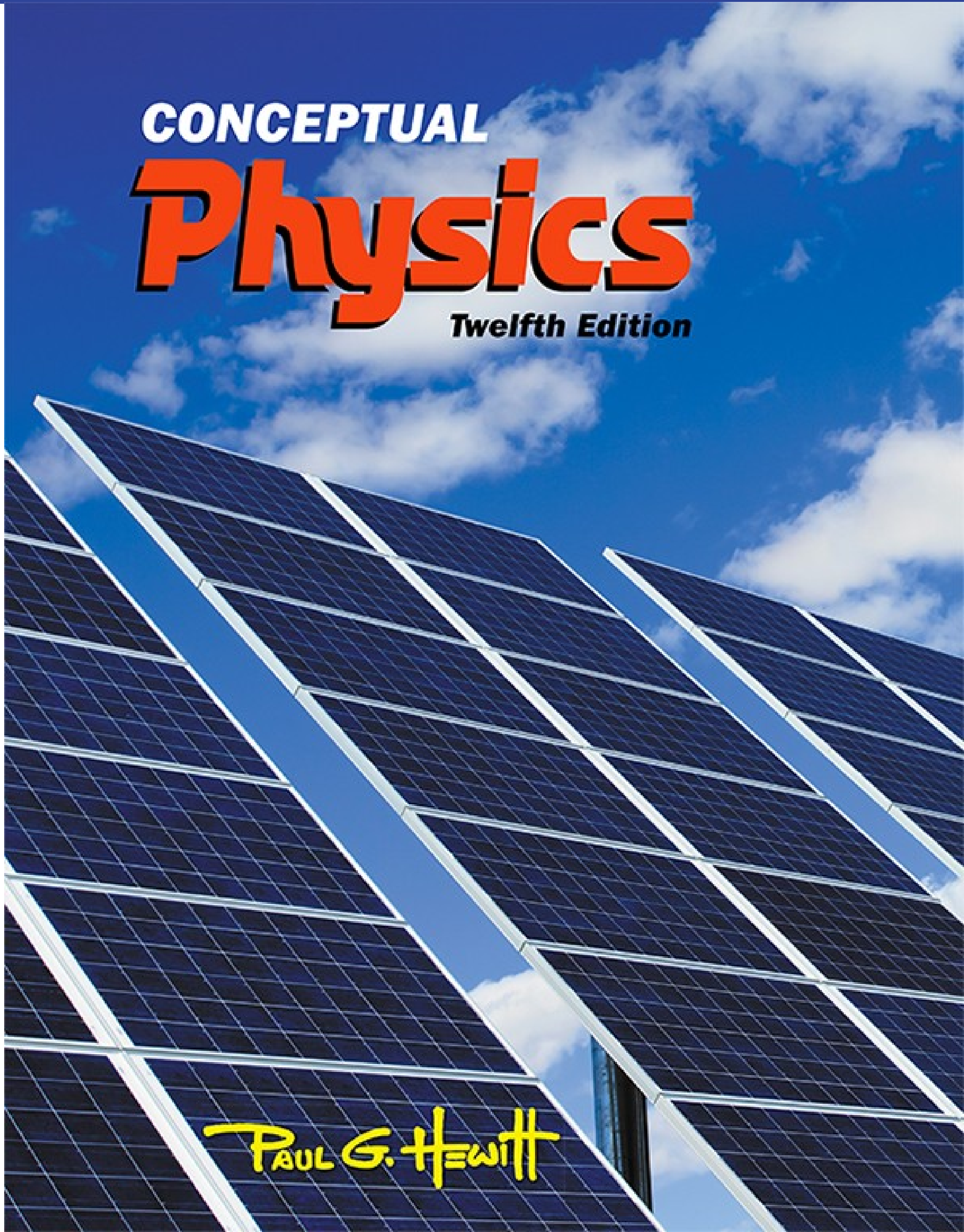
Lecture Outline

Chapter 9: Gravity

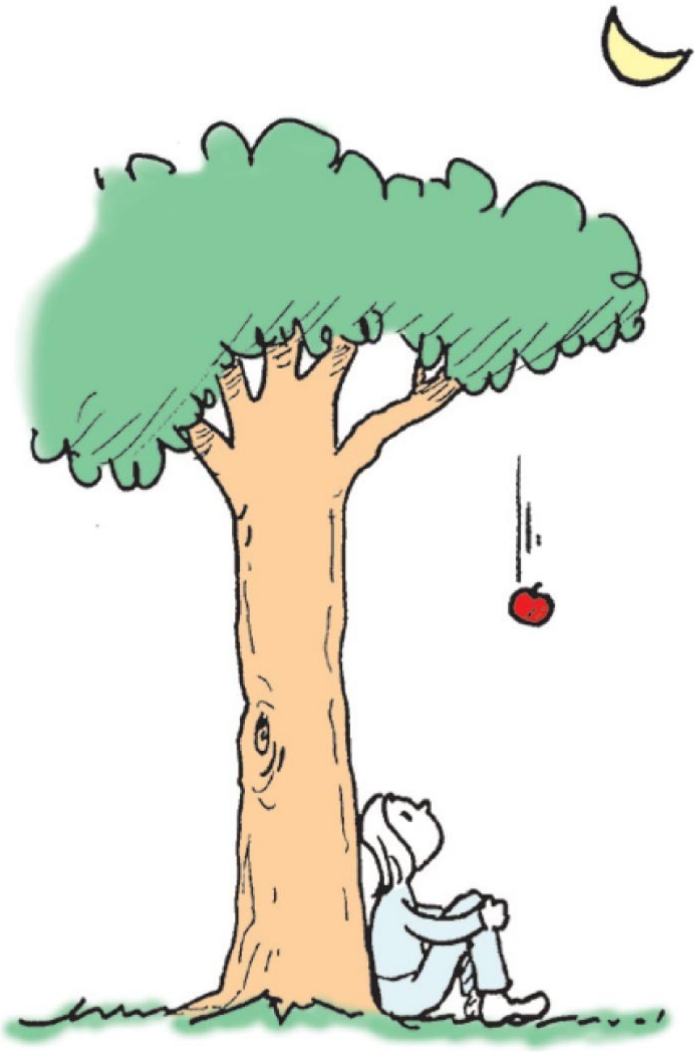


This lecture will help you understand:

- The Newtonian Synthesis
- The Universal Law of Gravity
- The Universal Gravitational Constant
- Gravity and Distance: Inverse-Square Law
- Weight and Weightlessness
- Ocean Tides
- Gravitational Fields
- Einstein's Theory of Gravitation
- Black Holes
- Universal Gravitation

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.

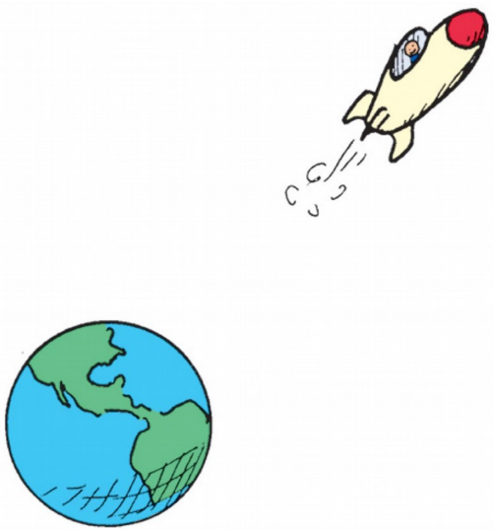


The Newtonian Synthesis, Continued

- In Aristotle's time, motion of planets and stars was *natural* – not governed by the same laws as objects on Earth.
- 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.
- Newtonian synthesis: The same set of laws apply to both celestial and terrestrial objects.

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 directly proportional to the product of their masses and inversely proportional to the square of the distance separating them.



The Universal Law of Gravity, Continued

- In equation form:

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

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

- Examples:
  - The greater the masses m_1 and m_2 of two bodies, the greater the force of attraction between them.
  - The greater the distance of separation *d*, the weaker the force of attraction

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."

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:
  $G = 6.67 \times 10^{-11}\ \mathrm{Nm^2/kg^2}$
- Once the value was known, the mass of Earth was calculated as 6×10^{24} kg

The Universal Gravitational Constant, *G*
CHECK YOUR NEIGHBOR

The universal gravitational constant, *G*, which links force to mass and distance, is similar to the familiar constant

A. π.
B. g.
C. acceleration due to gravity.
D. speed of uniform motion.

The Universal Gravitational Constant, *G*
CHECK YOUR ANSWER

The universal gravitational constant, *G*, which links force to mass and distance, is similar to the familiar constant

A. **π.**

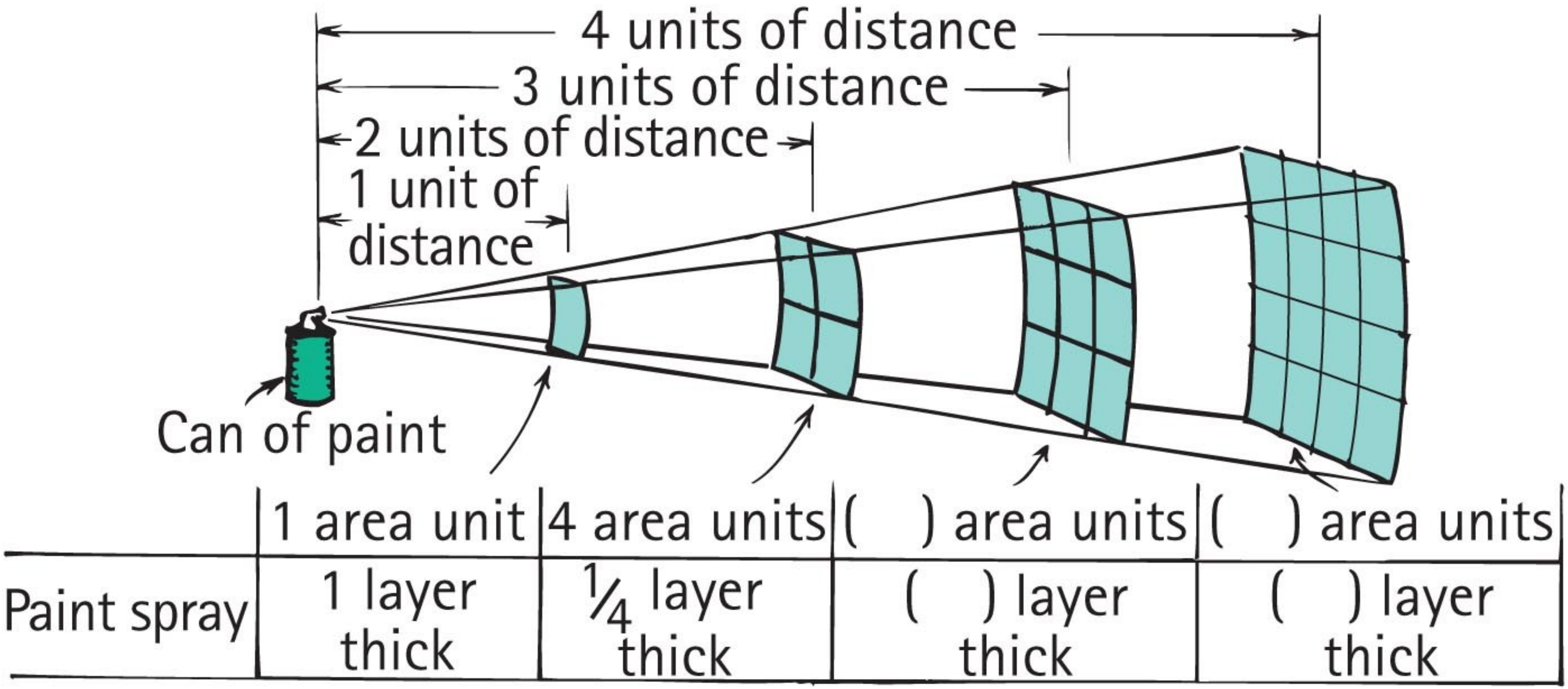
Explanation:

Just as π relates the circumference of a circle to its diameter, *G* relates force to mass and distance.

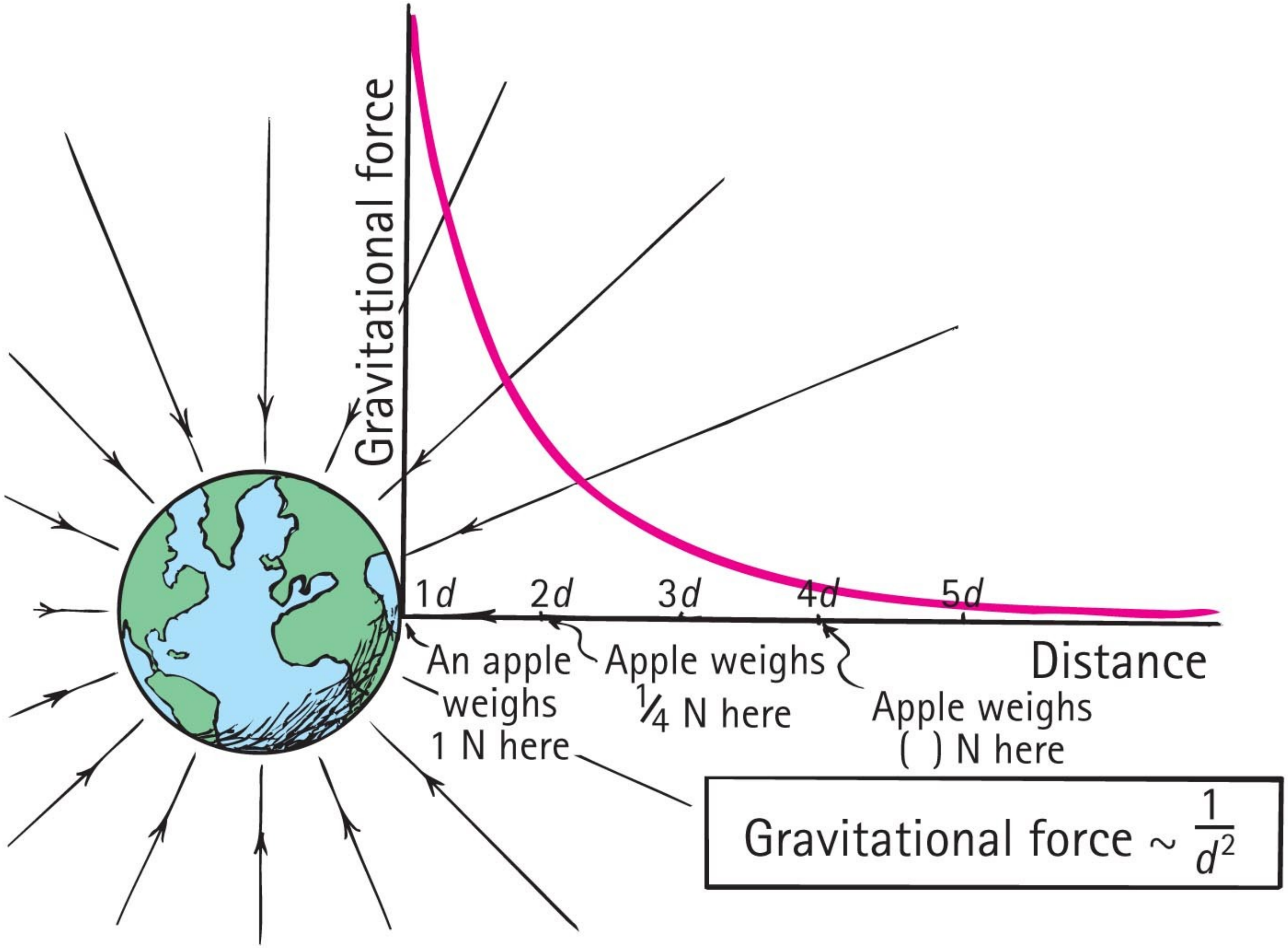
Gravity and Distance: The Inverse-Square Law

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

Inverse-Square Law



Inverse-Square Law, Continued



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.

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.

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

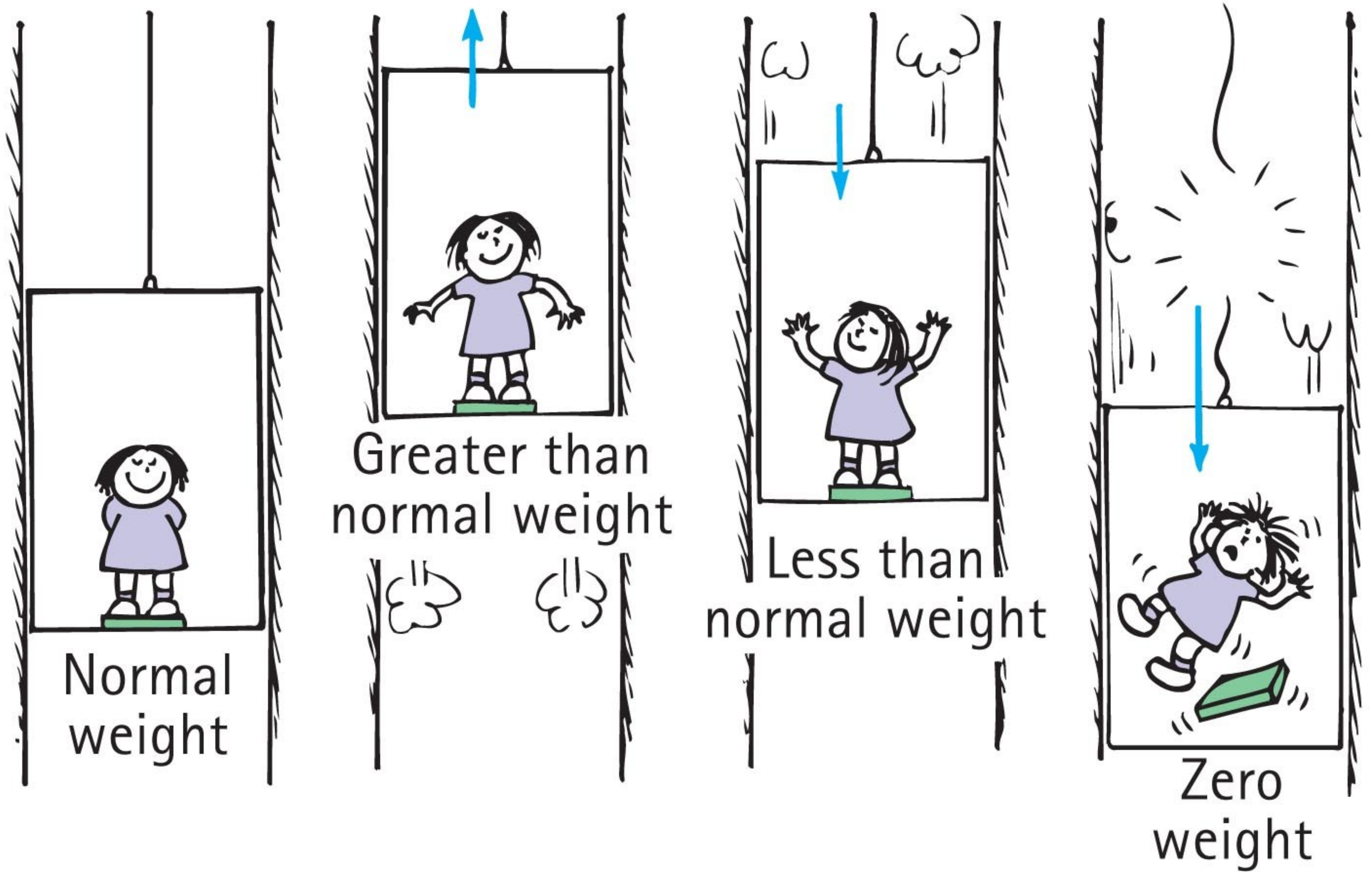
Weight and Weightlessness

- Weight:
  - force an object exerts against a supporting surface
  - Examples:
    - standing on a scale in an elevator accelerating downward, less compression in scale springs; weight is less
    - standing on a scale in an elevator accelerating upward, more compression in scale springs; weight is greater
    - at constant speed in an elevator, no change in weight

Weight and Weightlessness, Continued

- Weightlessness:
  - no support force, as in free fall
  - Example: Astronauts in orbit are without support forces and are in a continual state of weightlessness.

Weight and Weightlessness, Continued-1



Weight and Weightlessness
CHECK YOUR NEIGHBOR

When an elevator accelerates upward, your weight reading on a scale is

A. greater.
B. less.
C. zero.
D. the normal weight.

Weight and Weightlessness
CHECK YOUR ANSWER

When an elevator accelerates upward, your weight reading on a scale is

A. greater.

Explanation:

The support force pressing on you is greater, so you weigh more.

Weight and Weightlessness
CHECK YOUR NEIGHBOR, Continued

When an elevator accelerates downward, your weight reading is

A. greater.
B. less.
C. zero.
D. the normal weight.

Weight and Weightlessness
CHECK YOUR ANSWER, Continued

When an elevator accelerates downward, your weight reading is

B. less.

Explanation:

The support force pressing on you is less, so you weigh less. Question: Would you weigh less in an elevator that moves downward at constant velocity?

Weight and Weightlessness
CHECK YOUR NEIGHBOR, Continued-1

When the elevator cable breaks, the elevator falls freely, so your weight reading is

A. greater.
B. less.
C. zero.
D. the normal weight.

Weight and Weightlessness
CHECK YOUR ANSWER, Continued-1

When the elevator cable breaks, the elevator falls freely, so your weight reading is

C. **zero.**

Explanation:

There is still a downward gravitational force acting on you, but gravity is not felt as weight because there is no support force, so your weight is zero.

Weight and Weightlessness
CHECK YOUR NEIGHBOR, Continued-2

If you weigh yourself in an elevator, you'll weigh more when the elevator

A. moves upward.
B. moves downward.
C. accelerates upward.
D. All of the above.

Weight and Weightlessness
CHECK YOUR ANSWER, Continued-2

If you weigh yourself in an elevator, you'll weigh more when the elevator

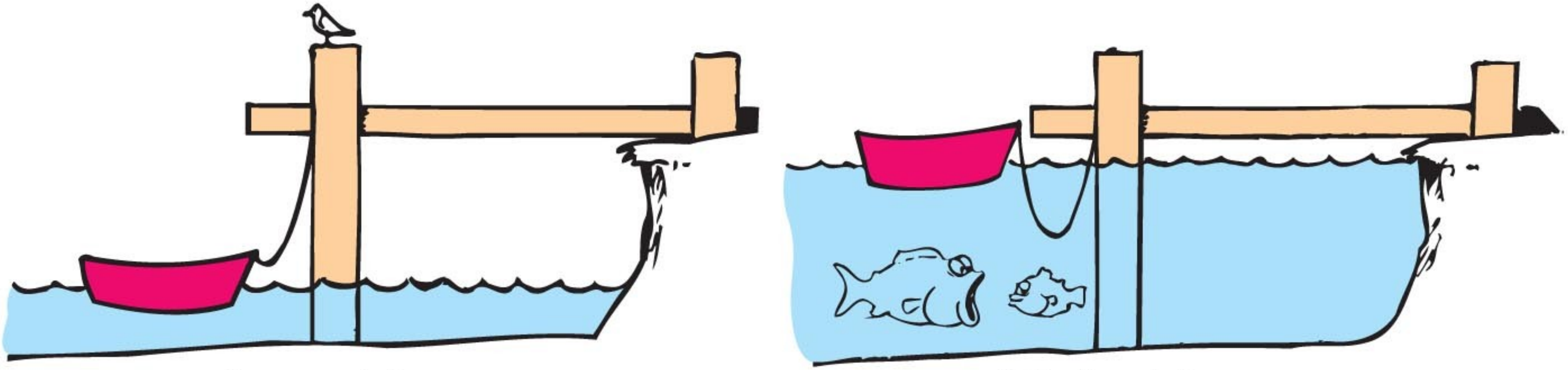
A. accelerates upward.

Explanation:

The support provided by the floor of an elevator is the same whether the elevator is at rest or moving at constant velocity. Only accelerated motion affects weight.

Ocean Tides

- The differences between ocean levels at different times of the day are called tides.



- There are typically two high tides and two low tides each day.

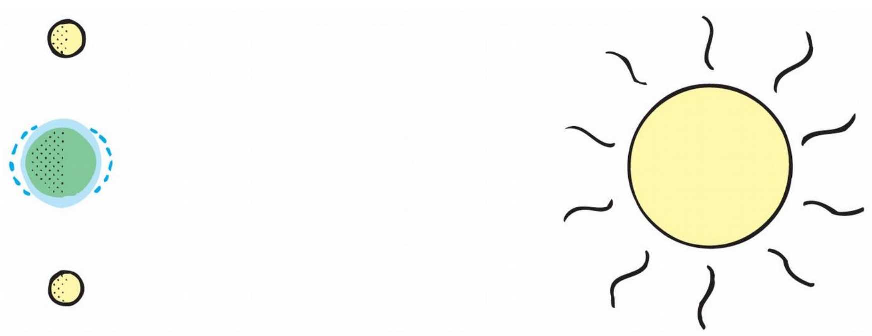
Ocean Tides, Continued

- Ocean tides are caused due to the gravitational attraction of the Moon.
- Unequal tugs on Earth's oceans causes a stretching effect that produces a pair of ocean bulges.
  - Because the two bulges are on opposite sides, high tides occur every 12 hours.

Ocean Tides, Continued-1

- During the new Moon or full Moon, the effects of Moon and Sun add up, causing most pronounced **spring tides.**

- When the Moon is halfway between a new and full Moon, the tides due to Sun and Moon partly cancel each other, causing least pronounced **neap tides.**

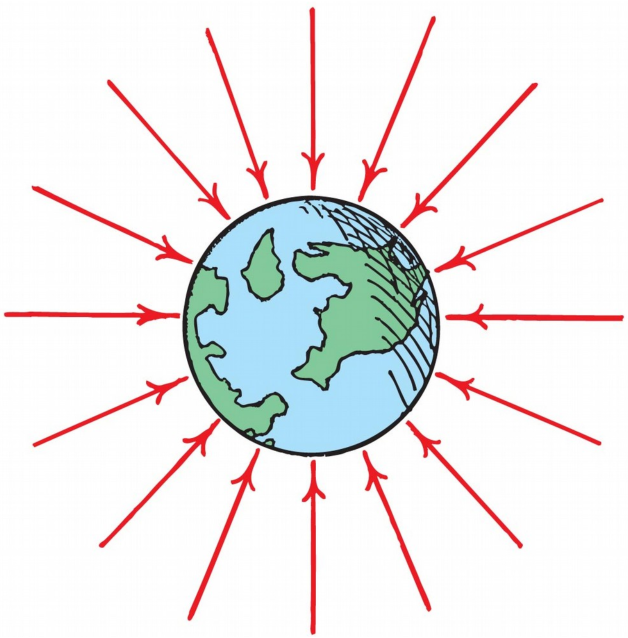


Gravitational Fields

- Interaction between Earth and Moon is *action at a distance*. How do they interact without touching?
- One way to think of this:
  - Earth is surrounded by a *gravitational field*.
  - Moon interacts with this *gravitational field*.
- **Gravitational field** is an alteration of space around Earth (or any object with mass).
  - Gravitational field is an example of a *force field* (another example: magnetic field).

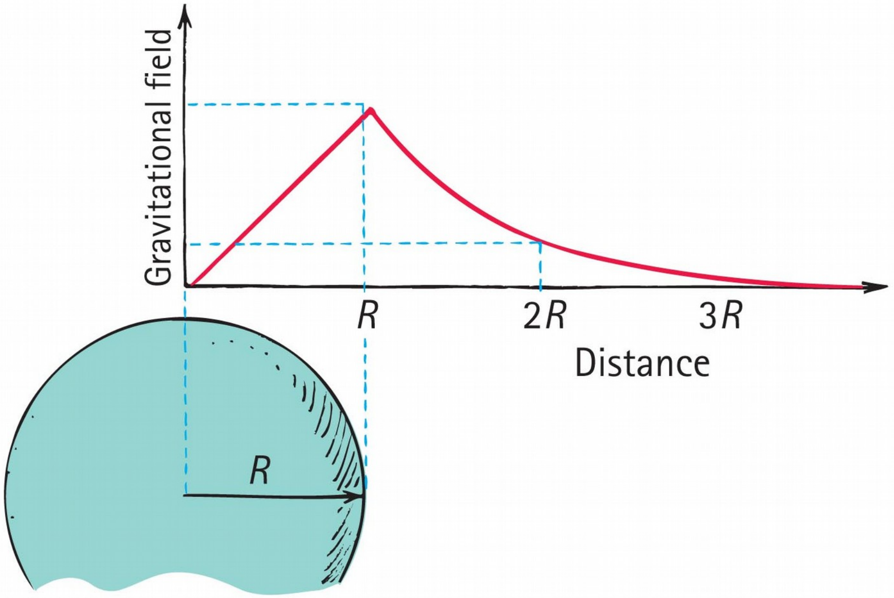
Gravitational Fields, Continued

- Fields are represented by field lines radiating into the object (Earth).
- The inward direction of arrows indicates that the force is always attractive to Earth.
- The crowding of arrows closer to Earth indicates that the magnitude of the force is larger closer to Earth.



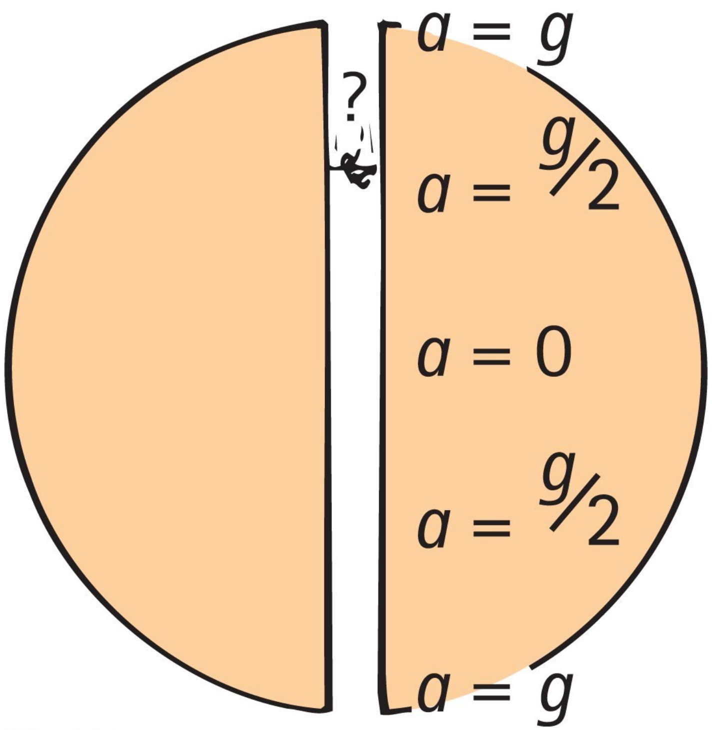
Gravitational Fields, Continued-1

- Inside a planet, it decreases to zero at the center
  - because pull from the mass of Earth below you is partly balanced by what is above you.
- Outside a planet, it decreases to zero (not at the same rate as inside), at infinity
  - because you are farther away from planet.

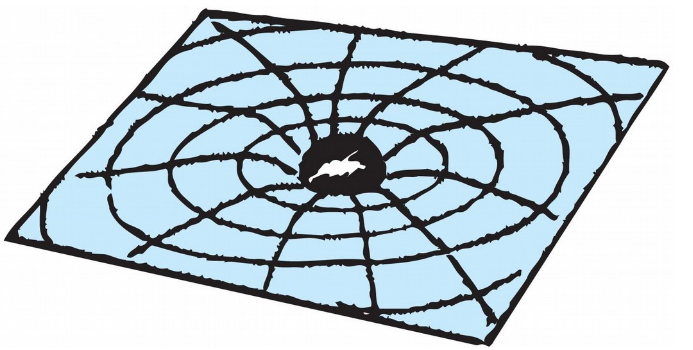


Gravitational Fields, Continued-2

- Suppose you dig a hole through Earth to the other side and jump through it.
- As you fall, your acceleration toward the center will go on decreasing.
- At the center, your acceleration will be zero.
- Past the center you will be pulled back up, but because you have acquired sufficient speed you will get to the other side.



Einstein's Theory of Gravitation



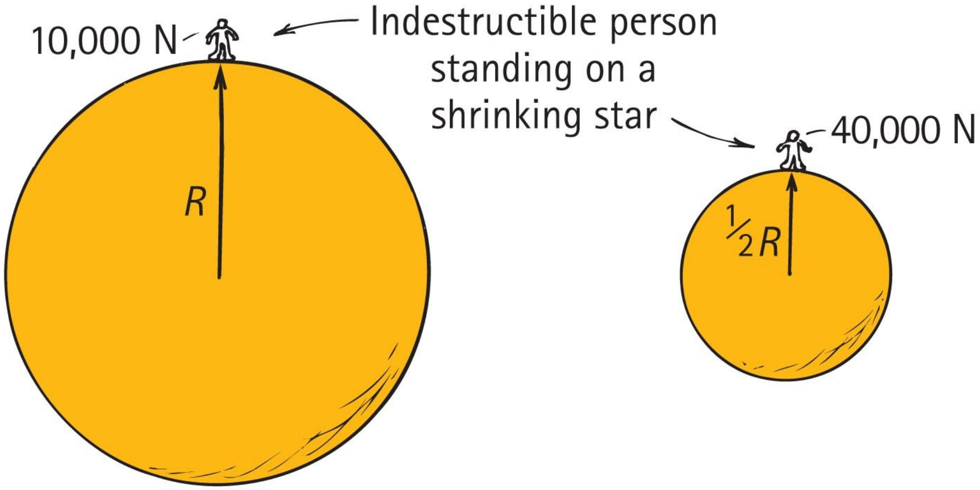
- Gravitational field is a warping of *space-time* by a planet
  - just as a massive ball would make a dent on the surface of a waterbed.
- The warped space-time affects the motion of other objects
  - just as a marble rolling on the waterbed "gravitates" to the dent.

Black Holes

- When a star shrinks, all of its mass is now concentrated in a smaller radius.
- So gravitational force on the surface increases because

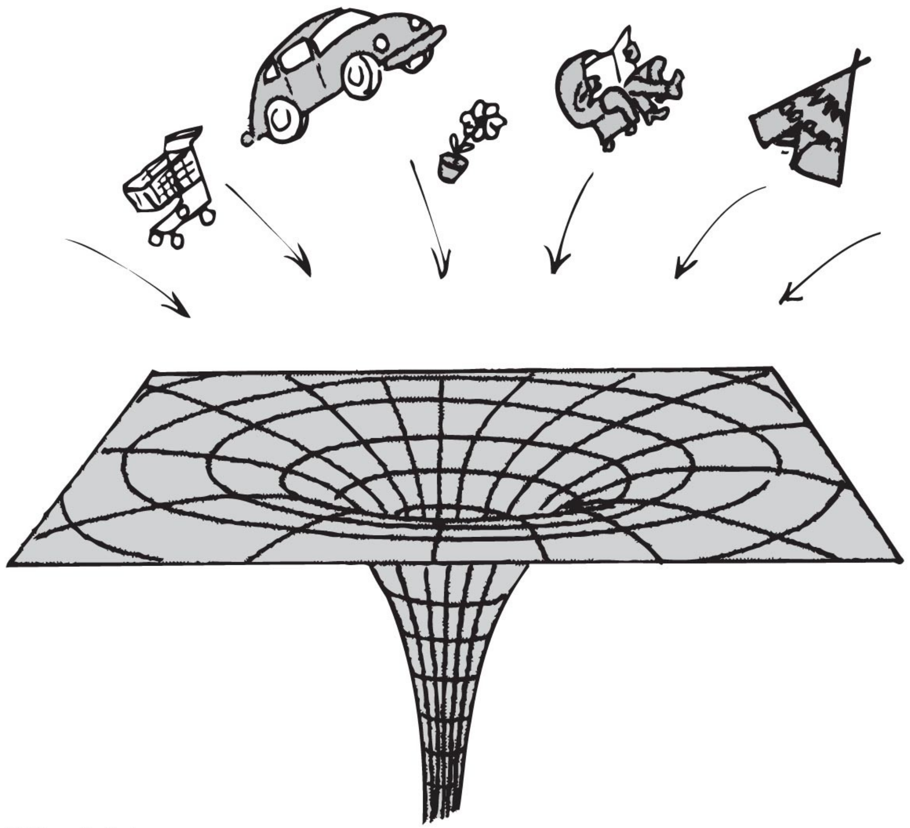
$$F = G\frac{m_1 m_2}{d^2}$$

When *d* decreases, *F* increases.



Black Holes, Continued

- **Black Hole**: When the star becomes so small and the gravitational force at the surface becomes so large that even light cannot escape the surface, anything in its vicinity will be attracted by warped space-time and lost forever.



Black Holes
CHECK YOUR NEIGHBOR

What would happen to Earth if the Sun became a black hole?

A. It would break away from the attraction of the Sun.
B. It would be pulled into the Sun.
C. It would become a black hole too.
D. None of the above.

Black Holes
CHECK YOUR ANSWER

What would happen to Earth if the Sun became a black hole?

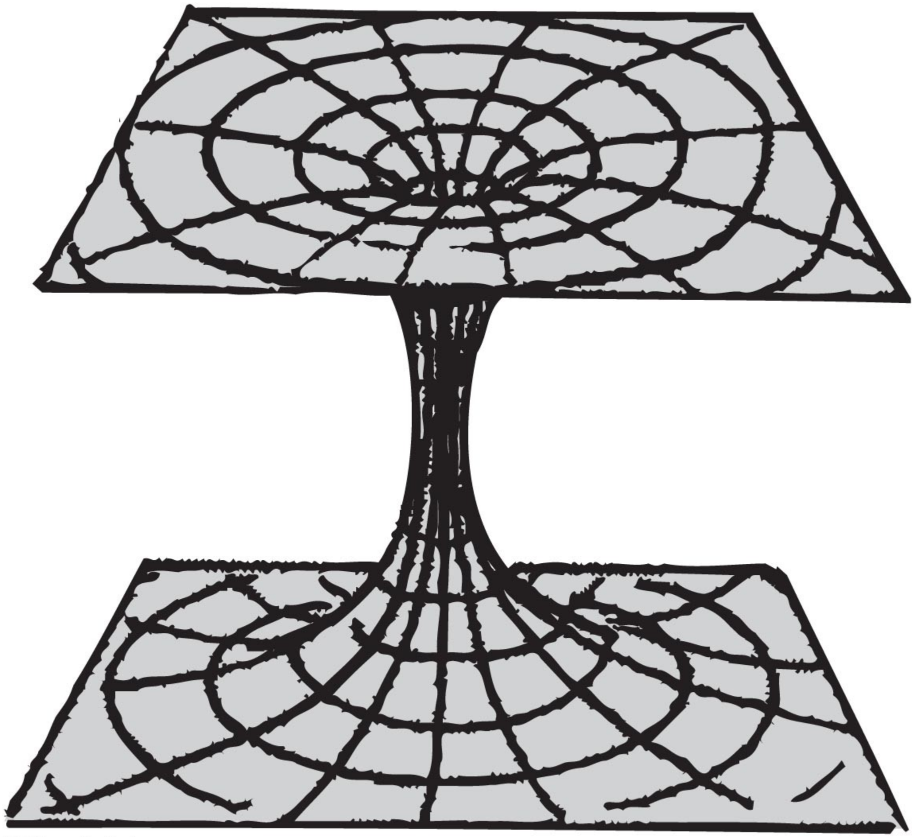
D. **None of the above.**

Explanation:

Letting the equation for gravity guide our thinking, we see that no mass changes, no distance from center to center changes, so there would be NO change in force between the shrunken Sun and Earth.

Wormhole

- **Wormhole**: An enormous distortion of space-time,
  - but instead of collapsing toward an infinitely dense point, the wormhole opens out again in some other part of the universe or different universe!
  - No wormholes have been found yet.



Universal Gravitation

- Universal gravitation
- Everything attracts everything else.
  - Example: Earth is round because of gravitation—all parts of Earth have been pulled in, making the surface equidistant from the center.
- The universe is expanding and accelerating outward.