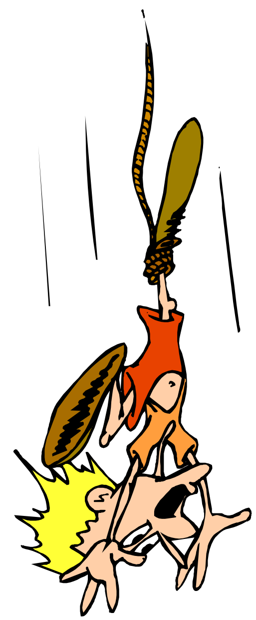
PHYSICS 220

Lecture 04

Forces and Motion in 1 D

Textbook Sections 3.2 – 3.6



Overview

- Last Lecture
  - Constant Acceleration

    $x = x_0 + v_0 t + \frac{1}{2} at^2$

    $v = v_0 + at$

    $v^2 = v_0^2 + 2a(x-x_0)$
  - Newton's second law: $\Sigma F = m\,a$

- Today
  - Friction
  - Tension
  - Gravity as force
  - Free Fall

Quiz

1) After winning a baseball game, one player drops a glove, while another tosses a glove into the air. How do the accelerations of the two gloves compare after release?

A) The one going down is larger

B) They are the same

C) The one going up is larger

2) Fred throws a ball 30 mph vertically upward. Which of the following statements are true about the ball's velocity at the very top of its trajectory. (Let up be the positive direction)

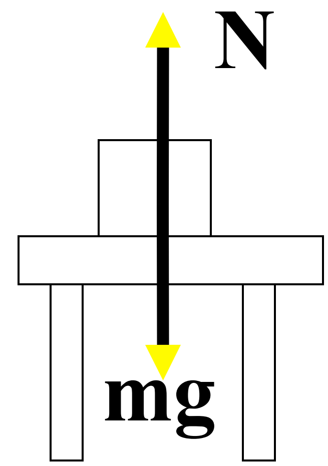
A) $v < 0$

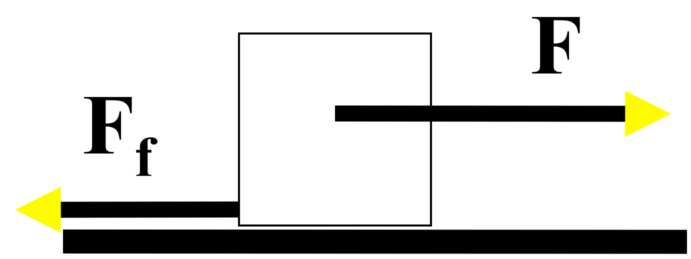
B) $v = 0$

C) $v > 0$

Contact Forces

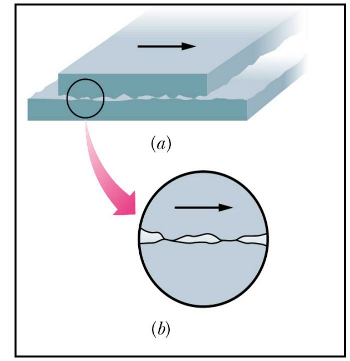
- Normal force: a contact force acting at an interface
  - perpendicular to the surface of contact
- Frictional force: another contact force acting at an interface
  - parallel to the surface of contact
  - resist motion of the two surfaces sliding past each other
  - always act opposite the direction of motion

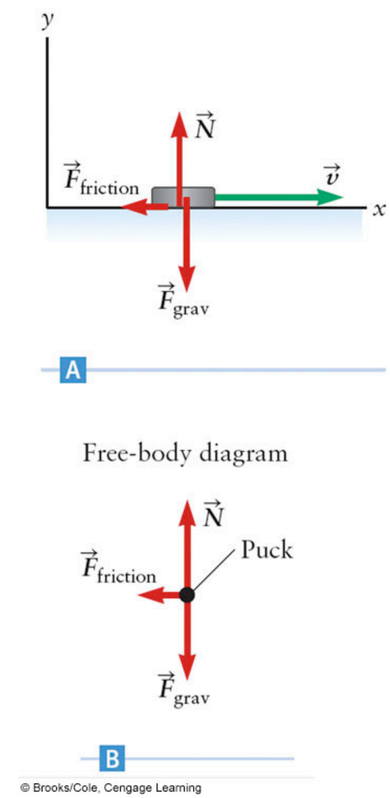




Friction

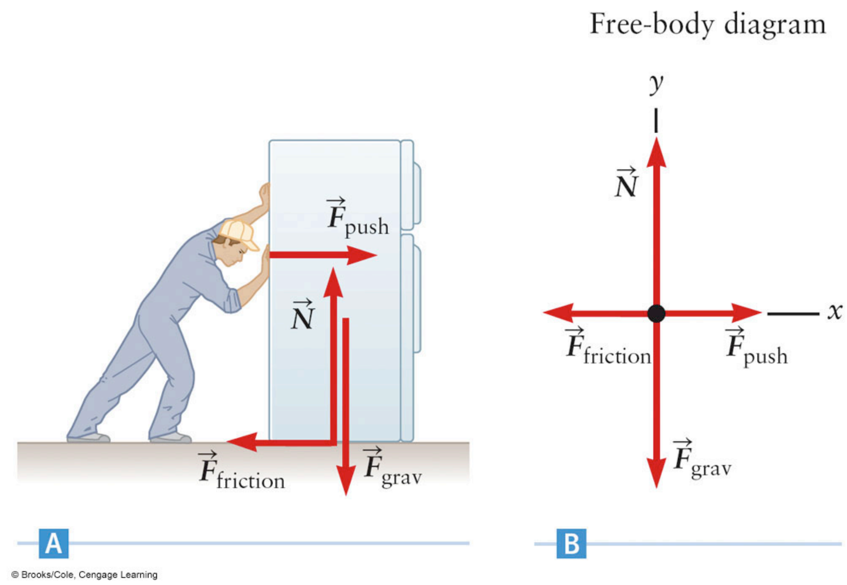
- Magnitude of frictional force is proportional to the normal force.
- Friction can be
  - Kinetic
    - Related to moving
    - $f_{kinetic} = \mu_k N$ μ_k coefficient of kinetic friction
  - Static
    - When objects are at rest
    - $f_{static} \leq \mu_s N$ μ_s coefficient of static friction
- Be Careful!
  - Static friction can be any value up to $\mu_s N$
    - has an upper limit of $\mu_s N$
  - Direction always opposes motion





Static Friction

- In many situations, the relevant surfaces are not slipping (moving) with respect to each other
- This situation involves what is known as static friction
- The amount of the push can vary without the object moving



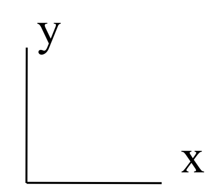
- $|F_{friction}| \leq \mu_s N$
  - Static indicates that the two surfaces are not moving relative to each other
- If the push is increased, the force of static friction also increases and again cancels the force of the push

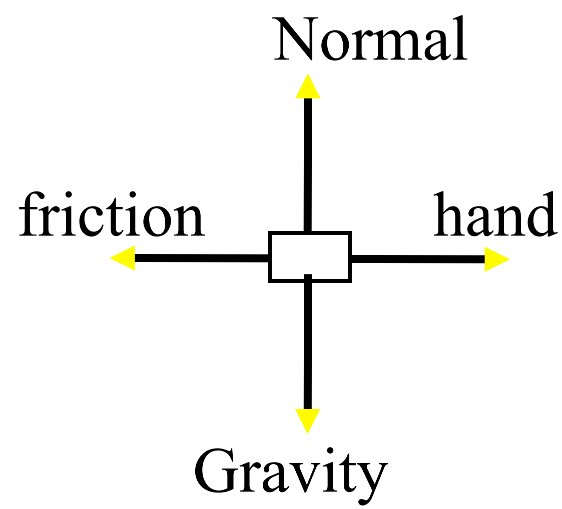
Static and Kinetic Friction

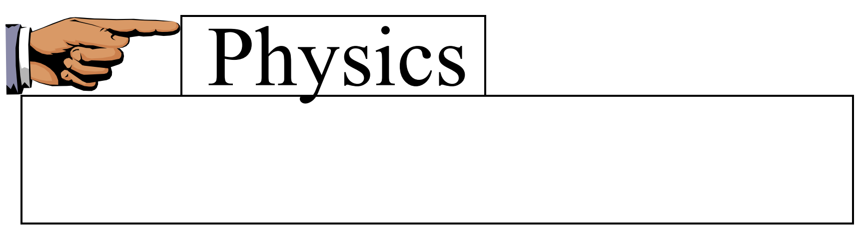
- Consider both the kinetic and static friction cases
  - Use the different coefficients of friction
- The force of kinetic friction is just $F_{friction} = \mu_k N$
- The force of static friction varies by $|F_{friction}| \leq \mu_s N$
- For a given combination of surfaces, generally $\mu_s > \mu_k$
  - It is more difficult to start something moving than it is to keep it moving once started

Book Pushed Across Table

- Book sliding across table
  - Isolate the object of interest (book)
  - Identify all forces acting on the object
    - Hand (to right)
    - Gravity (down)
    - Normal (table, up)
    - Friction (table, left)
  - Choose a coordinate system

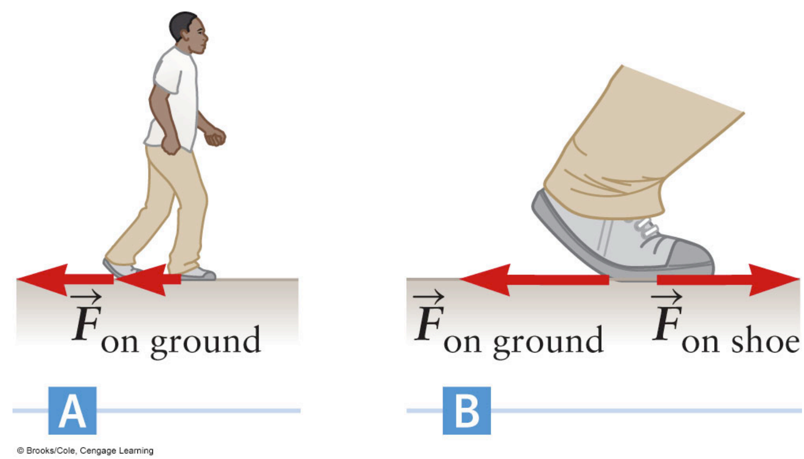


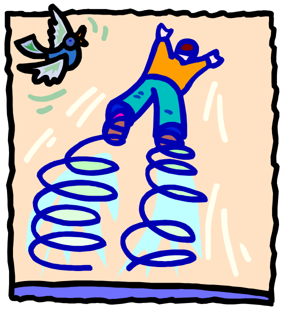




Friction and Walking

- The person "pushes" off during each step
- The bottoms of his shoes exert a force on the ground
  - This is
- If the shoes do not slip, the force is due to static friction
  - The shoes do not move relative to the ground
- Newton's Third Law tells us there is a reaction force
  -
- If the surface was so slippery that there was no frictional force, the person would slip
- The force of friction makes walking and running possible





Contact Force: Spring

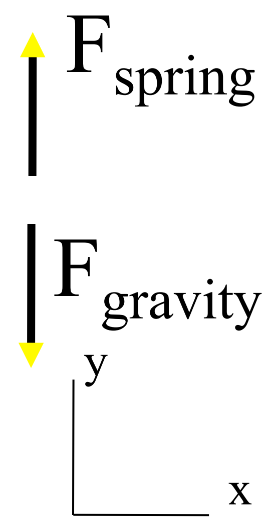
- Force exerted by a spring is directly proportional to the amount by which it is stretched or compressed.

  $F_{spring} = k\,x$ always trying to restore its original length

- Example: When a 5 kg mass is suspended from a spring, the spring stretches 8 cm. Determine the spring constant.

$$F_{spring} - F_{gravity} = 0$$
$$F_{spring} = F_{gravity}$$
$$k\,x = m\,g$$

$$k = m\,g / x$$
$$= (5\text{ kg}) \times (9.8\text{ m/s}^2) / (0.08\text{ m})$$
$$= 612\text{ N/m}$$

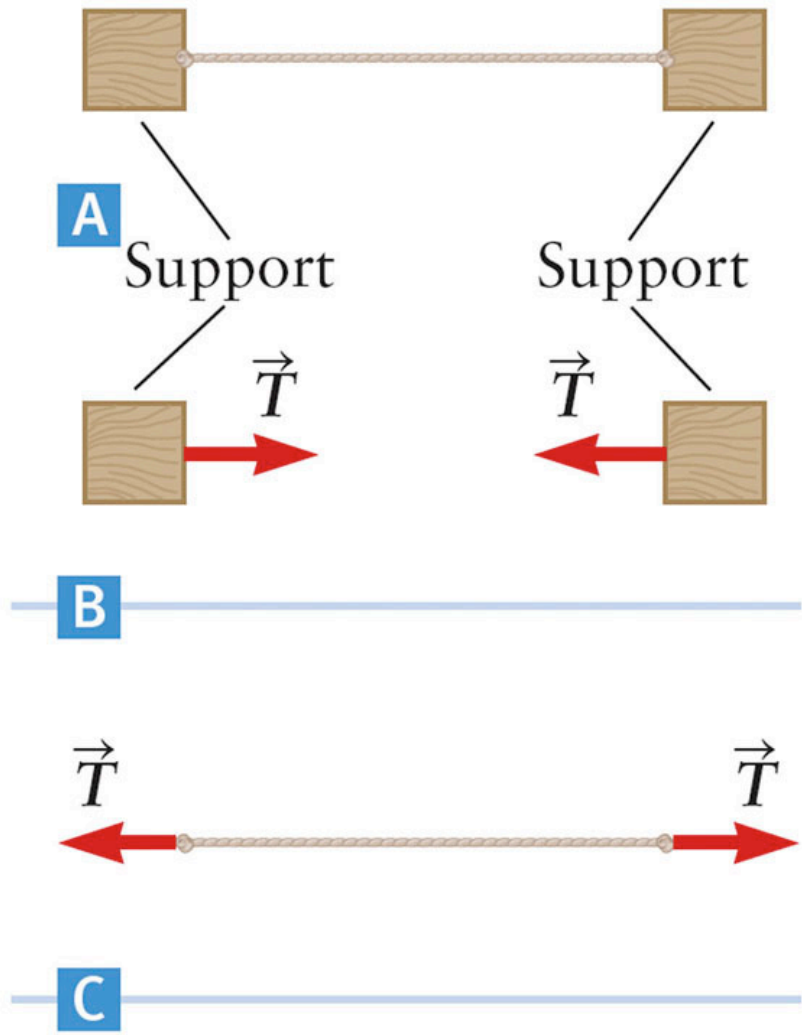


Contact Force: Tension

- Tension
  - A force transmitted by a rope, cord, cable or the like which transmits a force from one end to an object attached at the other end
  - The tension is the same for all points along a rope
    - This is true for all massless ropes
  - Tension has force units
- Ideal string (or cord, rope, etc.):
  - Always maintains constant tension everywhere
  - Has a zero mass
  - Tension is parallel to the string (no push; only pull)
- Pulleys can redirect forces
- Forces can be amplified

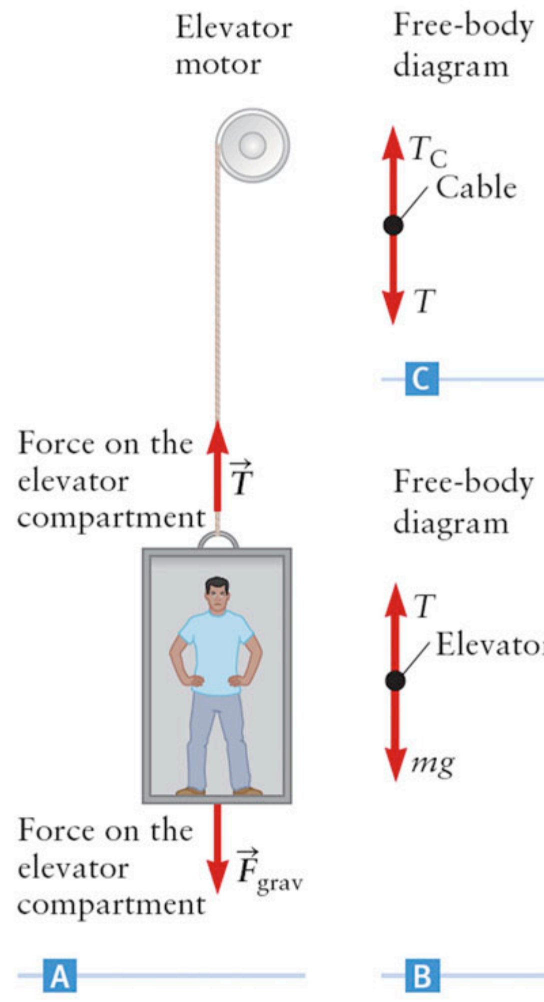
Tension

- Strings exert a force on the objects they are connected to
  - Cables and ropes act the same way
- The strings exert force due to their tension
  - The ends of the string both exert a force of magnitude T on the supports where they are connected
  - T is the tension in the string



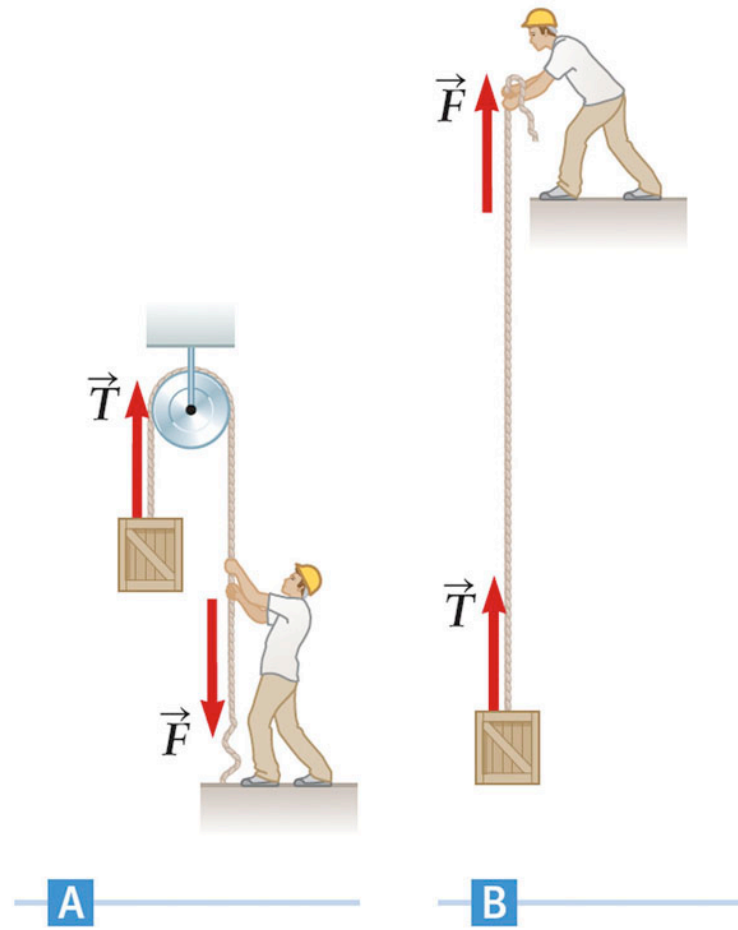
Elevator Cable

- Two forces are acting on the compartment
  - Gravity acting downward
  - Tension in cable acting upward, T
- Assume an acceleration upward
- Applying Newton's Second Law gives
  - $T = mg + ma$



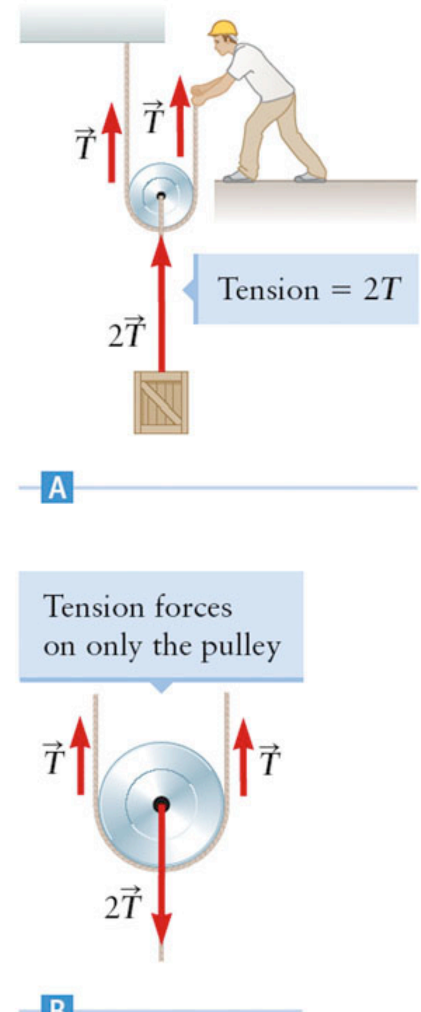
Pulleys

- We often need to change the direction of the force
- A simple pulley changes the direction of the force, but not the magnitude
  - See diagram
  - Assume the rope and pulley are both massless
  - Assume the cable does not slip on the pulley



Multiple Pulleys

- The person exerts a force of T on the rope
- The rope exerts a force of 2T on the pulley
- This force can be used to lift an object
- Complex sets of pulleys can amplify an applied force
  - The distance decreases to compensate for the increase in force



Tension Example

- Example: Determine force applied to string to suspend 45 kg mass hanging over pulley

$$T - W = 0$$

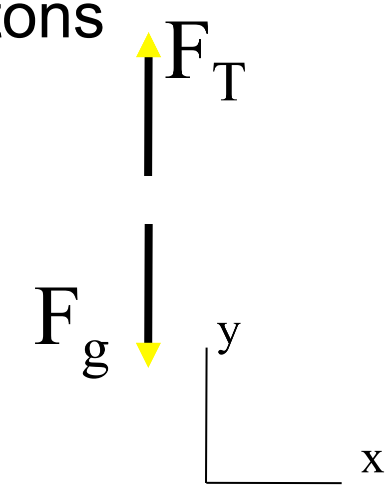
$$T = W$$

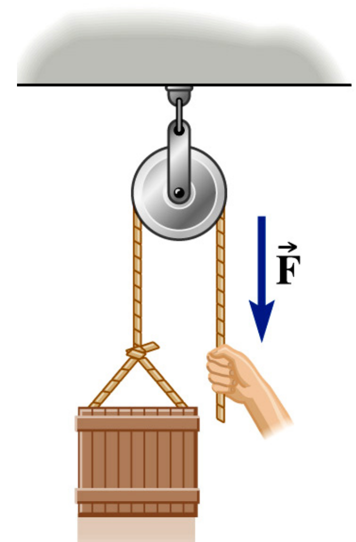
$$T = m\,g$$

$$= 45\text{ kg x }9.8\text{ m/s}^2$$

$$= 440\text{ N}$$

F = mg = 440 Newtons





Pulley Example

- Determine the force exerted by the hand to suspend the 45 kg mass as shown in the picture.

A) 220 N B) 440 N C) 660 N

D) 880 N E) 1100 N

$$\Sigma F = 0$$

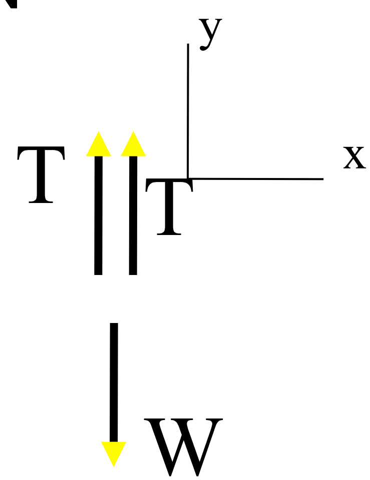
$$T + T - W = 0$$

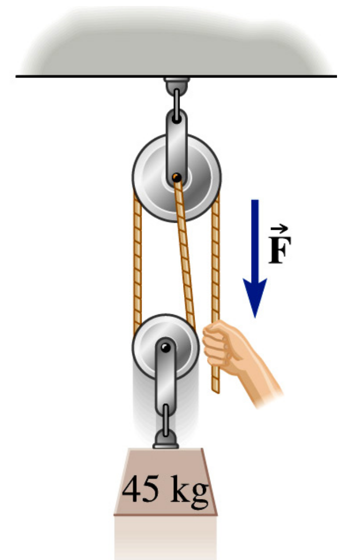
$$2\,T = W$$

$$T = m\,g / 2$$

$$= (45\text{ kg} \times (9.8\text{ m/s}^2)) / 2$$

$$= 220\text{ N}$$





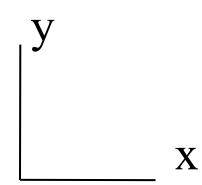
Remember the magnitude of the tension is the same everywhere along the rope!

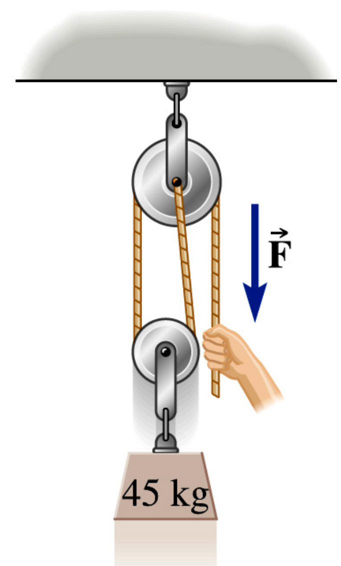
Pulley Example

- What is the force on the ceiling?

A) 220 N B) 440 N C) 660 N

D) 880 N E) 1100 N



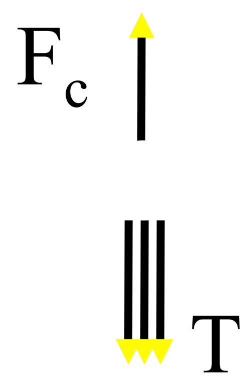


$$\Sigma F = 0$$

$$F_c - T - T - T = 0$$

$$F_c = 3\ T$$

$$F_c = 3 \text{ x } 220\text{ N} = 660\text{ N}$$



Pulley Example

Two boxes are connected by a string over a frictionless pulley. Box 1 has mass 1.5 kg, box 2 has a mass of 2.5 kg. Box 2 starts from rest 0.8 meters above the table, how long does it take to hit the table.

- Compare the acceleration of boxes 1 and 2

A) $|a_1| > |a_2|$ B) $|a_1| = |a_2|$ C) $|a_1| < |a_2|$

1) $T - m_1 g = m_1 a_1$

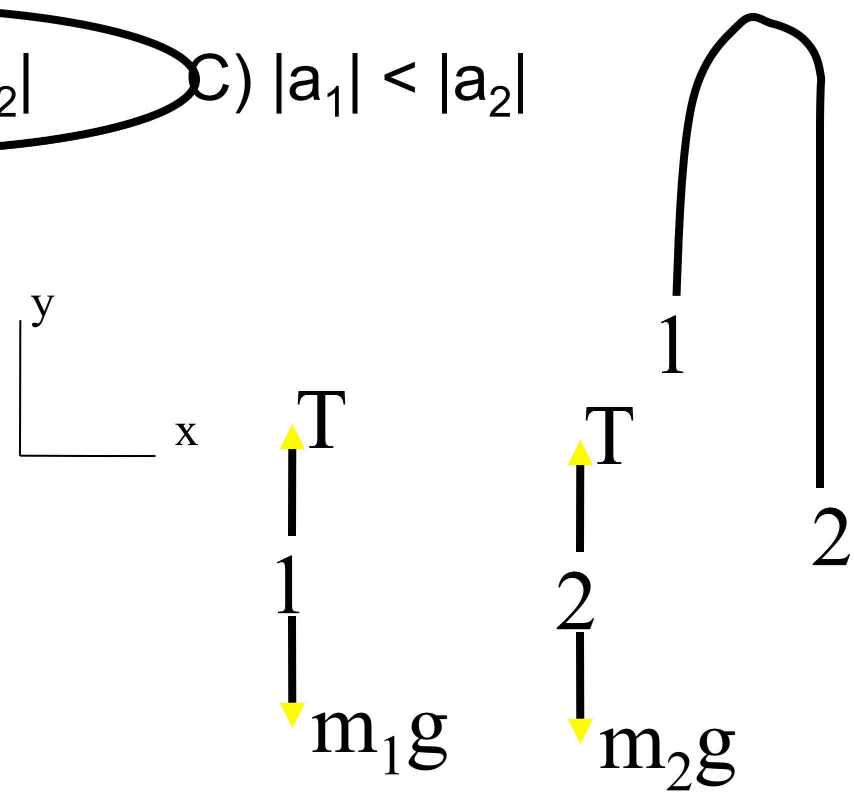
2) $T - m_2 g = -m_2 a_1$

using $a_1 = -a_2$

2) $T = m_2 g - m_2 a_1$

1) $m_2 g - m_2 a_1 - m_1 g = m_1 a_1$

$a_1 = (m_2 - m_1)g / (m_1 + m_2)$



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$a_1 = (m_2 - m_1)g \,/\, (m_1+m_2)$

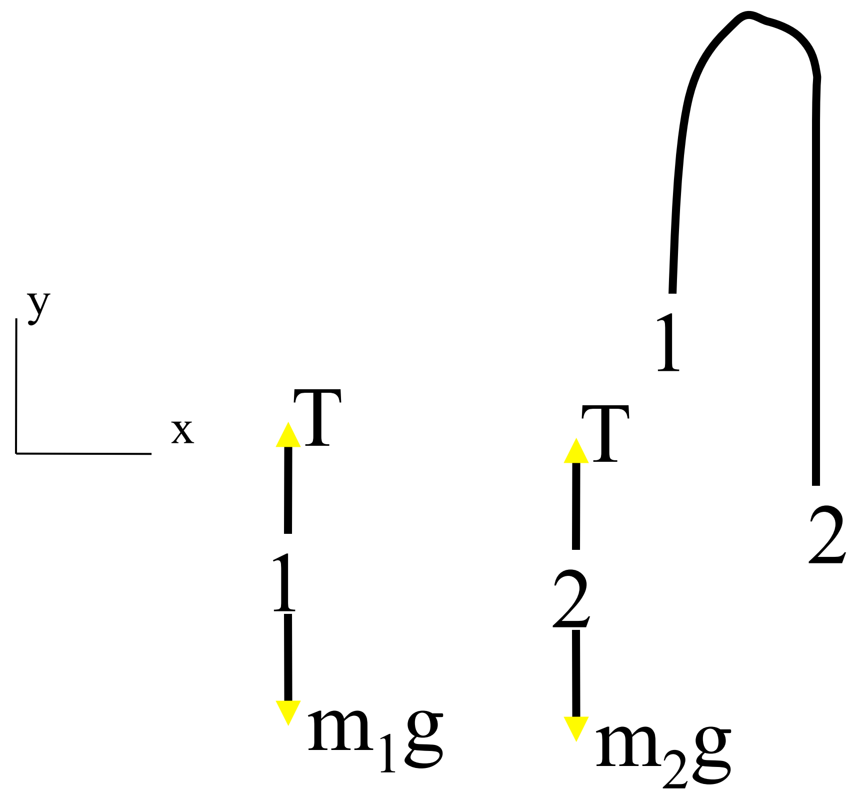
$a = 2.45 \text{ m/s}^2$

$\Delta x = v_0 t + \frac{1}{2} a t^2$

$\Delta x = \frac{1}{2} a t^2$

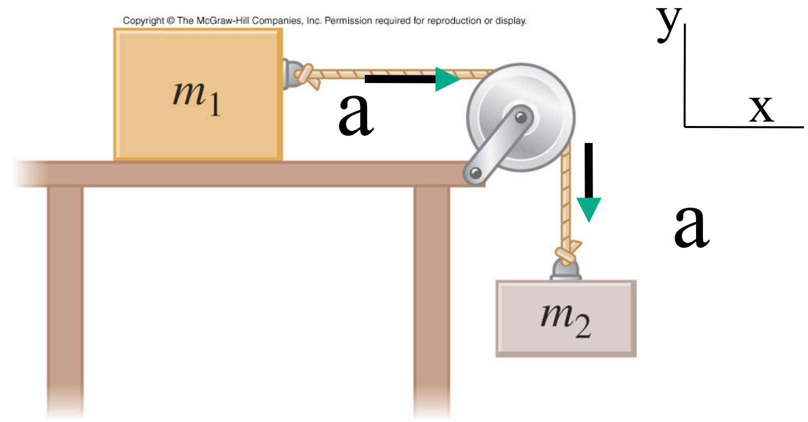
$t = \text{sqrt}(2\, \Delta x / a)$

$t = 0.81$ seconds



Two blocks one sliding one hanging

A block of mass m_1=3kg rests on a frictionless horizontal surface. A second block of mass m_2=2kg hangs from an ideal cord of negligible mass who runs over an ideal pulley. Block 2 starts from rest 0.8 meters above the floor, how long does it take to hit the floor?



x-direction Block 1: $T = m_1\, a_{1x}$ (1)

y-direction Block 2: $T - m_2\, g = m_2\, a_{2y}$ (2)

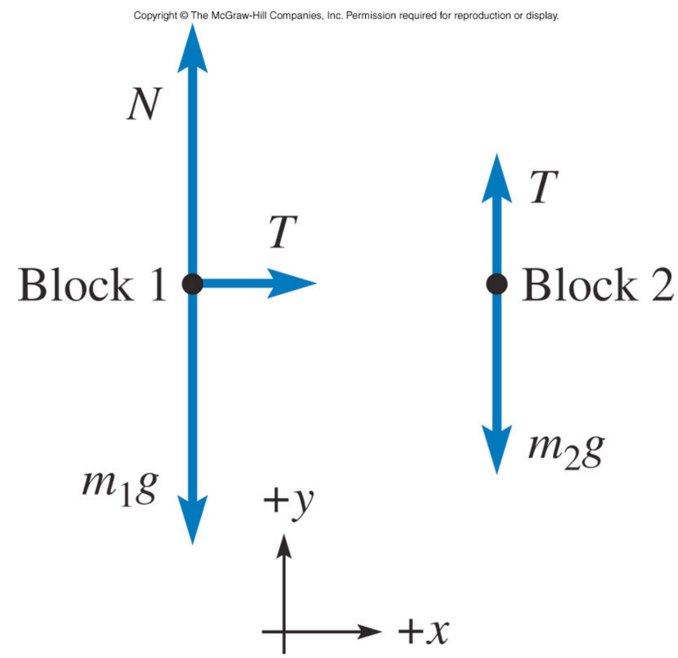
Note: $a_{1x}=a$ and $a_{2y}=-a$

Substitute (1) into (2) and use $a=a_{1x}=-a_{2y}$

$m_1 a - m_2\, g = -m_2 a$

$a=(m_2)g\,/\,(m_1+m_2)=(2kg/5kg)\times 9.8\ m/s^2=$

$a= 3.9\ m/s^2$



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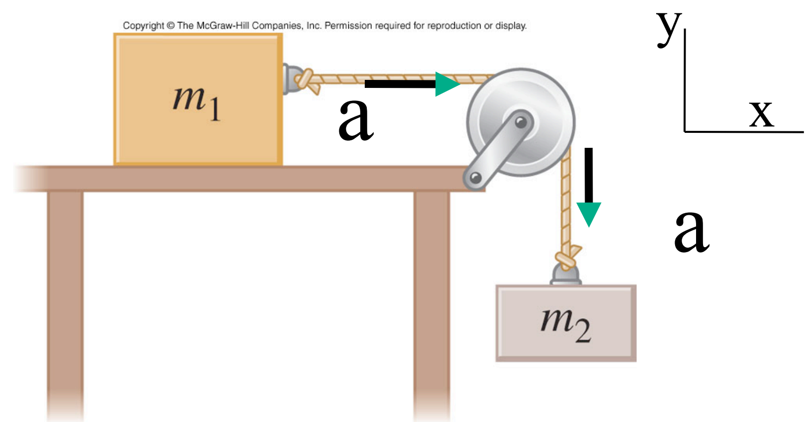


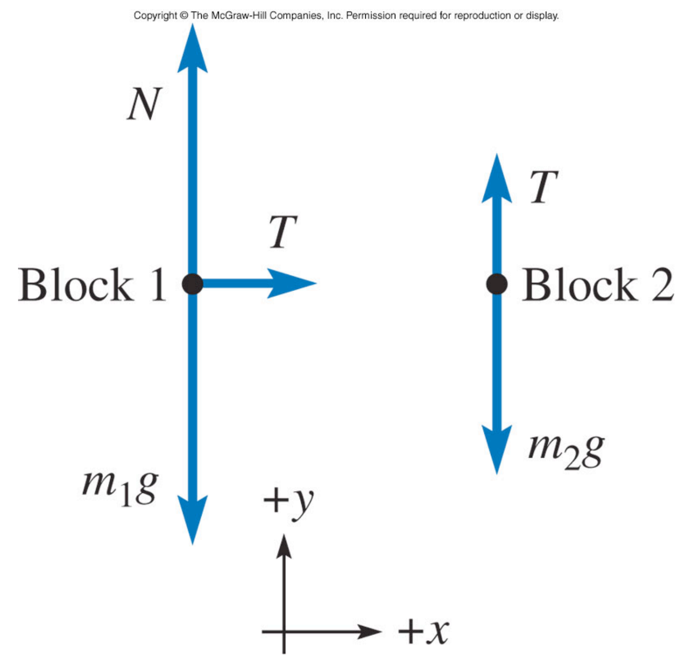
$a_1 = (m_2)g / (m_1+m_2)$

$a = 3.9 \text{ m/s}^2$

$\Delta y = v_0 t + \frac{1}{2} a t^2 = \frac{1}{2} a t^2$

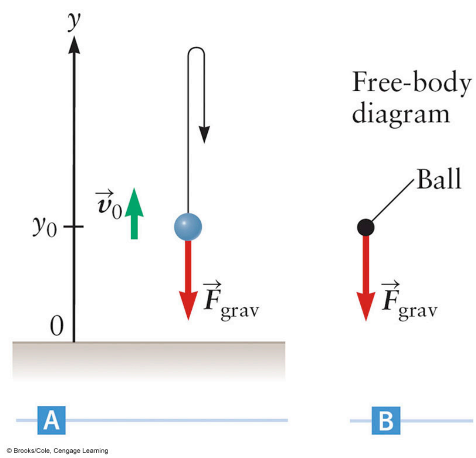
$t = \text{sqrt}(2 \Delta y/a)$

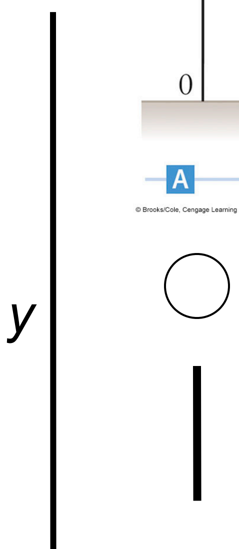
$t = 0.64$ seconds



Free Fall

- At the earth's surface freely falling bodies experience a constant acceleration of 9.8 m/s^2





g=9.8 m/s^2

There is a choice of axes:

1) Choose positive *y* up in which case a=g=-9.8 m/s^2

2) Choose positive *y* down in which case a=g=9.8 m/s^2

$$v = v_0 + gt$$

$$t = \sqrt{\frac{2\Delta x}{g}}$$

$$x = x_0 + v_0 t + \frac{1}{2} g t^2$$

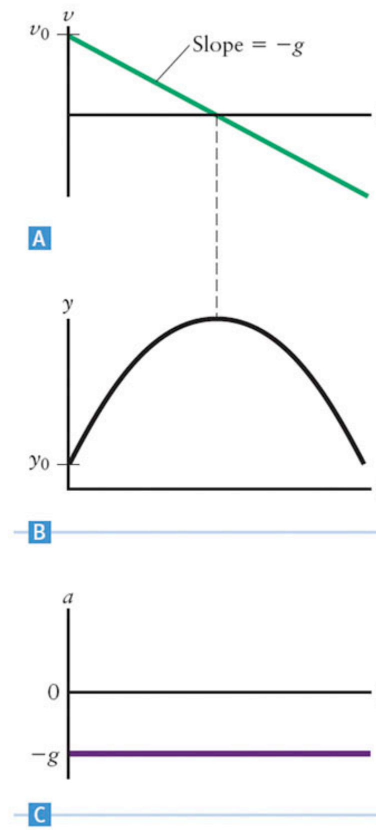
Free Fall

- Only **gravity** acts on the object when it is in free fall
  - Newton's 2nd Law $\Sigma F_y = ma_y$
  - Force is Weight = mg (near surface of earth)
    - $-mg = ma_y$
    - $a_y = -g$ (- sign tells us it is in –*y* direction or down)
- Acceleration is always g downwards
  - Velocity may be positive, zero or negative
  - Position may be positive, zero or negative
  - Acceleration is always g downwards
  - Velocity and acceleration are not always in the same direction

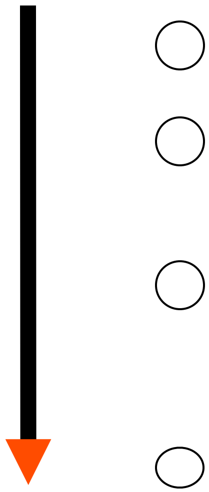
$$y = y_0 + v_{y0}t - \tfrac{1}{2}gt^2$$

$$v_y = v_{y0} - gt$$

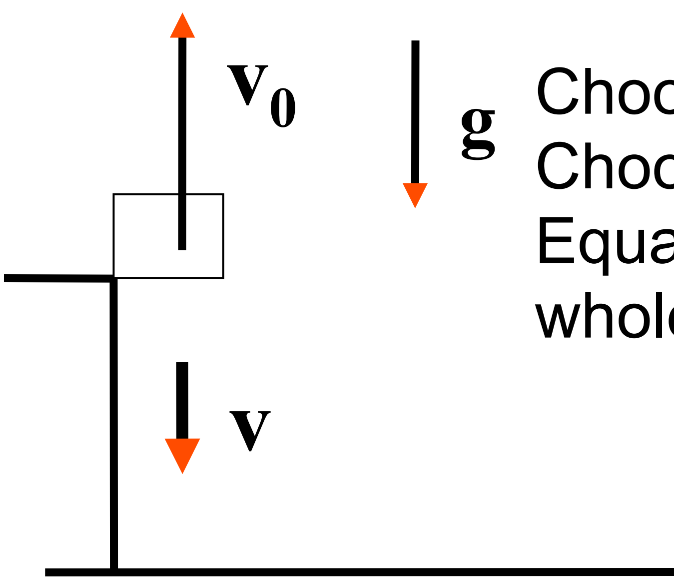
$$v_y^2 = v_{y0}^2 - 2g(y - y_0)$$



Example of Free Fall



$t = 0.00\text{s}$	$y = 0$	$v = 0$
$t = 0.20\text{s}$	$y = 0.196\text{m}$	$v = 1.96\text{m/s}$
$t = 0.40\text{s}$	$y = 0.785\text{m}$	$v = 3.92\text{m/s}$
$t = 0.64\text{s}$	$y = 2.0\text{m}$	$v = 6.28\text{m/s}$



Choose where y = 0
Choose positive direction
Equations cover the whole continuous motion

For y=0 and v=0:

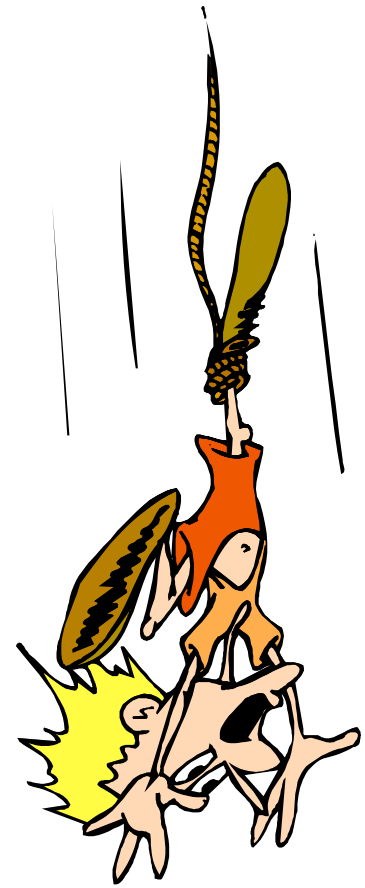
$$y = \frac{1}{2}at^2 = \frac{1}{2}9.8\frac{m}{s^2}t^2$$

$$\boxed{v = gt}$$

Free Fall

- Only force acting on object is GRAVITY
- Acceleration is ALWAYS g downwards
- Which will hit the ground first?

A) Penny B) Same C) Feather



Note: Free fall only works when air resistance is negligible!

Free Fall ACTS

Fred throws a ball 30 mph vertically upward. Which of the following statements are true about the ball's velocity and acceleration. (Let up be the positive direction)

On the way up?

A) $v < 0$ B) $v = 0$ C) $v > 0$

A) $a < 0$ B) $a = 0$ C) $a > 0$

On the way down?

A) $v < 0$ B) $v = 0$ C) $v > 0$

A) $a < 0$ B) $a = 0$ C) $a > 0$

ACT

Fred throws a ball 30 mph vertically upward and then catches it again at the same height he threw it from. What is the speed of the ball when he catches it? (Neglect air resistance)

A) v < 30 mph B) v = 30 mph C) v > 30 mph

$$v_y^2 = v_{y0}^2 - 2g(y-y_0)$$

$$v_y^2 = v_{y0}^2$$

ILQ

Dennis and Carmen are standing on the edge of a cliff. Dennis throws a basketball vertically upward, and at the same time Carmen throws a basketball vertically downward with the same initial speed. You are standing below the cliff observing this strange behavior.

Whose ball hits the ground first?

A) Dennis' ball

B) Carmen's ball

C) Same

Time for Dennis's ball to return to the dotted line:

$v = v_o - gt$

$v = -v_0$

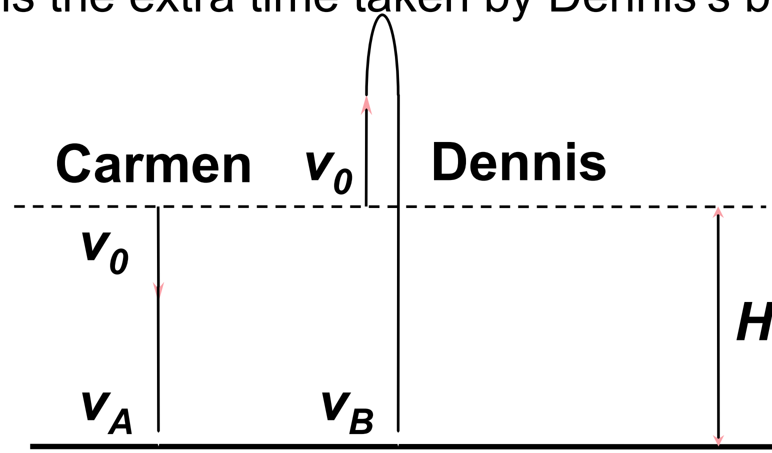
$t = 2\,v_0/g$

This is the extra time taken by Dennis's ball

$y = y_o + v_o t + \frac{1}{2} a t^2$

Dennis: $0 = H + v_o t - \frac{1}{2} g t^2$

Carmen: $0 = H - v_o t - \frac{1}{2} g t^2$



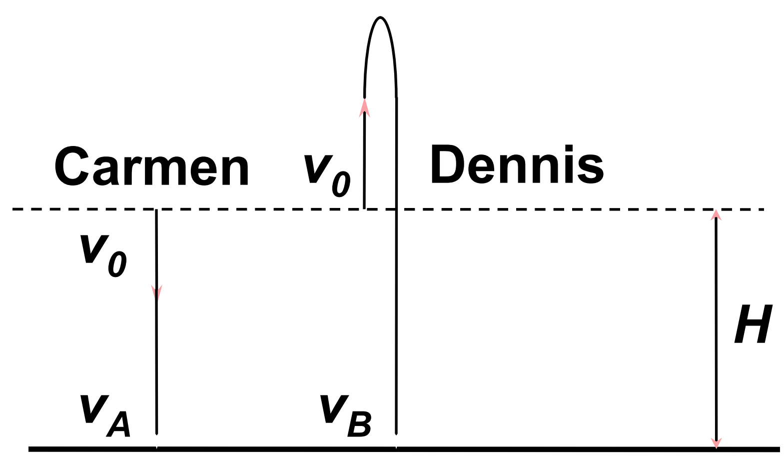
ILQ

Dennis and Carmen are standing on the edge of a cliff. Dennis throws a basketball vertically upward, and at the same time Carmen throws a basketball vertically downward with the same initial speed. You are standing below the cliff observing this strange behavior.

Whose ball is moving fastest when it hits the ground?

A) Dennis' ball
B) Carmen's ball
C) Same

Correct: $v^2 = v_0^2 - 2g\Delta y$



Summary of Concepts

- Friction
  - Parallel to the surface of contact
  - Always acts opposite the direction of motion
  - Magnitude of frictional force is proportional to the normal force
- Free Fall
  - Only force is gravity
  - Acceleration if 9.8 m/s^2 down
  - Velocity and acceleration are not always in the same direction

$$t = \sqrt{\frac{2\Delta x}{g}}$$