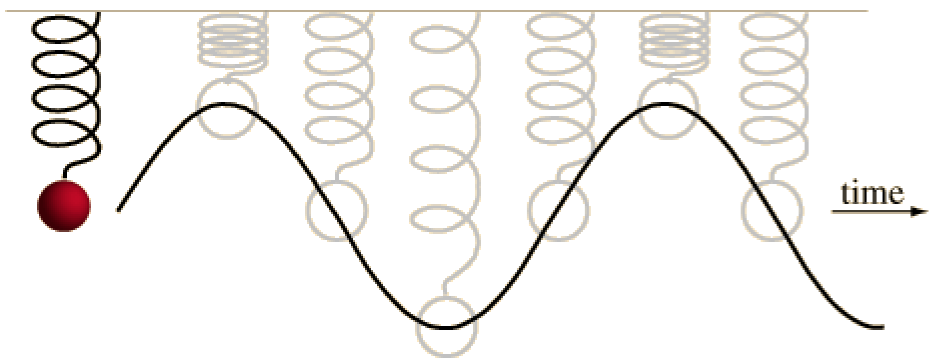
AP Lab #12: Simple Harmonic Motion (Big Idea 3.B.3)

In this investigation you will explore the concept of simple harmonic motion, using a harmonic oscillator (e.g., spring, pendulum). Specifically, you will determine the spring constant of a spring by measuring the period of a mass-spring system. You will also be able to design an experiment to verify your results by measuring the restoring force of the spring.

Simple Harmonic Motion Pre-Lab:

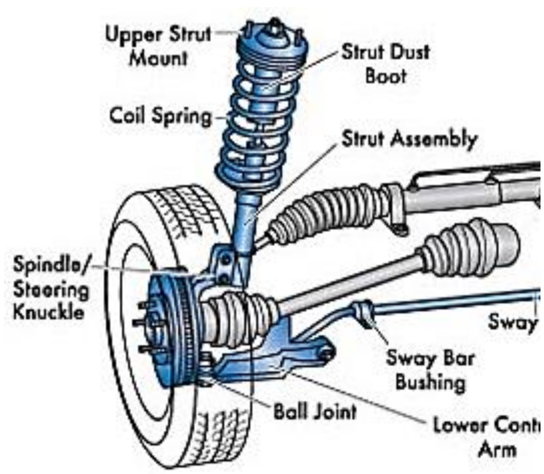
We are surrounded by everyday objects that vibrate or oscillate. Examples include a tree branch swaying back and forth, the wings of a butterfly flapping up and down, and a child swinging to and fro on a swing set. These are all examples of objects undergoing physical vibrations or simple harmonic motion (SHM). An object undergoing SHM will move toward one extreme position and then move in the opposite extreme position repeatedly. The position as a function of time graph for SHM is sinusoidal, as shown below:



The mass-spring system of a car resting on its shock absorbers or a bungee jumper bouncing up and down on a bungee cord are two other examples of SHM. A mass-spring system consists of a mass connected to a spring; the combined mass-spring system can then oscillate back and forth as a single unit. The period (T) of a mass-spring system may be summarized as: $T = 2\pi\sqrt{m/k}$ where *m* is the mass hanging from the spring and *k* is the spring constant measured in N/m. Recall that the spring constant measures the force per unit length needed to stretch or compress a spring. For example, a spring with k = 2 N/m requires 2 N of force to stretch it 1 meter. A 4 N force will stretch this spring 2 m, while a 1 N force would cause it to stretch 0.5 m. This is known as Hooke's Law, F = -kx, where a force, F, is required to stretch a spring (having a spring constant k) a distance, x. The negative sign is explained by the fact that the restoring force produced by the spring is in the opposite direction of the displacement of the spring. As the spring is stretched or compressed in one direction, it counters with a force in the opposite direction.

1) Other than those already discussed in this lab, what are some everyday objects that undergo SHM? (list five).

To smooth the ride of an automobile, the suspension of a car typically consists of four springs in combination with shock absorbers. The suspension mostly moves the axles up and down in response to the uneven road surface, but as every passenger knows, the chassis also oscillates. The upper mount of the suspension and the lower control arm connect the suspension to the chassis. The complexity of this system is illustrated to the right.



2) Imagine driving a car over a series of bumps in the road. Does the period of oscillation of the car depend upon how many people are in the car? That is, do more people in the car make the car bounce faster, slower, or does the additional mass not have any effect at all?

3) Imagine you were driving down a road and encountered a series of potholes, some deeper than others. Would the depth of the pothole have an effect on the period of oscillation of the car's suspension? Explain.

4) A car with four springs and passengers with a combined mass of 1450 kg hits a pothole. The spring constant for each individual spring is 56,000 N/m. Determine the period of oscillation of the car. Show your calculations.

5) The spring described in question #4 is 75 cm in its relaxed state. When installed in a car, the spring must be compressed to a length of 45 cm. How much force must a mechanic apply to the spring in order to install it into the car? Show your calculations.

6) Describe how you can measure the spring constant of the car spring described in the last two questions.

Simple Harmonic Motion Lab:

Materials: motion sensor probe, LabQuest 2, computer with Logger Pro (optional), mass set, large spring, tall ring stand, large ring clamp (used to suspend the spring), meter stick, video physics analysis app, timer

Part 1: Determining the Spring Constant from SHM

In this activity you will determine the spring constant of a spring by measuring the period of the mass-spring system. Please refer to the figure 1 to the right for the general set-up of the system.

1) Use a C-clamp or counter-weight to secure a large ring stand near the edge of a table. Use a large ring, pendulum clamp, or a bar to suspend a spring such that it hangs beyond the edge of the table.

2) Position a motion sensor on the floor directly under the spring. If a safety cage is available, place it over the sensor.

3) Adjust the LabQuest 2 rate to collect data at 10 Hz.

CAUTION: Do not overstretch the spring. Do not have excessive masses on the spring. Do not allow the spring to oscillate at a velocity that causes the mass to come off of the spring. Please work gently with the spring-mass system.

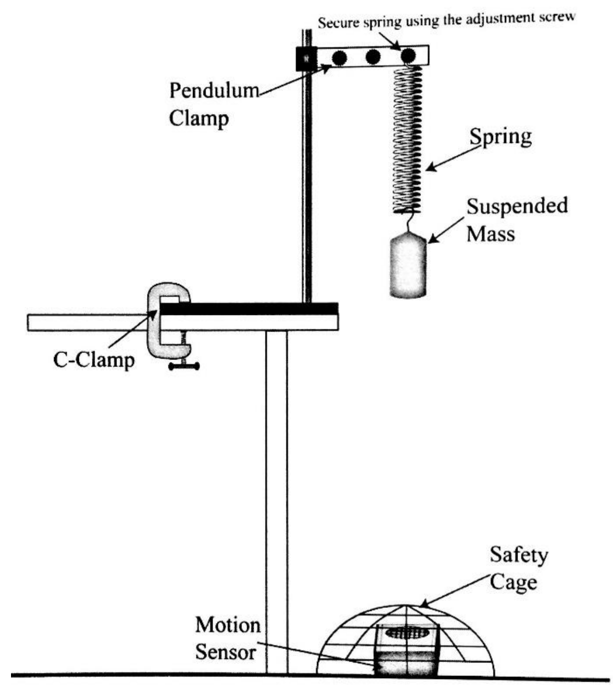


Figure 1

4) Hang a 200 gram mass on the end of the spring. The mass should stretch the spring at least 15 cm. Lift the mass about 15 cm and release to verify that the mass-spring system will oscillate freely without striking the edge of the table.

5) Design an experiment that determines the spring constant based on your measurement of the period of the spring-mass system. The spring constant may be determined using the formula that describes the relationship between the period and the spring constant of such a system: $T = 2\pi\sqrt{m/k}$. In this investigation, a motion probe will be used rather than a stopwatch to determine the period of the system. Complete multiple trials with replication and feel free to increase the mass, but do not exceed 500 grams.

6) As always, sketch free body diagrams of the system and create a data table suitable for your data set. Also, please show all of your calculations and include a labeled sketch of the apparatus.

7) Next, design an experiment to explore the effect of the amplitude of the spring on the period of oscillation. Determine if amplitude affects the oscillation of the mass-spring system.

Part 2: Determining the Spring Constant Directly

In this activity you will determine the spring constant of the spring directly using the principles of Hooke's Law.

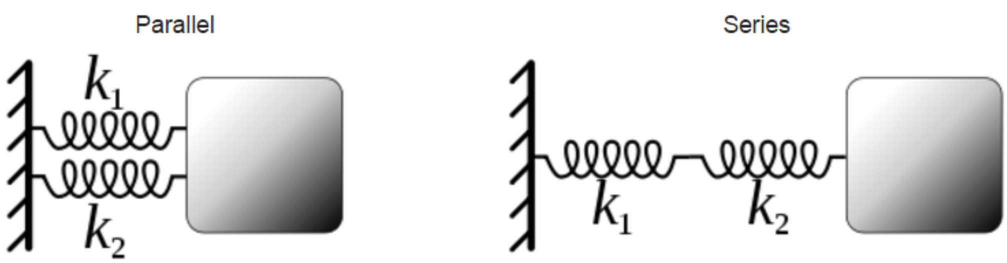
8) Design and perform an experiment that determines the spring constant using Hooke's Law, $F_s = -kx$. Create a data table suitable for your data set and show all calculations.

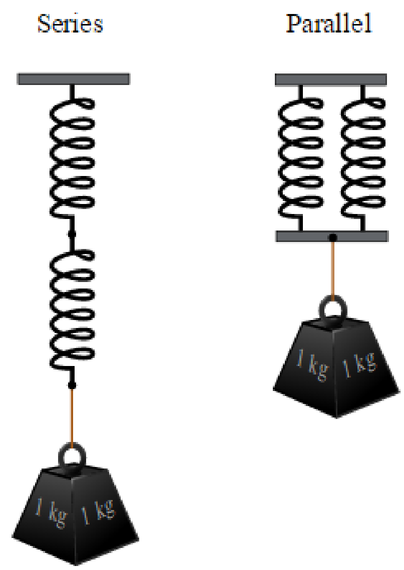
9) Using the data you collected, plot a graph that will allow you to determine the spring constant. Please ensure your graph is ¾- 1 page in size and labeled appropriately.

10) As always, calculate the percentage error between the two methods. Also consider calculating the percent difference between trials.

Part 3: Exploring Spring Combinations

In this activity you will explore the effect of various spring combinations on the oscillatory motion of the system. You will need to calculate the equivalent spring constant (k_{eq}). This can be expressed as $k_{eq} = k_1 + k_2$ for in parallel and in a series as $1/k_{eq} = 1/k_1 + 1/k_2$. This final part of the lab is meant to be open inquiry to extend and refine your knowledge of harmonic oscillators. College Board will not explicitly assess you on spring combinations on the AP Exam.





11) Design and perform an experiment that explores the spring constant using Hooke's Law, $F_s = -kx$ for various spring combinations. Create a data table suitable for your data set and show all calculations.

12) Compare and contrast the FBD for a horizontal oscillating system and a vertical oscillating system.

13) Using Hooke's Law as a starting point, attempt to derive the expressions used to calculate the spring constant for both parallel and series spring combinations.

14) Please self-assess your lab report using the rubric/checklist.