Problems for

The USAYPT Invitational Tournament

The Nueva School, San Mateo, California

February 4-5, 2023

Tuning Forks

The tuning fork has been used for frequency calibration since 1711, when it was invented by the great British trumpeter John Shore. For example, in the mid-1800s Leon Foucault used a tuning fork to calibrate the train whistle that drove his spinning mirror at a constant rate, allowing him to measure the speed of light to unprecedented accuracy. Unfortunately the frequency of a tuning fork can change, depending on the temperature or if it has been damaged in some way.

Explore the physics of pristine, and damaged, tuning forks. Test your hypotheses experimentally, until you have a robust model of the workings of a tuning fork that is both qualitatively and quantitatively accurate.

The Speed of Sound

The speed of sound in air is a well-understood simple function of temperature, or so we are to believe. In a recent paper[*], the speed of sound travelling in pipes was measured to travel about 5% slower than in open air. Moreover, time of flight measurements of the velocity of sound have been studied in depth for centuries, and continue to this day as any literature search will reveal.

Investigate, both theoretically and experimentally, the speed of sound in air. Go into as much depth as you can, but make sure to experimentally test any theory that you present.

Investigating Optical Depth

As light passes through a semi-opaque medium, it can be partially absorbed or scattered. Moreover the cross-section for absorption or scattering may be a function of the light's wavelength, producing such effects as blue skies and red sunsets. A recent paper[†] discusses simple laboratory procedures to measure the fractional absorption as a function of dye concentration and path length, however a satisfying explanation of their experimental results was beyond the scope of the paper.

Investigate, both experimentally and theoretically, the transmission of light through a semi-transparent medium. Go into as much depth as you can, but make sure to experimentally test any theory that you present.

The Electrostatic Pendulum

Consider a small ball with mass m and charge q suspended on an insulative string between two large metal plates separated by a distance d with a voltage drop V between them, what is the angle of deflection θ? The solution to this problem is simply $\theta = \arctan\left(\frac{qV}{mgd}\right)$, as one can easily show.

However, in practice, this problem is more complicated than it appears, as it makes many simplistic assumptions. One recent attempt to model this more realistically[‡] involves using the method of images rather than assuming a uniform electric field. Other more realistic models could involve modeling the charge distribution in the ball or the conducting plates. Alternatively, one could consider the mass and charge distribution of the insulating string, or one could consider various oscillations about equilibrium under various conditions.

Investigate, both theoretically and experimentally, the electrostatic pendulum, as well as fascinating extensions of your choosing. Go into as much depth as you can, but make sure to experimentally test any theory that you present.

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[*] Sidebottom, D.L., American Journal of Physics 88, 521 (2020)

[†] Lamelas, F. and Swaminathan, S., American Journal of Physics, 88, 137 (2020)

[‡] Goodman, Fischetti, and Hodges, American Journal of Physics 88, 222 (2020).

Note from the Problem Master

About the Problem Writing Process:

Each year I write, but do not solve, a slate of about a dozen problems on a variety of topics, and send them to the USAYPT President, who reads them over for clarity and makes suggestions. After another revision, the President sends them to the Tournament Director, who in turn sends them to the Board of Directors for ranking and comment. Finally, based on the Board's comments, the Tournament Director chooses four problems that work well together as the official problems for the next year. Therefore, like laws, the problems are as written, and it is up to each team to interpret them from then on.

Each *problem* is designed to be primarily a *research question*, rather than a traditional problem. Nobody already knows the answers, but we do have faith that you, the student, will contribute to our understanding of each question. By presenting your work, and debating the questions with colleagues, you demonstrate that you not only understand the physics involved, but are also an active participant in the scientific community.

Clarification of the term *investigate*:

All the problems require both a *theoretical* and an *experimental* investigation. To investigate something *theoretically*, it means that you must start with clearly stated assumptions and derive, or calculate, from those what you expect to measure. This process is called *deductive reasoning*. To investigate something *experimentally*, it means that you must control variables and test hypotheses. This is the process of *inductive reasoning*. Good science combines inductive and deductive reasoning. Good physics is both theoretically derivable and experimentally testable.

In practice, however, real things are complicated, so we usually start with grossly simplistic assumptions, called *hypotheses*, and use deductive reasoning to build a *toy model* that can predict the results of an experiment. Through the process of inductive reasoning, we compare our toy model to experimental measurements, and evaluate our assumptions. By iterating between deductive and inductive reasoning, we learn which assumptions to keep, and which need to be lifted, until the model's predictions match the experiment.

Academic honesty and sources of information:

When you embark on researching a new topic, often you will refer to a source for information, such as a: book, journal article, patent claim, data archive, or any other source of information. In all of these cases, it is important to be clear about where the information came from, which you do by citing each source in context. You never want to confuse your work with work done by others. Whenever possible, it is good practice to find, read, and cite *primary sources*, which were authored by the scientists who did the actual work. If you took the time to read the literature about a topic, and you make that clear, the jurors will reward you for it.

Understanding where data come from is particularly important in science. For example, it is acceptable to use public scientific data, so long as you analyze them yourselves and clearly cite where they came from. Even fundamental constants are measured (or used to define the SI), and need to be appropriately cited.

Additional hints and resources:

I maintain a blog located at: https://jkeohane.wordpress.com/ that contains advice for both the presenter and the opponent. It also contains two important tutorials about: physical modeling and error analysis. These provide more details and examples of what it means to investigate something theoretically and experimentally respectively.

Good luck working through these problems, and I look forward to seeing you at the next USAYPT invitational physics tournament.

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