Gravity Formulas

One force that is studied extensively in Physics is gravity. Gravity is a force that all objects on Earth experience. As was studied in the previous chapters, the acceleration of gravity on Earth is **g** = **9.8** m/s^2, and the gravitational force on an object of mass **m** is **mg**.

In this chapter, the Law of Universal Gravitation states that two objects of masses $\mathbf{m}_1$ and $\mathbf{m}_2$ exert a gravitational force on each other. The formula for the magnitude of the force F_G is $F_G = G\frac{m_1 m_2}{r^2}$ where **r** = the distance between the objects, and the gravitational constant $= G = 6.67 \times 10^{-11}\ \frac{N \cdot m^2}{kg^2}$. Stated in vector form, $\vec{F}_{12} = -G\frac{m_1 m_2}{r^2}\hat{r}_{21}$ where $\vec{F}_{12} =$ The force on particle 1 exerted by particle 2 as shown in figure 1 below, and $\hat{r}_{21} =$ The unit vector pointing from particle 2 to particle 1. Notice that $\vec{F}_{12} = -\vec{F}_{21}$ by Newton's Third Law.

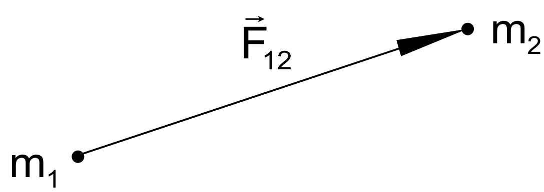

Figure 1: The above diagram shows the force on particle 1 exerted by particle 2.

Suppose that there are two or more forces acting on particle 1. The forces acting on particle 1 add up vectorially; i.e., $\vec{F}_1 = \sum_{i=2}^{n} \vec{F}_{1i}$.

Using the Law of Universal Gravitation, the gravitational field on an object of mass m by an object of mass M is $g_M = G\frac{M}{r^2}$. Just divide the Law of Universal Gravitation: $F_G = G\frac{Mm}{r^2}$ by m to get the above result. In vector notation, $\vec{g} = -G\frac{M}{r^2}\hat{r}$ where $\hat{r} =$ the radial vector pointing from mass M to the object of mass m_1. Hence, $\vec{g}$ is a vector that points from the object of mass m_1 to mass M. In particular, $g_E = G\frac{M_E}{r^2} = 9.8\ m/s^2$ where M_E = the mass of the Earth for many values of r.

<u>Escape Velocity</u>:

One concept that is used in astronomy and in space travel is “escape velocity”; i.e., what speed v does a spaceship, satellite, or rocket have to go in order to escape the gravitational pull of the Earth or any planet or moon. The answer is found by solving the equation for v: $F_G = G\frac{m_S M_E}{r^2} = m_S \frac{v^2}{r} =$ Centripetal force of the spaceship of mass m_S for v. The results are below: $G\frac{M_E}{r^2} = \frac{v^2}{r} \Rightarrow v = \sqrt{\frac{GM_E}{r}}$. Spaceships and satellites usually move in a circular orbit around the Earth before they escape the pull of the Earth.

Another formula that is used to figure out the escape velocity is $v = \frac{2\pi r}{T}$ where T = One period of revolution = 1 day = 86,400s for the Earth. $v = \frac{2\pi r}{T}$ is substituted into $v = \sqrt{\frac{GM_E}{r}}$ to get the height above the Earth the satellite or spaceship must go so that the Earth and the satellite or spaceship have the same period. If a satellite or spaceship has the same period as the Earth, then it is <u>geosynchronous</u>. If one does the math, **r = 4.23 x 10^7** meters from the center of the Earth. Subtracting the Earth’s radius of **6380** km, the satellite or spaceship must be approximately **36,000** km above the Earth’s surface.

When doing calculations that deal with the Earth or another planet or moon, **r** = the distance from the center of the Earth or another planet or moon.