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 indentified. 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.)

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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.

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In 1987 a team from the USA managed to make the first superconductor with a T_c 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?

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

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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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A similar material has the formula $HgBa_2Ca_2Cu_3O_8$. This material has a T_c of -138 °C.

10. How many atoms of each element are present in this material?

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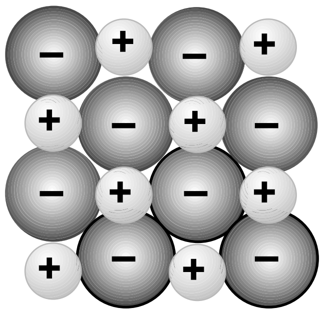
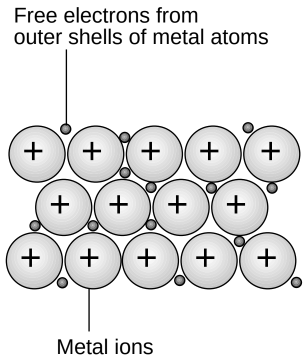
These superconductors are all ceramics and have several potential uses but it is difficult to make them into wires because they are brittle giant ionic materials.

11. Using the simple models of giant ionic and metallic structures shown below, explain why materials with giant ionic structures tend to be brittle, but metallic materials are malleable and ductile (they retain their new shape when they are deformed and can be drawn into wires).



Giant ionic structure



Metallic structure

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