The centers of mass of two spherical objects are separated by a distance $r$. If the distance between their centers is **halved**, what happens to the magnitude of the force of gravity between them?

$$F = G \frac{mM}{r^2}$$

A) It halves.
B) It doubles.
C) It quadruples.
D) It quarters.
E) It’s not so simple, we need more information.
Assignments

Announcements:
• Complete CAPA 8 and HW 8 this week.
• LA applications will close Oct 24: lacentral.colorado.edu
• Midterm 2 will be next Thursday. Will cover up through Ch. 8.2. with emphasis on Chs. 4-8.2.

Today:
• Finish our discussion of Energy and Power.
• Go on to Newton’s Law of Universal Gravitation.
Week 9 (Oct 20 - Oct 24)

- CAPA #8 is due Tue eve 11:59 PM. Recitation HW #8 is also due: see here.

- Midterm exam #2 is coming up this Thurs evening: Oct 23. For the location of the exam: click here. The exam will be cumulative through Chapter 8.2, with emphasis on material from Chapters 4-8.2.

- Available for you on D2L: (1) Two practice exams with and without solutions, one from PHYS1110 last semester and the other from PHYS2010 (Physics 1 for life scientists) several years ago. (2) Solutions to CAPA assignments and Written HWs. (3) Review video from Prof Dubson.

- On the course web site: (1) Lecture notes from Prof Dubson. (2) Course notes (my Powerpoints). (3) Videos of all lectures.
Exam Locations for Midterm #1 (Thursday Oct 23, 7:30-9:00 p.m.)

<table>
<thead>
<tr>
<th>My TA is</th>
<th>My midterm will be here:</th>
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<tbody>
<tr>
<td>Ashley Bellas</td>
<td>HALE 270</td>
</tr>
<tr>
<td>Edwin Bernardoni</td>
<td>CHEM 140</td>
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<tr>
<td>Doug Bopp</td>
<td>CHEM 142</td>
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<tr>
<td>Nathan Crossette</td>
<td>CHEM 140</td>
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<tr>
<td>Leon (Lili) Feng</td>
<td>MATH 100</td>
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<tr>
<td>Jake Fish</td>
<td>MATH 100</td>
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<tr>
<td>Kevin Gilmore</td>
<td>RAMY C250</td>
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<tr>
<td>Catherine Klauss</td>
<td>HALE 270</td>
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<tr>
<td>Adam Lamson</td>
<td>MUEN E050</td>
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<tr>
<td>Austin Steffen (8:00, 9:00, and 11:00 sections only)</td>
<td>DUAN G1B20</td>
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<tr>
<td>Austin Steffen (12:00 section only)</td>
<td>FLMG 155</td>
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<tr>
<td>Ye Tian</td>
<td>MUEN E050</td>
</tr>
<tr>
<td>Jiayi Xie</td>
<td>FLMG 155</td>
</tr>
</tbody>
</table>

*Early exam*: 5:00-6:30 in Duane G131 (one level above lecture hall)

*Extra time exam*: 5:00-7:30 in Duane G131 (one level above lecture hall)

To be admitted to the early or extra-time exam, you must be on Prof. Munsat’s list!
Assignments

Announcements:
• Complete CAPA 8 and HW 8 this week.
• LA applications will close Oct 24: lacentral.colorado.edu
• Midterm 2 will be next Thursday. Will cover up through Ch. 8.2 with emphasis on Chs. 4-8.2.

Today:
• Finish our discussion of Energy and Power.
• Go on to Newton’s Law of Universal Gravitation.
“Roller Coaster” Problems

Plots of potential energy versus position

h gives us PE: can replace h with PE.
No friction:

\[ E_{\text{tot}} = ME = KE + PE \]

is constant: horizontal line gives \( E_{\text{tot}} \).
Can read the PE & KE off the curve for every position.
“Roller Coaster” Problems

Plots of potential energy versus position

PhET Sim of a Skateboarder:
http://phet.colorado.edu/en/simulation/energy-skate-park
A cart rolls without friction along a track. The graph of PE vs. position is shown.

The total mechanical energy (KE + PE) is 0 kJ.

\[ E_{tot} = PE + KE = 0 \]

What is the MAX KE of the cart during its journey (to within 5kJ)?

A) 30 kJ  B) 50 kJ  C) -30 kJ  D) 10 kJ  E) None of these
Power is the rate at which work is done –

\[ P = \text{average power} = \frac{\text{work}}{\text{time}} \]

Units: \(1 \text{ W} = 1 \text{ J/s}\)

The difference between walking and running up these stairs is power – the change in gravitational potential energy is the same.
Some non-SI Units for Energy and Power

\[ P = \frac{E}{\Delta t} \quad \Rightarrow \quad E = P\Delta t \quad \text{[kWatt-hour]} \]

\[ 1kW \cdot hr = 1000J \div s \cdot 3600s = 3.6 \times 10^6 J, \quad \text{cost} \sim \$0.1 \]

Food Calorie = Cal = 4186J: 1 Cal = 1 kcal

1 cal = 4.186J = energy for \( \Delta T = 1^\circ \text{C} \) for 1g of H\(_2\)O

300 Cal candy bar \((1.26 \times 10^6 J \sim 1 / 3 \ kW \cdot hr)\)

Climb Gamow Tower (150 lb): \( \Delta PE = mgh = (68kg)(9.8m \div s^2)(35m) \]
\[ = 23,300J \cdot (1Cal \div 4186J) = 5.6Cal \]

Have to climb Gamow Tower 50 times to work off a candy bar?
No - the body is only about 20% efficient, so only need to climb it 10 times.
The difference between walking and running up these stairs is power – the change in gravitational potential energy is the same.

Power is the rate at which work is done –

\[
P = \text{average power} = \frac{\text{work}}{\text{time}}
\]

Units: 1 W = 1 J/s

The average power can be written in terms of a constant force and the average velocity:

\[
\overline{P} = \frac{W}{t} = \frac{Fd}{t} = F\bar{v}
\]
Newton’s Law of Universal Gravitation

**Insight:** what keeps the Moon in orbit around the Earth and the Earth in orbit around the Sun is exactly the same thing that causes an “apple to fall from a tree”.

“Every particle in the universe attracts every other particle with a force proportional to the product of their masses and inversely proportional to the square of the distance between them. The force points along the line joining the two particles.”
Newton’s Law of Universal Gravitation

Insight: what keeps the Moon in orbit around the Earth and the Earth in orbit around the Sun is exactly the same thing that causes an “apple to fall from a tree”.

\[ F = G \frac{m_1 m_2}{r^2} \]

\( G \approx 6.67 \times 10^{-11} \text{ SI Units} \)
Newton’s Law of Universal Gravitation

\[ F = G \frac{m_1 m_2}{r^2} \]

\[ G \approx 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2 \]

The Universal Gravitation constant \( G \) is measured experimentally. What are its units?

A) \( \text{kg m/s}^2 \)
B) \( \text{N m}^2/\text{kg}^2 \)
C) \( \text{kg}^2/\text{m}^2 \)
D) \( \text{N} \)

Don’t confuse \( G \) with \( g \)!
Newton’s Law of Universal Gravitation

\[ F = G \frac{m_1 m_2}{r^2} \]

\[ G \approx 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2 \]

1798: Henry Cavendish confirmed this formula experimentally.

**Example 1:** Force of attraction between 2 people.

\[ m_1 \approx m_2 \approx 70 \text{kg}, \quad r = 1 \text{m} \]

\[
F = G \frac{m_1 m_2}{r^2} = \left(6.67 \times 10^{-11}\right) 70^2 \text{N}
\]

\[
= 3.3 \times 10^{-7} \text{N} \left( \frac{1 \text{lb}}{4.4 \text{N}} \right)
\]

\[
= 7.5 \times 10^{-8} \text{lb} \approx 1 / 60 \text{ the weight of a single hair.}
\]
Newton’s Law of Universal Gravitation

Question: Objects are extended in space. Newton’s Law of Universal Gravitation is based on computing the distance between two objects – but which distance?

\[ R_{CM} = \text{distance between the “centers of mass” of the two objects.} \]
The centers of mass of two spherical objects are separated by a distance \( r \). If the distance between their centers is \textbf{halved}, what happens to the magnitude of the force of gravity between them?

\[ F = G \frac{mM}{r^2} \]

A) It halves.
B) It doubles.
C) It quadruples.
D) It quarters.
E) It’s not so simple, we need more information.
The centers of mass of two spherical objects are separated by a distance $r$. Assume $M > m$. Let $F_M$ be the magnitude of the gravitational force exerted by mass $M$ on mass $m$ and $F_m$ be the magnitude of the force exerted by mass $m$ on mass $M$.

$$F = G \frac{mM}{r^2}$$

Which of the following is correct:

A) $F_m > F_M$

B) $F_m < F_M$

C) $F_m = F_M$

D) It’s not so simple, we need more information.

By NIII
The centers of mass of two spherical objects are separated by a distance $r$. Assume $M > m$. Let $a_M$ be the magnitude of the acceleration of mass $M$ and $a_m$ be the magnitude of the acceleration of mass $m$.

\[ F = G \frac{mM}{r^2} \]

Which of the following is correct:

A) $a_m > a_M$
B) $a_m < a_M$
C) $a_m = a_M$
D) It’s not so simple, we need more information.

\[
\begin{align*}
Ma_M &= G \frac{mM}{r^2} \quad \rightarrow \quad a_M = G \frac{m}{r^2} \\
m a_m &= G \frac{mM}{r^2} \quad \rightarrow \quad a_m = G \frac{M}{r^2} > a_M
\end{align*}
\]
A small asteroid of mass $m$ is located between two giant planets with masses $M$ and $M/2$ as shown. The only force on $m$ is the gravitational attraction of the two planets.

$$F = G \frac{mM}{r^2}$$

What is the direction of the net force on the asteroid?

A) Left
B) Right
C) Zero
D) It’s not so simple, we need more information.

$$F_{net} = G \frac{m(M/2)}{(r/2)^2} - G \frac{mM}{r^2} = 2G \frac{mM}{r^2} - G \frac{mM}{r^2} = G \frac{mM}{r^2} > 0 \text{ (right)}$$