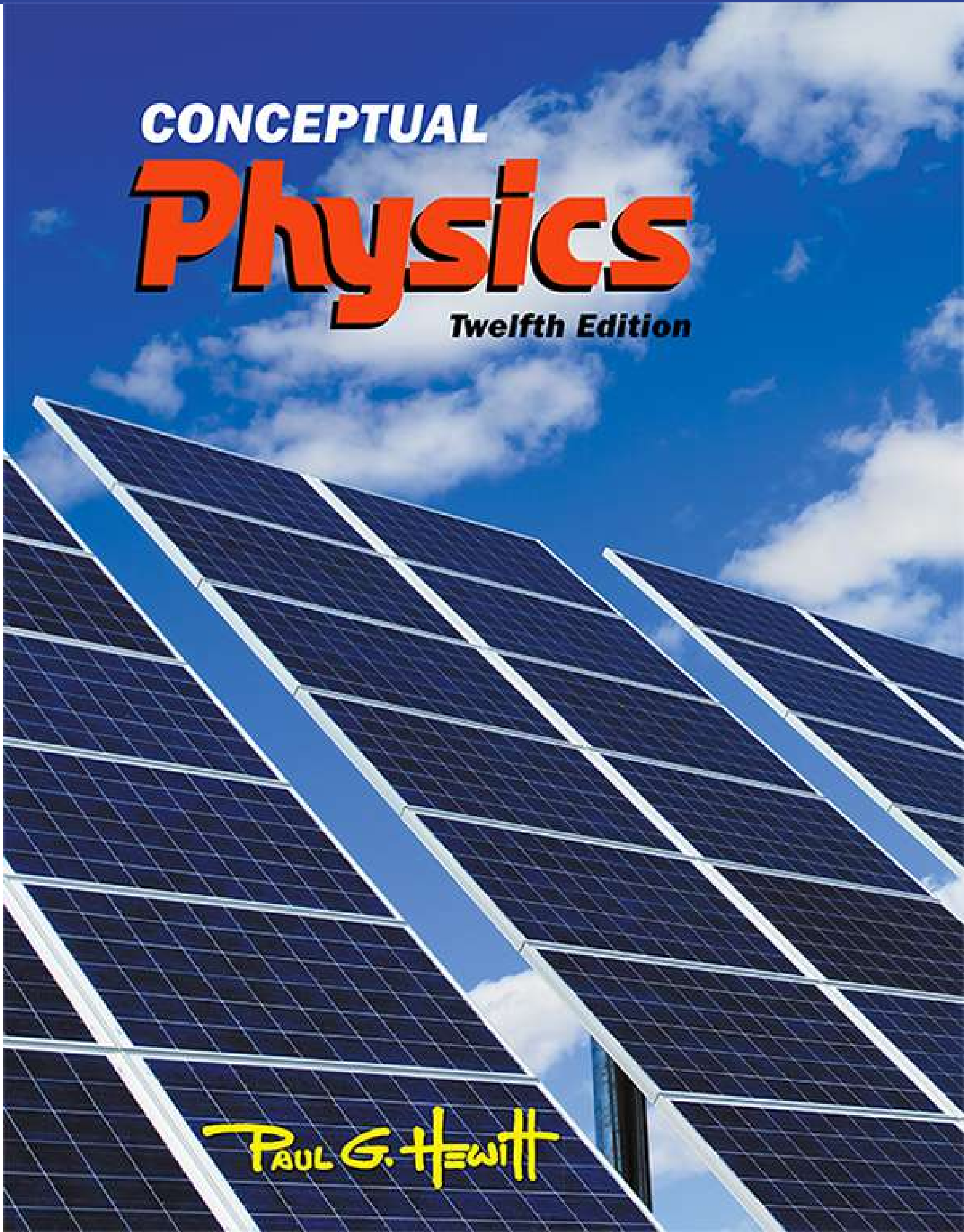
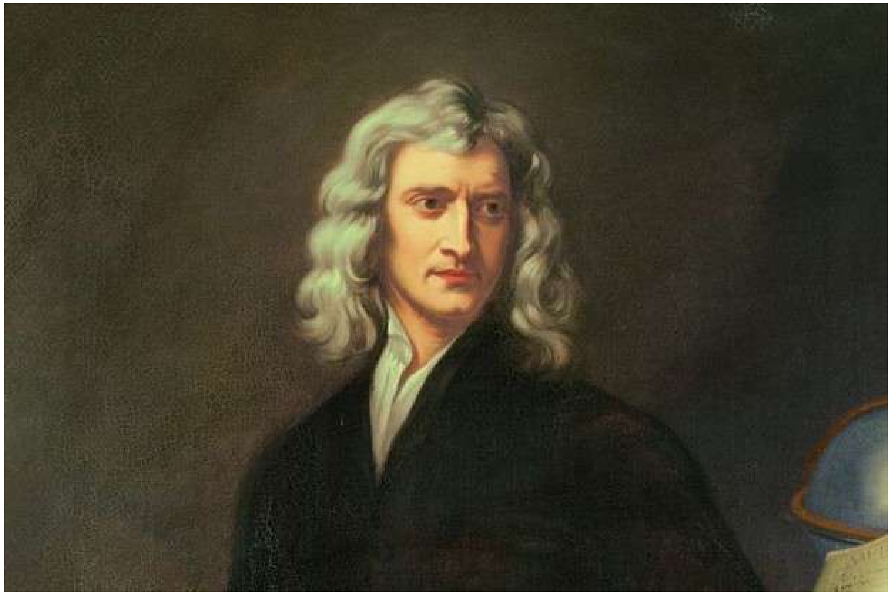
Chapter 9: Gravity



This lecture will help you understand:



- Sir
- Isaac
- Newton

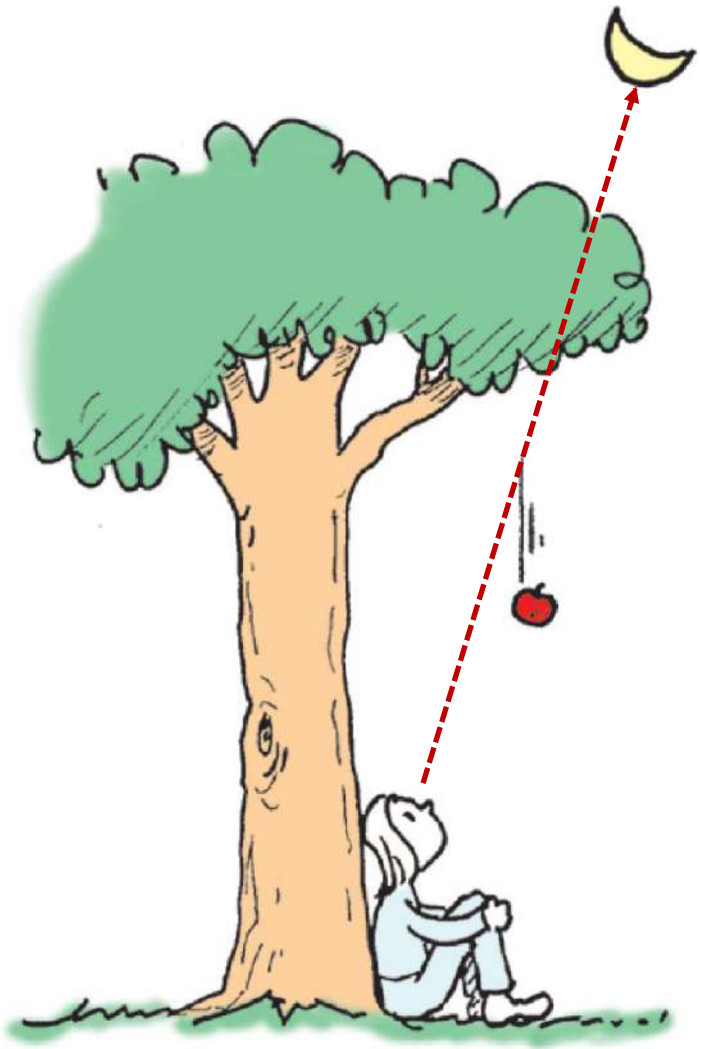
- The Newtonian Synthesis
- The Universal Law of Gravity

The Newtonian Synthesis

- Newton was not the first to discover gravity. Newton discovered that gravity is *universal*.

- Legend:

Newton, sitting under an apple tree, realizes that the Earth's pull on an apple extends also to pull on the Moon.

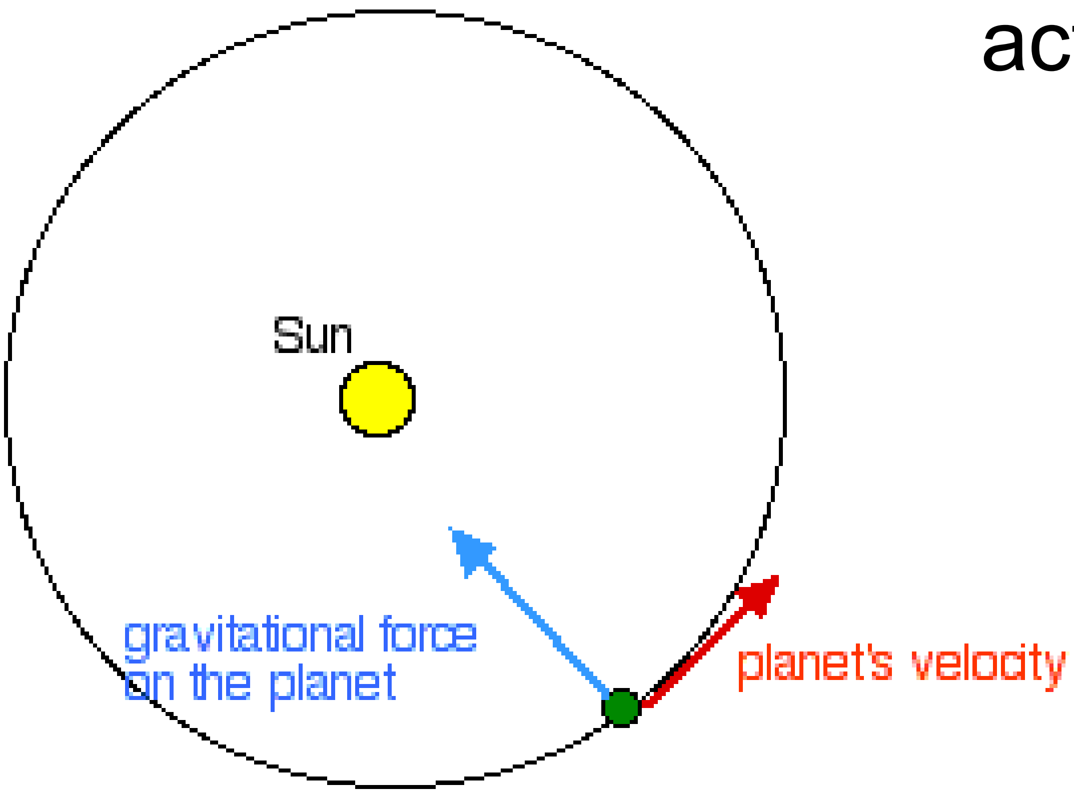


The Newtonian Synthesis, Continued

- In Aristotle's time, motion of planets and stars was *natural* – not governed by the same laws as objects on Earth.   The heavens were pure, and the motion of heavenly bodies was naturally the purest of forms: **a circle**.
- In his view, Earth's laws were different: Things fell to the ground because that was their *natural* state….to be at rest.
- Newton **synthesis** was the union of terrestrial (Earth) and cosmic (sun and planets) laws. *Gravity applied equally to Earth, sun and planets*.

Gravity causes apples to fall… Why not planets?

Newton recognized that a force directed toward the Sun must act on planets



This is similar to force that Earth exerts on an apple that falls toward it.

The Universal Law of Gravity
CHECK YOUR NEIGHBOR

Newton's most celebrated synthesis was and is of

A. earthly and heavenly laws.
B. weight on Earth and weightlessness in outer space.
C. masses and distances.
D. the paths of tossed rocks and the paths of satellites.

The Universal Law of Gravity
CHECK YOUR ANSWER

Newton's most celebrated synthesis was and is of

A. **earthly and heavenly laws.**

Comment:

This synthesis provided hope that other natural phenomena followed universal laws and ushered in the "Age of Enlightenment."

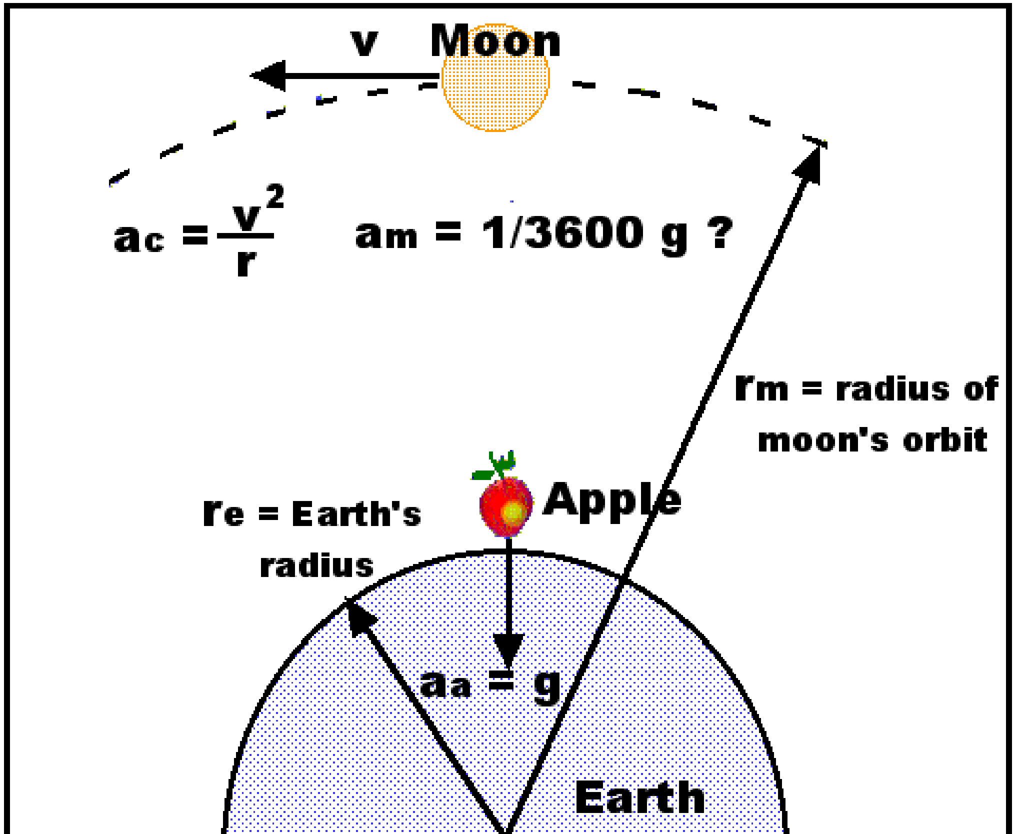
Just how do the same set of laws apply to both celestial and terrestrial objects?

The moon is 60x further from Earth's center than an apple.

The acceleration of the Moon due to gravity is:

NOT $\frac{1}{60}$ of 9.8 m/s^2,

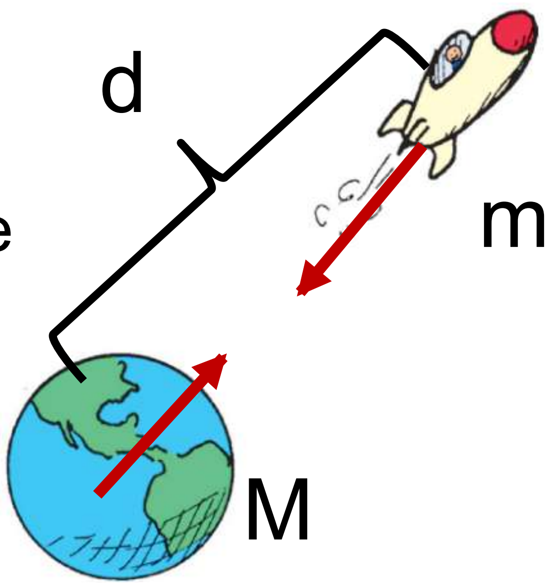
BUT $\frac{1}{60^2}$ of 9.8 m/s^2!



Does the centripetal acceleration of the moon equal the acceleration due to Earth's gravity at the moon's distance from Earth?

The Universal Law of Gravity

- Law of universal gravitation:
  - Everything pulls on everything else.
  - Every body attracts every other body with a force that is
  - a) directly proportional to the product of their masses and
  - b) inversely proportional to the square of the distance separating them.



The Universal Law of Gravity, Continued

- In equation form:

$$Force \sim \frac{mass_1 \text{ x } mass_2}{distance^2} \quad \text{or} \quad F \sim \frac{m_1 m_2}{d^2}$$

where *m* is the mass of the objects and *d* is the distance between their centers.

1. The greater the masses m_1 and m_2 of the two bodies, the **greater** the force of attraction between them.

2. The greater the distance of separation *d*, the **weaker** the force of attraction

The Universal Gravitational Constant, *G*

- Gravity is the *weakest* of four known fundamental forces
- With the gravitational constant *G*, we have the equation

$$F = G\,\frac{m_1 m_2}{d^2}$$

- Universal gravitational constant:

$$G = 6.67 \times 10^{-11}\ \mathrm{Nm^2/kg^2}$$

How does the value of G tell you that gravity is a very weak force?

It is tiny!

How do you measure this tiny constant G?

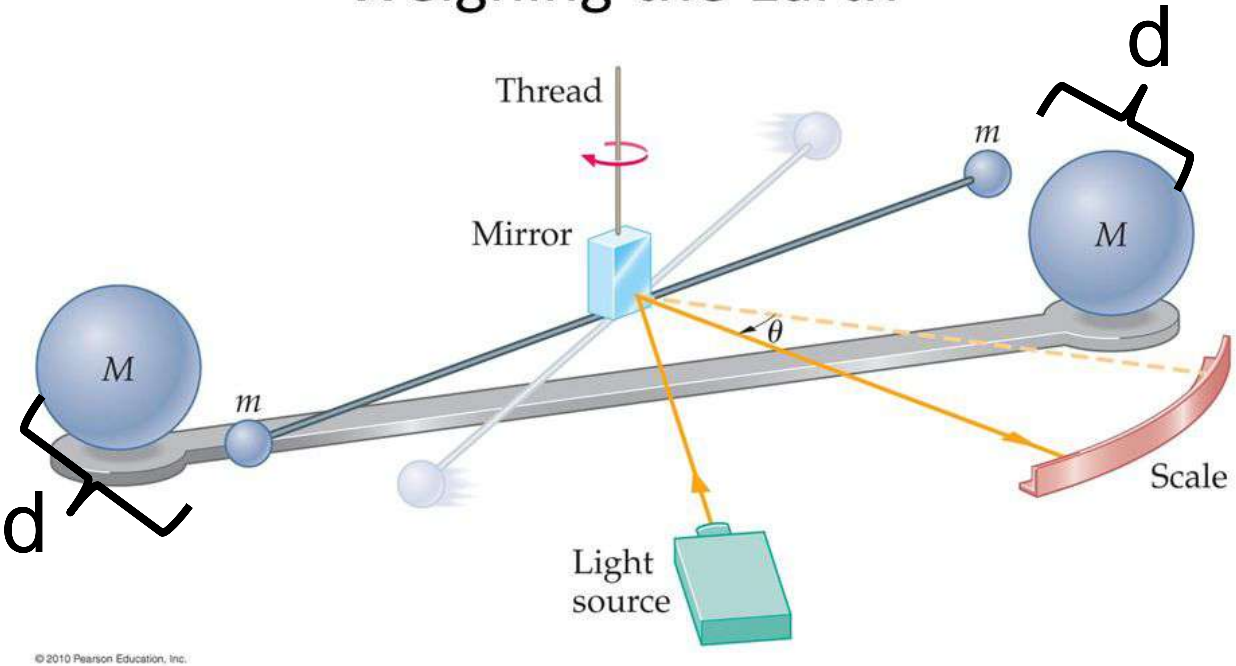
1. Measure force F caused by known masses m, M.
2. Use F, m, M and d to calculate G.

$$F = \frac{G \cdot m_1 \cdot m_2}{d^2}$$

$$F = \frac{G \cdot m \cdot M}{d^2}$$

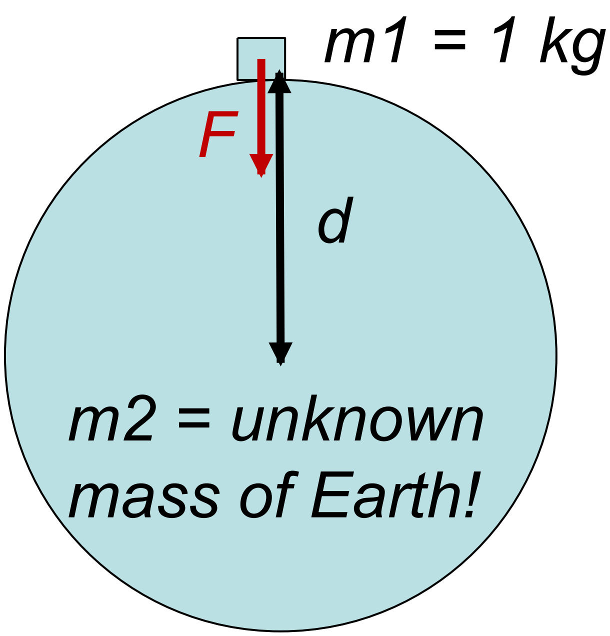
$$G = \frac{d^2 \cdot F}{m \cdot M}$$

The Cavendish Experiment –
"Weighing the Earth"



Now use the measured value of *G to calculate the mass of ("weighing") Earth!*

F = weight of m1
= 9.8 N

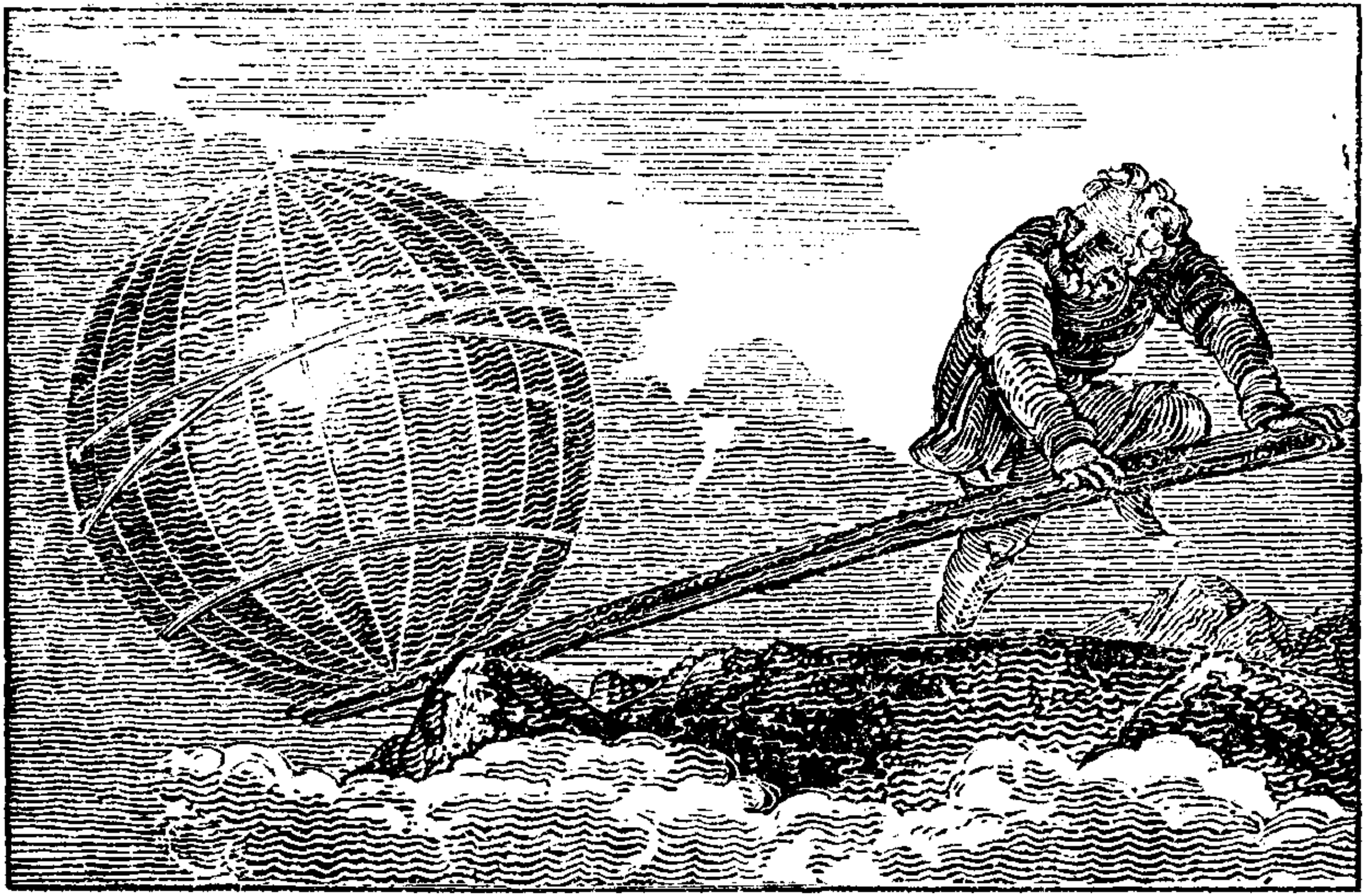


$$F = G\frac{m_1 m_2}{d^2}$$

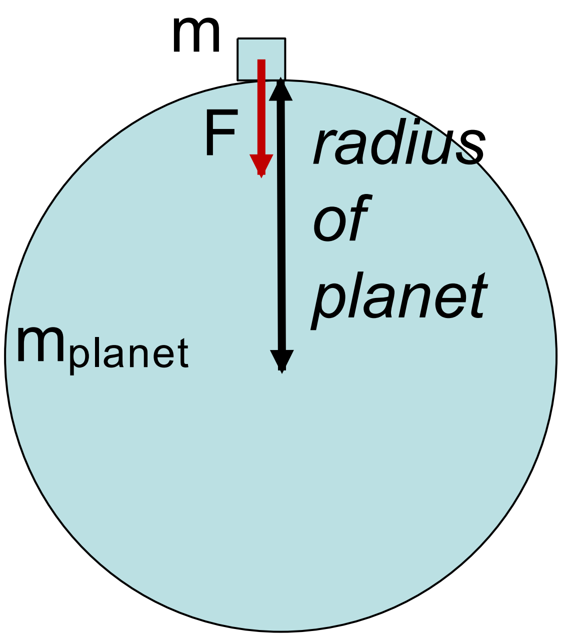
$$9.8\ \mathrm{N} = 6.67 \times 10^{-11}\,\mathrm{N{\cdot}m^2/kg^2}\,\frac{1\ \mathrm{kg} \times m_1}{(6.4 \times 10^6\ \mathrm{m})^2}$$

Solve for m2 = 6 x 10^{24} kg!

Weighing the Earth:



Ex: Little g is related to Big G!



Remember:

weight = m**g,** where g = 9.8 m/s^2

But the weight is simply the force of gravity F that a planet exerts on a mass:

$$F = \frac{Gm_1m_2}{d^2}$$

$$F = \frac{G \cdot m \cdot m_{planet}}{radius\ of\ planet^2}$$

$$g = \frac{G \cdot m_{planet}}{radius\ of\ planet^2}$$

= 9.8 m/s^2 for Earth

= different on other planets…

CHECK POINT

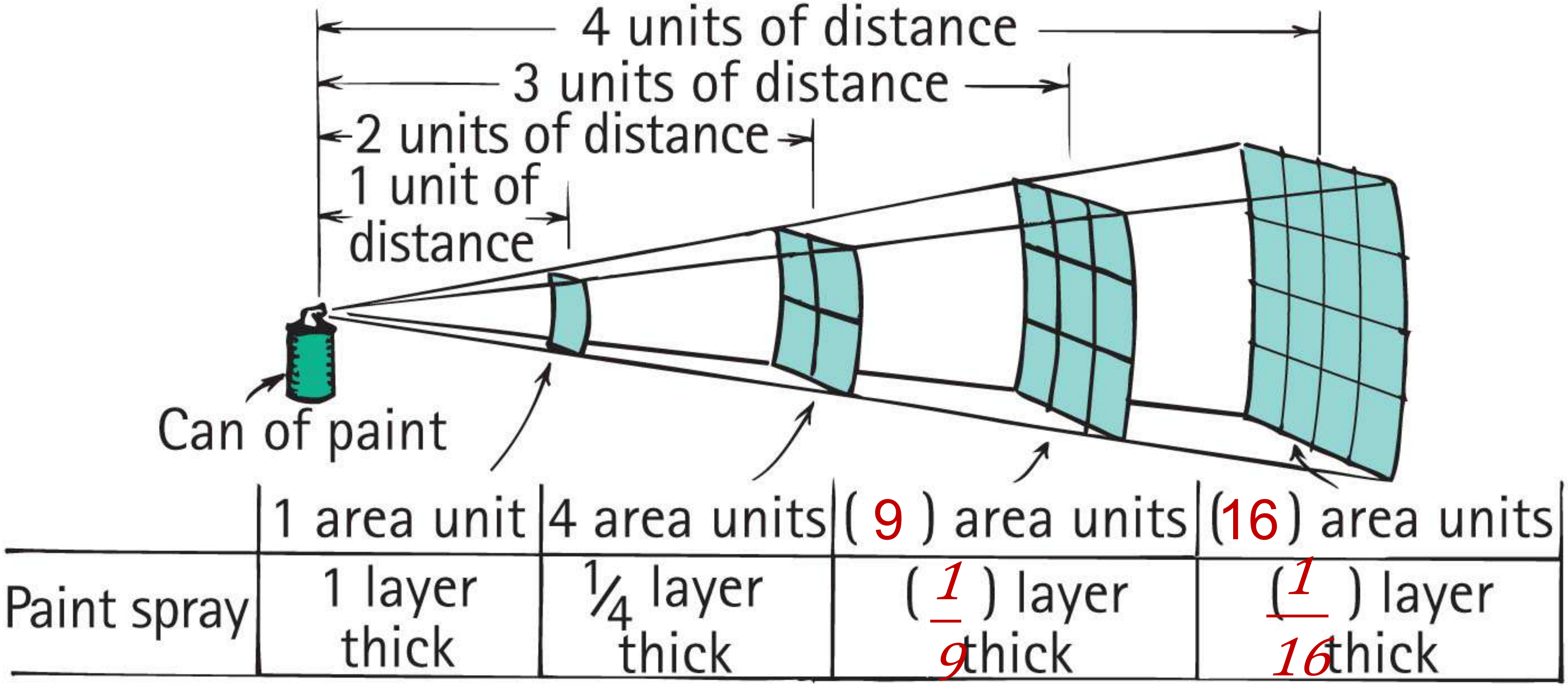
If there is an attractive force between all objects, why don't we feel ourselves gravitating toward massive buildings in our vicinity?

Gravity and Distance: The Inverse-Square Law

$$F = \frac{Gm_1m_2}{d^2}$$

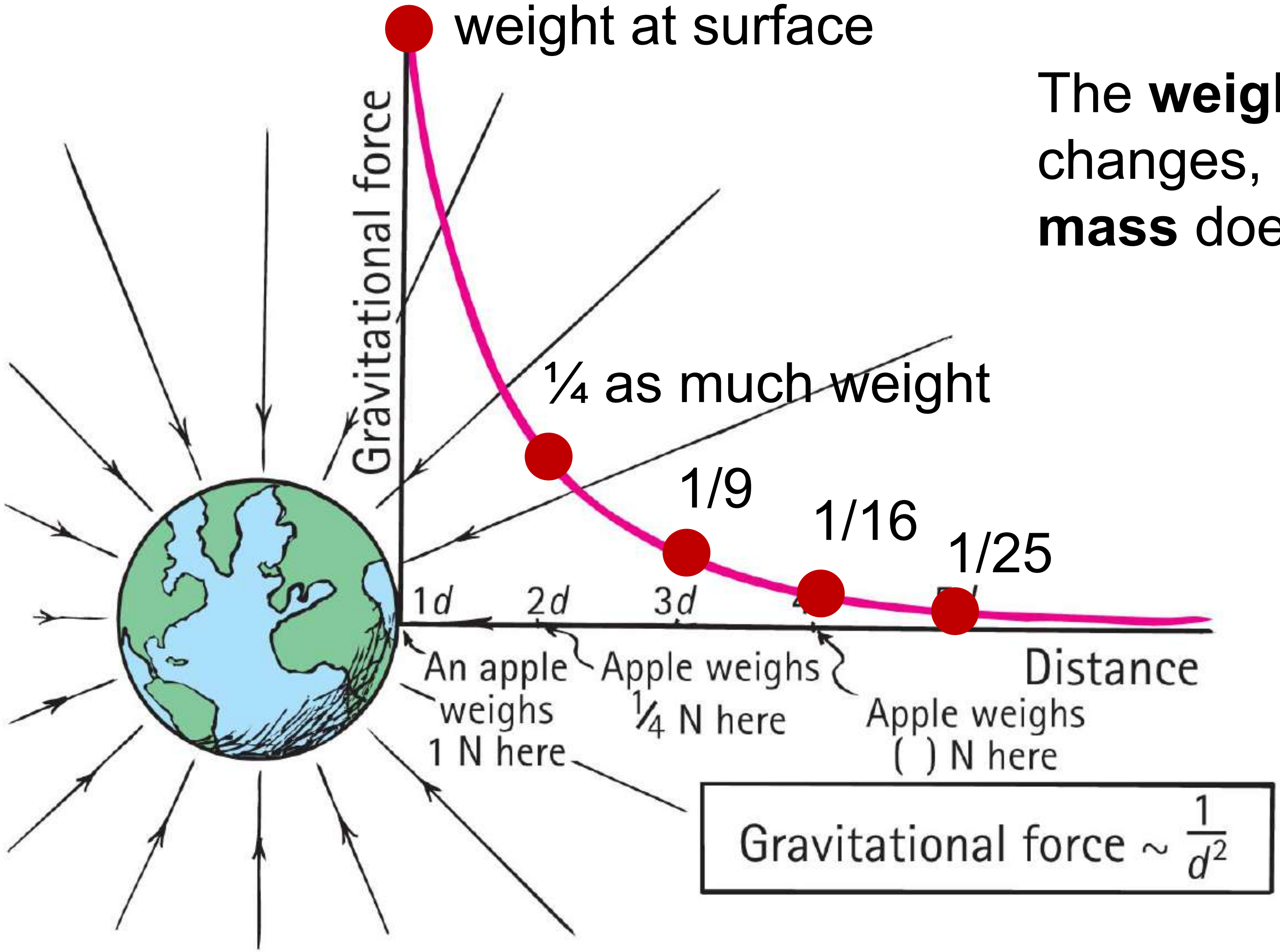
- Inverse-square law:
  - relates the intensity of an effect to the inverse-square of the distance from the cause.
  - in equation form: *intensity* = 1/*distance*^{2}.
  - As distance increases, force decreases.
  - even at great distances, force approaches but never reaches zero.

Inverse-Square Law



This law applies to light, the electric force and gravity!

Inverse-Square Law for Gravity on Earth:



The **weight** changes, but the **mass** does not.

Inverse-Square Law, Continued

A scholar weighs 800 N on Earth's surface. What will he weigh at..

…2x the distance?

$\frac{1}{4}$ of 800 N = 200 N

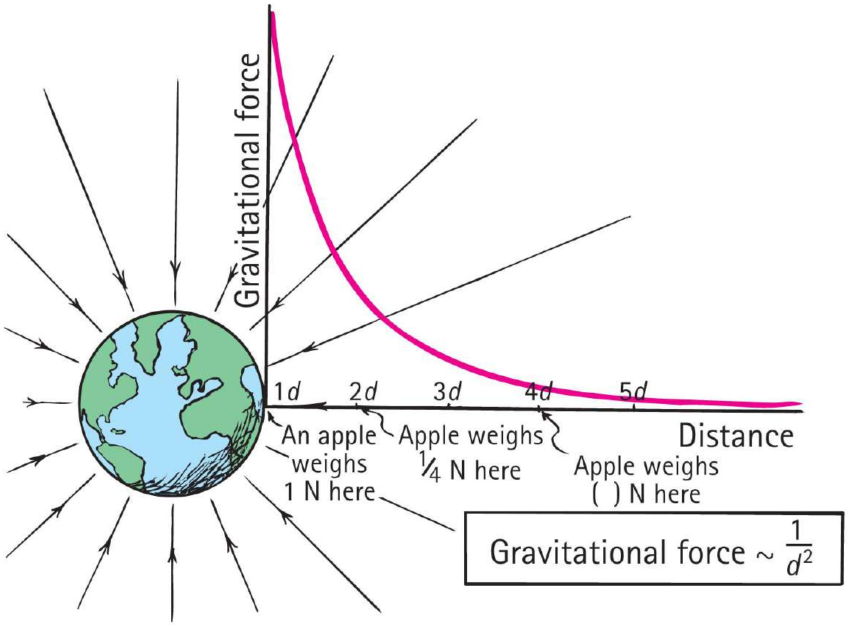
…3x the distance?

$\frac{1}{9}$ of 800 N = 89 N

….4x the distance?

$\frac{1}{16}$ of 800 N = 50 N

Does the force ever equal zero? no



CHECK POINT

1. By how much does the gravitational force between two objects decrease when the distance between their centers is doubled? Tripled? Increased tenfold?

2. Consider an apple at the top of a tree that is pulled by Earth's gravity with a force of 1 N. If the tree is twice as tall, will the force of gravity be 1/4 as strong? Defend your answer.

3. A child weighs 300 N at sea level. About how much does she weigh on top of Mt. Everest?

Gravity and Distance: The Inverse-Square Law
CHECK YOUR NEIGHBOR

The force of gravity between two planets depends on their

A. masses and distance apart.
B. planetary atmospheres.
C. rotational motions.
D. All of the above.

Gravity and Distance: The Inverse-Square Law
CHECK YOUR ANSWER

The force of gravity between two planets depends on their

A. masses and distance apart.

Explanation:

The equation for gravitational force, cites only masses and distances as variables. Rotation and atmospheres are irrelevant.

$$F = G\frac{m_1 m_2}{d^2}$$

Gravity and Distance: The Inverse-Square Law CHECK YOUR NEIGHBOR, Continued

If the masses of two planets are each somehow doubled, the force of gravity between them

A. doubles.
B. quadruples.
C. reduces by half.
D. reduces by one-quarter.

Gravity and Distance: The Inverse-Square Law CHECK YOUR ANSWER, Continued

If the masses of two planets are each somehow doubled, the force of gravity between them

B. quadruples.

Explanation:

Note that both masses double.

Then, double x double = quadruple

$$F = G\,\frac{m_1 m_2}{d^2}$$

Gravity and Distance: The Inverse-Square Law CHECK YOUR NEIGHBOR, Continued-1

If the mass of one planet is somehow doubled, the force of gravity between it and a neighboring planet

A. doubles.
B. quadruples
C. reduces by half.
D. reduces by one-quarter.

Gravity and Distance: The Inverse-Square Law CHECK YOUR ANSWER, Continued-1

If the mass of one planet is somehow doubled, the force of gravity between it and a neighboring planet

A. doubles.

Explanation:

Let the equation guide your thinking:
Note that if one mass doubles, then the force between them doubles.

$$F = G\frac{m_1 m_2}{d^2}$$

CHECK POINT

1. In Figure 9.2, we see that the Moon falls around Earth rather than straight into it. If the Moon's tangential velocity were zero, how would it move?

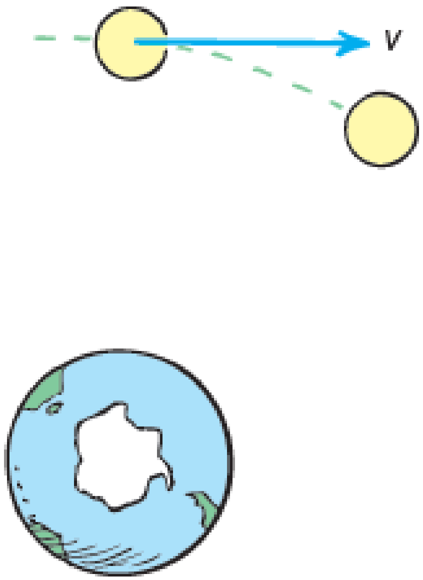
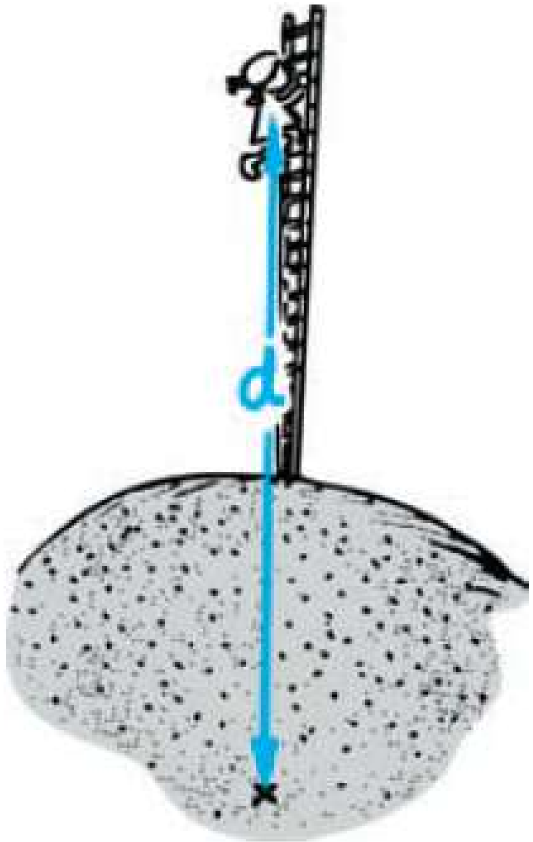


FIGURE 9.2
The tangential velocity of the Moon about Earth allows it to fall around Earth rather than directly into it. If this tangential velocity were reduced to zero, what would be the fate of the Moon?

Ex. A scholar weighs 400 N on Earth. She climbs a tall ladder so that she is 1 Earth radius above the surface:

How much does her weight change by?

How much does her mass change?



Take out a sheet of paper. Write the answers to these questions on it.

1. What did Newton discover about gravity?

2. What is the Newtonian synthesis?

3. In what sense does the Moon "fall"?

4. State Newton's law of universal gravitation in words. Then do the same with one equation.

5. What is the magnitude of the gravitational force between two 1-kg bodies that are 1 m apart?

6. What is the magnitude of Earth's gravitational force on a 1-kg body at Earth's surface?

7. When *G* was first measured by Henry Cavendish, newspapers of the time hailed his experiment as the "weighing Earth experiment." Why?

8. How does the force of gravity between two bodies change when the distance between them is doubled?

9. How does the thickness of paint sprayed on a surface change when the sprayer is held twice as far away?

10. Where do you weigh more: at the bottom of Death Valley or atop one of the peaks of the Sierra Nevada? Why?

Now take a photo of your paper.

Upload it to the Assignment in Teams by the end of the hour.