

## Gravitation

Reading: pp. 238-253  
 Syll. State.: 6.1.1-6.1.5—due  
 Tuesday 9/13/11 B.O.P

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## Newton's Law of Universal Gravitation

- “Every material particle in the Universe attracts every other material particle with a force that is directly proportional to the product of the masses of the particles and that is inversely proportional to the square of the distance between them.”

• *Principia*, Sir Isaac Newton

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## Gravitation

$$F_{12} = \frac{Gm_1m_2}{r^2} = -F_{21}$$

- $F_{12}$  = strength of gravitational force body 1 exerts on body 2
- $F_{21}$  = strength of gravitational force body 2 exerts on body 1
- $m_1$  and  $m_2$  = masses of the two bodies
- $r$  = separation distance between the center of mass for each of the bodies
- $G$  = Universal Gravitation constant  
 $= 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$

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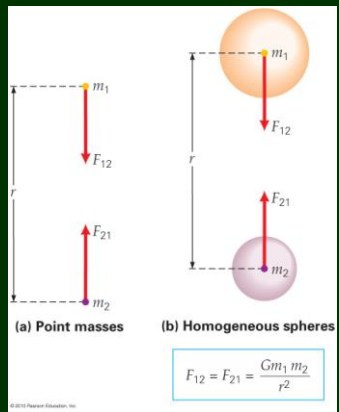
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## Gravitation

Gravitational forces are, essentially, acting as third-law force pairs.

Both masses exert the same size force on each other. Only the direction varies.

Gravitational force is ALWAYS and attractive force.




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## Sample Problem #1

- Find the force between the sun and the earth.

$$F = \frac{GmM}{R^2}$$

$$R = 1.5 \times 10^{11} \text{ m}$$

$$m = 5.98 \times 10^{24} \text{ kg}$$

$$M = 1.99 \times 10^{30} \text{ kg}$$

$$F = \frac{(6.67 \times 10^{-11} \text{ N}) (5.98 \times 10^{24} \text{ kg}) (1.99 \times 10^{30} \text{ kg})}{(1.5 \times 10^{11} \text{ m})^2}$$

$$F = 3.5 \times 10^{22} \text{ N}$$

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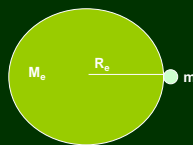
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- If a spherical object is uniform in mass, we can safely assume that the gravitational force due to this mass is exactly the same as if all the mass were concentrated at the very center.



- According to Newton's universal law of gravitation, what is the gravitational force between a 10.0 kg mass and the Earth?

$$F = \frac{GmM}{r^2} = \frac{(6.67 \times 10^{-11} \frac{\text{N}\cdot\text{m}^2}{\text{kg}^2}) (10.0 \text{ kg}) (5.98 \times 10^{24} \text{ kg})}{(6.38 \times 10^6 \text{ m})^2}$$

$$F = 98.0 \text{ N}$$

- Look like something else we know?

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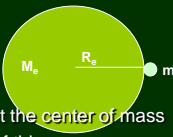
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- Yep! We just calculated the 10.00 kg mass' weight at the surface of Earth.



- **Assumption:** Mass is uniform, and all at the center of mass
- Therefore, for something at the surface of this mass, we can deduce that the following is true:
 
$$G \frac{(M_e m)}{(R_e)^2} = F_g = mg$$
- Thus we can conclude that the acceleration due to the gravity of a uniform mass is related to the radius of the large mass (in this example, Earth...)

$$g = G \frac{(M_e)}{(R_e)^2}$$


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## Gravitational Field Strength

- **g** = gravitational field strength of a uniform mass
- **g<sub>e</sub>, on average, = 9.81 N·kg<sup>-1</sup> = 9.81 m·s<sup>-2</sup> at its surface**
- **What is g for an astronaut on a space walk 160 km above the Earth's surface?**




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## Gravitational Field Strength

- **Gravitational Field**
- a "field of influence radiating outward from a particle of mass *m*"
- **Gravitational Field Strength** at a given point is **the force exerted per unit mass on a particle of small mass placed at that point.**
  - The strength of the gravitational field is equivalent to the acceleration of the particle (**g**) at that point
  - Units for the field strength, although they are equal to m s<sup>-2</sup>, are typically listed as **N kg<sup>-1</sup>**

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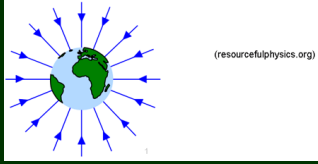
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## Gravitational Field (diagram)



- Gravitational field lines are vectors that always are directed radially toward the center of the mass.
- *(remember...the field lines (vectors) will indicate the direction a smaller mass will be pulled as a result of the gravitational force caused by the field...)*

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## Whiteboard problem!

- But first...Clickers out!

Predict—Which planet's gravitational field strength is closest in size to Earth's?



- What is  $g$  for other objects in our solar system?

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## Gravitational Field Strengths in our Solar System

Object	Mass (kg)	Radius (m)	Gravitational field strength (N/kg)
Sun	1.99e30	6.96e8	274
Mercury	3.30e23	2.44e6	3.70
Venus	4.87e24	6.05e6	8.87
Earth	5.98e24	6.38e6	9.80*
Moon	7.35e22	1.74e6	1.62
Mars	6.42e23	3.40e6	3.70
Jupiter	1.90e27	6.91e7	26.5
Saturn	5.69e26	6.03e7	10.4
Uranus	8.66e25	2.56e7	8.81
Neptune	1.03e26	2.48e7	11.2
Pluto	1.5e22	1.15e6	0.76

\*Note: Using more precise values for Earth,  $g = 9.81 \text{ N/kg}$

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## Clicker problem #2

- Determine the acceleration due to gravity at the surface of a planet that is 10 times more massive than the earth and has a radius 20 times larger.

$$g = G \frac{(M)}{(R)^2} \longrightarrow g = G \frac{(10M_E)}{(20R_e)^2} = \frac{10}{400} \left( G \frac{M_E}{R_e^2} \right)$$

$$g = \frac{1}{40} \left( G \frac{M_E}{R_e^2} \right) = \frac{1}{40} (g_e) \longrightarrow g = \left( \frac{1}{40} \right) 9.80 = 0.25 \text{ m} \cdot \text{s}^{-2}$$

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