CHAPTER 13

From superconductors to maglev trains

Investigations into the electrical properties of particular metals at different temperatures led to the identification of superconductivity and the exploration of possible applications

A magnet levitating above a superconductivity disc

Introduction

Material science, the study of the behaviour of materials, has become an increasingly relevant and important field. From studying the original discovery of superconductivity in metals cooled to within a few kelvin (K) of absolute zero to the present-day implementation of this property in magnetic resonance imaging and maglev trains, it becomes clear that future implementation of high-temperature superconductors may revolutionise our technological society.

13.1 Braggs' X-ray diffraction experiment

■ *Outline the methods used by the Braggs to determine crystal structure*

The X-ray diffraction experiment was designed so that one could use X-rays to study the internal structure of a particular crystal lattice. This method is still commonly used today.

The method was first developed by physicists Sir William Henry Bragg and his son, Sir William Lawrence Bragg. They gathered information on how electromagnetic radiation like X-rays would behave when they were scattered and subsequently interacted with each other to create an interference pattern. They stated that as an X-ray beam shone towards a lattice, the X-rays would be penetrative enough to reach different planes of the lattice and be scattered and reflected by these planes. These scattered or reflected X-rays would result in an interference pattern that could be detected and analysed to give information about the internal structure of the lattice.

The set-up of the experiment is shown in Figure 13.1 (a), and where the X-ray hits the lattice, it is enlarged to give rise to Figure 13.1(b). As shown in Figure 13.1 (a), the X-ray source produced a uniform beam of X-rays and the X-rays were directed towards the lattice, which was placed at an angle θ to the X-ray beam. The X-rays

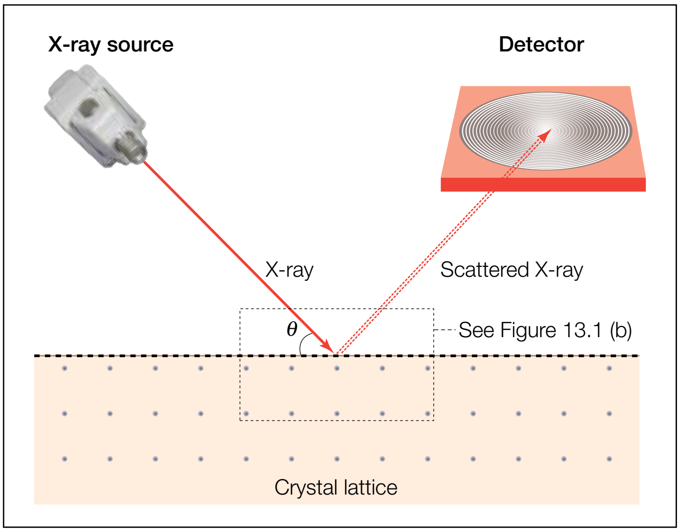


Figure 13.1 (a) The set-up of the Braggs' experiment

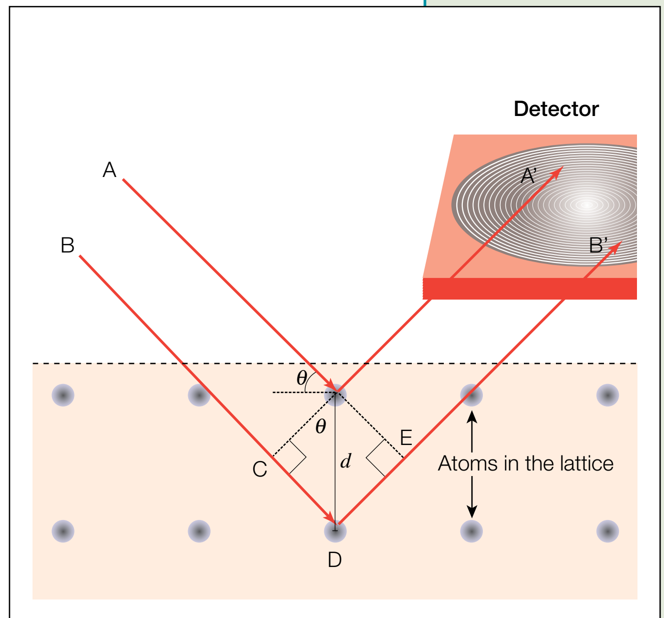


Figure 13.1 (b) An enlarged section of Figure 13.1 (a)

were scattered by the different planes of the lattice, and the detector was used to measure and record some of the scattered X-rays.

NOTE: X-rays scatter in all directions, but only ones that are of any use are measured. These are shown in the diagram.

To further understand the concept behind the experiment, we shall focus on Figure 13.1 (b). As you can see, the incident X-ray is represented by two parallel beams of X-rays A and B; A and B are initially in phase. Beam A strikes the first plane of the crystal and is scattered (reflected) to A′ and meanwhile, beam B strikes the second plane of the crystal and is scattered to B′—we assume A′ and B′ are at the position of the detector. A similar process also happens in the third and fourth plane and so forth, which is not shown here for the purpose of simplicity. Once the beams have reached A′ and B′ respectively, it is clear that the beam reaching B' has travelled a greater distance compared to that reaching A′. This extra distance travelled is CD plus DE, which equals to 2CD (since CD equals to DE) as shown in the diagram, and by simple trigonometry that CD = dsinθ, therefore 2CD = **2dsinθ**, where 'd' is the distance between the atoms in the lattice.

Now, do you think that because of the extra distance travelled by one beam but not the other, the two beams may be potentially out of phase when they reach the detector (A′ and B′)? They can be made in phase again if the difference in the distance is actually an integral multiple of the wavelength of the X-ray. In other words, we allow the difference to be by one, two or three—and so on—numbers of wavelengths (**nλ**), so that they are again in phase despite the difference in their travelled distance. Since d has a fixed value, the only way to adjust the extra travelled distance is by changing the size of the angle θ, which can be achieved by rotating the source of the X-rays and the detector. Hence in the next step, the apparatus is rotated until a constructive interference is recorded at the detector, which indicates the beams are again in phase. Clearly, when this occurs, we have **nλ = 2dsinθ**, where n is an integer, which is also known as the order of diffraction; it takes values of 1, 2, 3 and so on. λ is the wavelength of the X-ray measured in metres. Importantly, θ is the angle between the X-ray beam and the crystal surface to give constructive

SR

Simulation: Bragg's law

interference. 'd' is the distance between the atoms in the lattice. In the experiment, the wavelength of the source X-ray is known, and when the angle θ is measured, we can calculate the only unknown in this equation: 'd'. Furthermore, the same method can be used to find for 'd' in other orientations and so map out a precise picture of the arrangement of the lattice.

As mentioned before, this method is still commonly used today to study the structure of any unknown substance; because of the importance of their contribution, the Braggs (father and son) were awarded the Nobel Prize in Physics for their work on the X-ray diffraction experiment. The structure of metals, which are represented as the sea of electrons model, can be confirmed by this particular experiment.

13.2 Metal structure

- ***Identify that metals possess a crystal lattice structure***
- ***Describe conduction in metals as a free movement of electrons unimpeded by the lattice***

As discussed, metal has a structure that can be represented as the sea of electrons model (see Chapter 12). Generally, metals are excellent conductors of electricity due to the presence of the large number of delocalised electrons. These electrons are free to move, and so are able to conduct electricity. This means most metals have a high **conductivity** and low **resistance**, where conductivity is always inversely related to resistance.

13.3 The effects of impurities and temperature on conductivity of metals

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

A few factors may influence the conductivity of a metal conductor. Basically, anything that impedes the movement of the delocalised electrons would reduce the conductivity of the metal, and so increase its resistance. These factors include:

- temperature
- impurities
- cross-sectional area of the conductor
- length of the conductor
- electron density

Our focus in this module will be mainly on temperature, which will be discussed in detail in later sections.

Temperature

As temperature increases, the energy of the lattice increases. This leads to an increase in vibration of all the particles inside the lattice. This vibration will cause more collisions between the electrons and the lattice, impeding their movement. *Thus the increase in temperature will result in a decrease in its conductivity or increase in its* *resistance*. Also note, unlike semiconductors, no more electrons can be recruited into the conduction band because all the valence electrons are already in the conduction band for metals (see Chapter 12). Lowering the temperature has the opposite effect.

Impurities

Adding impurities is like adding obstacles to the movement of electrons. This impedes the electron movement, and hence *decreases the conductivity or increases the resistance*. An example of this is copper alloys that have impurities added. They are not as good conductors as pure copper metals.

Length

As you have learnt in the preliminary course, *the longer the conductor, the higher the resistance*. This is due to electrons needing to travel a longer distance, so there is a higher probability that collisions will occur.

Cross-sectional area of the conductor

The larger the cross-sectional area, the lower the resistance. The reason is that electrons can pass more easily through a conductor that has a larger cross-sectional area.

Electron density

Electron density refers to how many free electrons per unit volume of the conductor are able to carry out conduction. Some metals, like silver, naturally have more electron density than other metals; hence, these metals are naturally better conductors, and have a lower resistance.

Superconductivity

13.4

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

As mentioned before, temperature has a determining effect on the conductivity or resistance of a metal conductor. Increasing the temperature will increase the resistance of a metal conductor, while lowering the temperature has the opposite effect; this can be summarised as shown in Figure 13.2 (a). From this graph, one can conclude that in order to make a metal a good conductor, one of the easiest ways is to lower its temperature.

The graph shown in Figure 13.2 (b) demonstrates a similar pattern; however, one can see that as the temperature decreases, there will be a point where the resistance of the metal suddenly drops to zero. This effect is known as **superconductivity**, and the temperature needed for this to happen is known as the **critical temperature**. A metal or conductor that is exhibiting superconductivity is called a **superconductor**.

Definition

Superconductivity is the phenomenon exhibited by certain metals where they will have no resistance to the flow of electricity when their temperature is cooled below a certain value (critical temperature).

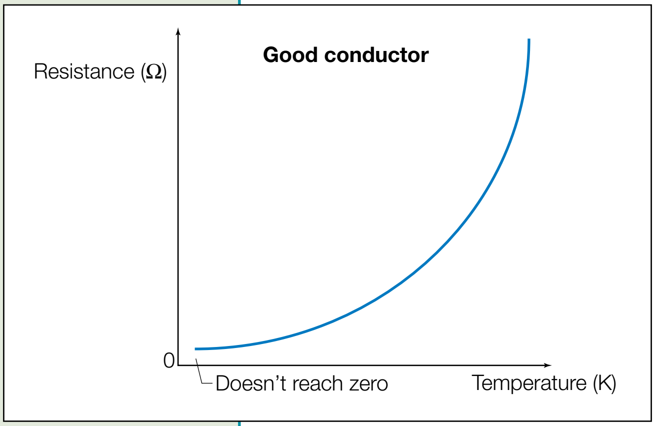


Figure 13.2 (a) Increasing temperature and resistance

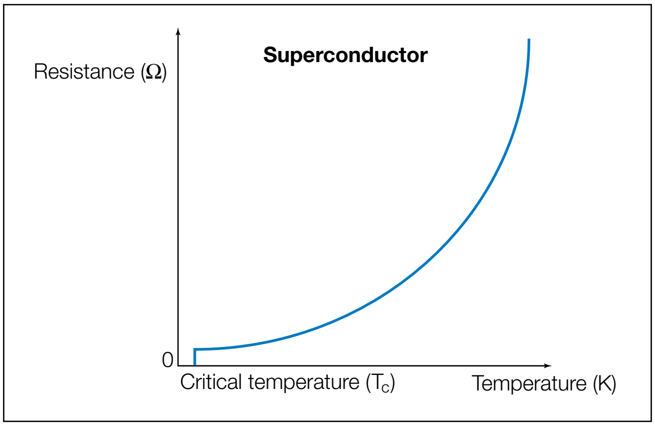


Figure 13.2 (b) Decreasing temperature and resistance

It is important to realise that not all metals can exhibit superconductivity. In other words, some metals, even when their temperature is cooled, can only behave in the way that has been described in Figure 13.2 (a). Also, a metal that can potentially exhibit superconductivity will only do so when its temperature is below the critical temperature. It is more correct to label a metal as a superconductor while it is demonstrating superconductivity.

More on superconductors

SECONDARY SOURCE INVESTIGATION

PFAs

H1

PHYSICS SKILLS

13.1A, 14.1A, H

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

We are now in the position to describe the types of superconductors. In general, we usually categorise superconductors into two main groups:

- type 1: Metal and metal alloys
- type 2: Oxides and ceramics

Type 1. Metal and metal alloys

There are numerous metals and metal alloys that can behave as superconductors. They were the first ones discovered in history. Some examples include:

Examples of types of superconductors. Bars of niobium, used in special steels, alloys and superconductors (left). Flexible tape of high temperature supconducting ceramic material (right)

Table 13.1

Metal and metal alloys	Critical temperature (T_c) Kelvin (K)
Aluminium	1.2 K
Mercury	4.2 K
Niobium-aluminium-germanium alloy	21 K

The advantages of these superconductors are:

- These metal and metal alloy superconductors are generally more workable, as with all metals; this means they are more **malleable** (able to be beaten into sheets) or **ductile** (able to be extruded into wires).
- They are generally tough and can withstand physical impact, as with all other metals.
- They are generally easily formulated and produced, as they are either just pure metals or simple alloys. They were the first to be discovered also for this reason.

The disadvantages are:

- These metal and metal alloy superconductors usually have very low critical temperatures, as shown in Table 13.1. These low critical temperatures are technically very hard to reach and maintain.
- They usually require liquid helium as a coolant to cool them down below their critical temperature. Liquid helium is much more expensive compared to the other common coolant used, liquid nitrogen, whose boiling point is –196 °C (77 K), which is not low enough for these metal and metal alloy superconductors.

Type 2. Oxides and ceramics

Again there are numerous examples in this category of superconductors, and new ones are constantly being developed. A few examples are given in Table 13.2.

Table 13.2

Oxides and ceramics	Critical temperature (T_c) Kelvin (K)
$YBa_2Cu_3O_7$	90 K
$HgBa_2Ca_2Cu_3O_{8+x}$	133 K

The *advantages* of this group of superconductors are basically to cover the disadvantages of metal and metal alloy superconductors. The main advantage is that one can use liquid nitrogen to reach the critical temperature, as well as maintain it. Note that liquid nitrogen has a boiling point which is low enough to cool the type 2 superconductors, but not type 1.

The *disadvantage*, on the other hand, is that they do not have some of the advantages of metal and metal alloy superconductors. They are more brittle and fragile, shatter more easily and are generally less workable, which can pose a problem if one is going to use them to make electric grids, where the material has to be extruded into very thin wires. Also, they are chemically less stable and tend to decompose in extreme conditions. Furthermore, they are often more difficult to produce, and for that reason they were the later ones to be invented.

13.5 Explaining superconductivity: the BCS theory

PFA H2

PFA H5

'Analyses the ways in which models, theories and laws in physics have been tested and validated'

'Identifies possible future directions of physics research'

TR

Mapping the PFAs
PFA scaffold H5

■ *Discuss the BCS theory*

Superconductivity was first observed in 1911. An explanation for the cause of superconductivity evaded the likes of Einstein, Feynman and Bohr. Bardeen, Cooper and Schrieffer (whose surnames give rise to the naming of the BCS theory) won the Nobel Prize in 1972 for their explanation, which is based on the existence of 'Cooper pairs'.

How has this theory been tested?

The BCS theory, when applied to the original family of low temperature superconductors (those elements that have a critical temperature within a few degrees of absolute zero, 0 K), has proven to be statistically correct in the way it predicts the actual critical temperature and the conduction that occurs.

However, a newer type of superconductor, known as the cuprates (due to the presence copper and oxygen in the substance), which have the ability to become superconducting at relatively high temperatures (i.e. their critical temperature is above that of liquid nitrogen) have made up the family of high-temperature superconductors. The BCS theory, when applied to these high-temperature superconductors, does not work.

Where to from here?

While further research into superconductivity proceeds in many facilities and universities around the world, newer theories using complex quantum theory ideas are being developed, tested and validated to explain what is happening in high-temperature superconductors. If we can understand the mechanism by which superconductivity occurs, we stand a better chance of making a room-temperature superconductor.

WWW→ USEFUL WEBSITES

Information about superconductors and their history:
http://superconductors.org/History.htm

The next question is why some materials lose their resistance completely when they are cooled below certain temperatures (Fig. 13.2b) while others do not (Fig. 13.2a). It is reasonable to predict that there must be something happening at these extremely low temperatures that results in this sudden drop in resistance. To account for this, a group of scientists including John Bardeen, Leon Cooper and John Schrieffer developed a theory known as the BCS theory, named after themselves, which later became the most accepted explanation for the sudden drop in resistance at temperatures below the critical temperatures. It is important to realise that the BCS theory is a quantum mechanical model, and therefore is associated with very complicated physics and mathematics if it is to be explained fully. However, at the HSC level, only the fundamental concept needs to be covered and the explanation is simplified.

The BCS theory is as follows:

1. Under low temperatures, that is, below the critical temperature, the vibration of the lattice is minimal.
2. The electron travelling at the front (first electron) attracts the lattice, as shown in Figure 13.3 (a).

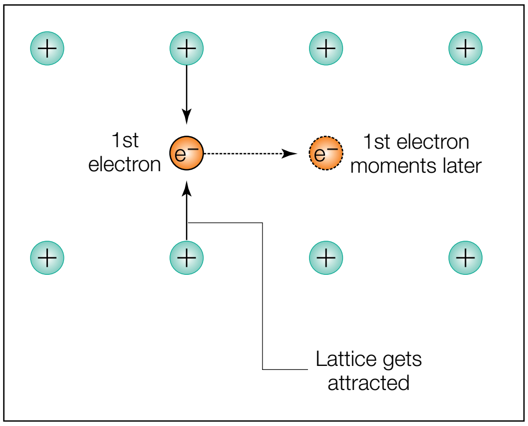


Figure 13.3 (a) BCS theory and Cooper pairs

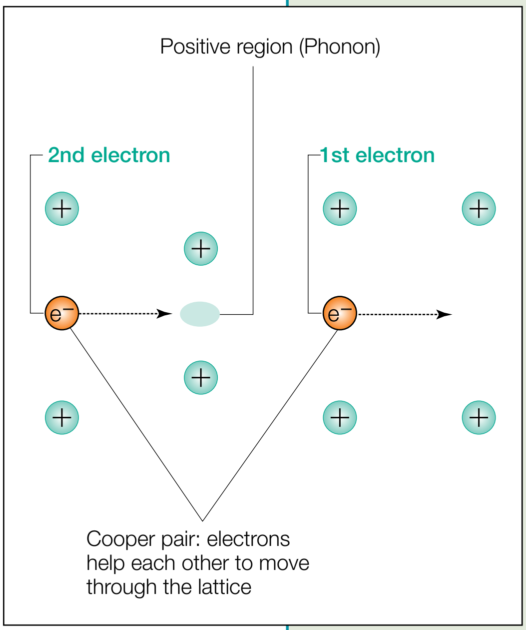


Figure 13.3 (b) Lattice response and distortion

3. The lattice responds, very slowly because they are heavier, and therefore distorts after the fast moving electron has passed this point, as shown in Figure 13.3 (b).
4. This creates a positive region behind the first electron, which attracts the next electron and helps it to move through the lattice. (Note that when the second electron reaches this positive region, the lattice would have recoiled back to its original position due to the elasticity of the lattice to allow the second electron to pass through.)
5. This process repeats as the electrons move through the lattice. These two electrons move through the lattice assisted and unimpeded in a pair called the **Cooper pair**.

The Meissner effect

FIRST-HAND INVESTIGATION

PHYSICS SKILLS

H12.1A, B, D
H12.2B
H12.3 A, D

TR

Risk assessment matrix

■ *Perform an investigation to demonstrate magnetic levitation*

Definition

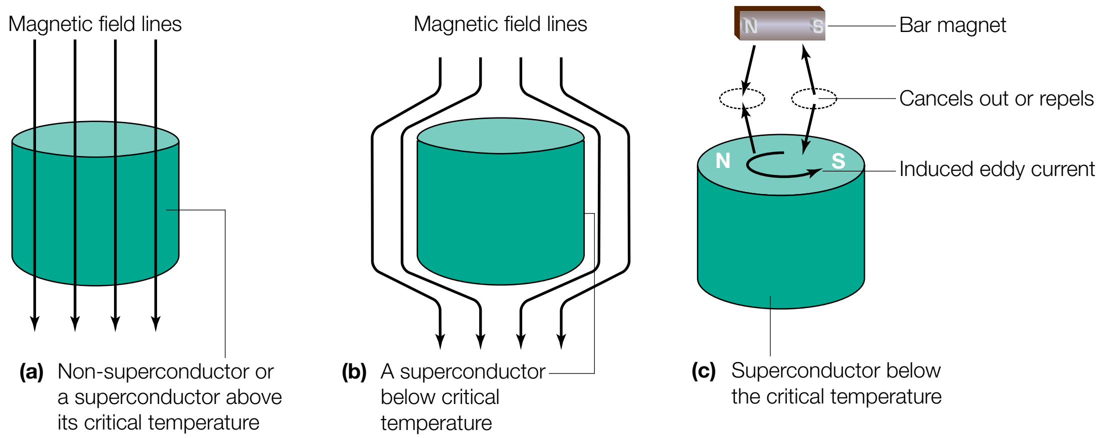
The phenomenon that a superconductor is able to totally exclude external magnetic fields, therefore its internal magnetic field is always zero, is known as the **Meissner effect**. The Meissner effect allows a superconductor to be able to levitate a small piece of magnet placed on top of it.

These definitions are illustrated in Figure 13.4 (b) and (c). Note that in Figure 13.4 (a), the magnetic field is able to penetrate through a normal piece of conductor. However, when the conductor changes to a superconductor, as shown in Figure 13.4 (b), it is able to exclude the external magnetic field and allow none of it to penetrate through. Figure 13.4 (c) shows a small bar magnet hovering over the superconductor.

The hovering or levitation of a small piece of magnet over a superconductor may be demonstrated in a school laboratory as shown in Figure 13.4 (c). The following is a summary of the procedure.

1. A piece of superconductor is cooled by immersing it in liquid nitrogen.
2. Use a pair of forceps to pick up a small piece of permanent magnet and carefully place it above the superconductor.
3. Describe the observations.
4. Describe what will happen when the magnet is forcefully pushed downwards.

Figure 13.4 **(a) to (c)** A demonstration of the Meissner effect: a small magnet is made to hover over a superconductor



NOTE: Liquid nitrogen has a temperature of –196 °C and can cause serious injuries if it is splashed on the skin or into the eyes. *Wearing of safety goggles and rubber gloves is mandatory for this demonstration.* Students must *not* be too close to the apparatus.

NOTE: Normal magnets can be made to levitate if placed carefully inside a glass tube. Liquid nitrogen and superconductors are not required.

13.6 Explaining the Meissner effect

H14.1 A, B, C, D, F, G

■ *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*

The physics behind the **Meissner effect** can be summarised as the following:

When an external magnetic field attempts to enter a superconductor, it induces a perfect eddy current to circulate in the superconductor. The current is 'perfect' as a result of zero resistance to the flow of electricity in the superconductor. This 'perfect' current flows in such a direction that the magnetic field it produces is just as strong, but in the opposite direction to the external magnetic field. This leads to a total cancellation of this external magnetic field and allows none of it to penetrate through the superconductor.

This idea can also be used to explain why a small magnet is able to hover over a piece of superconductor. In a sense, the perfect flow of induced current in the superconductor will allow it to set up magnetic poles that are strong enough to repel the small magnet forcefully enough to overcome its weight force.

The Meissner effect presents another property possessed by superconductors. Note, therefore, that superconductors have two very important properties:

1. Their electrical resistance is effectively zero.
2. They demonstrate the Meissner effect.

Also, these potential properties will only be exhibited when the potential superconductors are cooled below their critical temperature.

Applications of superconductors

- ***Gather and process information to describe how superconductors 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***

SECONDARY SOURCE INVESTIGATION

PFAs

H3, H4, H5

PHYSICS SKILLS

H12.3A, B, D
H12.4F
H13.1A, B, C, D, E

As a simple summary, superconductors are mainly used in applications for:

1. conducting electricity efficiently
2. generating very powerful magnetic fields

1. *Efficient conduction*: As discussed in Chapter 8, energy is lost as heat when a current flows through a conductor. The amount of heat lost (**P**) can be quantified by the equation $\mathbf{P = I^2 R}$, where **I** is the size of the current and **R** is the resistance of the wire. Superconductors have effectively zero resistance, so no heat loss will occur when the current passes through superconductors.
2. *Powerful magnets*: As discussed in Chapter 5, the strength of the magnetic field produced by an electromagnet is directly proportional to the current fed into it. However, there is a limit to the strength of the magnetic field produced. A very strong magnetic field requires a very large current, which inevitably results in a significant amount of energy loss as heat. In other words, some of the supplied electrical energy, apart from creating a magnetic field, is also lost as heat. As we increase the current in an attempt to create a stronger magnetic field, we will find more and more electrical energy is lost as heat rather than being converted into the required magnetic field, making the whole process very inefficient.

Hence, if we can use an electromagnet that has zero resistance, that is, one made from superconducting material, no heat loss will occur as the current flows, and all the electrical energy would go to produce the magnetic field. This not only makes the whole process more energy efficient but also allows the magnetic field to be stronger.

The extra benefit of a superconductor electromagnet is that there is a phenomenon known as a perpetuating current; once a current is established in the superconductor, because of the lack of resistance in the conductor, the flow of current will not diminish even if the power source is removed. This circulating current resides in the superconductor for a long period of time, generating a magnetic field without further energy input. This further enhances the energy efficiency.

Maglev train

Maglev trains make use of superconductors to build trains that can travel at a very high velocity. Currently such trains are still rare and are only available in a few countries, for example, China, Japan and Germany. The operation of these trains is technically quite complicated in terms of engineering and design. However, the basic principle behind such trains is still easy to understand. In simple terms, the operational principle of the maglev train can be divided into two sections:

- levitation
- propulsion.

Maglev train, Shanghai, China

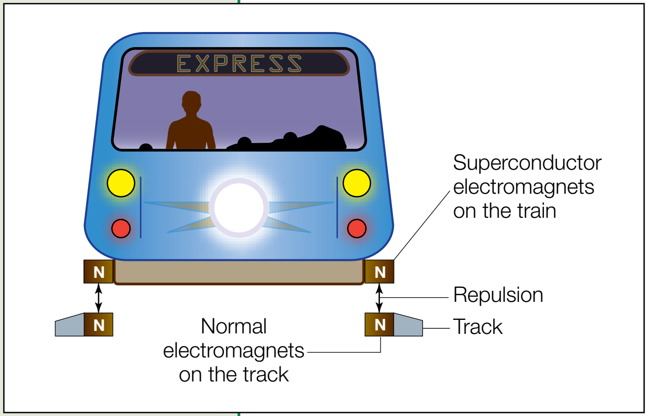


Figure 13.5 (a)
Magnets repulsion

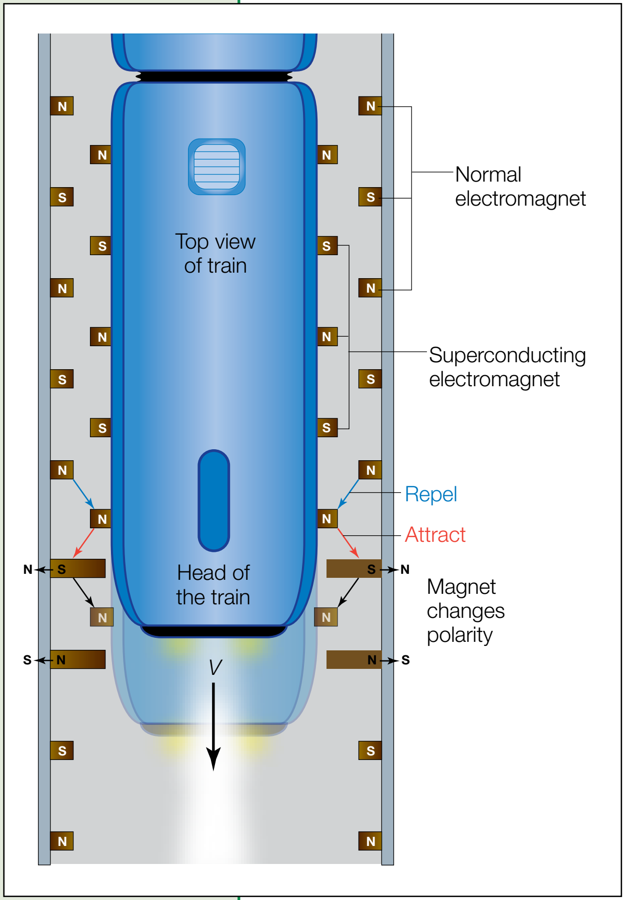
Levitation

Maglev trains are levitated off (hover over) the ground. To levitate the train, the magnets are set up between the train and the track such that they are made to have the same pole so that they can repel, as shown in Figure 13.5 (a). The repulsion is made strong enough to overcome the weight of the train and thus the train hovers. In theory, both the magnets can be made from superconductors. Superconductor magnets produce more powerful magnetic fields and are more energy efficient as discussed before; in addition, they are easier to control in terms of their magnetic polarities. However, the drawback of using superconductors is that they require coolants to keep their temperature below the critical temperature; also, the presence of superconductors makes the design more complicated and expensive. Weighing the costs and benefits, generally only the electromagnets on the trains are to be made from superconductors, whereas the electromagnets on the track are just made from normal conductors. It is much easier to just cool the limited numbers of superconductors on the train than try to cool down the entire track!

Propulsion

It is no use just to be able to hover the train above the ground, it also needs to be able to be propelled forward. To do this, another group of magnets is used; both the magnets on the side of the train and the magnets on the track are made to have alternating polarities. As shown in Figure 13.5 (b), the north poles at the head of the train are attracted by the south poles ahead of them and repelled by the north poles behind, and therefore the train moves forward. A similar process occurs along the entire length of the train. When the train moves forward, the north poles will be pulled back by the south poles on the track. If nothing is done, the train will move back before being pulled forward again, therefore oscillating but not accelerating. To resolve this problem, every time the train gets past one set of magnets on the track, the polarity of the magnets on either the train or the track (but not both) will need to reverse. For instance, as shown in Figure 13.5 (b), the original south poles on the track are changed to north poles

Figure 13.5 (b)
Top view of maglev train



such that they can keep propelling the train forward. As this process repeats, the train gets faster and faster.

Finally, as the train speeds up, it will take less time to reach the next set of magnetic poles on the track. This means the frequency with which the polarity changes needs to increase as well in order to synchronise with the increase in speed of the train. This also means the frequency with which the magnetic poles change effectively limits the speed of the train.

Advantages

First of all, the train is levitated off the ground, which means it is not making any physical contact with the track. This minimises the frictional drag the train experiences, and thus improves its maximum speed. Furthermore, no mechanical energy is lost to overcome the friction, which means the train is extremely energy efficient. In addition, the hovering makes the train extremely smooth to run, and the minimal contact results in less wear and tear, thus less effort is needed for maintenance.

Disadvantages

Superconductors are very expensive to run, mainly because they are designed to operate at very low temperatures and so there is a constant need for coolants. Also, low temperatures are technically difficult to confine, and therefore requires high technology. Currently, only a few countries have the technology and the financial capability to build such a train; these high costs are reflected in the high cost of tickets, making the maglev train less acceptable compared to the normal transport means.

Maglev trains are a relatively new technology and improvements are constantly being made. You are encouraged to do your own research on maglev trains and find out about the most current developments and modifications.

Switches and supercomputers

From the previous chapter, recall that the way to make integrated circuits powerful is to have as many devices as possible on a single chip. This is often limited by many factors. One of them is the heat produced by these devices. The fact that superconductors have effectively zero resistance and therefore effectively zero heat production when electricity flows through them means that the devices made from superconductors can be integrated closer than those made from ordinary semiconductors. This makes the integrated circuits made from superconductors far more powerful. Furthermore, the fact the devices are packed closer to each other means there will be even less delay in signal transfers between the devices, so these integrated circuits are also faster. These more powerful and faster operating integrated circuits lead to supercomputers, which are able to perform extremely complex operations at a much enhanced speed. These supercomputers may be employed for scientific or military purposes.

The only disadvantage of such a system is that they require coolants (e.g. liquid nitrogen) to run, so it is not feasible for personal use in homes. The need for coolant makes these computers technically difficult to run and very costly.

A supercomputer

Motors and generators

When superconductors are used in motors, the low resistance to the flow of electricity means that with any given amount of voltage, the net current flow in the motors will be bigger, which means the motors are made more powerful.

Also, as discussed, superconductors lose no heat when currents pass through them, making both superconducting motors and generators more energy efficient. Furthermore, because the devices are more energy efficient, they can be made smaller but still be able to carry out the same amount of work.

Power transmission lines

This is a very good future application of superconductors. Recall from Chapter 8 that large amounts of heat are lost through the transmission wires when they transmit electricity from the power station to households. As discussed in Chapter 8, one way to reduce the heat loss is to reduce the current size through the wires, and this can be done by increasing the voltage using a step-up transformer. However, even then, there will still be a large amount of energy loss over the transmission wires as a result of their reasonably large resistance.

The good news is that once transmission wires are made from superconductors, the resistance of the transmission wires can effectively be reduced to zero. As discussed before, this minimises the heat lost, which means all of the energy produced at the generator can be transferred to households, making the process almost 100% efficient. Minimal energy waste during transmission results in the whole process being more environmentally friendly. This also enables the power station to be built further away from large cities, which reduces pollution near metropolitan areas.

The other added benefit of the superconductor transmission wires is that they can carry the same amount of electricity with a much smaller diameter, which means the cost of manufacturing these transmission wires is greatly reduced.

Nevertheless, the major disadvantage of the system is that these wires need to be cooled below their critical temperatures, which requires liquid nitrogen. Unfortunately, as they are open to the environment, cooling will be very difficult and expensive to achieve and maintain. The other setback of the superconducting wires is that they only transmit DC. This is because in order for Cooper pairs to form, electrons need to travel in a constant direction. Oscillating electrons in the case of AC will cause the disturbance of Cooper pairs, so the disruption of superconductivity. The fact that our current power system operates on AC means that significant changes would be required if we were use DC to transmit electrical energy.

13.7 Limitations of using superconductivity

■ *Discuss the advantages of using superconductors and identify limitations to their use*

As demonstrated through all the applications described in the previous section, superconductivity will hugely benefit human beings and society: both increasing the energy efficiency of the operations as well as providing us with applications that are otherwise not possible. One of the negative aspects of using superconductors is their low operating temperature. Low temperature is extremely hard and expensive to reach; once established, it is very difficult to insulate from the surroundings. Associated with that, of course, is the huge cost and inconvenience.

Fortunately, with research, superconductors are being developed with higher and higher critical temperatures and already there are superconductors that can operate at critical temperatures over 100 K. In the near future, there is a possibility that superconductors that can operate at room temperature will be developed. Once this happens, we will be able to use superconductors without coolants or spending effort on maintaining the temperature. This will be a milestone in human history in terms of introducing perfectly energy efficient devices, super powerful computers and electronics, all of which will be economical to produce and easy to operate.

CHAPTER REVISION QUESTIONS

1. (a) Briefly describe the Braggs' X-ray diffraction experiment.
   (b) The Braggs developed the equation $n\lambda = 2d\sin\theta$ as a part of their experiment. Explain the meaning of each of the terms in the equation. What is the significance of this equation?
2. Explain how a change in temperature and adding impurities would affect the resistance of a metal conductor.
3. Discuss the importance of the critical temperature in the context of superconductors.
4. There are two types of superconductors—metal and metal alloy, and metal oxide and ceramic.
   (a) What is one significant feature of all metal-oxide and ceramic superconductors?
   (b) Evaluate the implication of this feature in the applications of superconductors.
5. Outline the theory used to explain superconductivity.
6. A small magnet is able to hover over a piece of superconductor.
   (a) What is the name of this phenomenon?
   (b) Offer a satisfactory explanation as to how it may happen.
   (c) Predict what will happen if one keeps pushing the magnet down towards the superconductor.
7. (a) What do you think the word 'maglev' stands for?
   (b) What is the superiority of the maglev train compared to the ordinary steam or electrically powered trains? Relate this superiority to the functional principle of the maglev train.
   (c) What are the drawbacks of the maglev train?
8. There are debates about whether it would be suitable to replace power transmission lines with superconductors. Justify your opinion on this debate.
9. Evaluate the impacts of the discovery of room temperature superconductors. In your answers, make reference to the current uses of superconductors.

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Answers to chapter revision questions