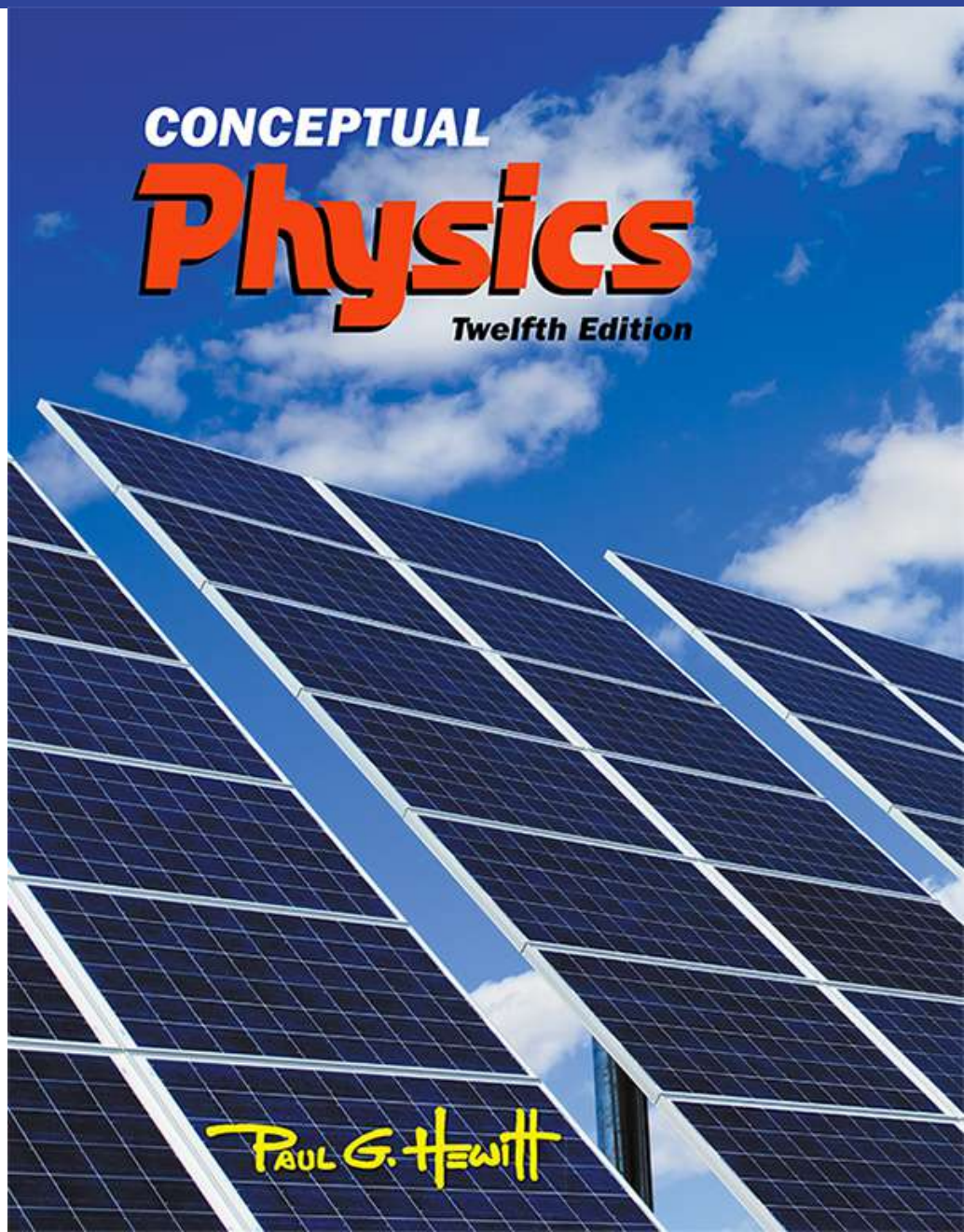
Lecture Outline

Chapter 9: Gravity

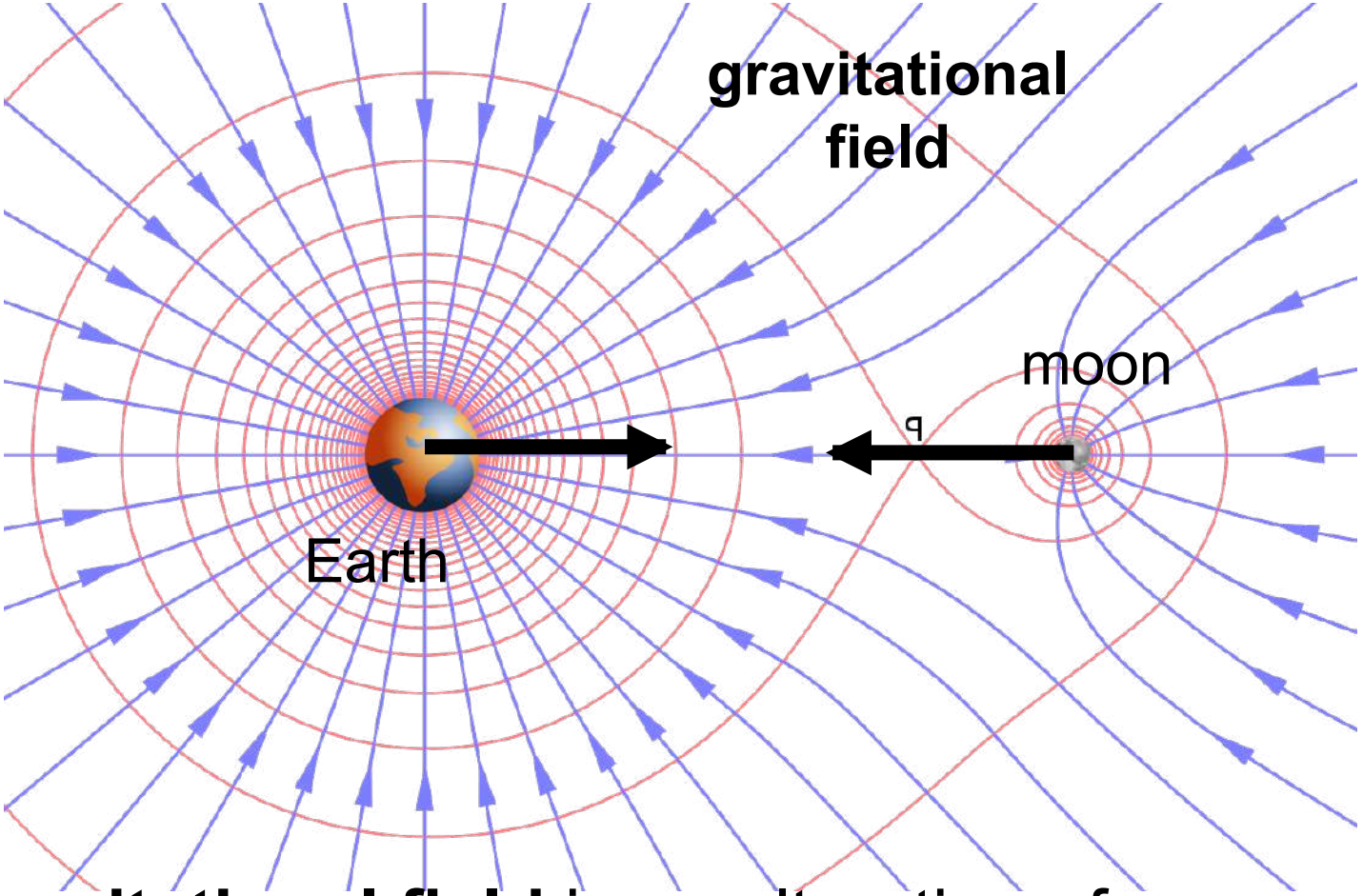
Sections 6-8
Fields
Einstein's Gravity
Black Holes
Universal Gravity



Gravitational Fields

- Interaction between Earth and Moon is *action at a distance*. How do they interact without touching?
-

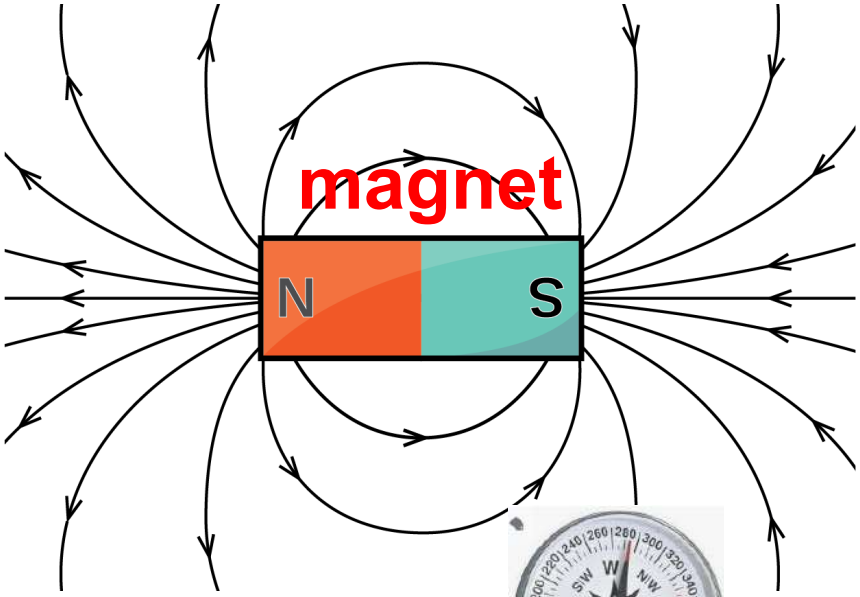
The gravitational field of Earth and Moon interact to produce a mutual attraction:



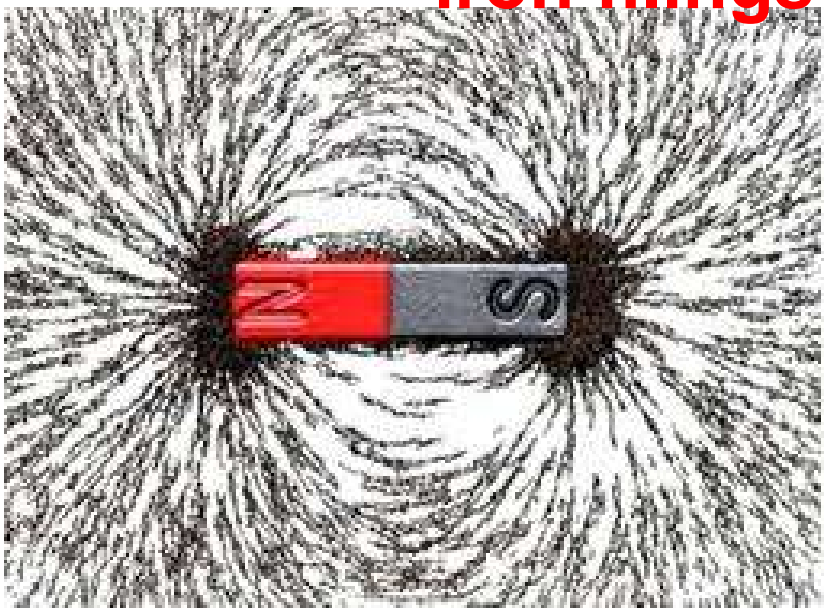
- **Gravitational field** is an alteration of space around Earth (or any object with mass).

Other Fields

- Gravitational field is an example of a *force field*
  Another example is a magnet's **magnetic field**



iron filings

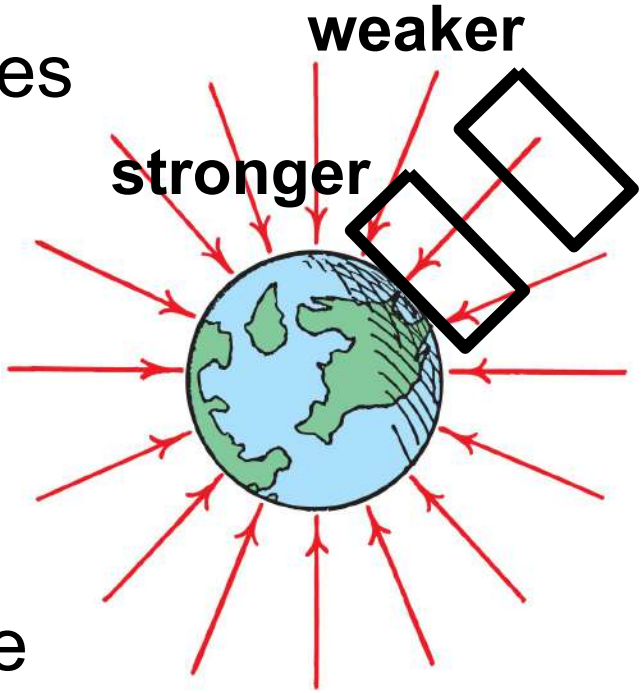


compass

A compass or iron filings placed in the magnet's field will interact with the field like Moon with Earth's field.

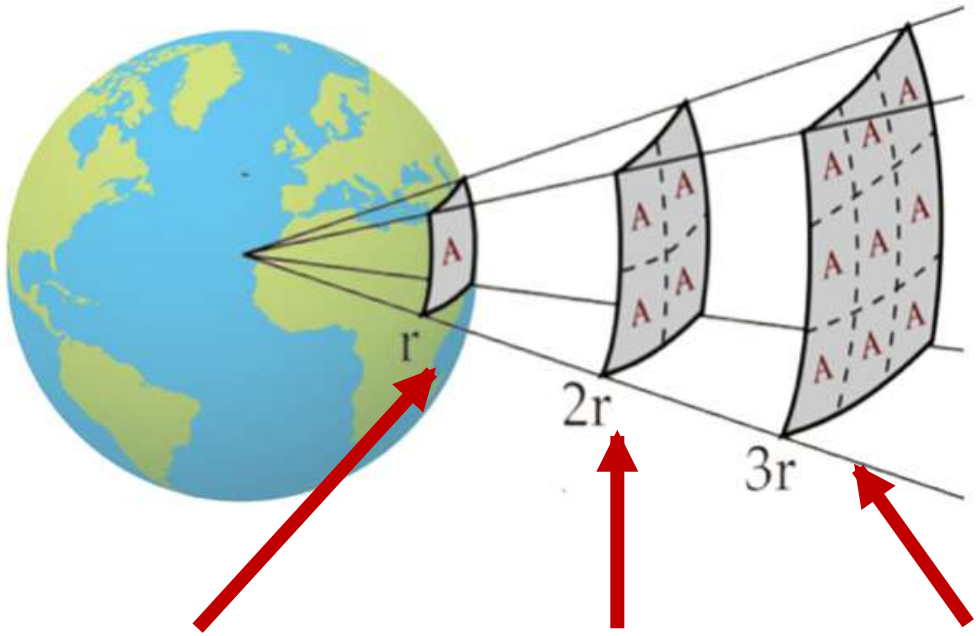
Gravitational Fields, Continued

- 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.
- Closer arrows → stronger field
- Further arrows → weaker field



To test how strong the field is—drop an object. Its acceleration = strength of field!

Outside the planet, this strength decreases according to the inverse square law:



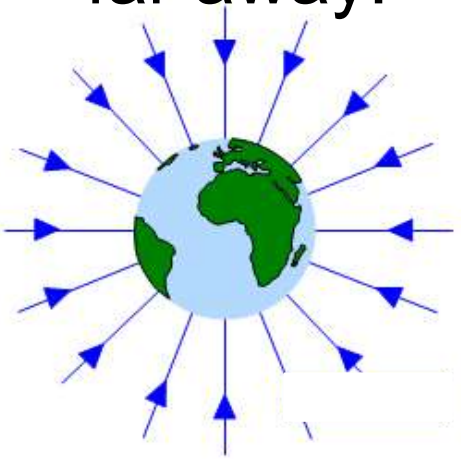
$g = 9.8\ m/s^2$

$\frac{1}{2^2} \cdot g = \frac{g}{4}$

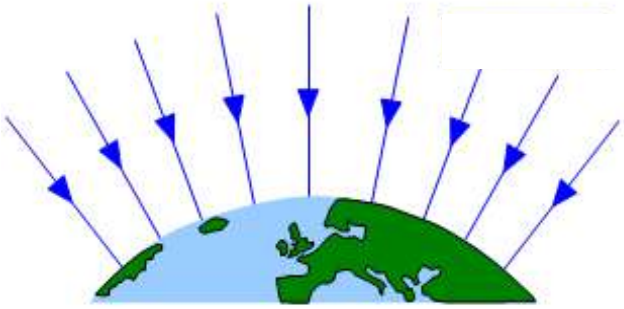
$\frac{1}{3^2} \cdot g = \frac{g}{9}$

As you get closer to the surface….

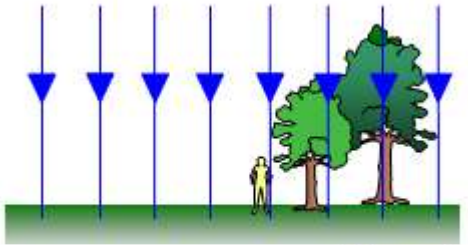
far away:



nearer:



At surface

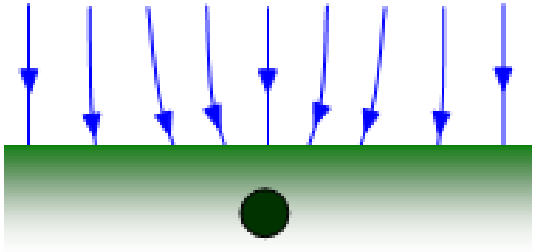


constant

At Earth's surface the field is nearly constant and equal to ≈ 10 m/s^2.

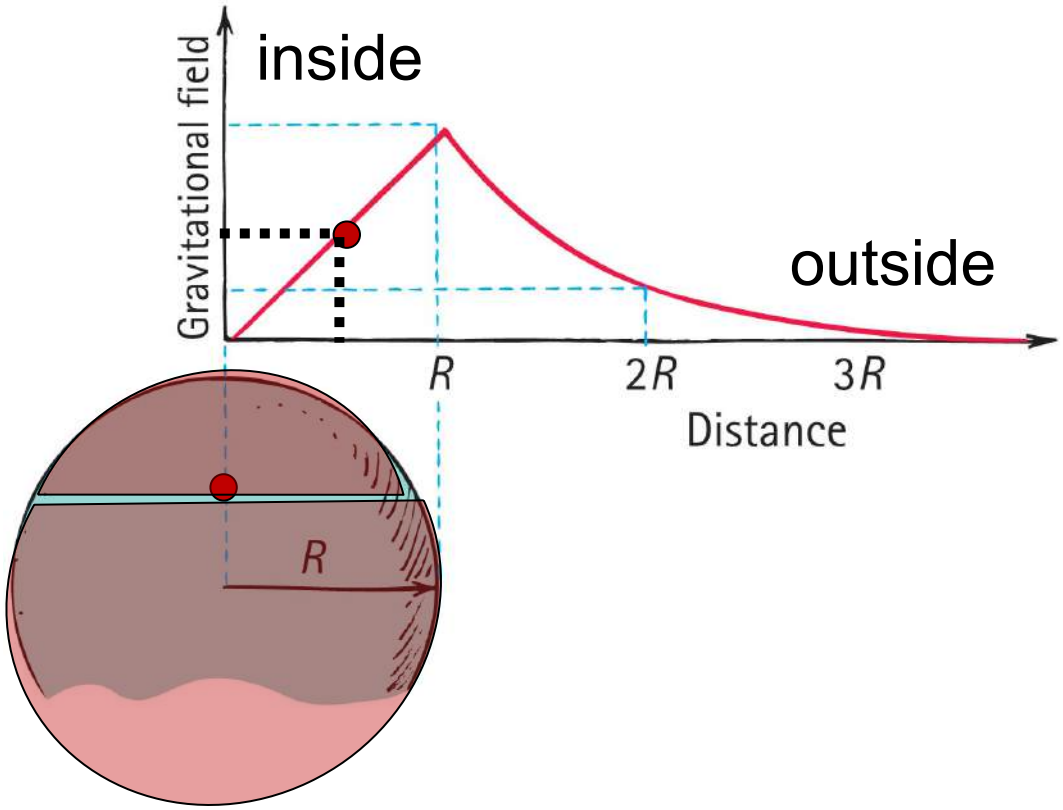
But it is stronger near dense metal deposits or weaker near large caverns.

This helps geologists find oil and minerals.



Gravitational Fields: Inside Earth and Out

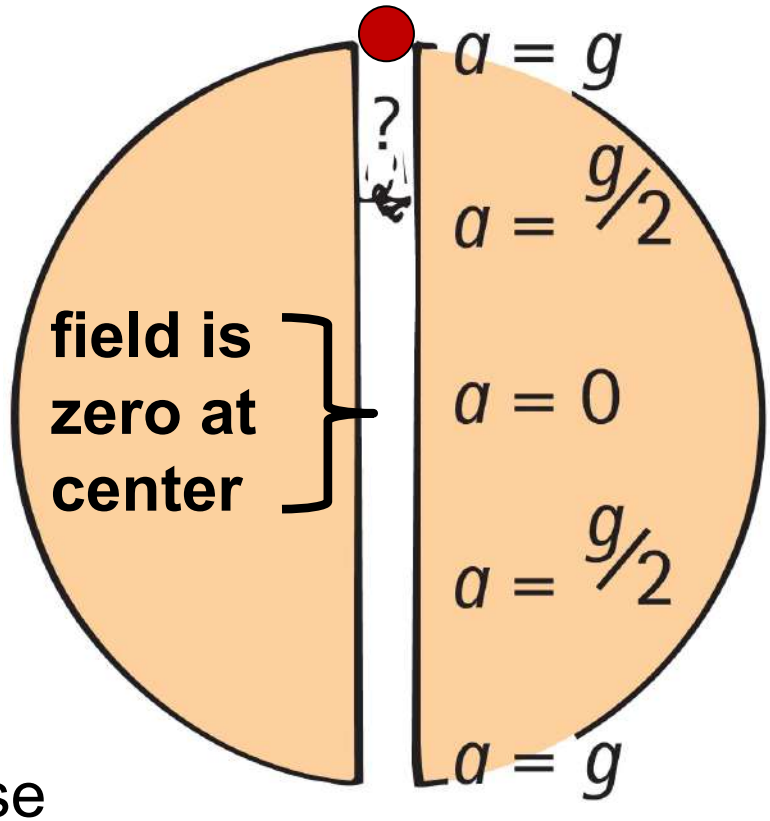
- Inside a planet, g decreases **to zero** at the center
  - because pull from the mass of Earth below you is partly balanced by what is above you.
  - **Half way down it is half of 9.8 m/s^2.**



- Outside a planet, it decreases towards zero (not at the same rate as inside).

Gravitational Fields, Continued-2

- Suppose you dig a hole through Earth to the other side and jump through it.
- As you fall toward the center, your acceleration decreases.
- At the center, your acceleration will be zero because you are pulled equally in all directions.
- But your speed is greatest there!
- Past the center you will be pulled back towards the center, but because you have acquired sufficient speed you will get to the other side.



Gravitational field inside a planet that is a hollow, thin shell of mass:

Look at point P.

Then look at areas A and B, which are part of the surface of the shell.

Area B has less mass than A, *but it is closer*.

So attraction from A and B are equal.

The field is zero.

Everywhere.

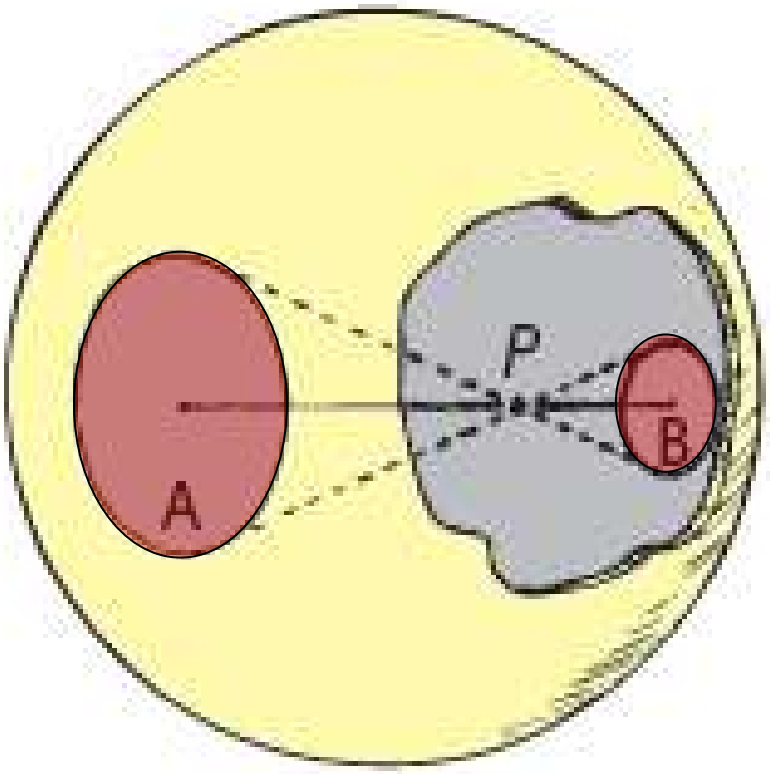


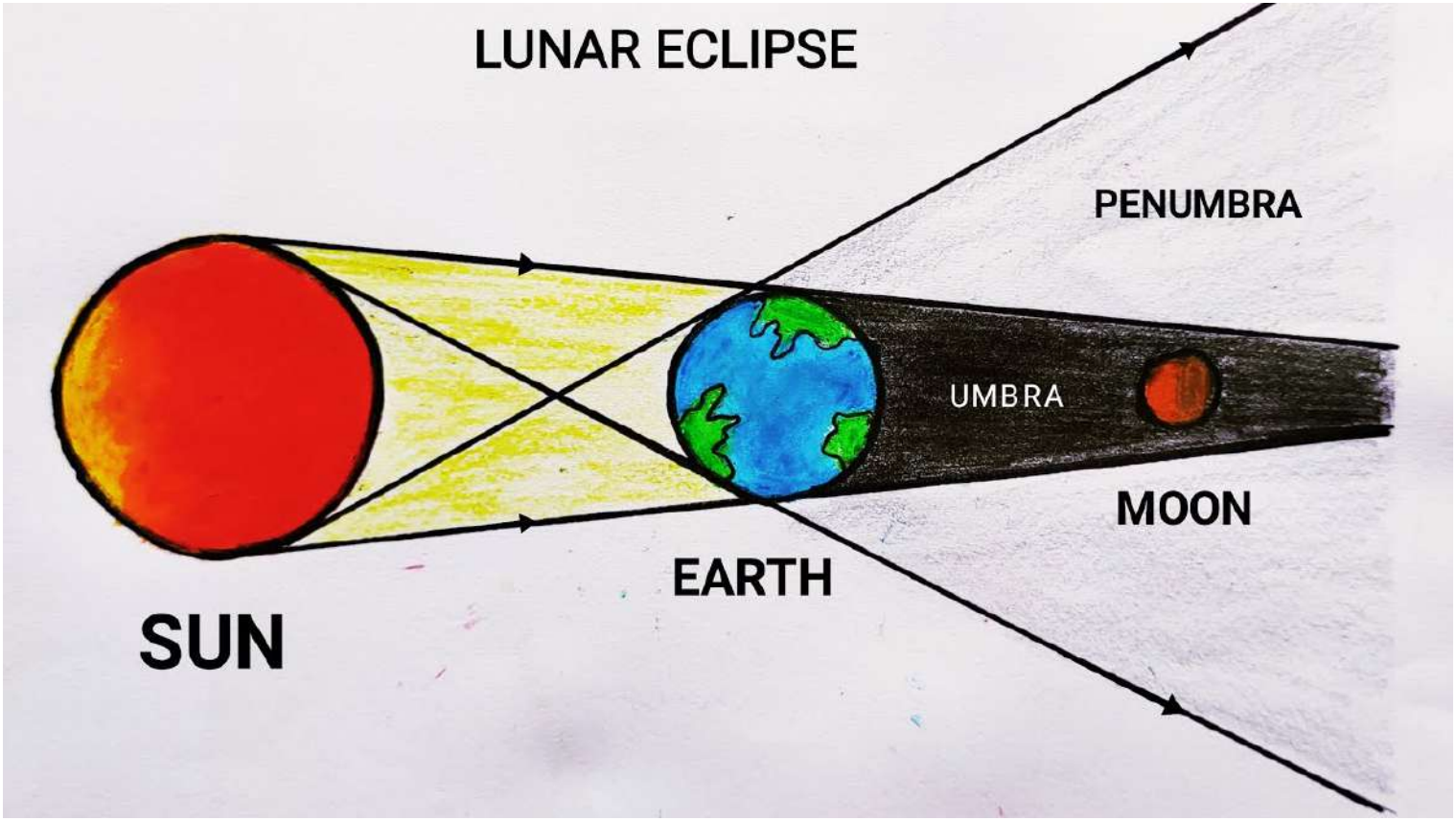
FIGURE 9.25

CHECK POINT

1. Suppose you stepped into a hole bored clear through the center of Earth and made no attempt to grab the edges at either end. Neglecting air drag, what kind of motion would you experience?

2. Halfway to the center of Earth, would the force of gravity on you be less than at the surface of Earth?

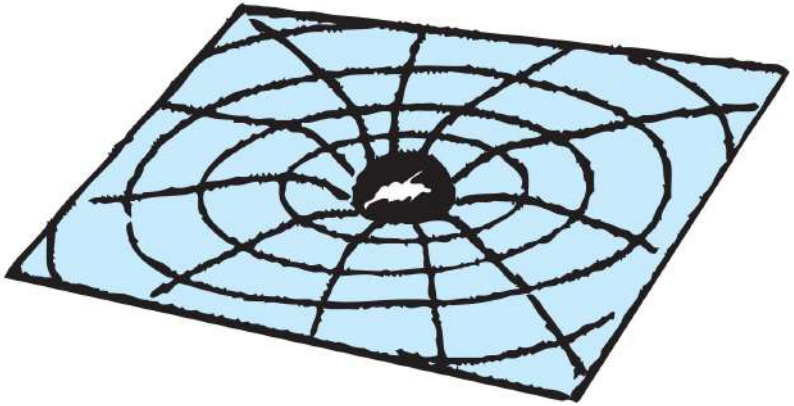
Can Earth shield (block) the Moon from the Sun's gravitational field?

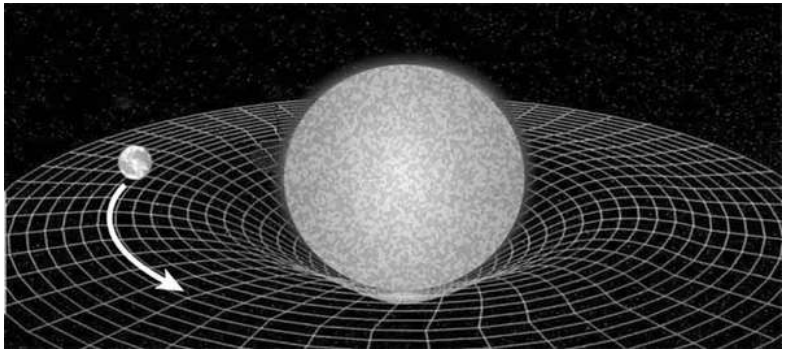


No. During a lunar eclipse, Moon's orbit would change.

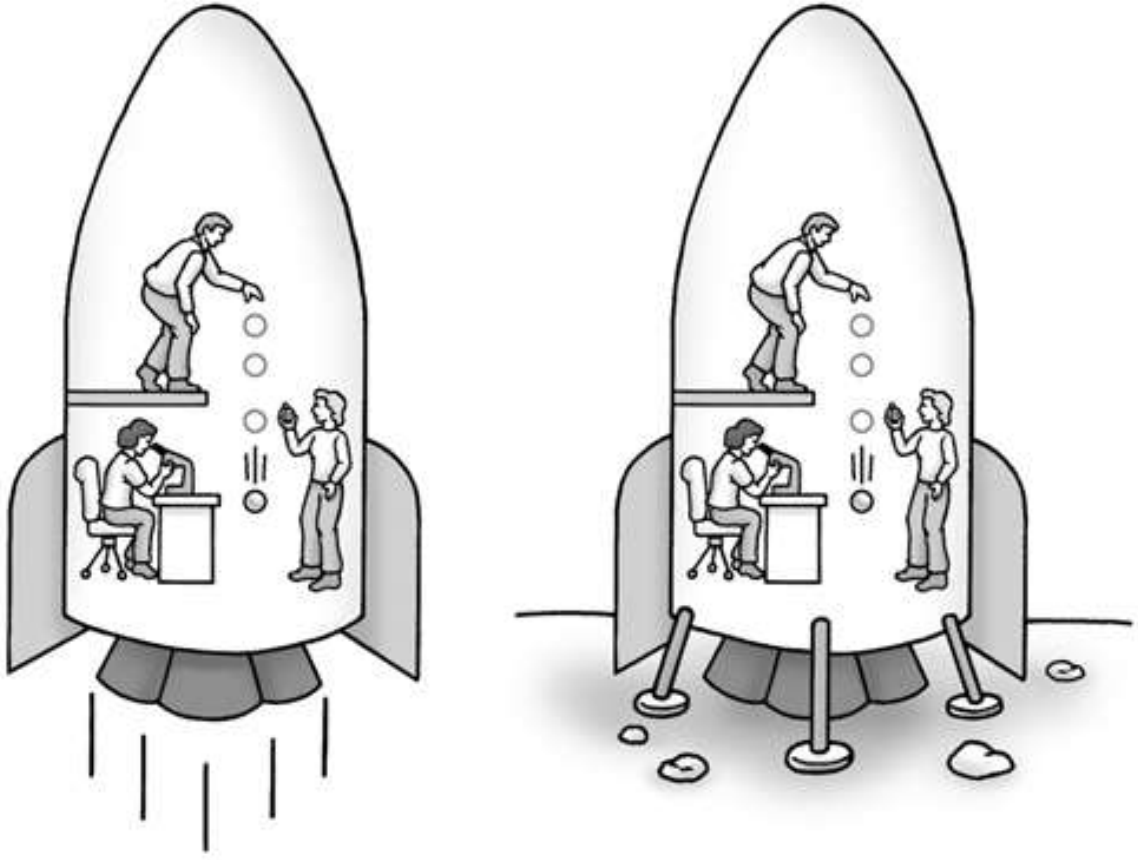
Einstein's Theory of Gravitation

- 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.





Einstein's Equivalence Principle: Gravity is equivalent to acceleration.

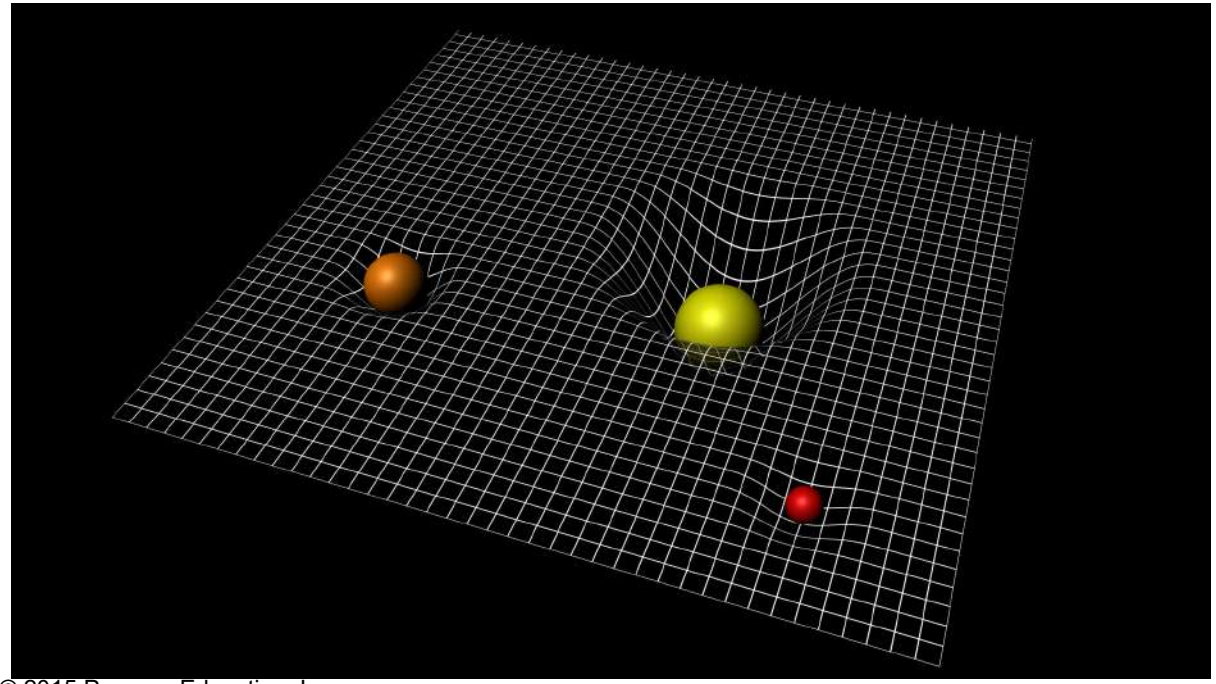


You cannot tell the difference between accelerating and gravity.

Newton vs. Einstein

Newton: Gravity is a *force*: $F = \frac{Gm_1m_1}{d^2}$.

Einstein: Gravity is the result of the curvature of spacetime.



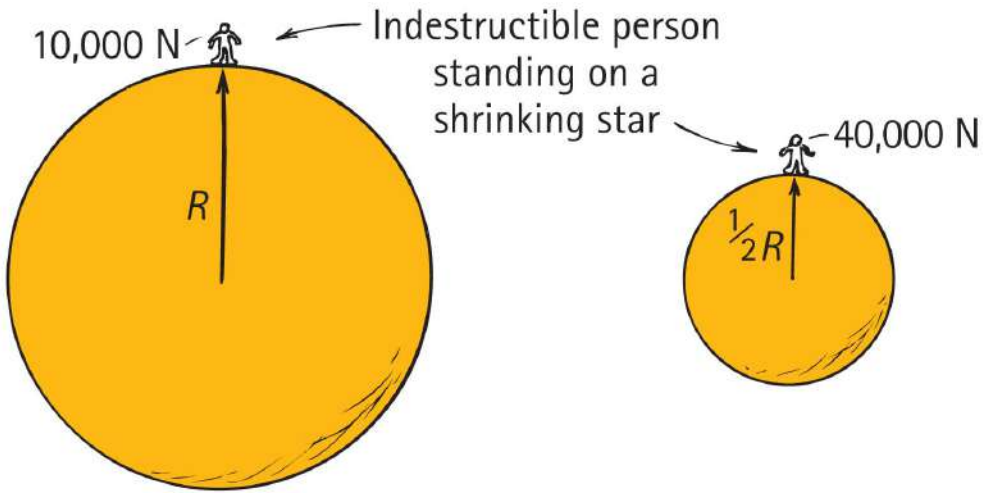
Spacetime tells matter how to move; matter tells spacetime how to curve.

---John Wheeler

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

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



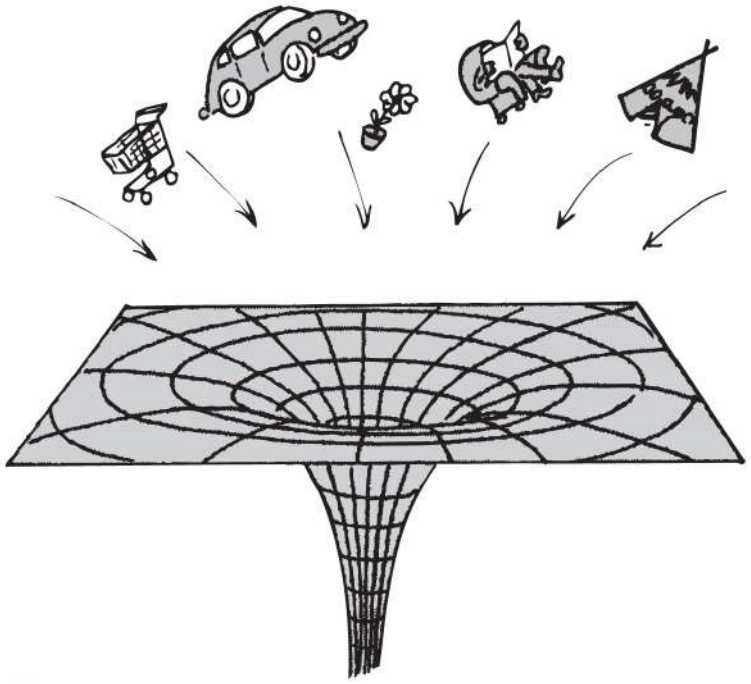
When *d* decreases, *F* increases.

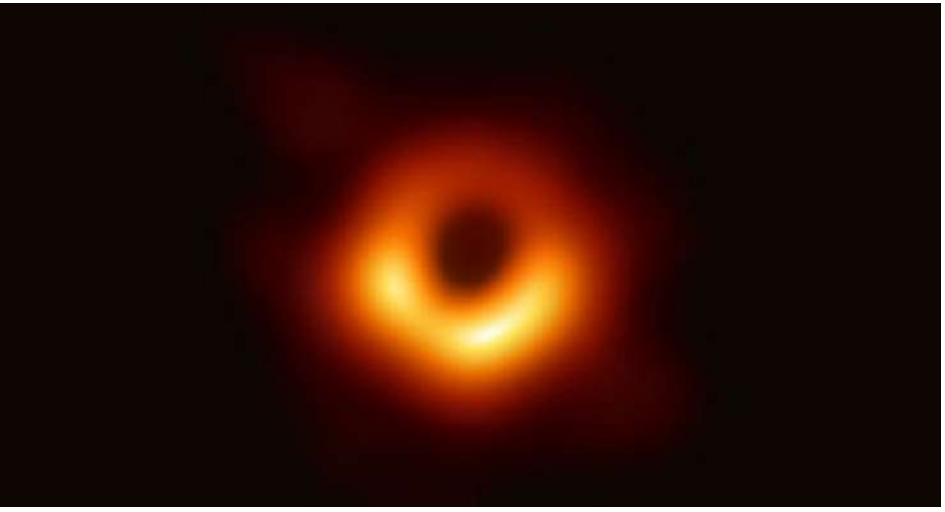
The stronger F is, the more speed you need to escape the gravity of a planet.

→ This speed is called the *escape velocity*.

- **Black Hole**:

When the star becomes so small and the gravitational force at the surface becomes so large that its escape velocity is greater than the speed of light.

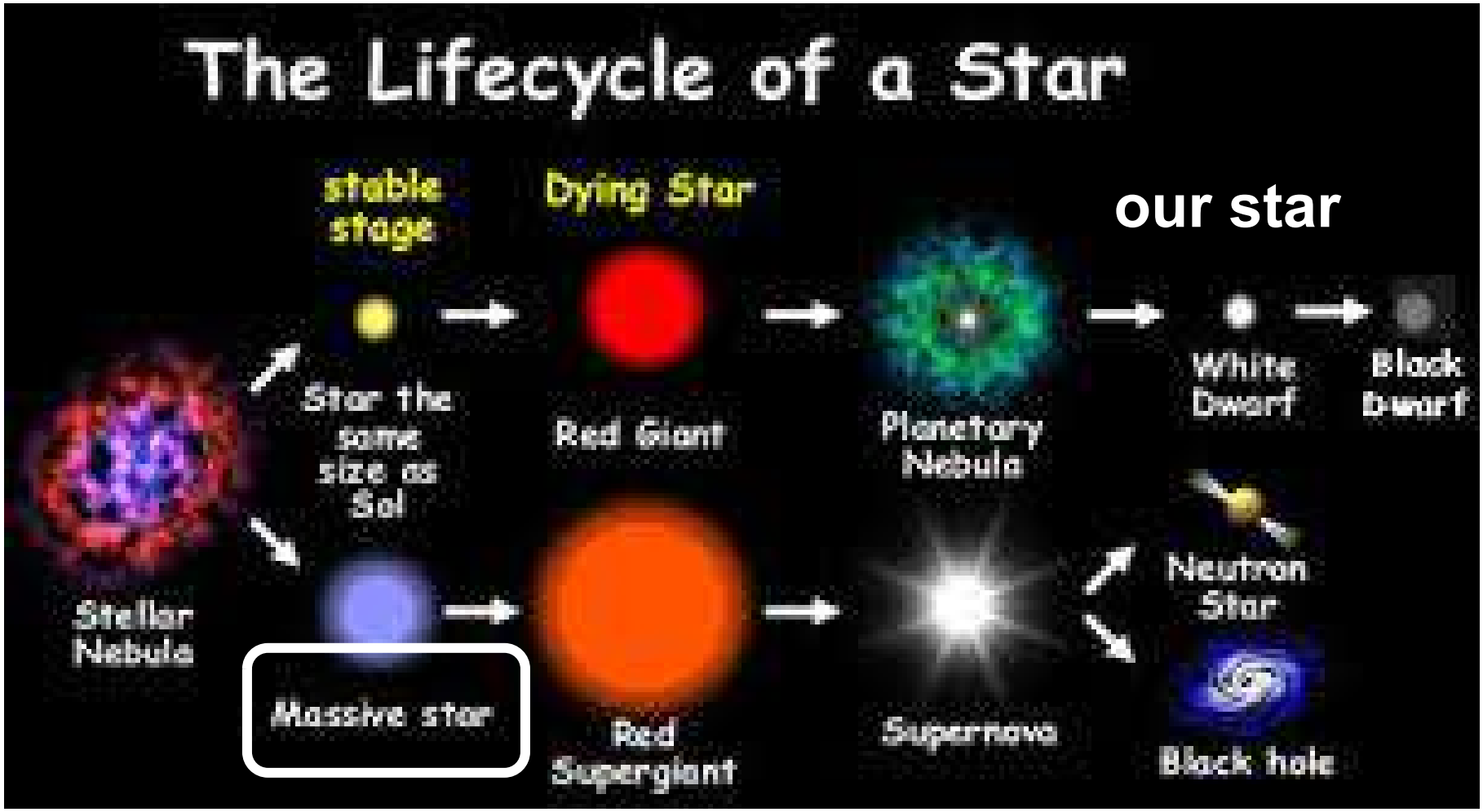




Light cannot escape it.

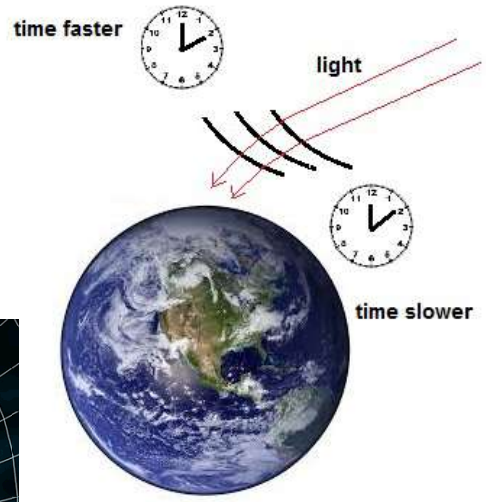
anything in its vicinity will be attracted by warped space-time and lost forever.

Black holes form when massive stars die:



Other oddities:

1. Time slows in stronger gravitational fields.
2. Falling into a black hole, you would become ***spaghettified***.
3. Far enough away from the black hole, the gravity is no different from the gravity of the star that collapsed…you could orbit it as usual.



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.

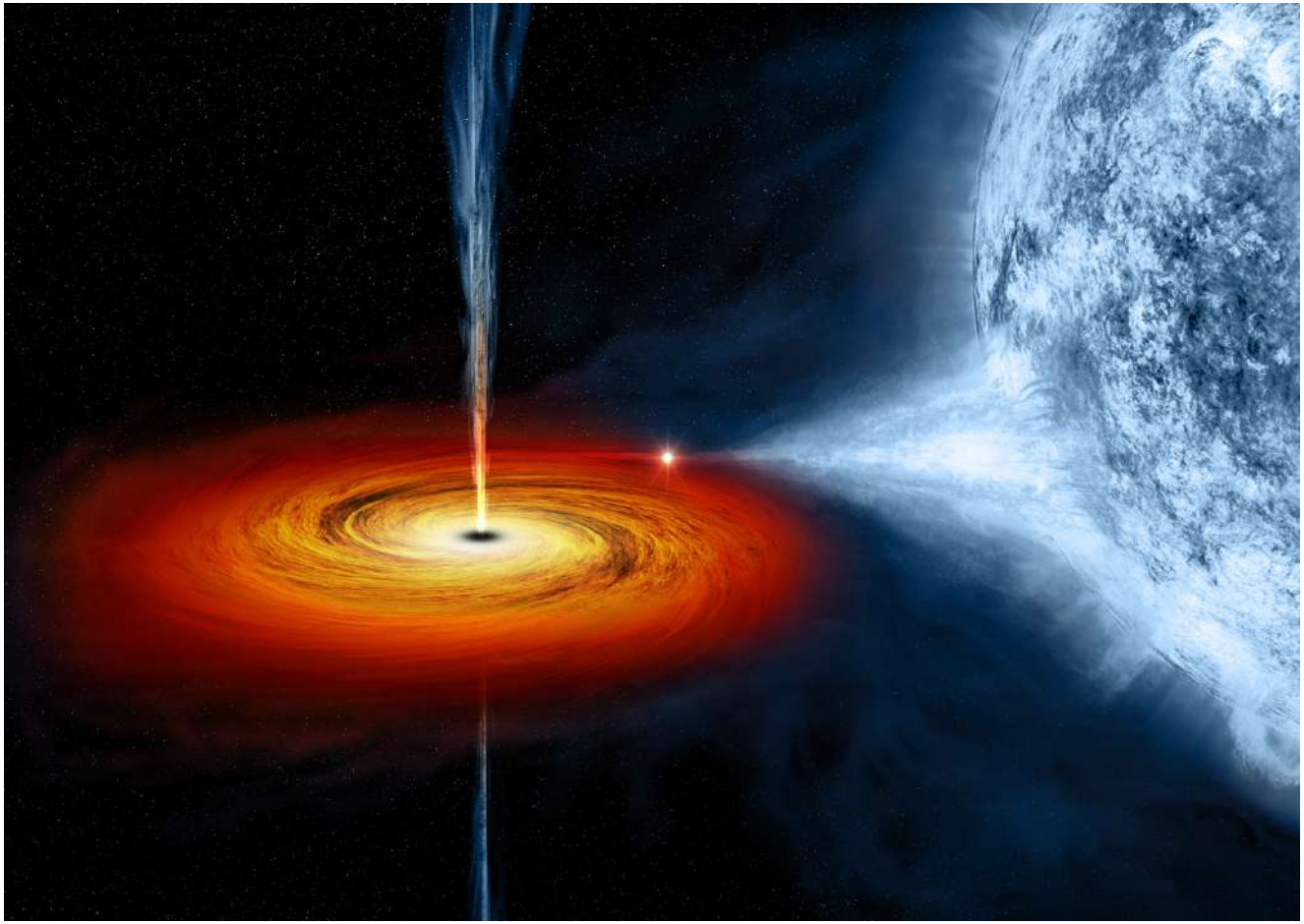
D. None of the above.

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

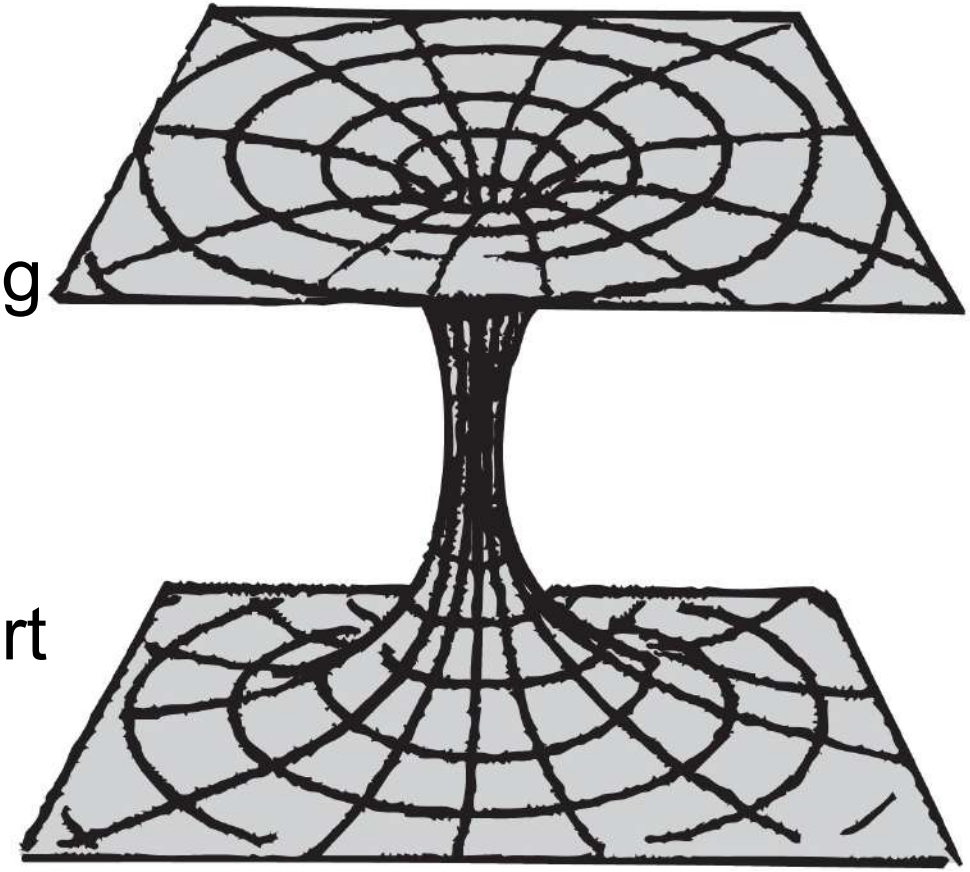
How do you see a black hole?

Matter falling into a black hole becomes heated to millions of degrees and emits much light.



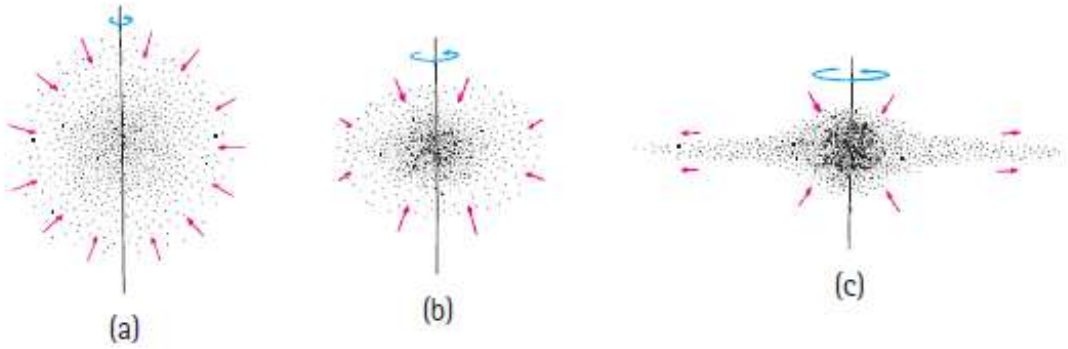
Wormhole

- **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

1. This is how the solar system formed:



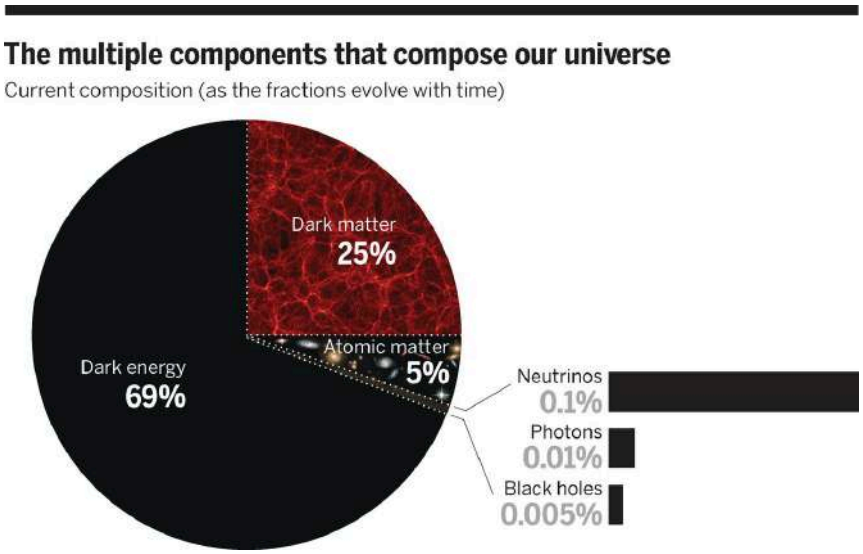
2. Everything attracts everything else.
   - Example: Earth is round because of gravitation—all parts of Earth have been pulled in, making the surface equidistant from the center.

3. Planets pull on other planets and disturb their orbits. These are called *perturbations*. That is how Neptune and Pluto were discovered.

Universal Truths:

- The universe is expanding and accelerating outward because of *dark energy*.
- Most matter has not been found:

  dark matter.



→ Newton's ideas helped usher in an Age of Reason in the 1700s. This influenced philosophers like John Locke, whose followers created a government based on reason.

Take a sheet of paper and write your name on it. Answer the following questions.

22. What is a gravitational field, and how can its strength be measured?

a) a force field around any mass

b) drop an object and measure its acceleration or weigh an object

23. What is the magnitude of the gravitational field at Earth's center?

0

24. For a planet of uniform density, how would the magnitude of the gravitational field halfway to the center compare with the field at the surface?

half as much

25. What would be the magnitude of the gravitational field anywhere inside a hollow, spherical planet?

0

26. Newton viewed the curving of the path of a planet as being caused by a force acting on the planet. How did Einstein view the curved path of a planet?

a result of the curvature of space

27. If Earth shrank but there was no change in its mass, what would happen to your weight at the surface?

increase

28. What happens to the strength of the gravitational field at the surface of a star that shrinks?

increase

29. Why is a black hole invisible?

light cannot escape it

30. What was the cause of perturbations discovered in the orbit of the planet Uranus? What greater discovery did this lead to?

a) the gravity of an unknow planet
b) Neptune

Take a photo of your answers.
Upload to Teams.
Now.
Due by end of period.