Gravitational Field Strength

A FORCE FIELD is a region of space surrounding an object that can exert a force on other objects; the field exerts a force only on objects placed within that region that are able to interact with that force.

The GRAVITATIONAL FIELD STRENGTH is the force, per kilogram of mass, acting on an object within a gravitational field. The gravitational field strength is a vector quantity because it has a direction. The gravitational field strength due to Earth always points toward Earth's centre. Gravitational field strength has units of newtons per kilogram. At Earth's surface, the gravitational field strength is 9.8 N/kg [down].

Figure 4 The gravitational force field surrounding Earth attracts all other objects placed within this field. The magnitude of Earth's gravitational field decreases as an object moves farther away from Earth's surface.

$$\vec{F} = m \cdot \vec{g}$$

$$\frac{9.8N}{kg} = \frac{9.8\frac{kg \cdot m}{s^2}}{kg} \; or \; \frac{9.8m}{s^2}$$

$$\vec{g} = \frac{\vec{F}}{m}$$

At the top of Mount Everest at an altitude of 8848 m above sea level, the magnitude of the gravitational field strength is 9.7647 N/kg.

Force of Gravity Around the World

Since Earth is not a perfect sphere, the magnitude of the gravitational field strength at Earth's surface varies according to the geographic location of the object.

Earth bulges out slightly at the equator due to the rotation of the planet. At the poles, an object at sea level is 21 km closer to Earth's centre than if it were at sea level at the equator. This means that the magnitude of the gravitational field strength is slightly greater at the poles than at the equator. The magnitude of the gravitational field strength gradually increases with latitude as you travel from the equator toward either pole.

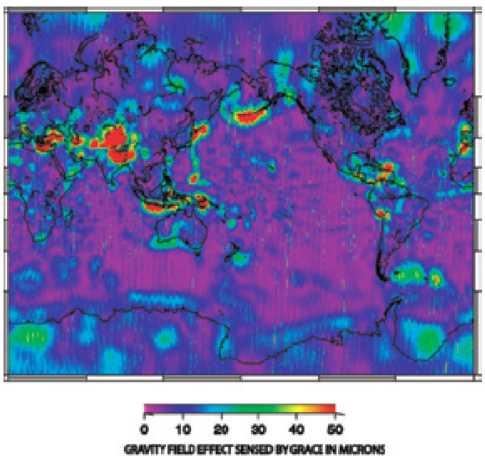


Figure 5 The magnitude of the gravitational field strength varies depending on the location on Earth's surface. On this map, red and yellow areas have a greater gravitational field strength.

Sec. 3.3 - Universal Gravitation

Learning Goal: By the end of today, I will be able to solve problems using the Universal Gravitation equation.

Newton's Law of Universal Gravitation

The force of gravitational attraction between any two objects is directly proportional to the product of the masses of the objects, and inversely proportional to the square of the distance between their centres.

Newton discovered the following proportionalities:

If m_2 and r are constant, $F_G \propto m_1$ (direct variation).

If m_1 and r are constant, $F_G \propto m_2$ (direct variation).

If m_1 and m_2 are constant, $F_G \propto \frac{1}{r^2}$ (inverse square variation).

Combining these statements, we obtain a joint variation:

$$F_G \propto \frac{m_1 m_2}{r^2}$$

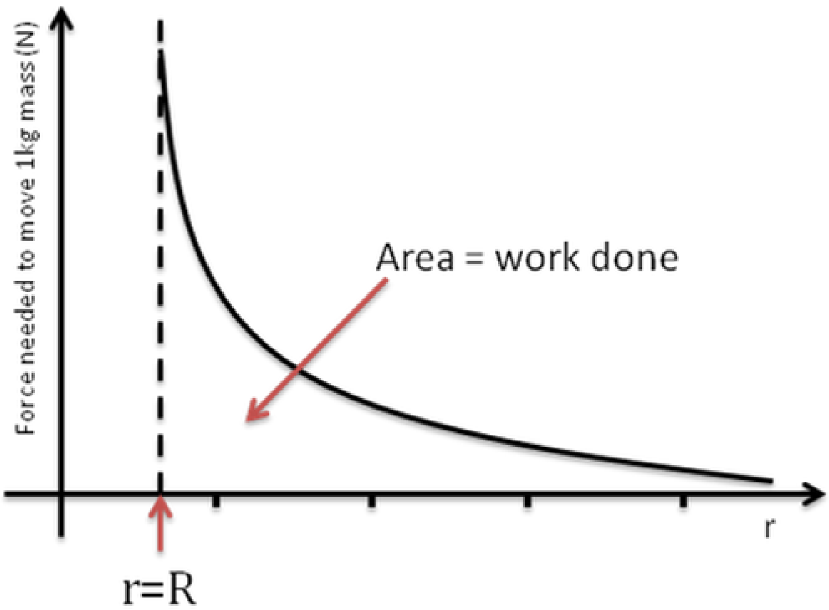
Finally, we can write the equation for the law of universal gravitation:

$$F_G = \frac{G m_1 m_2}{r^2}$$

where G is the universal gravitation constant.

$$G = 6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$$

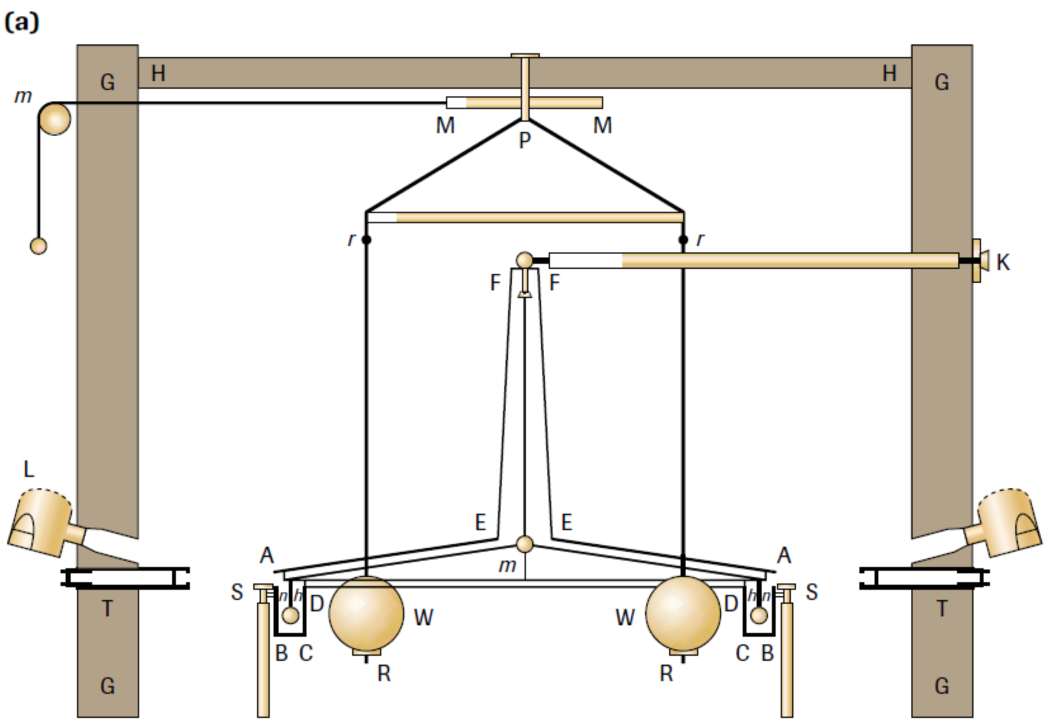
- There are two equal, but opposite forces present. For example, Earth pulls on you and you pull on Earth with a force of equal magnitude.
- For the force of attraction to be noticeable, at least one of the objects must be very large.
- The inverse square relationship between F_G and r means that the force of attraction diminishes rapidly as the two objects move apart. On the other hand, there is no value of r, no matter how large, that would reduce the force of attraction to zero. Every object in the universe exerts a force of attraction on every other object.
- The equation for the law of universal gravitation applies only to two spherical objects (such as Earth and the Sun), to two objects whose sizes are much smaller than their separation distance (for example, you and a friend separated by 1.0 km), or to a small object and a very large sphere (such as you and Earth).



$$F_G = \frac{Gm_1m_2}{r^2}$$

Determining the Universal Gravitation Constant

The numerical value of the universal gravitation constant *G* is extremely small; experimental determination of the value did not occur until more than a century after Newton formulated his law of universal gravitation. In 1798, British scientist Henry Cavendish (1731–1810), using the apparatus illustrated in **Figure 3**, succeeded in measuring the gravitational attraction between two small spheres that hung on a rod approximately 2 m long and two larger spheres mounted independently. Using this equipment, he derived a value of *G* that is fairly close to today's accepted value of 6.67×10^{-11} N·m²/kg². His experiment showed that gravitational force exists even for relatively small objects and, by establishing the value of the constant of proportionality *G*, he made it possible to use the law of universal gravitation in calculations. Cavendish's experimental determination of *G* was a great scientific triumph. Astronomers believe that its magnitude may influence the rate at which the universe is expanding.



Explanation Link

Old video

Example

$$F_G = \frac{Gm_1m_2}{r^2}$$

What would happen to F_G if the mass of one of the objects doubled?

What would happen to F_G if the distance between the objects doubled?

What would happen to F_G if you halved the mass of one object and tripled the distance between them?

Example

$$F_G = \frac{G m_1 m_2}{r^2}$$

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

A 50.0-kg student stands 6.38×10^{6} m from Earth's centre.
The mass of Earth is 5.98×10^{24} kg.
What is the magnitude of the force of gravity on the student?

SUMMARY Universal Gravitation

- Newton's law of universal gravitation states that the force of gravitational attraction between any two objects is directly proportional to the product of the masses of the objects and inversely proportional to the square of the distance between their centres.
- The universal gravitation constant, $G = 6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$, was first determined experimentally by Henry Cavendish in 1798.
- The law of universal gravitation is applied in analyzing the motions of bodies in the universe, such as planets in the solar system. (This analysis can lead to the discovery of other celestial bodies.)

Homework

Read pg 139-144

page 141 #3, 4, 5

page 143 #10, 11

pg 144 #3, 4