PHYS 1441 – Section 001
Lecture #9

Wednesday, June 18, 2014
Dr. Jaehoon Yu

- Newton's Laws Recap
- Application of Newton's Laws
- Force of Friction
- Uniform Circular Motion
- Centripetal Acceleration
- Unbanked and Banked highways
- Newton's Law of Universal Gravitation

Announcements

- Reading Assignments
  - CH5 – 4 and 5 – 9
- Please make sure that you pay for Quest homework access today!!
  - The deadline is tomorrow, Thursday, June 19!
  - You will lose all access to your homework site and grades if you do not pay by June 19.
    - 39 of you still haven't paid!!
  - NO extension for homework submission will be granted if you lose your access!!
- PLEASE do work on homework!
  - It will be very hard to pass this course without doing homework since it is 25%(!!!) of the entire grade!!

Special Project #3

- Using the fact that $g=9.80m/s^2$ on the Earth's surface, find the average density of the Earth.
  - Use the following information only but without computing the volume explicitly
    - The gravitational constant $G = 6.67 \times 10^{-11} N \cdot m^2/kg^2$
    - The radius of the Earth $R_E = 6.37 \times 10^3 km$
- 20 point extra credit
- Due: Monday, June 23
- You must show your OWN, detailed work to obtain any credit!!

Newton's First Law and Inertial Frames

Aristotle (384-322BC): *A natural state of a body is rest. Thus force is required to move an object. To move faster, ones needs larger forces.*

Galileo's statement on natural states of matter: *Any velocity once imparted to a moving body will be rigidly maintained as long as the external causes of retardation are removed!!*

Galileo's statement is formulated by Newton into the **1st law of motion (Law of Inertia)**: *In the absence of external forces, an object at rest remains at rest and an object in motion continues in motion with a constant velocity.*

What does this statement tell us?

- When no net force is exerted on an object, the acceleration of the object is 0.
- Any isolated object, the object that do not interact with its surroundings, is either at rest or moving at a constant velocity.
- Objects would like to keep its current state of motion, as long as there are no net force that interferes with the motion. This tendency is called the Inertia.

A frame of reference that is moving at a constant velocity is called the ***Inertial Frame***

Is a frame of reference with an acceleration an ***Inertial Frame?***

NO!

Newton's Second Law of Motion

The acceleration of an object is directly proportional to the net force exerted on it and is inversely proportional to the object's mass.

How do we write the above statement in a mathematical expression?

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

From this we obtain

$$\boxed{\sum_i \vec{F}_i = m\vec{a}}$$

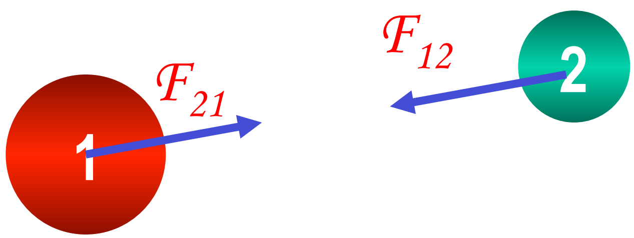
Newton's 2nd Law of Motion

Since it's a vector expression, each component must also satisfy:

$$\sum_i F_{ix} = ma_x \qquad \sum_i F_{iy} = ma_y \qquad \sum_i F_{iz} = ma_z$$

Newton's Third Law (Law of Action and Reaction)

If two objects interact, the force F_{21} that object 2 exerts on object 1 is equal in magnitude and opposite in direction to the force F_{12} object 1 exerts on object 2.



$$\boxed{\vec{F}_{12} = -\vec{F}_{21}}$$

*The reaction force is equal in magnitude to the action force but in opposite direction. These two forces always act **on different objects**.*

What is the reaction force to the force of a free falling object?

The gravitational force the object exerts on the Earth!

Stationary objects on top of a table has a reaction force (called the normal force) from table to balance the action force, the gravitational force.

Some Basic Information

When Newton's laws are applied, *external forces* are only of interest!!

Why?

Because, as described in Newton's first law, an object will keep its current motion unless non-zero net external force is applied.

Normal Force, ***n***:

The force that reacts to action forces due to the surface structure of an object. Its direction is always perpendicular to the surface.

Tension, ***T***:

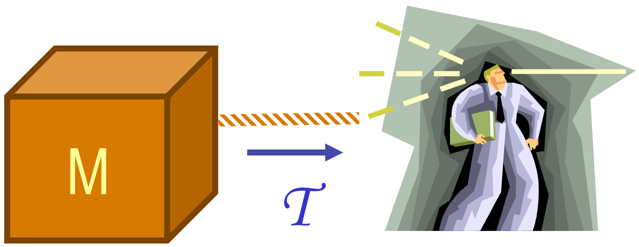
The reactionary force by a stringy object against an external force exerted on it.

Free-body diagram

A graphical tool which is a ***diagram of external forces on an object*** *and is extremely useful analyzing forces and motion!! Drawn only on an object.*

Applications of Newton's Laws

Suppose you are pulling a box on frictionless ice, using a rope.



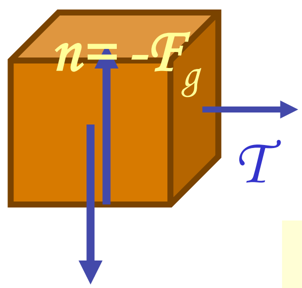
What are the forces being exerted on the box?

Gravitational force: $\mathbf{F}_g$

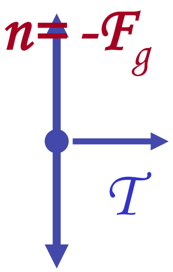
Normal force: $\mathbf{n}$

Tension force: $\mathbf{T}$

Free-body diagram



$F_g = -Mg$



$F_g = -Mg$

Total vector force:
$\mathbf{F} = \mathbf{F}_g + \mathbf{n} + \mathbf{T} = \mathbf{T}$

$$\sum F_x = T = Ma_x \qquad \boxed{a_x = \frac{T}{M}}$$

$$\sum F_y = -F_g + n = Ma_y = 0 \qquad \boxed{a_y = 0}$$

If T is a constant force, a_x, is constant

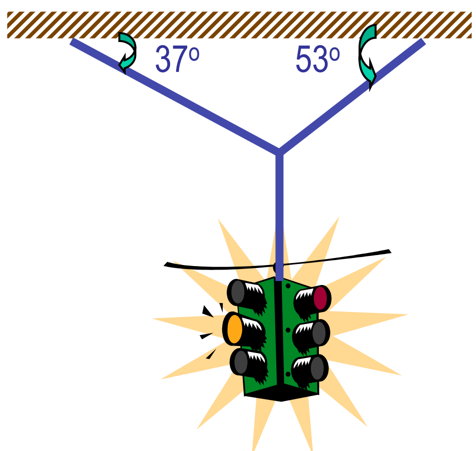
$$v_{xf} = v_{xi} + a_x t = v_{xi} + \left(\frac{T}{M}\right)t$$

$$\Delta x = x_f - x_i = v_{xi}t + \frac{1}{2}\left(\frac{T}{M}\right)t^2$$

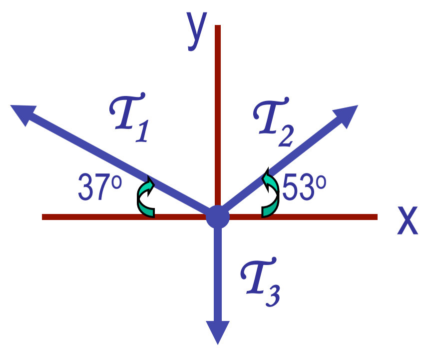
What happened to the motion in y-direction?

Example for Using Newton's Laws

A traffic light weighing 125 N hangs from a cable tied to two other cables fastened to a support. The upper cables make angles of 37.0º and 53.0º with the horizontal. Find the tension in the three cables.



Free-body Diagram



$$\vec{F} = \vec{T}_1 + \vec{T}_2 + \vec{T}_3 = m\vec{a} = 0$$ Newton's 2nd law

x-comp. of net force

$$F_x = \sum_{i=1}^{i=3} T_{ix} = 0 \quad -T_1\cos\left(37^\circ\right) + T_2\cos\left(53^\circ\right) = 0 \therefore T_1 = \frac{\cos\left(53^\circ\right)}{\cos\left(37^\circ\right)} T_2 = 0.754T_2$$

y-comp. of net force

$$F_y = \sum_{i=1}^{i=3} T_{iy} = 0$$

$$T_1\sin\left(37^\circ\right) + T_2\sin\left(53^\circ\right) - mg = 0$$

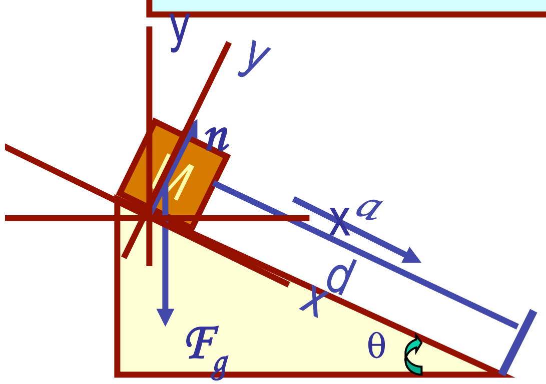
$$T_2\left[\sin\left(53^\circ\right) + 0.754\times\sin\left(37^\circ\right)\right] = 1.25T_2 = 125N$$

$$T_2 = 100N;\ T_1 = 0.754T_2 = 75.4N$$

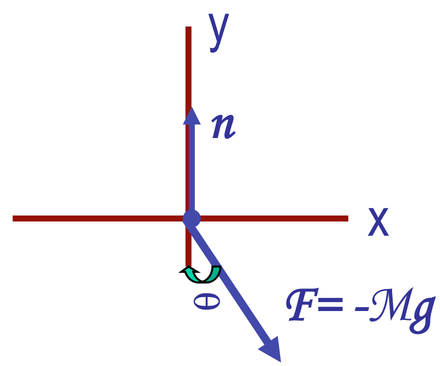
Example w/o Friction

A crate of mass M is placed on a frictionless inclined plane of angle θ.

a) Determine the acceleration of the crate after it is released.



Free-body Diagram



$$\vec{F} = \vec{F}_g + \vec{n} = m\vec{a}$$

$$F_x = Ma_x = F_{gx} = Mg\sin\theta$$

$$\boxed{a_x = g\sin\theta}$$

$$F_y = Ma_y = n - F_{gy} = n - mg\cos\theta = 0$$

Supposed the crate was released at the top of the incline, and the length of the incline is d. How long does it take for the crate to reach the bottom and what is its speed at the bottom?

$$d = v_{ix}t + \frac{1}{2}a_x t^2 = \frac{1}{2}g\sin\theta\, t^2$$

$$\boxed{\therefore t = \sqrt{\frac{2d}{g\sin\theta}}}$$

$$v_{xf} = v_{ix} + a_x t = g\sin\theta\sqrt{\frac{2d}{g\sin\theta}} = \sqrt{2dg\sin\theta}$$

$$\boxed{\therefore v_{xf} = \sqrt{2dg\sin\theta}}$$

Force of Friction

Resistive force exerted on a moving object due to viscosity or other types frictional property of the medium in or surface on which the object moves.

These forces are either proportional to the velocity or the normal force.

Force of static friction, f_s: *The resistive force exerted on the object until just before the beginning of its movement*

Empirical Formula

$$\left|\vec{f}_s\right| \le \mu_s \left|\vec{n}\right|$$

What does this formula tell you?

Frictional force increases till it reaches the limit!!

Beyond the limit, the object moves, and there is **NO MORE** static friction but kinetic friction takes it over.

Force of kinetic friction, f_k

$$\left|\vec{f}_k\right| = \mu_k \left|\vec{n}\right|$$

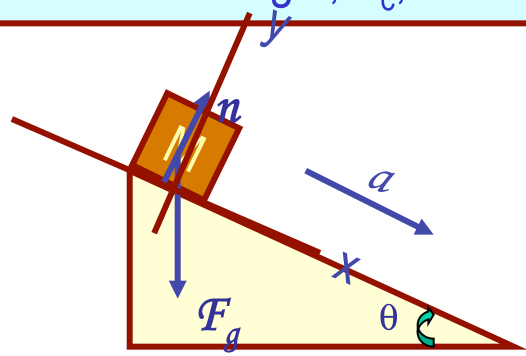
The resistive force exerted on the object during its movement

Which direction does kinetic friction apply?

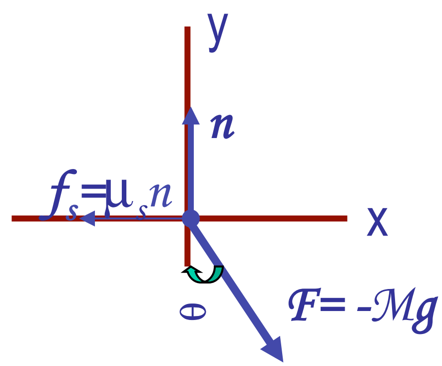
Opposite to the motion!

Example w/ Friction

Suppose a block is placed on a rough surface inclined relative to the horizontal. The inclination angle is increased till the block starts to move. Show that by measuring this critical angle, θ_c, one can determine coefficient of static friction, μ_s.



Free-body Diagram



Net force $\vec{F} = M\vec{a} = \vec{F}_g + \vec{n} + \vec{f}_s$

x comp. $F_x = F_{gx} - f_s = Mg\sin\theta - f_s = 0 \qquad f_s = \mu_s n = Mg\sin\theta_c$

y comp. $F_y = Ma_y = n - F_{gy} = n - Mg\cos\theta_c = 0 \qquad n = F_{gy} = Mg\cos\theta_c$

$$\mu_s = \frac{Mg\sin\theta_c}{n} = \frac{Mg\sin\theta_c}{Mg\cos\theta_c} = \tan\theta_c$$