Superconductors

This activity enables students to look at the topic of structure and bonding of metals and giant ionic compounds in the context of superconductors. It introduces some complex formulae and shows that they work in the same way as the simple formulae students are used to. The material also offers the opportunity for a discussion of the concept of 'blue skies' research.

Notes

The activity could be introduced by showing students a video clip illustrating the levitation properties of superconductors. There are some good, short clips on http://www.fys.uio.no/super/levitation/ (accessed December 2005).

A list of uses of superconductors is given in the student material. You may prefer to ask students to research this for themselves. There is a very good section on the website http://www.superconductors.org (accessed December 2005), which would be an excellent starting point for their research. The site has details of several uses and potential uses of superconductors and provides links to other related web pages.
Students could research one use and produce a poster on it. The posters could then be shared and discussed with the whole class. Ask students to think about the advantages and disadvantages of superconductors for each application.

Some students may be interested in how superconductors work. The above superconductors website has some good, clear explanations of this, particularly at http://www.superconductors.org/oxtheory.htm (accessed December 2005).

Answers to questions

1. A conductor is a substance that conducts heat or electricity. Metals usually conduct when solid.
2. A superconductor is a substance that conducts electricity without any resistance.
3. Advantage – no loss of energy.
   Disadvantage – high cost of cooling with liquid helium.
4. From 1911 to 1962 – 51 years.
5. Giant ionic compounds do not conduct when solid as they have no free electrons or other charged particles that can move to carry the current. As they do not ordinarily conduct, it is surprising to find them behaving as superconductors.
6. Nitrogen is far more common. Also, since nitrogen has a higher boiling point than helium, less pressure is needed to liquefy it, which means less energy is required to produce liquid nitrogen.
7. Yttrium, 1 atom; barium, 2; copper, 3; oxygen, 7. This compound is called yttrium barium copper oxide (but is usually referred to as YBCO).
8. The compound could be made to superconduct by cooling in liquid nitrogen, which is a lot cheaper than liquid helium.
9. The material contains mercury, thallium, barium, calcium, copper, oxygen.
10. Mercury, 1 atom; barium, 2; calcium, 2; copper, 3; oxygen, 8.
11. If the planes (or sheets) of atoms in a metallic structure slide over each other, the atoms end up in an identical environment to the one they have just left and they are still held in place by the 'sea' of delocalised or free electrons. If planes of ions slide over each other in an ionic structure, a displacement of one ion across leads to an arrangement in which ions of like charge are touching. These ions repel each other and the structure shatters.

Blue skies research

These questions are designed to stimulate discussion, rather than requiring full written answers. Examples of discoveries that have been made by chance or when researchers were looking for something else include the glue in Post-it® notes (scientists were searching for a strong glue), polythene and Teflon®.

The discovery of the hole in the ozone layer is an example of something that was missed by those with the most data. The credit for the discovery went to Molina and Rowland in the mid-80s but NASA had relevant data right back to the mid-1970s.

However, NASA scientists missed the discovery because their data had not been properly analysed. There are more details on this story on the NASA website http://www.nas.nasa.gov/About/Education/Ozone/history.html (accessed December 2005).

Superconductors

1. What is a conductor? Which type of substance usually conducts when solid?

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Superconductivity was first observed in 1911. The Dutch physicist Heike Onnes found that when mercury was cooled in liquid helium to -269 °C its electrical resistance dropped to zero. Onnes called this strange behaviour superconductivity – the ability to conduct electricity without any resistance, so that an electric current, once started, continues to flow forever. This is the closest thing to a perpetual motion machine that exists in nature.

2. What is a superconductor?

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Materials only become superconducting below a particular temperature, which is different for each material. This temperature is known as the critical temperature, or T_c. Right from their initial discovery it was clear that superconductors could be very useful because they can carry electricity without any loss of energy. Unfortunately, the cost of cooling the material with liquid helium was so high that it outweighed the energy saving (except in a few specialised devices).

3. What would be the main advantage and the main disadvantage of using superconductors for power cables?

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Over the next few decades other superconductors were discovered. In 1941 an alloy that becomes a superconductor at -257 °C was found; in 1953 one with a T_c of -255.5 °C was identified. These temperatures are still very close to absolute zero (-273 °C) and very expensive liquid helium was still required to cool the materials enough to make them become superconducting. In 1962 the first commercial superconducting wire was produced.

4. How long was it from the discovery of superconductivity until it was first used commercially?

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In 1986 a breakthrough discovery was made. Scientists at the IBM research laboratory in Switzerland created a brittle ceramic compound made of lanthanum, barium, copper and oxygen that became a superconductor at the highest critical temperature then known, -243°C. Ceramics are giant ionic compounds so researchers had not previously considered them as superconductors.

5. Why is it surprising that a giant ionic compound can behave as a superconductor? (Use ideas about structure and bonding in your answer.)

The race was on to find superconductors with higher and higher critical temperatures (T_c). In particular, researchers wanted to find one that could be cooled with liquid nitrogen instead of liquid helium. Liquid nitrogen has a boiling point of -196 °C and is a lot cheaper than liquid helium (liquid helium costs about the same as wine; liquid nitrogen about the same as milk). -196 °C is still very cold (a household freezer can go down to about -20 °C) but there are more potential applications for materials that superconduct at this temperature because the cost of cooling is so much lower than for materials that have to be cooled with liquid helium.

Composition of the Earth's atmosphere

Gas	Percentage of atmosphere
Nitrogen	78.08
Oxygen	20.94
Argon	0.93
Carbon dioxide	0.0335
Other Noble gases	0.00244

Both nitrogen and helium can be extracted from the air by fractional distillation.

6. Explain why helium is so much more expensive than nitrogen. Give two reasons.

In 1987 a team from the USA managed to make the first superconductor with a Tc higher than the boiling point of liquid nitrogen. This compound has the formula $YBa_2Cu_3O_7$, with a T_c of -181 °C.

7. Use a Periodic Table to find out the names of the elements in $YBa_2Cu_3O_7$. How many atoms of each element are present in this material? Can you suggest what it might be called?

8. Why were scientists excited to find that the Tc of this compound was above -196 °C?

The world record for the highest T_c is currently -135 °C. The compound has the formula $(Hg_{0.8}Tl_{0.2})Ba_2Ca_2Cu_3O_{8.33}$. This formula looks unusual because it does not contain only whole numbers but this is the simplest way of writing it.

9. Use a Periodic Table to find out what the elements in this material are called.

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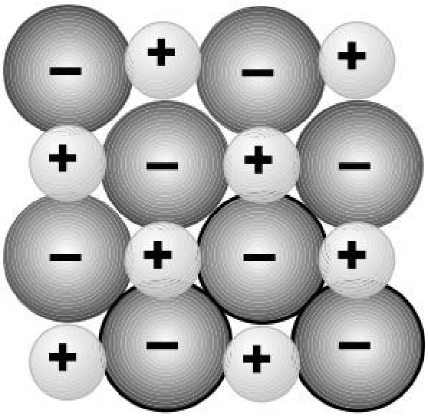

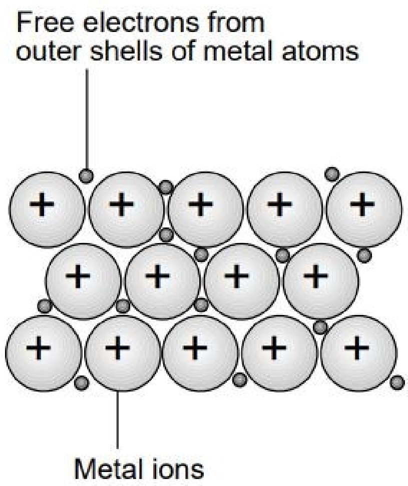

Uses of superconductors

Superconductors are used in the following applications:

- Maglev (magnetic levitation) trains. These work because a superconductor repels a magnetic field so a magnet will float above a superconductor – this virtually eliminates the friction between the train and the track. However, there are safety concerns about the strong magnetic fields used as these could be a risk to human health.
- Large hadron collider or particle accelerator. This use of superconductors was developed at the Rutherford Appleton Laboratory in Oxfordshire, UK in the 1960s. The latest and biggest large hadron collider is currently being built in Switzerland by a coalition of scientific organisations from several countries. Superconductors are used to make extremely powerful electromagnets to accelerate charged particles very fast (to near the speed of light).
- SQUIDs (**S**uperconducting **QU**antum **I**nterference **D**evices) are used to detect even the weakest magnetic field. They are used in mine detection equipment to help in the removal of land mines.
- The USA is developing "E-bombs". These are devices that make use of strong, superconductorderived magnetic fields to create a fast, high-intensity electromagnetic pulse that can disable an enemy's electronic equipment. These devices were first used in wartime in March 2003 when USA forces attacked an Iraqi broadcast facility. They can release two billion watts of energy at once.

The following uses of superconductors are under development:

- Making electricity generation more efficient
- Very fast computing.

Other impacts of superconductors on technology will depend on either finding superconductors that work at far higher temperatures than those known at present, or finding cheaper ways of achieving the very cold temperatures currently needed to make them work. Blue skies research Scientific research that does not have a particular commercial aim in view is called blue skies research. Many discoveries are made 'by chance' when scientists are trying to find out something else. The discovery of superconductivity was made nearly 100 years ago but technological applications have really only become available in the last 10 years or so.

Think about the following questions and discuss them with others:

- Is it important that blue skies research is carried out?
- Who should fund it?
- Why is it important that scientists record all their observations – even ones which do not fit the pattern they were expecting?
- Do you know of any scientific developments that were made by chance – maybe when the researchers concerned were looking for something else?