Phone Physics

Teacher Research Academy
Sponsored by Lawrence Livermore National Laboratory
June 22 – 26, 2020 | Time: 8:30am–2:30pm

Workshop Summary: Smartphones have the potential to revolutionize how students learn physics. This online 5-day workshop will introduce teachers to dozens of powerful hands-on activities designed to explore core disciplinary ideas in physics. The activities will exploit the highly sensitive and precise sensors in the smartphones that your students own, and of which they are expert users. You will be amazed at the performance of the sensors and the diverse set of high-precision experiments that are now possible. These activities are designed to require minimal additional equipment beyond the smartphone, allowing them to be conducted in classrooms with limited resources. In fact, many of the activities are well-suited for students to perform outside of class. The ability for students to do experiments at home will enable novel teaching approaches and learning opportunities. It will also allow students in distance learning programs to engage in sophisticated experimental activities. During this workshop, you will gain experience in using the sensors in carefully crafted experiments as well as in open-ended explorations that can be adapted to the specific needs of your students. The activities are designed to be easily adaptable, so teachers of all levels are encouraged to participate. At the conclusion of the workshop, you will be prepared to lead your students into a new world of high-precision measurements and analysis for learning physics.

The class will be conducted remotely using videoconferencing. You will need a smartphone (IOS or Android) and the ability to connect to the videoconference. We will start with a general survey of the sensors and assure that all the participants are comfortable using the applications. We will then begin a journey though a series of experimental activities that use the suite of sensors in smartphones. For each activity we will follow a general format that will be repeated several times a day:

1) Introduce activity and discuss potential experimental designs
2) Provide time for workshop participants to conduct the activity on their own (instructor will be continuously available to help via videoconference)
3) Regroup for discussion and sharing of results/challenges
4) Discuss alternative approaches and extensions of the activity

The Technology Revolution: The remarkable advances in microelectronics and communication technologies provide an unprecedented opportunity for a sea change in high school physics education. The suite of sensors, computational analysis power, and real-time visualization capabilities on a smartphone can revolutionize the student learning experience using a sophisticated interface that they have already mastered. All common smartphones include:

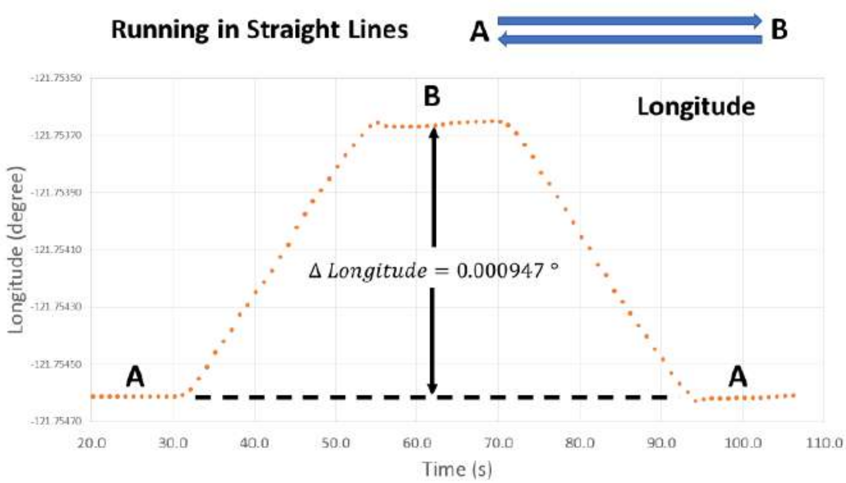
- 3-axis accelerometer
- 3-axis gyroscope
- 3-axis magnetometer
- Barometric pressure transducer
- High-fidelity microphone
- Speaker system
- Position locating system using GPS
- High-resolution optical video camera
- Exceptional computational power for fast data processing and analysis
- High-resolution graphical interface with touch screen
- Bluetooth and Wi-Fi that enable communication and data transfer

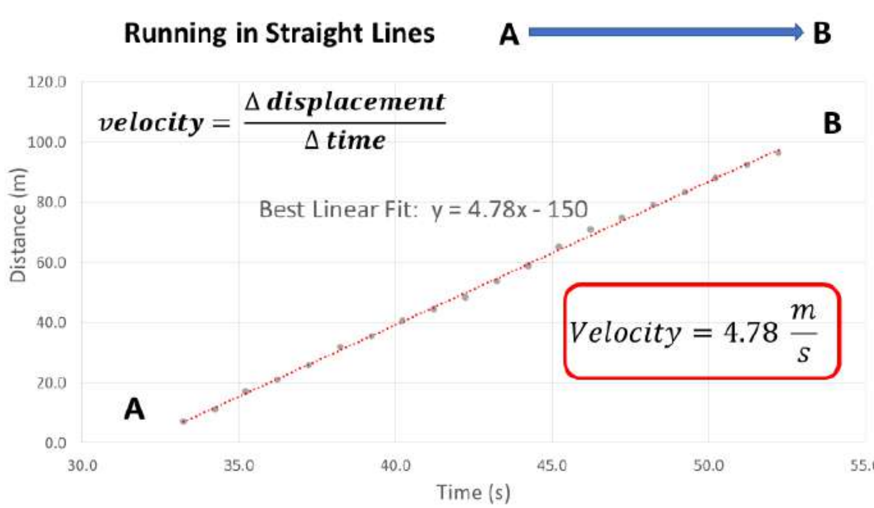
Workshop Topics and Example Activities

Each activity is structured to meet NGSS standards, maintaining an inquiry-based and easily adaptable approach to learning physics.

I. Displacement and Velocity

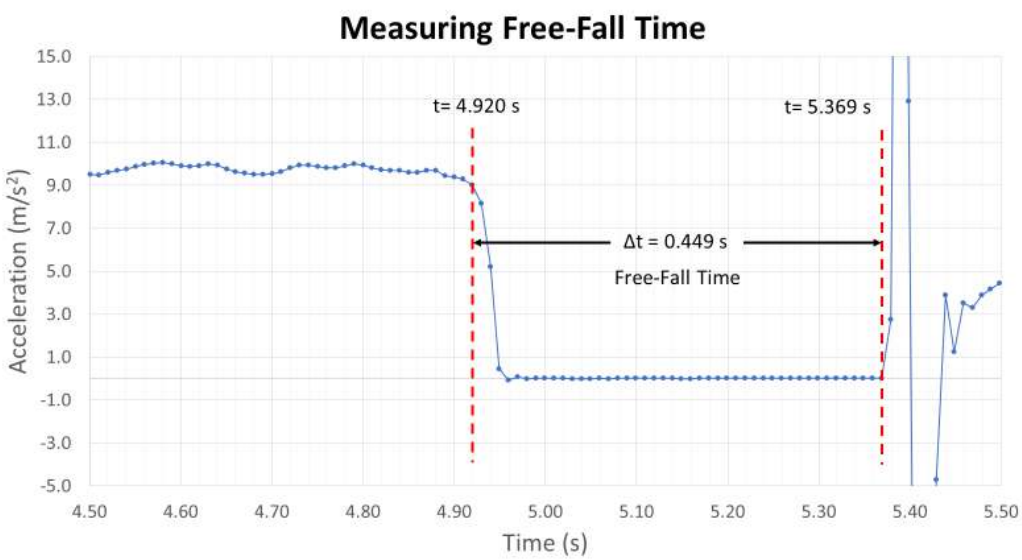
Students run, walk, or drive from point to point with their phones. The GPS sensor on the phone collects latitude and longitude data every second during the experiment. Students calculate the displacement and distances using the latitude and longitude data. By plotting displacement versus time, students can determine velocity and speed. In the process of learning the foundations of motion in one dimension, students learn about GPS operation and the global coordinate system; practice using significant figures in calculations (eight significant figures in the GPS data); learn how to use spreadsheets for graphing/analysis; and solidify their understanding of scalars and vectors.

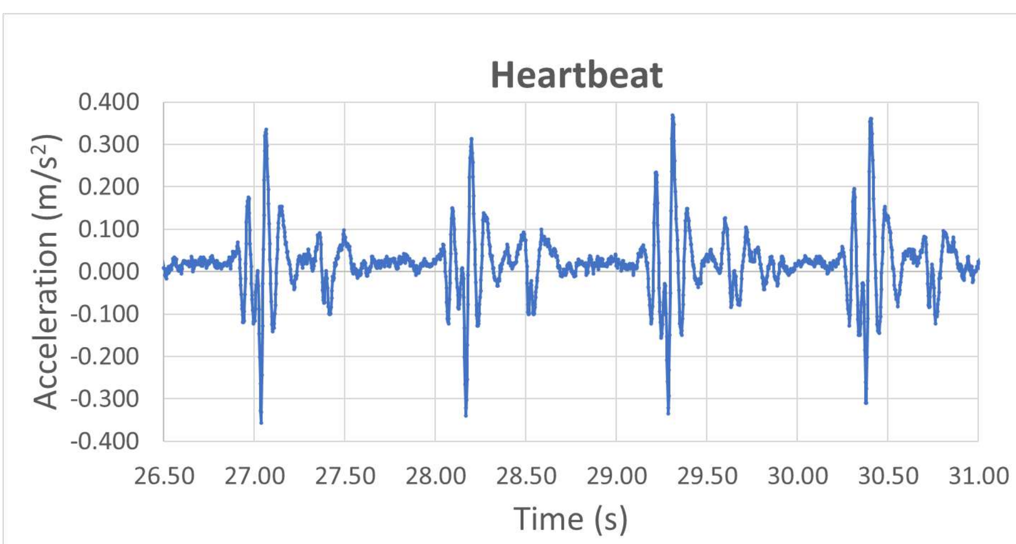




II. Accelerated Motion

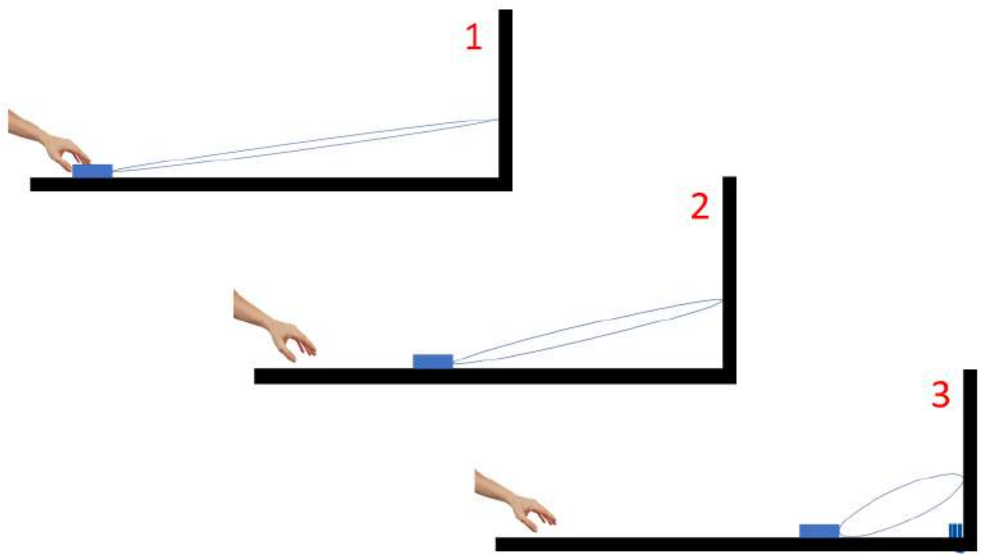
Students use the 3-axis accelerometer to measure acceleration for a wide range of scenarios. As demonstrated by the data in the first figure below, students carefully drop their phones and measure the freefall time by observing the time in which the sensor does not measure the force of gravity within the phone's reference frame. Students can accurately calculate ***g*** if they know the height or they can calculate the height using the known value of ***g***. In the second figure, the student places the phone on their chest and measures the acceleration of the phone that results from their heartbeat. The accelerometer also provides a power tool for measuring impulse and enables evaluation of engineering designs to reduce the impulse from collisions (this is an indirect measurement, so the phone is not part of the collision). This provides an alternative to the classical egg drop and allows student to conduct repeated design-build-test cycles.

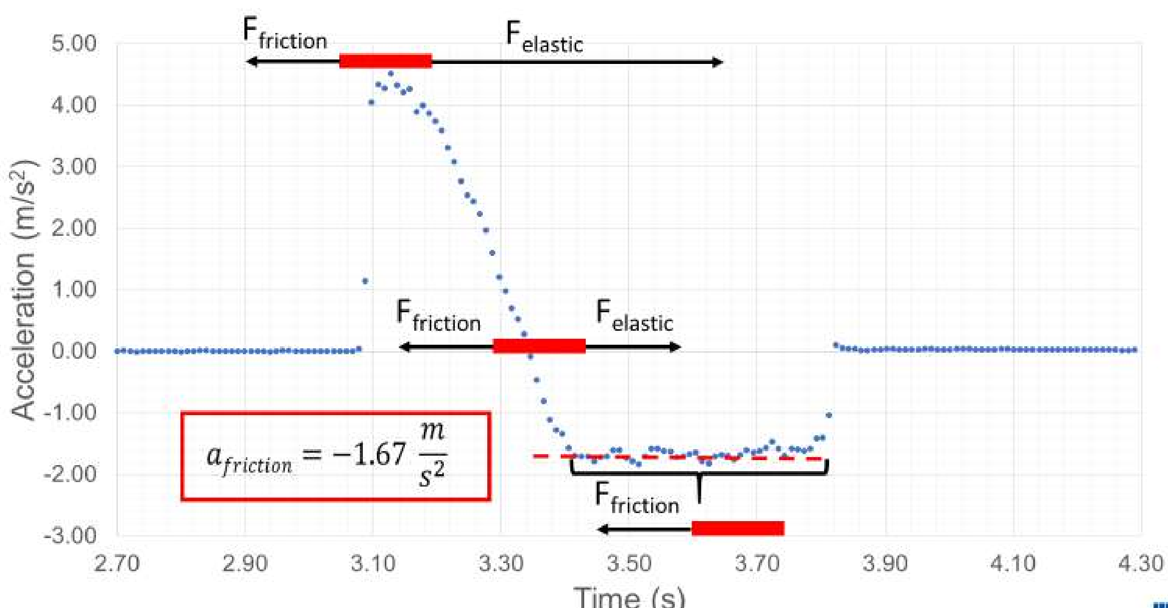




III. Forces

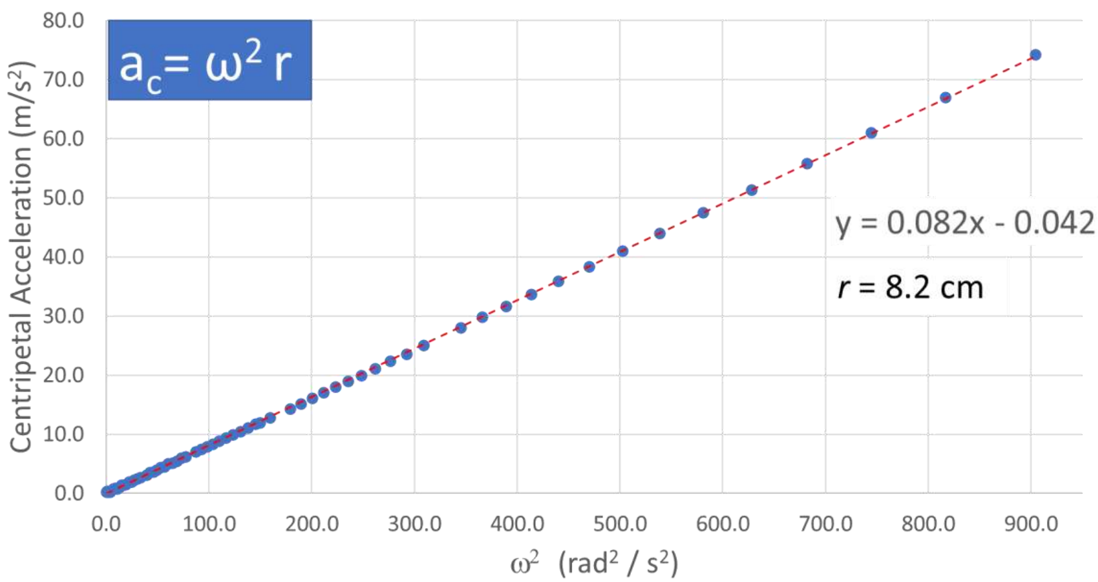
Student explore Newton's second law of motion using the accelerometer. In this simple experiment, the phone is initially accelerated using the elastic force produced by the elastic potential energy of a rubber band. After the rubber band returns to its equilibrium length, the phone experiences a constant negative acceleration due to the force of friction. Students measure the value of the acceleration and can then calculate the coefficient of dynamic friction. They practice creating free body diagrams and can do a series of experiments that explore dynamic and static friction for different surface properties.

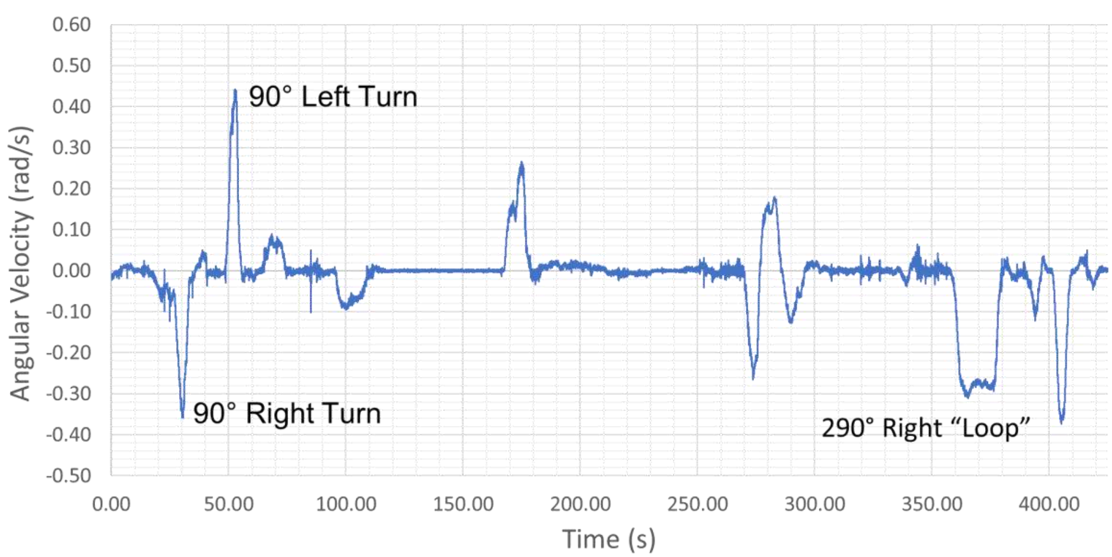




IV. Rotational Motion

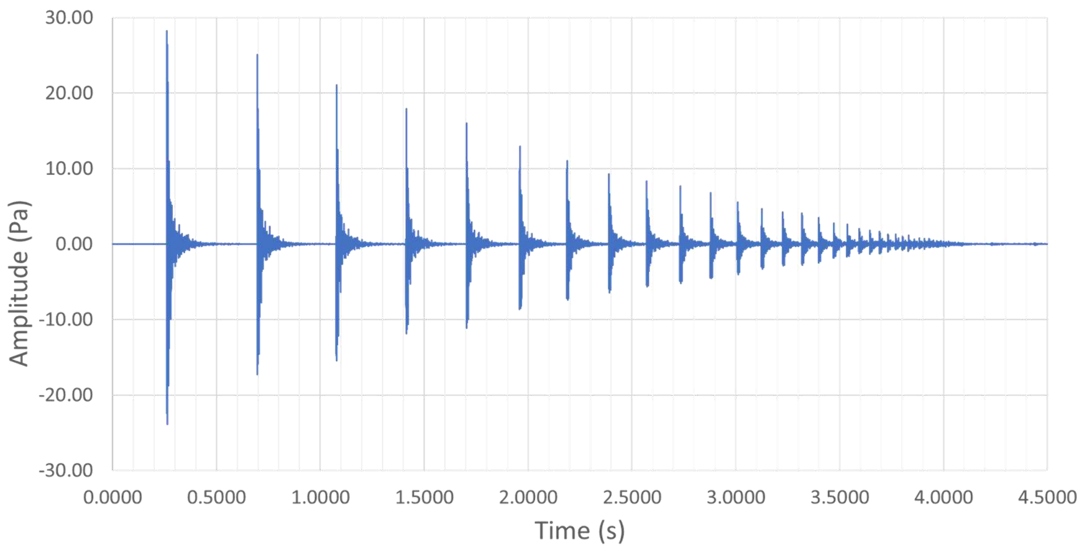
Students will use the 3-axis gyroscope to explore rotational motion. They will measure angular velocities and explore the relationship between angular velocity and centripetal acceleration. In the first graph below, the centripetal acceleration (using the accelerometer) is measured simultaneously with the angular velocity (using the gyroscope) for a phone rotating in a salad spinner over a range of angular velocities. In the bottom figure, the angular velocity is measured during a trip in a car. Students will determine how to relate the angular velocity data to the angle and direction of each turn. This information can then be used to identify positions on a map. In other activities students can precisely measure the moment of inertia of their phones.

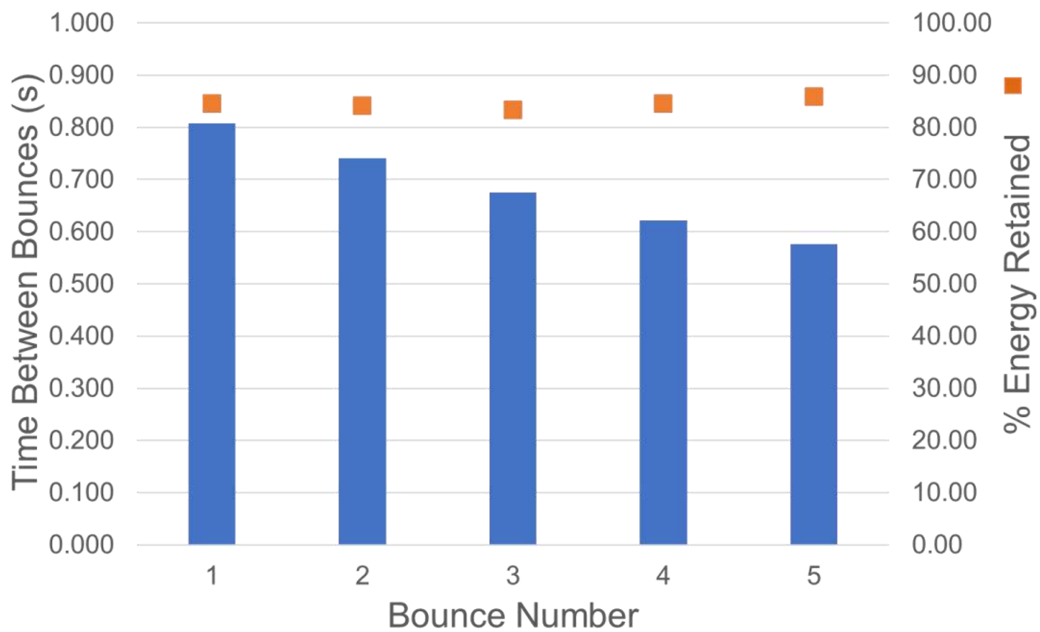




V. Conservation of Energy and Inelastic Collisions

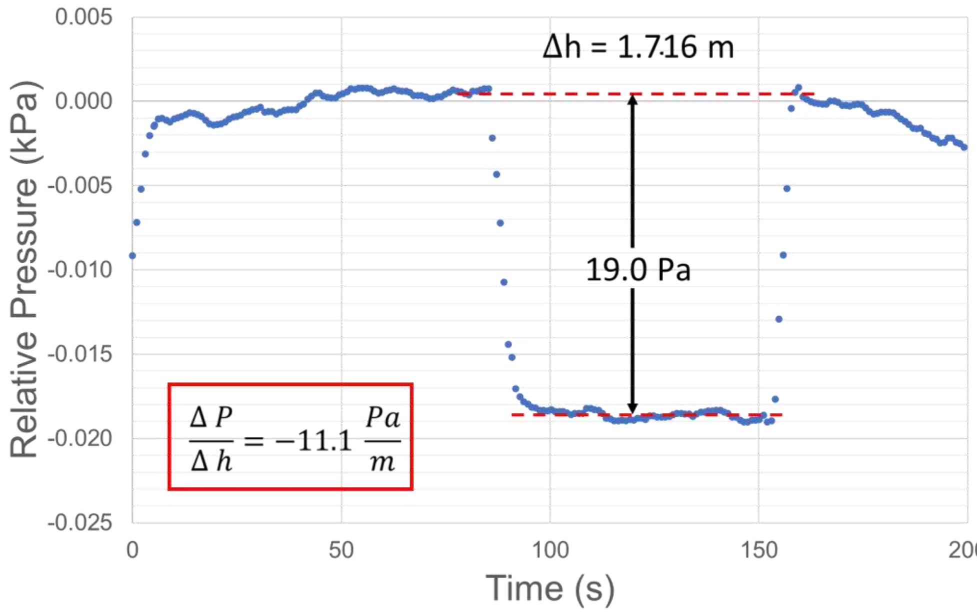
Students will explore the loss of energy during collisions. They will drop a ball onto a surface and measure the time between each bounce. The first figure shows the measured sound wave associated with each sequential bounce. The time of each bounce is precisely determined from the high-speed microphone data (48,000 points per second). Using equations of motion for an object experiencing constant acceleration, students can calculate the velocity of the ball before and after hitting the surface. These data then allow the calculation of kinetic and potential energy before and after each collision. Students can explore a range of balls and surfaces to examine the variation in energy lost during inelastic collisions.

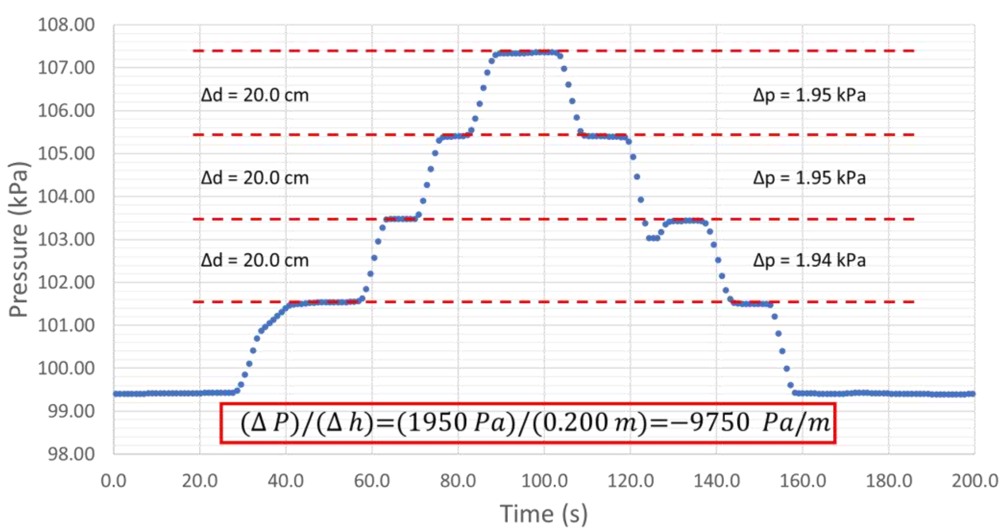




VI. States of Matter: Fluids

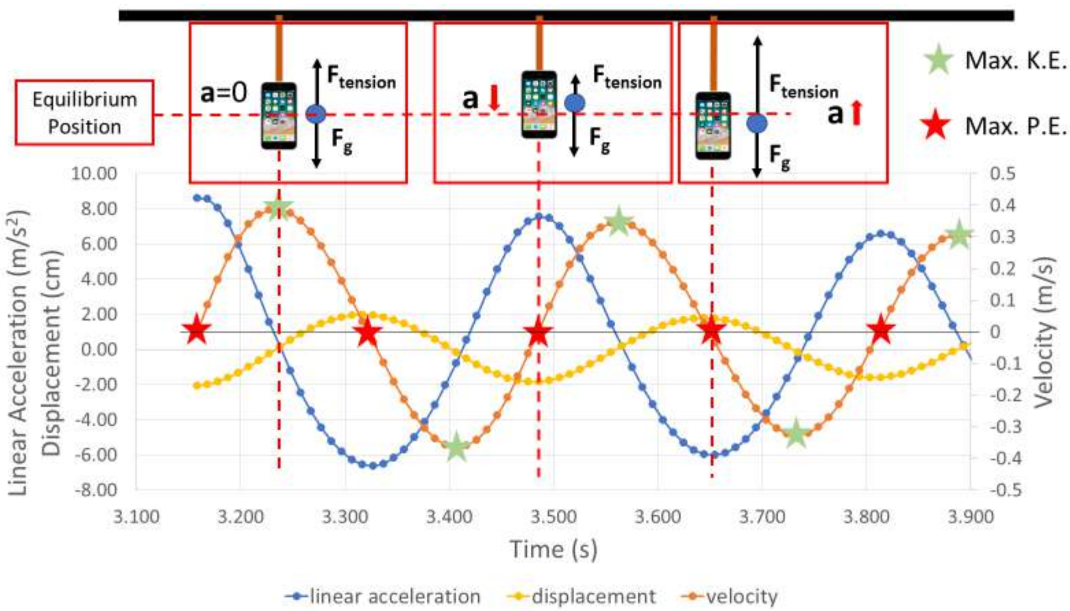
Students examine the properties of fluids. The two figures below provide data for measurements of pressure versus altitude in air (top) and pressure versus depth in water (bottom). The experiments provide very precise data that can be combined with the hydrostatic formula to calculate the density of air and water. This activity provides students with a visual opportunity to explore the differences between precision and accuracy of measurements. The sensitivity of the barometer and continuous variation of atmospheric pressure in most environments present an ideal opportunity to introduce the use of controls in experimental designs (data in top figure used a control to improve measurement).

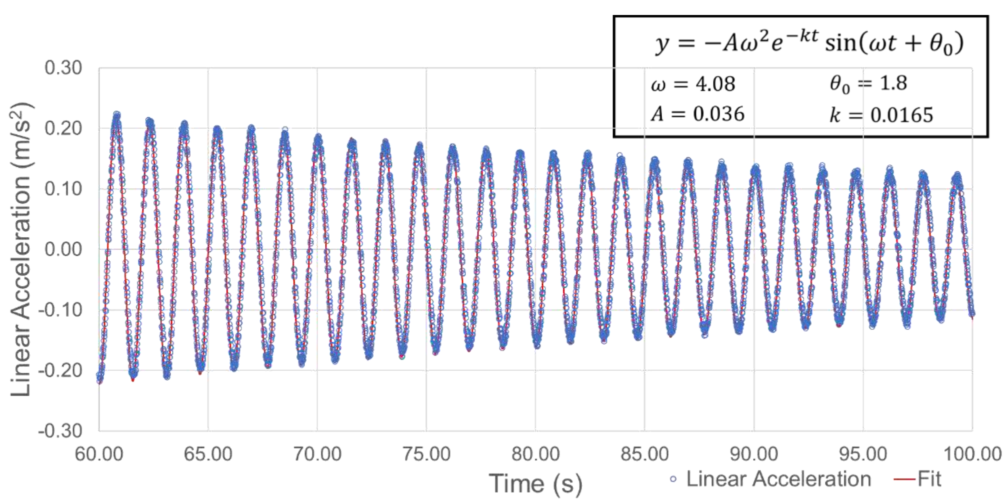




VII. Harmonic Motion and Waves

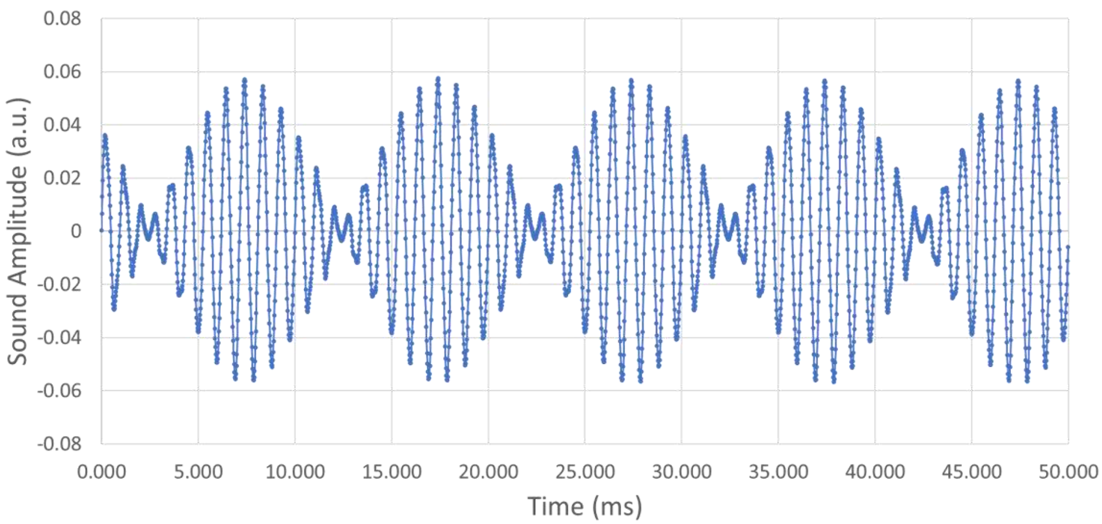
Students will explore harmonic motion via springs, pendulums, and cantilevers. In the top figure, linear acceleration was measured for an oscillating phone suspended by a rubber band. From that data, students can calculate the velocity and displacement values, which are shown in the plot. Students can also measure the period of a pendulum with high precision, allowing them to calculate the acceleration due to gravity with an accuracy of <0.5%. The bottom plot shows pendulum data as well as the excellent fit to the damped harmonic oscillator. Students can also demonstrate the principles of an atomic force microscope using the precise measurement of cantilever oscillations.



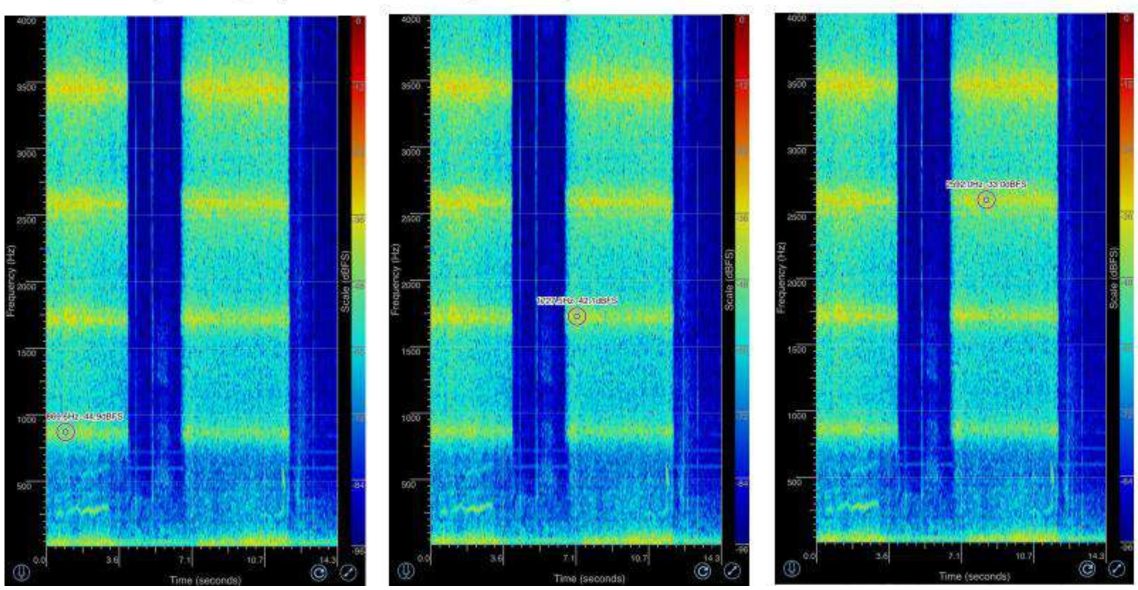


VIII. Mechanical Waves and Sound

Students will be able to use the microphone, speakers, and internal computational power of their phones to explore pressure modulations as a function of time produced by vibrations – sound waves. The beat pattern produce by the interference of two sound waves is shown in the top figure. The bottom figure displays the frequency spectrum of an open pipe resonator (student blowing over the top of a straw). Smartphone-based experimentation with sound waves enables students to explore properties of waves including period, wave speed, amplitude, and interference in a series of experiments with visually impactful data. The activities include a voice recognition experiment using visual inspection of time-dependent frequency patterns.



Frequency Spectrum: Open Pipe with L = 19.7 cm, D = 0.5 cm



IX. Magnetic Fields

Students use the magnetometer to measure the magnetic field of the earth, small magnets, and current-carrying wires. The top figure displays the magnetic field of the earth as a student rotates 360 degrees. Students use the data and geometric analysis to determine the angle and magnitude of earth's magnetic field. The bottom figure shows the measurement of magnetic field as a function of distance from a current-carrying wire, which allows them to beautifully demonstrate the inverse square law (and calculate the vacuum permeability). The activities include an opportunity to investigate magnetic storage, in which students encode and read out binary numbers in ferromagnetic materials (heads of nails).