Title: The Mysteries of Deep Cold: Inquiry Activities with Liquid Nitrogen

NSF GK-12 Fellow: Sierra Love Stowell (Boulder, CO)

Grade Level: 8th

Type of Lesson: STEM, Physical Science

Objective: Students will understand the relationship between temperature, pressure and volume by bringing common objects to extremely cold temperature using liquid nitrogen. Students will also explore energy transfer and loss and discuss states of matter and how they are affected by the relationship between temperature, pressure and volume.

Standards:
BVSD Science Content Standard: Students know and understand common properties, forms, and changes in matter and energy (Science Standard 2).

BVSD Enduring Understandings: Science involves a particular way of knowing that includes relying on empirical evidence, logical arguments, skepticism, and peer review. ... Matter has properties related to its structure that can be measured and used to identify, classify and describe substances or objects. Matter has mass and takes up space. Energy can occur in different forms and it is necessary to cause change or do work.

BVSD Essential Questions: How do people use the process of science to investigate questions about the natural world? What is matter? How does the structure of matter explain its properties and the changes that it undergoes?

BVSD Essential Learnings: <u>PSY5:</u> Uses the particulate model of matter to explain the physical properties of solids, liquids, gases, and plasma state and their changes.

a. Accurately describes the particulate model for solid, liquid, gas and plasma including the arrangement, motion and energy of the particles.
b. Using the kinetic molecular theory, predicts how changes in temperature affect the behavior of particle of matter.
c. Uses the particulate model to explain the changes in energy and molecular motion that take place in phase transitions among solids, liquids and gases.

Background Information:

Nitrogen is a chemical element (N) that is a colorless, odorless, tasteless, and mostly **inert** (not chemically reactive). It is a **diatomic** (molecule made of two atoms) gas at

standard conditions (20^oC, 1 atm) which makes up 78% of the Earth's atmosphere and is important in industrial chemistry (it is found in ammonia, nitric acid, organic nitrates used for propellants, fertilizers, explosives, and cyanides). It is also central to life on earth: it is a central element in amino acids, proteins, DNA and RNA, as well as neurotransmitters and alkaloids (chemical signals). It was discovered by the Scottish physician Daniel Rutherford in 1772.

Liquid nitrogen (LN_2) is nitrogen in a liquid state (it has to be at a very low temperature to get to a liquid state). It is made industrially by **fractional distillation** of liquid atmospheric air. [Fractional distillation is the separation of a mixture into its parts (for example, separating chemical compounds by their boiling points by heating them to a temperature at which several parts of the compound will evaporate).] LN_2 is a colorless, clear liquid with a density of 0.807 g/mL at its boiling point. At atmospheric pressure, LN_2 boils at 77K, -196^oC, -321^oF; it is called **cryogenic** because it can cause living tissues to freeze rapidly on contact (which can lead to **frostbite**). LN_2 is stored in insulated vacuum flasks which maintain 77K and keep the liquid at a slow boil, recycling the N_2 gas. LN_2 can be converted to a solid by putting it in a vacuum chamber with a rotary pump; it will freeze at 63K, -210^oC, -346^oF. LN_2 does not make a very good coolant because it immediately boils on contact with a warmer object, enveloping the object in insulating nitrogen gas (a demonstration of the Leidenfrost effect). Nitrogen was first liquefied by Polish physicists Zygmunt Wróblewski and Karol Olszewski in 1883.

Objects and substances placed in liquid nitrogen freeze because of **conduction**, a form of heat transfer. In solids, conduction happens because of the vibrations of molecules in their lattice and the energy transported by free electrons. In gases and liquids, conduction happens because of the collisions and diffusion of molecules during their random motion.

Resources:

Lesson Vocabulary: (introduced prior to the lesson and reinforced through the lesson)
Condensation- the process by which a gas or vapor changes to a liquid
Energy- the capacity of system to do work
Gas- the state of matter distinguished from solid and liquid states by relatively low density and viscosity, relatively great expansion and contraction with changes in pressure and temperature, the ability to diffuse readily, and the spontaneous tendency to become uniformly distributed throughout any container
Heat- a form of energy associated with the motion of atoms or molecules and capable of being transmitted through solid and fluid media by conduction, through fluid media by convection and through empty space by radiation
Liquid- the state of matter in which a substance exhibits a characteristic readiness to flow, little or no tendency to disperse, and relatively high incompressibility
Matter- physical substance or material in general which occupies space and possesses mass

Particulate model- model of matter describing all matter as composed of particles with space in between them; the relative distance between particles and the motion of the particles can be used to explain the phases of matter
Phase change- a change from one state to another without a change in chemical composition
Temperature- a measure of the average kinetic energy of the particles in a sample of matter, expressed in terms of units or degrees designated on a standard scale

Materials Required:
Liquid nitrogen, dewer (these can be tricky to obtain; try the University of Colorado, http://www.colorado.edu/facilitiesmanagement/distmail/materiel/DryIceandLiquidNitrogen.html)
Gloves, goggles, lab coat
Styrofoam container (small ice chest; easier to see than in dewer)
Bananas, saltines, paper towels, flowers
Ball and hoop (metal)
Rubber bands, rubber bouncy balls
Copper pennies (post-1985), hammer
Safety Information: Liquid nitrogen is obviously extremely cold and can cause severe freeze burns if it contacts bare skin longer than a few seconds. A few droplets bouncing around will not hurt: as the liquid at the edge of the droplet begins to vaporize due to the high temperature of the air, the gas forms a protective pocket around the droplet, so the droplets will bounce right off (this is why the droplets appear to float on room-temperature surfaces). Students should NOT handle the liquid nitrogen and should exercise caution in handling any object that has been frozen. Students should wear goggles.

Engagement: Start by reminding the students what they have been studying so far and review the phase of matter and phase changes between the different states. Show a brief clip about life in Antarctica, e.g.: http://www.youtube.com/watch?v=jmvTVOLZxpo. Engage them in a discussion about the following questions: What happens to living tissues in extreme cold? What do animals do to avoid phase changes? Does anyone know what the coldest place on Earth is? What about space, how cold is space? What is the coldest thing you can think of? Does anyone know what nitrogen is? Then explain that nitrogen is a chemical element; it is an inert (doesn't react) diatomic (two atoms in a molecule) gas that makes up %78 percent of Earth's atmosphere. It's also really important in living things because atoms of nitrogen are part of DNA, amino acids, and proteins.

Ask the class, if nitrogen is a gas, how would we get liquid nitrogen? Explain that we get it by increasing the pressure and decreasing the temperature (and by fractional distillation from the atmosphere). Increasing the pressure and decreasing the temperature decreases the energy of the molecules of the gas so that they slow down and become liquid. Liquid nitrogen is really, really cold: it boils at 77K, -196^{o}C, -321^{o}F. If we kept decreasing the temperature and increasing the pressure, it wouldn't even become solid until it was 63K, -210^{o}C, -346^{o}F!

Exploration: The liquid nitrogen will be used to explore the effects of extreme cold on different substances, which will help us understand the relationship between temperature, pressure, and volume. Show the students a banana and ask them to make predictions about what will happen to the banana when placed in the liquid nitrogen. Freeze the banana and then hammer a nail into wood using the now-very-hard banana. Then show the students a saltine cracker and ask them to predict what will happen to the saltine when it is frozen. Bring enough saltines that anyone who wants to eat one can try it. Ask the students why the banana and the saltine behave differently when they are frozen (the high water content of the banana locks all the molecules into place but the dry saltine shatters easily). Allow the students to choose the next few objects to freeze (have pennies, paper towels and flowers on hand).

Explanation: Things like bananas and wet paper towels have a high water content, so the water freezes and locks in the molecules. The pennies shatter because the zinc on the inside is very brittle when frozen. Ask the students why things get cold when placed in liquid nitrogen and introduce the concept of conduction. Conduction is when heat energy is transferred from substances with relatively higher heat energy to substances with relatively lower heat energy: the stuff we put into liquid nitrogen didn't get colder because the liquid nitrogen changed it, but because the stuff transferred all its heat to the liquid nitrogen. Compared to the liquid nitrogen (which boils at -196^{o}C), the banana is really hot (23^{o}C). If we could measure the liquid nitrogen when we put the banana in it, what do you think we would see? We might see the liquid nitrogen get a tiny bit warmer as all the heat energy from the banana was conducted into the liquid nitrogen.

Elaboration & Extension: Ask the students what they think is happening inside the substances when the substances are placed in the liquid nitrogen; direct them to specifically think about volume. Show the ball and hoop and demonstrate that the ball will not fit through the hoop. Ask them to predict what will happen when the ball is frozen. Freeze the ball and pass it through the hoop. Ask them what will happen if both are frozen and freeze both. Review the relationship between temperature, pressure, and volume. If the metal ball and hoop are not available, another way to approach this concept is to use an inflated balloon and place it in the liquid nitrogen (it shrinks) and then remove it to the air (it re-inflates).

Evaluation: Conclude the lesson by asking the students to write down in their science notebooks what they learned and why changing temperature, pressure, and volume might be important in industry and their everyday lives.