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Schrödinger's Otter – Supplement for Educators

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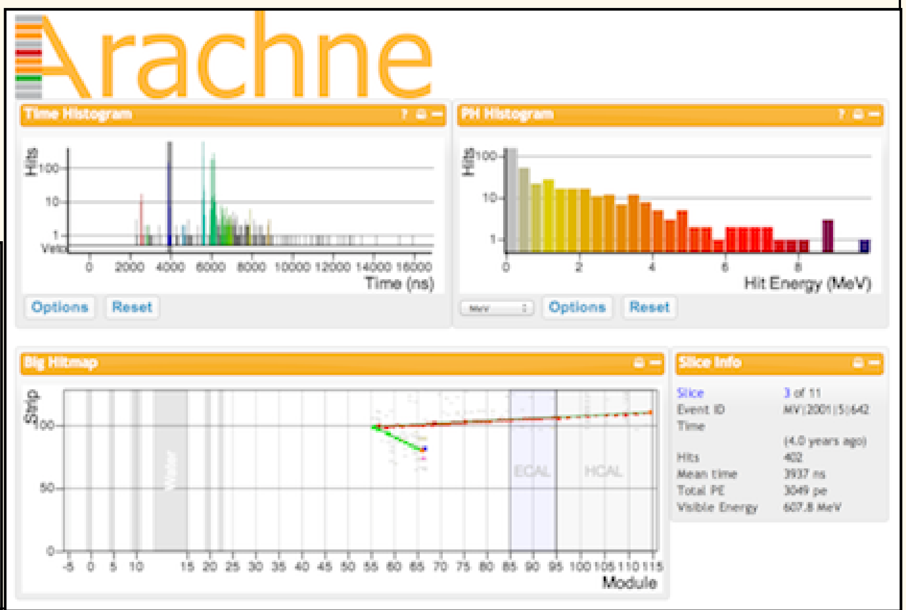
In this Supplement for Educators we describe demonstrations, activities, and teaching methods we have found particularly useful or interesting. We hope you do too! Please send us your comments, and let us know if you have specific topics or teaching issues you'd like to see addressed in future editions.

Learn About Neutrinos

Neutrino experiments have become very important in particle physics, and you can learn about some of this exciting work on your own or in your classroom. The MINERvA neutrino experiment has recently released a website containing instructional materials, exercises, and easy-to-access online tools that let you look at real neutrino data in a running detector to make your own discoveries!

Visit http://neutrino-classroom.org to discover lots of interesting details about how neutrinos are detected, how they are made in beams, and what it looks like when they interact with matter. Exercises are included so that students can use neutrino data to understand momentum conservation, and to measure how unstable particles decay over time.

Materials are included for instructors and students, including presentations, videos, links, and lesson plans that are useable in a high school classroom.



The Arachne web page, showing a 2.1 GeV quasi-elastic ν_μ interaction in the MINERvA detector. A muon goes up and right while a proton goes down and right. If you measure carefully, you will find that the up and down momenta of these particles exactly cancel, indicating that the neutrino came in horizontally from the left.

Buoyancy Puzzles

Set a clear bowl (or beaker) of water on a balance scale, and put it in balance. (You can do this on an electronic scale as well, but it is easier for the whole class to see what happens with a balance scale.) Now, take a mass attached to a string and dunk it into the water. The mass should be something that will sink, i.e., with a density greater than that of water. Hold the string so that the mass is submerged in the water, but not actually touching the bottom of the beaker. The question is: what happens to the scale?

Of course, this should be posed as a question *before* the actual demonstration: describe what you will do, and then

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ask the students to predict what will happen. For maximum effect, encourage them to formulate an answer on their own, and commit to it – for example using flashcards – *before* letting them discuss the problem with their peers.

Many students will predict that nothing will change, but what you will observe is that the side of the balance with the beaker moves *down*. (With an electronic scale, the scale reading will *increase*.) Why? Lead them to the answer through a sequence of questions along the following lines: When the mass is in the water, what are the forces on it? [Answer: weight (down), tension force from string (up) and buoyant force from water (up). As a prelude to this exercise, you can hang the mass from a spring scale and show that the scale reading decreases when the mass is submerged, to demonstrate that there is indeed a buoyant force. This should be done off the scale, of course!] Next, if the water pushes up on the mass, does the mass push on the water? [Answer: Yes, by Newton's 3rd Law.] So there is an extra downward force (from the mass) on this side of the scale, and that pushes it down.

In another classic buoyancy problem, a boat floats in a lake with a rock in it. The rock is thrown overboard, and sinks to the bottom. What happens to the water level on the shore of the lake? Does it rise, fall, or stay the same? This one can be demonstrated with a fish tank (lake) and tupperware bowl (boat). Put a mass in the boat, and mark the water level with a piece of masking tape. Then after posing the question, take the mass out of the boat and let it sink to the bottom of the tank.

The water level will go down. Why? When the rock is in the boat, the boat displaces an amount of water whose weight is equal to the combined weight of boat plus rock. After the rock goes overboard, however, the water displaced is an amount whose weight is equal to the weight of the boat, plus an amount equal to the *volume* of the rock (since it is completely submerged). But this is a *smaller* amount of displaced water, since it is no longer enough to actually hold up the rock. So less water is displaced, and the water level at the shore decreases.

Resonance Demonstrations

An easy demonstration of resonance in oscillating systems involves just a simple pendulum. Demonstrate the natural frequency of this oscillator by letting it swing and noting (or even measuring) the period. Best results are obtained by measuring (with a stopwatch or smartphone) the time for, say, 10 complete cycles, and then dividing by 10. This result can be compared to the theory for a simple pendulum:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where l is the length of the pendulum and $g = 9.8\ \mathrm{m/s^2}$ is the acceleration due to gravity. You can also illustrate the dependence of the period on l; quadruple the pendulum length, and the period should double, etc.

Then you can illustrate resonance by "driving" the pendulum in various ways. Hold (or have the students hold) the end of the string and move your hand slowly back and forth over a short distance (low frequency, small amplitude driving force). The pendulum just moves back and forth with your hand. Next, move your hand rapidly back and forth (high frequency driving force), still with a small amplitude motion. Again, the pendulum does not respond much. It moves back and forth too, but in a fairly chaotic way and without ever developing a large amplitude. In fact, if you move it quickly enough, the pendulum bob will hardly move at all due to its inertia.

Finally, move your hand back and forth at something like the resonant frequency (you can feel this!). Now, even with a small hand motion, the pendulum can get a large amplitude – there is an efficient transfer of energy from your hand to it.

A variant on this requires some setup. Tie about 75 cm of string between two supports (chair backs work fine). Hang

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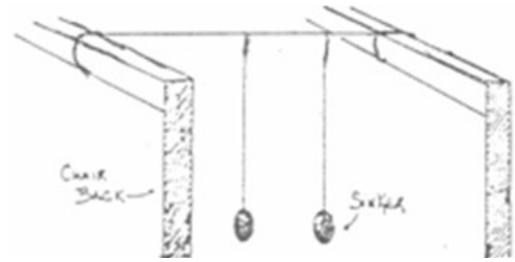
two pendulums of equal length from the horizontal string using pieces of string about 40 cm long. The two pendulums should hang about 20-30 cm apart. Now start one of the pendulums swinging, with the other at rest. The swinging pendulum moves the horizontal string slightly at its natural oscillation frequency. The horizontal string then moves the pivot of the other pendulum very slightly, at the same frequency, just as your hand did with the single pendulum above. Since the second pendulum has the same natural frequency (is "on resonance"), it eventually acquires a large amplitude. Indeed, after some time the energy will transfer almost completely from one pendulum to the other, and then back again.

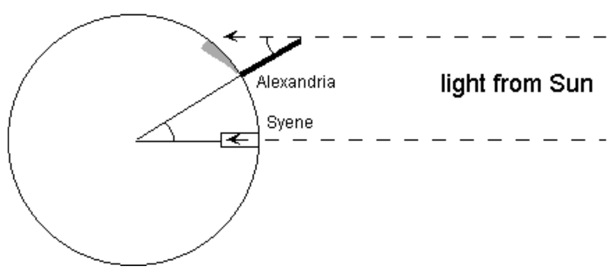


An extension would be to add one or two additional pendulums with different lengths, say one longer than 40 cm and another shorter. Their natural frequencies are thus different (see formula above), and these will not be excited much by the 40 cm "driving" pendulum. Only the equal-length pendulums will be resonant, and the energy will be transferred back and forth between them, with the others doing almost nothing.

Measure the Size of the Earth

Eratosthenes was a Greek scholar in the Egyptian city of Alexandria, the great center of learning of the Mediterranean world in the days of the ascendancy of the Roman Empire. He is credited with having applied simple geometric reasoning to obtain an excellent estimation of the Earth's circumference. With very simple instruments, you and your students can make a similar observation today and measure the Earth's circumference without going all the way around the world.

Eratosthenes had read in a traveler's diary that in the city of Syene, at (local) noon on the summer solstice, sunlight would shine straight down a well and illuminate its bottom. Thus on this day the sun was directly overhead in Syene (see figure). On the same day he determined the sun's angle of elevation in Alexandria, where he lived, by measuring the length of the shadow cast by a stick of known length. Notice that the angle between the stick and the rays from the sun is the same (two parallel lines cut by a transversal) as the angle from Syene to Alexandria at the center of Earth. He then reasoned that this angle is to 360° as the distance from Syene to Alexandria is to the circumference of Earth. The distance between the cities was known to Egyptian surveyors, so this simple proportionality allowed the circumference of Earth to be determined quite accurately, to within about 15% of the modern value.



<u>What You Will Need</u>: A stick at least one foot long which can be driven into the ground (or a "plumber's helper"); a measuring device (tape measure or ruler); a carpenter's level; possibly a flat board or piece of cardboard; a watch and a way to get somewhere else (car, bus, plane, whatever).

<u>Time Required</u>: Two days when you can make observations of the sun's altitude between 11:15 AM to 12:45 PM Eastern Standard Time (12:15 PM to 1:45 PM Eastern Daylight Time). One of these days should be at your location and the other day at least 150 miles north or south of your location. You need not go exactly due north or south, but the experimental results are easier to interpret if you don't wander too far east or west. If necessary, the observations can be made several days apart, but this will require some corrections, so it will be easier to deal with your data if you can do this on consecutive days.

<u>What to Do</u>: Drive your stick (gnomon) into a level, smooth (ideally no grass) piece of ground, making it as close to vertical as possible. If the ground is not level, use a board or piece of cardboard to cast the shadow on. Use the carpenter's level to make sure the board is level and the gnomon vertical. Beginning about 11:15 AM EST (12:15 PM EDT), carefully measure and record the length of the stick's shadow every 10 minutes. Continue this until you are certain that you have observed the shadow at its shortest. Before you remove the stick from the ground, carefully measure the length of that part of the stick above ground. This procedure should be exactly repeated at the second site.

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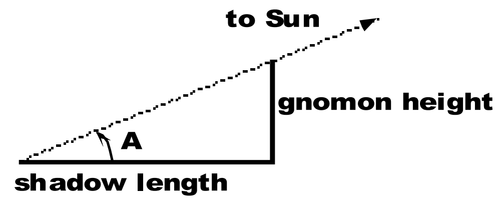
Convert your measurements of the shadow's shortest length and the gnomon's height to an altitude of the Sun at local noon as follows. First, compute the ratio

$$\frac{\text{length of stick}}{\text{length of shadow}}$$



How shadow length and gnomon height determine the altitude A of the Sun

for your two observation points. Next, use your calculator to compute the arc tangent (inv tan or $\tan^{-1}$) of the ratio. Your result is the elevation of the Sun. If the Sun has changed position in the sky significantly between your observations, you will have to correct for this by determining the declination of the Sun on these two dates. If you observe on consecutive days, this shouldn't be a big problem.

Measure the difference between the two elevations you measured... this is how much higher (or lower) the Sun is in the sky at your new location. If you know the distance you travelled North or South, then you can set up a proportionality: The distance you travelled over the Earth's circumference is the same as the angular difference over 360 degrees. Since you know everything except for the circumference, you can solve for that.

<u>Questions for Discussion</u>:

(1) What are some sources of uncertainty in this measurement? Include numerical estimates of each and how these estimates affect your result. How might each source of error could be reduced?

(2) You may have noticed that the noon shadow was shorter depending upon how far south you were for each of your measurements. How far south would you have to go on June 21 (the summer solstice) in order to make the noon shadow completely disappear? A diagram may be helpful here.

(3) How could you prove that this effect is really due to the curvature of the Earth rather than the Sun just being a short distance away from a flat Earth? (This is not easy!)