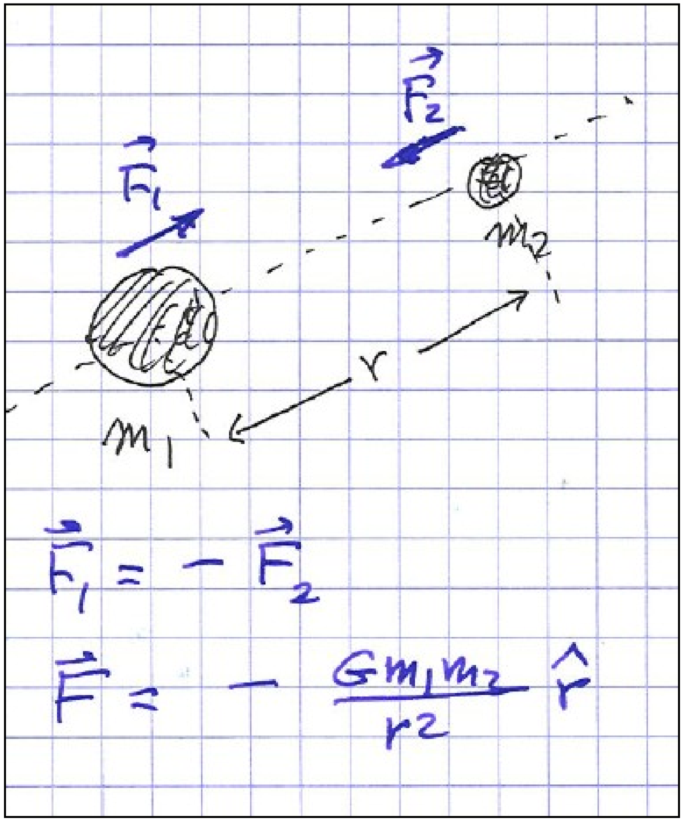
$$= 0 \text{ by Newton's third law}$$

$$(\vec{F}_2 = -\vec{F}_1)$$

$\delta\vec{P} = 0$ so $\vec{P}$ is constant.

Q.E.D.

The Theory of Universal Gravitation (Isaac Newton, 1687)

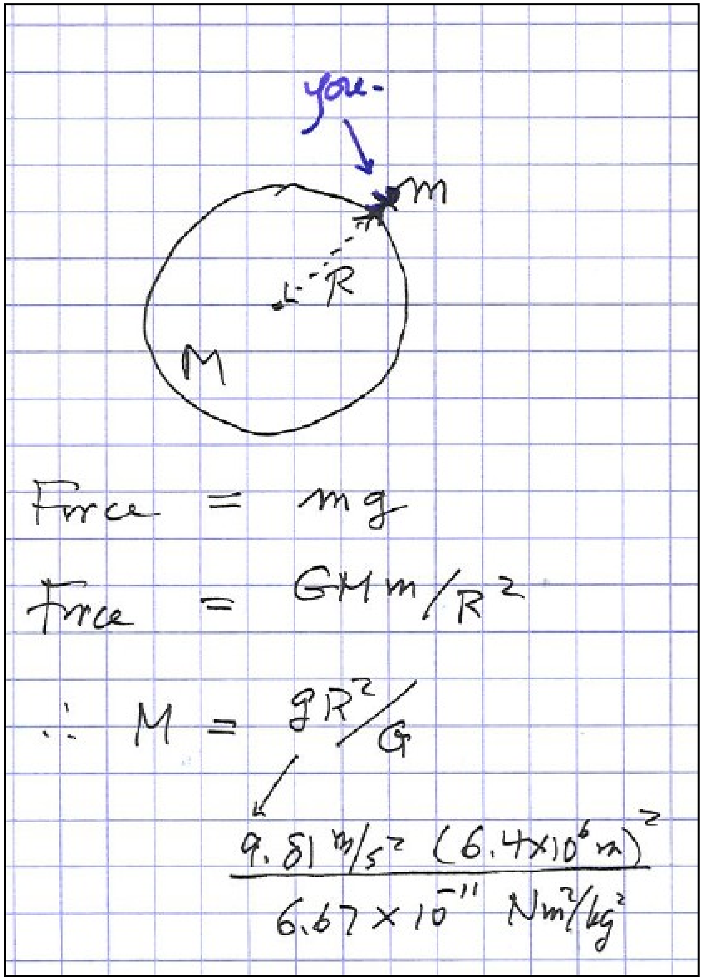


$$\vec{F}_1 = -\vec{F}_2$$

$$\vec{F} = -\frac{Gm_1m_2}{r^2}\hat{r}$$

The first measurement of the universal gravitational constant was by Henry Cavendish (1798); $G = 6.67 \times 10^{-11}$ N m^2/kg^2

Exercise. Calculate the mass of the Earth.



Force = mg

Force = GMm/R^2

$$\therefore M = gR^2/G$$

$$\frac{9.81\ \mathrm{m/s^2}\ (6.4\times10^{6}\ \mathrm{m})^2}{6.67\times10^{-11}\ \mathrm{Nm^2/kg^2}}$$

The standard unit of force: 1 N = 1 kg m/s^2