# General Physics (PHY 2130)

## Lecture 10

- Other types of friction forces, air resistance
- Connected objects. Tension.
- Reference frames.

http://www.physics.wayne.edu/~apetrov/PHY2130/

Wayne State University

# Lightning Review

Last lecture:

1. Examples of application of Second Newton's Law
   - ✓ gravity and apparent weight
   - ✓ contact forces: normal force and friction

# Recall: Applying Newton's Laws

- Assumptions
  - Objects behave as particles
    - can ignore rotational motion (for now)
  - Masses of strings or ropes are negligible
  - Interested only in the forces acting on the object

# Recall: Applying Newton's Laws

- Make a sketch of the situation described in the problem, introduce a coordinate frame
- Draw a free body diagram for the isolated object under consideration and label all the forces acting on it
- Resolve the forces into x- and y-components, using a convenient coordinate system
- Apply equations, keeping track of signs
- Solve the resulting equations

# Lightning Review

Last lecture:

1. Examples of application of Second Newton's Law
   - ✓ gravity and apparent weight
   - ✓ contact forces: normal force and friction

Review Problem: A box full of books rests on a wooden floor. The normal force the floor exerts on the box is 250 N.

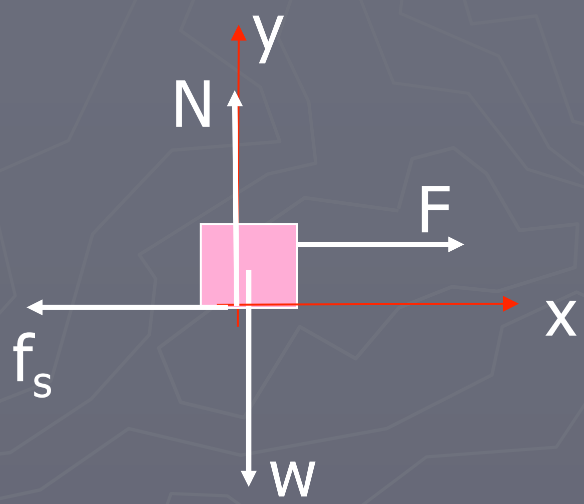
(a) You push horizontally on the box with a force of 120 N, but it refuses to budge. What can you say about the coefficient of friction between the box and the floor?

(b) If you must push horizontally on the box with 150 N force to start it sliding, what is the coefficient of static friction?

**Example:** **A box full of books rests on a wooden floor. The normal force the floor exerts on the box is 250 N.**

**(a) You push horizontally on the box with a force of 120 N, but it refuses to budge. What can you say about the coefficient of friction between the box and the floor?**

FBD for box:




Apply Newton's 2nd Law

$$(1) \quad \sum F_y = N - w = 0$$

$$(2) \quad \sum F_x = F - f_s = 0$$

$$f_s \leq \mu_s N \quad \Rightarrow \quad \frac{f_s}{N} \leq \mu_s$$

The box refuses to budge, $\Longrightarrow \dfrac{f_s}{N} < \mu_s$

From (2): $F = f_s \Rightarrow \dfrac{f_s}{N} = \dfrac{F}{N} = \dfrac{120N}{250N} = 0.48 < \mu_s$

$\mu_s > 0.48.$

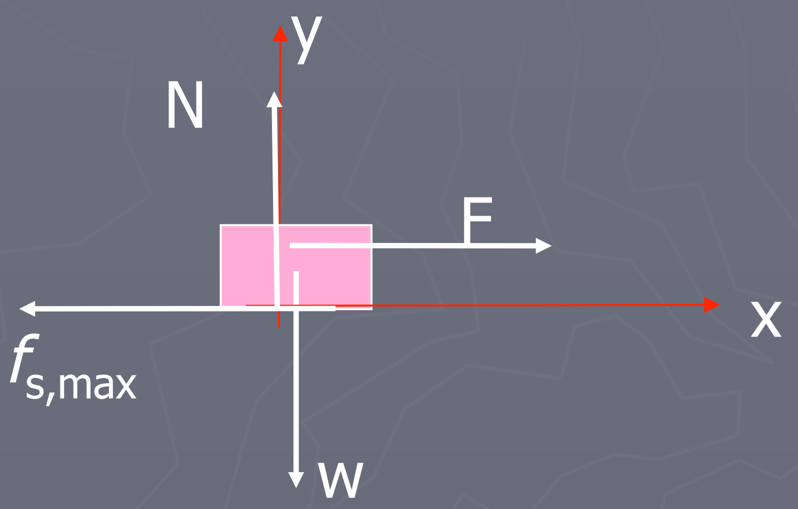
**(b) If you must push horizontally on the box with 150 N force to start it sliding, what is the coefficient of static friction?**

Apply Newton's 2nd Law

$$(1)\sum F_y = N - w = 0$$

$$(2)\sum F_x = F - f_{s,\max} = 0$$

$$f_s \le \mu_s N \quad \Rightarrow \quad \frac{f_s}{N} \le \mu_s$$




The box starts sliding, the friction force is $f_{s,max}$ here

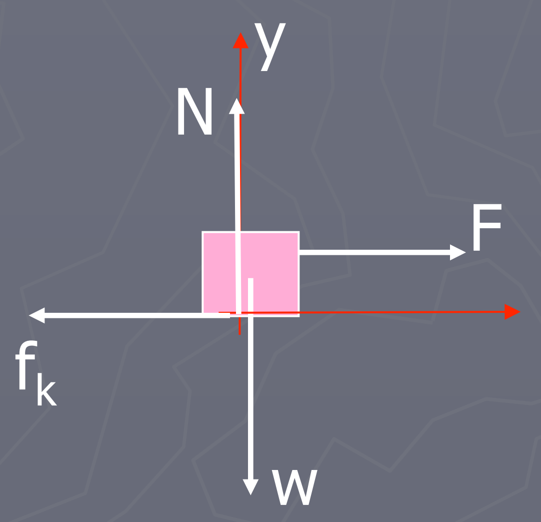
From (2): $F = f_{s,\max} \Rightarrow \mu_s = \frac{f_{s,\max}}{N} = \frac{F}{N} = \frac{150N}{250N} = 0.60$

$\mu_s = 0.60.$

**Example continued:**

**(c) Once the box is sliding, you only have to push with a force of 120 N to keep it sliding. What is the coefficient of kinetic friction?**

FBD for box




Apply Newton's 2nd Law

$$(1)\sum F_y = N - w = 0$$

$$(2)\sum F_x = F - f_k = 0$$

From 2: $F = f_k = \mu_k N$

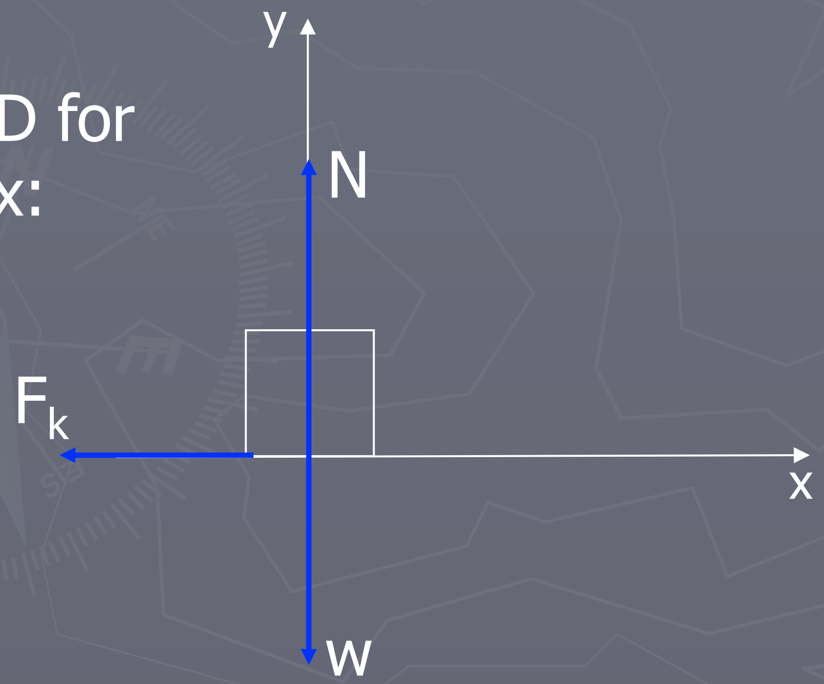
$$\mu_k = \frac{F}{N} = \frac{120\ \mathrm{N}}{250\ \mathrm{N}} = 0.48$$

$$\mu_k = 0.48$$

# Do you remember kinematics?

Example: A box slides across a rough surface. If the coefficient of kinetic friction is 0.3, what is the acceleration of the box? If the initial speed of the box is 10.0 m/s, how long does it take for the box to come to rest?

FBD for box:

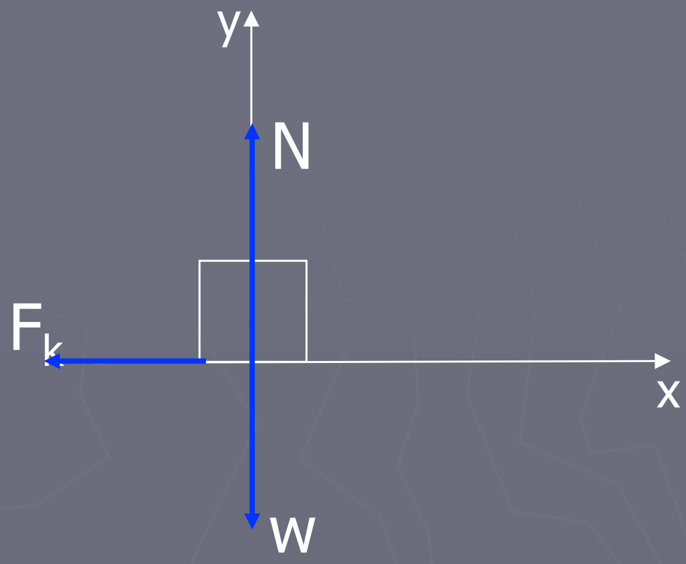



Apply Newton's 2nd Law:

$$\sum F_x = -F_k = ma$$
$$\sum F_y = N - w = 0$$

(1) $-F_k = ma$

(2) $N - w = 0 \quad \therefore N = w = mg$




From (1): $-F_k = -\mu_k N = -\mu_k mg = ma$

Solving for a:

$$a = -\mu_k g = -(0.3)\left(9.8\ \mathrm{m/s^2}\right) = -2.94\ \mathrm{m/s^2}$$

If the initial speed of the box is 10.0 m/s, how long does it take for the box to come to rest?

Given:

$a = -2.94\ m/s^2$,
$v_{ix}=10.0\ m/s$,

$v_{fx}= 0.0\ m/s$

Find: $\Delta t=?$

Solution:

$$v_{fx} = v_{ix} + a_x \Delta t = 0$$

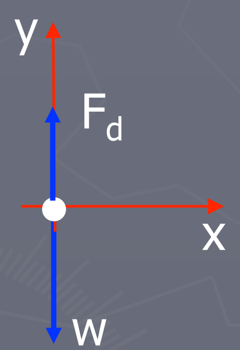
$$\Delta t = -\frac{v_{ix}}{a_x} = -\frac{+10.0\ \text{m/s}}{-2.94\ \text{m/s}^2} = 3.40\ \text{sec}$$

# Air Resistance and Terminal Speed

- Another type of friction is air resistance
- Air resistance is proportional to the speed of the object
- When the upward force of air resistance equals the downward force of gravity, the net force on the object is zero
- The constant speed of the object is the *terminal speed*

# Air Resistance

Imagine that a stone is dropped from the edge of a cliff. If air resistance *cannot* be ignored, the FBD for the stone is:




Apply Newton's Second Law

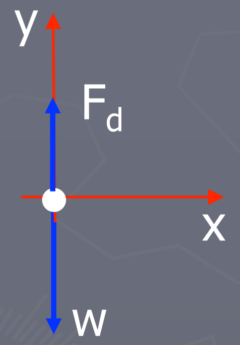
$$\sum F_y = F_d - w = ma$$

Where $F_d$ is the magnitude of the drag force on the stone. This force is directed opposite the object's velocity.

Assume that $F_d = bv^2$

b is a parameter that depends on the size and shape of the object.

Since $F_d \propto v^2$, can the object be in equilibrium?




$$\sum F_y = F_d - w = ma$$

If $a$ = 0, then

$$F_d - w = o$$

$$bv^2 - mg = 0$$

Yes, the object can be in dynamic equilibrium, (moving with constant speed).

$$\text{when } v = v_t = \sqrt{\frac{mg}{b}}$$

$v_t$ is called terminal speed

Example: A paratrooper with a fully loaded pack has a mass of 120 kg. The force due to air resistance has a magnitude of $F_d = bv^2$, where $b = 0.14\ \mathrm{N\ s^2/m^2}$.

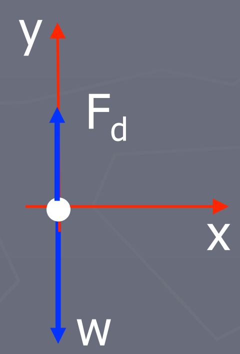
(a) If he/she falls with a speed of 64 m/s, what is the force of air resistance?

$$F_d = bv^2 = (0.14\ \mathrm{N\ s^2/m^2})(64\ \mathrm{m/s})^2 = 570\ \mathrm{N}$$

Example continued:

## (b) What is the paratrooper's acceleration?

FBD:




Apply Newton's Second Law and solve for a.

$$\sum F_y = F_d - w = ma$$

$$a = \frac{F_d - mg}{m} = -5.1\ \text{m/s}^2$$

## (c) What is the paratrooper's terminal speed?

$$\sum F_y = F_d - w = ma = 0$$

$$bv_t^2 - mg = 0$$

$$v_t = \sqrt{\frac{mg}{b}} = 92\ \text{m/s}$$

# Connected objects. Tension.

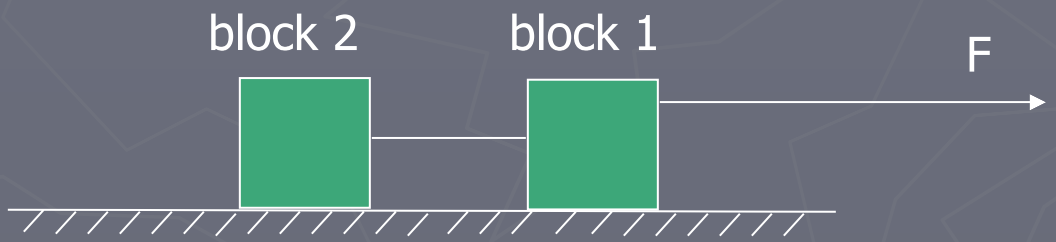
# Tension

Tension is the force transmitted through a “rope” from one end to the other.

An **ideal** cord has zero mass, does not stretch, and the tension is the same throughout the cord.

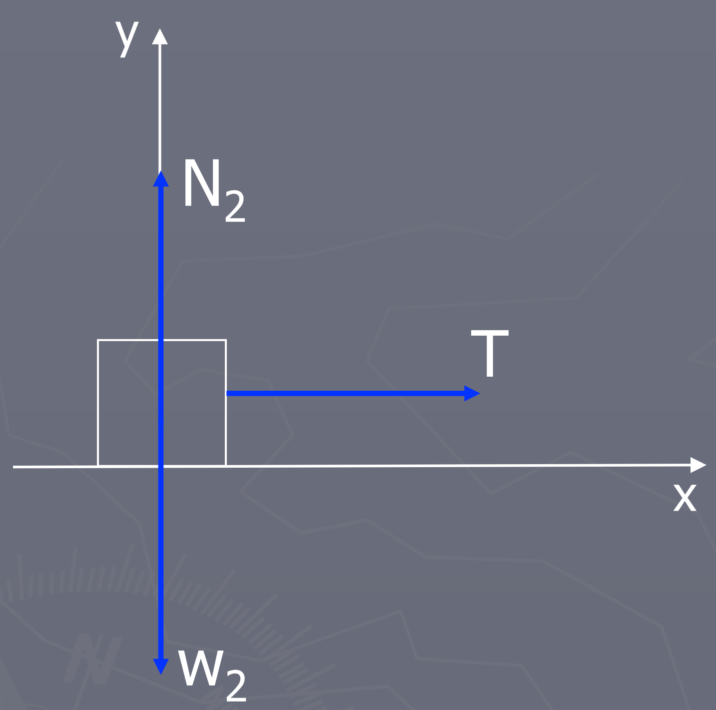
Example: Find the tension in the cord connecting the two blocks as shown. A force of 10.0 N is applied to the right on block 1. Assume a frictionless surface. The masses are

$m_1$ = 3.00 kg and $m_2$ = 1.00 kg.

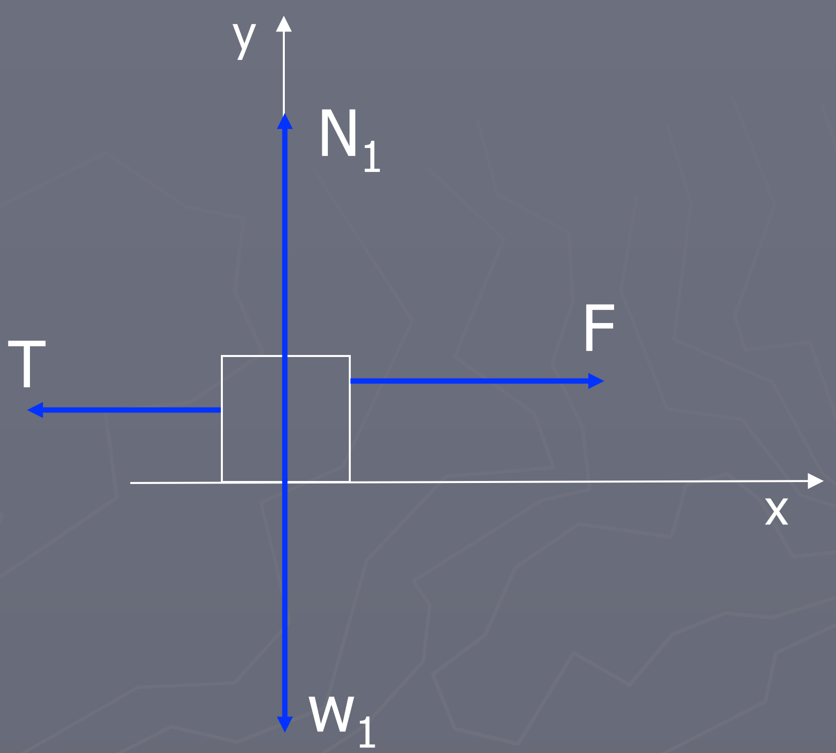



Assume that the rope stays taut so that both blocks have the same acceleration.

FBD for block 2:




FBD for block 1:




Apply Newton's 2nd Law to each block:

$$\sum F_x = T = m_2 a$$

$$\sum F_y = N_2 - w_2 = 0$$

$$\sum F_x = F - T = m_1 a$$

$$\sum F_y = N_1 - w_1 = 0$$

Example continued:

$$F - T = m_1 a \quad (1)$$

$$T = m_2 a \quad (2)$$

These two equations contain the unknowns: *a* and *T*.

To solve for T, a must be eliminated. Solve for a in (2) and substitute in (1).

$$F - T = m_1 a = m_1\left(\frac{T}{m_2}\right)$$

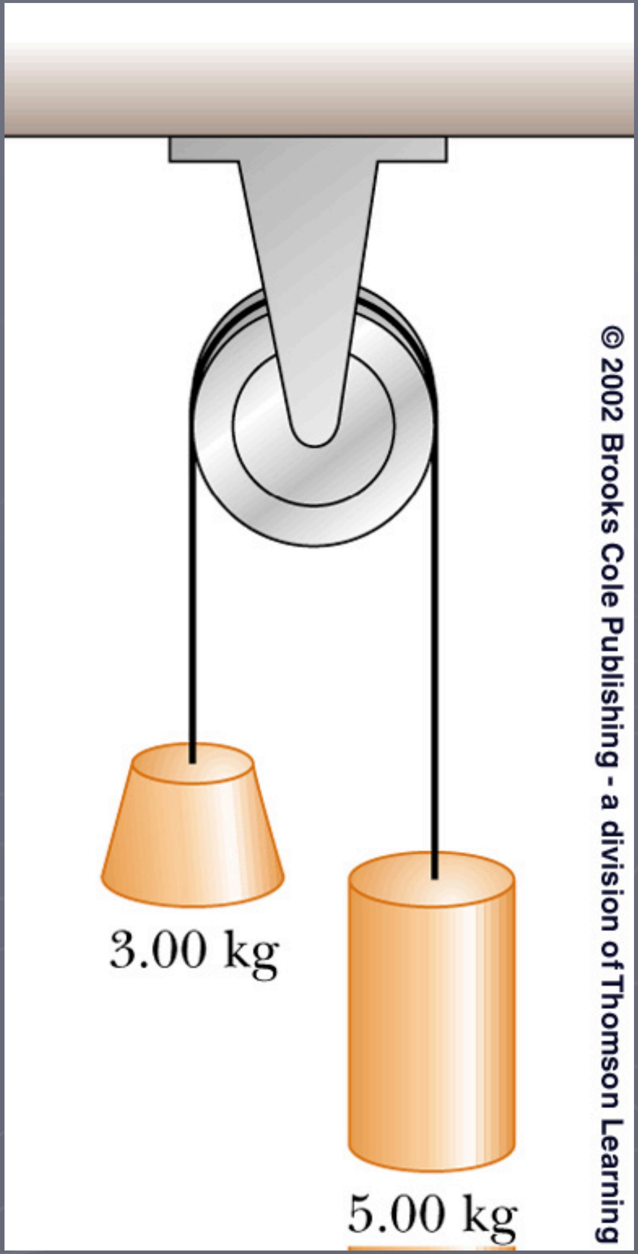
$$F = m_1\left(\frac{T}{m_2}\right) + T = \left(1 + \frac{m_1}{m_2}\right)T$$

$$\therefore T = \frac{F}{\left(1 + \frac{m_1}{m_2}\right)} = \frac{10\ \text{N}}{\left(1 + \frac{3\ \text{kg}}{1\ \text{kg}}\right)} = 2.5\ \text{N}$$

# Connected Objects

This example leads to the following observations/suggestions:

- Apply Newton's Laws separately to each object
- The acceleration of both objects will be the same
- The tension is the same in each diagram
- Solve the simultaneous equations



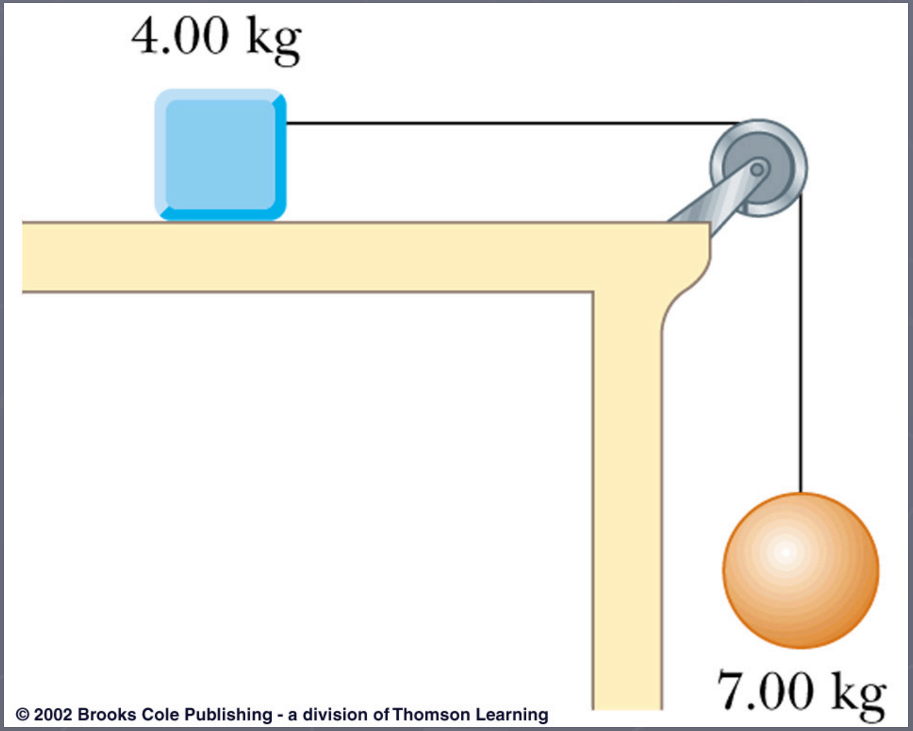
# More About Connected Objects

- Treating the system as one object allows an alternative method or a check
  - Use only external forces
    - Not the tension – it's internal
  - The mass is the mass of the system
- Doesn't tell you anything about any internal forces

# Example: Connected Objects

## Problem:

Two objects $m_1$=4.00 kg and $m_2$=7.00 kg are connected by a light string that passes over a frictionless pulley. The coefficient of sliding friction between the 4.00 kg object an the surface is 0.300. Find the acceleration of the two objects and the tension of the string.




- Apply Newton's Laws separately to each object
- The acceleration of both objects will be the same
- The tension is the same in each diagram
- Solve the simultaneous equations

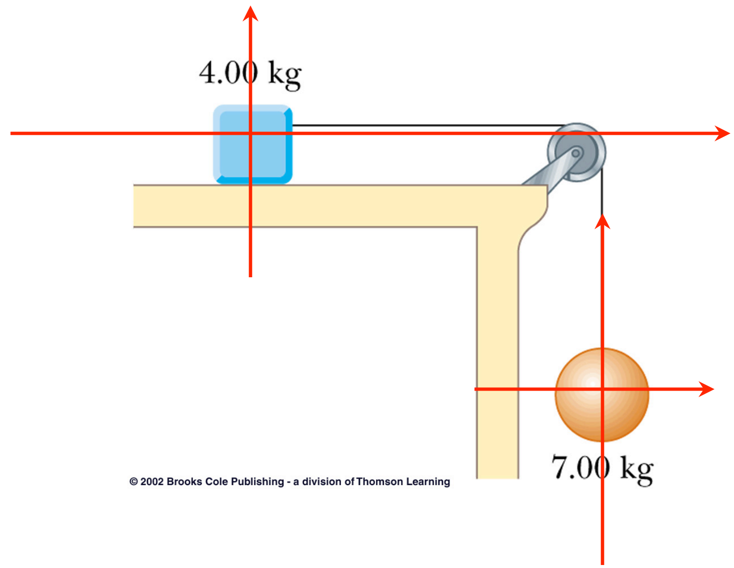
# Example: Connected Objects

<u>Given</u>:

mass1: $m_1$=4.00 kg
mass2: $m_2$=7.00 kg
friction: $\mu$=0.300

<u>Find</u>:

Tensions **T**=?
Acceleration **a**=?



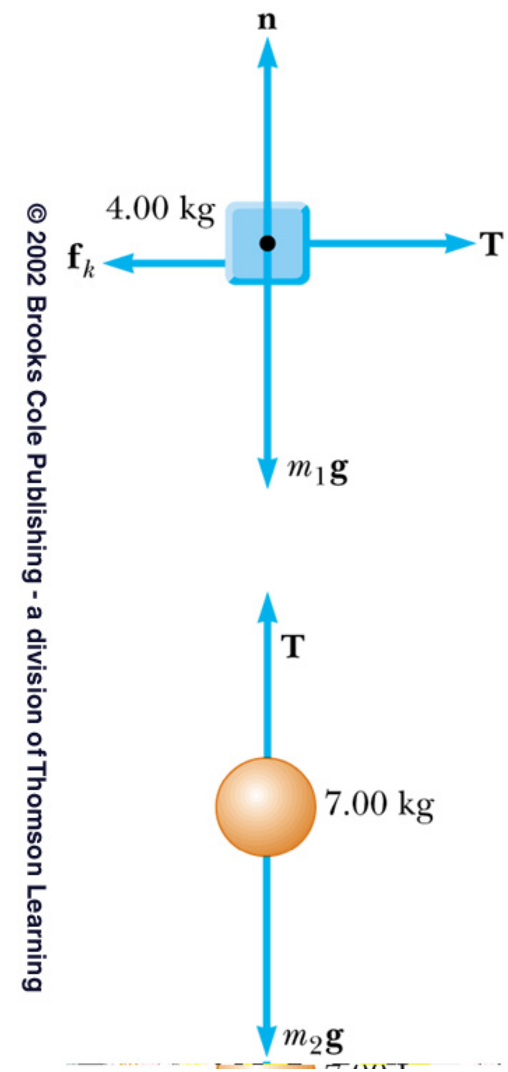

1. Introduce <u>two coordinate frames</u>:
   Oy: y’s are directed up
   Ox: x’s are directed right

<u>*Note*</u>: $\sum \vec{F} = m\vec{a}, \quad and \quad f_k = \mu n$

$$\left.\begin{aligned} Mass1: Ox_1 &: \sum F_x = T - f_k = m_1 a, \\ Oy_1 &: \sum F_y = n - m_1 g = 0. \\ Mass2: Oy_2 &: \sum F_y = m_2 g - T = m_2 a. \end{aligned}\right\}$$

Solving those equations:

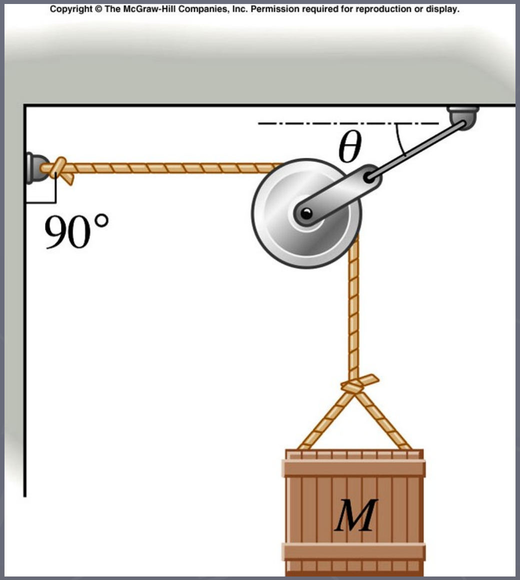
a = 5.16 m/s²
T = 32.4 N ✓



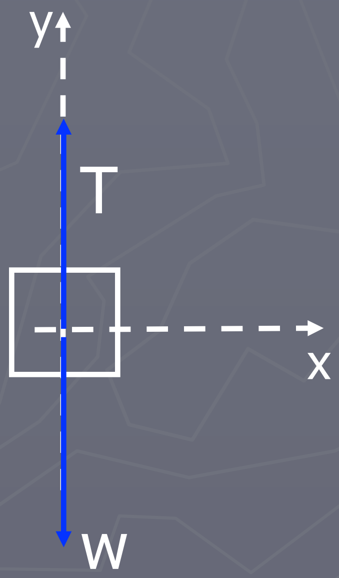
# More About Connected Objects

- Note that the forces could also be applied at an angle
  - It is very important to properly draw a FBD
  - It is very important to properly introduce a coordinate frame
  - It is very important to properly write components of the forces

**Example:** A pulley is hung from the ceiling by a rope. A block of mass 12 kg is suspended by another rope that passes over the pulley and is attached to the wall. The rope fastened to the wall makes a right angle with the wall. Neglect the masses of the rope and the pulley. Find the tension in the rope from which the pulley hangs and the angle θ.




**FDB for the mass M**



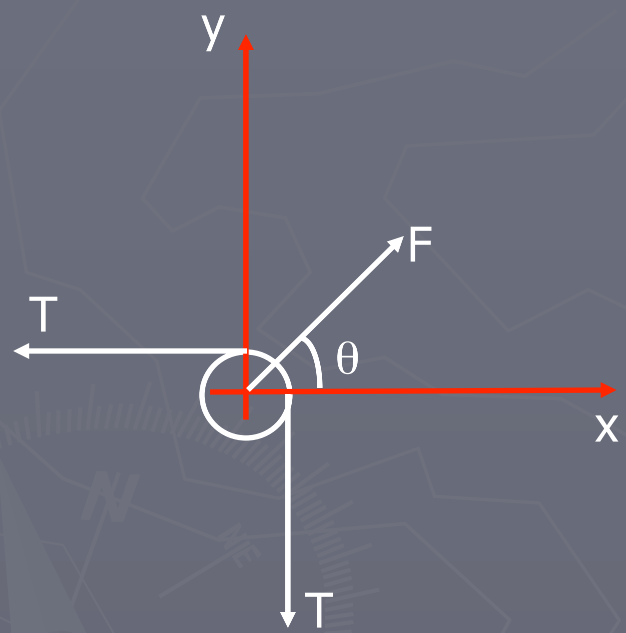

Apply Newton's 2nd Law to the mass M:

$$\sum F_y = T - w = 0$$

$$T = w = Mg = 12kg \times 9.8m/s^2 = 117.6N$$

Example continued:

FBD for the pulley:




Apply Newton's 2nd Law:

$$\sum F_x = F\cos\theta - T = 0$$
$$\sum F_y = F\sin\theta - T = 0$$

$$\therefore T = F\cos\theta = F\sin\theta$$

$$\tan\theta = 1 \;\Rightarrow\; \theta = 45^0$$

$$F = \sqrt{2}T = \sqrt{2}Mg$$
$$= \sqrt{2}(12kg)(9.8m/s^2)$$
$$= 166.3\,N$$

$F = 166.3\ N$ and $\theta = 45^0$

# Reference Frames

For Newton's Second Law to be valid it must be applied in an inertial reference frame. An inertial reference frame is one where Newton's First law is valid.