LUMAT Research Symposium

Engaging learners in math and science through modern technologies

Organized by LUMAT Science Research Forum & The Finnish Mathematics and Science Education Research Association

2021 UBC Physics Olympics!

Organized jointly by
- UBC Dept of Physics and Astronomy, Faculty of Science &
- UBC Dept of Curriculum and Pedagogy, Faculty of Education

A Physics Lab in Your Pocket: Physics Olympics Go Online

Drs. Marina Milner-Bolotin & Valery Milner

The University of British Columbia, Vancouver, Canada

Our Context

UBC, Vancouver, Canada

Physics courses: VM

Physics Methods: MMB

Secondary physics: MMB + VM

Organized by LUMAT Science Research Forum & The Finnish Mathematics and Science Education Research Association

42 Years of UBC Physics Olympics


Feature Article

FOUR DECADES OF HIGH SCHOOL PHYSICS OLYMPICS COMPETITIONS AT THE UNIVERSITY OF BRITISH COLUMBIA

BY THERESA LIAO, JANIS MCKENNA, AND MARINA MILNER-BOLOTIN

University of British Columbia (UBC) Physics Olympics is a high school physics competition held annually at UBC in Vancouver. This annual outreach event attracts over 450 high school students, competing in teams, and over 55 teachers/coaches from across the province. This competition, organized by the Department of Physics and Astronomy and the Department of Curriculum and Pedagogy at UBC, is one of the largest and oldest high school physics competitions of its kind in North America.

The competition consists of six hands-on events (heats), of which two are pre-built by the students in the months before the competition. In recent years, it also included professional development workshops and networking opportunities for physics teachers/coaches who accompany the teams to the competition.

PARTICIPATION

Each school may enter one student team, which participates in all 6 events. A team may have a maximum of 15 registered students, of which at most 5 can participate in a given event. Events are designed so undersized teams are not penalized. Each event is run and judged by a UBC

Fig. 1 Student volunteers from the 2016 UBC Physics Olympics.

We receive about 60 registrations annually from all across BC, as far as Terrace [1], Mackenzie [2], and Invermere [2], [3] (1360 km, 970 km and 840 km driving distance from UBC respectively).

PROGRAM DEVELOPMENT

Over 60 UBC students and 10 faculty members (Fig. 1) volunteer for the event annually. The heats are designed, prototyped and tested beginning in autumn, with some of

Theresa Liao, <communications@phas.ubc.ca>

Janis McKenna

Department of Physics &

Historically

Day-long event on campus

Secondary BC students

600+ participants, 60+ teams

6 different events

2 events are pre-builds

4 events at UBC (hands-on)

Special event for physics teachers

2021: During COVID-19

Day-long event virtually

Secondary BC students

400+ participants, 40+ teams

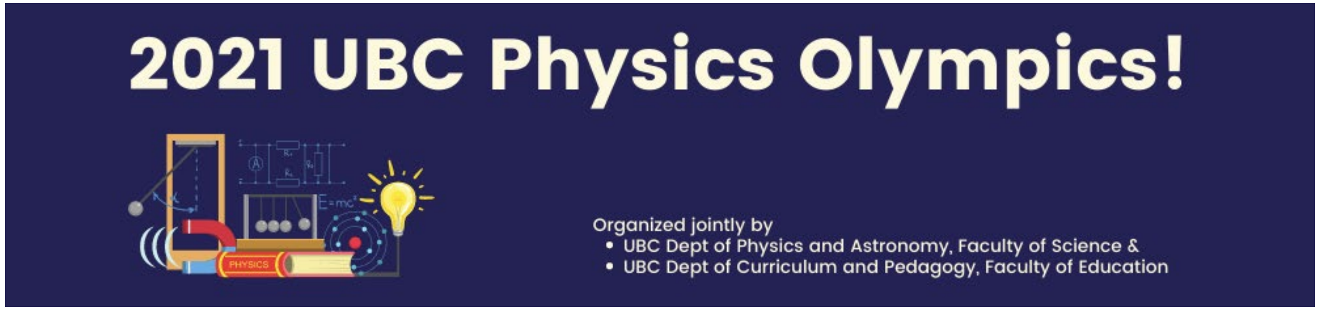
5 different events

2 events are pre-builds

3 events on the day remotely

Special event for physics teachers

http://physoly.phas.ubc.ca/

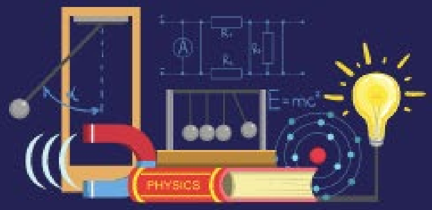


UBC Physics Olympics

It is a team effort. More than 40 volunteers faculty, staff and students from the Department of Physics and Astronomy (Faculty of Science) and the Department of Curriculum and Pedagogy (Faculty of Education) collaborate to make it happen.

https://physoly.phas.ubc.ca/

2021 UBC Physics Olympics!



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Physics Lab at Home: Two Challenges

Determining (1) the acceleration of Free Fall and (2) speed of sound at 0ºC using a PhyPhox physics app

phyphox
physical phone experiments

Phyphox is designed by Sebastian Staacks and Physics Educators at the University of Aachen, Germany

I am a physicist with a PhD in solid state physics at the RWTH Aachen University, where I develop the app "phyphox" and come up with strange ways to use smartphone sensors in physics education.

E-Mail: staacks@physik.rwth-aachen.de

Physics Phone Experiments =

= PHY PHO X

phyphox®

physical phone experiments

Objectives for the 2021 Phyphox Challenge

<u>The objective of this challenge is to complete two research projects by using a smartphone as the primary scientific instrument (and in Project 2, the only instrument).</u>

In using your smartphone with phyphox, the following is permitted:

I. Establish a communication channel between your smartphone and your computer (of any type, including tablets).

II. Use multiple smartphones with phyphox.

III. Create your own custom-designed phyphox experiments using any method described on the phyphox website.

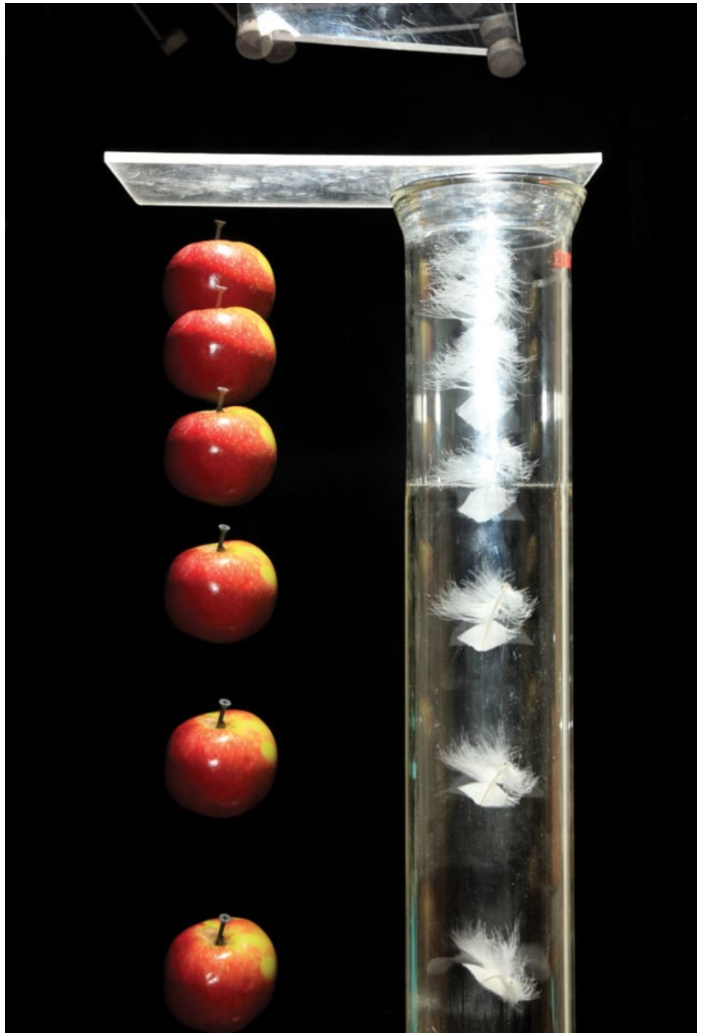
IV. Process the collected data on either the smartphone itself (e.g., using the built-in capabilities of phyphox) or any external computer of your choice.

In contrast, it is **NOT** permitted to

V. Communicate with other *measuring devices or sensors* (e.g., Arduino circuitry or an external GPS, etc.).

VI. Use any other App, even if it is installed on the same smartphone, for taking measurements.

Failing to comply with the above restrictions will lead to disqualification of the team.



https://physicsworld.com/a/the-descent-of-mass/

How We Judged Students' Submissions

- **We had 42 teams in all!**
- **35 teams submitted the videos!**
- **We created a rubric for judging submissions**
- Each video was judged by at least 2 judges
- Many videos were judged by 3 or more judges

- We judged by how many valid methods were suggested to measure g
- How the procedure was explained and communicated

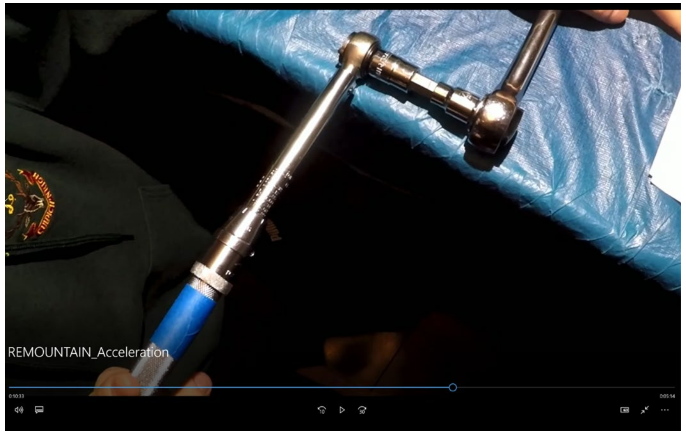
Challenge 1: Determining the value of *g*

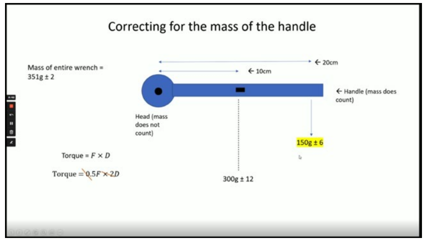
In this project your task is to determine experimentally the value of the gravitational acceleration, g, while adhering to the following rules:

a) Instrumentation. You may use your smartphone(s) with phyphox and any other external instrument (e.g., ruler, thermometer, scale, etc.) provided the additional instruments are **NOT** communicating with any of the smartphones.

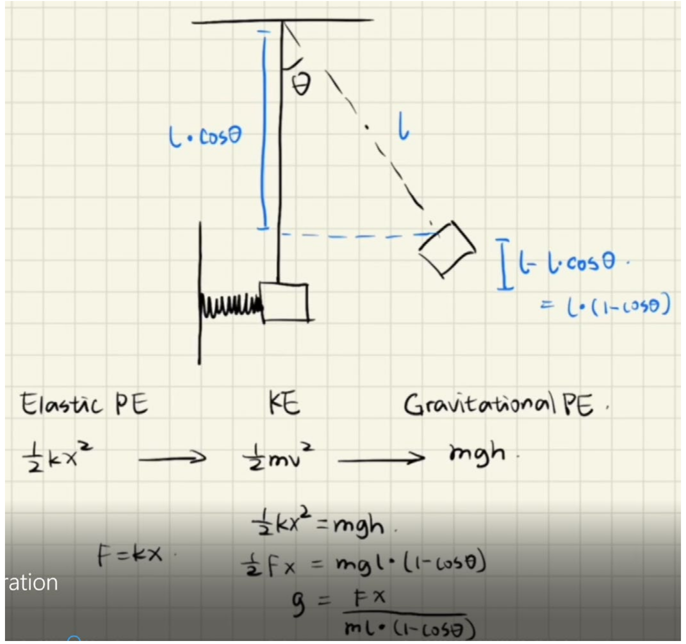
b) Physical constants. You are **NOT** allowed to use any known physical constants, such as the density of materials, the mass of the Earth, etc., unless you determine it experimentally yourself using instrumentation outlined in a). If you determine such a constant experimentally, then you must explain how you made the measurement.

How Creative Can One be with Measuring *g*?

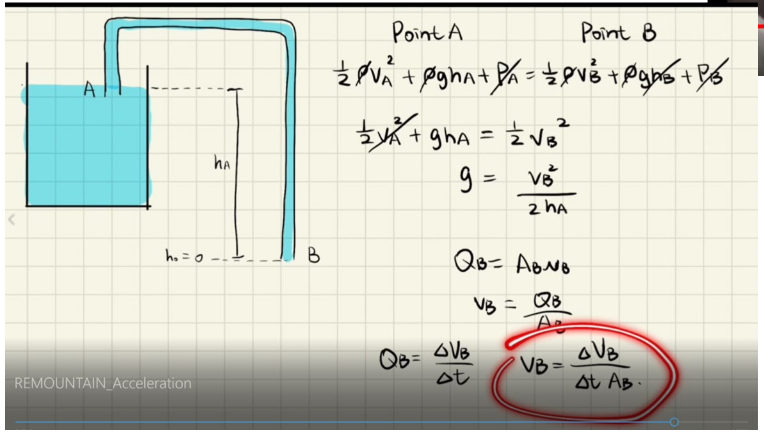




A torque wrench and a bucket of water!



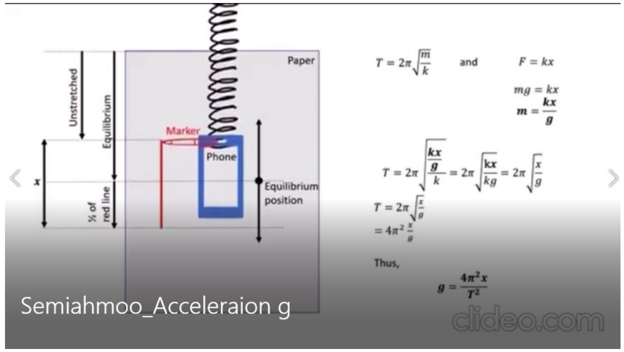
A spring collision



Bernoulli's principle

Acoustic stopwatch to measure free fall time

A plane with circular motion



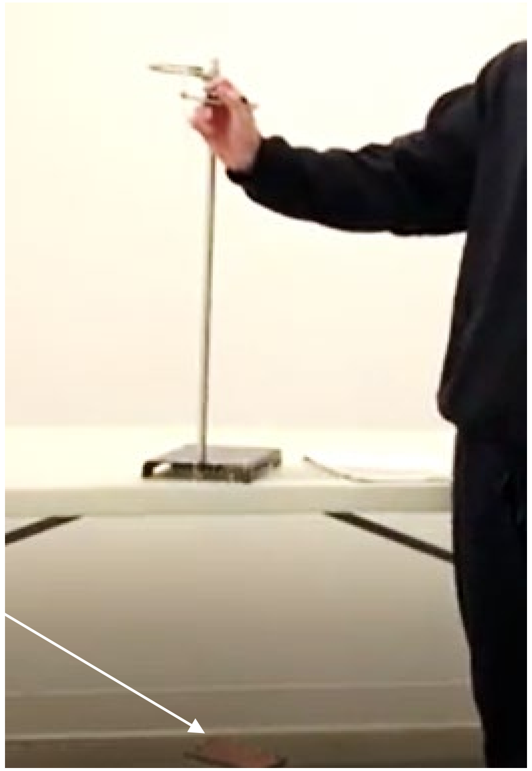
A phone oscillating on a vertical spring

Methods for Measuring *g*

- Free fall (from Project on Acceleration)
- Pendulum (from Project on Acceleration)
- Barometer (pressure changes with height)
- GPS

Free fall

Pendulum

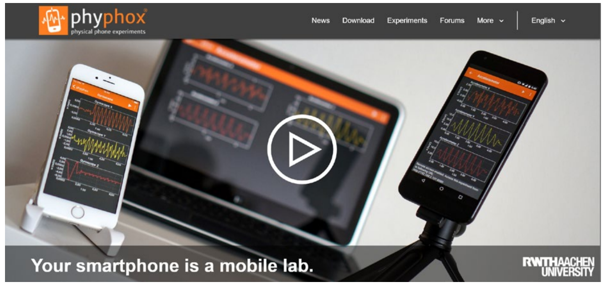


… BUT not using another ruler ☺

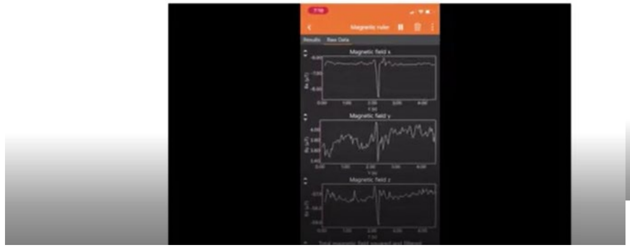
How Many Methods were proposed?
How Many Sensors were used??

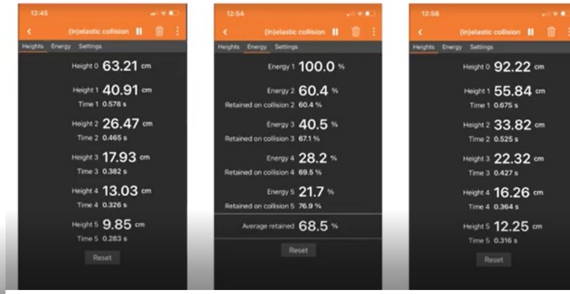
1. Free fall (g components)
2. Free fall (absolute g)
3. Incline Plane
4. Projectile motion
5. Pendulum
6. Vertical spring
7. Elevator
8. Ball bounce (collisions)
9. Circular Motion
10. Motor – Potential energy
11. Pendulum – potential energy
12. Torque Wrench
13. Bernoulli's effect
14. Pressure

1. Accelerometer
2. Magnetometer
3. Acoustic sensor
4. Light sensor
5. Microphone
6. ~~Video Analysis~~
7. ~~External timers~~
8. ~~Using other devices to collect data during the experiment~~



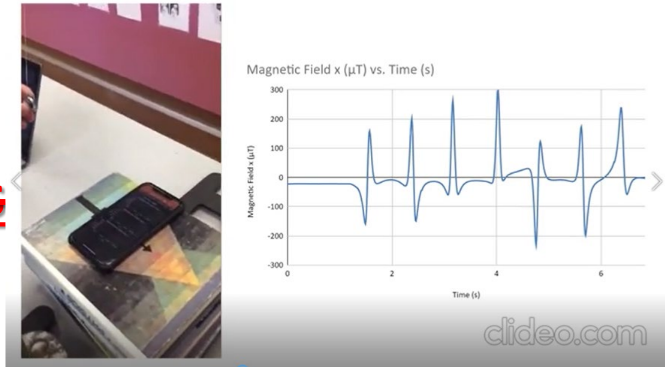
Phyphox magnetic ruler

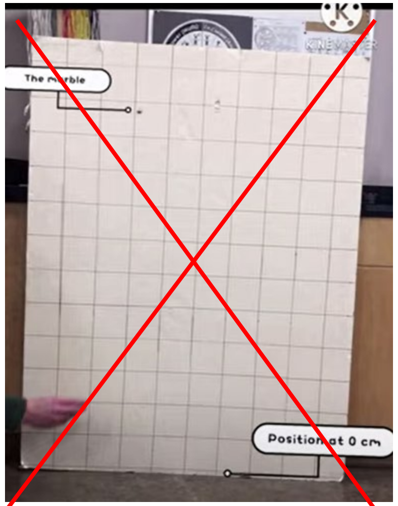




Inelastic collision sensor

Magnetic sensor





Video Analysis of projectile motion

Challenge 2: Determining speed of sound @ 0°C

a) **Instrumentation.** **You may use a smartphone ONLY!** Any other common measuring devices, such as a ruler or a thermometer are NOT allowed! For example, if you say that you carried out an experiment outdoors and the temperature was 0 degrees, you are required to explain how you determined the outside air temperature (and using a weather forecast is not allowed either).

b) **Physical constants.** You can use the values of any fundamental physical constants and material properties, such as the gravitational acceleration, g, thermal expansion of water, density of air, etc. However, you are **NOT allowed to use well known facts** not related to science, such as knowing that the length of a standard Letter page is 11” or that a gallon of milk weighs 8.6 pounds.

c) Physical laws. You **ARE** allowed to use the known dependence of the speed of sound on temperature, and other laws describing how a material property depends on various physical parameters.

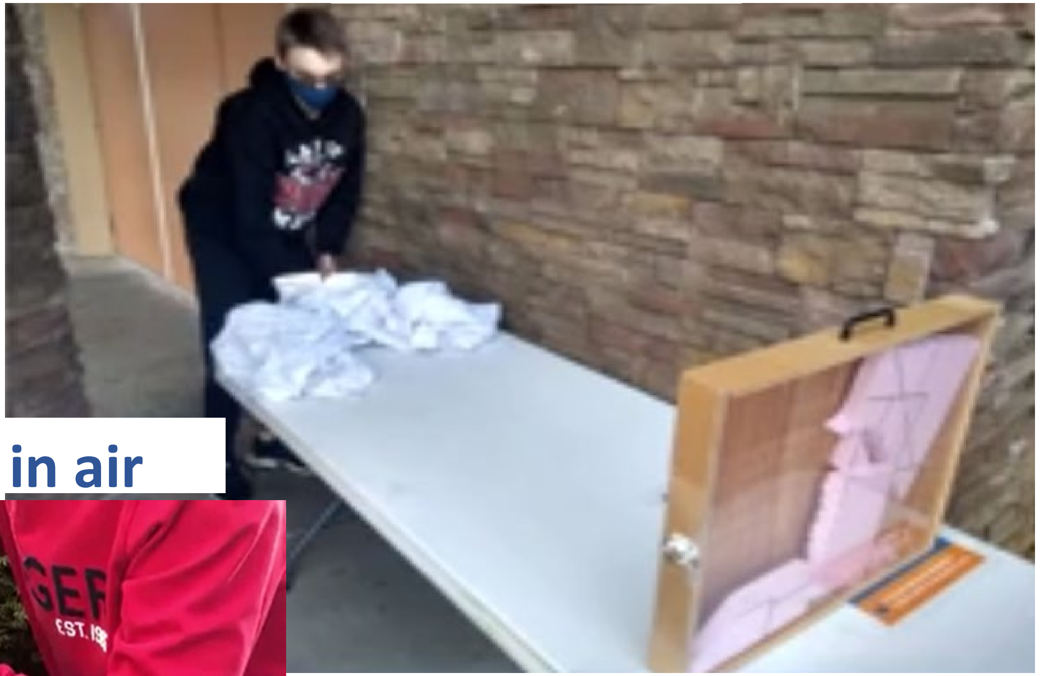
How Many Methods were proposed? How Many Sensors were used??

1. Sound propagation: sound travels from one smartphone to another
2. Echo (“sonar”): sound reflects from a wall back to the phone
3. Doppler effect: frequency of sound changes with the speed of sound
4. Standing waves: resonant frequency depends on the speed of sound
5. Wave Interference: fringe pattern depends on the speed of sound
6. Air pressure: can be translated to the speed of sound

Methods for Measuring Speed of Sound in Air @ 0°C

Propagation of sound

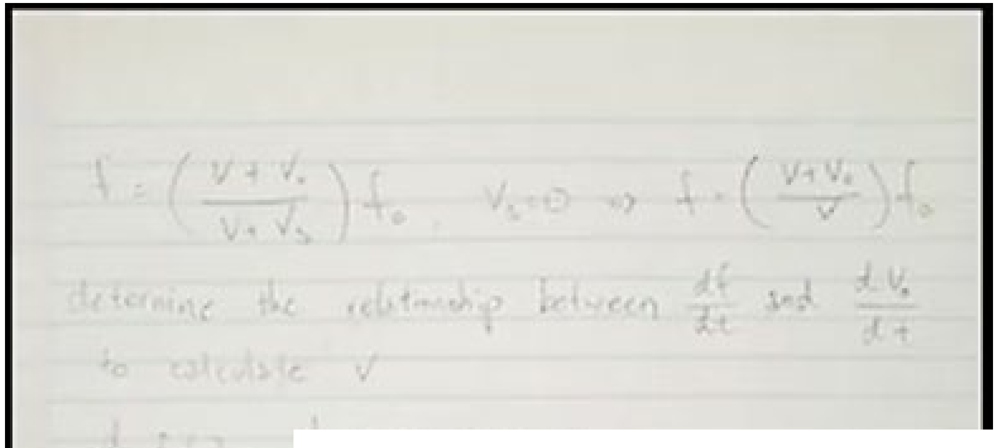
Sound echoes



Standing waves in air column

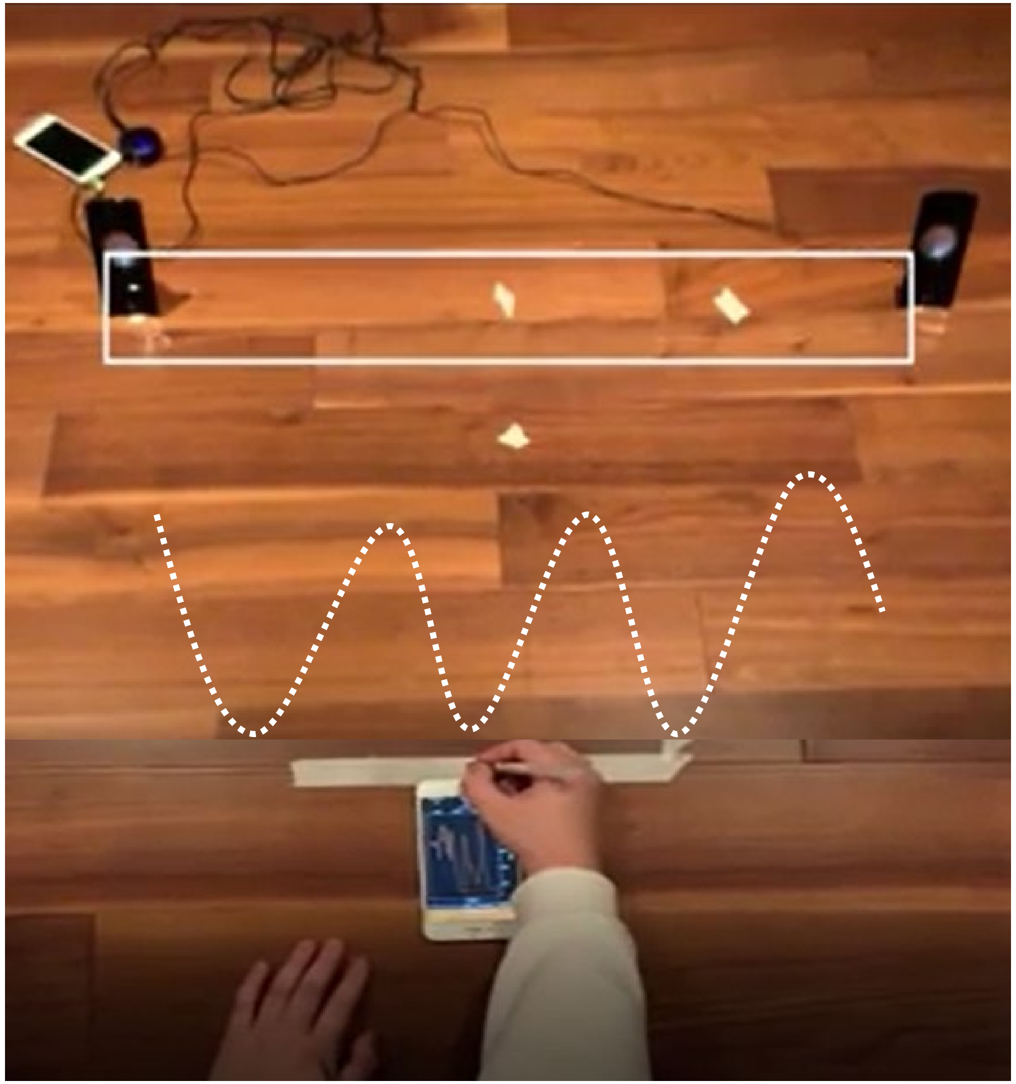
Methods for Measuring Speed of Sound in Air @ 0°C

Doppler effect (calculations)



Doppler effect (experiment)

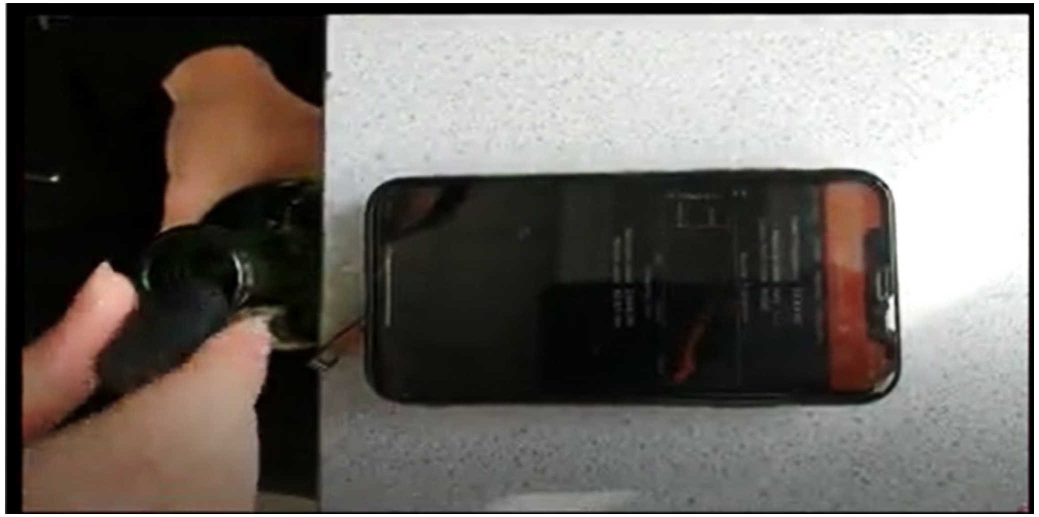
Wave interference



Methods for Measuring Speed of Sound in Air

Kundt's tube with baby powder

Un-corking a wine bottle and measuring the spectrum of sound



The challenge was to measure the speed of sound at zero degrees Celsius. Not everywhere in BC the temperature drops to zero degrees in February. The student had to design a method to measure temperature.

Designing a Thermometer

MEASURE THE MOLES OF GAS

$$HCH_3COO + NaHCO_3 \longrightarrow NaCH_3COO + H_2O + CO_2$$

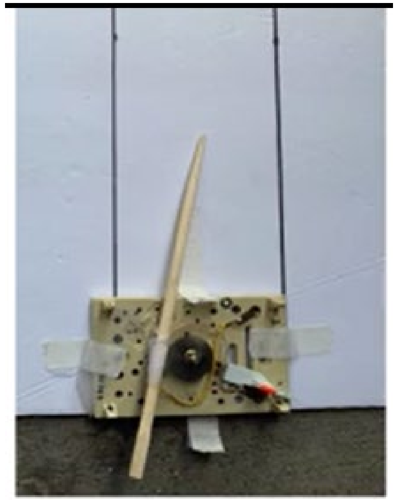
- Pressure of an ideal gas
- Thermal expansion
- Bimetallic strip

Archimedes Principle to find Volume

Submerging a smartphone in ice-cold water

$$\boxed{\begin{aligned} PV &= nRT \\ \therefore T &= PV/nR \end{aligned}}$$

Bimetallic strip



Thermal expansion of a gas for 0º reference

Designing a Thermometer: Creative solution

Dolbear's law: $$T = 50 + \frac{N - 40}{4}$$

where T = temperature (°Fahrenheit)

N = number of chirps per minute

"Theoretical cricket" chirps (-32) times per minute at 0º C

Disclaimer: No crickets were harmed in this experiment

Doing Real Science: Uncertainty Calculations

Random Error	Percentage Error	Systematic Error

$$\text{random error} = \frac{\Delta g}{g\ ave} \times 100\% = \frac{0.9}{9.947} \times 100\% = 9.04\%$$

$$\text{Percentage error} = \frac{|\text{theoretical} - \text{experimental}|}{\text{theoretical}} \times 100\% = \frac{|9.81 - 9.947|}{9.81} \times 100\% = 1.39\%$$

$$\text{systematic error} = ||\text{percentage error} - \text{random error}|| = |1.39 - 9.04| \times 100\% = 7.65\%$$

mean value of g=13.80965181

uncertainty=(18.13492654 - 9.951109361)/(2 √24)
=0.835257343...

Measurement	Causes of Uncertainty	Error Range
Acceleration	- Imprecise start and end on Phyphox recording	$\pm 0.03 m/s^2$
Apparent Weight	- Inaccurate digital scale	$\pm 0.3 N$

$$Error\ a = \frac{0.030}{0.239} = 12.55\% \qquad Error\ F_N = \frac{0.3}{3.8} = 7.89\%$$

$$Total\ Error = 20.44\%$$

SATE_Acceleration_g

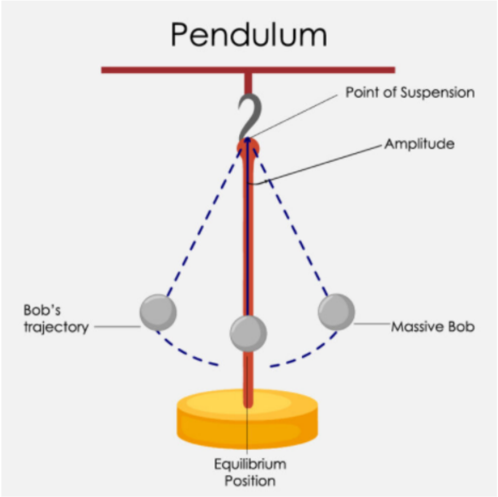
$$g = 8.09\ m/s^2 \pm 1.65\ m/s^2$$

Uncertainty
(m/s²)

0.2779000874

While some teams knew how to calculate uncertainties, others were uncertain about it. While some teams were able to calculate it to an extraordinary number of sig figs…

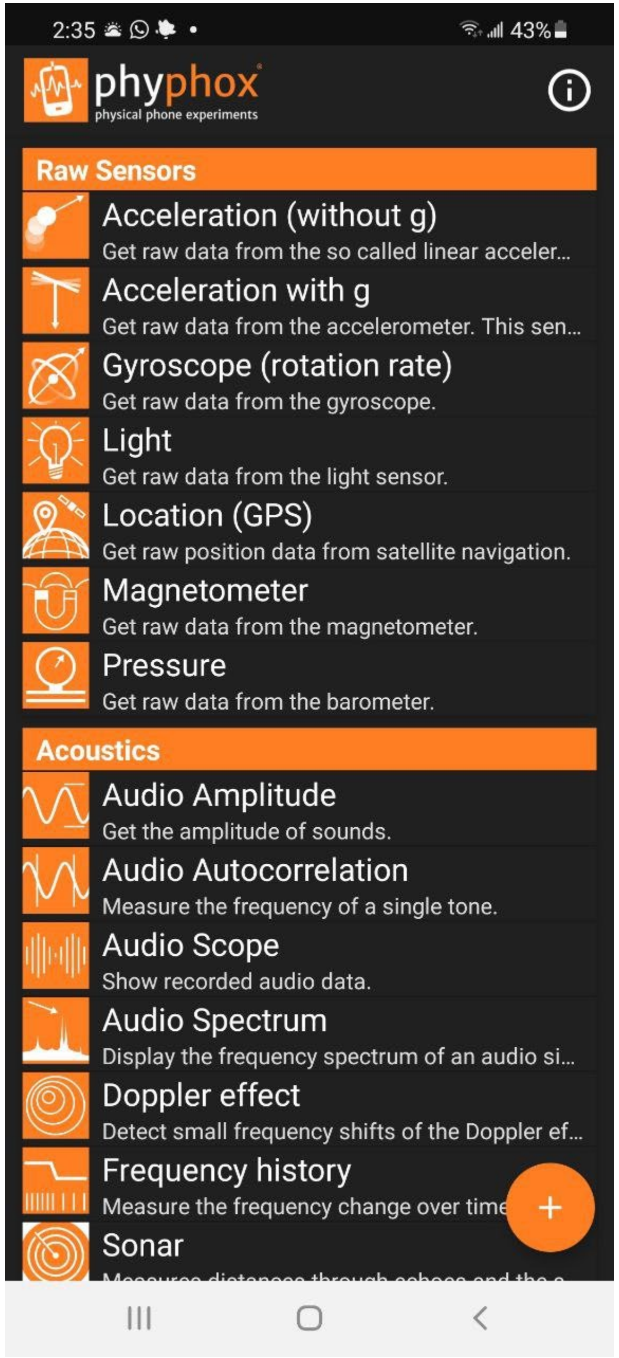
Physicists have accomplished the first most precise and accurate measurement of Newtonian gravitational constant G



The Gravitational Constant denoted by the letter G appears in Sir Isaac Newton's law of universal gravitation which states that any two objects exert a gravitational force of attraction on each other. The value of Newtonian gravitational constant G (also called

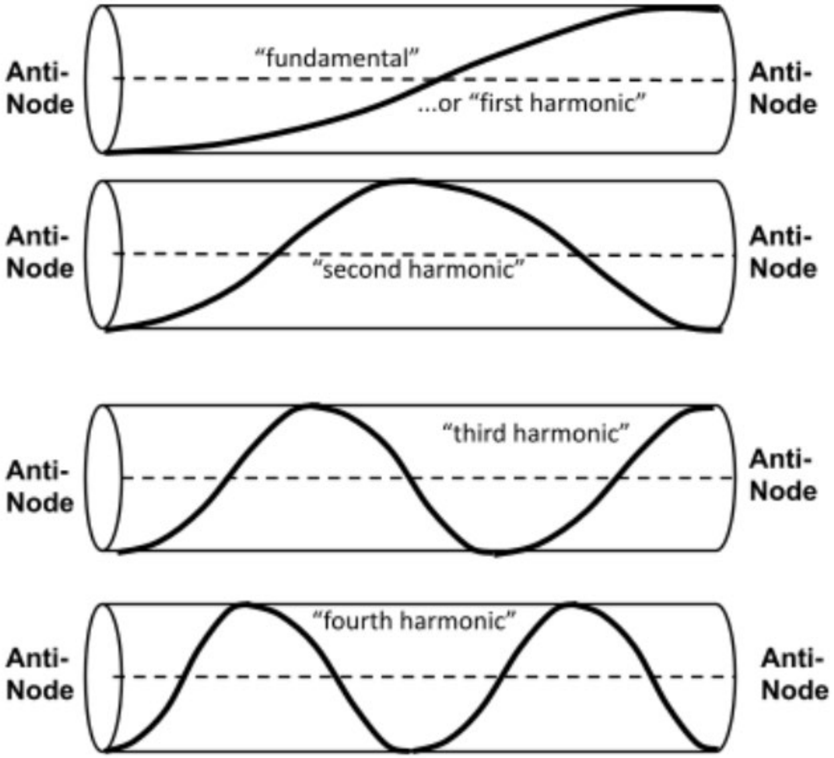
$G = 6.674184 \times 10^{-11}\ m^3kg^{-1}s^{-2}$

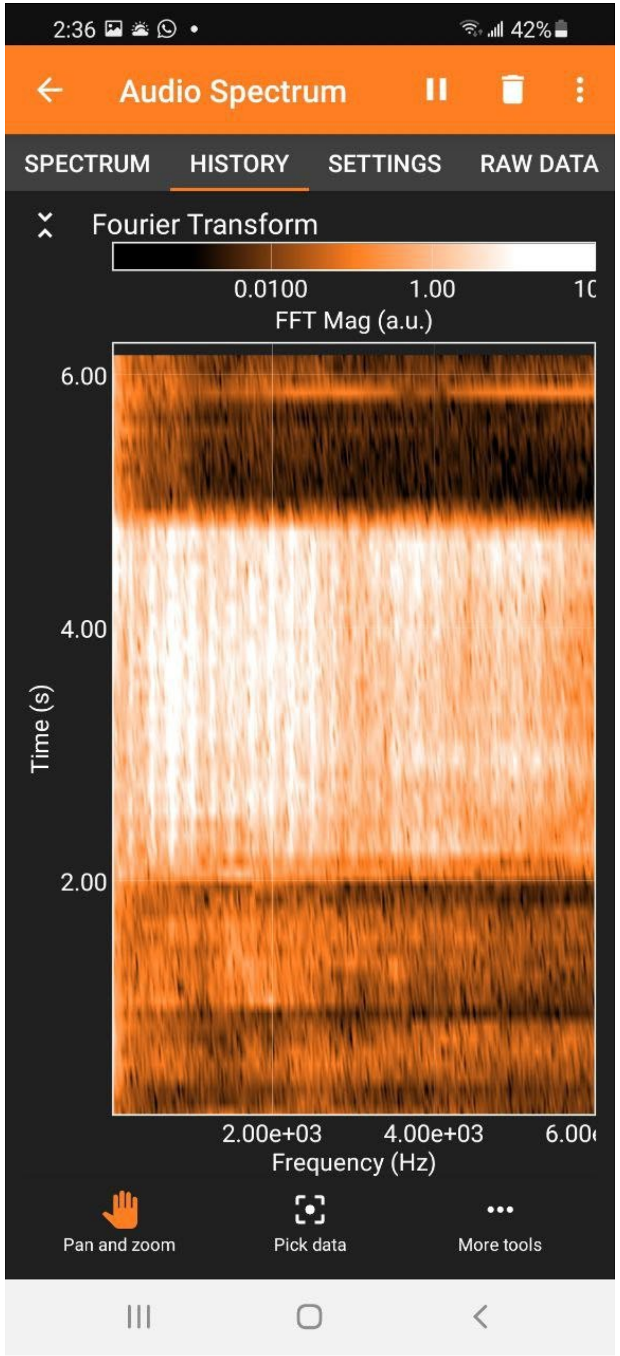
Qing L et al 2018. Measurements of the gravitational constant using two independent methods. *Nature*. 560. https://doi.org/10.1038/s41586-018-0431-5

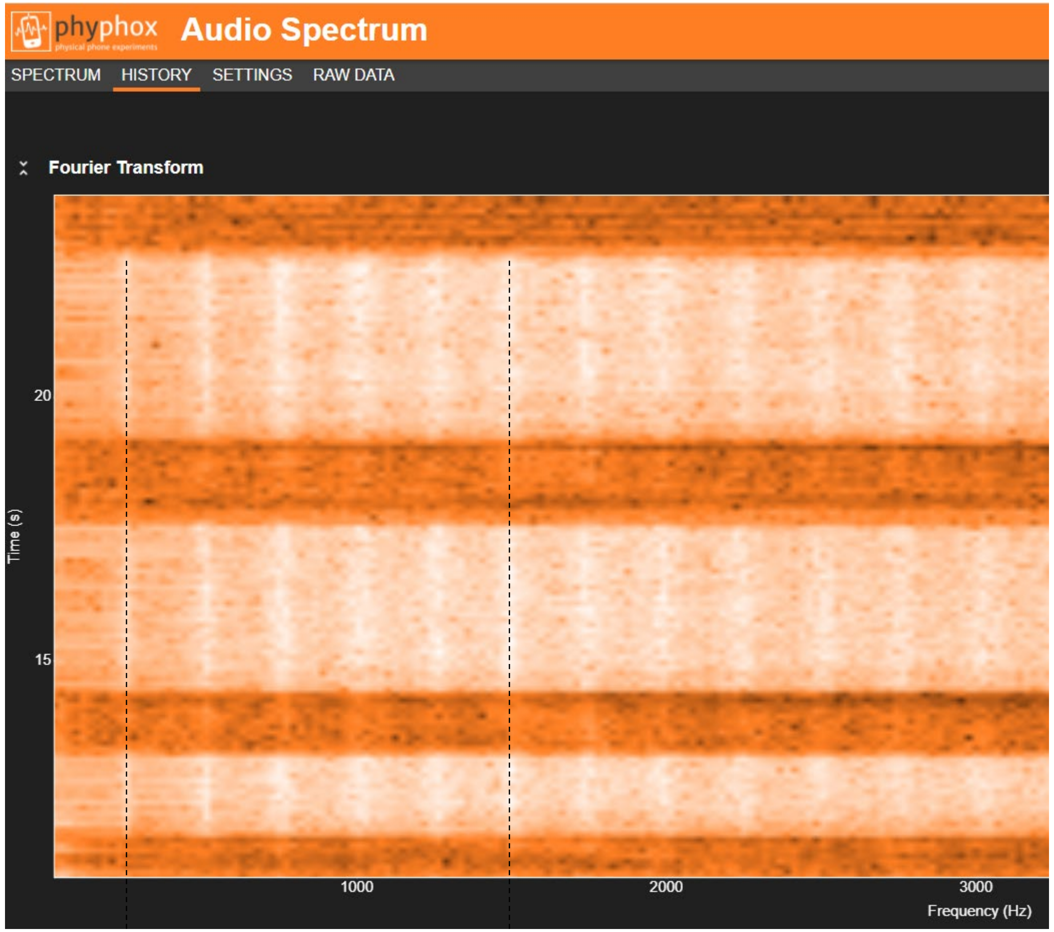


Phyphox Experiment

"Open Open" Standing waves





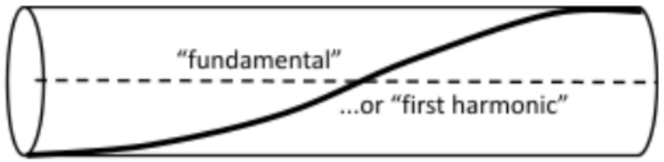


258 Hz 1500 Hz

Fundamental mode:

$$f_1 = \frac{1500-258}{5} = 248.4 \text{ Hz}$$

Fundamental mode:



$$\lambda_1 = 2L = 2 \times 0.67 \text{ m}=1.34 \text{ m}$$

$$v_{\text{wave}} = \lambda \times f$$

$$v_{\text{sound}} = 1.34\text{m} \times 248.4\text{Hz} = \boxed{332.9 \text{ m/s}}$$