Pendulum Motion

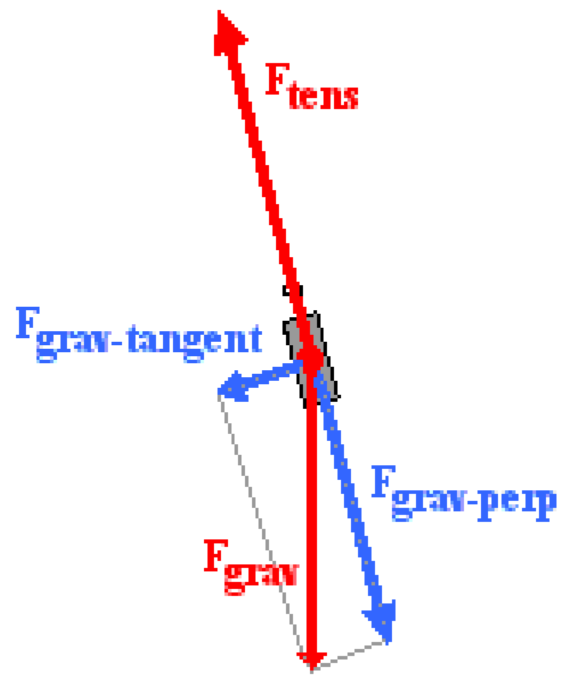
A simple pendulum consists of a relatively massive object hung by a string from a fixed support. It typically hangs vertically in its equilibrium position. The massive object is affectionately referred to as the *pendulum bob*. When the bob is displaced from equilibrium and then released, it begins its back and forth vibration about its fixed equilibrium position. The motion is regular and repeating, an example of periodic motion.

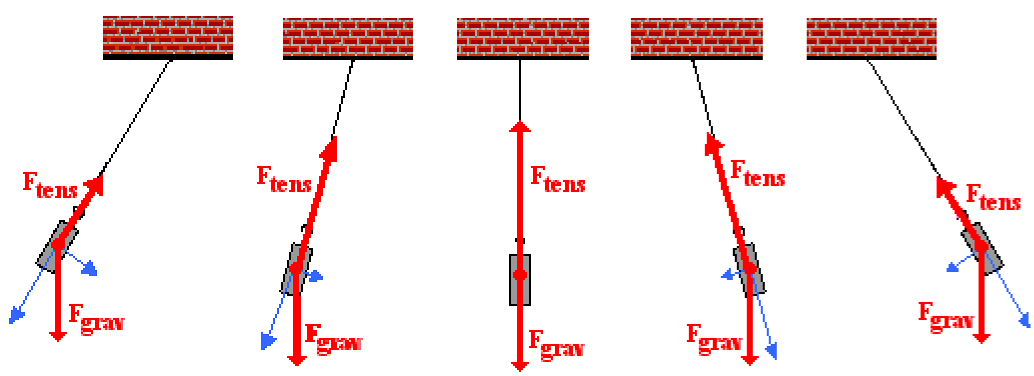
Force Analysis of a Pendulum

we know that when an object that is vibrating is acted upon by a restoring force. The restoring force causes the vibrating object to slow down as it moves away from the equilibrium position and to speed up as it approaches the equilibrium position. It is this restoring force that is responsible for the vibration. So what forces act upon a pendulum bob? And what is the restoring force for a pendulum? There are two dominant forces acting upon a pendulum *bob* at all times during the course of its motion. There is the force of gravity that acts downward upon the bob. It results from the Earth's mass attracting the mass of the bob. And there is a tension force acting upward and towards the pivot point of the pendulum. The tension force results from the string pulling upon the *bob* of the pendulum. In our discussion, we will *ignore* the influence of air resistance - a third force that always opposes the motion of the bob as it swings to and fro. The air resistance force is relatively weak compared to the two dominant forces.

The gravity force is highly predictable; it is always in the same direction (down) and always of the same magnitude - mass*9.8 N/kg. The tension force is considerably less predictable. Both its direction and its magnitude change as the bob swings to and fro. The direction of the tension force is always towards the pivot point. So as the bob swings to the left of its equilibrium position, the tension force is at an angle - directed upwards and to the right. And as the bob swings to the right of its equilibrium position, the tension is directed upwards and to the left. The diagram below depicts the direction of these two forces at five different positions over the course of the pendulum's path.

Free Body Diagram
(with components)





There are a couple comments to be made. First, observe the diagram for when the bob is displaced to its maximum displacement to the right of the equilibrium position. This is the position in which the pendulum bob momentarily has a velocity of 0 m/s and is changing its direction. The tension force (F-tension) and the perpendicular component of gravity (F gravity-perpendicular) balance each other. At this instant in time, there is no net force directed along the axis that is perpendicular to the motion. Since the motion of the object is *momentarily paused*, there is no need for a centripetal force.

Second, observe the diagram for when the bob is at the equilibrium position (the string is completely vertical). When at this position, there is no component of force along the tangent direction. When moving through the equilibrium position, the restoring force is momentarily absent. Having been *restored* to the equilibrium position, there is no restoring force. The restoring force is only needed when the pendulum bob has been displaced away from the equilibrium position. You might also notice that the tension force (F tension) is greater than the perpendicular component of gravity (F gravity-perpendicular) when the bob moves through this equilibrium position. Since the bob is in motion along a circular arc, there must be a net centripetal force at this position.