For small angles, the pendulum's motion is simple harmonic

As with a mass-spring system, the restoring force of a simple pendulum is not constant. Instead, the magnitude of the restoring force varies with the bob's distance from the equilibrium position. The magnitude of the restoring force is proportional to sin θ. When the maximum angle of displacement θ is relatively small ($<15°$), sin θ is approximately equal to θ in radians. As a result, the restoring force is very nearly proportional to the displacement and the pendulum's motion is an excellent approximation of simple harmonic motion. We will assume small angles of displacement unless otherwise noted.

Because a simple pendulum vibrates with simple harmonic motion, many of our earlier conclusions for a mass-spring system apply here. At maximum displacement, the restoring force and acceleration reach a maximum while the speed becomes zero. Conversely, at equilibrium, the restoring force and acceleration become zero and speed reaches a maximum. **Table 1** on the following page illustrates the analogy between a simple pendulum and a mass-spring system.

Gravitational potential increases as a pendulum's displacement increases

As with the mass-spring system, the mechanical energy of a simple pendulum is conserved in an ideal (frictionless) system. However, the spring's potential energy is elastic, while the pendulum's potential energy is gravitational. We define the gravitational potential energy of a pendulum to be zero when it is at the lowest point of its swing.

Figure 5 illustrates how a pendulum's mechanical energy changes as the pendulum oscillates. At maximum displacement from equilibrium, a pendulum's energy is entirely gravitational potential energy. As the pendulum swings toward equilibrium, it gains kinetic energy and loses potential energy. At the equilibrium position, its energy becomes solely kinetic.

As the pendulum swings past its equilibrium position, the kinetic energy decreases while the gravitational potential energy increases. At maximum displacement from equilibrium, the pendulum's energy is once again entirely gravitational potential energy.

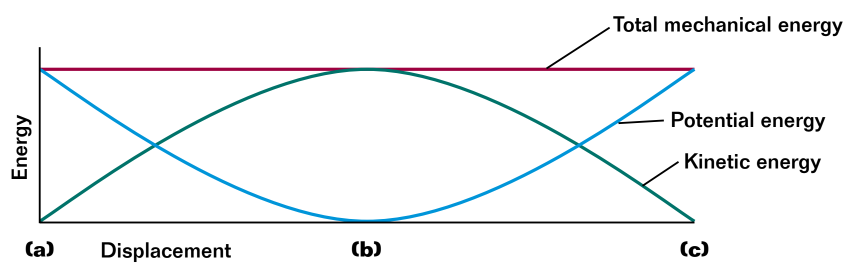

Figure 5
Whether at maximum displacement **(a),** equilibrium **(b),** or maximum displacement in the other direction **(c),** the pendulum's total mechanical energy remains the same. However, as the graph shows, the pendulum's kinetic energy and potential energy are constantly changing.

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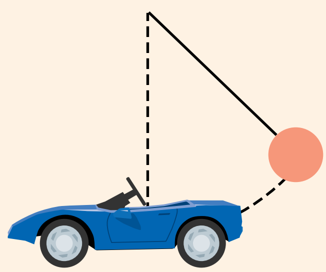
Quick Lab

Energy of a Pendulum

MATERIALS LIST

- pendulum bob and string
- tape
- toy car
- protractor
- meterstick or tape measure



Tie one end of a piece of string around the pendulum bob, and use tape to secure it in place. Set the toy car on a smooth surface, and hold the string of the pendulum directly above the car so that the bob rests on the car. Use your other hand to pull back the bob of the pendulum, and have your partner measure the angle of the pendulum with the protractor.

Release the pendulum so that the bob strikes the car. Measure the displacement of the car. What happened to the pendulum's potential energy after you released the bob? Repeat the process using different angles. How can you account for your results?