G R A V I T A T I O N.

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Gravitation.

Historical,- Introduction

Gallilleo

Newton

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b. Discovery of the law of universal gravitation and,

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Gravity.

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GRAVITATION.

The real significance of Newton's discovery of universal gravitation is fully appreciated by but few. To a certain degree, all men are acquainted with it, for it is that force which gives weight to a body or causes it to fall toward the center of the earth. But it goes still farther, determining the position of the planetary bodies, and holding them in their orbits.

A large number of Philosophers before Newton were aware of the motion of terrestial bodies, and contributed something that aided in the discovery of this law. Of these we will mention but one; Gallilleo, for it was by looking from the heights of Gallilleo's discovery that Newton was enabled to discover the great law which he did

Gallilleo was born at Pisa, Italy, Feb. 14, 1564. He early showed a fondness for mathematics, and at the age of twenty was a distinguished geometrician. Five years later, he was appointed Professor of Mathematics at Pisa. It was here, while seated in a church that he noticed the slow and uniform swinging of a lamp, and inferred that this principle might be used as a measure of time. This idea he carried out fifty years later.

He wrote many excellent treatises on science, and constructed many machines of public utility for the state. Among some of his inventions were the thermometer, the proportional compass, and the microscope. He was the founder of Experimental Science, and first formulated the principle of virtual velocities. He investigated the true laws of motion, and by experiment, demonstrated that gravity acts on all bodies alike, and that bodies of unequal weights will fall thru the same space in equal times.

One of the peculiarities of Gallilleo was to tell others what he knew himself. This trait led him into difficulty. The members of the Inquisition, hearing of his discoveries, became alarmed and had him imprisoned for teaching that which was contrary to the Church doctrine. After imprisonment, for some time, he was allowed to return to Florence, where he again took up his study, surrounded by affectionate pupils. His works written at this time were preserved by a faithful friend and afterwards enabled Newton to deduce the law of universal gravitation. After four years of blindness, he died, Jan. 9, 1642, the same year in which Newton was born.

Sir Isaac Newton was born on Christmas day, 1642,,in Lincolnshire, England. He, like his predecessor, Gallilleo, early developed a taste for mathematics and applied himself to this study on entering Trinity College, Cambridge. He made rapid strides and in the year in which he graduated, committed to writing his first discovery in fluxious. While at home and seated in his mother's orchard, he noticed the falling of the apples with a constantly accellerating speed. This led him to the solution of the mystery as to what force retains the moon and planets in their orbits, and why the earth approaches and receides from the sun without ever deviating from its course. The answer was: Perhaps the same force that drew the apple to the ground holds the planets in their orbits. Here he applied the law as established by Gallilleo. The stumbling block of these earlier philosophers, was that they could not account for the motion of the planets. Their motion being at defiance with all motions with which they were acquainted. They also saw that anybody, to have motion, must be acted upon by a continuous force. Newton was probably the first to see the fallacy of this, and clearly formulated it in his laws of motion: viz:- "A body once set in motion and acted on by no force will move forever in a straight line with a uniform velocity."

2nd. "If a moving body be acted on by any force, its deviation from the motion defined in the first law will be in the direction of the force and proportional to it."

3d. Action and reaction are equal, and in opposite directions. The first law is the funda mental one, and on these three laws hinge the basis of his discoveries. The reason for these laws remaining unknown for so long is that there was no case on the earht's surface where a body was not acted upon by some force, and hence no means of experiment. Newton conceived this great principle as enumerated in the first law, and working from it, was enabled to answer the question as to why the moon does not fly off at a tangent from its path around the earth. To find the force required to do this, he made a circulation using 7000 miles as the diameter of the earth, and 60 half diameters as the distance of the moon from the earth. He found his results to be too small by 2.2 feet, he consequently laid the problem aside for twenty years, when hearing that Picard in France had discovered that the former measurements of the earth's diameter were too small by about one sixth. Figuring from this new measurement, he found the amount of fall was 16.1 feet per minute on 1/3600 of the force of gravity of the earth, which corresponds exactly to the law of the inverse square of the distance.

To extend the law to the other planets, we need only to apply Kepler's third law, and we find that every planet gravitates toward the sun inversely as the square of the distance. The pathway of the body was proven by Newton in accordance with Kepler's 1st. law, that it would be elliptical in shape with the sun in one of its foci. Calculations on all the planets has proven that this law holds good, there being not a single deviation from it.

In the case of Comets, there is an apparent exception. The tail seems to be repelled. Theories have been advanced to account for it, but the one that seems to be most plausible is that the sun exerts an electrical repellent force on the vaporized portion in the tail. In consequence of this universality of attraction, we have this great law formulated:- "Every particle of matter in the universe attracts every other particle with a force directly as their masses and inversely as the square of the distance which separates them."

GRAVITY.(from Modern Latin derivative of gravitate; derivative of Latin gravitas, heaviness; derivative of gravis, heavy.

In its widest sense, the tendency which all bodies exibit to approach others with a force directly as their mass and inversely proportional to the square of the distance between them. In general gravity gives weight to all substances in nature. The rising of vapor; the falling of rain; the wind; the flow of streams over the sloping surface of the land are all caused by the attraction of the great mass of the earth on the comparatively small masses of matter on its surface, causing bodies to fall with a constantly accellerating speed passing over a distance of 16.1 ft., the first second three times that distance the second, five times that distance the third, and so on.

The variations of gravity on the earth's surface are due to the following causes. The earth is not a perfect sphere, but a spheriod, with the diameter at the equater about 43 Kilometers greater than the diameter thru the poles. Gravity would thus have a less value at the equater than at the poles, they being farther from the earth's center. The centrifugal force at the equater causes the body to loose weight, which amounts to about 1/289 of its weight. Of course, this decreses toward the poles. Gravity also varies with the altitude. The length of a second's pendulum at the equater is 99.103 cm. and at the poles it is 99.610 cm. These lengths are taken at sea-level, and the formula for gravity in this case is:- $g = \pi^2 l$.

The first experimental determination of gravity was performed by Richer, in 1672. He took a clock from Paris to Cayenne, and found that it lost 2 1/2 minutes daily. It was regulated at Cayenne, and when taken back to Paris it was found to gain 2 1/2 minutes. This was due as can be readily seen to the form of the earth. There have been many ways devised to determine gravity such as:- Inclined Plane "Dilute Gravity" Atwood's machine; Spiral spring; pendulum and an instrument called the reversible pendulum. To measure the force of gravity at Manhattan, we have employed two ways as follows:

Simple pendulum:- A brass plumb bob was suspended by means of a fine thread. It was set in vibration thru a small arc and the time of vibration obtained by means of a stop watch at the instant the pendulum assumes the verticle. It here has its maximum speed and hence can be more accurately determined when it passes some denoted point or plumb-line near it. The formula for the pendulum is:-

$$t = \pi\sqrt{\frac{l}{g}}\left[1+\left(\frac{1}{2}\right)^2 k^2+\left(\frac{1\cdot 3}{2\cdot 4}\right)^2 k^2+\dots\right] \text{ Where } k=\sin\frac{\theta_c}{2}$$

For ordinary readings it is not carried out so far, using the simple equation $g = \frac{4\pi^2 l}{t^2}$.

READINGS:-

Length of Pendulum.	No. Vibrations.	Time	Time of Single Vibration.
280.1 cm	10.	33.4 sec.	3.34 sec.
"	"	33.6 "	3.36 "
"	"	33.6 "	3.36 "
"	"	33.4 "	3.34 "
"	"	33.8 "	3.38 "
"	"	34. "	3.4 "
"	"	33.6 "	3.36 "
"	"	33.8 "	3.38 "
"	"	33.4	3.34 "
"	"	33.4 "	3.34 "
"	"	33.4 "	3.34 "
"	"	33.4 "	3.34 "
"	"	33.6 "	3.36 "
"	"	33.2 "	3.32 "
"	"	33.2 "	3.32 "
"	"	33.6 "	3.36 "
"	"	33.6 "	3.36 "
"	"	33.2 "	3.32 "
"	"	33.4 "	3.34 "
		mean 33.5"	mean 3.35"

Corrected for $\frac{9}{2220}$ sec. = 3.359 sec.

$$g = \frac{4(3.1416)^2\ 280.1}{(3.359)^2} = 980.07 \text{ dynes}$$

REVERSIBLE PENDULUM. This is similar to the simple pendulum, but more accurate. It is based on the principle of interchangebility of the centers of suspension and osciliation. The rod of the pendulum carries two knife edges, which are adjustable. They are then so arranged then when the pendulum swings from knife-edge No. 1, No. 2 will be near the center of oscillation. It is then reversed, No. 2 being the supporting one and by this means, when they vibrate in equal periods in both positions, the distance between the two knife edges is found to be the length of the pendulum. The formula is the same for this one as for the simple pendulum.

Readings:-

Length of Pendulum

90.9 cm. = maximum length.
90.3 " = minimum "
90.6 " = mean "

T = 19.1 sec. — corrected for variation of stop-watch.

$$g = \frac{4(3.1416)^2\ 90.6}{(19.1)^2} = 980.35 \text{ dynes.}$$

Spiral Spring:- When the spring is oscillating, and when it is at either its maximum or minimum elongation, the energy contained in it will all be potential. Hence, we must find a point where it is all Kinetic, and then equate the two. We find the Potential Energy $\frac{1}{2}Ka^2$

when A is the distance displaced by a mass M.

The Kinetic Energy at the end of the spring is equal to $\frac{2\pi^2 a^2 m}{T^2}$ and that of the spring itself $\frac{2\pi^2 a^2 m_s}{3T^2}$ A, being the distance of displacement. M, the mass of the body on the end of the spring and Ms the mass of the spring T, time of vibration.

Hence the total K.E. would be the K.E. of the mass $\left(\frac{2\pi^2 a^2 m}{T^2}\right)$ + the K.E. of the spring $\left(\frac{2\pi^2 a^2 m_s}{3T^2}\right)$ or $\frac{2\pi^2 a^2}{T^2}\left(m + \frac{m_s}{3}\right)$. Equating P.E. $= \frac{1}{2}Ka^2$ K.E. $= \frac{2\pi^2 a^2}{T^2}\left(m + \frac{m_s}{3}\right)$ or $\frac{1}{2}K = \frac{2\pi^2}{T^2}\left(m + \frac{m_s}{3}\right)$.

If we now add an over weight to the mass on the spring, we will get a deflection for that certain amount.

Let G = gravity. D., deflection by the small mass M, and we get $K = \frac{mg}{D}$

Substituting this for K above we get $g = \frac{\frac{4\pi^2 D}{T^2}\left(m + \frac{m_s}{3}\right)}{m}$.

Owing to lack of apparatus, we were unable to obtain readings by this method.

By taking the mean of the readings for the Simple Pendulum (980.07 dynes) and the Reversible Pendulum (980.35 dynes), we get 980.21 dynes as the value of the force of gravity at Manhattan.