USAYPT 2027 Problems
California Institute of Technology, Pasadena, CA
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Friction On a Roll

In basic physics, friction is often idealized as either static or kinetic, and dependent on only a few variables. Real tires exhibit more complex behavior. Explore experimentally and theoretically how rolling and braking friction [1] depend on tire inflation pressure, speed, and surface conditions. Develop a model describing energy losses due to deformation and slip, and analyze how the conditions that minimize rolling friction differ from those that maximize braking performance. Extrapolate your work to automobile tires, and discuss the corresponding implications for fuel efficiency and carbon emissions.

Standing Waves

Explore how the frequency of standing waves on a string depends on the length, tension, linear density, and amplitude. Study an open string experimentally, here meaning a string under tension between two mechanically fixed end points (such as the bridge and nut of a guitar). Then consider a string whose effective vibrating length is shortened, and tension increased, by pressing it against the neck of an instrument with fixed frets (again a guitar provides a common example). Does the increase in tension have a measurable effect on the frequency? Measure the frequencies of open and fretted strings across a musical instrument, and compare them to the intended notes of the tuning system (for example, equal temperament). Consider whether the location of the frets should be adjusted.

Diodes

Diodes can be made from crystals such as galena, oxidized metals, or other semiconducting materials. Construct some [2], investigate their current-voltage characteristics, and study their reproducibility. Develop a model that explains their observed rectifying behavior, and identify the main sources of variability. Compare your results with the performance of modern commercial diodes. Discuss the applications of different types of diode. Consider using your home-made devices in a “foxhole radio.”

Walking Statues

The Moai of Rapa Nui were probably moved by rocking them from side to side, causing them to walk forward without toppling. Investigate, through theory and small-scale experiment, how a tall rigid body can advance through controlled rocking. Define the variables that affect step size, effort, and stability. Propose and test a quantitative model of this process. Determine whether an optimal base geometry exists under your criteria, and relate that to the shape of the actual Moai. See [Lipo *et al.*, *J. Arch. Sci.* **40**, p. 2859 (2013)](#) .

Footnotes and General Notes from the Problem Master

[1] Rolling friction is undesirable, causing energy loss even when rolling on level ground at nearly constant velocity. Braking friction results in desirable deceleration when the rider or driver takes action to reduce their speed. All experiments should be performed under controlled, safe conditions using tires sized for a bicycle or smaller.

[2] A team's "home-made" diode(s) should be based on the materials mentioned in the problem statement, such as naturally-occurring minerals and other inexpensive supplies. Students should also characterize the behavior of some commercial diodes, and explain why the latter (at a cost of pennies) offer such superior performance.

Clarification of the Term Investigate

All problems require both a theoretical and an experimental investigation. The former means to 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, you must control variables and test hypotheses. This is the process of inductive reasoning. Good science combines both types of reasoning. Good physics is both theoretically derivable and experimentally testable.

It is intended that teams conduct their investigations primarily using resources generally available in a well-stocked high school lab. Clever use of inexpensive components is more impressive than accessing equipment from a university or corporation.

Real things are often complicated, so physicists often craft a simplified model that can predict the results of an experiment. We compare our 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 modified. Ideally, the model’s predictions match the experimental results within quantifiable uncertainties. In practice, do not be dismayed if there remains some distance between model predictions and experimental data. You should however strive to explain why.

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, data archive, etc. 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. Whenever possible, you should find, read, and cite primary sources 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. AI can be used as a co-generation tool and brainstorming, not as a source of knowledge and truth.

Good luck working through these problems! I look forward to seeing you at an upcoming tournament.

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