# A Modern Arduino Approach for Advanced Physics Laboratories in the Time of COVID

## An Introduction for Laboratory Courses

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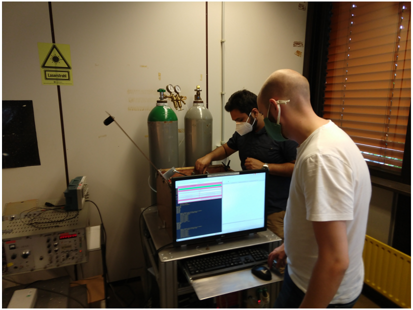
# Overview of Our Lab Course

- $\mathcal{O}$(150 students)
- Students grouped in pairs
- 4-6 exp. per group
  - Discussion
  - Experiment
  - Report
- $\mathcal{O}$(10) exp. run each day
- COVID hygiene requirements
- Some exp. supervisors are remote (difficult to facilitate)



**Need to add experiments that operate well in both in-person and remote!**

# What Does a Take-Home Experiment Look like?

Student

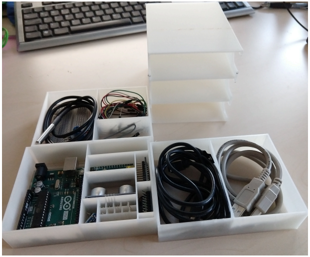
- Collects the equipment
- Connects to Zoom (or similar) when starting experiment (agreed times with teacher)
- Remains connected to Zoom while performing experiment
- If problems occur, ask teacher/tutor
- After completing, return equipment

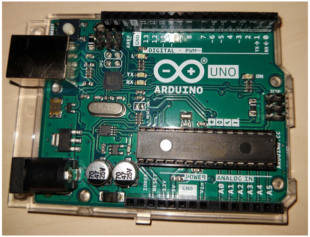
Teacher/Tutor

- Connects to Zoom to ask students questions about experiment
- Remains connected to Zoom: Respond to problems/questions from students
- Confirm that equipment returned in satisfactory condition
- Grade student report and issue feedback

# An Experiment that Works At-Home and University

- What to look for in a good experiment for in-person and at-home?
  - Compact
  - Inexpensive
  - Easy-to-use
  - Modular
- Microcontrollers (Arduino) are good candidates
  - Fit most of above requirements
  - Many useful sensors
  - Interface with computers





# Our Experiment Overview

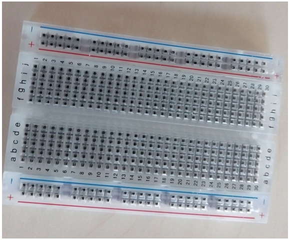
- Primary Student Outcome:
  - Students measure various physics phenomena and learn how to collect data using modern microcontrollers like Arduino

- Students can perform the following measurements:
  - Blink an LED
  - Displacement, velocity, acceleration
  - Apparent weight
  - Speed of sound
  - Vectors of Earth's grav. and mag. fields
  - *Planck's constant*
  - Latent heat of fusion of water
  - *Heart rate*
  - *Cosmic ray background*

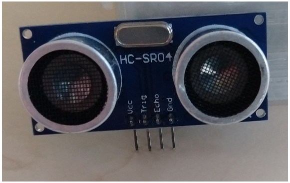
Many of these measurements can be compared those made by sensors and apps in mobile phones, etc.

*Will discuss in more detail later

# Components Part I



Breadboard
(make circuit connections)




HC-SR04 Sonic Motion Sensor

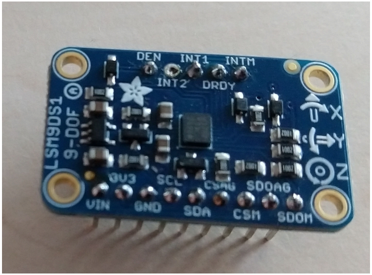
Temperature Sensor

KY-039 Heart Rate Sensor

# Components Part II


Analog-to-Digital-Converter (ADC)


Digital-to-Analog-Converter (DAC)



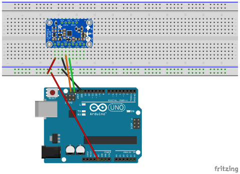

Accelerometer

LED

# A More In-Depth View Of Student Expectations During Lab

Students are expected to do the following for each module of the experiment:

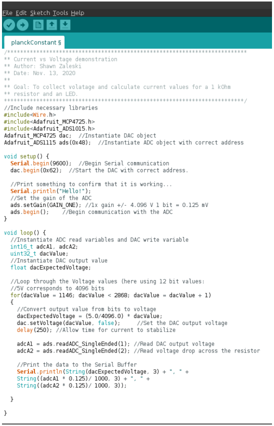
- Build circuit
  - **Generally simple circuits with pictures of circuit in manual**
- Write Arduino code to collect data measurements
  - **Students not expected to have prior knowledge**
  - **Many hints in lab manual**
- Write PYTHON program to record data for analysis
  - **Our students have significant prior training**
  - **New items for them specific to Arduino learned, e.g. Serial communication**
- Analyze the data to create a plot or perform a calculation
- Present the results along with error analysis of the data



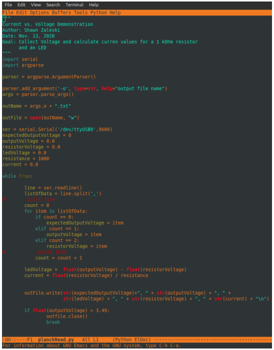
# Student Analysis of the Experiment

Students are expected to submit the following in their reports to their experiment supervisor:

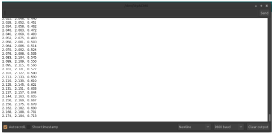
## Arduino Code




## PYTHON code

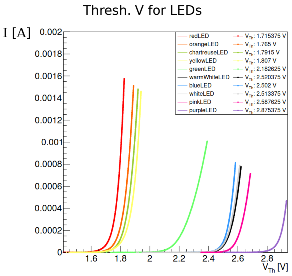


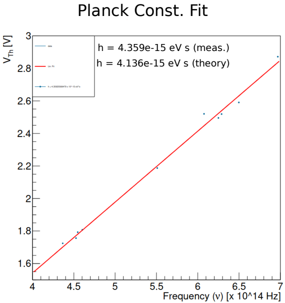

## Data & Results



# Planck's Constant

- Students write Arduino code to measure the following:
  - Voltage across LED
  - Voltage current through resistor
- Students write PYTHON code to generate:
  - I-V curve for each LED
  - Find $V_{Th}$ for each LED
  - Plot $V_{Th}$ vs $\nu$
  - Slope of fit is $h$
- DELIVERABLES:
  - I-V plot with all LEDs
  - Plot with fit for $h$
  - Commented Arduino code
  - Commented PYTHON code



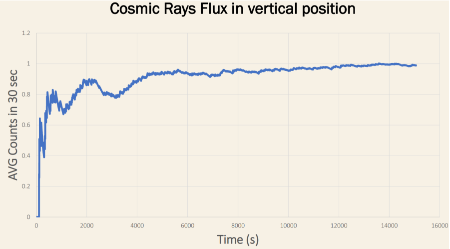
# Heart Rate Monitoring

DEMO, example of sensor response that students are looking for

- Students write Arduino code to measure voltage pulse from blood movement in finger
- Students write PYTHON code to calculate heart rate from Arduino data
- DELIVERABLES:
  - Commented Arduino code
  - Commented PYTHON code
  - Heart Rate calculation

# Geiger-Mueller counter for Arduino

- Students write Arduino code to collect cosmic ray muon counts using PIN photodiode counter
- Students write PYTHON code to collect data from Arduino and plot
- DELIVERABLES:
  - Commented Arduino code
  - Commented PYTHON code
  - Plot of muon counts as function of time
  - Poisson histogram of number of counts within time window

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# Student Feedback

In our first offerings (12 students) we asked them for anonymous feedback. Here's what they said:

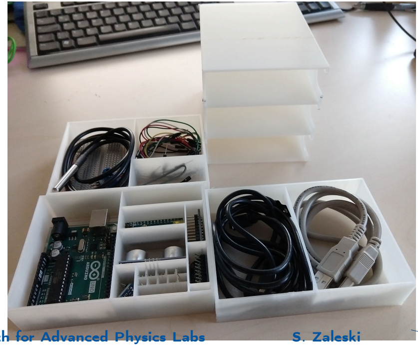
- Experiments are easy to work with
- Many simple experiments allowed focusing on specific aspects of microcontrollers
- Enjoyed working with microcontrollers
- Combining multiple technologies (Arduino program & PYTHON program)
- Learning 2nd programming language (C-style Arduino)
- Planck's constant experiment

Student's generally agreed that:

- They learned a lot about working with Arduino
- The Arduino made the experiment more interesting

# Summary

- Overall, the experiment operates successfully in-person
- This experiment is well positioned to operate either in person, or at home
- We had our first students on 8 March 2021
- Students complete entire experiment within 8 hours
- Students gain familiarity with Microcontrollers in context of well-understood physics principles
- Identified a few places for improvement



# BACKUP

BACKUP

# Lab Course Experiments

- Covers detector topics with HEP and Solid State physics applications
- Students complete 5-7 of the experiments

High Energy Physics

- Particle detectors and radiation protection
- Compton scattering and gamma spectroscopy
- Angular correlation
- Moessbauer effect
- X-ray spectroscopy
- Gas detectors and statistics
- GEM detectors
- Data analysis LEP
- Detector principles
- Stern-Gerlach
- Mini-Auger

Solid-State Physics

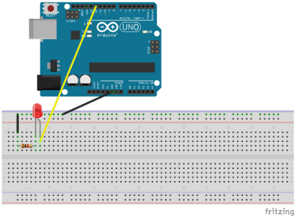
- Thin film technology
- Scanning Tunneling Microscope
- X-ray diffraction
- Magneto-optic Kerr effect
- Neodymium YAG laser
- Electrical conductivity in metals and semiconductors
- Magnetic phase transitions
- NMR spectrometer
- Data acquistion with LABVIEW
- Ultrasound computed tomography
- Characterization of Ultra-short laser pulses

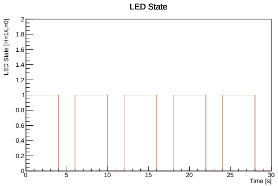
# Experiment Structure

- Experiments are 1-2 day experiments
- 1-3 groups of 2 students each
- Students arrive at 9:00 and begin with a discussion part
  - Attendance is taken by experiment supervisor
  - Students answer basic theory and technical questions related to experiment (expected to read manual prior)
  - Brief instruction on setup
- Students then work the remainder of the 1st day completing tasks outline in manual
- Students contact exp. supervisor in event of problems and questions
- Students work until 18:00 and turn off equipment
- Students come back to start following day if 2-day exp.
- Students submit lab report to lab supervisor within 2 weeks of completing exp.

# Blinking An LED

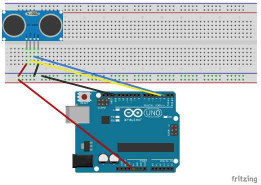
- Students write Arduino code to accept input from PC to turn LED on/off
- Students write PYTHON code to turn LED on/off with Arduino
- Students keep the LED on longer than off
- Cycle $\mathcal{O}(5)$ times
- PYTHON code should also store data for plotting
- DELIVERABLES:
  - Commented Arduino code
  - Commented PYTHON code
  - Plot of LED state as function of time

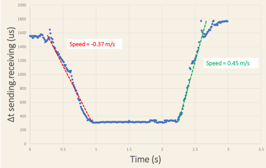


# Kinematics and the Speed of Sound

- Students write Arduino code to send and receive sound wave with HC-SR04
- Students write PYTHON program to store position of object from sensor
- Analysis will determine:
  1. displacement
  2. velocity
  3. acceleration
- Students measure time that wave takes to travel distance
- Calculate speed of sound
- DELIVERABLES:
  - Commented Arduino code
  - Commented PYTHON code
  - Kinematic plots
  - Speed of sound value

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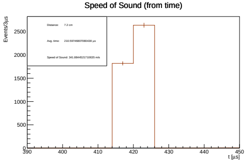
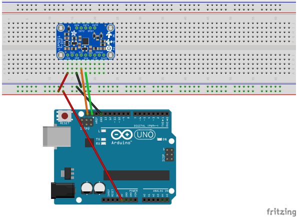
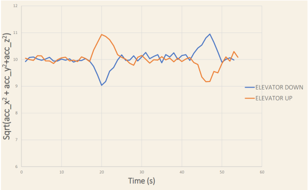



$d = 7.2$ cm, $< t >= 0.2106$ ms, $v = 341.9$ m/s

# Accelerometer: Earth's Grav. and Mag. Fields

- Students write Arduino code to collect values for:
  1. acceleration
  2. magnetic field
- Students write PYTHON code to collect values from Arduino and calculate the vectors
- DELIVERABLES:
  - Commented Arduino code
  - Commented PYTHON code
  - Vector calculations for the Earth's grav. and mag. fields

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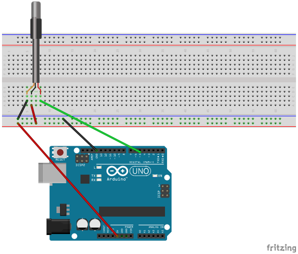
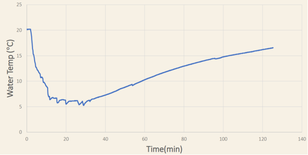
# Temperature Sensor: Specific Heat Capacity

- Students write Arduino code to collect temperature from temp sensor
- Students write PYTHON code to collect values from Arduino
- DELIVERABLES:
  - Commented Arduino code
  - Commented PYTHON code
  - Plot of temperature vs. time
  - Calculation of specific heat capacity of water
  - *REVISION* Will use latent heat of fusion of water

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