5.3: Newton's Law of Gravitation

Newton noted that the ratio of the centripetal acceleration of the Moon in its orbit around the Earth to the acceleration of an apple falling to the surface of the Earth was inversely as the squares of the distances of Moon and apple from the centre of the Earth. Together with other lines of evidence, this led Newton to propose his universal law of gravitation:

Every particle in the Universe attracts every other particle with a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them. In symbols:

$$F = \frac{GM_1M_2}{r^2}. \quad \mathrm{N} \tag{5.3.1}$$

Here, G is the Universal Gravitational Constant. The word "universal" implies an assumption that its value is the same anywhere in the Universe, and the word "constant" implies that it does not vary with time. We shall here accept and adopt these assumptions, while noting that it is a legitimate cosmological question to consider what implications there may be if either of them is not so.

Of all the fundamental physical constants, G is among those whose numerical value has been determined with least precision. Its currently accepted value is $6.6726 \times 10^{-11} \mathrm{N\,m^2\,kg^{-2}}$. It is worth noting that, while the product GM for the Sun is known with very great precision, the mass of the Sun is not known to any higher degree of precision than that of the gravitational constant.

Exercise. Determine the *dimensions* (in terms of M, L and T) of the gravitational constant. Assume that the period of pulsation of a variable star depends on its mass, its average radius and on the value of the gravitational constant, and show that the period of pulsation must be inversely proportional to the square root of its average density.

The gravitational field is often held to be the weakest of the four forces of nature, but to aver this is to compare incomparables. While it is true that the electrostatic force between two electrons is far, far greater than the gravitational force between them, it is equally true that the gravitational force between Sun and Earth is far, far greater than the electrostatic force between them. This example shows that it makes no sense merely to state that electrical forces are stronger than gravitational forces. Thus any statement about the relative strengths of the four forces of nature has to be phrased with care and precision.