Physics with Phone Sensors – Virtual Workshop

Sponsored by Lawrence Livermore National Laboratory

June 20 – June 24, 2022

Time: 8:30 AM – 2:30 PM (Pacific Standard Time)

Introduction: The National Research Council provides a vision for STEM education which puts science investigation and engineering design at the center of teaching and learning science. This vision is articulated in *A Framework for K-12 Science Education* and the resulting Next Generation Science Standards. While most physics teachers embrace this approach, the practical implementation of three-dimensional learning comes with many challenges. Fortuitously, the advent of smartphones provides a technological solution which greatly facilitates the three-dimensional learning approach and provides connections to many real-world experiences of today's students. The remarkable capabilities of smartphones have the potential to revolutionize how students learn physics far beyond what was imagined when the "Framework" was introduced.

Workshop Summary: This virtual 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 which students own and use daily. Smartphones enable small groups or individuals to conduct inquiry-based investigation that have historically not been possible in educational settings. The rapid technical advances in microfabrication technologies and the associated IT infrastructure now enable every student with the opportunity to use a tool with unprecedented capability in their educational journey.

The activities that will be explored in the workshop are designed to require minimal additional equipment beyond the smart phone, allowing them to be conducted in classrooms with limited resources. In fact, many of the activities are well suited for students to conduct 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 very sophisticated experimental activities. During this workshop participants will gain experience using the sensors in carefully crafted experiments as well as in open ended explorations that can be adapted to the specific needs of students with different backgrounds. The activities are designed to be easily adaptable, so physics teachers at both the high school and introductory college level will all find activities that will challenge their students. At the conclusion of the workshop, participants will be prepared to lead physics students into a new world of experimental design, high precision measurements, and data analysis.

The class will be conducted remotely over video conferencing. Participants will need a smartphone (IOS or Android), ability to use a spreadsheet, and the capability to connect to the video conference. US participants will receive a kit containing a handful of items to facilitate the experiments (list of items can be made available to other participants). Over the course of the week, participants will use a variety of the sensors in smartphones to explore a wide range of disciplinary core ideas and enhance their experimental skills. For each activity we will follow a general format that will be repeated several times a day:

1) Introduce the activity and discuss potential experimental designs
2) Workshop participants will be given time to conduct the activity on their own (instructor will be available online to assist)
3) Group discussion and sharing of results via Slack (this allows immediate feedback and iteration on experiments)
4) Discuss alternative approaches and extensions of the activity

Smart Phones Sensors and Capabilities: Remarkable technological advances in microelectronics and communication technologies, driven by extensive commercial investments, have resulted the individual ownership of smartphones with unprecedented capabilities. The suite of sensors, computational analysis power, and real-time visualization capabilities on a smartphone are combined with a sophisticated interface that students have mastered through extensive practice. Such advances would never have been driven by educational needs, but fortunately it is available for educators to exploit. 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
- Blue-tooth and Wi-Fi that enable communication and data transfer

Examples of experimental activities that we will cover in the workshop are contained on the following pages. Many more examples are available at: Physics with Phones | Science and Technology (llnl.gov).

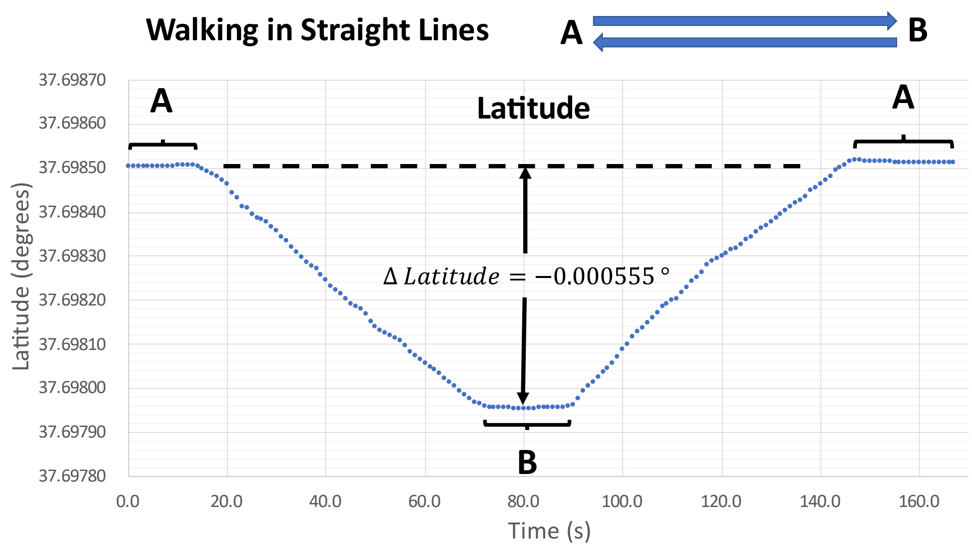
If you have any questions about the workshop, feel free to contact David Rakestraw: rakestraw1@llnl.gov. I know committing to a weeklong workshop is a significant investment in time and I want to make sure you have all the information you need before making such a valuable investment of your time.

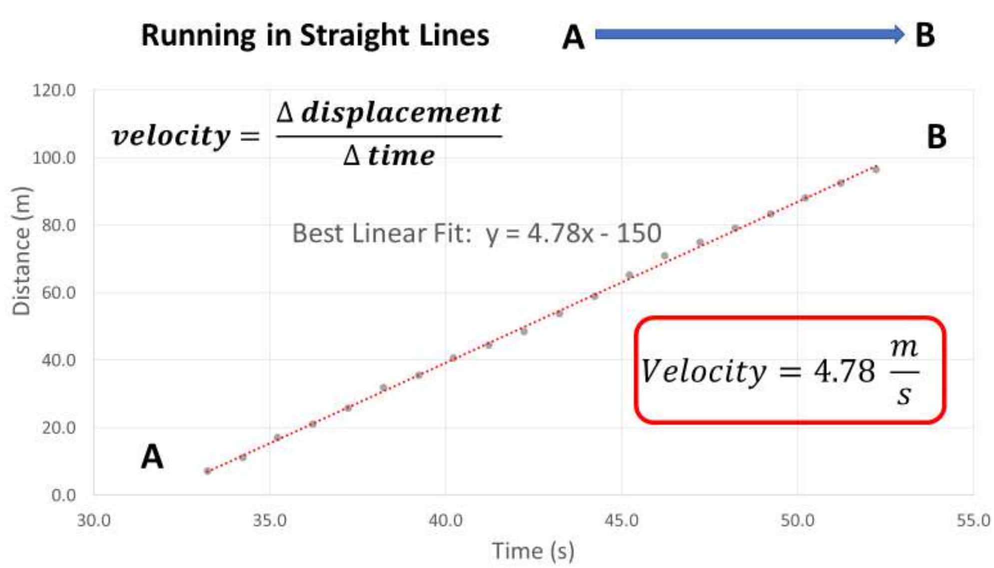
Registration Link: Teacher Research Academy | Science and Technology (llnl.gov)

Some examples of activities are shared on the following pages. New activities are being developed continuously and will be included in the workshop.

I. Displacement and Velocity

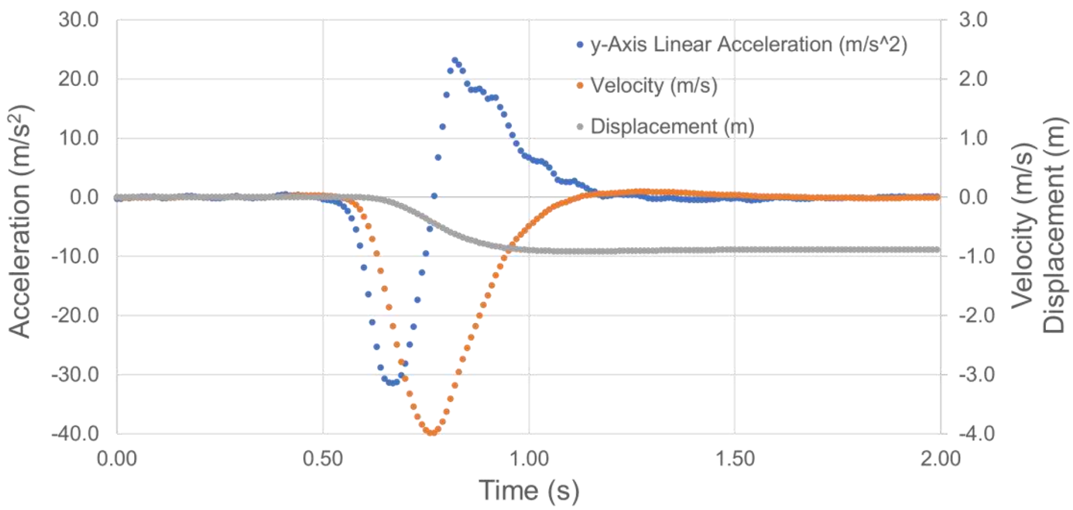
Students run, walk or drive from point to point with their phone. The GPS sensor on the phone collects latitude and longitude data every second. Students are able to calculate the displacement and distances from the latitude and longitude data. By plotting displacement vs time, students can determine velocity and speed. In the process of learning the foundations of motion in one dimension, students learn about GPS operation, the global coordinate system, practice using significant figures in calculations (8 significant figures in the GPS data), learn how to use spreadsheets for graphing/analysis and solidify their understanding of scalers and vectors.

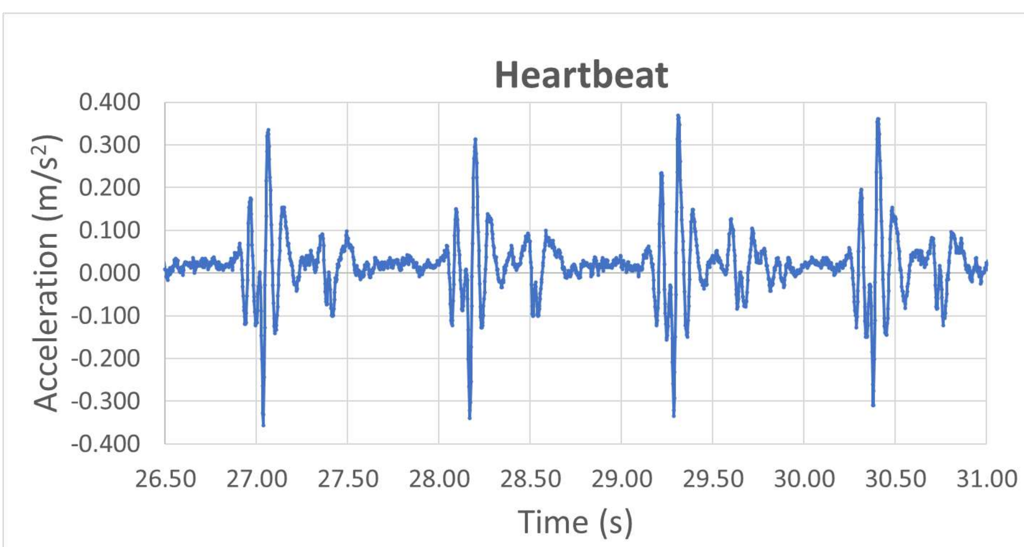




II. Accelerated Motion

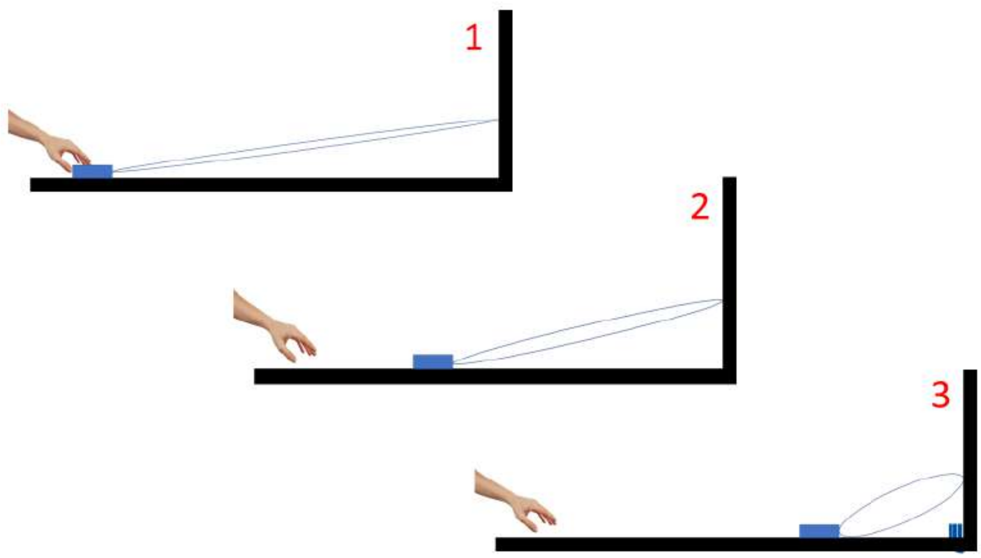
Students use the 3-axis accelerometer to measure acceleration for a wide range of scenarios. In the first figure, students hold a phone in their hand close to their bodies and then extend their arm quickly. The blue data points map out the measured acceleration of the phone during that movement. Examining the change in sign of the acceleration allows them to conceptualize the meaning a change in rate. From the acceleration data, students then then calculate the velocity and displacement at every point in time during the movement. This provides a very powerful investigation of kinematics. In the second figure, the student places the phone on their chest and measures the acceleration of the phone that results from their heartbeat. This seismocardiogram can provide detailed information about the cardiac cycle and is an excellent opportunity to engage students with interest in the life sciences.

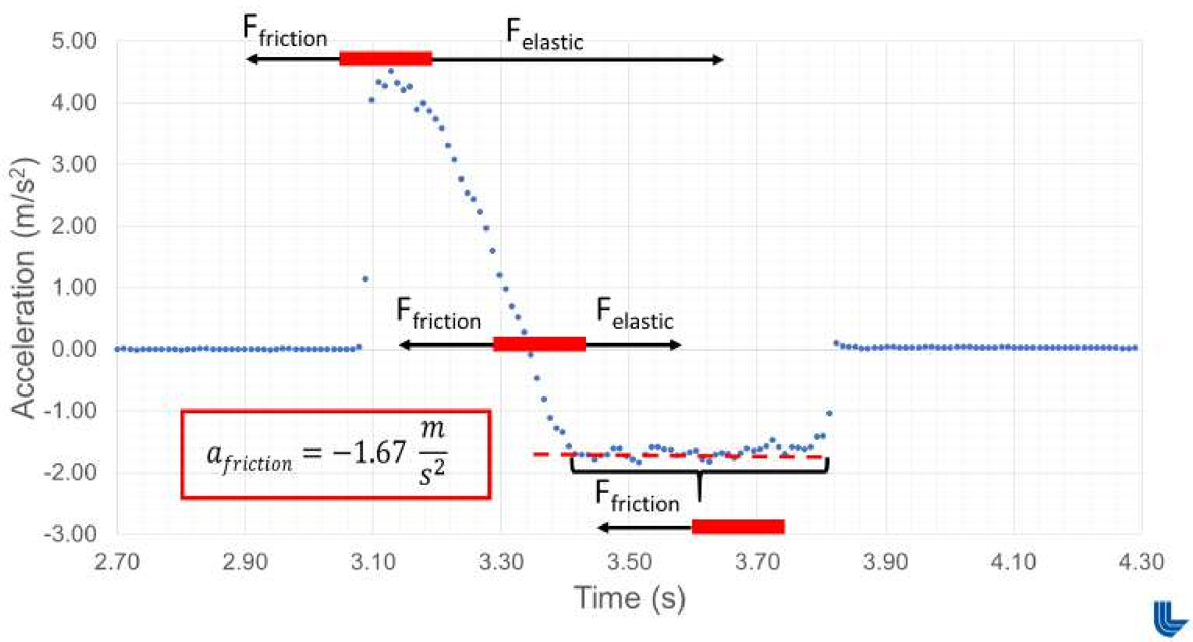




III. Forces

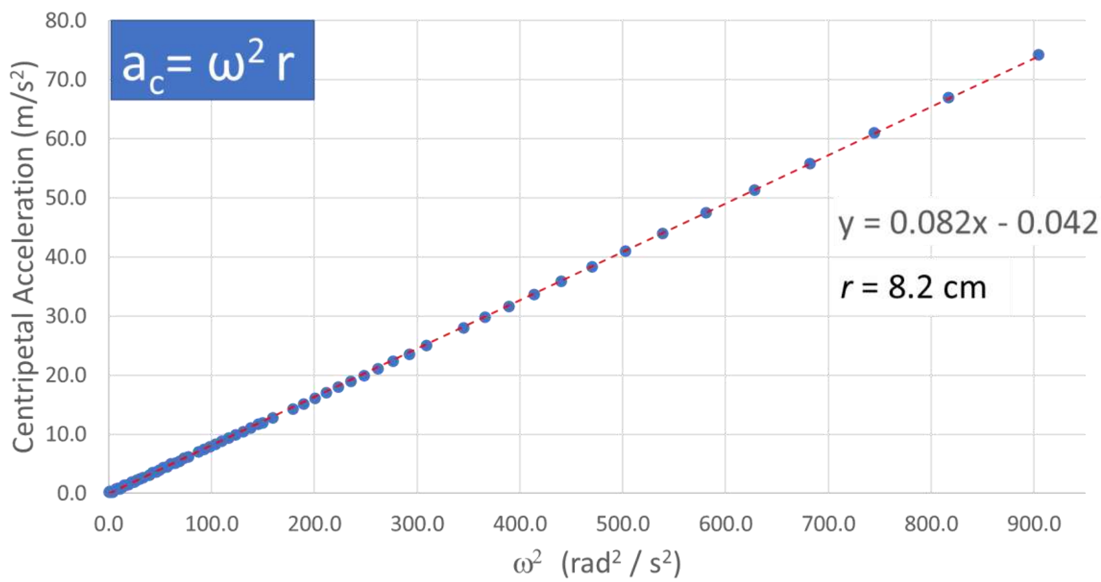
Student explore Newton's 2nd Law using the accelerometer. In this simple experiment, the phone is initially accelerated using the elastic force produced by the elastic potential energy of a rubber band. After the rubber band returns to its equilibrium length, the phone experiences a constant negative acceleration due to the force of friction. Students measure the value of the acceleration and can then calculate the coefficient of dynamic friction. Students practice creating free body diagrams and can do a series of experiments that explore dynamic and static friction for different surfaces.

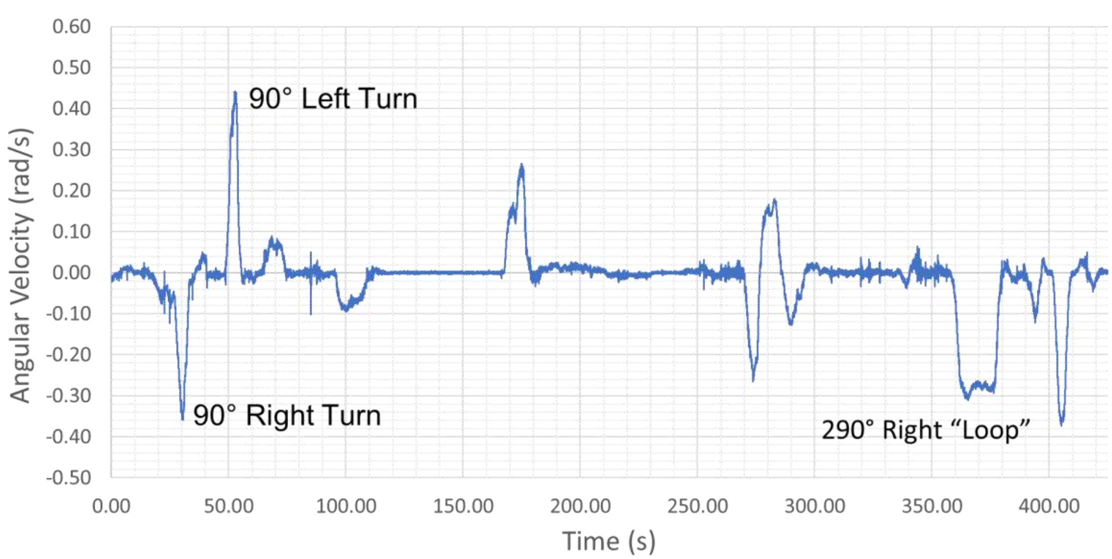




IV. Rotational Motion

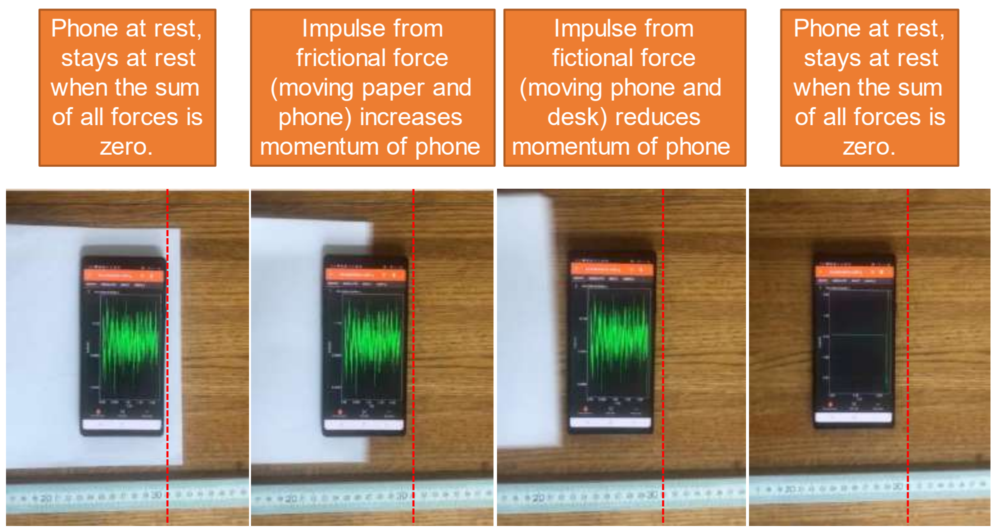
Students will use the 3-axis gyroscope to explore rotational motion. They will measure angular velocities and explore the relationship between angular velocity and centripetal acceleration. In the first graph below, the centripetal acceleration (using the accelerometer) is measured simultaneously with 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.

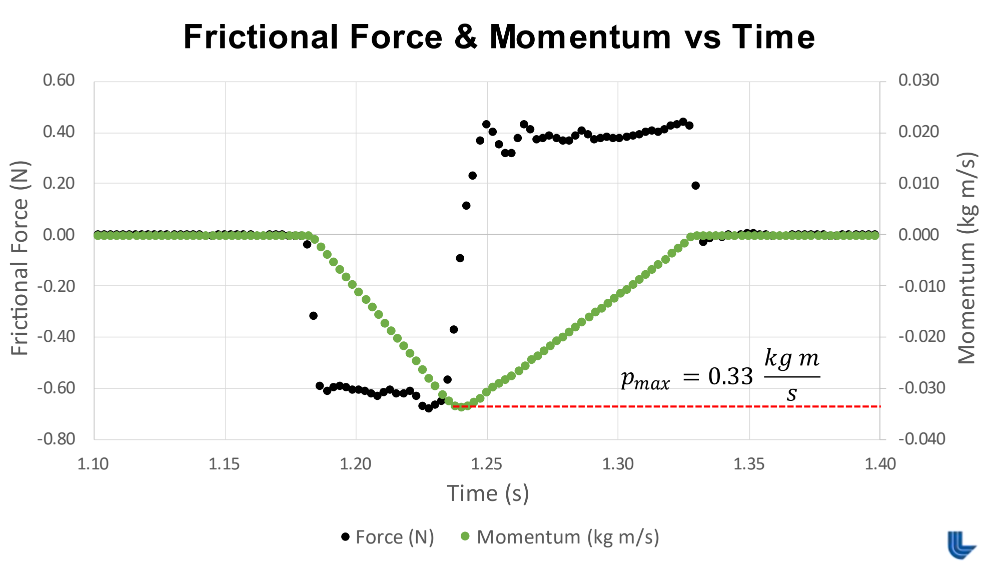




V. Investigating Impulse and Momentum

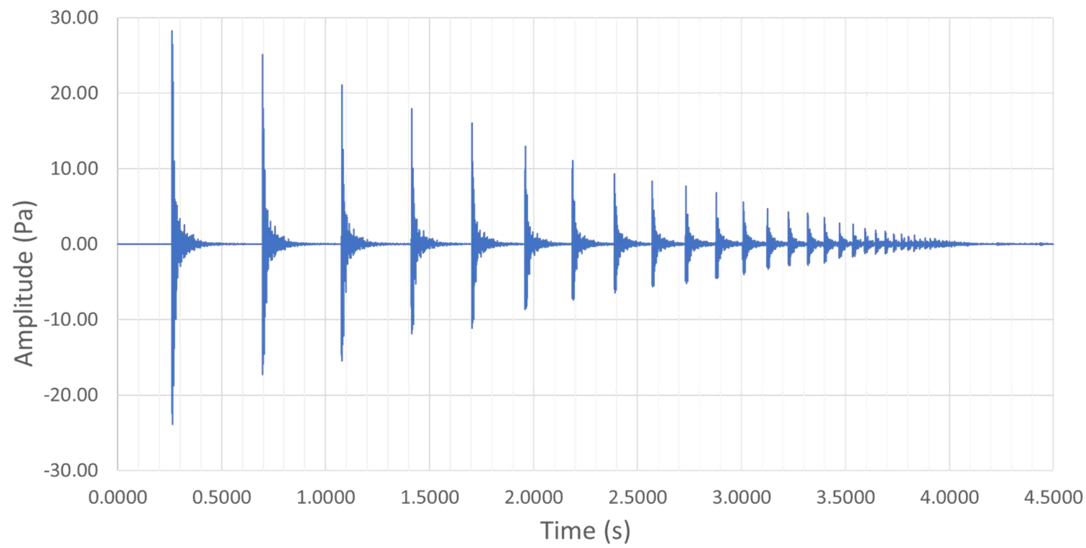
Students will directly measure the acceleration that results from an impulse and calculate the resulting force and momentum. This experiment mimics that classic "magic trick" where a tablecloth is pulled out from under a dish. In this case, an initial impulse is provided by the frictional force that is applied to the phone when a piece of paper is pulled out from under it. This impulse results in an increase in the phone's momentum. A second impulse then results from the frictional force of the phone and the desk which slows (negative acceleration) the phone to a stop. This experiment provides a very elegant way for students to study impulse that has historically been difficult to study experimentally due to the rapid time scales. Additional experiments activities include using the accelerometer to measure the vibrations introduced from an impulse and evaluating experimental designs to reduce the effect (quantitative replacement of the "egg drop"

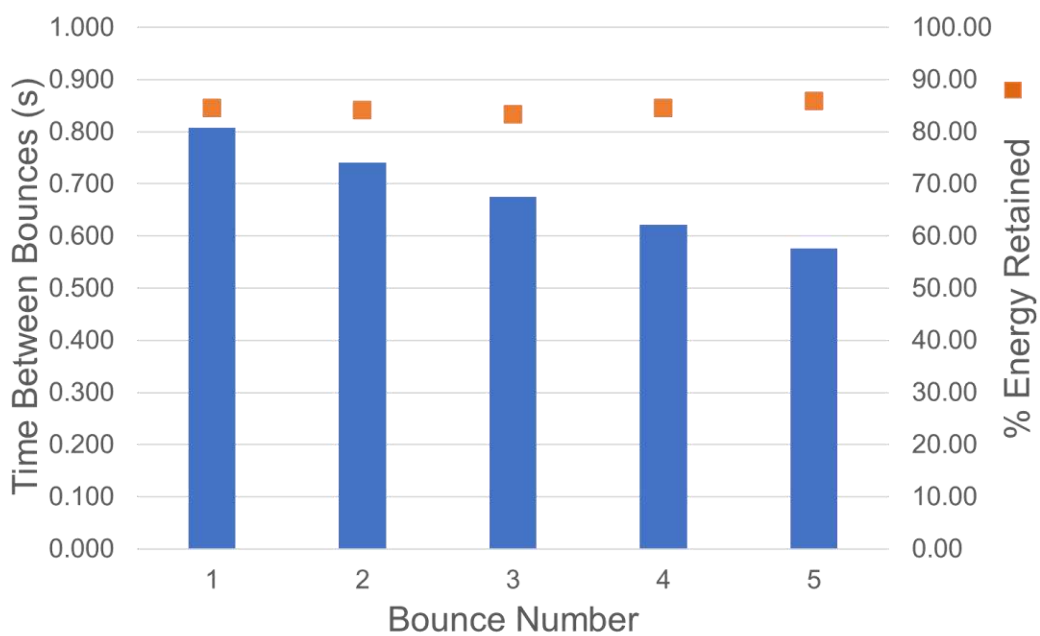




VI. Conservation of Energy and Inelastic Collisions

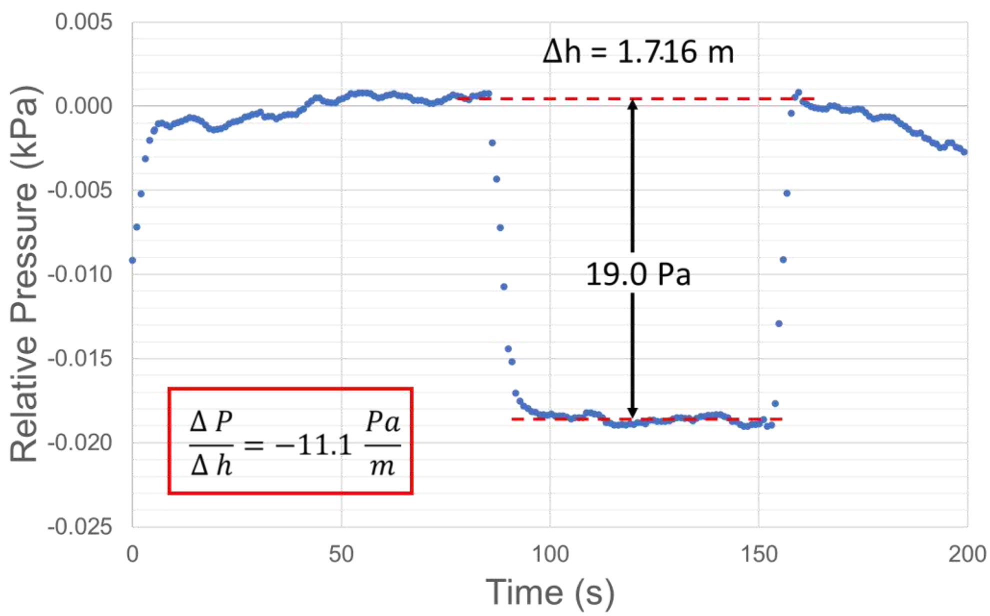
Students will explore the loss of energy during collisions. Students drop a ball onto a surface and measure the time between each bounce. The first figure shows the measured sound wave associated with each sequential bounce. The time of each bounce is precisely determined from the high-speed microphone 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. This data then allows 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.

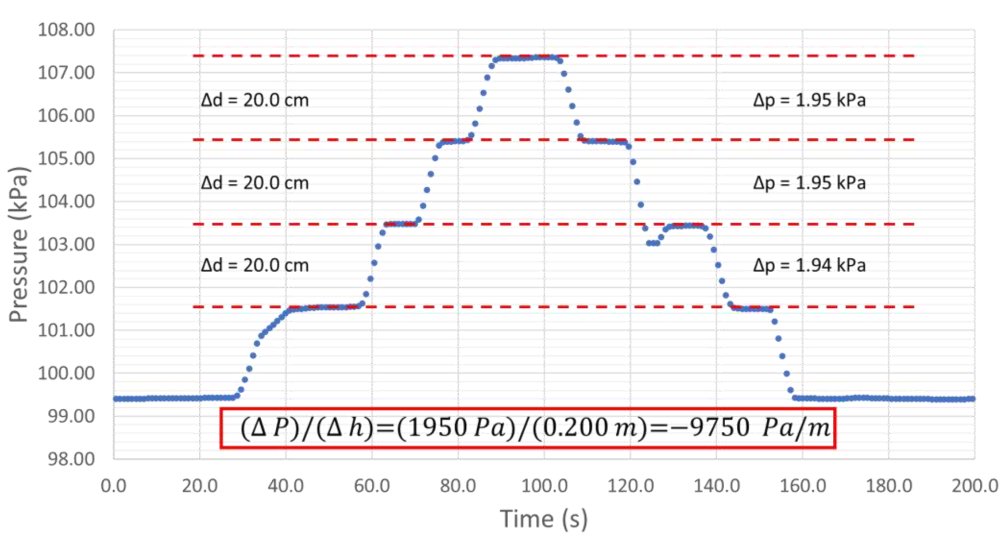




VII. States of Matter: Fluids

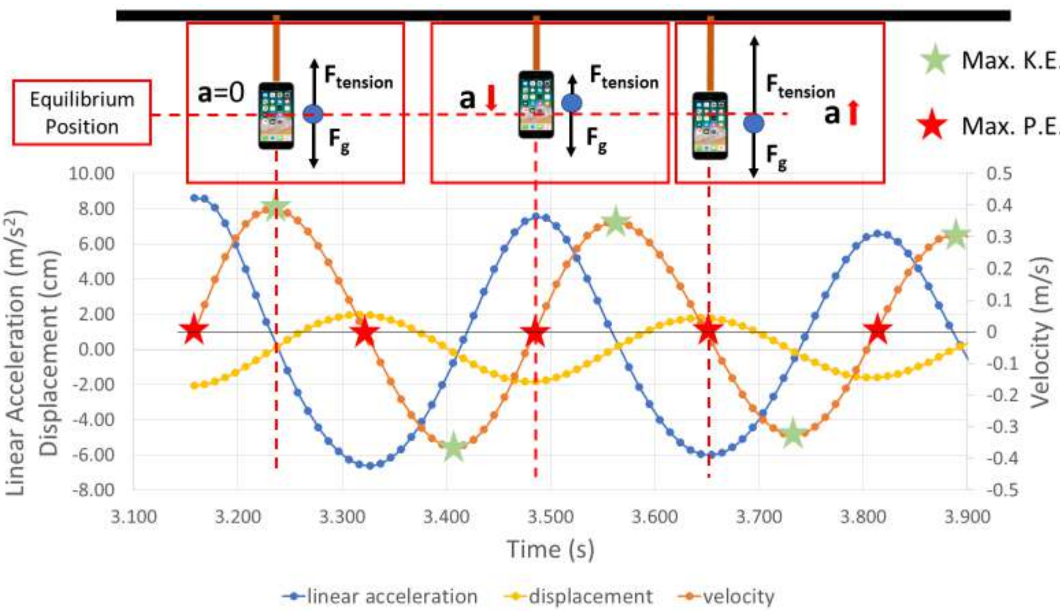
Students examine the properties of fluids. The two figures below provide data for measurements of pressure vs altitude in air (top) and pressure vs depth in water (bottom). The experiments provide very precise data that can be combined with the hydrostatic formula to calculate the density of air and 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 presents an ideal opportunity to introduce the use of controls in experimental designs (data in top figure used a control to improve measurement).

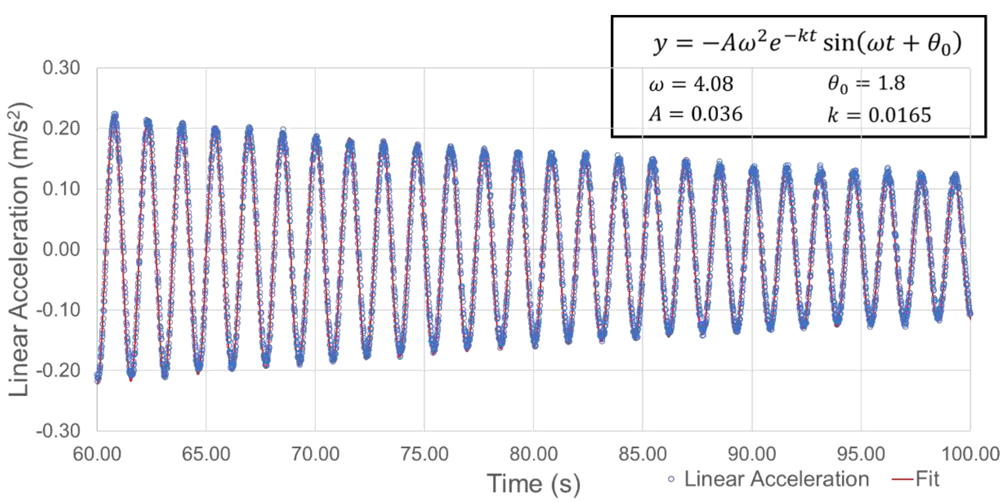




VIII. Harmonic Motion and Waves

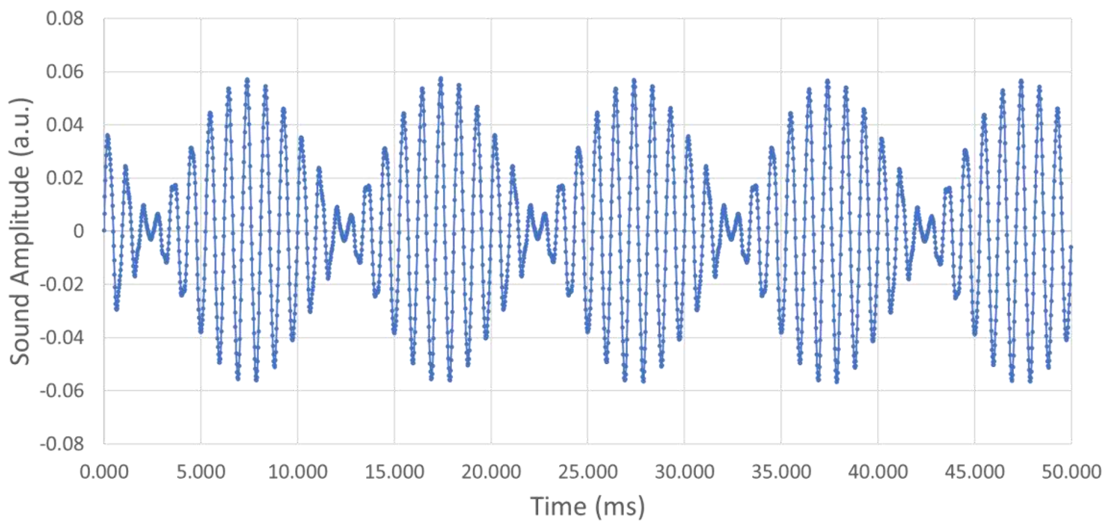
Students will explore harmonic motion via springs, pendulums and cantilevers. In the top figure, linear acceleration was measured for an oscillating phone suspended by a rubber band. From that data, students can calculate the velocity and displacement values which are shown in the plot. Students can 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.



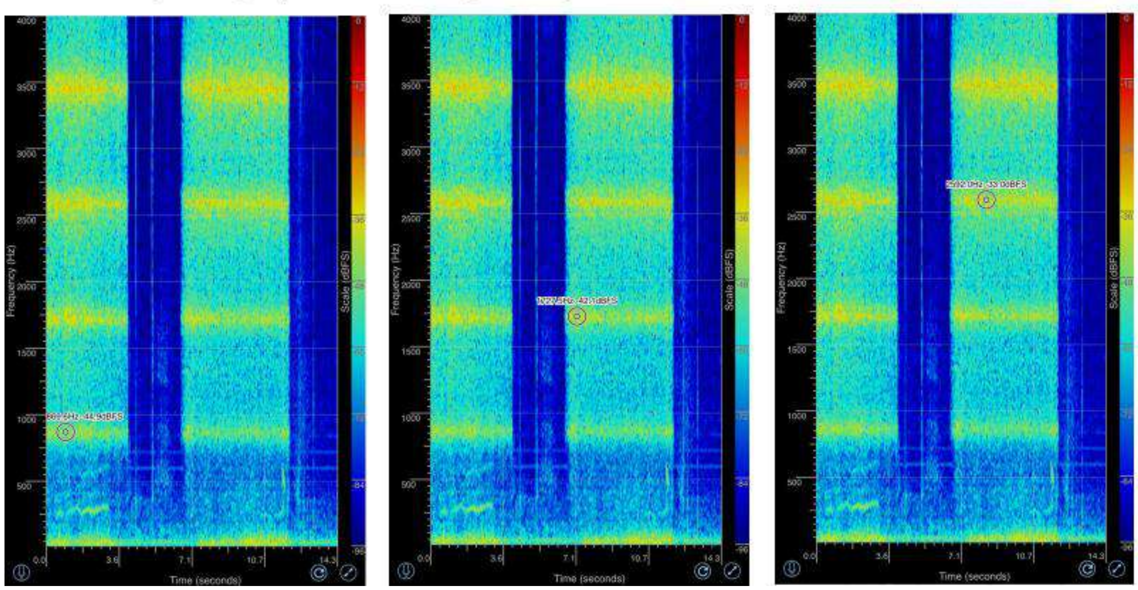


IX. Mechanical Waves and Sound

Students will be able to use the microphone, speakers and internal computational power of their phones to explore pressure modulations as 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 very 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



X. Electromagnetic Waves

Students will investigate a wide range of phenomena using the displays, cameras, and microwave antennas of their phones. The first figure is from an activity that uses the display as a light source which enables the elegant study of color by addition. This is often done as a demonstration ("colored shadows") in class. With the use of their phone displays, students can investigate many combinations on their own. In the second figure, student investigate the microscopic structure of displays by examining a magnified image of the individual elements of a electronic display. The magnification is accomplished by using a water drop as a lens on the front facing camera. Many other activities with polarization, diffraction, reflectance spectroscopy, and the investigation of microwaves are possible.

Shadow with Red, Green and Blue Light Source

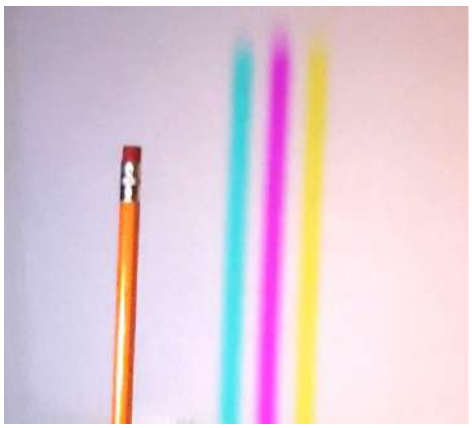
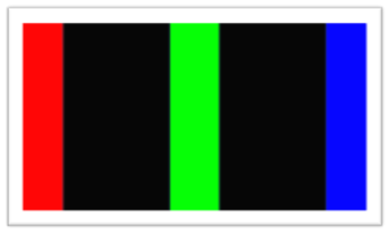


Image using Phone Camera



Light Source

Green + Blue → Cyan

Red + Blue → Magenta

Red + Green → Yellow

Red + Green + Blue → White

iPhone 12: AMOLED Display

"White"

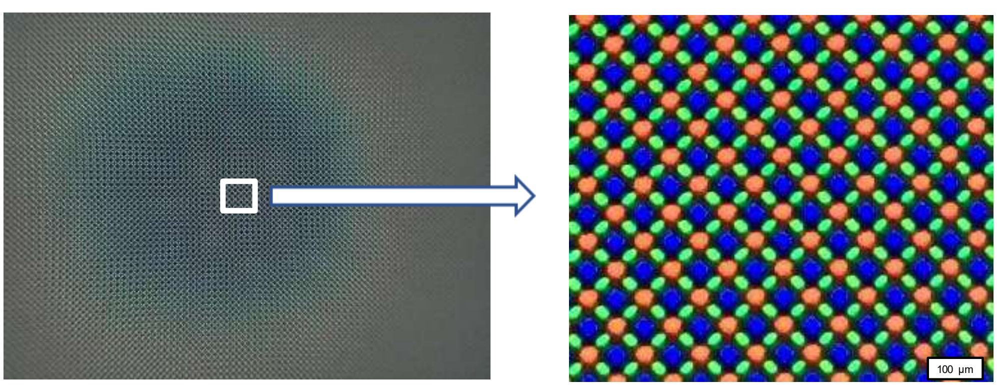


Image of display: magnification using water drop lens

Zoom in on the image

XI. 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 student to beautifully demonstrate the inverse square law (and calculate the vacuum permeability). The activities include an opportunity investigate magnetic storage where students encode and read out binary numbers in ferromagnetic materials (heads of nails).