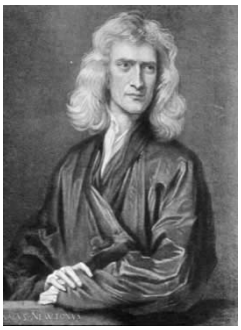
Announcements 25 Mar 09

- **Homework #7**
  - **Written homework due at the beginning of class on Friday**
  - **Online homework due on Tuesday next week**
- **Office hours**
  - **Thursday 2:00 to 3:30 pm this week**

1

The Force of Gravity

Sir Isaac Newton



?

Is there a connection between these two motions?

Apple falling from a tree vs. Moon orbiting Earth

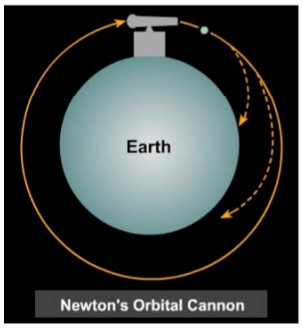
2

Newton's profound insight

Imagine the force pulling on the apple has a range that extends far above the tree

Imagine a large canon on top of a tall mountain

What happens to the projectile if its Initial horizontal speed is very large?



The speed can be large enough for the projectile to reach orbit and continuously fall toward the center of the Earth

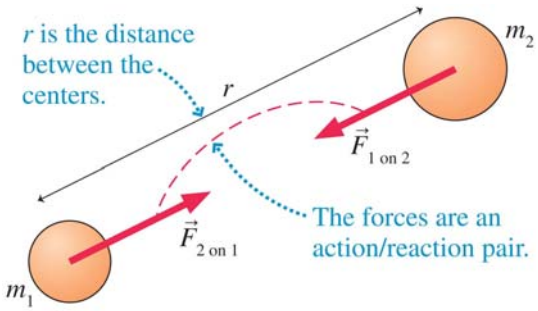
➔ The Moon orbits the Earth by continuously falling toward its center

➔ Connection between "celestial mechanics" and "earthly mechanics"

3

The Force of Gravity

➔"universal" law
i.e. applies everywhere in the Universe



Newton's law of gravity If two objects with masses m_1 and m_2 are a distance r apart, the objects exert attractive forces on each other of magnitude

$$F_{1\text{on}2} = F_{2\text{on}1} = \frac{Gm_1m_2}{r^2} \qquad (6.21)$$

The forces are directed along the line joining the two objects.

The constant G is called the **gravitational constant.** In the SI system of units, G has the value

$$G = 6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2$$

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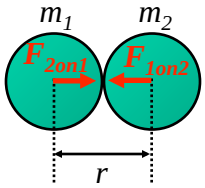
Gravitational force problem 1

A typical bowling ball is spherical, weighs 16 pounds, and has a diameter of 8.5 in. Suppose two bowling balls are right next to each other in the rack. What is the gravitational force between the two—magnitude and direction?



Assume all the mass is concentrated at the center of each ball

Prepare

Know	*Find*
$w_1 = 16$ lb	$F_{1on2} = ?$
$w_2 = 16$ lb	

$$r = 8.5 \text{ in} = 8.5 \text{ in} \frac{0.0254 \text{ m}}{1 \text{ in}} = 0.216 \text{ m}$$

$$w_1 = 16 \text{ lb} \cdot \frac{4.54 \text{ N}}{1 \text{ lb}} = 72.6 \text{ N}$$

Solve

$$m_1 = \frac{w_1}{g} = \frac{72.6 \text{ N}}{9.8 \text{ m/s}^2} = 7.27 \text{ kg}$$

$$F_{1on2} = G\frac{m_1 m_2}{r^2} = \left(6.67 \times 10^{-11} N \cdot m^2/kg^2\right)\frac{(7.27kg)^2}{(0.216m)^2} = 7.55 \times 10^{-8} N$$

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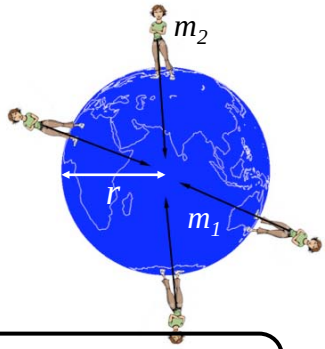
Gravitational force problem 2

What is the magnitude and direction of the force of gravity on a 60 kg person?



Know	*Find*
$m_1 = 5.98 \times 10^{24}$ kg	$F_{1on2} = ?$
$m_2 = 60$ kg	
$r = 6.37 \times 10^6$ m	

Force exerted by the Earth on the person:

$$F_{1on2} = G\frac{m_1 m_2}{r^2} = \left(6.67 \times 10^{-11} N \cdot m^2/kg^2\right)\frac{\left(5.98 \times 10^{24} kg\right)(60kg)}{\left(6.37 \times 10^6 m\right)^2} = 590N$$

Weight of the person:

$$w = m_2 g = (60kg)\left(9.8 \text{ m/s}^2\right) = 590\text{N}$$

Gravitational acceleration on the surface of a planet can be generalized as

$$g_{planet} = G \cdot \frac{M_{planet}}{\left(R_{planet}\right)^2}$$

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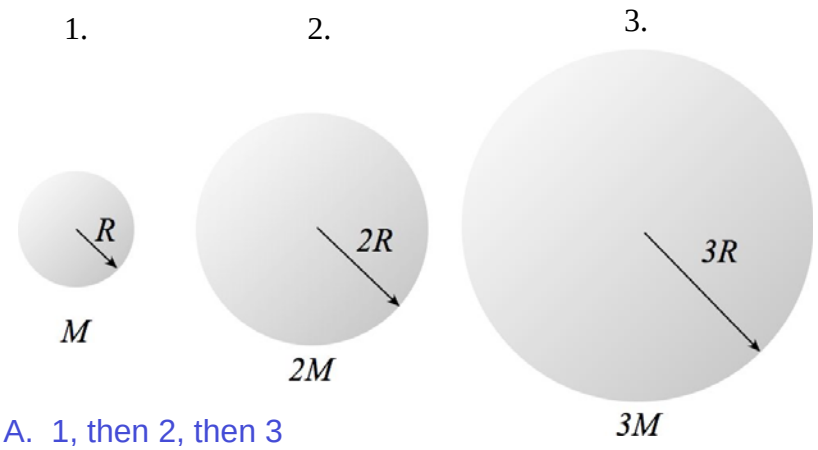
Gravity on other worlds

PRS

A 60 kg person stands on each of the following planets. Rank order her weight on the three bodies, from highest to lowest.



A. 1, then 2, then 3
B. 3, then 2, then 1
C. All the same

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Announcements 27 Mar 09

- **Lost texbook**
- **Grades updated**
- **Homework #7**
  - **Online homework #7 due on Tuesday by 8 am**
  - **Written + online homework #8 will be due on Friday next week**
- **Exam 2**
  - **Tuesday April 7 from 7 to 9 pm**
  - **Includes material from homeworks #4, #5, #6, #7, #8**
  - **More info on Monday**

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Chapter 7
Rotational Motion

Topics:

- Angular and tangential acceleration
- Linear and rotational motion compared
- Torque
- Center of gravity
- Newton's second law for rotation

Force causes an object to undergo a *linear* acceleration

Torque causes an object to undergo an *angular* acceleration

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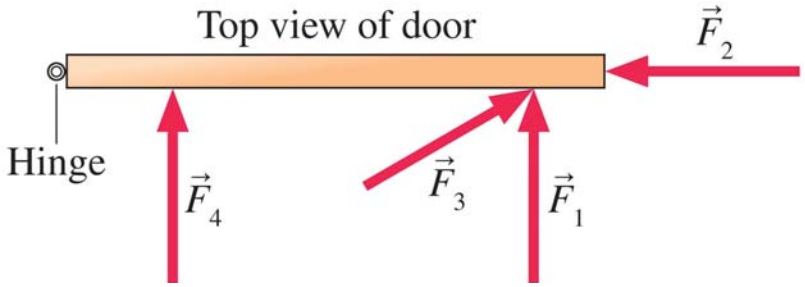
Torque

Which force would be most effective in opening the door?



DEMOS: **Turn large bolt by hand vs. with a wrench**
Torque wheel

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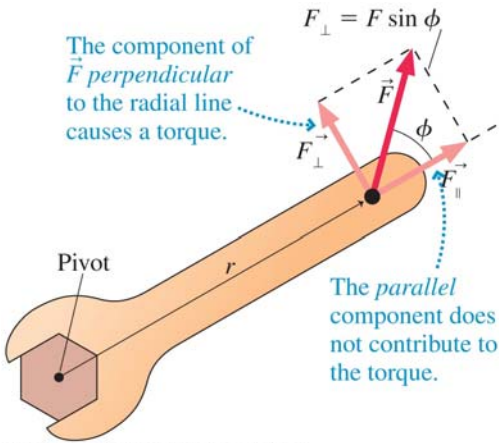
Interpreting Torque

Torque is due to the component of the force *perpendicular* to the radial line.



$$\tau = rF_\perp = rF\sin\phi$$

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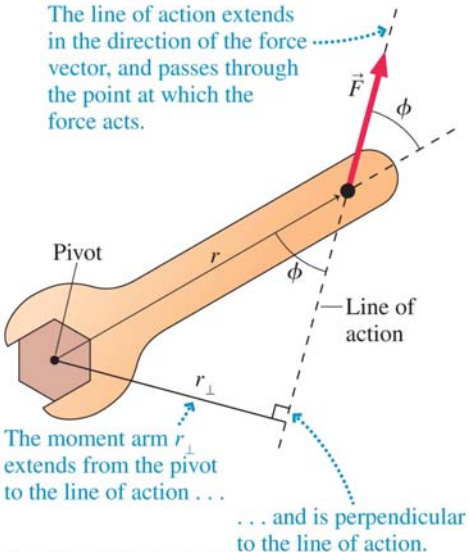
A Second Interpretation of Torque



$$\tau = r_\perp F = rF\sin\phi$$

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Torque Sample Problem

Revolutionaries attempt to pull down a statue of the Great Leader by pulling on a rope tied to the top of his head. The statue is 17 m tall, and they pull with a force of 4200 N at an angle of 65° to the horizontal. What is the torque they exert on the statue? If they are standing to the right of the statue, is the torque positive or negative?

Draw a picture

Choose a pivot point

Calculate force perpendicular to radial line

Calculate torque

$\tau < 0$ if motion is clockwise

$\tau > 0$ if motion in counter-clockwise

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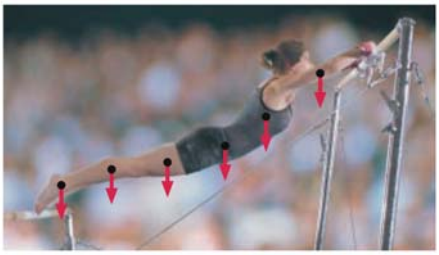
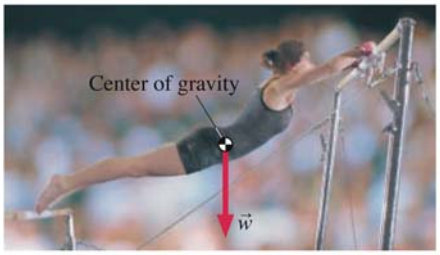
Center of Gravity



Gravity exerts a force and a torque on each particle that makes up the gymnast

=

The gymnast responds as if her entire weight acts at her center of gravity



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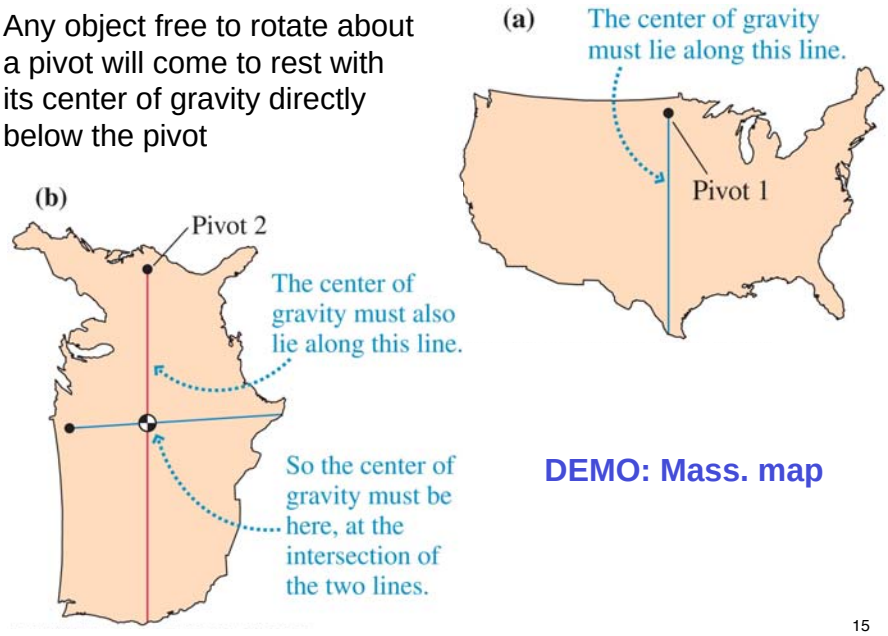
Finding the Center of Gravity

Any object free to rotate about a pivot will come to rest with its center of gravity directly below the pivot



DEMO: Mass. map

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Announcements 30 Mar 09

- **Homework #7**
  - **Online homework #7 due on Tuesday by 8 am**
  - **Written + online homework #8 due on Friday**
- **Exam 2**
  - **Tuesday April 7 from 7 to 9 pm**
  - **Includes material from homeworks #4, #5, #6, #7, #8**
  - **See full info on course blog**

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Calculating the Center-of-Gravity Position

TACTICS BOX 7.1 Finding the center of gravity Exercise 12

1. Choose an origin for your coordinate system. You can choose any convenient point as the origin.
2. Determine the coordinates (x_1, y_1), (x_2, y_2), (x_3, y_3), . . . for the particles of mass $m_1, m_2, m_3, \ldots$ respectively.
3. The x-coordinate of the center of gravity is

$$x_{cg} = \frac{x_1 m_1 + x_2 m_2 + x_3 m_3 + \cdots}{m_1 + m_2 + m_3 + \cdots} \quad (7.9)$$

4. Similarly, the y-coordinate of the center of gravity is

$$y_{cg} = \frac{y_1 m_1 + y_2 m_2 + y_3 m_3 + \cdots}{m_1 + m_2 + m_3 + \cdots} \quad (7.10)$$

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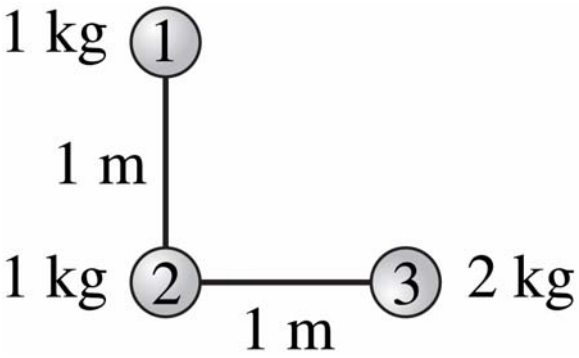
Center of Gravity Sample Problem

An object consists of the three balls shown, connected by massless rods. Find the *x*- and *y*-positions of the object's center of gravity.



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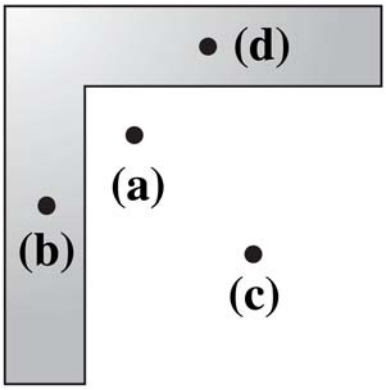
Center of Gravity Question

PRS

Which point could be the center of gravity of this L-shaped piece?



DEMO: **Center of gravity toys**

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Chapter 8
Equilibrium and Elasticity

Topics:

- Torque and static equilibrium
- ~~The spring force~~
- ~~Hooke's law~~
- ~~Elastic materials~~
- ~~The elastic limit~~

Sample question:

How does a dancer balance so gracefully *en pointe*?

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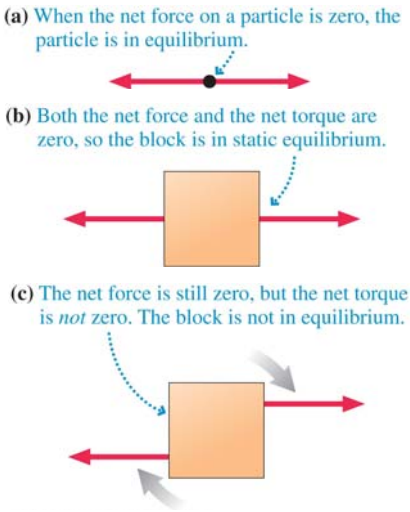
Torque and Static Equilibrium

For an extended object to be in equilibrium, the net force *and* the net torque must be zero.



$$\left.\begin{aligned}\textstyle\sum F_x &= 0\\ \textstyle\sum F_y &= 0\end{aligned}\right\}\ \text{No net force}$$

$$\textstyle\sum \tau = 0\ \}\ \text{No net torque}$$

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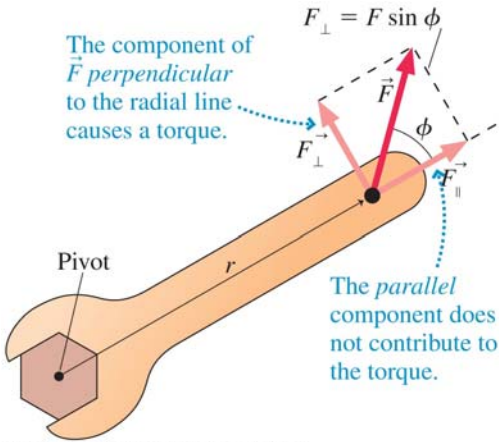
Interpreting Torque

Torque is due to the component of the force *perpendicular* to the radial line.



$$\tau = rF_\perp = rF\sin\phi$$

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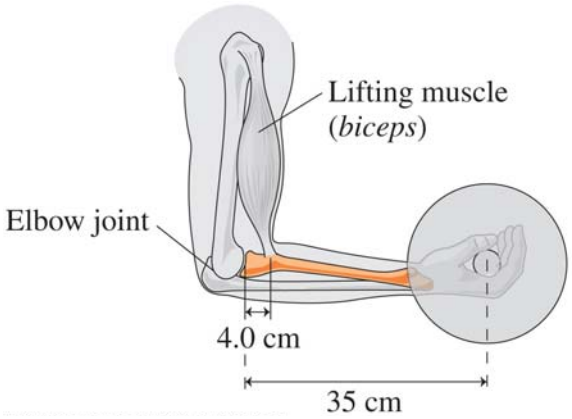
Lifting Weights, How Much Force?

What is the tension in the tendon connecting the biceps muscle to the bone while holding a 900 N barbell stationary?

What is the force exerted by the elbow on the forearm bones?



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Solving Static Equilibrium Problems

PROBLEM-SOLVING STRATEGY 8.1 **Static equilibrium problems**

PREPARE Model the object as a simple shape. Draw a visual overview that shows all forces and distances. List known information.

- Pick an axis or pivot about which the torques will be calculated.
- Determine the torque about this pivot point due to each force acting on the object.
- Determine the sign of each torque about this pivot point.

SOLVE The mathematical steps are based on the fact that an object in static equilibrium has no net force and no net torque.

$$\vec{F}_{\text{net}} = \vec{0} \quad \text{and} \quad \tau_{\text{net}} = 0$$

- Write equations for $\sum F_x = 0$, $\sum F_y = 0$, $\sum \tau = 0$.
- Solve the resulting equations.

Counter clockwise rotation: torque > 0
Clockwise rotation: torque < 0

ASSESS Check that your result is reasonable and answers the question.

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