

Lesson 43: Simple Harmonic Motion

As far back as Lesson 31 we started talking about ideas like period and frequency, and more recently in Lesson 39 Hooke's Law.

- We can bring these ideas together now to look more carefully at the idea of **Simple Harmonic Motion (SHM)**.
- **Simple harmonic motion** is any situation where an object...
 1. repeats its motion over and over again in a fixed pattern that has a certain period.
 2. there is a restoring force causing it to move back to its equilibrium point (where it was at rest before any force was applied to it). The restoring force is directly related to the amount of displacement from equilibrium (that's Hooke's Law).
- **SHM** happens to objects that are **simple harmonic oscillators**.

If we look at situations where a mass is attached to an elastic object (like a spring), we can use our knowledge of the forces acting on it to start making predictions of how it will move.

- If the mass is stretched away from equilibrium, the restoring force will pull it back to equilibrium. The amount of restoring force would be calculated using $F_s = -kx$.
- Besides the restoring force (calculated using Hooke's Law) you may have to take other forces into account.
 - One example of this sort of situation would be a spring hanging vertically. Then you would need to take the force due to gravity into account.

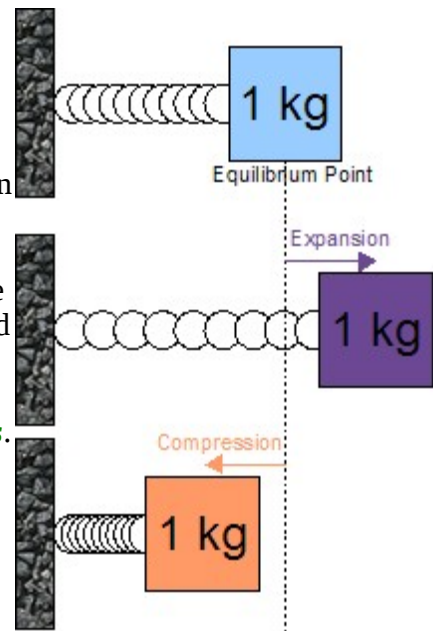


Illustration 1: A mass starts at its equilibrium point, is stretched outwards, and then bounces back and forth, including compressing past its equilibrium point.

Example 1: A spring is attached to the ceiling dangling downwards to make a basic scale for measuring masses. The spring constant is 38.9 N/m. At first it is just hanging there on its own at its equilibrium point. If a 1.3 kg mass is hung from the spring, **determine** how far it will stretch.

In this position, the amount of gravitational force pulling it down will be balanced by the restoring force pulling it up and the mass will just hang at its position with a net force of zero acting on it.

$$\begin{aligned}
 F_{NET} &= F_s + F_g \\
 0 &= F_s + F_g \\
 F_s &= F_g \\
 kx &= mg \\
 x &= \frac{mg}{k} = \frac{1.3(9.81)}{38.9} = 0.33 \text{ m}
 \end{aligned}$$

Skip the negative sign in the elastic restoring force and gravity, since in elastic situations the sign is based on expansion or compression, while in gravity its based on up and down directions.

Because it will just hang at this position on its own forever, this is its new equilibrium point *with the mass attached*. We would still continue to do calculations of the restoring force using the original equilibrium point.

Example 2: A person standing next to the scale with the mass attached tugs down on the mass and then lets go. **Sketch** a diagram showing the forces acting on the mass as it bounces up and down (SHM).

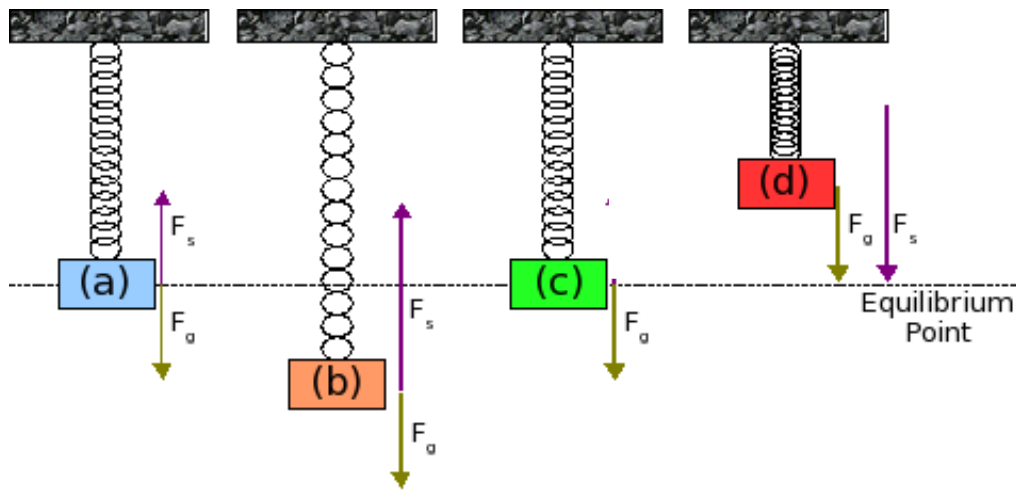


Illustration 2: Mass bouncing on spring.

- This is the original position at the equilibrium point before the person pulled on it. F_s and F_g are equal, so the net force is zero.
- The person has pulled the mass down and let go. Since it is pulled further away from the equilibrium point, the F_s is bigger. The net force is upwards, pulling the mass upwards so it accelerates up.
- At this point F_s and F_g are equal again so the net force is zero. This does not mean that the mass stops; instead it will continue moving the way it is already, which means it continues to move upwards.
- Compressed the spring will be pushing the mass down. F_g is also down. The net force will be acting downwards, which will slow down and eventually stop the mass. Then the mass will start to accelerate down and speed up.

The mass will continue to bounce up and down.

Pendulums are also an example of SHM, although they are not perfect.

- When a pendulum is just sitting on its own at its equilibrium point, it has no reason to do anything at all.
- If it is pulled off to the side, there will be a restoring force trying to get it back to the equilibrium point.
 - This restoring force is actually a component of the force due to gravity.
- As the pendulum is pulled off to the side at a bigger and bigger angle, the restoring force does increase, but it does not do it in a steady, linear way.
 - Since the restoring force is **not** directly related to the displacement, we can't say it is SHM.
 - What we can do is keep the angle fairly small (less than about 15°), for which the force does increase almost linearly, so we can say it is SHM for angles up to 15° .

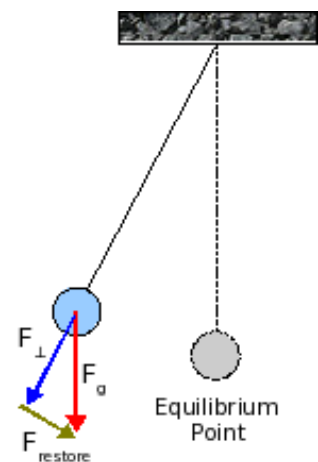


Illustration 3: Pendulum pulled off to the side.

Example 3: A 2.0kg mass is attached to the end of a pendulum. If the pendulum is held out at a 10° angle from equilibrium, **determine** the restoring force.

If you look at Illustration 3, you'll see that if the pendulum is pulled off to the side at a 10° angle, the angle will also be 10° in the diagram for the components as shown in Illustration 4.

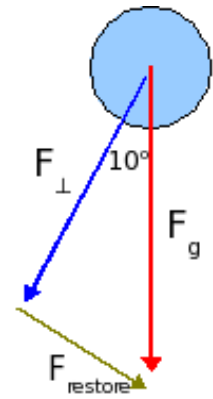
$$\sin \theta = \frac{\text{opp}}{\text{hyp}}$$

$$\sin \theta = \frac{F_{\text{restore}}}{F_g}$$

$$F_{\text{restore}} = \sin \theta F_g$$

$$F_{\text{restore}} = \sin 10^\circ (2.0)(9.81)$$

$$F_{\text{restore}} = 3.4 \text{ N}$$



*Illustration 4:
Components of
force due to
gravity.*