Newton's Law of Universal Gravitation

by

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P3.6A Explain earth-moon interactions (orbital motion) in terms of forces.

P3.6d Calculate force, masses, or distance, given any three of these quantities, by applying the Law of Universal Gravitation, given the value of G.

Items:

1) Law of Universal Gravitation.

2) Acceleration due to gravity of the Earth.

3) Planetary gravitation.

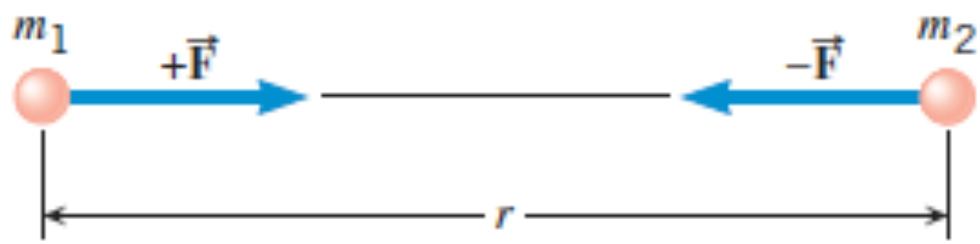
Sir Isaac Newton (1642-1727)

He is one of the greatest scientists

He connected gravity and planetary forces.

The Law of Universal Gravitation

Newton decided that every apple, every rock, every particle in the universe attracts, and is attracted to, every other particle in the universe.
Consider two particles that have masses m_1 and m_2, and are separated by a distance r.



The two particles are attracted by gravitational forces + F and -F.
The gravitational force (F) that each exerts on the other is directed along a line joining the particles.

$+\vec{F}$ is the gravitational force exerted on particle 1 by particle 2. $-\vec{F}$ is the gravitational force exerted on particle 2 by particle 1.

Newton proposed that the strength of the gravitational force between two masses (m_1 and m_2) is proportional to the masses and inversely proportional to the square of the distance (r) between them.

Newton's Law of Universal Gravitation
$F = G\frac{m_1 m_2}{r^2}$

G is the universal gravitational constant. $G = 6.673 \times 10^{-11}$ N.m ^{2}/kg^2

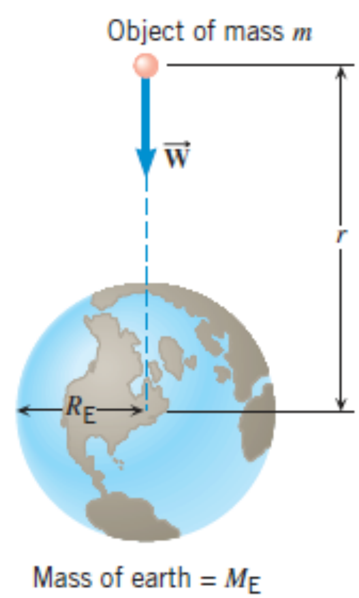
The unit of Force is Newton (N).

The force of attraction between small objects is not zero, but it is too small for ordinary measuring instruments and is insignificant for practical purposes.

Earth's Gravitational Force Strength or Acceleration due to Gravity

The weight of a body at the surface of the Earth is the gravitational force that the Earth exerts on that body. The weight always acts downward, toward the center of the earth.

The picture below shows how the weight (W) of an object of mass (m) is a force directed toward the center of the earth. M_E is the mass of the Earth.



Weight is W = m.g   *(**g: Acceleration due to gravity or** gravitational field strength).*

According to Newton's Law of Universal Gravitation, the force of attraction between the mass and Earth is :

$$F = G\, m_E\, m \,/\, r^2$$

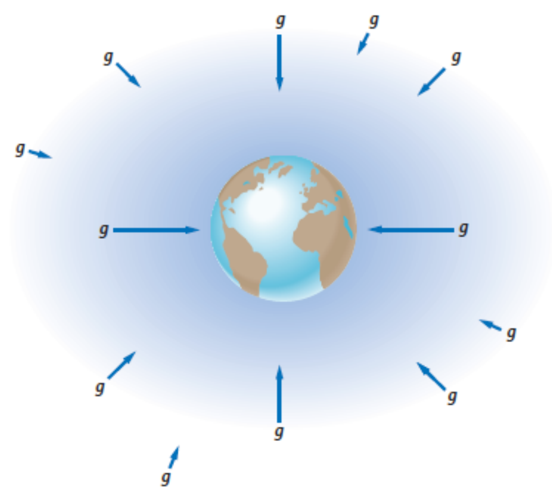
W = F

$$m.g = F = G\, m_E\, m \,/\, r^2$$

so

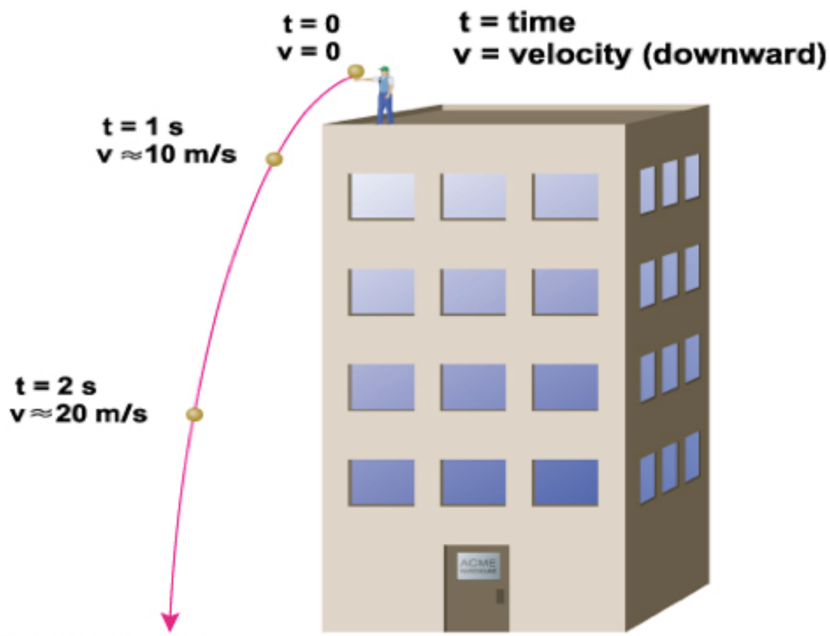
$$g = G\, m_E \,/\, r^2 = 9.8 \text{ m/s}^2$$

So, Earth is surrounded by a gravitational force field $g = 9.8 \text{ m/s}^2$ that pulls every mass towards its center.



Example 1: *A Person Drops a Ball.*

Suppose a person drops a ball from the top of a building with no initial velocity. The ball drops as free-fall with acceleration of 9.8 m/s^2 or approximately 10 m/s^2 .So, the velocity increases about 10 m/s every each second.



At t = 1 s, the velocity is approximately 10 m/s.

At t = 2 s, the velocity is approximately 20 m/s.

Example 2: *Attraction Between Two Apples.*

What is the force of attraction between two apples, each with a mass of 0.5 kg, held so that their center are 10 cm apart?

Data Table				
m_1	m_2	r	G	F_{net}
0.5 kg	0.5 kg	10 cm = 0.1 m	6.673×10^{-11} N.m ^{2}/kg^2	?

Apply Newton's Law of Universal Gravitation: the force of attraction is given by the formula:

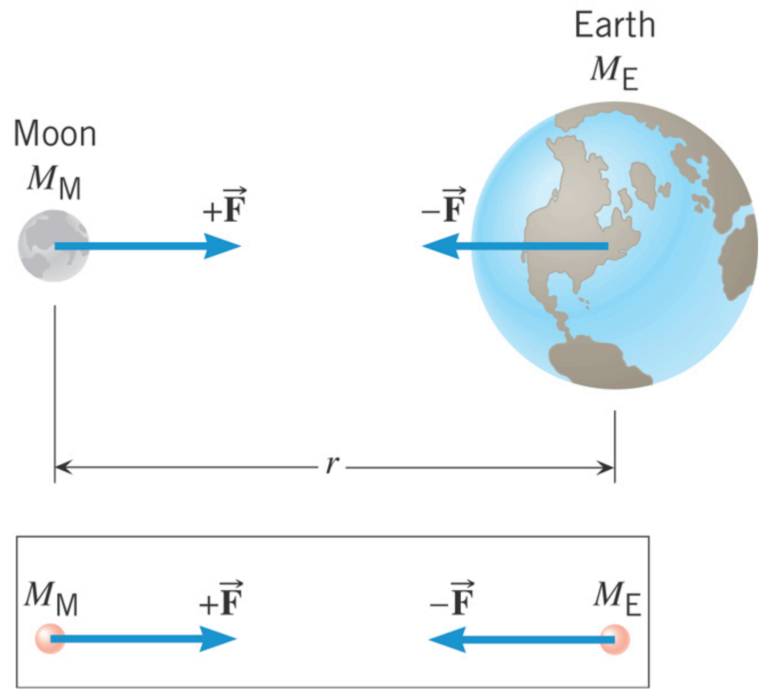
$$F = G\, m_1\, m_2 / r^2$$

Put the values of m_1 , m_2 , r and G in the formula

$$F = (6.673 \times 10^{-11})(0.5)(0.5) / (0.1)^2$$
$$= 1.7 \times 10^{-9}\ \mathrm{N}$$

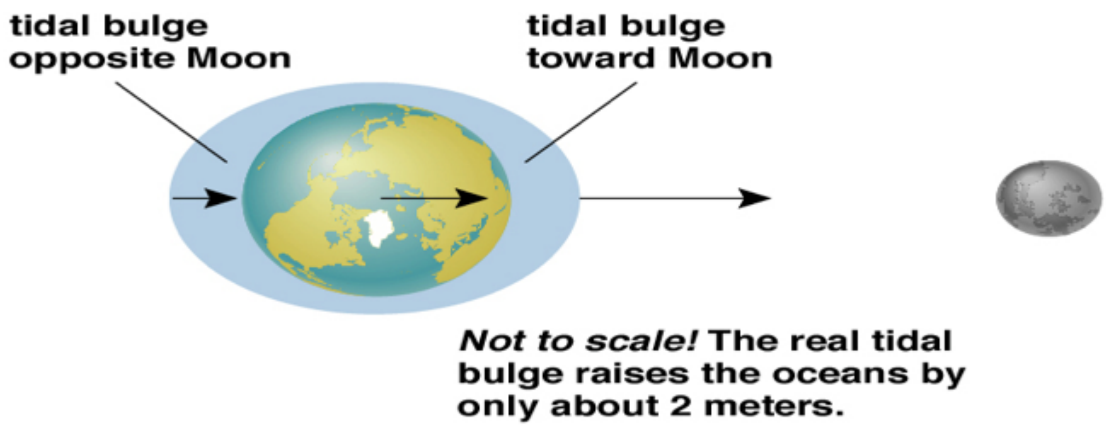
Example 3: *The Force of Attraction Between the Earth and the Moon*.

The Earth and Moon are mostly spherical. Newton's law of Gravitation may be applied using the distance between their centers as if they were point particles.



$$F = GM_M M_E / r^2$$

Example 4: *Tides*



Example 5: *Gravitational Force Between Two Nimitz-class Aircraft Carriers.*

References:

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2) Cutnell, J. D. & Johnson, K. W. (1998). *Cutnell & Johnson Physics, Fourth Edition*. New York: John Wiley & Sons, Inc.

The edition was dedicated to the memory of Stella Kupferberg, Director of the Photo Department: "We miss you, Stella, and shall always remember that a well-chosen photograph should speak for itself, without the need for a lengthy explanation"

3) Martindale, D. G. & Heath, R. W. & Konrad, W. W. & Macnaughton, R. R. & Carle, M. A. (1992). *Heath Physics.* Lexington: D.C. Heath and Company

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