PHYS 1443 – Section 003
Lecture #8

Wednesday, Sept. 22, 2003

Dr. Jaehoon Yu

- Newton's Laws of Motion
  - Free-body Diagrams
  - Applications of Newton's Laws
- Friction
- Newton's Laws and Uniform Circular Motion
- Non-uniform Circular Motion
- Motion in an Accelerated Frames

Remember the first term exam on Monday, Sept. 29!!

Announcement

- Thank you for your response to my test message.
  - We only have two people left
- Can I speak to:
  - Robyn Barber & James Mann after the class?
- Quiz
  - Problem #2 does not have an answer.
  - Average score is 2.6.

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?

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

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

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

From the above vector expression, what do you conclude the dimension and unit of force are?

The dimension of force is $[m][a] = [M][LT^{-2}]$

The unit of force in SI is $[Force] = [m][a] = [M][LT^{-2}] = kg \cdot m/s^2$

For ease of use, we define a new derived unit called, a Newton (N)

$$1N \equiv 1kg \cdot m/s^2 \approx \frac{1}{4} lbs$$

Gravitational Force and Weight

Gravitational Force, F_g

The attractive force exerted on an object by the Earth

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

Weight of an object with mass M is

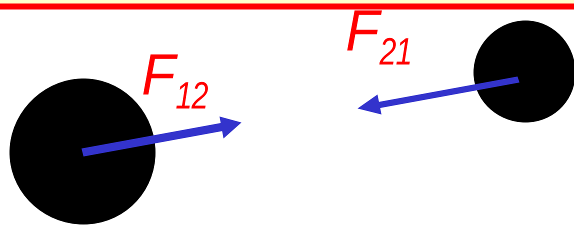
$$W = \left|\vec{F}_G\right| = M\left|\vec{g}\right| = Mg$$

Since weight depends on the magnitude of gravitational acceleration, g, it varies depending on geographical location.

By measuring the forces one can determine masses. This is why you can measure mass using spring scale.

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

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



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

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

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

The force exerted by the ground when it completed the motion.

Stationary objects on top of a table has a reaction force (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:*

Reaction force that reacts to gravitational force due to the surface structure of an object. Its direction is 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.*

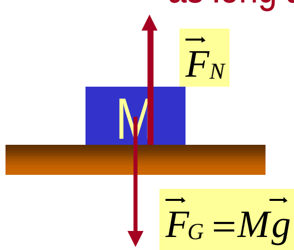
Free Body Diagrams

- Diagrams of vector forces acting on an object

⇒ A great tool to solve a problem using forces or using dynamics

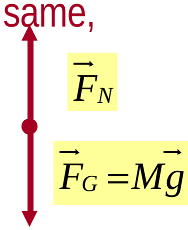
1. Select a point on an object and w/ information given
2. Identify all the forces acting only on the selected object
3. Define a reference frame with positive and negative axes specified
4. Draw arrows to represent the force vectors on the selected point
5. Write down net force vector equation
6. Write down the forces in components to solve the problems

⇒ No matter which one we choose to draw the diagram on, the results should be the same, as long as they are from the same motion



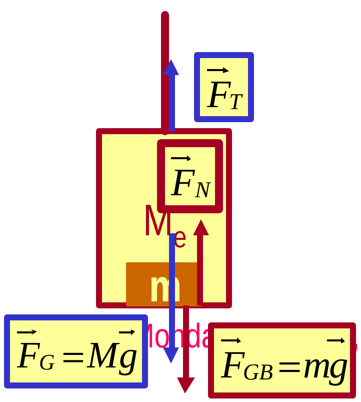
Which one would you like to select to draw FBD?

What do you think are the forces acting on this object?



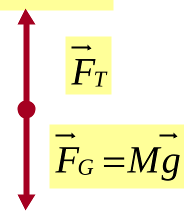
Gravitational force

A force supporting the object exerted by the floor



Which one would you like to select to draw FBD?

What do you think are the forces acting on this elevator?



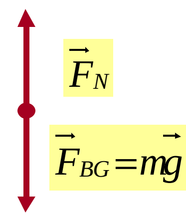
Gravitational force

The force pulling the elevator (Tension)

What about the box in the elevator?

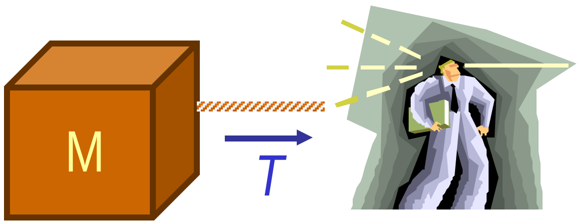
Gravitational force

Normal force



Applications of Newton's Laws

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



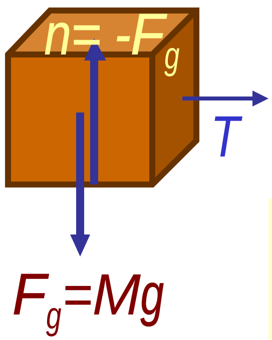
What are the forces being exerted on the box?

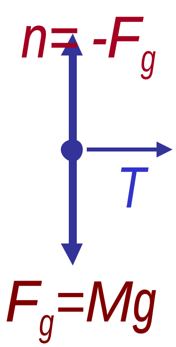
Gravitational force: F_g

Normal force: n

Tension force: T

Free-body diagram





Total force:
$F = F_g + n + T = T$

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

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

If T is a constant force, a_x, is constant

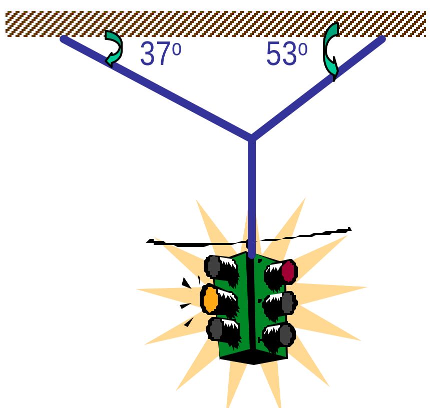
$$v_{xf} = v_{xi} + a_x t = v_{xi} + \left(\frac{T}{M}\right)t$$

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

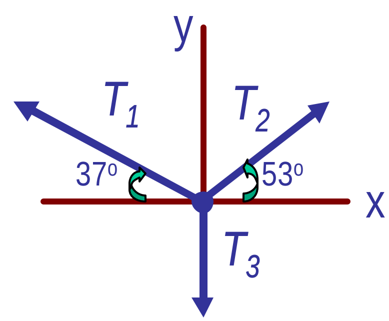
What happened to the motion in y-direction?

Example of 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 37.0° and 53.0° with the horizontal. Find the tension in the three cables.



Free-body Diagram



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

x-comp. of net force

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

y-comp. of net force

$$\boxed{F_y = \sum_{i=1}^{i=3} T_{iy} = 0} \quad \boxed{T_1 \sin\left(37^o\right) + T_2 \sin\left(53^o\right) - mg = 0}$$

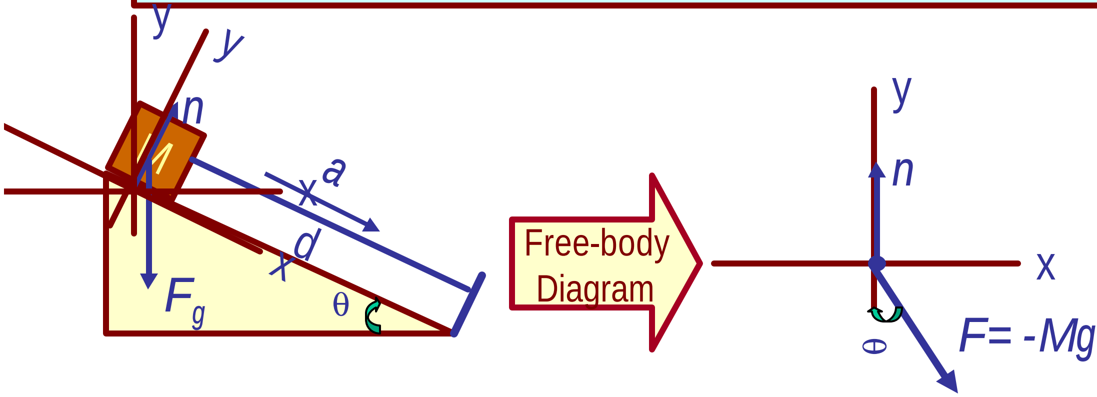
$$\boxed{T_2\left[\sin\left(53^o\right) + 0.754 \times \sin\left(37^o\right)\right] = 1.25 T_2 = 125\,N}$$

$$\boxed{T_2 = 100\,N; \quad T_1 = 0.754 T_2 = 75.4\,N}$$

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.



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

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

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

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

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?

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

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

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

Forces 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 velocity or 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

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

What does this formula tell you?

Frictional force increases till it reaches to the limit!!

Beyond the limit, there is no more static frictional force but kinetic frictional force takes it over.

Force of kinetic friction, f_k: *The resistive force exerted on the object during its movement*

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