Physics Experiment: Investigating Simple Harmonic Motion in Springs and Pendulums

Aim

To investigate and compare the behavior of simple harmonic oscillators by analyzing spring-mass systems and simple pendulums, and to verify the factors affecting their periods of oscillation.

Theory

Simple Harmonic Motion (SHM) is a type of periodic motion where the restoring force is directly proportional to the displacement and acts in the direction opposite to that of displacement. The two classic examples of SHM are:

1. **Spring-Mass System**:
    - Governed by Hooke's Law: $F = -kx$
    - Period of oscillation: $T = 2\pi\sqrt{m/k}$
    - Where m is the mass and k is the spring constant
2. **Simple Pendulum**:
    - For small angles, the motion approximates SHM
    - Period of oscillation: $T = 2\pi\sqrt{L/g}$
    - Where L is the length of the pendulum and g is the acceleration due to gravity

Both systems exhibit similar mathematical behavior described by the differential equation:
$d^2x/dt^2 + \omega^2 x = 0$

Where ω is the angular frequency related to the period by $\omega = 2\pi/T$.

Objective

1. To verify the relationship between mass and period in a spring-mass system
2. To verify the relationship between length and period in a simple pendulum
3. To compare the energy transformations in both systems
4. To investigate the effect of damping on the amplitude of oscillations
5. To analyze the phase relationships between displacement, velocity, and acceleration

Procedure

Part A: Spring-Mass System

1. **Setup**:
    - Mount a spring vertically from a rigid support
    - Attach different masses to the spring
    - Set up a position sensor to record the oscillation
2. **Measurements**:
    - Measure the spring constant k using Hooke's law ($F = kx$)
    - Displace different masses from equilibrium and release
    - Record the position vs. time data
    - Measure the period of oscillation for each mass
3. **Analysis**:
    - Plot a graph of T^2 vs. mass
    - Verify the relation $T = 2\pi\sqrt{(m/k)}$
    - Calculate potential and kinetic energy at different positions
    - Analyze the total energy conservation

Part B: Simple Pendulum

1. **Setup**:
    - Suspend a bob of negligible mass from a string of variable length
    - Set up an angle sensor to record the oscillation
2. **Measurements**:
    - Vary the length of the pendulum
    - For each length, displace the pendulum to a small angle (less than 10°)
    - Record the angular position vs. time data
    - Measure the period of oscillation for each length
3. **Analysis**:
    - Plot a graph of T^2 vs. length
    - Verify the relation $T = 2\pi\sqrt{(L/g)}$
    - Calculate the value of g from the slope
    - Investigate deviations at larger angles

Pretest

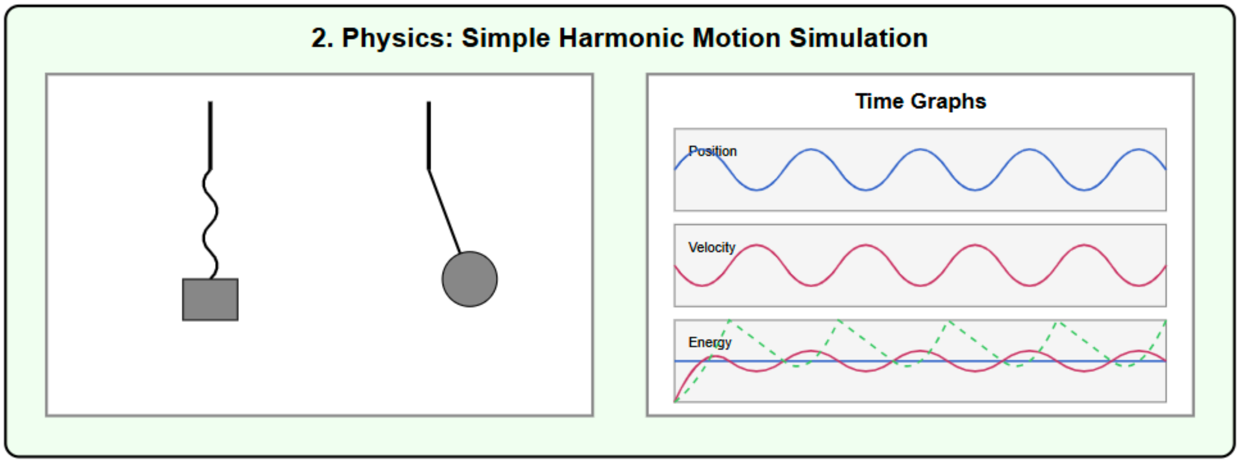
1. What is the phase difference between velocity and displacement in SHM?
2. How does doubling the mass affect the period of a spring-mass system?
3. When is the kinetic energy maximum in a simple pendulum's motion?
4. What happens to the period of a simple pendulum if the experiment is performed on the moon?
5. How would damping affect the amplitude and period of oscillations?

Simulation

The interactive SHM simulation should include:

1. **Dual Display Panel**:
   - Split-screen showing both spring-mass system and simple pendulum simultaneously
   - Option to view one system in fullscreen for detailed analysis
2. **Spring-Mass System Visualization**:
   - Vertically mounted spring with attached mass
   - Motion trail to visualize the path
   - Real-time graphs for:
     - Position vs. time
     - Velocity vs. time
     - Acceleration vs. time
     - Kinetic, potential, and total energy vs. time
3. **Pendulum System Visualization**:
   - Pendulum with adjustable string length and bob mass
   - Angular position indicator
   - Motion trail to visualize the path
   - Real-time graphs for:
     - Angular position vs. time
     - Angular velocity vs. time
     - Kinetic, potential, and total energy vs. time
4. **Control Parameters**:
   - Spring-Mass System:
     - Mass slider (0.1 kg to 1.0 kg)
     - Spring constant slider (10 N/m to 100 N/m)
     - Initial displacement slider
     - Damping coefficient slider
   - Pendulum System:
     - Length slider (0.1 m to 1.0 m)
     - Initial angle slider (0° to 90°)
     - Gravitational acceleration slider (to simulate different planets)
     - Damping coefficient slider
5. **Measurement Tools**:
   - Period calculator with automatic detection
   - Frequency calculator
   - Energy balance analyzer

    - Phase difference calculator between position, velocity, and acceleration
6. **Interactive Features**:
    - Play/pause/reset controls
    - Slow motion and speed up options
    - Option to overlay theoretical predictions on experimental graphs
    - Data export functionality for further analysis



The above image is a representation of a sample experiment simulation

Assignment

1. Using the simulation, investigate how the period of a spring-mass system varies with mass. Plot T^2 vs. m and determine the spring constant from the slope.
2. For a pendulum, determine how the period varies with length. Plot T^2 vs. L and calculate the value of g from your data.
3. Investigate the effect of amplitude on the period of a pendulum. At what angle does the small-angle approximation begin to break down significantly?
4. Compare the energy transformations in both systems. When is PE maximum and KE minimum?
5. Introduce damping into both systems and describe how the amplitude decays over time. Determine the damping coefficient from your data.
6. Derive the equation for a damped harmonic oscillator and use the simulation to verify your results.
7. Analyze the phase relationships between position, velocity, and acceleration in both systems.

References

1. Halliday, Resnick, and Walker, "Fundamentals of Physics", Wiley.
2. H.C. Verma, "Concepts of Physics", Bharati Bhawan Publishers.

3. I.E. Irodov, "Problems in General Physics", MIR Publishers.
4. Feynman, Leighton, and Sands, "The Feynman Lectures on Physics, Vol. 1", Pearson.
5. Serway and Jewett, "Physics for Scientists and Engineers", Cengage Learning.

Feedback

1. Did the simulation help you understand the mathematical relationships governing SHM?
2. Were you able to clearly observe the energy transformations in both systems?
3. How well did the experimental results match with theoretical predictions?
4. Did the visual representations help you understand the phase relationships?
5. What additional parameters would you like to investigate in future experiments?
