

Lecture 6.

1. Forces

There are four fundamental forces in our universe:

1. Gravitational force
2. Electromagnetic force
3. Strong force
4. Weak force

2. Gravitational force

Between any two objects with masses m_1 and m_2 there is a gravitational force pulling them towards each other. This force of gravitational attraction is directly dependent upon the masses of both objects and inversely proportional to the square of the distance which separates their centers.

$$F = G \frac{m_1 m_2}{r^2}$$

Since the gravitational force is directly proportional to the mass of both interacting objects, more massive objects will attract each other with a greater gravitational force. So as the mass of either object increases, the force of gravitational attraction between them also increases. If the mass of one of the objects is doubled, then the force of gravity between them is doubled; if the mass of one of the objects is tripled, then the force of gravity between them is tripled; if the mass of both of the objects is doubled, then the force of gravity between them is quadrupled; and so on.

Since gravitational force is inversely proportional to the separation distance between the two interacting objects, more separation distance will result in weaker gravitational forces. So as two objects are separated from each other, the force of gravitational attraction between them also decreases. If the separation distance between two objects is doubled (increased by a factor of 2), then the force of gravitational attraction is decreased by a factor of 4 (2 raised to the second power). If the separation distance between any two objects is tripled (increased by a factor of 3), then the force of gravitational attraction is decreased by a factor of 9 (3 raised to the second power).

Actually, this is where the magnitude of the free fall acceleration comes from. If we consider gravitational attraction between an object of mass m and Earth, it can be written as:

$$F = G \frac{mM_E}{R_E^2} = mg$$

where

$$g = G \frac{M_E}{R_E^2}$$

Using this equation we can find free fall acceleration for different planets using their masses and radii.

3. Escape velocity

If you throw an object straight up, it will rise until the free fall acceleration stops it, then returns it to Earth. Gravity's force diminishes as distance from the center of the Earth increases, however. So if you can throw the object with enough initial upward velocity so that gravity's decreasing force can never quite slow it to a complete stop, its decreasing velocity can always be just high enough to overcome gravity's pull. The initial velocity needed to achieve that condition is called escape velocity.

$$V_{esc} = \sqrt{\frac{2GM}{R}}$$

From the surface of the Earth, escape velocity (ignoring air friction) is about 7 miles per second, or 25,000 miles per hour. Given that initial speed, an object needs no additional force applied to completely escape Earth's gravity.

