9.4 From ideas to implementation: 4. Superconductivity

Syllabus reference (October 2002 version)		
4. Investigations into the electrical properties of particular metals at different temperatures led to the identification of superconductivity and the exploration of possible applications	*Students learn to*: outline the methods used by the Braggs to determine crystal structure identify that metals possess a crystal lattice structure describe conduction in metals as a free movement of electrons unimpeded by the lattice identify that resistance in metals is increased by the presence of impurities and scattering of electrons by lattice vibrations describe the occurrence in superconductors below their	*Students*: process information to identify some of the metals, metal alloys and compounds that have been identified as exhibiting the property of superconductivity and the critical temperatures perform an investigation to demonstrate magnetic levitation analyse information to explain why a magnet is able to hover above a superconducting material that has reached the temperature at which it is superconducting gather and process information to describe how superconductors and the

	critical temperature of a population of electron pairs unaffected by electrical resistance discuss the BCS theory discuss the advantages of using superconductors and identify limitations to their use	s and the effects of magnetic fields have been applied to develop a maglev train process information to discuss possible applications of superconductivity and the effects of those applications on computers, generators and motors and transmission of electricity through power grids

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outline the methods used by the Braggs to determine crystal structure

Sir William and Lawrence Bragg studied crystals using X-rays. They examined the patterns produced by the X-rays after the rays passed through the crystal and hit a photographic screen. The patterns were used to determine the internal structure of the crystals.

X-rays were produced by allowing high energy cathode rays to strike a metal anode. These rays were directed at a crystal of a metal salt. (The first tried were sodium chloride, NaCl, and zinc sulfide, ZnS).

A photographic plate was placed in the path of the X-rays exiting the crystal. The X-rays hitting the photographic plate produced a pattern of bright spots.

Calculation of the angles between the bright spots forming the pattern on the photographic plate allowed the Braggs to determine the internal structure of the crystal.

The Braggs' work was direct evidence for the periodic atomic structure of crystals postulated for several centuries.

Their research provided a method, used for the next 50 years, to determine a number of simple crystal structures.

A mathematical expression, Braggs Law, developed for explaining these patterns of X-rays, allowed the future study of material structure using other types of electromagnetic (e-m) beams.

The application of this technique has been crucial in determining the structure of important biological substances, such as DNA, and in the development of the transistor and microchip.

identify that metals possess a crystal lattice structure

The atoms in a crystal are in a regular repeating pattern called the crystal lattice.

A crystal lattice is defined by a repeated three-dimensional unit.

The basic building block of these crystalline structures is known as the "unit cell" and this "unit cell" repeats itself over and over to form a lattice.

When a pure metal starts to form from a cooling molten state, the atoms arrange themselves in an ordered geometrical pattern that is repeated over and over again producing a crystalline structure.

describe conduction in metals as a free movement of

electrons unimpeded by the lattice

In a metal, the valence electrons are thought of as being shared by all the positive ions. Therefore, the electrons are free to move throughout the crystal lattice.

Metals have many electrons that are free to move.

Metals are good conductors of electricity.

identify that resistance in metals is increased by the presence of impurities and scattering of electrons by lattice vibrations

Chemical impurities disrupt the lattice integrity which, in turn, impedes the free movement of electrons. Similarily, free electron movement is impeded by rapid minor position changes (vibrations) in the lattice. The vibrating lattice collides with free moving electrons, thus deflecting or scattering them from their linear progress through the crystal.

process information to identify some of the metals, metal alloys and compounds that have been identified as exhibiting the property of superconductivity and the critical temperatures

Your teacher may give you Internet sites to research. One such site is:

Superconductor Information for the Beginner Joe Eck, superconductors.org, USA.

To **process** the sources you research, assess their reliability by comparing the information provided on that site with similar information from other sources. Look for consistency of information.

A table like the one below is an effective tool to assist you to process the information.

MATERIAL	TYPE	CRITICAL TEMPERATURE (T_c) (K)
mercury	metal	4.15
tin	metal	3.69
lead	metal	9.20
TlBaCaCuO	ceramic	125

describe the occurrence in superconductors below their critical temperature of a population of electron pairs unaffected by electrical resistance

Electrons are the charge carriers in a metal. At room temperatures, the metallic bonds (the lattice) holding the conductor together vibrates and interferes with electron movement through the conductor. Along with impurities and imperfections in the lattice itself, these three factors are responsible for resistance effects (energy loss and restricted current flow) in a conductor.

Superconductivity describes the state reached in a conductor when the resistance to electron movement in a conductor drops to zero. Research has shown that there are two types of superconductors. For a number of pure metals, superconductivity occurs at temperatures from close to absolute zero and up to 23K (Type I). For another group of conductors, ones that have been manufactured using alloys of metals and metal oxides, superconductivity (Type II) has been demonstrated to occur at higher temperatures (in the range of 120 K).

At temperatures below the critical temperature, lattice effects impeding electron movement changes dramatically from impeding to assisting electron flow. That assistance comes about by an effect that pairs electrons and assists them to move freely through the conductor. The theory is called the BCS theory and is more fully explained in the next section.

discuss the BCS theory

The **BCS** theory (after is proponents US physicists John **B**ardeen, Leon **C**ooper and John **S**chrieffer) explains superconductivity in terms of electron pairs and packets of sound waves related to lattice vibrations (called phonons).

At temperatures below the critical temperature for particular metals (or metal alloys), the movement of electrons is enhanced by lattice vibrations (phonons) which cause electric field effects resulting in electron pairing (by overcoming what would normally be strong repulsive forces between like charges) and an assisted passage through the lattice with negligible energy loss.

At temperatures below the critical temperature for the particular conductor, the cooper pairs (as the electron pairs are called) stay together. Because resistance is effectively zero, very narrow wires can carry very large currents. The lower the temperature, below the critical temperature, the higher that current can be. That current produces a magnetic field around the conductor. The strength of the magnetic field will reach a point where it will cause the loss of the superconducting state thus putting an effective limit on the current that can flow in any particular superconductor.

The practical application of superconductors is based on the combination of critical temperature (T_C the point below which superconductivity occurs), the critical field (H_C the strength above which superconductivity is stopped) and the current density (J_C above which superconductivity ceases).

perform an investigation to demonstrate magnetic levitation

Your teacher will explain how this investigation can be **performed** safely in your course. The effect is called the Meissner Effect.

The Meissner Effect

analyse information to explain why a magnet is able to hover above a superconducting material that has reached the temperature at which it is superconducting

A superconductor will not allow a magnetic field to penetrate its interior.

An external magnetic field causes currents to flow inside the super conductor. These currents generate a magnetic field inside the superconductor that just balances the field that would have otherwise penetrated the material.

This effect was discovered in1933 by Meissner and Ochsenfeld and is known as the Meissner Effect.

A magnet placed above a superconductor that is cooled below its critical temperature will induce a field inside the superconductor by the Meissner Effect. That field balances the external field and causes the magnet to "levitate" above the superconductor.

gather and process information to describe how superconductors and the effects of magnetic fields have been applied to develop a maglev train

Engineering journals and the Internet should be good data sources to **gather** information about the "maglev" train. Use a search engine and type in some of the words like *Maglev* or *applications of superconductivity.*

Process your information making sure you assess its reliability by comparing information from various sources.
The following links may be useful:

Overview of Maglev R&D Railway Technical Research Institute, Japan.

Maglev Quicklinks Innovative Transport Technologies, University of Washington, USA.

process information to discuss possible applications of superconductivity and the effects of those applications on computers, generators and motors and transmission of electricity through power grids

Process your information and check its reliability by comparing with information from other sources. The information provided with the following syllabus dot point demonstrates the scope and depth required. The best place to gather up-to-date information is on the Internet.

One place to start is **Uses for superconductors** Joe Eck, Superconductors.org, US

discuss the advantages of using superconductors and identify limitations to their use

Superconductors and their applications provide significant advantages as indicated in the following examples:

Superconductors carry large currents with no heat loss and can generate very strong magnetic fields.

Particle accelerators that use superconducting electro-magnets are cheaper to run because they use less electricity to produce the needed magnetic fields.

Superconductors have beneficial applications in medical imaging techniques. **SQUIDs (S**uperconducting **QU**antum **I**nterference **D**evices) are sensitive enough to detect the very weak magnetic fields caused by electrical currents in the human brain. The devices have allowed doctors to develop better images of brain disorders.

Superconductors have been used in Japan to make experimental, magnetically levitated trains.

Electric generators made with superconducting wire are far more efficient, and about half the size, than conventional generators wound with copper wire.

New superconductive films may result in the miniaturisation and increased speed of computer chips.

The limitations of superconductors include the technical difficulties of achieving and reliably sustaining the extremely low temperatures required to achieve superconductivity. The materials, of which they are made, are often brittle, are hard to manufacture and they are difficult to make into wire.