

## THE MISSING ENERGY MYSTERY: POPCORN & NEUTRINOS

(Thanks to Steve Stevenoski and Eric Muhs, United States)

### Lesson at a glance



By measuring popcorn before and after popping, students will investigate the concepts behind beta decay, neutrinos and the South Pole IceCube Project that is searching for neutrino sources in the universe.

### Background

The first law of thermodynamics, also known as the law of conservation of energy, states that energy can neither be created nor destroyed. This lab models a reaction in which there was an apparent loss of energy, which led to the discovery of a particle called a neutrino.

In 1931, study of nuclear reactions showed that when a neutron changed into a proton in a process called 'beta decay', it released an electron which called a beta particle. However, careful measurements showed that the proton and the beta particle together had slightly less energy than the original neutron.

This led Wolfgang Pauli, an Austrian theoretical physicist, to propose that another particle was released during beta decay, which carried the missing energy. Since the particle would have to have a neutral charge and small mass, it was called a neutrino (which means 'little neutral one'). It wasn't until 1956 that scientists first experimentally detected a particle fitting these characteristics.

The IceCube Project in Antarctica is looking for high-energy neutrinos that originate from specific sources deep in space. Since neutrinos have no charge, they are not deflected by magnetic fields and travel in a straight line. Consequently, we can tell where a neutrino is coming from by its path and, in this way, learn about the sources that are producing high-energy particles.

Neutrinos cannot be seen directly, but their paths can be detected by their interaction with other particles. When muon neutrinos (there are two other types--- an electron neutrino and a tau neutrino) interact with nucleons (protons or neutrons), the incident neutrino is destroyed and a muon is produced. The muon is a charged particle which continues in the same direction as the incident neutrino. The muon lasts only 2.2 microseconds before it decays. It tugs on the electrons inside atoms it passes via the electromagnetic force. After the muon passes, the electrons return to their prior state, releasing photons and resulting in a faint blue light known as Cherenkov radiation.

The IceCube experiment is set up at the South Pole because the ice is transparent enough for the faint blue light to be seen by special instruments called photodetectors, which amplify the signal so it can be recorded in digital form by computers. Holes are drilled deep in the ice by a hot water drill and a series of photomultiplier tubes are carefully lowered into the ice between depths of 1.5 and 2.5 kilometres. The deep ice is essentially bubble free and very clean, so the light can travel up to a couple hundred metres before being adsorbed and up to 50 metres without scattering.

The big challenge is make sure the muon is produced by a neutrino rather than from the much more numerous cosmic rays. Muons from the Northern Hemisphere decay before they can reach the detector at the South Pole. Neutrinos, however, can travel all the way through the Earth because they rarely react with other particles. So, the path of the muon must be reconstructed using the time when light was detected at each module. If it came from within the Earth (from the Northern Hemisphere), we know it must be from a neutrino. If it came from the atmosphere and was heading toward the Earth's interior, it was most likely from a cosmic ray. For every one neutrino muon, there are about 10 million cosmic ray muons!



## *Time*

**Preparation:** ~1 hour

**Class time:** two 50-minute class periods

## *Materials*

*(per class)*

2 kinds of popcorn (such as two different brands or kinds)

*(per group of students)*

popcorn popper (Air poppers are easiest to use because they do not need oil.)

popcorn (~40-100 grams per team, depending upon the popcorn popper)

container for kernels and container for popped corn

data recording sheet, student notebook, or computers with spreadsheet software

balance (sensitive enough to measure to at least 0.1 g, and preferably to 0.01 g)

## *Advance Preparation*

Before the lab:

1. Get the popcorn, the popcorn poppers (poppers may be either purchased – e.g., at thrift stores, or brought in advance by the students), and the balances.
2. Try the experiment in advance to become familiar with it.
3. Test the circuits to make sure there is enough wattage for all popcorn poppers simultaneously.

## *Activity Directions*

1. Ask the students if they think popcorn weighs the same, more, or less after it is popped. Have them make a prediction and explain their reasoning.
2. Ask them how they could test their predictions. What equipment will they need? How will they control the variables?
3. Remind them of the safety precautions and discuss the importance of accurate data collection and recording. (Don't eat the popcorn before measurements are complete!)
4. Review the proper use of the balances and the popcorn poppers, then divide the students into teams and give each team 40-100 grams of popcorn (depending on the type of popper being used), and a balance. Give half of the teams one kind of popcorn, and half the other kind.
5. While the students are doing the experiment, circulate among the teams and ask them guiding questions such as:

Why not pop just one kernel?

According to the data, is your hypothesis correct? Did the mass of the kernels increase, decrease, or stay the same?

What variables are there in this experiment?

What difficulties did you encounter? How were you able to overcome them?

6. After all the groups are done with the experiment, bring the whole class together and discuss the results.
7. Tell the students about the discovery of neutrinos and ask them how the experiment they just conducted relates to this discovery.
8. Discuss how neutrinos are being used to 'map' part of the universe and why Antarctic is the ideal place for this kind of study.

## **Caution**

If you are going to allow the students to eat the popcorn, take special precautions to wash lab tables, have clean containers, wash hands, and stress that students not eat the popcorn until after all the measurements are taken.

## Discussion

1. How many teams found a gain in mass? A loss? The same mass?
2. Why might teams get different results? (*Get beyond 'bad measurements' – some possibilities are: Variation in popcorn? Variation in popcorn popper temperature or speed of popping? Variation in what group decided to count, e.g. what to do in terms of data and calculations with unpopped or partially popped corn.*)
3. What variables affected the results of this experiment? Would it matter if new or old corn was used? Why?
4. According to the Law of Conservation of Mass, can mass be lost? If mass was lost, where did it go? (*The students should figure out that the 'lost' mass is due to the water contained in the kernel escaping as steam.*)
5. How is this experiment an analogy for the beta decay process?
6. It took scientists a long time between proposing the neutrino as a hypothetical particle and collecting evidence which proved its existence. Are there other outstanding open questions in physics or science, where a theoretical answer is in place, but the evidence needed to prove the theory is lacking?

## Extensions/Adaptations

1. Use a video camera to record individual corns popping (probably from a flat pan, beware of spattering oil. Use a motion analysis software (LoggerPro by Vernier Software) to make quantitative measurements of energy. Many individual energy estimates can be combined to produce an energy spectrum for the popped corn. This work should produce a data set suitable for statistical analysis.
2. Calculate the initial pressure inside the kernel, based on available quantitative measurements and reasonable quantitative assumptions.
3. Develop a method to collect, condense, and weigh the water vapour released by the popping corn. Re-examine the earlier conclusions about conservation of mass vs. mass loss with this new information.
4. Prepare popcorn kernels at different states of dehydration (using different times in a drying chamber or low oven) and compare popping energy spectra.
5. Invent a way to damage the seed coats of the popcorn, and examine the effect of this damage on popping. Challenges include be able to quantify both the extent of the damage, and the effect on popping.
6. Use an infrared camera to collect pictures of the popped kernels. What new kinds of analysis are possible with this new way to look at this phenomenon?

## Links

IceCube Neutrino detector main website: <http://icecube.wisc.edu/>

IceCube Education & Outreach site: <http://www.icecube.wisc.edu/outreach/>

YouTube Movie about the detector: <http://www.youtube.com/watch?v=nx5wphtHBZQ>

Popcorn popping in super-slow motion:  
<http://www.youtube.com/watch?v=CXDstfD9eJ0>

An IceCube light sensor that is being readied for deployment at the South Pole. IceCube collaboration Photograph

