Investigating Planets Name:____Block:______ **E1:R2**

FYI: Stories of Gravity and FYI: Gravitational Force

1. Read FYI: *Stories of Gravity* and FYI: *Gravitational Force*

   As you read answer the following questions about the readings:

1. What did Galileo contribute to our understanding of gravity?

2. What did Isaac Newton contribute to our understanding of gravity?

3. What did the Apollo 15 Hammer and Feather experiment test?

4. For an astronaut, what does g (gee) mean?

5. How do astronauts simulate the weightlessness they will feel in space?

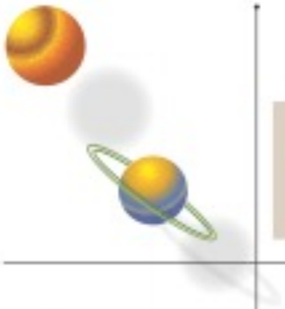
6. What three things does Newton's Law of Universal Gravitation basically say?
   a.

   b.

   c.

7. What is the surface gravitational acceleration on Earth?

8. In your own words, what's the difference between mass and weight?



FYI Stories of Gravity

Galileo

Figure 1-12: Drawing of Sir Isaac Newton sitting under an apple tree

Standing atop the Leaning Tower of Pisa, Italian astronomer Galileo Galilei (1564 -1642) dropped balls of different masses over the side and therefore demonstrated that the time it takes an object to fall is not dependent on its mass... or so the story goes. This story was first reported by one of Galileo's pupils, so it could be true, but today, it is generally not believed. What is known to be true, however, is that Galileo conducted experiments rolling balls down ramps that demonstrated exactly the same thing—that the acceleration of a rolling or falling object is independent of the object's mass. He was not the first person to claim this, but he was the first (as far as we know) to prove it experimentally.

Sir Isaac Newton

According to another popular myth, Newton somehow discovered gravity after an apple fell on his head. This isn't true, of course. Newton didn't "discover" gravity. Nor is it likely that an apple actually hit him on the head. However, Newton did develop the theory of universal gravitation. And there is evidence to suggest that the falling of an apple may have played a role in this. According to various contemporaries of Newton:

Sir Isaac Newton walking in his Garden had the first thought of his System of Gravitation, upon seeing an Apple falling down from the Tree. (Essay on the Civil War in France, Voltaire, 1727) In the year 1666... [Newton] was musing in a garden [and] it came into his thought that the power of gravity (which brought an apple from a tree to the ground) was not limited to a certain distance from earth, but that this power must extend much further than was usually thought. Why not as high as the Moon said he to himself & if so, that must influence her motion & perhaps retain her in her orbit, whereupon he fell to calculating what would be the effect of that supposition... (King's College, Cambridge, Keynes MS, pp. 10-12. Conduitt's account of Newton's life at Cambridge, written shortly after Newton's death)

When formerly, the notion of gravitation came into [Newton's] mind. It was occasioned by the fall of an apple, as he sat in contemplative mood. Why should that apple always descend perpendicularly to the ground, thought he to himself. Why should it not go sideways or upwards, but constantly to the earth's centre.
(Memoirs of Sir Isaac Newton's Life, William Stukeley, pp. 19-20, also written shortly after Newton's death)

Apollo 15 Hammer and Feather Drop

In late July and early August of 1971, Apollo 15 astronauts Commander David Scott and Lunar Module pilot James Irwin spent almost three days on the surface of the moon, while Command Unit Pilot Alfred Worden orbited above. At the end of their last moon walk, Commander Scott performed a unique version of Galileo's famous "Tower of Pisa demonstration." Scott held a hammer and a feather out in front of him at about the same height and then dropped them at the same time. Because there was no air resistance, the feather and hammer, which had very different masses, hit the moon's surface at the same time—within the limits of the experiment. This demonstration was captured in a movie that can still be viewed today. (Check for it on the *Investigating Planets* page of the *IA* Web site.)

Figure 1-13: Astronaut David Scott dropped a hammer and a feather on the moon. They hit the ground simultaneously.

Shuttle Launch

It's a few seconds before liftoff, and the main engines have already begun, so everything is shaking. The solid-fuel boosters ignite and the shuttle rises slowly into the air, accelerating toward space. The astronauts are pressed back in their seats and jerked around as they rise, experiencing g forces stronger than Earth's gravitational force.

The term g, or gee, is used for the acceleration experienced on Earth's surface. During a launch of the space shuttle, astronauts experience about 3 g. This means that they weigh about three times as much as they do on the ground. They feel like they are being pushed hard into their seats. Then, once they are in orbit, they are experiencing 0 g, also called weightlessness or microgravity. Thus, in a very short period of time, the astronauts and the shuttle experience 1 g to 3 g to 0 g. Astronauts must train to deal with this, and the shuttles must be built to accommodate it.

Figure 1-14: Photograph of Astronaut Ellen Ochoa, the first Hispanic woman to fly in space, experiencing microgravity as she orbits Earth

Vomit Comet

The actor Tom Hanks skillfully gets through his lines for the scene being shot. Nothing unusual about that, except this isn't just any scene. It is a scene for the movie *Apollo 13*, and Tom Hanks, his fellow actors, and the crew are all onboard the Vomit Comet. The Vomit Comet, which NASA prefers to call the Weightless Wonder, is any NASA airplane that flies in a parabola and provides its passengers with brief experiences of weightlessness. The weightlessness only lasts about 23 to 25 seconds, but this is enough time to bounce around, practice maneuvers, try experiments both for fun and for research, or even shoot scenes for a movie.

Figure 1-15: Photograph of airbags similar to those used by Pathfinder to land on Mars

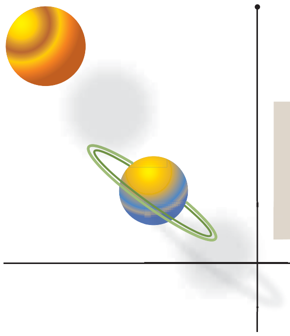
The plane flies up and down in large parabolas. As it reaches the top of its flight and begins to head down, all the objects within the plane, including the people, begin falling toward Earth's surface under the effects of the planet's gravitational acceleration; however, the plane itself is moving with this fall, so the experience is one of weightlessness, or microgravity! Then the airplane sweeps upward again, and everything crashes to the ground. The process repeats, over and over. The experience makes many of the plane's passengers sick—hence the name.

The plane's parabola can be changed to generate other gravity effects onboard the Vomit Comet. For example, the Apollo astronauts were able to experience one-sixth g as part of their training to go to the moon. And scientists and researchers can create the experience of Martian gravity to test space suits and other equipment for possible future missions to Mars!

Pathfinder Airbags

In December 1996, the Mars Pathfinder was launched from Earth. Seven months later, it arrived on Mars through a unique landing maneuver. Using a system of airbags, the lander literally bounced its way to a stop on the planet!

The lander, having already been slowed down considerably by the Martian atmosphere and by means of a parachute, filled its airbags and then hit the surface. It bounced about 16 meters high under Mars's gravitational acceleration—which is less than Earth's, so the bounce was higher than it would have been here—came down again, and bounced at least a dozen more times before finally coming to rest.



FYI

Gravitational Force

What is gravity? **Gravity** is an informal word for what scientists call **gravitational force**. It is the attractive force, or pulling, in which one object acts upon another object because of the masses of both objects. Or, put another way, since a **force** is a push or pull that causes an object to move, gravity is a pull between objects.

Newton's Law of Universal Gravitation

Newton's law of universal gravitation states:

Every object in the universe attracts every other object with a force directed along the line of centers of mass for the two objects. This force is proportional to the product of their masses and inversely proportional to the square of the separation between the centers of the two masses.

$$\text{Gravitational Force} = \frac{\text{Gravitational Constant x Mass 1 x Mass 2}}{(\text{Distance between Centers of Mass})^2}$$

$$F_g = \frac{G\,M_1\,M_2}{d^2}$$

- F_g is the gravitational force between the two objects.
- G is the gravitational constant, 6.67×10^{-11} $\text{N·m}^2/\text{kg}^2$. It is a fundamental constant of physics.
- M_1 and M_2 are the masses of the two objects.
- d is the distance between the centers of the two objects.

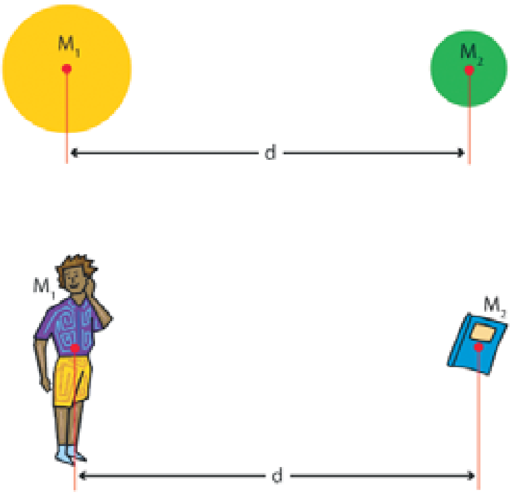


Figure 1-16: Diagrams illustrating the factors involved in Newton's law of universal gravitation. All objects attract each other, and the force of gravitational attraction between any two objects depends upon the masses of the objects and the inverse square of the distance between the centers of the objects.

This may seem complicated, but it basically says three important things:

1. There is a gravitational force between all objects.

   For example, there is a gravitational force between you and this book; there is a gravitational force between you and Earth; and there is even a gravitational force between you and the sun!

2. The larger the masses of the objects involved, the greater the gravitational force.

   For example, Earth has a much, much larger mass than this book does. Hence, while there is a gravitational force between you and this book, the gravitational force between you and Earth is much stronger. So you are pulled down toward Earth but not sideways toward the book!

3. The gravitational force between the objects decreases rapidly with increasing distance between those objects. Specifically, the gravitational force between any two objects is inversely proportional to the square of the distance between those objects.

   For example, the distance between you and the sun's center is incredibly large, while the distance between you and Earth's center is very small, comparatively. So though the sun has a much greater mass than Earth does, the gravitational force between you and Earth is much stronger. Thus, you aren't pulled off Earth by the sun!

Surface Gravitation

The gravitational force experienced on a planet's surface can be calculated by using the planet's mass for M_1 (kg) and the planet's radius for d (m). Thus, both the mass of a planet and the size of a planet, as defined by the planet's radius, determine the surface gravitation of that planet.

The gravitational acceleration experienced on Earth's surface is about 9.8 m/s².

$$g = 9.8 \text{ m/s}^2$$

Other planets and moons, each with their own mass and radius, have differing values for g. The value of g on our moon is about 1/6 that of Earth—about 1.6 m/s².

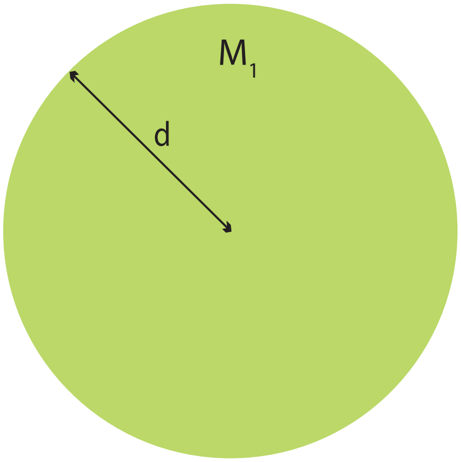


Figure 1-17: Diagram illustrating the factors involved in calculating surface gravitation. The gravitational force (F_g) experienced on the surface of a planet depends on the mass of the planet (M_1) and the radius of the planet (d).

Weight

Weight depends on a planet's surface gravitation. This means that objects weigh different amounts on different planets. On Earth, weight is equal to the mass of the object multiplied by g.

$$F_g = mg$$

- F_g is the weight of an object as experienced on Earth. It is the force acting on the object.
- m is the mass of the object—the amount of matter in the object.
- g is the acceleration of gravity experienced on Earth.

  Note: This is a version of Newton's 2nd Law: force equals mass times acceleration, or

$$F = ma.$$

An object's weight on another planet can be calculated by multiplying the object's mass by the surface gravitational acceleration on that planet.

An object's weight on another planet can also be calculated using that object's weight on Earth and the surface gravitational acceleration experienced on the other planet IF it is defined relative to the surface gravitational acceleration experienced on Earth (1 gee).

Figure 1-18: Drawing of scales and a balance—instruments used to measure weight. Weight depends on the gravitational acceleration experienced on the surface of a planet.