PHYS 1443 – Section 001
Lecture #6

Tuesday, June 14, 2011

Dr. Jaehoon Yu

- Newton's Laws of Motion
  - Newton's third law of motion
  - Categories of Forces
- Free Body Diagram
- Application of Newton's Laws
- Force of friction

Announcements

- Mid-term exam
  - In the class on Tuesday, June 21, 2011
  - Covers: CH 1.1 – what we finish Monday, June 20 plus Appendices A and B
  - Mixture of free response problems and multiple choice problems
- Bring your special project #2 during the intermission

Special Project for Extra Credit

A large man and a small boy stand facing each other on **frictionless ice**. They put their hands together and push against each other so that they move apart. a) Who moves away with the higher speed, by how much and why? b) Who moves farther in the same elapsed time, by how much and why?

- Derive the formulae for the two problems above in much more detail and explain your logic in a greater detail than what is in this lecture note.
- Be sure to clearly define each variables used in your derivation.
- Each problem is 10 points.
- Due is Monday, June 20.

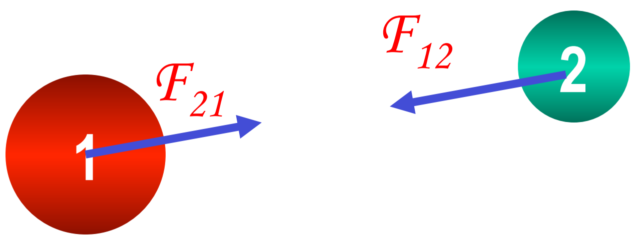
Special Project for Extra Credit

A 92kg astronaut tied to an 11000kg space craft with a 100m bungee cord pushes the space craft with a force P=36N in space. Assuming there is no loss of energy at the end of the cord, and the cord does not extend beyond its original length, the astronaut and the space craft get pulled back toward each other by the cord toward a head-on collision.

- What are the speeds of the astronaut and the space craft just before they collide? (10 points)
- What are the magnitudes of the accelerations of the astronaut and the space craft if they come to a full stop in 0.5m from the point of initial contact? (10 points)
- What are the magnitudes of the forces exerting on the astronaut and the space craft when they come to a full stop? 6 points)
- Due is Wednesday, June 22.

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} that object 1 exerts on object 2.



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

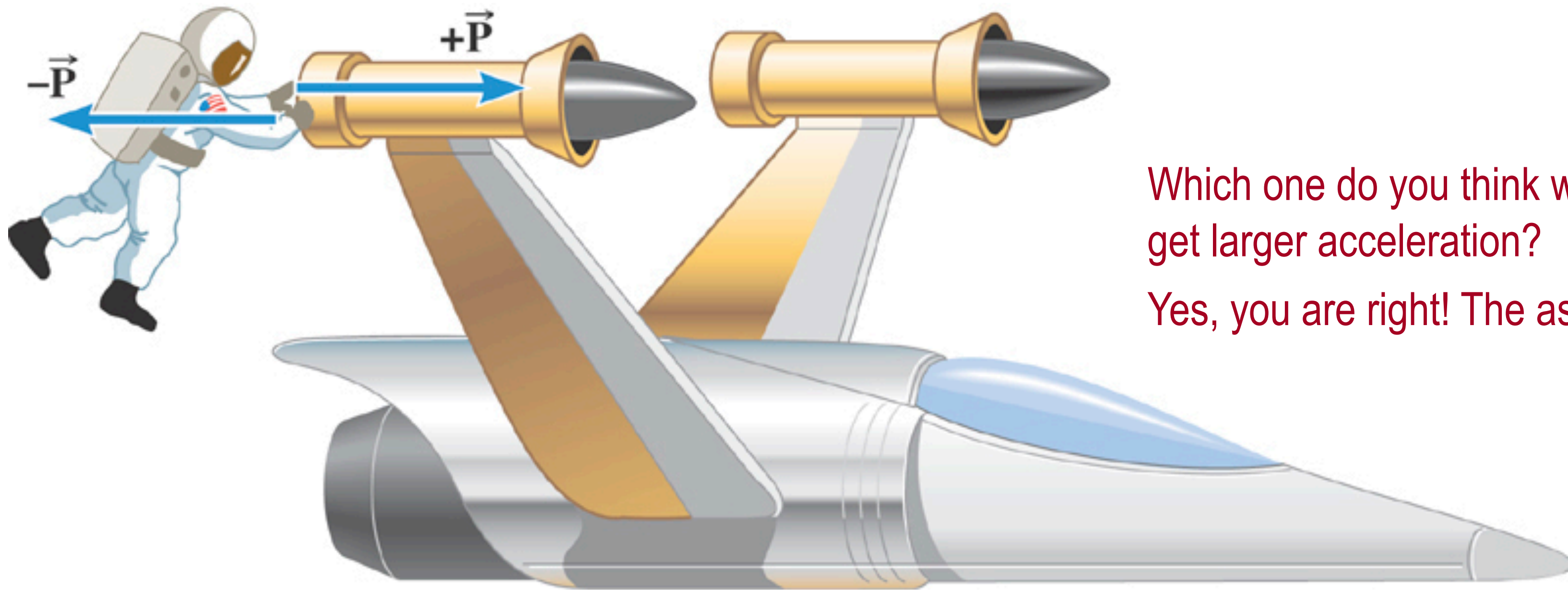
The reaction force is equal in magnitude to the action force but in opposite direction. These two forces always act ***<u>on different objects</u>****.*

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

The gravitational force exerted by the object to the Earth!

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

Ex. The Accelerations Produced by Action and Reaction Forces



Which one do you think will get larger acceleration?

Yes, you are right! The astronaut!

Suppose that the magnitude of the force P is 36 N. If the mass of the spacecraft is 11,000 kg and the mass of the astronaut is 92 kg, what are the accelerations?

Ex. continued

Force exerted on the space craft by the astronaut $\sum \vec{\mathbf{F}} = \vec{\mathbf{P}}$

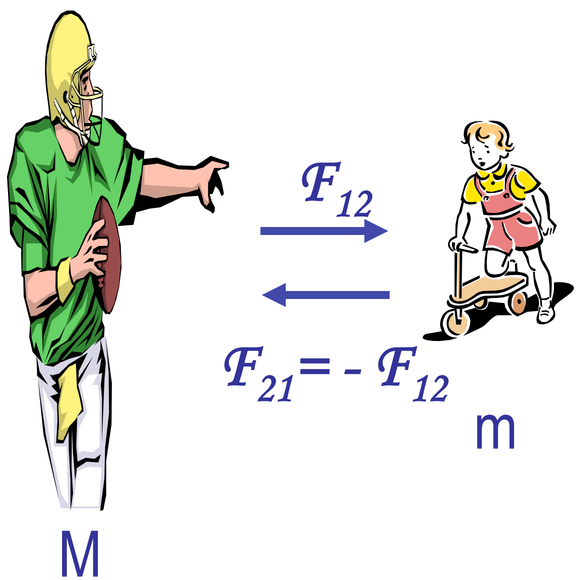
Force exerted on the astronaut by the space craft $\sum \vec{\mathbf{F}} = -\vec{\mathbf{P}}$

space craft's acceleration $$\vec{\mathbf{a}}_s = \frac{\vec{\mathbf{P}}}{m_s} = \frac{+36\,\vec{i}\ \mathrm{N}}{11{,}000\ \mathrm{kg}} = +0.0033\vec{i}\ \mathrm{m/s^2}$$

astronaut's acceleration $$\vec{\mathbf{a}}_A = \frac{-\vec{\mathbf{P}}}{m_A} = \frac{-36\,\vec{i}\ \mathrm{N}}{92\ \mathrm{kg}} = -0.39\vec{i}\ \mathrm{m/s^2}$$

Example of Newton's 3rd Law

A large man and a small boy stand facing each other on **frictionless ice**. They put their hands together and push against each other so that they move apart. a) Who moves away with the higher speed and by how much?



$$\vec{F}_{12} = -\vec{F}_{21} \Rightarrow \left|\vec{F}_{12}\right| = \left|\vec{F}_{21}\right| = F$$

$$\vec{F}_{12} = m\vec{a}_b \Rightarrow F_{12x} = ma_{bx}, \quad F_{12y} = ma_{by} = 0$$

$$\vec{F}_{21} = M\vec{a}_M \Rightarrow F_{21x} = Ma_{Mx}, \quad F_{21y} = Ma_{My} = 0$$

Since $\vec{F}_{12} = -\vec{F}_{21}$ and $\left|\vec{F}_{12}\right| = \left|-\vec{F}_{21}\right| = F$

Establish the equation $\Rightarrow$ $ma_{bx} = F = Ma_{Mx}$ **Divide by m** $\Rightarrow$ $a_{bx} = \frac{F}{m} = \frac{M}{m} a_{Mx}$

Example of Newton's 3rd Law, cnt'd

Man's velocity

$$v_{Mxf} = v_{Mxi} + a_{Mx}t = a_{Mx}t$$

Boy's velocity

$$v_{bxf} = v_{bxi} + a_{bx}t = a_{bx}t = \frac{M}{m}a_{Mx}t = \frac{M}{m}v_{Mxf}$$

So boy's velocity is higher than man's, if M>m, by the ratio of the masses.

b) Who moves farther while their hands are in contact?

Boy's displacement

$$x_b = v_{bxi}t + \frac{1}{2}a_{bx}t^2 = \frac{M}{2m}a_{Mx}t^2$$

$$x_b = \frac{M}{m}\left(\frac{1}{2}a_{Mx}t^2\right) = \frac{M}{m}x_M$$

Man's displacement

Given in the same time interval, since the boy has higher acceleration and thereby higher speed, he moves farther than the man.

Categories of Forces

- Fundamental Forces: Truly unique forces that cannot be derived from any other forces
  - Total of three fundamental forces
    - Gravitational Force
    - Electro-Weak Force
    - Strong Nuclear Force
- Non-fundamental forces: Forces that can be derived from fundamental forces
  - Friction
  - Tension in a rope
  - Normal or support forces

Gravitational Force and Weight

Gravitational Force, $\mathcal{F}_g$

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

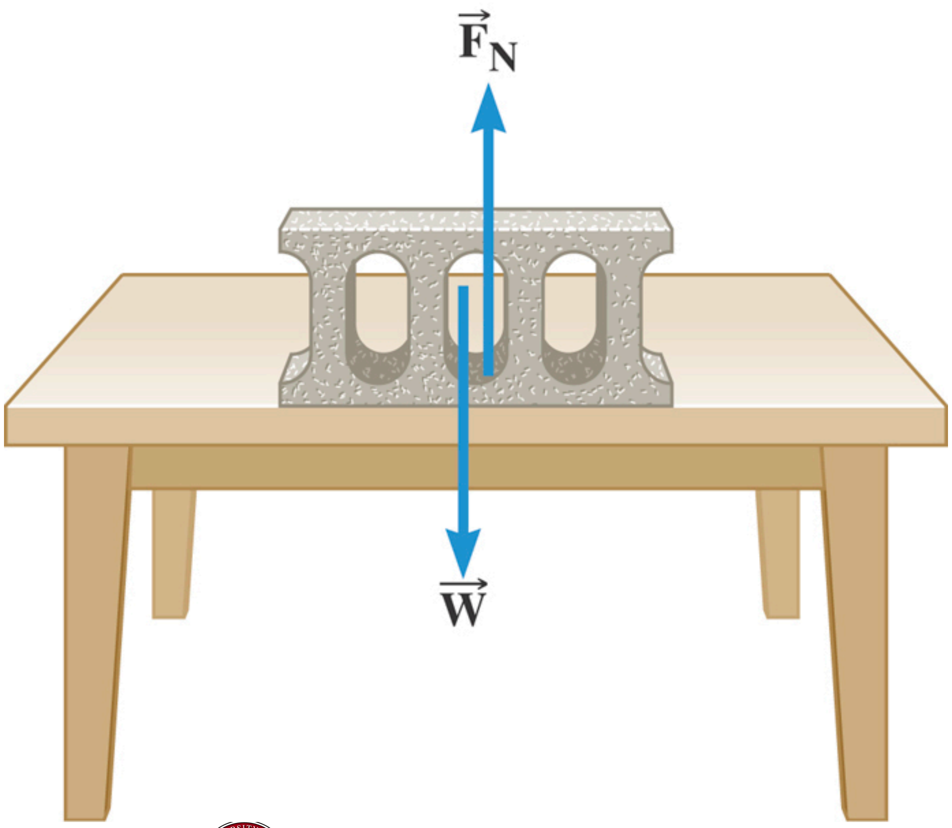
$$W = \left|\vec{F}_G\right| = M\left|\vec{g}\right| = Mg$$

*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 the spring scale.

The Normal Force

The normal force is one component of the force that a surface exerts on an object with which it is in contact – namely, the component that is **perpendicular to the surface**.

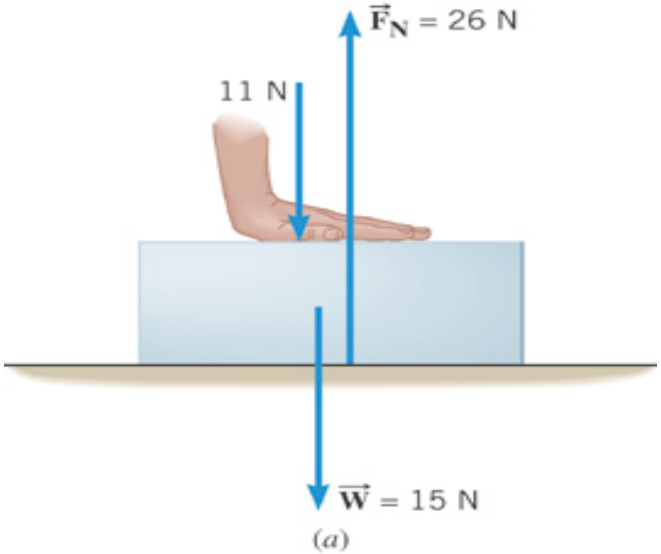


Some normal force exercises

Case 1: Hand pushing down on the book

$$F_N - 11\text{ N} - 15\text{ N} = 0$$

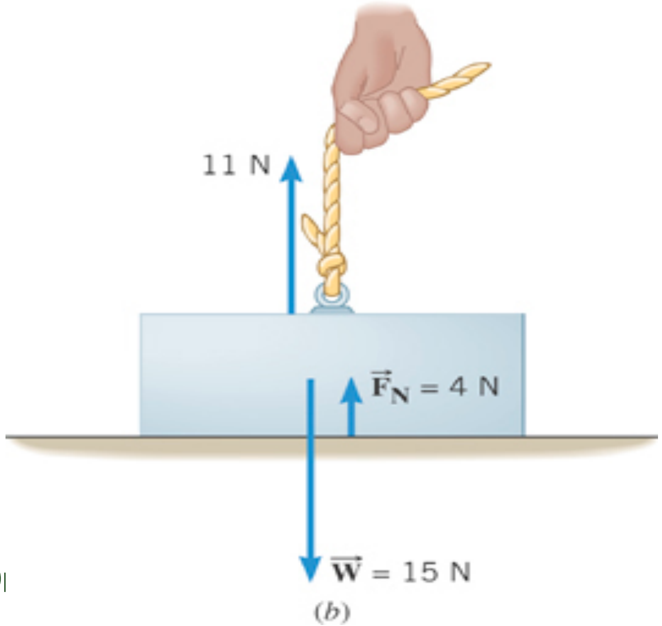
$$F_N = 26\text{ N}$$



Case 2: Hand pulling up the book

$$F_N + 11\text{ N} - 15\text{ N} = 0$$

$$F_N = 4\text{ N}$$



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 action forces 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

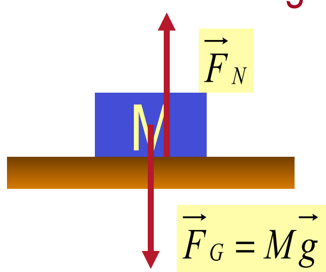
*A graphical tool which is a **diagram of external forces on an object** and is extremely useful analyzing forces and motion!! Drawn only on an object.*

Free Body Diagrams and Solving Problems

- Free-body diagram: A diagram 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 in the problem
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

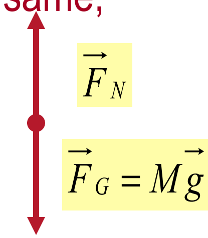
- No matter which one we choose to draw the diagram on, the results should be the same, as long as they are from the same motion

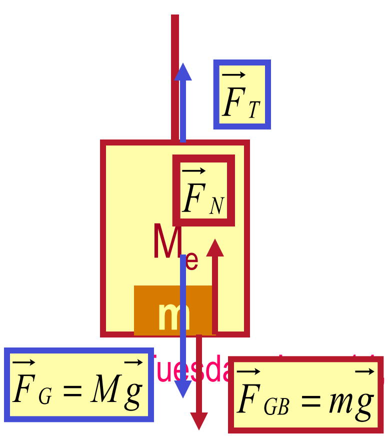


Which one would you like to select to draw FBD?
What do you think are the forces acting on this object?

Gravitational force

the force supporting the object exerted by the floor

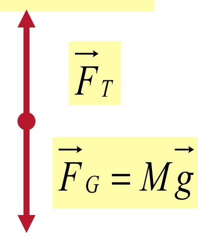




Which one would you like to select to draw FBD?
What do you think are the forces acting on this elevator?

Gravitational force

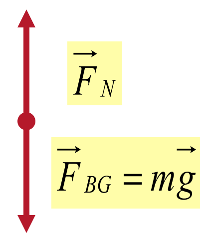
The force pulling the elevator (Tension)



What about the box in the elevator?

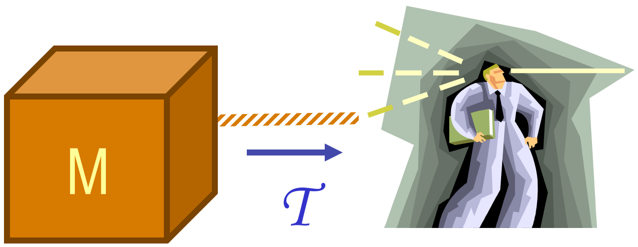
Gravitational force

Normal force



Applications of Newton's Laws

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



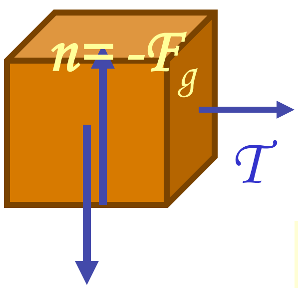
What are the forces being exerted on the box?

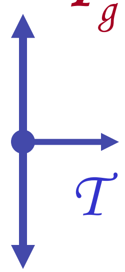
Gravitational force: $\boldsymbol{F_g}$

Normal force: $\boldsymbol{n}$

Tension force: $\boldsymbol{T}$

Free-body diagram





Total force:
$\boldsymbol{F}=\boldsymbol{F_g}+\boldsymbol{n}+\boldsymbol{T}=\boldsymbol{T}$

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

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

If T *is a constant force,* a_x*, is constant*

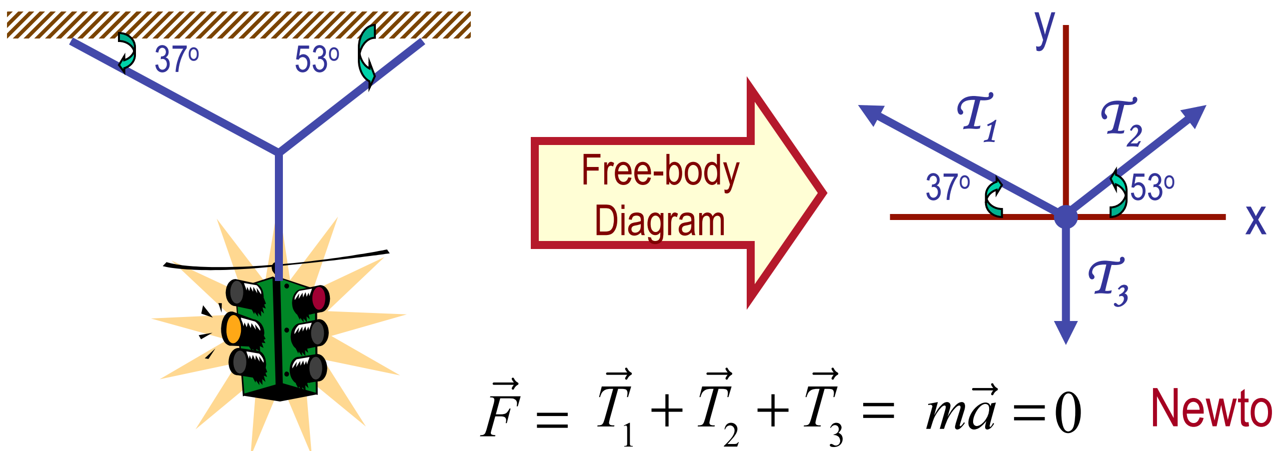
$$v_{xf} = v_{xi} + a_x t = v_{xi} + \left(\frac{T}{M}\right)t$$

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

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



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

x-comp. of net force

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

y-comp. of net force

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

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

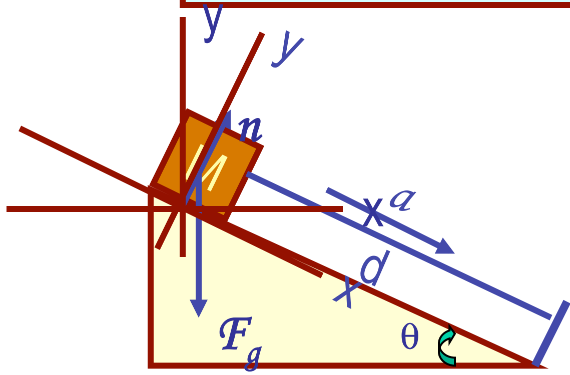
$$T_2\left[\sin(53^\circ) + 0.754 \times \sin(37^\circ)\right] = 1.25 T_2 = 125N$$

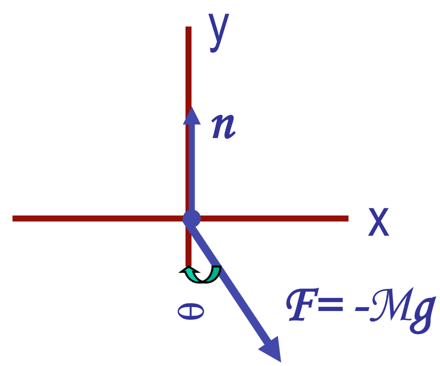
$$T_2 = 100N; \quad T_1 = 0.754, \quad T_2 = 75.4N$$

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.





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

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

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

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

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?

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

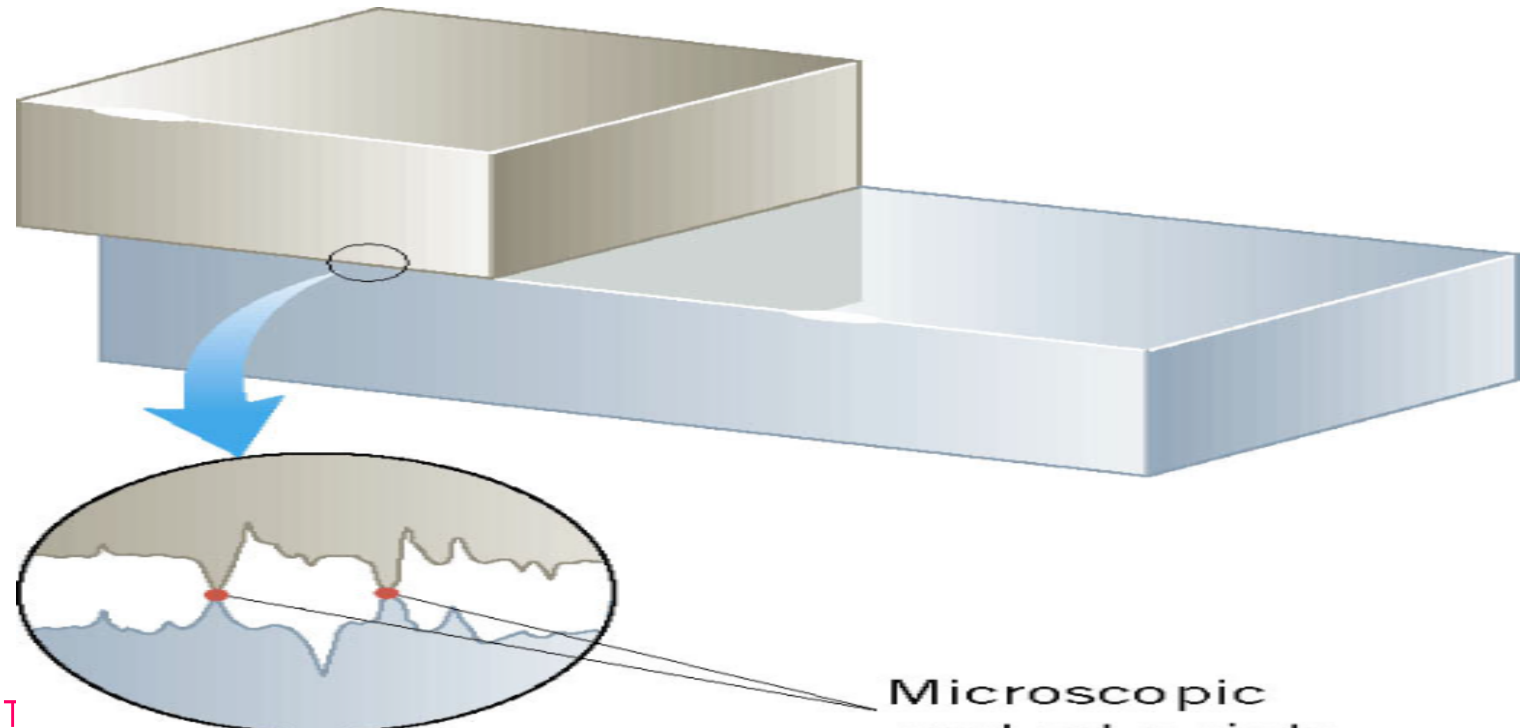
$$\boxed{\therefore t = \sqrt{\frac{2d}{g\sin\theta}}}$$

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

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

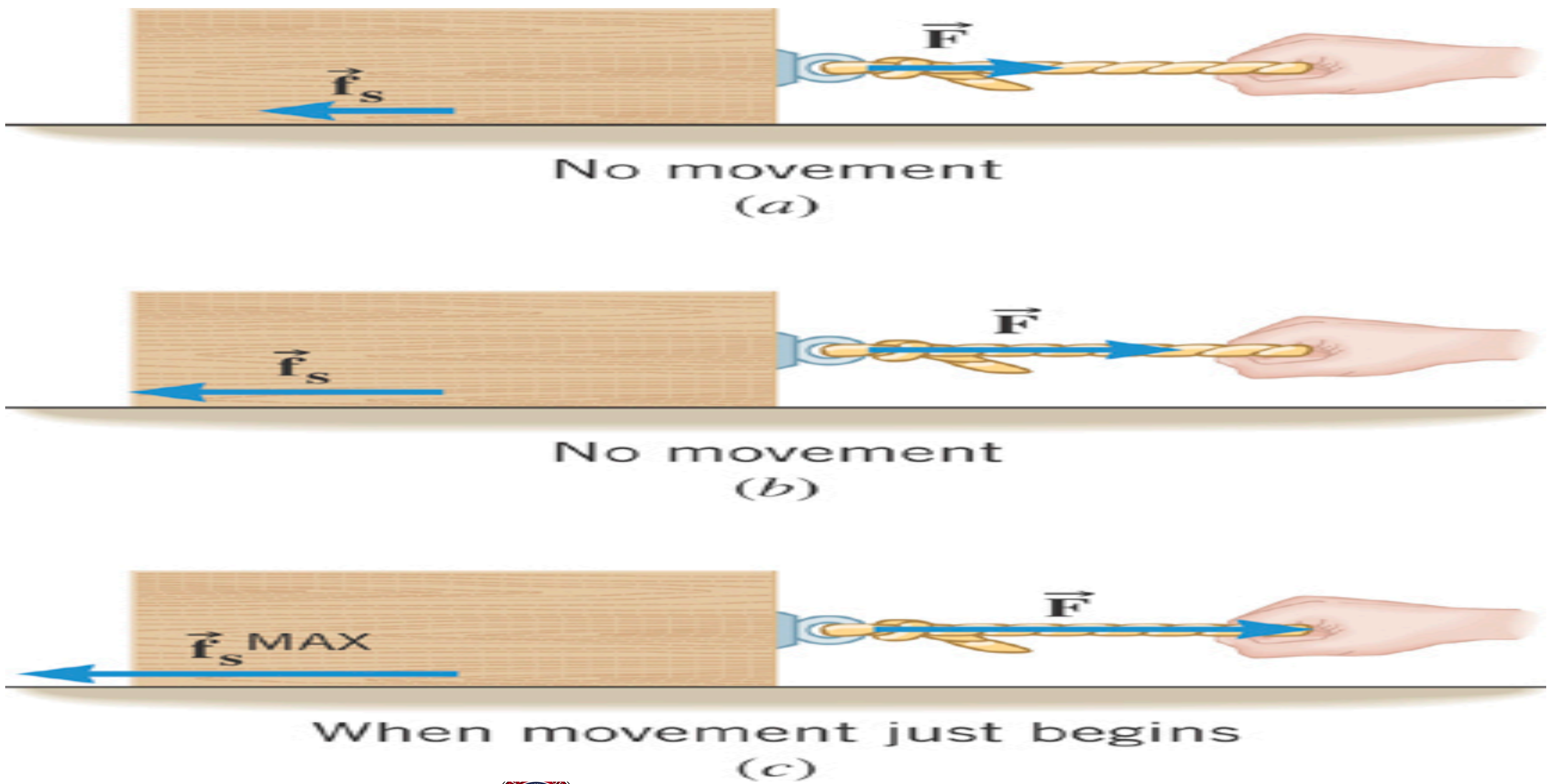
Friction Force

When an object is in contact with a surface there is a force acting on that object. The component of this force that is parallel to the surface is called the ***friction force***. <u>*This resistive force is exerted on a moving object due to viscosity or other types of frictional property of the medium in or surface on which the object moves.*</u> <u>*Always opposite to the movement!!*</u>



Static Friction

When the two surfaces are not sliding across one another the friction is called ***static friction***. *The resistive force exerted on the object up to the time just before the object starts moving.*



Magnitude of the Static Friction

The magnitude of the static friction force can have any value from zero up to the maximum value.

$$f_s \le f_s^{MAX}$$

$$f_s^{MAX} = \mu_s F_N$$

$0 < \mu_s < 1$ is called the **coefficient of static friction**.

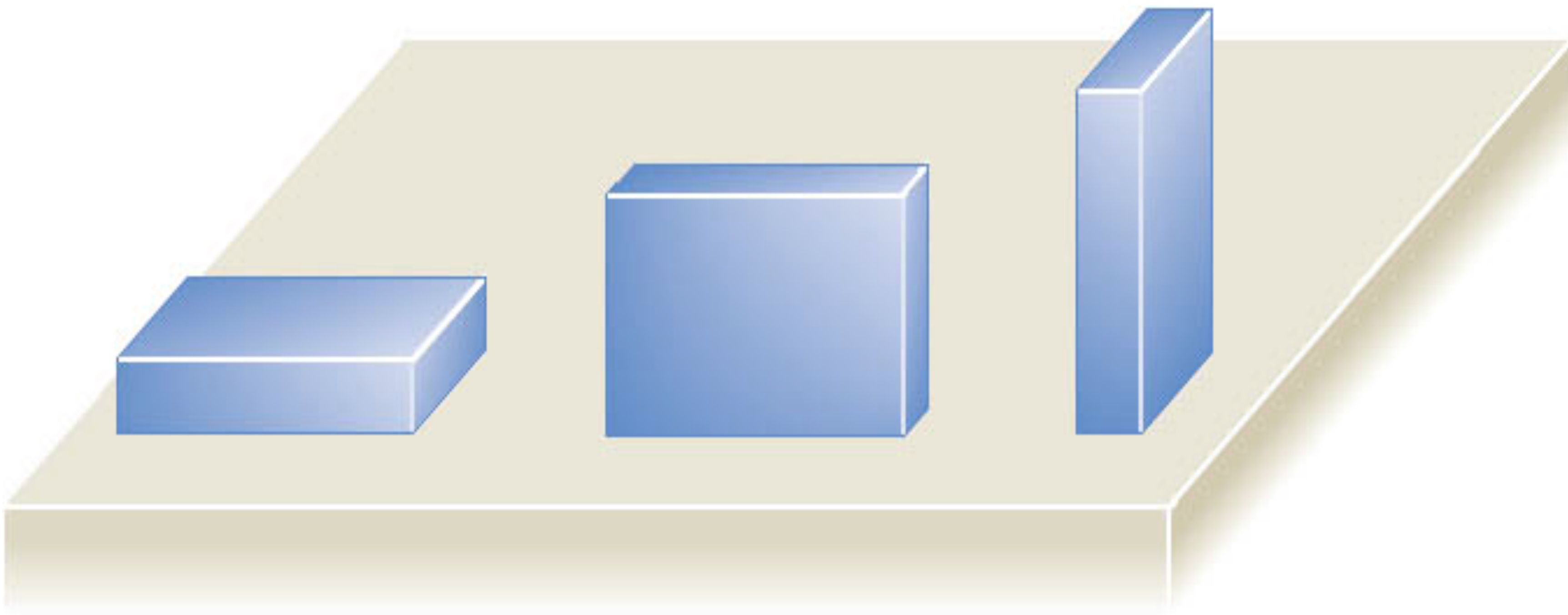
What is the unit? None

Once the object starts moving, there is **NO MORE** static friction!!

Kinetic friction applies during the move!!

Note that the magnitude of the frictional force **does not depend on the contact area of the surfaces**.

$$f_s^{MAX} = \mu_s F_N$$



Kinetic Friction

Static friction opposes the *impending* relative motion between two objects.

Kinetic friction opposes the relative sliding motions that is happening. ***The resistive force exerted on the object during its movement.*** ***Normally much smaller than static friction!!***

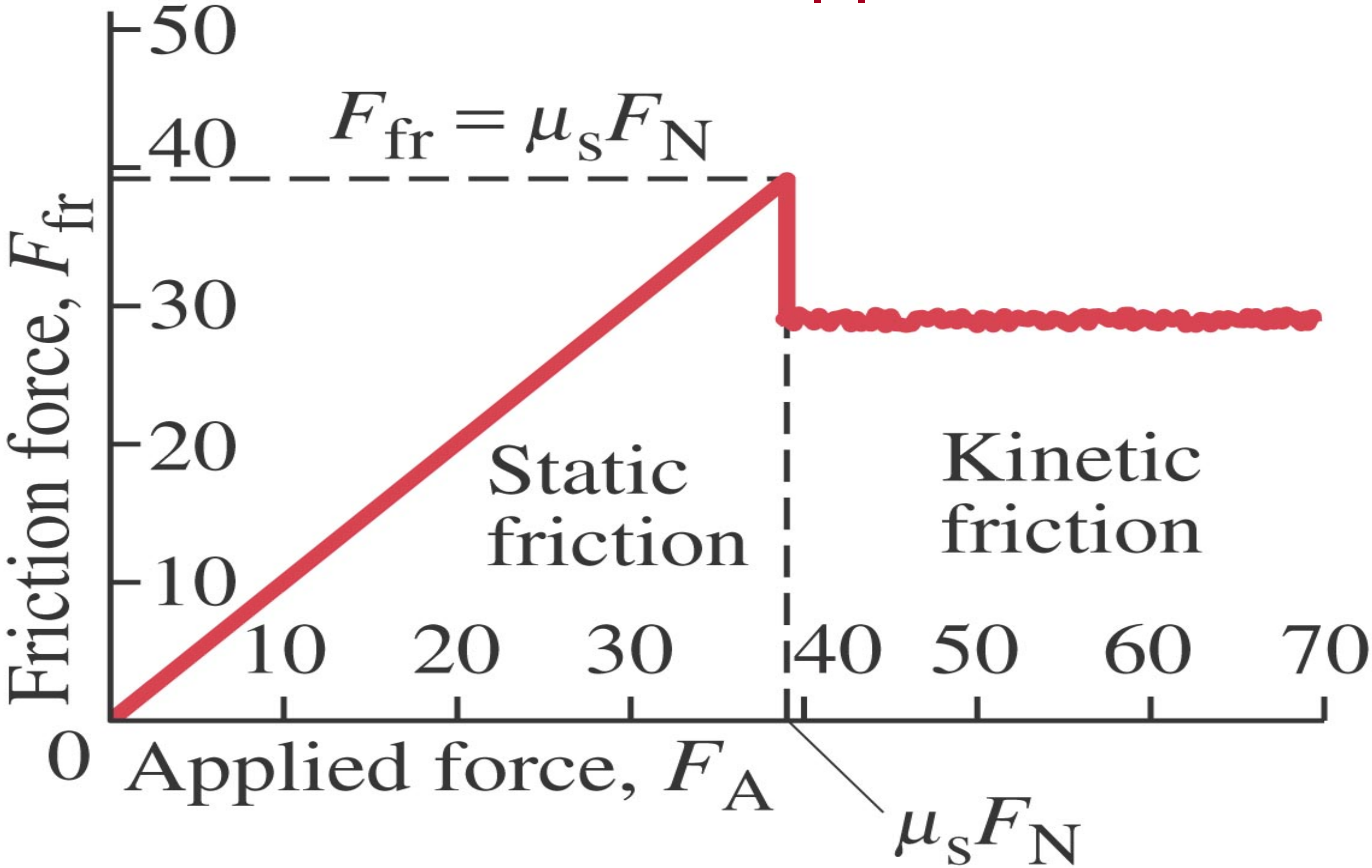
$$f_k = \mu_k F_N$$

$0 < \mu_k < 1$ is called the **coefficient of kinetic friction**.

What is the direction of friction forces? **opposite to the movement**

Figure 5.3

Friction Force vs Applied Force



Coefficients of Friction

TABLE 5–1 Coefficients of Friction†

Surfaces	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Wood on wood	0.4	0.2
Ice on ice	0.1	0.03
Metal on metal (lubricated)	0.15	0.07
Steel on steel (unlubricated)	0.7	0.6
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Rubber on other solid surfaces	1–4	1
Teflon® on Teflon in air	0.04	0.04
Teflon on steel in air	0.04	0.04
Lubricated ball bearings	<0.01	<0.01
Synovial joints (in human limbs)	0.01	0.01

†Values are approximate and intended only as a guide.

What are these?