Making Materials Matter: Measuring Magnetism

Introduction

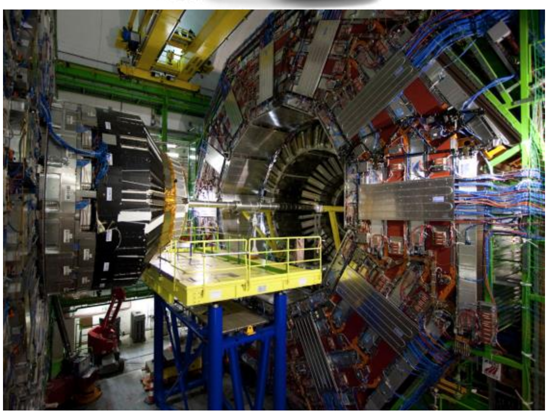
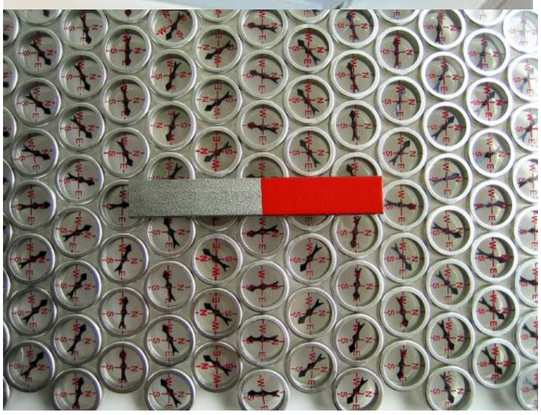
Magnets are critical for a whole variety of modern applications. Perhaps the most noticeable are in motors and generators, but they are also an essential part of speakers, rubbish separators and many other devices. In science, magnets are essential in particle accelerators and in devices such as MRI and NMR scanners

The KS3 curriculum introduces magnets and their uses. Pupils get a good idea of the differences and similarities between permanent and electromagnets and understand a little of their basic properties. However, there tends to be little focus on the different materials used and on how much the properties of these can vary.

This project focusses on testing magnets in two different ways, using tests that can be easily understood to emphasise just how different magnetic materials can be. From this they can start to consider ideas about the thought process behind choosing a magnetic material for a particular application

The tests used were:

- Hanging masses off the magnet to measure the maximum pulling force of the magnets (it is amazing how much force is required even for a small magnet)
- Moving magnets together until they attract and measuring this distance

Research

The students will need to do some independent research into different types of material used for permanent magnet and what the key performance criteria are for these. These are roughly summarised below:

Performance Criteria

Field strength

'Permanent' magnetic materials must be magnetised by applying a large magnetic field in a particular direction (this can be demonstrated with a small rod of steel, for example a bit of a paperclip. By rubbing one end with one pole of a strong magnet and the other end with the other, the paperclip will become magnetised. If stuck onto a small piece of wood (a coffee stirrer works well) and floated on water it will align with the Earth's magnetic field – you have made a compass!).

Once this field is removed, the amount of magnetic field remaining in the material gives the "strength" of the permanent magnet. Technically this is known as the remanent field of the magnetic material

Ability to be demagnetised

If a magnet is put in too large a magnetic field it will lose its magnetism/will have its magnetic moment put into the direction of the applied field. This is also strongly dependent on the shape of the magnet. If the material is long in the direction of magnetism then it is hard to demagnetise, if it is short then it is much easier. This means that long rods magnetised along their length are very stable, but this reduces as you make the rod shorter (with thin discs performing very poorly)

Maximum operating temperature

Above particular fields a magnet will lose its magnetism. For permanent magnetic materials this will not be recovered on cooling below this temperature without also applying a large magnetic field

Cost

For any real application, the performance of the magnet has to be compared to how much it costs!

Weight

Magnets are often used in motors and other moving devices. There is a strong driver for these devices, and so the magnets involved to be light

Materials

Neodymium Iron Boron (NdFeB)

These are the strongest permanent magnets known, with very strong magnetic fields. Because they are very strong they can be used in very small sizes and in unfavourable shapes such as thin discs. This makes them perfect for devices like small, high-performance motors or headphones

However, they are also the most expensive, with prices varying significantly depending on rare-Earth element supply. They have to be made by heating powder and are brittle once formed, so are relatively difficult to make and to shape. They also have poor temperature stability, with a very low maximum operating temperature and also a significant decrease in field performance at cryogenic temperatures.

Samarium Cobalt (SmCo)

These are slightly weaker than NdFeB but are still very strong. In general they are only used where NdFeB cannot work, such as at elevated or cryogenic temperatures.

AlNiCo

Confusingly, this series of magnetic materials are mostly made of iron, with aluminium, nickel and/or cobalt additions. They have a weaker magnetic field and are easier to demagnetise than NdFeB, but not significantly so. This means that they are less suitable to very small sizes and thin shapes.
AlNiCo is still expensive, but much cheaper than the two rare-earth magnets above. They are also much easier to make as they can be made by pouring molten metal, and the final product is more ductile and is less likely to crack in use. This means AlNiCo is commonly used for large magnets such as in big motors where NdFeB would be too expensive and the magnet would be extremely difficult to make. The operating temperature is also much higher, making them much better for any applications involving heat.

Ferrite (ceramic)

Made from iron oxide. These are significantly weaker than NdFeB, and are also very easily demagnetised (a nice demonstration to show this is that you can flip the poles of a ferrite magnet by rubbing them with the appropriate ends of a NdFeB magnet). This means they are rarely used for high-performance applications

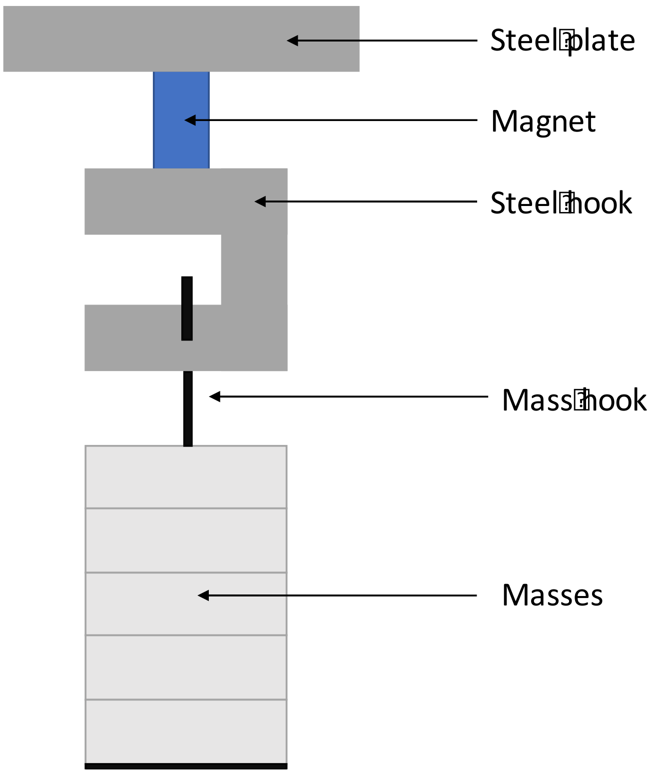
However, they are extremely cheap, so they are commonly used for things like fridge magnets where cost is the main driver. The other advantage of ferrite is that it is considerably lighter than any of the other materials (which are mostly iron-based). This means it is sometimes used for cheap motors for small devices.

Equipment Required

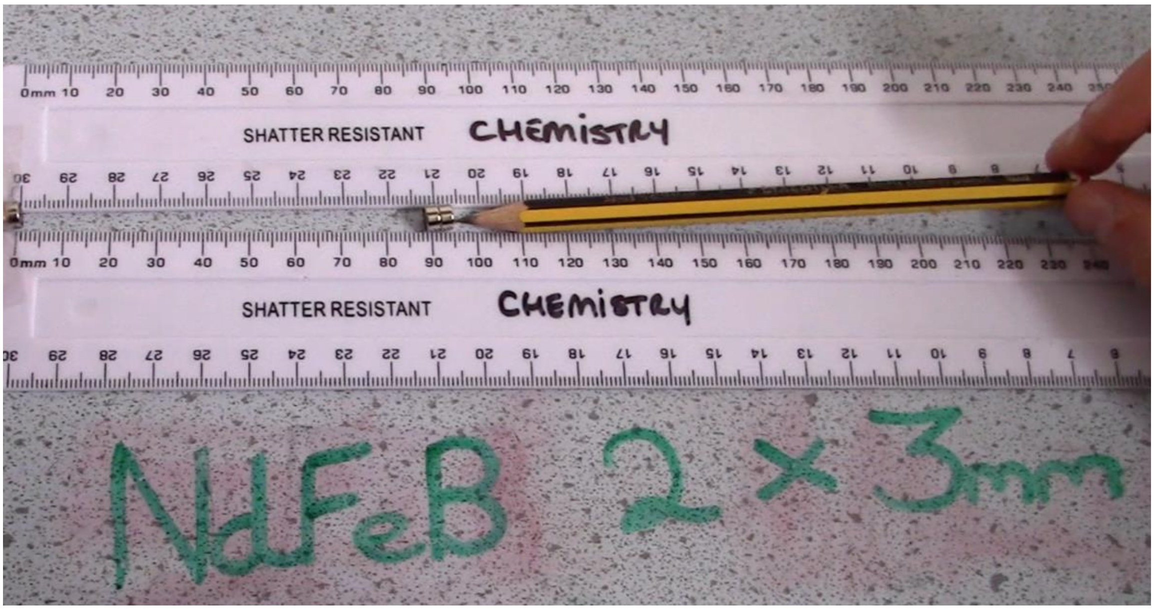
- Magnets of different materials (ideally all of the same size and shape). These are available cheaply from http://www.first4magnets.com/ and other places. 6mm x 6mm is a good size as it limits the risk of pinching fingers and keeps the force required to separate the magnets to a measurable level.
- Masses. Standard school lab masses on a mass hook to suspend off the magnets and measure the forces involved. In absence of this, a large water bottle could be filled with different amounts of water instead
- A hook to suspend the masses off (a picture hook works well). This needs a flat side for the magnet to attach to and must be magnetic
- If using a small magnet then a second piece of steel to hold is useful
- A ruler
- If available a video camera (though can do by eye if necessary)

Experiments

1. *Magnetic force using weights*
   - Stick magnet to hook and to piece of metal to hold
   - Attach masses to mass hook
   - Attempt to lift mass hook and masses using hook
   - See how much mass can be lifted before the magnet disconnects from the hook
   - Repeat with different magnetic materials
   - This could also be repeated with different sizes/shapes of magnet



2. *Magnetic attraction distance*
    - Fix one magnet at the zero point of a ruler using blu-tack, plasticine or similar
    - Start the other magnet a long way away (with opposite poles towards each other, marking the poles beforehand is very useful), then slowly push it along the ruler towards the other magnet
    - Record what distance the magnet stops requiring pushing and is attracted to the other magnet. This can be done by eye, but it is more fun to film the experiment and work it out by playing it back
    - Repeat a few times with each magnet, then do the same for the other magnets



Some notes on the experiments

You would expect pretty similar results from both experiments. However, the ferrite magnets will perform much better in the attraction test than the weight test (though they will be the worst both times. This is likely to be because they only have a small force, but they are also much lighter.

Health and Safety

- Some of the magnets are strong and can cause issues for people with pacemakers. Check that there are none close by. Keep the magnets small (for the 6x6mm magnets used the distance that a pacemaker would be affected was only about 10cm)
- Pinching risk between magnets. Magnets can easily fly towards each other/other objects. This can be minimised by using small magnets and magnets with coatings
- Weights falling on people. Minimise by using small magnets and so needing smaller masses. Make pupils lift masses up rather than suspend them on a hanging magnet to reduce risk of falling