Astronomy in the Ice

Lab Title: The Mystery of the Missing Mass -- Popcorn & Neutrinos

Overview --Abstract of the activity

1. Students will mass popcorn before and after popping. Is the Law of Conservation of Mass violated?
2. Students will learn about beta decay, neutrinos, and the South Pole Amanda Project looking for neutrinos. (Amanda stands for Antarctic Muon and Neutrino Detector Array.)

Rationale

This lab models a reaction in which there was an apparent loss of mass which led to the proposal of the neutrino in 1931 by Wolfgang Pauli. In beta decay experiments, scientists found an apparent loss of mass. Either the Law of Conservation of Mass was not true in beta decay, or there was another unknown, and, at that time, undetectable particle, which was released and ultimately responsible for the "loss" of mass.

In the process of doing this lab, students will see the value of accurate measurements and the use of the scientific method when confronted with an apparent contradiction in basic scientific laws.

Grade Level/Discipline

With adaptation, this lab can be used in grades 9-12, in physical science, chemistry, physics or integrated science classes.

Objectives -- Skills

Skills the students will use or learn include:

Using a balance.
Recording data.
Calculating an average.
Using significant figures.
Using the tare on the balance.

Advanced students could also use this lab to develop additional concepts:

Calculate the kinetic and potential energy of popcorn trajectory.
Calculate the initial velocity of popcorn kernel.
Calculate the initial pressure inside the kernel.
Calculate the average mass loss and report a standard deviation.

National Standards

Wisconsin standards applicable are similar to National Standards:

A.12.4	C. 12.6	D. 12.3	D. 12.12
B 12.4	D. 12.1	D. 12.7	E. 12.1
B. 12.4	D. 12.2	D. 12.8	

<u>Teacher Preparation for Activity</u>

Materials List

<u>Materials need for each lab team</u>:

* Popcorn popper. (Note: The kind of popcorn popper may matter. For the basic experiment, air poppers are easier to use because there is not a complication of weighing and keeping track of the oil, and cleaning up the oil. To get enough popcorn poppers, it may be possible to buy them at garage sales or thrift stores, or have students bring them in.
* Popcorn (about 40-100 grams per team, depending upon the popcorn popper.
* Container for kernels and container for popped corn. (Note: Teacher needs to make a decision whether students will be allowed to eat the popcorn. If so, special precautions need to be taken to wash lab tables, have clean containers, wash hands, and stress that students not eat the popcorn until after the measurements are all taken.)
* Check the wattage of the popcorn poppers and the number of circuits available in room so as to not overload the circuits.
* Advanced students will need a high temperature thermometer (to 300° F) if they are going to determine boiling temperature of oil if they are working with Ideal Gas Laws.)
* Data recording sheet or student notebook.

<u>Materials needed by the entire class</u>:

* Two kinds of popcorn (such as two different brands or kinds; or new and "old.)"
* Balances. Ideally one per team. Ideally electronic, but triple beam will work. Ideally you will be able to measure to the 0.01 g, but 0.1 g will be enough for students to see a loss of mass.

<u>Pre-activity set-up</u>

1. Before the lab, the teacher should have the materials ready:
   Get the popcorn.
   Have the popcorn poppers on hand, either purchased or brought in in advance by the students.
   Have the clean containers, and materials to wash tables and hands if the students are going to eat the popcorn.
   Have the balances ready to go.
2. Try the lab in advance to become familiar with it.
3. Try out the circuits to make sure have enough power for all popcorn poppers simultaneously.

<u>Time Frame – (estimated two 50 minute periods, or one 100 minute period)</u>

* Introduction of activity (see below) – estimated 15-20
* The lab itself including – estimated 20 minutes
  Massing the unpopped kernels. Popping Massing popped kernels.
* Calculations by team – estimated 20 minutes
* Questions to be answered by the team – estimated 10 minutes
* Class discussion of what happened, why, Law of Conservation of Mass – est. 10-15 min.
* New information from teacher: why neutrinos were proposed & Amanda Project – 20 min
* Follow-up questions by students – estimated 15 minutes

Teaching Sequence

Engagement and Exploration (Student Inquiry Activity)
Introduction before lab– estimated 15-20 minutes (longer if students make own data table)

- Question to be addressed: Does popcorn weigh the same, more, or less after it is popped? Students make a prediction and explain their reasoning. How could you find out? Some ideas that might be introduced into the discussion as hypotheses are:
  - The popcorn might increase mass, since popcorn does get bigger when popped.
  - The popcorn might get smaller, since popcorn is less fluffier. Jar of popcorn seems heavy compared to a handful or even bag or popcorn.
  - The popcorn might stay the same, due to Law of Conservation of Mass.)

- What to do to weigh popcorn, use of balance and popcorn popper

- Importance of accurate data collection and recording. (Don't eat popcorn before measurements are complete.)

- Safety precautions. (Don't get burned. If eating is allowed, what cleanliness measures must be taken.)

Explanation (Discussion questions for team to answer during the lab)

1. Why did we not pop just one kernel?
2. According to the data, is your hypothesis correct? Did the mass of the kernels increase, decrease, or stay the same?
3. If teams get different results from your team, why might that be? What variables are there in this experiment? (Get beyond "bad measurements." Ideas for teacher: 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.
4. What were the difficulties you encountered out this lab? Were you able to overcome them, if so, how?

Explanation (Discussion questions with whole class after the lab.

1. How many teams found a gain in mass? A loss? The same mass?
2. What variables affect the results of this experiment? In other words, why would different teams measure different percentages of mass change? Would it matter if new or old corn was used? Why?
3. 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.)

<u>Teacher introduces new information and concepts</u>:
In 1931 scientists had a real puzzle on their hands. Study of nuclear reactions showed that when a neutron changed into a proton it released an electron which was called a beta particle. However, careful measurements showed that the proton and the beta particle did not have as much energy as the original neutron. This led Wofgang Pauli to conclude that either the Law of Conservation of Energy did not always apply, or something else was going on.

Pauli proposed that another particle was released during beta decay which carried the missing energy. (This is analogous to proposing water vapor as the "missing mass" in the popcorn experiment.) Since the particle would have to have a neutral charge, and small mass, he called it a neutrino (which means little neutral one). It was very exciting twenty-eight years later, in 1959, when in Clyde Cowan and Fred Reines experimentally detected a particle fitting the expected characteristics of the neutrino.

Explain beta decay. Beta decay occurs in the nucleus when a neutron changes to a proton, releasing a beta particle (electron) and a neutrino. There are various causes of beta decay, such as gamma rays, cosmic rays from outer space, and unstable isotopes of some elements (for example carbon 14 to nitrogen 14; potassium 40 to calcium 40).

The connection to polar research. The Amanda Project is looking for neutrinos that originate from specific sources deep in space. It is not known where neutrinos from space are coming from. Since neutrinos do not have a charge, they are not deflected by magnetic fields and travel in a straight line. Consequently, if the path of a neutrino can be determined, it may be possible to know where it is coming from.

Neutrinos can not be seen directly, but their path can be detected by their interaction with other particles. When neutrinos 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, but before it decays it has a polarizing effect on atoms it passes. The muon 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. This faint blue light is known as Cherenkov radiation. This Cherenkov radiation can be detected by special instruments which contain photomultiplier tubes. The photomultiplier tubes receive the photon pulse and amplify the signal so it can be recorded in digital form by computers for later analysis.

The Amanda experiment is set up at the South Pole because of the transparency and density of the ice. Transparency is necessary so the light can be seen by the photodetectors. Holes are drilled deep in the ice by a hot water drill. Then a series of photomultiplier tubes are carefully lowered into the ice as deep as 2 ½ kilometers. The photomultiplier instruments have to be put deep into the ice so that no light from the surface affects them.

Another problem to be overcome in this research is to filter out the muons that might come from the sun or other sources. What is of interest is muons that come from neutrinos. Muons that come from the sun or other sources would get stopped by the earth or thick ice. The earth or thick ice remove muons which would have occurred from the sun or other sources. However, neutrinos can travel all the way through the earth!! (Neutrinos can travel through the earth because they rarely react with other particles.) So, the detectors at the South Pole are faced to the north to use the earth as a filter. If the photomultiplier tubes detect Cherenkov radiation, it probably came from muons resulting from neutrinos which came through the earth.

Exchange (Students Draw Conclusions)

1. How does this lab model the problem posed by the apparent loss of mass in observations of reactions in which beta decay occurs.
2. Can you think of other analogies or models for an apparent loss of mass in a reaction?
3. Where did the "lost" mass go when the popcorn was popped?
4. What particle in beta decay does the steam represent?
5. What are some of properties of neutrinos which made them difficult to detect? (Chargeless which makes them react with other particles very rarely (small cross-section), seemingly massless.)
6. What is the goal of the Amanda project and how does it work?

Evaluation (Assessing Student Performance)

How can the teacher assess student outcome? Possibly include rubrics, other suggestions for evaluating student knowledge.

Lab Report

Answering questions asked in several sections above.

Test

Poster, diagram, or concept map that shows the relationships. See attached.

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Inspired by lesson presented in Astronomy in the Ice class and input from other teacher participants.

Background

What do your colleagues need to know about the science behind this activity?

The teacher needs to understand:

Law of Conservation of Energy.

Origin of proposal about neutrinos.

Beta decay

Variables in a lab.

How the Amanda Project works and why.

Explanation with links to original research (historical and current) – See attached.

Possible misconceptions

Relationship of mass and energy

Amanda detects neutrinos directly. (Amanda actually detects photons created by passage of muon created by the neutrino.)

Resources – See atttached

References, websites

Student Reproducible Masters – See Concept Map Assessment attached

Concept Map Assessment

Construct a concept map showing the relationships of the following terms, concepts, or events related to neutrinos and neutrino research.

Resource for learning about Concept Maps is the Field-tested Learning Assessment Guide (FLAG) that is part of the National Institute for Science Education's Innovations in Science, Technology, Engineering and Mathematics web site: http://www.wcer.wisc.edu/nise/cl1/flag. Once there, be sure click to into the Classroom Assessment Techniques (CATs) section, and select the Concept Map CAT.

The FLAG site is highly recommended because it is designed to introduce new assessment methods to science faculty who teach introductory college courses. It is very "hands-on" in its design and includes examples. The FLAG is funded by the National Science Foundation and is a dynamic site – your tested examples of concept maps from your courses would be a welcome addition.

Wolfgang Pauli
Clyde Cowen and Fred Reines
Law of Conservation of Energy
Neutrino
Beta Decay
Neutron
Proton
Electron
Gamma Rays
Cosmic Rays
Muon
Electromagnetic force
Photons
Blue light
Cherenkov radiation
Photomultiplier
Ice
South Pole
Deep holes
Earth as filter
Massless
Chargeless
Path of neutrinos
Deep space
Computer analysis