

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 $\mathbf{g} = 9.8 \text{ m/s}^2$, and the gravitational force on an object of mass \mathbf{m} is \mathbf{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 \mathbf{r} = the distance between the

objects, and the gravitational constant = $G = 6.67 \times 10^{-11} \frac{\text{N} \cdot \text{m}^2}{\text{kg}^2}$. 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.

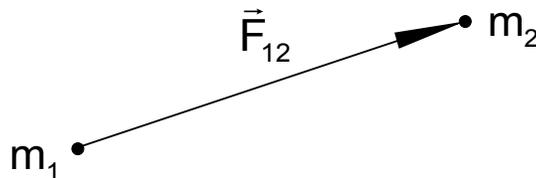


Figure 1: The above diagram shows the force on particle 1 exerted by particle 2.

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 \mathbf{m} by an object of mass \mathbf{M} is $g_M = G \frac{M}{r^2}$. Just divide the Law of Universal

Gravitation: $F_G = G \frac{Mm}{r^2}$ by \mathbf{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 \mathbf{M} to the object of mass \mathbf{m}_1 . Hence, \vec{g} is a vector that points from the object of mass \mathbf{m}_1 to mass \mathbf{M} . In particular,

$g_E = G \frac{M_E}{r^2} = 9.8 \text{ m/s}^2$ where M_E = the mass of the Earth for many values of \mathbf{r} .

Escape Velocity:

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 $= 86,400$ s 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 geosynchronous. If one does the math, $r = 4.23 \times 10^7$ 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.