

Quadrant II – Transcript and Related Materials

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Unit: I

Module Name: Earth's Gravity: Acceleration Due To Gravity, Change With Latitude And Altitude, mass and Density

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NOTES:

EARTH'S GRAVITY

Gravitation is a natural phenomenon by which all objects attract each Other; In everyday life, gravitation is best known as the agency that endows objects with weight. Gravitation is responsible for keeping the Earth and the Other planets in their Orbits around the Sun; for keeping the Moon in its orbit around the Earth; for the formation Of tides; for convection (by which hot fluids rise); for heating the interiors of evolving stars and planets to very high temperatures; and for various other phenomena that we observe. Gravitation is also the reason for the very existence of the Earth, the Sun, and most macroscopic Objects ill the universe; without it, matter would not have coalesced into these large masses, and life, as we know it, would not exist.

Gravitation is the force of attraction between two bodies, such as the Earth and our body. The

'Strength of this attraction depends on the mass of the two bodies and the distance between them.

Isaac Newton's theory of universal gravitation states the following:

Every single point mass attracts every other point mass by a force pointing along the line combining the two. The force is proportional to the product of the two masses and inversely proportional to the square of the distance between the point masses:

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

Assuming SI units, F is measured in newtons (N), m_1 and m_2 in kilograms (kg), r in metres (m), and the constant G is approximately equal to $6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$

Earth's gravity

The gravitational field is numerically equal to the acceleration of objects under its influence, and its value at the Earth's surface, denoted as g , is approximately 9.8 m/s^2 . This means that, ignoring air resistance, an object falling freely near the earth's surface increases in speed by 9.807 m/s for each second of its descent. Thus, an object starting from rest will attain a speed of 9.807 m/s after one second, 19.614 m/s after two seconds, and so on. According to Newton's 3rd Law, the Earth itself experiences an equal and opposite force to that acting on the falling object, meaning that the Earth also accelerates towards the Object. However, because the mass of the Earth is huge, the measurable acceleration of the Earth by this same force is negligible, when measured relative to the system's center of mass. The unit of gravity is the Gal (in honor of Galileo). One Gal equals 1 cm/sec^2 .

The precise strength of the Earth's gravity varies depending on location. The nominal "average" value at the Earth's surface, known as standard gravity is, by definition, 9.80665 m/s^2 (approx. 980 gals). However this figure varies place to place (usually a few milligals or less), for reasons mentioned below. The symbol g should not be confused with G , the gravitational constant, or g , the abbreviation gram (which is not italicized).

Variations on Earth

The strength (or apparent strength) of Earth's gravity varies with latitude, altitude, and local topography and geology (rock density). For most purposes the gravitational force is assumed to act in a line directly towards a point at the center of the Earth, but for very precise work the direction can also vary slightly because the Earth is not a perfectly uniform sphere.

Gravity surveys exploit the very small changes in gravity from place to place that are caused by changes in subsurface rock density. Higher gravity values are found over rocks that are denser, and lower gravity values are found over rocks that are less dense.

Latitude

Gravity is weaker at lower latitudes (nearer the equator), for two reasons. The first is due to rotation or spin of the earth. At the equator the angular velocity of an object (on or near the surface of the earth) is the highest. Objects on latitudes closer to the poles are moving progressively slower. At the equator some of the gravitational force is used to keep the object in its circular path (that is to provide a centripetal force). The speed of rotation decreases towards the poles, so does the centripetal force, resulting in higher gravitational force. Earlier the same phenomenon was explained in terms of centrifugal force, which would be higher at the equator, thus countering and lowering the gravity value.

The second reason of higher gravity towards the poles is the Earth's equatorial bulge (itself also caused by rotation and angular velocity). The bulge of the earth causes objects at the equator to be farther from the planet's centre than objects at the poles. Because the force due to gravitational attraction between two bodies (the Earth and the object being weighed) varies inversely with the square of the distance between them, objects at the equator experience weaker gravitational pull than objects at the poles.

In combination, the equatorial bulge and the effects of centripetal force, mean that at sea-level, gravitational acceleration increases from about 9.780 m/s^2 at the equator to about 9.832 m/s^2 at the poles, so an object will weigh about 0.5% more at the poles than at the equator.

Altitude

Gravity decreases with altitude, since greater altitude means greater distance from the Earth's center. All other things being equal, an increase in altitude from sea level to the top of Mount Everest (8,850 meters) causes a weight decrease of about 0.28%. (An additional factor affecting apparent weight is the decrease in air density at altitude, which increases an object's buoyancy).

It is a common misconception to assume that astronauts in orbit are weightless because they have flown high enough to "escape" the Earth's gravity. In fact, at an altitude of 250 miles (roughly the height that the Space Shuttle flies) gravity is still nearly 90% as strong as at the Earth's surface, and weightlessness actually occurs because orbiting objects are in free-fall.

If the Earth was of perfectly uniform composition then, during a descent to the centre of the Earth, gravity would decrease linearly with distance, reaching zero at the centre. In reality, (theoretically) the gravitational field should peak within the Earth at the core-mantle boundary where it should have a value of 10.7 m/s^2 .

Local topography (mass variations) and Geology

Local variations in topography (such as the presence of mountains) and geology (such as the density of rocks in the vicinity) cause fluctuations in the Earth's gravitational field, known as gravitational anomalies.

A huge mountain would locally attract a pendulum or plumb line or a gravimeter, so that there would be a minute deviation from the main gravitational field directed towards the center of the earth. The massive mountain mass would cause its own local attraction. Similarly the presence of very dense rocks (like some ore bodies) in a locality would result in higher than expected gravity readings (positive anomalies) on a sensitive gravimeter placed above them.

Sedimentary rocks, especially salt domes associated with oil fields are less dense than normal crustal rocks, and will result in negative anomalies.

The study of these anomalies forms the basis of gravitational geophysics. The fluctuations are measured with highly sensitive gravimeters, the effect of topography and other known factors is subtracted, and from the resulting data, conclusions are drawn. Such techniques are now used by prospectors to find oil and mineral deposits. Denser rocks (often containing mineral ores) cause higher than normal local gravitational fields on the Earth's surface. Less dense sedimentary rocks cause the opposite. Paris, France has been shown by this method to almost certainly be sitting on a huge, untouchable oilfield.