USE OF LIQUID NITROGEN

OBJECTIVES

1. To observe the change in state of liquid nitrogen to gaseous nitrogen.
2. To demonstrate kinetic theory.
3. To demonstrate the dependence of conductivity on temperature.
4. To demonstrate the effect of temperature on the behaviour of materials.

BACKGROUND INFORMATION

Nitrogen gas composes 78% of the Earth's atmosphere. It is a colourless, odourless and non-flammable gas. It is used in the electrical industry where the presence of oxygen gas may cause fires. Nitrogen gas is also used in producing chemicals safely, the food packaging industries and in the drying and preparation of refrigeration systems.

At temperatures below -196^{o}C (77K), nitrogen is a liquid. One volume of liquid nitrogen gives 651 volumes of gaseous nitrogen at 100 000 Pa and 273 K. When liquid nitrogen comes into contact with objects at room temperature it boils rapidly from the heat energy emitted by the objects. The "smoke" that is seen emanating from the liquid nitrogen is not the nitrogen gas itself - since nitrogen gas is colourless – it is the water vapour in the air condensing as the much cooler nitrogen gas passes through the air.

MATERIALS

- Dewar/thermos flask of liquid nitrogen (about 1-2 litres)
- Oven mitt or insulated gloves

PROCEDURE

1. While wearing gloves, carefully pour a small amount of the liquid nitrogen from the dewar into the flask/canister. Swirl. At first the liquid nitrogen will vaporise very quickly as the canister is initially much warmer than the liquid nitrogen.
2. After approximately 10 seconds, pour about 1-2 litres of the liquid nitrogen into the canister.

Materials Science

MATERIALS

- Banana x 2
- Flowers
- Knife
- Metal tongs
- Conventional freezer
- Hammer
- Nail
- Small block of wood

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PROCEDURE

- 24 hours before this activity, cut one banana in half and place one half in a conventional freezer. Wrap the other half in cling wrap and store in the refrigerator.
- Use the hammer to begin to insert a nail into a block of wood.
- On the day of the activity immerse the remaining banana in the liquid nitrogen. Use the banana to hammer the nail into the wood. After a number of strikes, the banana will probably break.
- Compare the fruit in the banana frozen in liquid nitrogen with the banana frozen in a conventional freezer.
- Immerse the flowers, one at a time, in the liquid nitrogen. Tap the flowers on the bench or use your hand to crush the frozen flowers.

QUESTIONS

1. Describe the properties of the banana frozen in liquid nitrogen. *Brittle and hard*
2. Compare the appearance of the banana fruit frozen in liquid nitrogen with that frozen in a conventional freezer. *The banana in the liquid nitrogen still has the same appearance as a fresh banana. The banana frozen in a conventional freezer appears to have damaged cells.*
3. Describe the properties of the flower frozen in liquid nitrogen. *Brittle and hard*
4. Explain the change in properties you observed. *Fruits and flowers contain a lot of water. When water freezes to ice it becomes very hard and brittle. It is the frozen water content that makes the fruits and flowers hard and brittle. The fruits and flowers are particularly brittle compared to a large block of ice because the ice crystals are not well aligned so there are weaknesses along the boundaries between the ice crystals.*

EXTENSION

Try Glowsticks – the reaction is stopped when the glowstick is put in liquid nitrogen but begins again as the glowstick warms up.

Electricity

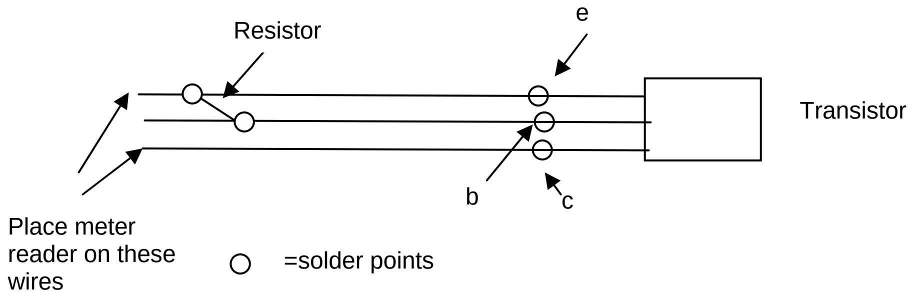
MATERIALS

- Wire wound 1.2k Ohms resistor (Dick Smith)
- Soldering iron and solder
- Transistor (Dick Smith DS548)
- Three wires (each 50cm long)
- Biased resistor 1k ohm (Dick Smith)
- Relay or small transformer
- 7 x 50cm Insulated electrical wire with about 1-2cm of insulation stripped from the ends
- Multimeter

PROCEDURE

1. Connect both ends of the resistor to two pieces of electrical wire (use a soldering iron, alligator clips or just twist the wires).
2. Attach the other ends to the multimeter. Measure the resistance of the resistor at room temperature.
3. Holding the two unattached ends of wire out of the liquid nitrogen, immerse the resistor in the liquid.
4. Attach the multimeter and measure the resistance of the resistor.

5. Repeat with the relay.
6. For the transistor, set up as follows then repeat the above steps.



QUESTIONS

1. Did the resistance of the resistor, increase or decrease? What happened to the resistance of the transistor? *The resistance of the resistor increased as the temperature dropped. The resistance of the transformer (a conductor) decreased as the temperature dropped.*
2. Explain the change in resistance. *The transformer is a conductor made of coiled metal wire. In a metal, the number of free electrons to carry charge is constant. But, as the temperature drops, there are fewer thermal vibrations causing resistance, so the resistance of the transformer decreases. The resistor has very few free electrons to carry electricity. With a decrease in heat energy available, there are even fewer electrons available to carry charge. This outweighs the benefit of decreased thermal vibrations so the resistor exhibits increased resistance.*

EXTENSION

Try submersing an LED attached to a 9V battery. The LED is a semi-conductor so its resistance will decrease in the cold. As it warms up again the light will get brighter.

Try using a heat gun on the resistor, semi-conductor and conductor and observe the resistance changes. Is it what you expect?

States of Matter and Kinetic Theory

MATERIALS

- Balloon
- Metre stick (ruler or piece of dowel)
- Sticky tape

PROCEDURE

1. Inflate the balloon to approximately 15cm diameter.
2. Use sticky tape to attach the balloon to the metre stick.
3. Insert the balloon into the liquid nitrogen. Hold for approximately 20 seconds.
4. Remove the balloon from the liquid nitrogen.

QUESTIONS

1. Describe what happened when the balloon was placed in the liquid nitrogen. *The balloon shrank in the liquid nitrogen and expanded when brought back to room temperature.*
2. Explain the change you observed in the balloon using particle and kinetic theory. *As the gas particles cool down in the liquid nitrogen, they move around inside the balloon at a slower*

speed. This exerts less pressure on the internal sides of the balloon and the balloon shrinks in size.

REAL WORLD APPLICATIONS

Freezing foods – Liquid nitrogen freezes food much more quickly than conventional freezers so stops the water leaking from the cells and forming crystals that damage the structure of the cells in the food. It is also used in shrink-fitting metal parts.

Shrink-fitting metals - At room temperature, the metal part to be fitted is too large to fit inside the hole intended for it. Liquid nitrogen cools the metal part, making it contract enough to fit into the hole. As the chilled metal part warms back up to room temperature, it expands inside the hole to make an extremely tight fit.

CURRICULUM CONCEPTS ADDRESSED

Chemistry

R3.5—The ideal gas equation may be used to relate the volume of a gas at defined temperature and pressure to its quantity in moles.

Physics

E1.2 — Energy manifests itself in various forms, including: potential energy associated with gravitational, electric and magnetic fields; kinetic energy related to the motion of matter; and nuclear energy, which links to the concept of mass–energy equivalence.

E2.4 — The transference of energy within or between systems can be explained using the laws of thermodynamics.

Biology

Key Idea: Cells have a chemical composition that must be maintained for the continued life of the cell.

RESOURCES USED TO DEVELOP THIS ACTIVITY

1. BOC Gases. http://www.boc.ebcnet.co.uk/nitrogen/index.html (accessed 6 November 2008).
2. Kuehner, N. & A. http://members.mrtc.com/anvk/cryogenics/cryogenics.html (accessed 6 November 2008).
3. Toreki, R. 2006. http://www.ilpi.com/genchem/demo/liquidnitrogen/index.html (accessed 7 November 2008).
4. Institute of Physics. 2006. http://www.ioppublishing.com/activity/education/Projects/Teaching%20Advanced%20Physics/Electricity/Electrical%20Resistance/page_3560.html (accessed 7 November 2008).

POTENTIAL HAZARDS

Temperature related

- The **extremely low temperature** of the liquid can cause severe burn-like damage to the skin either by contact with the fluid, surfaces cooled by the fluid or evolving gases. The hazard level is comparable to that of handling boiling water.
- The low temperature of the vapour can cause damage to softer tissues *e.g*. eyes and lungs but may not affect the skin during short exposure.
- Skin can freeze and adhere to liquid nitrogen cooled surfaces causing tearing on removal.
- Soft materials *e.g*. rubber and plastics become brittle when cooled by liquid nitrogen and may shatter unexpectedly.
- Liquid oxygen may condense in containers of liquid nitrogen or vessels cooled by liquid nitrogen. This can be extremely hazardous because of the pressure rise on the slightest degree of warming above the boiling point of oxygen (-183°C) and the possibility of **explosive reaction** with oxidisable material.

Vapour related

- Thermal stress damage can be caused to containers because of large, rapid changes of temperature
- Large volumes of nitrogen gas are evolved from small volumes of liquid nitrogen (1 litre of liquid giving 0.7 m^3 of vapour) and this can easily replace normal air in poorly ventilated areas leading to the danger of asphyxiation. It should be noted that oxygen normally constitutes 21% of air. Atmospheres containing less than 10% oxygen can result in brain damage and death (the gasping reflex is triggered by excess carbon dioxide and not by shortage of oxygen), levels of 18% or less are dangerous and entry into regions with levels less than 20% is not recommended.
- Oxygen condensed into leaking containers can explode on heating following resealing or blockage with ice.

PRECAUTIONS

Handling

- Liquid nitrogen should only be used in well-ventilated areas.
- Only containers or fittings (pipes, tongs *etc*.) that have been designed specifically for use with cryogenic liquids may be used as non-specialised equipment may crack or fail. In particular, food type vacuum flasks must not be used as they can implode resulting in flying glass fragments.
- Warm dewars should be filled slowly to reduce temperature shock effects and to minimise splashing. Storage dewars should not be not be over-pressured when filling a globular dewar. The minimum pressure required to maintain a flow of liquid should be used.
- Containers of liquid nitrogen must be suitably vented and unlikely to block due to ice formation.
- **Skin contact** with either liquid nitrogen or items cooled by liquid nitrogen should be avoided as serious burns may occur. Care must be taken with gloves, wrist-bands or bracelets which may trap liquid nitrogen close to the skin.
- **Personal Protective Equipment**, especially safety glasses, must be worn to protect against splashes, freezing vapour, failure of glass apparatus or brittle failure of items cooled by liquid nitrogen

Personal Protective Equipment

The following equipment should be worn when handling or dispensing liquid nitrogen:

- Face shield or safety glasses.
- Dry insulated gloves when handling equipment that has been in contact with the liquid. *NB* there is dispute over the advisability of wearing gloves while handling liquid nitrogen because there is a possibility that gloves could fill with liquid and therefore prolong hand contact which would make burns more severe. If gloves are worn they should be loose fitting and easily removed.
- Lab coat or overalls are advisable to minimise skin contact and also trousers *over* shoe/boot tops to prevent shoes filling in the event of a spillage.

First Aid Measures

EYE

- If product comes in contact with eyes remove the patient from gas source or contaminated area.
- Take the patient to the nearest eye wash, shower or other source of clean water.
- Open eyelid/s wide to allow material to evaporate
- Gently rinse affects eye/s with clean, cool water for at least 15 minutes. Have the patient lie or sit down and tilt the head back. Hold the eyelid/s open and pour water slowly over the eyeball/s at the inner corners, letting the water run out of the outer corners.
- The patient may be in pain and wanting to close eyes. It is important that the material is rinsed