Bright Salt: Structural

Objectives

Students will:

- Understand how defects in the crystal structure can cause excited states.
- Visualise the fluorescence of a chemical in an excited state as it returns to ground state, following its irradiation in a nuclear reactor.
- Explore how thermal fluorescence can be used in the nuclear industry to diagnose and monitor radiation exposure.

Fast facts

Subject: Chemistry

Age range: 5+ years old

Ambassador preparation time: 1-2 hours

Demonstration time required: 5 minutes

Location: Science Fair

Overview

Salt has an ionic lattice crystal structure. However, this structure is not perfect, and defects can be present. When material is irradiated with gamma radiation energy, some of the electrons in the sodium chloride crystal move to a higher energy state. The crystalline structure of the sodium chloride allows some of these electrons to be trapped in energy levels above the ground state. These trapped electrons cause the crystals to change colour (to orange-brown). This is because the repositioned electrons affect the way that light is reflected by the crystal.

When the sample is heated, there is sufficient energy for the electrons to escape the energy well. These electrons return to their ground state by emitting energy in the form of light. This is thermal fluorescence. The amount of light released is proportional to the amount of radiation energy absorbed by the crystal.

Equipment

- Irradiated salt
- Hot plate
- Aluminium foil boat
- Safety goggles -
- Fire extinguisher & heat blanket
- Pyrex screen
- 'Hot surface' and 'Do not touch' label
- Eye wash kit
- Tweezers

Links to purchase the equipment are given at the end of the guide (Equipment Purchase Links section).

Precautions

The salt is safe to handle and is non-toxic, but you should NOT eat it. This is because the plastic bottle is not food-grade certified and food-grade sanitary precautions were not taken when the salt was transferred into the plastic bottles.

Procedure

1. Turn on the hot plate to a medium-high setting prior to the science fair, so that it will be hot at the time of the demonstration. Pre-heat the aluminium foil boats.

2. In front of the hotplate, introduce a Pyrex screen with a 'hot surface' sign.

3. When the students arrive, show them the sample of the irradiated table salt which is orange-brown in colour.

4. Turn off the lights or use a blackout box.

> ***Tip*** *– The darker the room the better to observe the sparkle.*

5. Sprinkle several grains of the orange salt into the aluminium foil boat on the hot surface. You will see obvious flashes of light from each crystal you drop onto the hot surface. Have the students observe with their sense of sight and sense of hearing. The heated salt sparkles, and a sizzling sound may be detected.

> ***Tip*** *- You may want to do this for small groups of students so that they can get close enough to the hot plate to observe the small flashes of light.*

6. Turn on the lights and note the colour of the salt sample, which is now white.

7. Turn off the hot plate and remove the aluminium foil boat from the hot plate with tweezers. Tip the aluminium foil boat so that the salt collects in a corner.

8. Return any left-over orange salt to the container and close the cap tightly. The de-activated (white) salt can be safely disposed of in a regular household bin.

> *Light and humidity will cause the stored energy to be released. Once the salt returns to its white form it will no longer luminesce when heated.*

Discussion

Salt has the crystal structure of an ionic lattice. An ionic compound is a giant structure of ions. The ions have a regular, repeating arrangement called an ionic lattice. The lattice is formed because the ions attract each other and form a regular pattern with oppositely charged ions next to each other. The lattice structure looks like this:

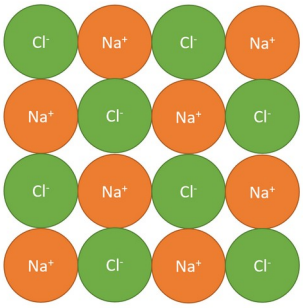

Figure 1 Sodium chloride (NaCl) energy ground state crystal structure

However, these crystal structures aren't perfect and sometimes there are defects. These defects can be caused by the energy within the nuclear reactor.

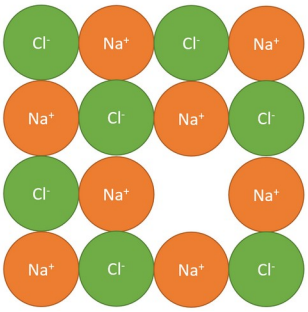

Figure 2 Sodium chloride (NaCl) crystal structure with a defect

Because of the defect, when sodium chloride is irradiated the electrons move around with all the energy from the reactor and an electron can move into that vacant spot. This produces a colour centre, hence the brown colour. This is because the repositioned electrons affect the way that light is reflected by the crystal.

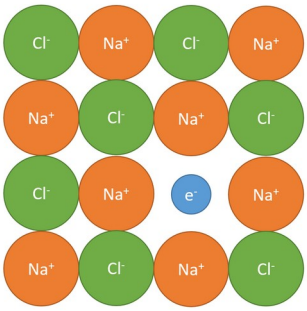

Figure 3 Sodium chloride (NaCl) energy excited state crystal structure

However, when you apply heat, you see thermo-luminescence and a colour change. This is because when the crystals are heated, the heat energy raises the trapped electrons to an even higher energy state where they are free to drop down to the ground state. As the trapped electrons are freed, their excess energy is released in the form of visible light. This phenomenon is called thermoluminescence, or thermal fluorescence. The amount of light released is proportional to the amount of radiation energy absorbed by the crystal. The heating also decreases the rigidity of the crystal lattice, allowing the salt crystals to revert to their original, defect-free state, which is white in colour. The salt is not radioactive.

Real-World Application

The concepts involved in this demonstration can be related to devices used to detect radiation exposure.

Radiation workers wear film badges called TLDs (Thermoluminescent dosimeters). Gamma rays that hit the badge are stored as energy in the badge. The badge uses a lithium fluoride (LiF) film (rather than sodium chloride, although the elements are in the same periodic groups, meaning they'll have the same physical and hence structural properties), which "stores energy" when exposed to ionizing radiation.

After a set period of time the nuclear worker will change their badge. The used badge is heated to release its stored energy and the amount of energy that is released is measured with a light-sensitive instrument (e.g., a photomultiplier tube). The amount of light released corresponds to the energy that was deposited in the lithium fluoride salt as the ionizing radiation passed through the material. The radiation dose received by the radiation worker can therefore be calculated.

Figure 4 Image of a TLD (Thermoluminescent dosimeter)

Equipment Purchase Links

• Irradiated salt:

https://www.carolina.com/specialty-chemicals-s/sodium-chloride-irradiated-crystal-laboratory-grade-20-g/888940.pr

• Hotplate:

https://www.amazon.co.uk/Uten-1250-1500W-Continuously-Thermostats-Overheating/dp/B08NHGMWFJ/ref=sr_1_6?crid=2LSNUZ83TOI6B&keywords=hot%2Bplate&qid=1641894163&sprefix=hot%2Bplate%2Caps%2C369&sr=8-6&th=1

• Aluminium foil boat:

https://www.amazon.co.uk/Trays-Muffin-Dishes-Pastry-Aluminium/dp/B08K8GDNBC/ref=sr_1_2_sspa?crid=C569LPEWSTH4&keywords=small+foil+dish&qid=1686214417&sprefix=small+foil+dish%2Caps%2C165&sr=8-2-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1

• Safety goggles:

https://www.amazon.co.uk/Safety-Glasses-Goggles-Protective-Eyewear/dp/B08NB9H71Y/ref=sr_1_31?keywords=safety+goggles&qid=1641895343&sr=8-31

• Fire extinguisher & heat blanket:

https://www.amazon.co.uk/FireShield-Powder-Fire-Extinguisher-Blanket/dp/B08WRJ4NZT/ref=sr_1_4_sspa?crid=34SCQM4TZCJ90&keywords=fire+extinguisher&qid=1641895632&sprefix=fire+estin%2Caps%2C151&sr=8-4-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzTFBMMjlaOVBPRkVUJmVuY3J5cHRlZElkPUEwNTU4NTkwMllMTFdaOTVIVlFVTCZlbmNyeXB0ZWRBZElkPUEwNzA3MjE1QVo3WExUT0owOVQ3JndpZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ==

• Pyrex screen:

https://www.amazon.co.uk/TANGZON-Perspex-Protection-Transaction-Partition/dp/B09V7RDNTL/ref=sr_1_1_sspa?crid=14PYUK4TXJ22L&keywords=plastic+screen&qid=1686213804&sprefix=plastic+screen%2Caps%2C146&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1

• 'Hot surface' and 'Do not touch' label:

https://www.amazon.co.uk/Caution-surface-touch-safety-sign/dp/B07YL1D9WH/ref=sr_1_5?crid=KCXGX8GB1SFM&keywords=Caution+hot+surface+do+not+touch+safety+sticker&qid=1641895790&sprefix=caution+hot+surface+do+not+touch+safety+sticker%2Caps%2C167&sr=8-5

• Eye wash kit:

https://www.amazon.co.uk/HypaClens-Eyewash-Station-Bottles-Dressings/dp/B01BLEVGWE/ref=sr_1_8?crid=1W0XIGMV0PAP8&keywords=eye%2Bwash%2Bstation&qid=1641895266&sprefix=eye%2Bwash%2B%2Caps%2C121&sr=8-8&th=1

• Tweezers:

https://www.amazon.co.uk/Tweezers-Professional-Slanted-Stainless-Precision/dp/B0971KDBHF/ref=sr_1_6?crid=18QIT7GA2OFIL&keywords=tweezers&qid=1686213918&sprefix=twee%2Caps%2C339&sr=8-6