SPH4U UNIVERSITY PHYSICS

ELECTRIC, GRAVITATIONAL, & ... FIELDS

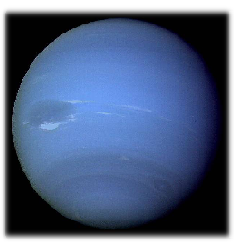
☞ Newtonian Gravitation (P.288-293)

Newtonian Gravitation

Early in the formation of our galaxy, tiny gravitational effects between particles began to draw matter together into slightly denser configurations. Those, in turn, exerted even greater gravitational forces, resulting in more mass joining the newly forming structures. Gravity accounts for the overall structure of the entire universe, despite being the weakest of the four fundamental forces.

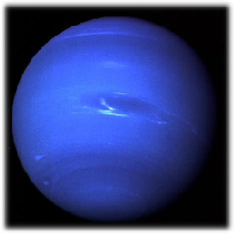
Newtonian Gravitation

By the late 1700s, scientists had identified all the inner terrestrial planets as well as the gas giants, Jupiter and Saturn. Then, British astronomer William Herschel used observations of the relative movements of the stars to determine that a presumed "star" was actually an additional planet. The new planet was Uranus.



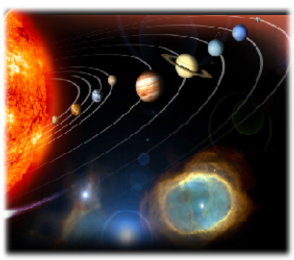
Newtonian Gravitation

Scientists then observed that Uranus's path was anomalous. It seemed to respond to the pull of another distant but unknown body. Using mathematical analysis, scientists predicted where the unknown body would have to be and began searching for it. In 1846, scientists discovered the planet Neptune.



Universal Law of Gravitation

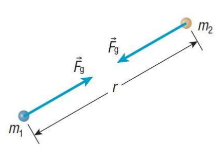
The force that causes Uranus to wobble slightly in its orbit is gravity – the same force that causes Earth and the other planets to revolve around the Sun. Sir Isaac Newton used known data about the solar system to describe the system of physical laws that govern the movement of celestial bodies around the Sun. Through this inquiry, he formulated the ***universal law of gravitation****.*



Universal Law of Gravitation

Universal Law of Gravitation

There is a gravitational attraction between any two objects. If the objects have masses m_1 and m_2 and their centres are separated by a distance r, the magnitude of the gravitational force on either object is directly proportional to the product of m_1 and m_2 and inversely proportional to the square of r.



Universal Law of Gravitation

UNIVERSAL LAW OF GRAVITATION

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

where F_g is the force of gravity (N)
G is the universal gravitational constant (6.67×10^{-11} N·m²/kg²)
m is the mass of each of the objects (kg)
r is the distance between the centres of the masses (m)

NOTE!
For the force to be noticeable, at least one of the objects must have a very large mass relative to the distance between the object centres.

Universal Gravitation

PRACTICE

1. A 65.0 kg astronaut is walking on the surface of the Moon, which has a mean radius of 1.74×10^3 km and a mass of 7.35×10^{22} kg. What is the weight of the astronaut?

   F_g = 105 N ☜ recall that weight is another term for F_g

Universal Gravitation

PRACTICE

2. In an experiment, an 8.0 kg lead sphere is brought close to a 1.5 kg mass. The gravitational force between the two objects is 1.28×10^{-8} N. How far apart are the centres of the objects?

   r = 0.25 m

Universal Gravitation

PRACTICE

3. The radius of the planet Uranus is 4.3 times the radius of Earth. The mass of Uranus is 14.7 times the mass of Earth. How does the gravitational force on the surface of Uranus compare to that on Earth?

$F_{URANUS} = 0.80 \times F_{EARTH}$

Universal Gravitation

NOTE!

Newton's law of gravitation plays a key role in physics for two reasons.

① *His work showed for the first time that the laws of physics apply to all objects. The same force that causes a leaf to fall from a tree also keeps planets in orbit around the Sun. This fact had a profound effect on how people viewed the universe.*

② *The law provided us with an equation to calculate and understand the motions of a wide variety of celestial objects, including planets, moon, and comets.*

The Value of g

On Earth, we can calculate the acceleration due to the force of gravity, g, from the universal law of gravitation. Near Earth's surface, g has an approximate value of 9.8 m/s². The precise value of g, however, decreases with increasing height above Earth's surface based on the inverse-square law ($F_g \propto 1/r^2$). The value of g also varies on the surface of Earth because the surface varies in distance from the centre of Earth.

Altitude (km)	g (m/s^2)
1 000	7.33
2 000	5.68
3 000	4.53
4 000	3.70
5 000	3.08
6 000	2.60
7 000	2.23
8 000	1.93
9 000	1.69
10 000	1.49
50 000	0.13

Finding G

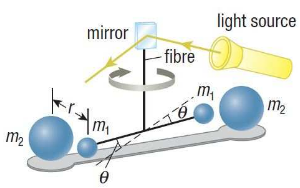
The numerical value of G, the universal gravitational constant, was not determined experimentally until 1798 by Henry Cavendish (more than 70 years after Newton's death). Cavendish realized that if he could determine the value of G, he could then determine the mass of the Sun, the planets, and other celestial bodies.

NOTE!

Cavendish, a brilliant experimentalist, designed a torsion balance that allowed him to measure G.

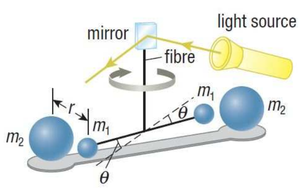
Finding G

A torsion balance is a device that can measure extremely small amounts of the rotation of a thin wire. It consists of (a) two spheres connected together by a bar that is then suspended from the centre by a thin wire and (b) another pair of large spheres placed close to the suspended masses. It is the gravitational force between the pairs of masses that causes the mass-bar system to rotate.



Finding G

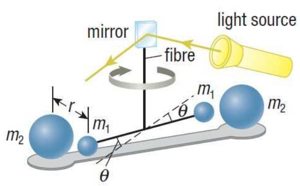
By carefully measuring the angle of rotation Cavendish was able to determine the force on the mass-bar system. By also measuring the masses of the spheres as well as their separation and inserting the values into the universal law of gravitation, Cavendish was able to measure G.



Finding G

UNIVERSAL GRAVITATION CONSTANT (G)

- determined experimentally by Henry Cavendish
- used a torsion balance



Universal Gravitation

PRACTICE

4. Eris, a dwarf planet, is the ninth most massive body orbiting the Sun. It is more massive than Pluto and three times farther away from the Sun. Eris is estimated to have a radius of approximately 1200 km.
   (a) Suppose that an astronaut stands on Eris and drops a rock from a height of 0.30 m. The rock takes 0.87 s to reach the surface. Calculate the value of g on Eris.

   (a) $g = 0.79\ m/s^2$[down]

Universal Gravitation

PRACTICE

4. Eris, a dwarf planet, is the ninth most massive body orbiting the Sun. It is more massive than Pluto and three times farther away from the Sun. Eris is estimated to have a radius of approximately 1200 km.
   (b) Calculate the mass of Eris.

   (b) Use $F_g = m_{rock}g$ & $F_g = Gm_{rock}m_{Eris}/r^2$
   $m_{Eris} = 1.7 \times 10^{22}$ kg

Universal Gravitation

PRACTICE

5. Three large, spherical asteroids in space are arranged at the corners of a right triangle as shown. Given the following information find the net force on asteroid A due to asteroid B and C.

$m_A = 1.0 \times 10^{20}$ kg

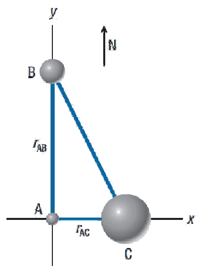
$m_B = 2.0 \times 10^{20}$ kg $r_{AB} = 5.0 \times 10^{10}$ m

$m_C = 4.0 \times 10^{20}$ kg $r_{AC} = 2.5 \times 10^{10}$ m

$F_{gAB} = 5.3 \times 10^8$ N[N]

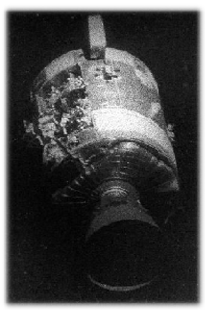
$F_{gAC} = 4.3 \times 10^9$ N[E]

$F_{gA} = 4.3 \times 10^9$ N[N83°E]



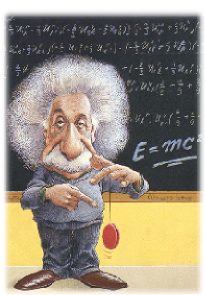
Newtonian Gravitation – DYK?

Newton's law of universal gravitation has stood the test of time and the extended limits of space. As far into space as astronomers can observe, celestial bodies move according to Newton's law. As well, the astronauts of the crippled Apollo 13 spacecraft owe their lives to the dependability and predictability of the Moon's gravity.



Newtonian Gravitation – DYK?

Although Albert Einstein took a different approach in describing gravity in his general theory of relativity, most calculations that need to be made can use Newton's law of universal gravitation and make accurate predictions.



Activity: Universal Gravitation (Inv.6.1.1/P.308)

BACKGROUND

In this activity you will model the trajectory of a rocket at varying altitudes.

INSTRUCTIONS

A. Follow procedure steps 1-4.
B. Answer analysis questions (a)-(e)
C. Answer Q.4,11/P.296

NOTE!

Step 3 do a manual fit of the data using LoggerPro (i.e. set the limits of x to 8.0 x 10^{-17} and 3.0 x 10^{-14})

(b) If $F_G = Gm_1m_2/r^2$ ☞ $F_Gr^2 = Gm_1m_2$ & $m = F_Gr^2$ so ...

(d) If $F_G = Gm_1m_2/r^2$ ☞ $G = F_Gr^2/m_1m_2$ & so ...

✔ Check Your Learning

TEXTBOOK

P.296 Q.2,3