

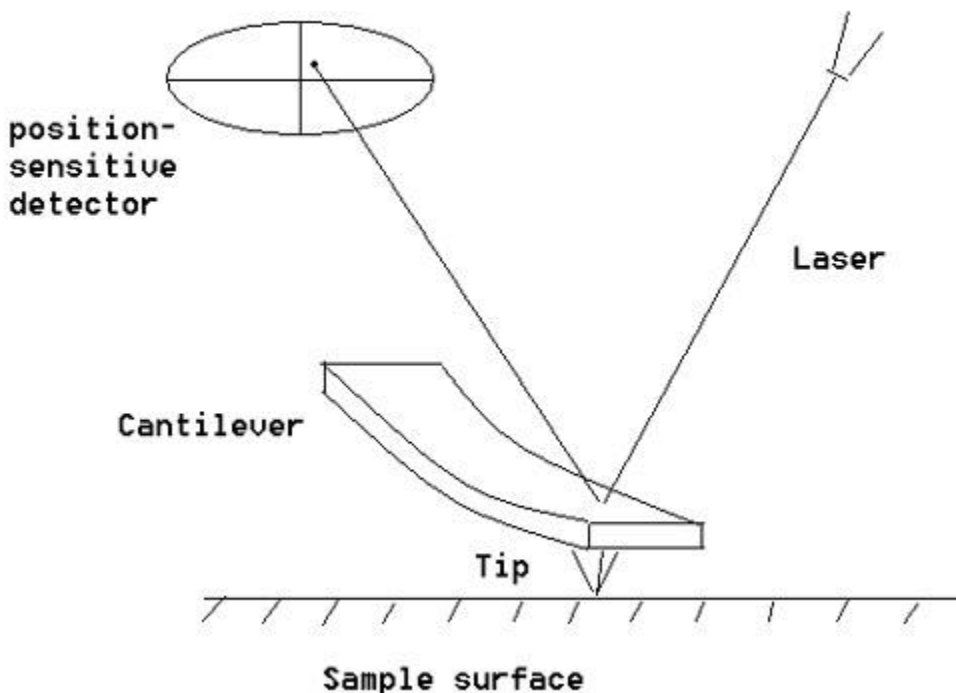
Simple Harmonic Motion and Damping

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Background:

Atomic Force Microscopy, or AFM, is used to characterize materials. It is used to measure local properties, like height, friction and magnetism. It does this using a probe and has two modes, contact and non-contact. It scans over a small area using a cantilever with a probe attached. AFM measures the vertical and lateral deflections of the cantilever. A laser beam is used to reflect off the cantilever where it then strikes a photo sensitive detector. The photo sensor consists of four segments. The difference in the signal from the four segments allows the AFM to determine the location of the tip. The AFM relies on the force between the tip and the surface in non-contact mode. When the tip is brought close to the sample surface, forces between the sample surface and the tip cause the cantilever to deflect according to Hooke's Law. In non-contact mode the tip of the cantilever is oscillated at its resonant frequency or just above it. The van der Waals forces causes the frequency of the cantilever to decrease. This decrease in resonant frequency of the cantilever along with the feedback loop system maintains a constant oscillation amplitude or frequency by adjusting the distance between the tip and the sample surface. By measuring this tip to sample distance at each data point the AFM scanning software constructs a topographic image of the surface of the sample. This tip to sample distance ranges from a few nanometers to a few picometers. The image below shows the location of each part of an AFM.



In thinking about AFM and how I can bring this activity to my students, I began to realize that the cantilever when operating is in simple harmonic motion, or SHM. In class each year we study SHM in spring and pendulums, but we do not introduce any external forces to the system we use. This activity will allow students to observe SHM as well as alter it so that they can see the forces that alter the frequency of oscillation in an oscillating spring system.

Subject: AP Physics 1, grade 11 or 12

Suggested Time: 3-5 classes of 50 minutes

Alignment with AP Physics 1 Curriculum:

Science Practice 2: The student can use mathematics appropriately.

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

Science Practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question.

Science Practice 5: The student can perform data analysis and evaluation of evidence.

Science Practice 6: The student can work with scientific explanations and theories.

Essential Knowledge 3.B.2: Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.

- a. An object can be drawn as if it was extracted from its environment and the interactions with the environment identified.
- b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force.
- c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the with spring translation from the free-body diagram to the algebraic representation.

Essential Knowledge 3.B.3: Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples should include gravitational force exerted by the Earth on a simple pendulum and mass-spring oscillator.

- For a spring that exerts a linear restoring force, the period of a mass-spring oscillator increases with mass and decreases with spring stiffness. (a)

- Minima, maxima, and zeros of position, velocity and acceleration are features of harmonic motion. Students should be able to calculate force and acceleration for any given displacement for an object oscillating on a spring. (c)

Learner Objectives

Learning Objective 3.B.2.1: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.

Learning Objective 3.B.3.1: The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties.

Learning Objective 3.B.3.2: The student is able to design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by restoring force.

Learning Objective 3.B.3.3: The student can analyze data to identify qualitative or quantitative relationships between given values and variables associated with objects in oscillatory motion to use that data to determine the value of an unknown.

Learning Objective 3.B.3.4: The student is able to construct a qualitative and/or a quantitative explanation of oscillatory behavior given evidence of a restoring force.

Introduction:

Background Knowledge:

Students should have a good understanding of the following before this activity

1. Basic Linear Dynamics, Newton's Laws, especially $\Sigma F = ma$.
2. Hooke's Law
3. Resolving vectors and vector addition
4. Data collection and analysis

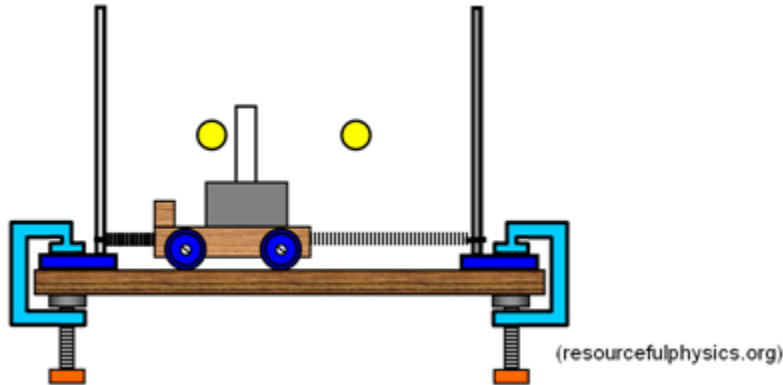
Materials:

Springs, Masses, Ring stand, Paper plates, Magnets, Tape, Beaker, Water or other fluids, Vernier Motion probe, Labquest

Lesson Plan:

Part 1—Recognizing simple harmonic motion, SHM

Set up the following demonstration.



Place a cart between two support rods. Attach springs on each end and add weights to the cart so that the cart oscillates with a period of about 2 seconds. You can use the motion detector to see the position time graph. Discuss this motion and how it is SHM with you students.

Questions to ask:

1. Where is the velocity greatest?
2. Where is the acceleration the greatest?
3. Sketch the free body diagram for the cart.
4. Where is the force the greatest? You can ask this for various points along the path of the cart.

Part 2—Have students perform SHM of a spring lab. Determine the spring constant and period of oscillation of your spring. Vary mass and amplitude when conducting your experiment. Students should write a lab report with the following components: title, objective, materials, procedure, data, data analysis and conclusion.

Extension: Have students repeat their procedure using two springs in series and two springs in parallel with the same masses used for a single spring. Keep the amplitude constant. How are these two similar and different? How do you determine the spring constants for these two? Sketch the free body diagram for each example here.

Part 3—Introduce students to the engineering process. damping

Engineering Design Process

1. Define the problem
2. Research the problem
3. Develop possible solutions
4. Choose the best solution
5. Create a prototype
6. Test and evaluate
7. Communicate the solution
8. Redesign

Demonstration: Show water oscillating in a U-tube. Have students notice how the water oscillating in the tube dissipates quickly. This is due to the friction between the water and the tube.

Shock absorbers on car suspensions act to dampen the springs as a car goes over a bump or pot hole. The passengers in the car do not want to experience the SHM the bump would cause in the vehicle. The shock absorbers take the energy from the springs and converts it to heat. This allows the spring to lose the energy before it cause the car to bounce down the road.

Students need to devise a method to dampen the motion of a single spring so that the oscillation dissipates as quickly as possible. Students must use the engineering process and show evidence of each step in their lab report. Students need to use the motion detector to graph displacement versus time for the spring without damping and with damping. Include these graphs in your lab report.

Resources:

<http://physics.info/sho/>

<http://science.howstuffworks.com/engineering/structural/smart-structure.htm>

<http://www.maurer.eu/>

References:

<http://www.nanoscience.gatech.edu/zlwang/research/afm.html>

http://tap.iop.org/vibration/shm/301/page_46554.html

<http://www.scienceclarified.com/everyday/Real-Life-Physics-Vol-2/Oscillation-Real-life-applications.html>

<https://mobiloil.com/en/article/car-maintenance/advanced-car-maintenance-tips/how-shock-absorbers-work>

Student Sheet for lab

Spring Constant and Simple Harmonic Motion

Objectives:

1. Determine the spring constant for a spring.
2. Determine the relationship between mass and frequency.
3. Determine the relationship between amplitude and frequency.

Materials:

Hooke's Law apparatus or pendulum clamp, ring stand, springs, mass set, ruler or meter stick, stop watch, beaker, water, paper plates, tape, magnets motion detector, Labquest

Directions:

Choose a spring. Determine the spring constant of the spring without distorting or damaging the spring. While doing this please keep in mind Hooke's Law, $F = -kx$. (Remember the negative comes from the fact that the spring's force is a restoring force and opposes the gravitational force.) Record the mass and spring extension for each trial you perform. You need at least four data points. Graph your data and determine the spring constant from you graph, not the data points.

Once you have the spring constant for your spring, investigate the relationship between mass and period of the spring. Take several measurements. When recording the time of oscillation be sure to measure at least ten oscillations so that you can determine the average period. Graph period versus mass and period squared versus mass. Which one seems to be the correct relationship and why?

Now repeat and change the amplitude, keeping the mass fixed. Do not choose an amplitude that shoots the masses across the room or deforms the springs. What do you notice about small changes in amplitude and the period? How are they related?

Using the Motion Detector

While measuring the period of the spring use a motion detector to measure its motion. You will need a position versus time graph on the Labquest. Be sure to show me this graph and save the file for later comparison.

Extension: Choose a different spring and determine the spring constant for the new spring. Hang the two springs in parallel, side by side. Determine the period of oscillation using a small amplitude and one of the masses you used in the previous portion of the lab. Knowing each spring constant and the period of oscillation, determine the effective spring constant of the system of springs. What is the relationship between the individual spring constants and the combined spring constant?

Damping

Your challenge is to now decrease the springs oscillation as quickly as possible. To do this you must use something to dampen the oscillation. You are introducing another force to the object. You may use any

materials readily available to you, those that I have provided, or you may use other materials, but I must approve your plan before you begin. Plan your solution using the engineering process.

1. Define the problem
2. Research the problem
3. Develop possible solutions
4. Choose the best solution
5. Create a prototype
6. Test and evaluate
7. Communicate the solution
8. Redesign

Each step must be accounted for in your lab notebook. Lab report and engineering process will be graded based on the rubrics below.

Record position time data with the motion detector and Labquest. Be sure to include this graph in your lab report.

Grading Rubric

Purpose	1	2	3	4	5	10
Statement of what was done				X	X	3
Statement of how it was done				X	X	3
Statement of what was used to do it				X	X	3
one paragraph (grammar)		X	X	X	X	1
Principles and Theory	1	2	3	4	5	5
Explanation of the experiment				X	X	3
Explanation of how the measurement is done			X	X	X	2
Data Tables	1	2	3	4	5	10
Data Tables are complete						5
Data Tables are labeled correctly						5
Calculations and Analysis	1	2	3	4	5	15
Results stated						5
Compare results to reality						5
Graphs						5
Conclusions	1	2	3	4	5	10
Stated accurate conclusion based on data						5
Identified sources of error						5

50 points

Engineering Process Rubric

Problem	1	2	3	4	5	10
Statement of the problem						5
Research	1	2	3	4	5	15
Background research includes all aspects of the problem						10
Background research includes multiple sources						5
Possible Solutions/Choosing the solution	1	2	3	4	5	15
Possible solutions are given						10
Feasible Solution is chose						5
Prototype	1	2	3	4	5	25
Prototype is based on solution chosen						15
Prototype is working						10
Test and Evaluate	1	2	3	4	5	10
Thorough testing done						5
Evaluation of results						5
Results given						
Communicate the Solution	1	2	3	4	5	15
Method of communication is reasonable						5
Communication of solution is thorough						10
Redesign	1	2	3	4	5	10
Reasons for redesign are based in testing						5
Redesign is thought out						5

100 point possible