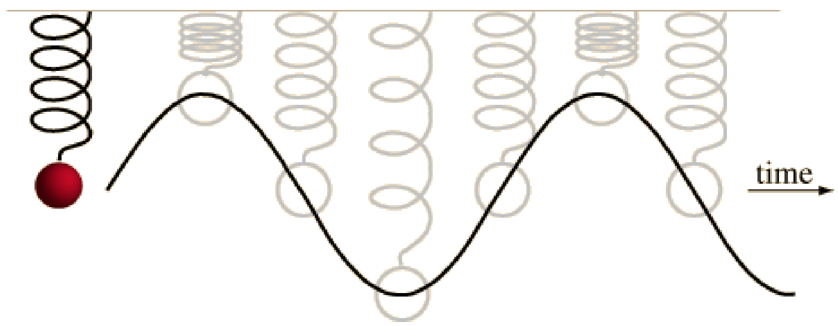
AP Lab #12: Simple Harmonic Motion (Big Idea 3.B.3)

Question: How can I design experiments to relate the period and frequency of spring block oscillators and pendulums to other variables, such as spring constant, mass, amplitude, velocity, angle displaced, and pendulum length.

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. Recall 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. Another oscillator you will explore in this lab is a pendulum. As you recently learned, the period of a pendulum displaced small angles is expressed as $T_p = 2\pi\sqrt{l/g}$.

P1) 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.

P2) 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?

P3) 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.

P4) 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.

P5) 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.

P6) Describe how you can measure the spring constant of the car spring described in the last two questions.

P7) A pendulum of length 20 cm and mass 1 kg is displaced an angle of 10° from the vertical. What is the maximum speed pendulum? (0.25 m/s)

P8) A pendulum of length 0.5 m and mass 5 kg is displaced an angle of 14° from the vertical. What is the speed of the pendulum when its angle from the vertical is 7°?

Simple Harmonic Motion Exploration:

Suggested Materials: motion sensor, 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, string, photogates, etc.

Part 1: Determining the effects of spring constant, amplitude, velocity, and mass for a spring-mass oscillator.

In this activity you will design an experiment to measure the spring constant (k) for a spring-block oscillator and the effects of amplitude and mass on the period. Feel free to modify the apparatus to the right, as this is only one <u>*suggested*</u> *way to explore the question.*

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.

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.

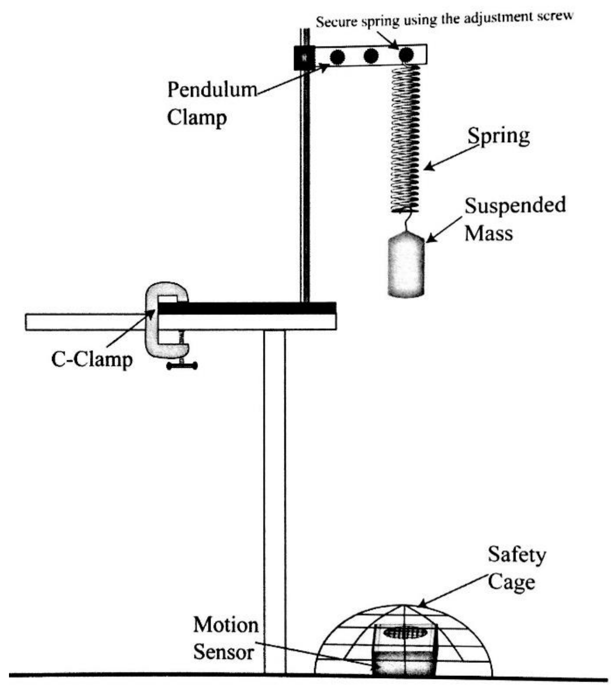


Figure 1

Before moving on, make sure you have collected replicable data involving all four variables (e.g., spring constant, velocity, amplitude, mass)

Make your claim to address the question based on your evidence.

Part 2: Determining the effects of mass, angle displacement, and length on the period and frequency of a pendulum.

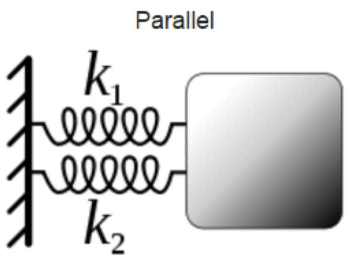
In this activity you will design experiments to explore the effects of mass, angle displacement, and length on the period and frequency of a pendulum.

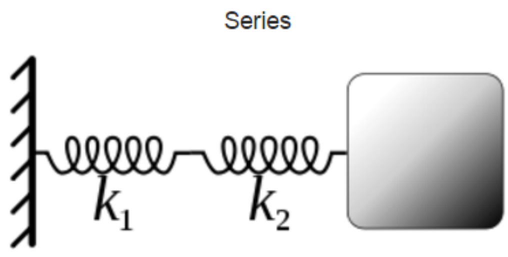
Before moving on, make sure you have collected replicable data involving all four variables (e.g., mass of bob, angle displaced, velocity, and pendulum length).

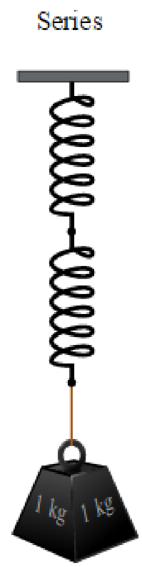
Make your claim to address the question based on your evidence.

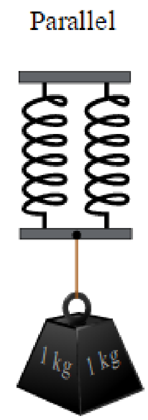
Part 3: Exploring Series and Parallel Spring Combinations

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. Please show all steps in your derivation and, as always, feel free to ask me for guidance.

14). Coin Opportunity: Design a pi-endulum, in which the period of the oscillator is equal to 3.14 s. Build and test the pi-endulum to earn some coins. Could you setup a spring-block oscillator to also have a period of pi? Give it a try and see if you can master this challenge for maximum coinage.

Please self-assess your STEM Journal using the rubric/checklist.