# Physics 1021

Spring 2012
Chapter 7

## Announcements

- This week's homework …. 2 parts
- Quiz on Friday, Ch. 4
- Today's class:
  - Newton's third law
  - Friction
  - Pulleys
  - tension

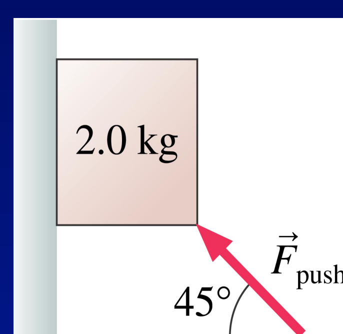
# Friction

*New Topic*



## Example

- A 2.0 kg wood box slides down a vertical wood wall at a constant speed while you push upward on it at a 45° angle. For wood on wood, the coefficient of kinetic friction is $\mu_k = 0.20$. What is $F_{push}$?
- **What magnitude of force should you apply to cause the box to slide down with a 0.1 g acceleration?**



## Ponderable

- A 2.0 kg wood box slides down a vertical wood wall at a constant speed while you push upward on it at a 45° angle. For wood on wood, the coefficient of kinetic friction is $\mu_k = 0.20$. What is $F_{push}$?
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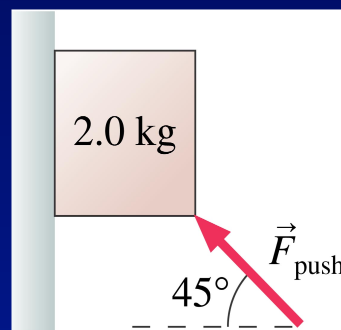





## Tangible: What is the static friction coefficient: Can it be greater than 1?

**By Group Number:**

1. **of an eraser on a whiteboard?**
2. **of an upside-down eraser on a whiteboard?**
3. **of a book on a whiteboard?**
4. **of a calculator on a whiteboard?**
5. **of a pen (not rolling) on a whiteboard?**

**Steps:**

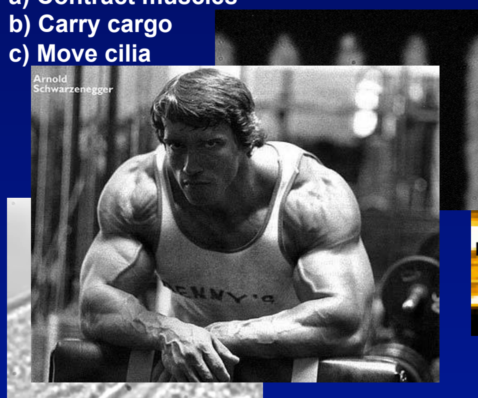
1. **Brainstorm how to do this**
2. **Make calculations, estimate the value**
3. **Get your materials -- ask me or Qi for help here**
4. **Make measurements**

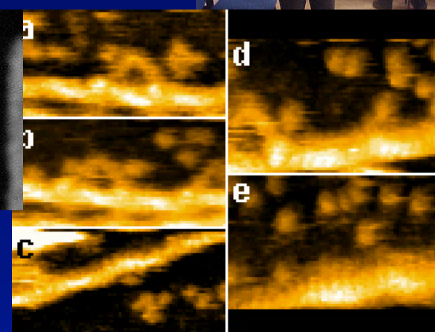
## Molecular motors: Ando – AFM movies of My V

Myosin motors move along actin fibers in living things as seen in these videos made by atomic force microscopy (AFM):

Newton's Third Law at work to

a) Contract muscles
b) Carry cargo
c) Move cilia



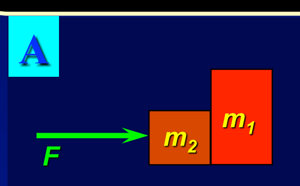

6.8 fps, Scan area, 150 × 75 nm$^2$

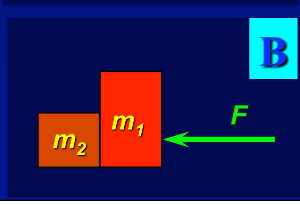


## *ConcepTest 7.1* *Contact Force I*

If you push with force F on either the heavy box ($m_1$) or the light box ($m_2$) and they accelerate together, in which of the two cases below is the contact force between the two boxes larger?

1) case A
2) case B
3) same in both cases



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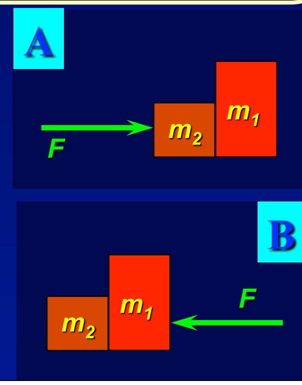
1) case A
2) case B
3) same in both cases

The acceleration of both masses together is the same in either case. But the contact force is the ***only*** force that accelerates $m_1$ in case A (or $m_2$ in case B). Since $m_1$ is the larger mass, it requires the larger contact force to achieve the same acceleration.

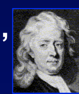



# Newton's 3rd Law

*New Topic*

# Newton's Third Law


Is boxing glove A hitting glove B, or is glove B hitting glove A?



The gloves hit each other


For every action there is an equal and opposite reaction.

For the boxing gloves:

Action: A pushes on B

Reaction: B pushes on A

$$F_{A\ on\ B} = -F_{B\ on\ A}$$

Action and Reaction forces:

- have the same magnitude
- are in opposite directions
- act on different objects

Phys 1021 Ch 7, p 11

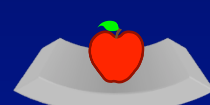
# Third Law Example

Action: force of the Earth on the apple (gravity)

Reaction: NOT force of the table on the apple
BUT force of the apple on the Earth

How can a table exert a force on an apple?

No apple, no force

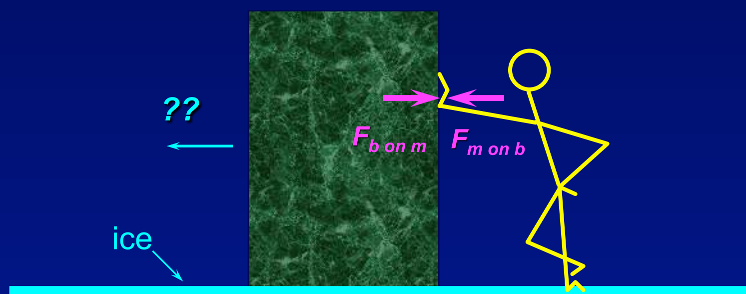


With the apple, the table bends ever so slightly so there is a force upward (like a diving board)

Phys 1021 Ch 7, p 12

## Newton's 3rd Law

- Since $F_{b\ on\ m}$ = $-F_{m\ on\ b}$ then why isn't $F_{net} = 0$?

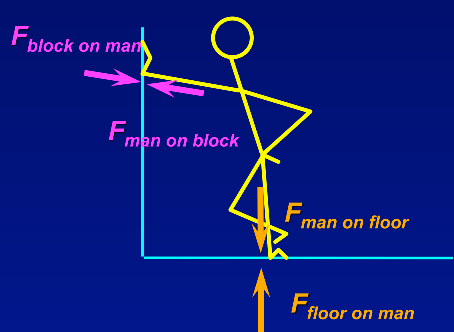



**Example of "Bad Thinking"!**



## Newton's 3rd Law

- $F_{A\ on\ B} = -F_{B\ on\ A}$
- Action-reaction forces always occur in pairs!
- Action-reaction forces always act on different objects! – block ON man, man ON block

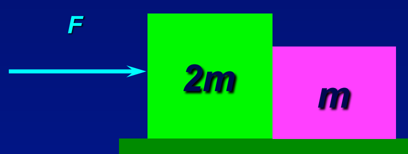



This is why you need to use a Free Body Diagram and consider the net force on the block… only $F_{man\ on\ block}$

## *ConcepTest 7.2* *Contact Force II*

Two blocks of masses *2m* and *m* are in contact on a horizontal frictionless surface. If a force *F* is applied to mass *2m*, what is the force on mass *m* ?

1) 2 *F*
2) *F*
3) 1/2 *F*
4) 1/3 *F*
5) 1/4 *F*



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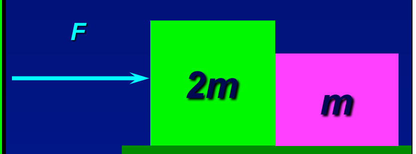
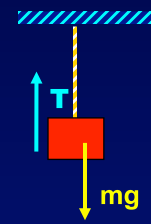
1) 2 *F*
2) *F*
3) 1/2 *F*
4) 1/3 *F*
5) 1/4 *F*

The force *F* leads to a specific acceleration of the entire system. In order for mass *m* to accelerate at the same rate, the force on it must be smaller!

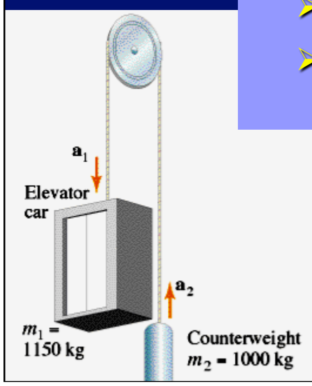


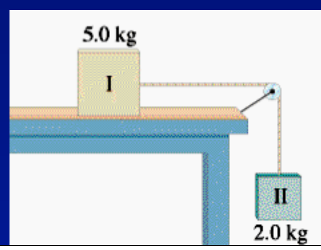
# Tension

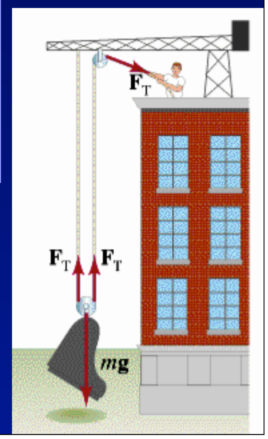
- *Tension (T)* is the magnitude of the force acting along the rope.
  - The force you'd feel if you cut the rope and grabbed the ends.

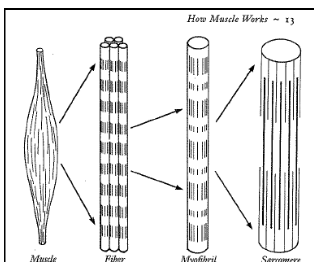



- Why are ropes useful?
  - to pull from a distance
  - to change the direction of a force



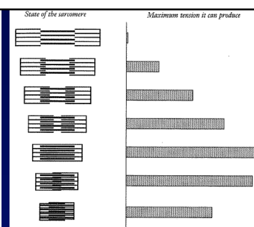




FIGURE 2.4. The force a muscle can exert relative to the degree of interdigitation of the filaments of its sarcomeres.

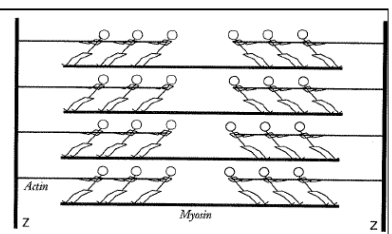
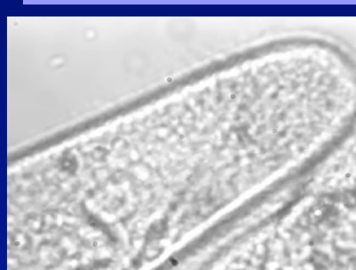
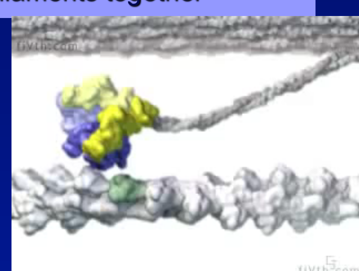



FIGURE 2.3. A sarcomere, represented diagrammatically, an idealization based on many pictures like Figure 2.2.

- Why is tension useful?
  - It's what makes muscles work
  - Muscles can only contract
  - Myosin motors pull actin/myosin filaments together





## Summary

**Newton's third law** Every force occurs as one member of an action/reaction pair of forces.

- The two members of an action/reaction pair act on two *different* objects.
- The two members of an action/reaction pair are equal in magnitude but opposite in direction: $\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$.



## ConcepTest 7.3 Tension

- You tie a rope to a tree and you pull on the rope with a force of *100 N*. What is the tension in the rope?

(1) *0 N*
(2) *50 N*
(3) *100 N*
(4) *150 N*
(5) *200 N*

## *ConcepTest 7.3* Tension

- You tie a rope to a tree and you pull on the rope with a force of *100 N*. What is the tension in the rope?

(1) *0 N*
(2) *50 N*
(3) *100 N*
(4) *150 N*
(5) *200 N*

The tension in the rope is the force that the rope "feels" across any section of it (or that you would feel if you replaced a piece of the rope). Since you are pulling with a force of *100 N*, that is the tension in the rope.



## *ConcepTest 7.4* Tension

- Two tug-of-war opponents each pull with a force of *100 N* on opposite ends of a rope. What is the tension in the rope?

(1) *0 N*
(2) *50 N*
(3) *100 N*
(4) *150 N*
(5) *200 N*

## *ConcepTest 7.4* Tension

- Two tug-of-war opponents each pull with a force of *100 N* on opposite ends of a rope. What is the tension in the rope?

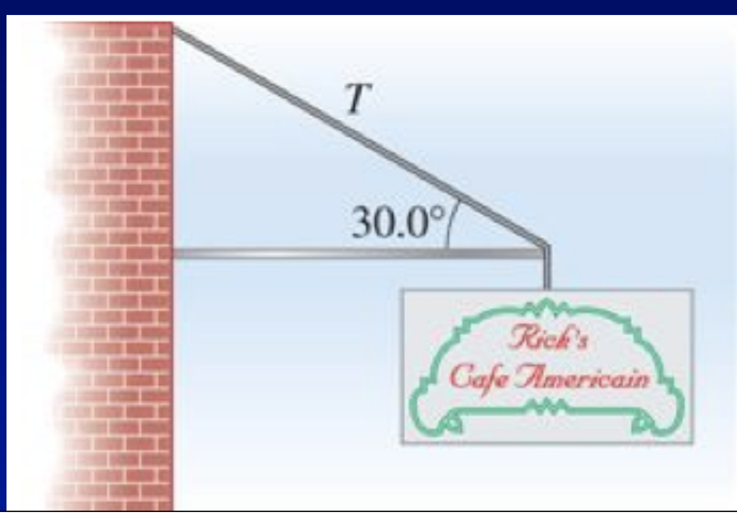
(1) *0 N*
(2) *50 N*
(3) *100 N*
(4) *150 N*
(5) *200 N*

This is literally the identical situation to the previous question. The tension is not 200 N !! Whether the other end of the rope is pulled by a person, or pulled by a tree, the tension in the rope is still 100 N !!



## Tension Example

A 200.0-N sign is suspended from a horizontal strut of negligible weight. The force exerted on the strut by the wall is horizontal. Draw an FBD to show the forces acting on the strut. Find the tension T in the diagonal cable supporting the strut.



## Ponderable: Hanging plastic ball

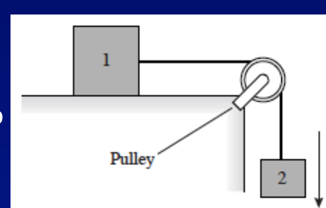
- In an electricity experiment, an electrically charged plastic ball (mass = 100 g) is suspended on a 60 cm long string. When a charged rod is brought near the ball, the rod exerts a horizontal electrical force $\boldsymbol{F}_{elec}$ on it, causing the ball to swing out to a 20° angle and remain at rest there.
- **What is the magnitude of the electric force $F_{elec}$?**
- **What is the tension in the string?**



## Kinetic constraints

When two or more objects are connected by strings, pulleys, or are rigidly connected, then they no longer move independently. The constraints between their positions, velocities and accelerations can be used to ease the solving of their motion.

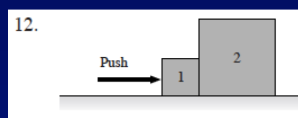
For example in the picture below, all three types of constraints are in play:

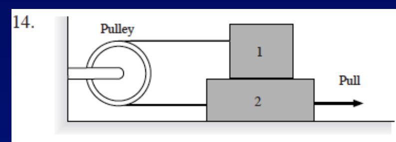


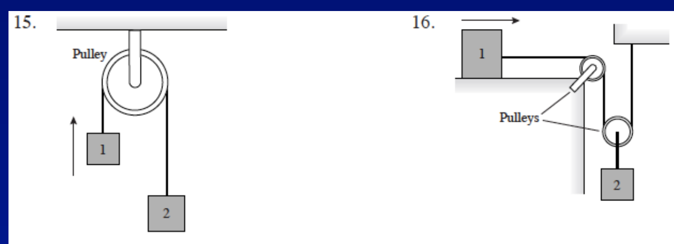

- Ropes: Masses 1 and 2 move and accelerate at the same rate
- Pulleys: The velocity of the masses is equal to the radius times the angular velocity of the pulley (as are the linear and angular accelerations
- Rigid body: All points at a given distance from the pulley center have the same acceleration.

## Acceleration constraints

**For each picture, write the acceleration constraint in terms of *components. For example, write $(a_1)_x = (a_2)_y$, if that is the appropriate answer, rather than $a_1 = a_2$***



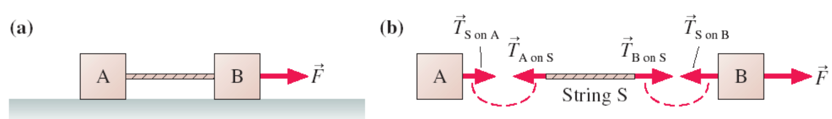






## The Massless String Approximation

FIGURE 7.22 The string's tension pulls forward on block A, backward on block B.




**Often in physics and engineering problems the mass of the string or rope is much less than the masses of the objects that it connects. In such cases, we can adopt the following massless string approximation:**

$$T_{B\ on\ S} = T_{A\ on\ S} \qquad \text{(massless string approximation)}$$

**Third law: $T_{sonA} = T_{sonB}$**

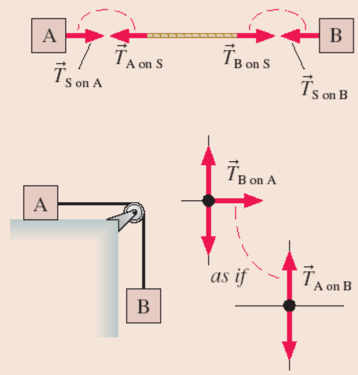
## Applications

### Strings and pulleys

The tension in a string or rope pulls in both directions. The tension is constant in a string if the string is:

- Massless, or
- In equilibrium

Objects connected by massless strings passing over massless, frictionless pulleys act *as if* they interact via an action/reaction pair of forces.

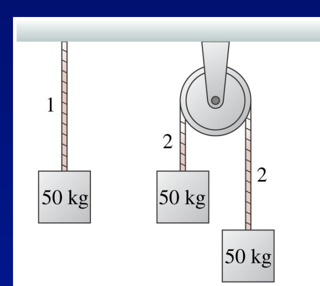





## *ConcepTest 7.5* *Tension*

All three 50 kg blocks are at rest. Is the tension in rope 2 greater than, less than, or equal to the tension in rope 1?

A. Equal to
B. Greater than
C. Less than



## ConcepTest 7.5 Tension

All three 50 kg blocks are at rest. Is the tension in rope 2 greater than, less than, or equal to the tension in rope 1?

A. Equal to
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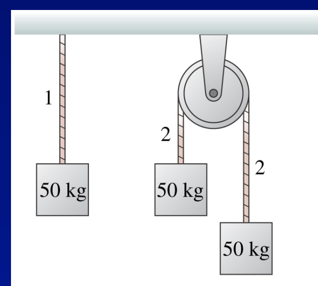
Each block feels an upward force of 490 N, which is provided by the tension. Therefore both ropes have the same tension.

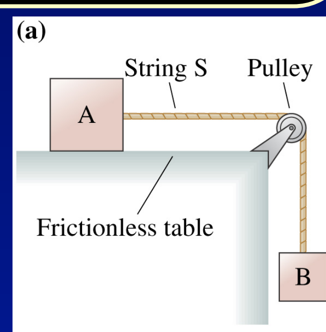





## ConcepTest 7.6 Tension II

In the figure, is the tension in the string greater than, less than, or equal to the gravity on block B?

A. Equal to
B. Greater than
C. Less than



## *ConcepTest 7.6* *Tension II*

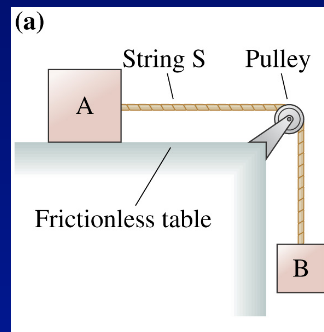
In the figure, is the tension in the string greater than, less than, or equal to the gravity on block B?

A. Equal to

B. Greater than

C. Less than

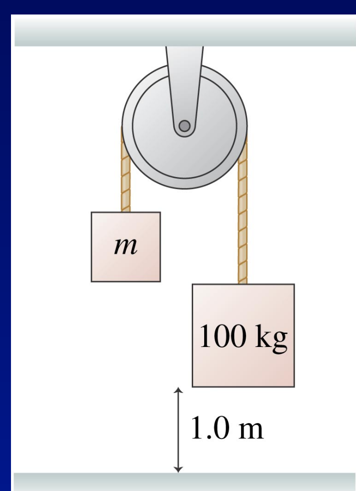
The blocks are accelerating, since there is no force to hinder block A. This means that the net force on B {mg – T} is not zero and is downward. Thus mg > T





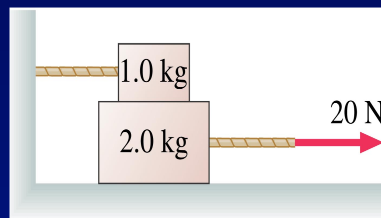

## Atwood's machine

- An Atwood's machine is shown in the figure. The 100 kg block on the right side takes 6.0 s to reach the floor after it is released from rest.
- **What is the mass of the block on the left side?**



## Ponderable: Sliding blocks

- A 1.0 kg block is tied to the wall with a rope. It sits on top of a 2.0 kg block. The lower block is pulled to the right with a tension force of 20 N. The coefficient of kinetic friction at both the lower and upper surfaces of the 2.0 kg block is $\mu_k = 0.40$




**What is the tension in the rope attached to the 1.0 kg block?**
**What is the acceleration of the 2.0 kg block?**



## Tangible: Stretch it yourself

1. **Take one rubber band and hang a 200 mg mass from it. How far does it stretch? Call this length $l_0$.**
2. **Combine two rubber bands in a chain (end to end) and hang a 200 mg mass from the combination. How far does it stretch? Why?**

**For the questions below, answer only in integer numbers of rubber bands**

3. **About how many identical rubber bands must be combined ( and how ) to stretch by $l_0$ under the load of a 500 g mass? Try this. Calculate the force on each rubber band? Draw the fbd for the mass. Draw the fbd for each rubber band.**
4. **About how many identical rubber bands must be combined ( and how ) to stretch by $l_0$ under the load of a 100 g mass? Try this. Calculate the force on each rubber band? Draw the fbd for the mass.**

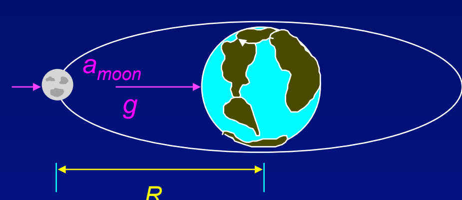
# Gravity

*New Topic*



## Law of Gravitation
**(Courtesy of Newton)**

- Newton suspected that gravity acts not only here on Earth but everywhere!
- By analyzing the motions of the Moon and the planets he proposed the ***Universal Law of Gravitation:***




$$F = G\frac{Mm}{R^2}$$

where $G = 6.67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$

**Direction:** attractive along the line between the centers of the two masses

## *ConcepTest 6.2* Earth and Moon I

Which is stronger, the Earth's pull on the Moon, or the Moon's pull on the Earth?

1) the Earth pulls harder on the Moon
2) the Moon pulls harder on the Earth
3) they pull on each other equally
4) there is no force between the Earth and the Moon
5) it depends upon where the Moon is in its orbit at that time



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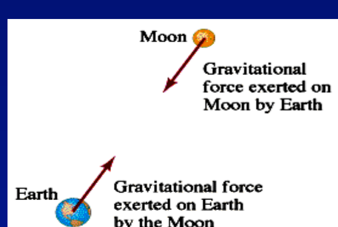
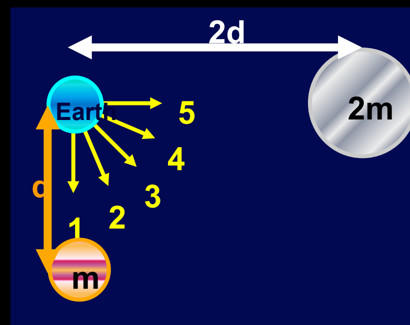



$$|F_{12}| = G\frac{m_1 m_2}{R_{12}^2} = |F_{21}|$$

## *ConcepTest 6.3* Force Vectors

A planet of mass m is a distance d from Earth. Another planet of mass 2m is a distance 2d from Earth. Which force vector best represents the direction of the total gravitation force on Earth?



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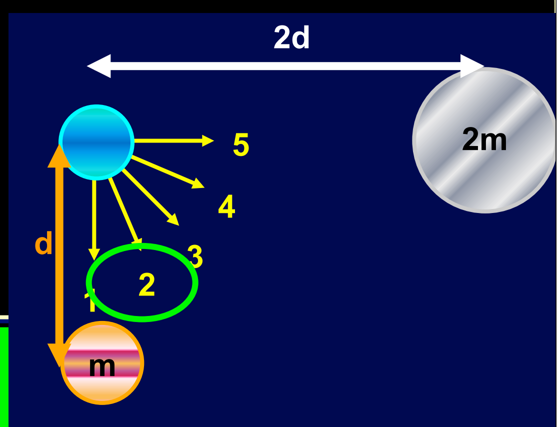


**The force of gravity on the Earth due to m is greater than the force due to 2m, which means that the force component pointing down in the figure is greater than the component pointing to the right.**

$F_{2m} = GM_E(2m) / (2d)^2 = ½\ GMm / d^2$

$F_m = GM_E\ m / d^2 = GMm / d^2$

# How do we get weight?

- Near the earth's surface...

$$\left|F_g\right| = G\frac{M_E m}{R_E^2} = m\underbrace{\left(G\frac{M_E}{R_E^2}\right)}_{= g}$$

$$g = G\frac{M_E}{R_E^2} = 9.8\ m/s^2$$

**Weight** Force of attraction between an object and an astronomical body (Earth, Moon, etc.)

Weight = Force of gravity: W = m g

Weight (like any force) is a vector. units: newtons (N)

**Mass** scalar units: kilogram (kg)

Phys 1021 Ch 7, p 43