GRAVITY

gravity (g): *Ltn*. for "weighty" ---> a force that attracts all matter to other matter in the universe.

gravity = mass interacting with mass [New concept *via* Newton!]

> According to Aristotle (384-322 B.C.E.); one could work out all the laws that govern the universe by pure thought, and that it was not necessary to check by observations.
>
> *Aristotle's* geocentric ("*egocentric*") concept of universe proclaimed that the earth was motionless and located at the center of the universe.
> "*Objects are pulled to earth because they wish to return to it*." (or center of universe).
> "*The natural place of things is on the ground, therefore they try to seek that place*."

What factors determine the strength of gravity between matter?

1) masses of the objects [more mass ----> more gravitational attraction] " direct relationship"

2) distance between the bodies [more distance ----> less gravitational attraction] " inverse relationship"

Newton's Law of Universal Gravitation: ----------------------------------->

$$F \sim \frac{m_1 m_2}{d^2}$$

Published in 1687, thus culminating the "scientific revolution" started in 1543 by Copernicus.

"*Every particle of matter attracts every other particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.*" -----> **inverse-square law**

How can we envision the strength of the earth's gravitational attraction on matter?

a) Observe motion of objets in "free fall." This *indirectly* tells us about the magnitude of (g).

b) Determine how fast an object must move in order to escape the earth's gravitational attraction;

- old cliche: "*Everything that goes up must come down*."

"**escape velocity**"(v_e) to leave earth's gravitational field = 6.98 mi./s, = 11.2 km/s, ~ 25,000 mph
[from moon = 1.5 mi./s, from mars = 3.2 mi./s, from solar system (at earth's distance) = 42 km/s!]

* (v_e) is also the maximum velocity of an incoming object!

* Objects weigh 5.88 x less on the moon because (g) on moon = 1.62 m/s^2 (*or* 5.31 ft/s^2)

Zero Gravity & Humans:

>Since this condition cannot be reproduced on earth for more than about 30 seconds, original thoughts were that an astronaut's heart might race uncontrollably, and a swift death would follow.
[In 1959 NASA first sends the chimps "Able & Baker" into space for sixty five minute ride.]

>During long-duration weightless flight;

* Loss of muscle mass (& heart). After four months on Mir; 40 % of muscle mass is lost.
* Muscles gradually atrophy (in the absence of work).
* Face swells as body fluids drift upward, and the brain begins to signal the body to get rid of this excess fluid by urination more and drinking less ----> dehydration.
* Density of bones (especially, pelvis and legs) decreases by about 1.5% each month (approximately what a post-menopausal woman loses in a year by osteoporosis). Unlike on earth where our bones are constantly renewed, in space there is almost no renewal. No one has returned from long-duration flight without bone loss of around 12-20%.

During a 972 day trip to Mars (260 days each way) a healthy 45 year-old could see bone deterioration and weakness to the state of severe osteoporosis.

[**~ 0.33 g's are needed for humans to maintain proper bone density for the long term**.] **mars ~ 0.38 g**

* Weakened immune system.
* Record in space is 438 days (*Rus*. Dr. Valery V. Polyakov in MIR space station). Two hours of exercise each day was required.

What is the universal gravitational constant (G)?

In Newton's time no instrument was capable of measuring the attractive force between two very small masses (ex; 1 kg). and Newton's calculations were thus not exact. It would not be for another 70 years before (G) was determined, and the *actual* attractive force between two point masses could be determined. This (G) is a "constant of proportionality" (*a.k.a.* "Newton's constant") which expresses a numerical relation between two 1.0 kg masses at a separation distance of 1.0 meter, and the attractive force between them.

In 1798, *Br*. Henry Cavendish discovered that;

"*the attractive force between two 1.0 kg masses whose centers are separated by 1.0 meter will be attracted to each other with a force of* 6.67×10^{-11}N." [This value is a very, very small force of attraction!]

The small magnitude of (G) means that the attractive force between two objects of ordinary sizes (man-sized) is extremely small (and explains why frictional forces prevent people from coming together).

Cavendish weighs the earth?

- With this (G) value, the mass of the earth can be obtained using -------------->

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

If $F = ma = mg$, then ... $mg = \frac{GM_e M}{d^2} \longrightarrow M_e = \frac{gd^2}{G} = \frac{(9.8\ m/s^2)(6.371 \times 10^6\ m)^2}{(6.673 \times 10^{-11}\ N\text{-}m^2/kg^2)} = \mathbf{5.976 \times 10^{24}\ kg}$

$= 6 \times 10^{21}$ tons!

Orbital Motion:

In early 1665 Newton was 22 received his degree from Trinity College at Cambridge University. When the plague broke out in southern England in the summer (killing more than one tenth of the population of London between July and September), the University was closed in the Autumn. Newton then went to his home town in Woolsthorpe (Co. Lincolnshire) where his widowed mother lived. Normally with one's access to a library and academic contacts suspended, one would expect a bit of dormancy of ideas, but this is just what Newton needed. With his formal introduction to mathematics he did not need further contact, and he would spend the next "18 golden months" without distractions doing mathematics. As well as mathematics, he turns his attention to unsolved planetary problems. (Kepler Problem)

<u>According to Newton</u>; Sitting one day in the family apple orchard in 1666, he saw an apple (Flower of Kent) fall. What "struck" Newton at the sight was not the thought that the apple must be drawn to the earth by something; that conception was far older than Newton. What struck him was the conjecture that the same pulling force, which reaches to the top of the tree, might go on reaching out beyond the earth and its air, ending endlessly into space. His thought was that this force might reach beyond the trees and mountains to the moon, and hold the moon in its orbit. There he calculated what force from earth (falling off as the square of the distance) would hold the moon, and compared it with the known force of gravity at tree height. "The forces agreed pretty nearly." Ironically, the unit of force (Newton) is about the magnitude of attraction between an apple and the earth!

“If I can see further than any others it is because I have stood on the shoulders of giants before me.” ----> *(Galileo & Kepler)*

>What he showed was that the familiar fall of apples and stones to the ground and the orbit of the moon are due to one and the same cause.

>His proofs help solidify Kepler’s laws.

>Newton assumes that gravity follows the “inverse-square law.” Knowing that the moon is about 60 earth radii away, then (g) should be acting on the moon about $(60)^2$ times less than on the earth’s surface. The downward (a) of the moon should then be $^{1}/_{3,600}$ of (a) near earth’s surface.

>According to Newton; when an apple falls 16 ft (4.9 m) in one second, the moon should fall $^{1}/_{3,600}$ of that distance from a straight line; which is $^{1}/_{16}$ of an inch ----> 0.0014 m <u>*or*</u> 1.4 mm.