Researchers in Schools

Mastering Magnets: What's the big attraction to these critical materials?

Pupil Name

Coursebook Designed by Dr. Mackie

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Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
1			
2			
3			
4			
5			
6 (Feedback)			
7 (Feedback)			

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1	Baseline assignment - see page 16	
Tutorial 2	Summary question - see page 22	
Tutorial 3	Summary question – see page 29	
Tutorial 4	Summary question – see page 34	
Tutorial 5	Final assignment – see page 41	

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on 9th August	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Course Rationale

Welcome to the Uni-pathways program!

You have been identified as someone who has the potential to go to a highly selective university. This course is designed to help you get a better understanding of what a highly selective university is, what it is like to do university-style tutorials, and why university can benefit you. This is so that when you come to making decisions soon about your GCSEs and post-16 pathway – e.g., sixth form, college, or apprenticeship, you are well informed and will make the best decision for you!

During this course, we will be learning about some of the research I did during my PhD. We will also talk about the routes into and progression through university, and what it is like to be a researcher. A PhD differs from anything else you would do at university because to pass at the end and achieve the title of Dr. you must contribute brand new research.

Figure 1 – Sm-Co powders and the solid magnets made during my PhD

In my PhD, I investigated how to make a type of permanent magnet called Samarium-Cobalt (Sm-Co) that is used in electric motors, aircraft, and spacecraft, where the temperatures are very high, and the magnets get very hot. Sm-Co is usually made by heating powders of these elements (and a few others) together and making a solid magnet. This usually takes hours, but I investigated a new method which instead did this in minutes. The questions I had to answer were around the quality of the Sm-Co magnet that could be made by this technique. What I was able to show at the end was the best 'recipe' to make fully solid Sm-Co magnets, as well as provide a better understand the benefits and drawbacks of the technique.

The drive for this research is that we are facing a crisis about a resource called 'the rare-earth elements'. These elements (samarium is one example) are critical to making the most powerful permanent magnets and around 90% of the world's production of the rare-earth elements comes from China. In 2010 China decided to restrict the supply of the rare-earth elements to the rest of the world. Permanent magnets are used everywhere in everyday life – headphones, computer hard-drives, mobile phones, electric cars, wind turbines, electrical generators, and as we move to a more electric society, the demand for powerful permanent magnets is only increasing! Therefore, a lot of research is being done to look at other types of permanent magnets that use less rare-earth elements, or as I did in my PhD finding ways to make the permanent magnets by better methods, so that we waste less of these critical materials.

Figure 2 – Classic bar magnet with iron filings demonstrating the magnetic field

Over this course we will learn the basics about magnets and then develop this further to understand what makes a permanent magnet permanent. We will look at the two most powerful permanent magnets Neodymium Iron Boron and Samarium Cobalt. We will discuss whether it is fair for a country to restrict supply of a critical resources and what could be done around this issue. Finally, we will look at how I made my permanent magnets. We will not only develop your subject knowledge, but also your critical thinking and writing ability. These are skills that will be invaluable to your future careers even if you choose not to go to university. The course will conclude with a demonstration of what you have learned with a fun assignment where you will compete for funding with a research proposal of your design.

Uni Pathways Mark Scheme 2020

	Subject Knowledge	Critical Thinking	Written Communication
1st	The work shows a depth of knowledge and understanding of key concepts and scientific methods, through engaging with relevant sources. Knowledge is used to build and support highly effective scientific arguments and explanations.	Analyses key scientific evidence, arguments, and reasoning. Interprets meaning and makes connections. Identifies and critically evaluates key scientific arguments and evidence, deciding on their credibility, strength, and relative significance, drawing convincing conclusions.	The work has a coherent flow and is well structured. The writing style is appropriate; scientific language and key scientific terms are used accurately and effectively to support the arguments and explanations made. There are no, or very few, errors in spelling or grammar. Consistent referencing, appropriate paragraphing and use of correctly labelled tables and graphs matching the style taught in the course.
2:1	The work shows an understanding of key concepts and scientific methods, drawing on relevant sources. Knowledge is used to build and support effective scientific arguments and explanations.	Analyses relevant scientific evidence, arguments, and reasoning. Identifies and critically evaluates relevant scientific arguments and evidence, deciding on their credibility and strength, drawing reasonable conclusions. Shows some understanding of the relative value of evidence and arguments.	The work is well-structured. The writing style is appropriate; scientific language and key terms are used correctly. There are few errors in spelling or grammar. Mostly consistent referencing and use of tables and figures; matching the style taught in the course.
2:2	The work shows an understanding of key concepts and scientific methods, with no major misconceptions. Beginning to apply this knowledge to build and support effective scientific arguments and explanations.	Identifies and uses basic scientific evidence, arguments, and reasoning. Showing some understanding of the quality of scientific arguments and evidence. Not yet showing understanding of the relative value of evidence and arguments.	The work has some structure. The writing style can sometimes be informal; occasionally scientific language and key terms are not used when it would be appropriate to do so. There are some errors in grammar and spelling do not get in the way of communicating the content. Referencing has some consistency; matching the style taught in the course Limited use of tables and graphs.
3rd	Shows a developing understanding of key concepts and scientific methods, with some misconceptions. Does not yet apply this knowledge to build and support scientific arguments and explanations.	Beginning to analyse scientific evidence, arguments, and reasoning. Describes evidence and arguments, while not yet evaluating them.	The grammar, spelling, style, and structure of the work need improving in order to communicate ideas to the reader. Scientific language, key terms and references are not always used correctly. Limited, or no use of tables and graphs.

Baseline Assignment: Pupil Feedback Report

Name of Pupil	
Name of School	
Name of RIS teacher	
Title of Assignment	

How your assignment is graded:

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Marks

OVERALL MARK / 100		FINAL MARK / 100 (including any deductions)	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the teacher should give an explanation in this section:

Mark Breakdown and Feedback

Subject knowledge	
	mark
Critical thinking	
	mark
Written communication	
	mark

Final Assignment: Pupil Feedback Report

Name of Pupil	
Name of School	
Name of RIS teacher	
Title of Assignment	

How your assignment is graded:

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Marks

OVERALL MARK / 100		FINAL MARK / 100 (including any deductions)	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the teacher should give an explanation in this section:

Mark Breakdown and Feedback

Subject knowledge	
	mark
Critical thinking	
	mark
Written communication	
	mark

Subject Vocabulary

Word	Definition	In a sentence
Pole	Region where magnetic fields go out from or go into the magnet	A magnet has a north and south pole
Magnetic field	Magnetic force is carried by the magnetic field. At any point in the field there will be a direction of force.	A permanent magnet creates its own magnetic field with direction of force travelling north to south
Magnetic moment	Turning force that a magnet will experience within a magnetic field	The magnet will be rotated so that the magnetic moment will point in the same direction of the magnetic field
Magnetism	General classification of a physical property of a material or object that is affected by or concerns magnetic fields	Permanent magnets and electromagnets are used in everyday objects because of their magnetism
Lanthanide	The lanthanide or lanthanoid series of chemical elements comprises the 15 metallic chemical elements with atomic numbers 57–71,	Samarium is an element found in the Lanthanide series on the periodic table of elements
Ferromagnetism	Magnetic classification of elements Fe, Co, Ni	A ferromagnet is strongly affected by magnetic fields
Magnetic exchange	Quantum mechanical phenomena that makes magnetic moments of each atom inside a magnetic domain all point in the same direction	A ferromagnet can be made into a permanent magnet because magnetic exchange will keep the magnetic moments pointing in the same direction
Magnetic domain	Region in which the magnetic moments of atoms are grouped together and aligned	An unmagnetised ferromagnet is made up of lots of magnetic domains pointing in random directions
Hysteresis loop	A graph plot of a magnet's magnetisation against a magnetic field applied to the magnet	A hysteresis loop is used to measure how useful a permanent magnet is
Remanence	A measure of the magnetic strength of a permanent magnet	The remanence of a magnet is measured from a hysteresis loop
Coercivity	A measure of the magnet's resistance to demagnetisation	The coercivity is a measure of how tough a permanent magnet is and is measured from a hysteresis loop

Energy product	An overall measure of how much work a permanent magnet can do. Essentially remanence multiplied by coercivity.	The most powerful permanent magnets have the largest energy products
Permanent magnet	A ferromagnet that has been magnetised by a magnetic field and kept magnetic via a coercivity mechanism	Sm-Co is a type of permanent magnet because it maintains its magnetisation
Coercivity mechanism	Way by which a permanent magnet stays magnetised and resists demagnetisation	Domain wall pinning is the coercivity mechanism used by Sm-Co type permanent magnets
Magneto-crystalline anisotropy	Coercivity mechanism derived from the crystal structure of the permanent magnet	Nd-Fe-B permanent magnets use magneto-crystalline anisotropy as their coercivity mechanism
Domain wall pinning	Coercivity mechanism derived from creating a microstructure that stops domain walls from moving	Sm-Co permanent magnets use domain wall pinning as their coercivity mechanism
Crystal structure	The arrangement of atoms in a solid material	Iron has a crystal structure that is cubic
Powder sintering	The process of heating powders of a material below the melting temperature to fuse together to make a solid, dense material	Powders of Sm-Co were sintered to make a solid magnet
Field-Assisted Sintering Technique (FAST)	A technique that uses electric current and mechanical pressure to rapidly sinter powders	During my PhD I investigated the FAST process to make Sm-Co magnets

Launch Event

The launch event is your opportunity to learn more about this course and Uni Pathways. You will watch some videos, listen to your teacher and have some discussion. Below is some room to make notes for some of the videos you will watch during the event.

Virtual Campus Tours

Notes…

The Scholars Programme Alumni

Notes…

Student Ambassadors

Notes…

Tutorial 1 – Permanent magnets: how do they work!?

What is the Purpose of Tutorial 1?

- To learn the main properties of magnets and their uses
- To identify magnetic and non-magnetic materials
- To identify Iron, Nickel, Cobalt and the Lanthanide element group on the periodic table of elements
- To learn about ferromagnetism

<u>Magnets: the basics</u>

What do permanent magnets do to other permanent magnets? What about other materials? Are you able to stick the magnet to anything in the lab? Where will it not stick? Share with the group and write them down:

Stick: _____

Won't stick: _____

Having seen what we can stick a magnet to, let's have a quick check to see what you already know!

Fill in the missing words with the following word bank (some words can be re-used).

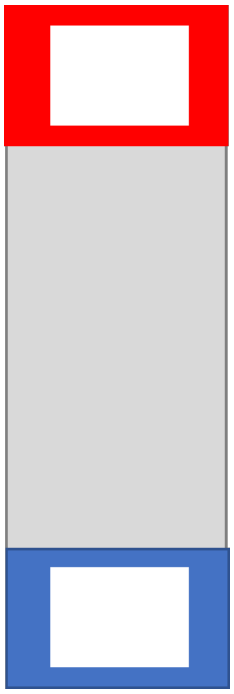
Word bank: *North, Pole, Attracted, Repelled*

1. Magnets always have a _____ and south _____
2. Magnets are _____ when two south poles are brought together
3. Magnets are _____ when a north and south pole are brought together
4. Magnets are _____ when two north poles are brought together

Magnets act the way they do because they create and are affected by magnetic fields. You may have seen before how iron filings will arrange themselves to represent the

magnetic field. We represent the shape and direction of magnetic fields by drawing line diagrams that come out of the magnet.

Complete the following figure by labelling the magnetic poles with a letter and drawing the shape of the magnetic field lines from a bar magnet. Add arrows to show the direction of the magnetic field on your line drawing.



When a magnet is affected by a magnetic field it will experience a turning force as it tries to rotate to line up in the direction of the magnetic field. This is called the magnetic moment of a magnet and can be represented by an arrow which points from south to north. This way of representing how a permanent magnet will be affected by a magnetic field is helpful, especially when we have lots of magnets interacting with one another.

Hinge point question: Draw the magnetic moment for the bar magnet above (an arrow inside the bar magnet)

<u>Applications of magnets</u>

Because of their unique properties, permanent magnets are found in lots of applications. They are unique because they can produce a magnetic field without a continuous

expenditure of energy – compared to electromagnets, permanent magnets don't have an off button!

Their magnetic fields are used to move or rotate other magnets/conductors (motors, actuators) or generate electricity (generators/turbines). Magnetic fields also affect charged particles (e.g., electrons) so can be used to control and guide charged particles, so are used in high powered microscopes or particle colliders. Another common use of permanent magnets is to separate magnetic and non-magnetic materials/powders. Permanent magnets are used in wind turbines and the largest ones will require enormous magnets that weigh over two tonnes. This is just a short list of applications, but the main takeaway is they are a lot more common and essential to everyday life than most people think.

Some examples of where you find permanent magnets these days are:

Headphones (speakers), electric cars (motors, sensors), aeroplanes (motors, couplings, sensors), computer hard-drives (actuators, read-heads), hospitals (MRIs), trucks (magnetic brakes), trains (maglev).

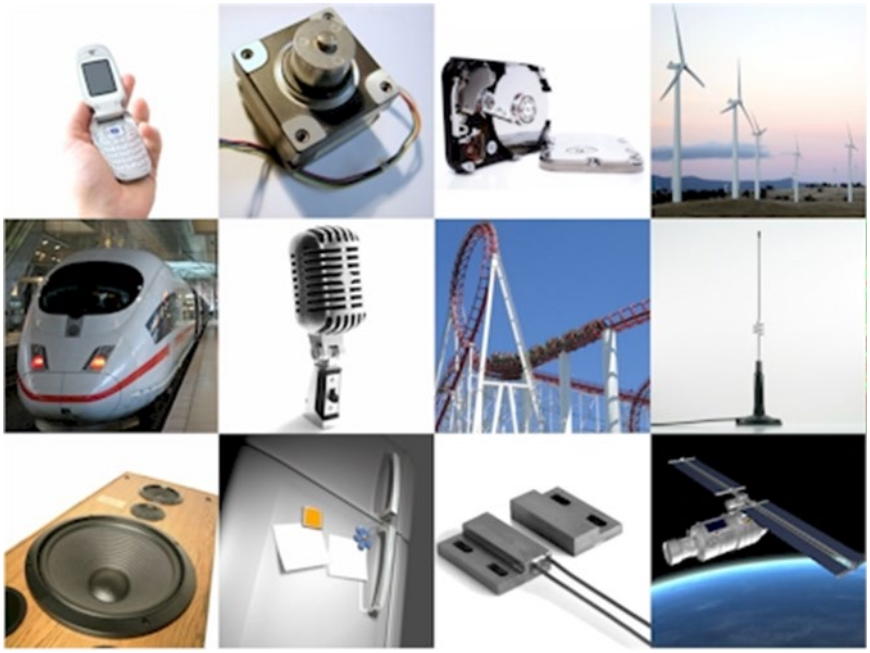


Figure 3 – Some everyday examples of where permanent magnets are used

As electrification becomes more common place within the world, the uses of permanent magnets will only increase as well.

<u>Magnetic elements and the Lanthanide group</u>

We have found that not all materials will be affected by the magnetic field produced by the permanent magnet. This is because it matters what elements these materials are made of.

Which elements does a material need to have to be magnetic?

Magnetic elements: ……..

Let's find these elements on the periodic table of elements. **Highlight these elements so they stand out**. What do you notice about where each of these elements are found relative to each other on the periodic table of elements?

Group → / Period ↓	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca		21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	* *	103 Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
			*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb		
			* *	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No		

Figure 4 – The periodic table of elements

There are some other elements that can be magnetic (at very cold temperatures!) or are important to making permanent magnets. These elements are **Nd - Neodymium**, **Sm - Samarium** and **Dy – Dysprosium**. **Try and find these elements and highlight them so they stand out**. The row that these elements are found in is called the **Lanthanide group**.

Ferromagnetism

Up until now we have talked about whether an element is magnetic or not, but a lot of elements or materials are a little bit magnetic – it is just not as obvious as it is for Iron, Nickel or Cobalt!

How an element or material is affected by a magnetic field will determine its magnetic classification. Most elements (e.g. oxygen) or materials are defined as paramagnetic, which means they will become slightly magnetic in very strong magnetic fields. They also go back to being non-magnetic when the magnetic field is removed. A lot of elements and substances (e.g. water) are defined as diamagnetic, which means they almost completely unaffected by a magnetic field.

We are interested in the elements **Iron, Nickel and Cobalt**, which are defined as **ferromagnetic** and respond strongly to an external magnetic field. In fact, the word 'ferro' refers to iron, so ferromagnetism translates to 'magnetic like iron', which was because iron was first discovered to have magnetic properties.

Magnetic exchange

Technically, every atom behaves like a little magnet. If we wanted to, we could represent the little magnets with arrows to represent their magnetic moment.

For paramagnetic and diamagnetic materials, the magnetic moments of each atom are arranged in such a way that the atomic fields of the atoms cancel out any large-scale magnetic effects. This means they aren't naturally magnetic and won't be affected by magnetic fields.

However, the magnetic moments in ferromagnetic elements are organised by an internal force that organises the magnetic moments to all point in the same direction, which creates the large-scale magnetic properties we observe. The magnetic moments inside the

ferromagnet will always want to point in the same direction – naturally, but especially with the help of an external magnetic field.

The internal force that aligns the magnetic moments in ferromagnets like iron, cobalt, and nickel, is a quantum effect called **magnetic exchange**.

It is worth noting early that not all ferromagnets are permanent magnets. While magnetic exchange will try to align the magnetic moments inside ferromagnets, there are other effects that try to fight against this. The magnetic moments in a ferromagnet will always align strongly with an external magnetic field, but only permanent magnets will stay this way when the external magnetic field is turned off.

Activity

A magnetic field is applied to two elements – A and B. Identify which one is ferromagnetic and which one is paramagnetic.

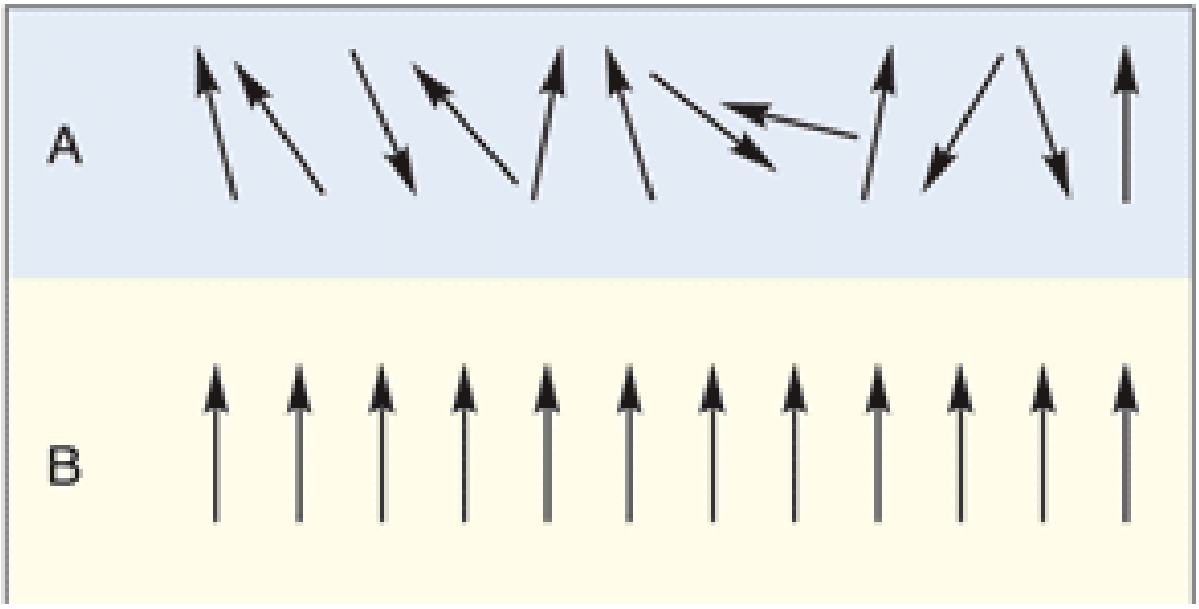


Figure 5 – A magnetic field is applied up the page. The magnetic moments of two elements (A and B) are affected by the magnetic field differently.

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Homework - baseline assignment

Why does a fridge magnet 'stick' to your fridge door and not a wooden table?

Details:

Use what we have learned in tutorial 1 and, combined with some of your own research (see examples from Wikipedia or hyperphysics below), write an essay (around 500 words/1 page) that answers the baseline assignment question.

- http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/elemag.html
- https://en.wikipedia.org/wiki/Ferromagnetism

Success criteria – how to structure your assignment and what to include:

Some topics you may wish to include:

- A brief description a magnet's features and that it creates a magnetic field
- Which elements are ferromagnetic?
- Which element(s) do you expect to be in your fridge door for it to be affected by the magnetic field of the fridge magnet?
- A brief explanation of ferromagnetism

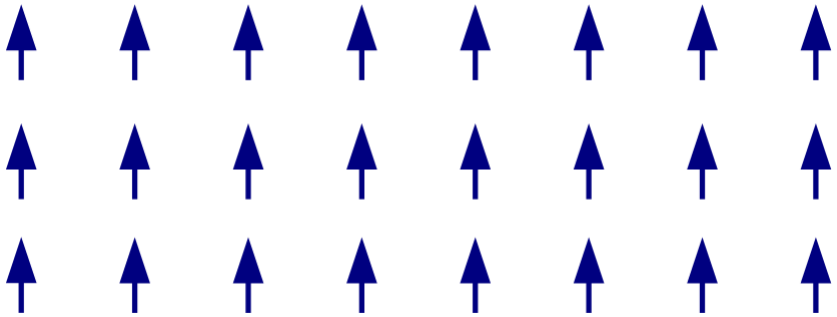
In this assignment, show me that you understand:

- Magnetic poles and magnetic fields
- Which elements are ferromagnetic?
- Which elements are strongly affected by magnetic fields, and which are not

Show me that you are able to:

- Write an essay with correct spelling and grammar
- Add pictures, with a number and labels
- State your sources of information at the end of your essay

Tutorial 2 – Putting the 'permanent' in permanent magnets



What is the Purpose of Tutorial 2?

- Students demonstrate understanding of magnetic domains through correct use in describing permanent magnets
- Students can explain how a hysteresis loop is created and what it is used to measure
- Students comprehend and can demonstrate correct use of technical terms to describe magnets – magnetization, coercivity and energy product, hysteresis loop

Recap activity

5 questions that recap the main learning objectives of tutorial 1

1. Ferromagnetism can be derived to mean "behaves like _____ in a magnetic field" Fill in the blank - Which element does this refer to?

2. Iron, Nickel are two ferromagnetic elements. What is the third ferromagnetic metal element? _____

3. Neodymium (Nd), Samarium (Sm) and Dysprosium (Dy) are elements located in which group of the periodic table of elements?
   _____

4. Magnetic m_____ is the turning force of a magnet within a magnetic field

5. An interaction occurs in ferromagnetic materials that keeps all the atomic magnetic moments within the magnet pointing in the same direction. What is this called?

   a) Exchange b) Electrostatic c) Moment

Why isn't iron magnetic all the time – magnetic domains

We've established ferromagnets are made up of lots of little magnets. Magnetic exchange will naturally try to align all the atomic magnetic moments, but there are other magnetic effects that do not want all the magnetic moments pointing in the same direction (note – just take this at face value for now!). A compromise is found where lots of small regions in the permanent magnet are created, which are called **domains**. Within each domain the magnetic moments are all aligned. This satisfies magnetic exchange. But it also means that adjacent domains can have their respective magnetic moments pointing in opposite directions. This is shown in Figure 6 with a ferromagnet in an unmagnetised state (e.g., a steel panel inside your fridge door).

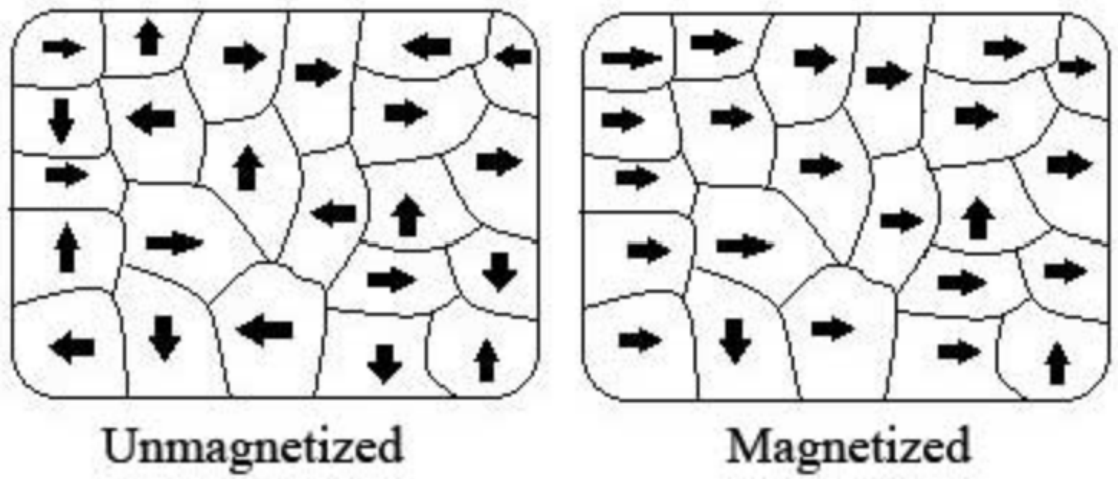


Figure 6 – Magnetic domains for a ferromagnet in a unmagnetised state and magnetised state. An external magnetic field would have been applied left to right →.

A ferromagnet is initially **unmagnetised state** when first made, which means the magnetic domains are random within the ferromagnet (see Figure 6). Due to the randomised magnetic moments, there is no overall magnetisation of the ferromagnet (each domain cancels out another domain).

When a magnetic field is applied to a ferromagnet, the magnetic moments in each domain will rotate to align with the direction of the magnetic field. The ferromagnet has been **magnetised.** Demonstration of this is shown in Figure 6, where an external magnetic field has aligned the magnetic domains with a field going from left to right.

Magnetic saturation

The strongest a magnet can become is when a 'single' domain makes up the entire magnet – the magnet cannot become any more magnetic (we say it has reached **magnetic saturation**). This happens when a strong enough external magnetic field is used to align all the magnetic domains of the ferromagnet.

Activity 1

The prepared cut outs which show the sequence of domain growth under an external magnetic field in a ferromagnet. Put them in the correct order and write underneath what is happening at each stage to the magnetic moments in the domains and external magnetic field.

Keywords to include: Magnetic moments, magnetic domain, external magnetic field, rotate

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Permanent magnets

Naturally, if the external magnetic field is turned off, the reverse of above process will occur and the magnetic moments in the domains will rotate back to how they were in the unmagnetised state. This is what happens for most ferromagnetic materials when you 'unstick' a permanent magnet from them (e.g., your fridge door which contains steel sheet)

However, permanent magnets have a trick up their sleeve! They have special properties that can keep the ferromagnet in the magnetised state. The ideal permanent magnet tries to keep the ferromagnet in the saturated state and is very difficult to demagnetise.

Permanent magnets are able to permanently create magnetic fields and do work. They can be returned to the unmagnetised state if a strong enough magnetic field is applied, or the permanent magnet is heated up.

How good is your magnet? Check using the hysteresis loop

We measure and check how 'strong' and 'permanent' a magnet is using special equipment that applies external magnetic fields and measures the response of the permanent magnet.

An external magnetic field is applied to the magnet in one direction (let's call this positive) and the strength of the permanent magnet is measured. The external magnetic field is then applied in the negative direction. The strength of the permanent magnet (magnetisation) is measured as this happens. The process is repeated until a hysteresis loop is mapped out.

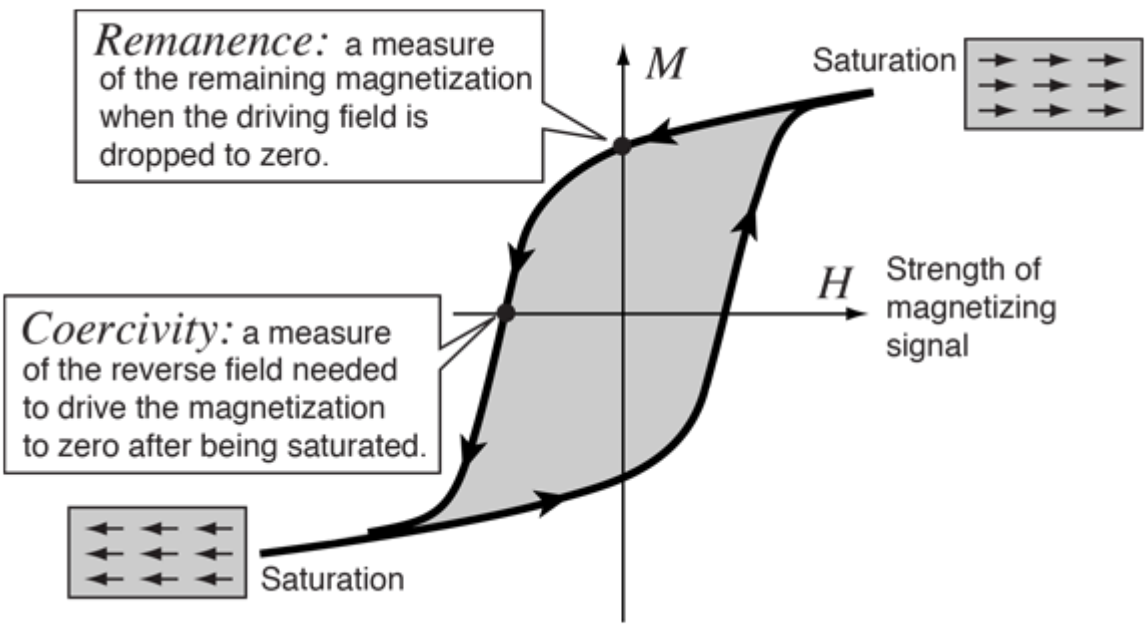

Figure 7 – A hysteresis loop of a permanent magnet showing its response (magnetisation, M) to an external magnetic field (H).

Remanence, Coercivity and Energy Product – magnets summarised!

The key magnetic properties of a permanent magnet are the **remanence** which is a measure of how 'strong' the magnet is (think of this in terms of how attractive or repulsive the magnet will be). Remanence can be thought of as the 'remaining magnetisation' in a permanent magnet when an external magnetic field is turned off. It is measured where the hysteresis loop crosses the y-axis. To make powerful permanent magnets, the remanence needs to be as large as possible.

The other magnetic property is called the **coercivity**, which is a measure of how much magnetic field (or energy) is required to 'demagnetise' a magnet (i.e., make the magnetic domains point in random directions) and can be thought of 'tough' a magnet is. We measure this where the hysteresis loop crosses the x-axis. This is how much magnetic field (or think of it as energy) is required to 'flip' the magnetisation of the magnet. For permanent magnets, we also want this to be as large as possible, so that the magnet will stay magnetic!

These two properties can be combined to give us a third property called the energy product. As a rule of thumb, the larger the energy product, the more powerful the permanent magnet is. If the permanent magnet is more powerful, this means it be made smaller and still have the same pushing or pulling effect.

Activity 3

1. On your hysteresis loop (Figure 8), label the following magnetic properties on the y and x asis: Magnetisation (M), Coercivity (Hc) for one of the curves.

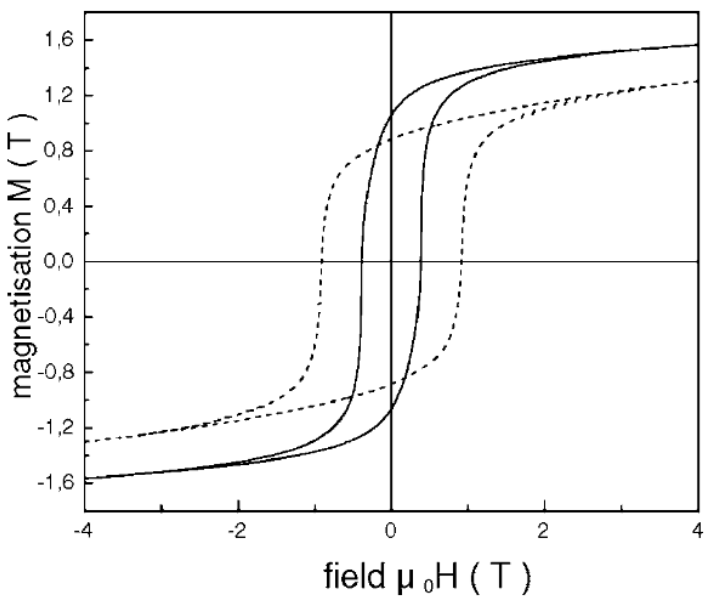

Figure 8 – Hysteresis loops of two Nd-Fe-B permanent magnets (full and dashed curves)

2. Look at the graph axes. What units do we measure magnetisation with?

   .....

3. Look at the graph axes. What units do we measure coercivity with?

   .....

4. Which of the two magnets (full and dashed curves) has the larger remanence? Try to justify your answer with a value for the remanence/magnetisation.

   .....
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5. Which of the two magnets (full and dashed curves) has the larger coercivity? Try to justify your answer with a value for the coercivity.

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Characterising magnets

During my PhD I made a lot of permanent magnets by different methods and with different materials added. To understand the effect of the different methods and materials, I would measure their magnetic properties using hysteresis loops. I gathered a lot of data on the magnetic properties of the permanent magnets I made and then analysed the graphs just like you have done. These were skills learned during my science lessons, but obviously developed and practised during University, such that when I was leading my own research and making my own experiments, I had the confidence and skills to be successful.

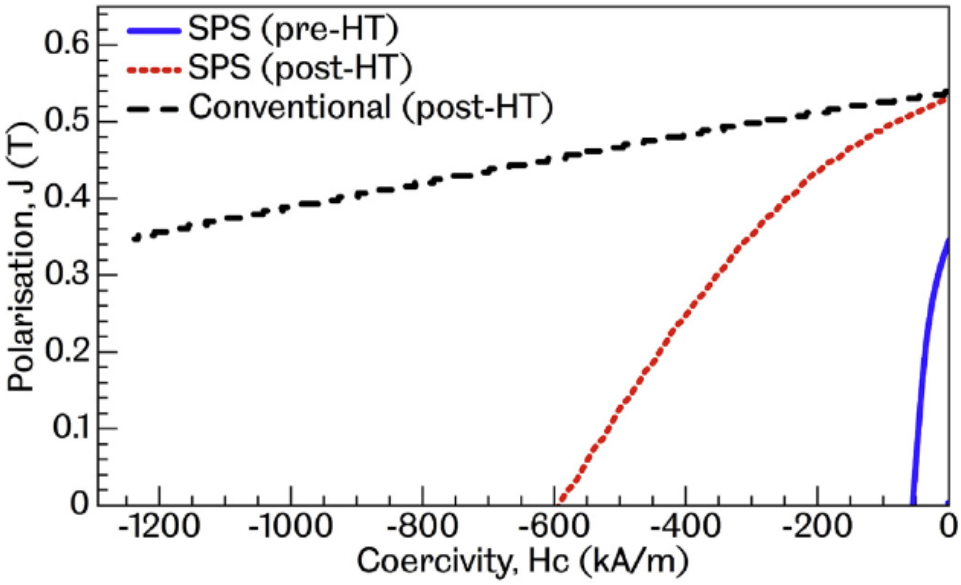

Figure 9 – Part of a hysteresis loop for a Sm-Co permanent magnet (red dash) made during my PhD

Summary activity

Fill in the missing words to complete the summarising statements of tutorial 2:

Ferromagnets are made up of small regions called magnetic _____.

A strong external magnetic field will create a single domain state at which the magnet will reach magnetic _____

A _____ loop is mapped out when an external magnetic field is applied to a permanent magnet and its response measured

The _____ is a measure of how attractive or repulsive a permanent magnet is

The _____ is a measure of how resistant to demagnetisation a permanent magnet is

Homework

Do permanent magnets stay magnetic forever? If not, what do think can demagnetise a permanent magnet? The large magnetic fields that are used to demagnetise a permanent magnet have large energy values. Think of other forms of energy stores that could cause instability in the permanent magnet. You can write down your thoughts below:

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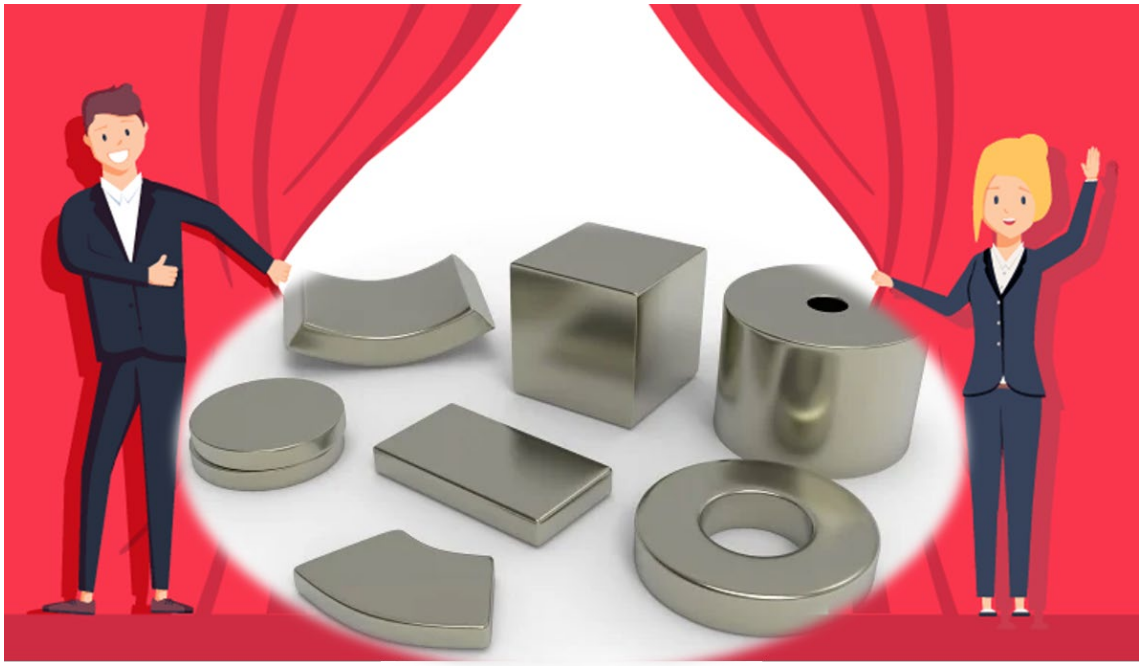
Tutorial 3 – Introducing the rare-earth permanent magnets!



What is the Purpose of Tutorial 3?

- You will be able to identify and describe the differences between the two mechanisms for magnetic coercivity – magneto-crystalline anisotropy and magnetic domain pinning
- You will be able to explain what an alloy is and be introduced to two rare-earth permanent magnet alloys – Nd-Fe-B and Sm-Co
- You will be introduced to the Sm-Co magnets I made during my PhD

<u>Recap activity</u>

Five questions that recap the main learning objectives of tutorial 2:

1. We call regions within ferromagnets with aligned magnetic moments: d……

2. True or False: Are ferromagnets fully magnetised from the moment they are first made?

   …….....

3. What are the independent (x-axis) and dependent (y-axis) variables when a ferromagnet's magnetic properties are measured?

   ……

4. What is the magnetic property used to measure how 'strong' a ferromagnet is? (hint - remember this is where a hysteresis loop crosses the y-axis)

   ……

5. What is the magnetic property used to measure how 'tough' a ferromagnet is? (hint - remember this is where a hysteresis loop crosses the x-axis)

……

What causes coercivity?

Understanding what causes permanent magnets to have large coercivities is fundamental if we are to make stronger and more effective permanent magnets. The two main mechanisms are magneto-crystalline anisotropy and magnetic domain pinning.

Magneto-crystalline anisotropy

This is how the magnetic properties (hence the **magneto** part of the word) are affected by how the atoms are arranged within a solid substance.

Atoms within solid materials are typically arranged in ordered rows that, in three-dimensions, form shapes such as cubes and prisms. This is the **crystal structure** and is the '**crystalline**' part of magneto-crystalline anisotropy.

Magnetic exchange in ferromagnets will try to keep the magnetic moments of individual atoms pointing in the same direction. Within the crystal structure, certain directions will be 'easier' for the atomic magnetic moments to point along than others. Having a 'preferred' direction is the '**anisotropy**' of magneto-crystalline anisotropy.

Activity 1:

Join up the words to the definitions, then use some connectives to summarise magneto-crystalline anisotropy in a sentence.

Magneto	Dependent on a direction
Crystalline	The magnetic moments of individual atoms
Anisotropy	Crystal structure of a solid material

Using the above key-words and connected phrases, try to put into a sentence the definition for magneto-crystalline anisotropy:

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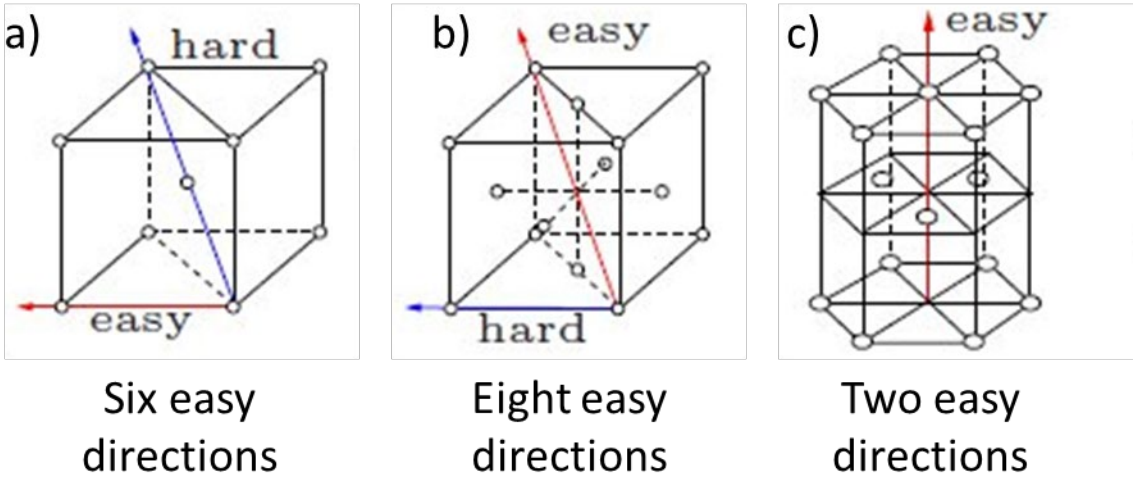


Figure 10 – Examples of easy and hard directions of magnetisation for a) face cubic, b) body cubic, and c) hexagonal crystal structures

Exploiting the magneto-crystalline anisotropy is one way to achieve large coercivities in permanent magnets. If there is only one 'preferred' direction for the magnetic moments to point in, then the magnetic moments will try to stay pointing in that direction and be more resistant to change. This can be done by changing the chemistry (type of atoms and crystal structure) of the permanent magnet. For example, alloying with certain elements may change from a cubic to hexagonal crystal structure.

However, it is worth noting that real materials are not made up of a single crystal throughout, but instead are made up of lots of crystal structures that are fused together. Therefore, the difficulty in making good permanent magnets is trying to get all the individual crystals to align. Any defects or irregularity to a permanent magnet can greatly impact the coercivity and magnetisation.

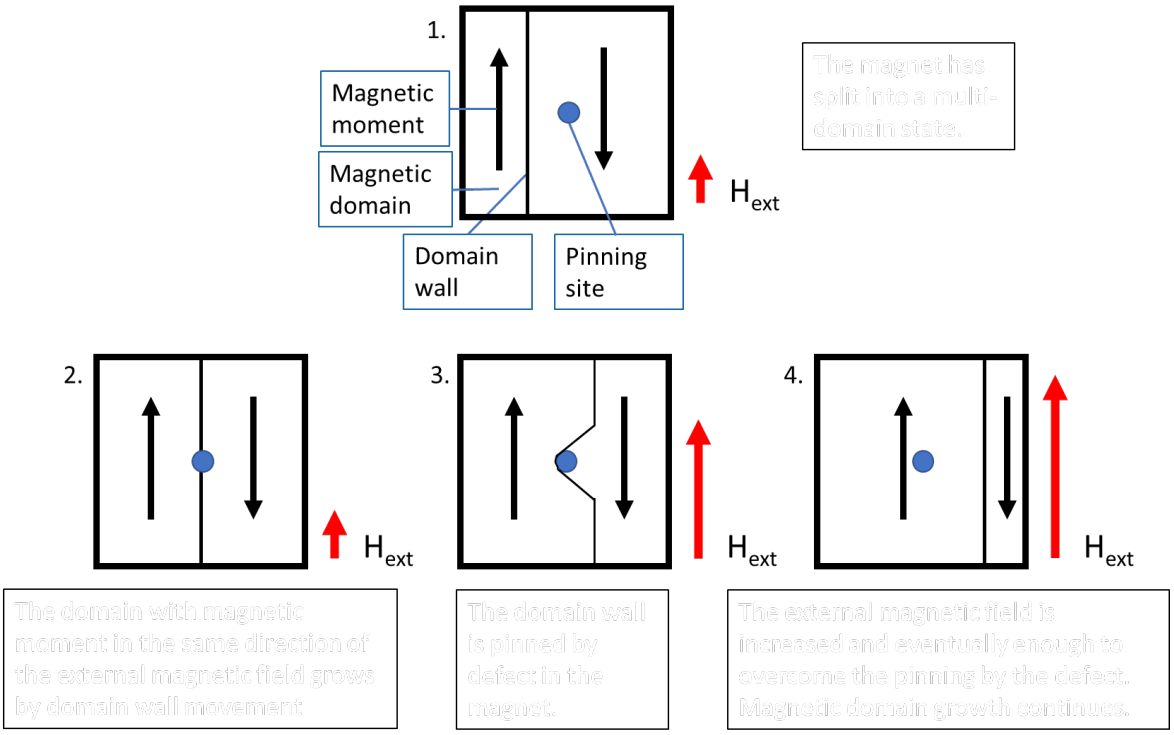
Domain pinning

Another mechanism for coercivity is to stop the magnetic domains from 'growing' or 'moving'. When a magnet is in the process of being demagnetised, the magnet goes from a single domain state back to multiple domains. By making it a lot more difficult for the magnetic domains to move, it makes the magnet much harder to demagnetise, and therefore the coercivity is larger.

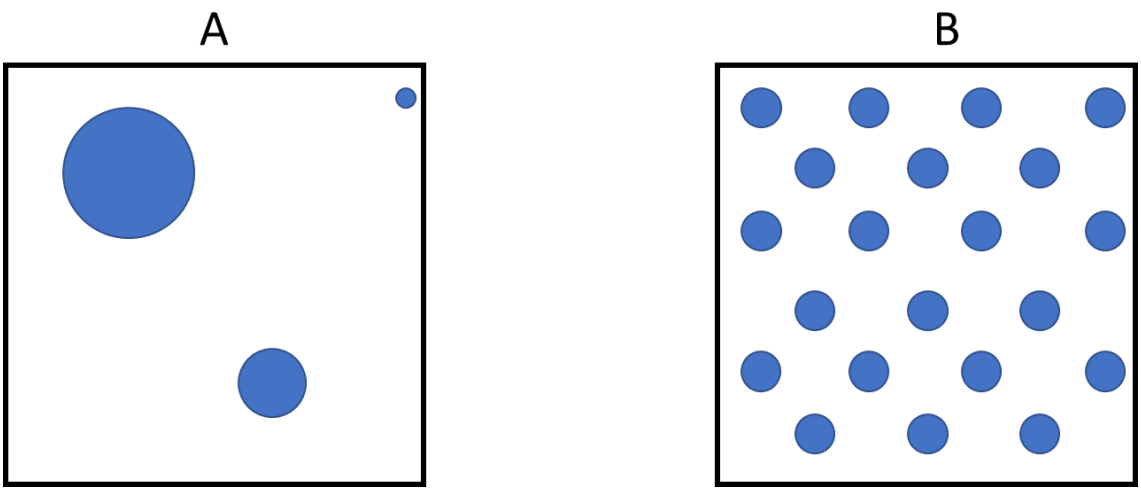
To make domain wall growth and movement more difficult, obstacles need to be put in the way. Sometimes these are naturally occurring in the magnet but often they are random in size and location, and therefore not very effective. Instead, we can develop and engineer the chemistry and process of manufacture of the permanent magnet so within it there are regular obstacles that are very effective at pinning domains.

Activity 2

1. Stick in the correct description for each stage showing the process for domain pinning.



2. Which of A and B do you think would be more effective for domain pinning? Explain why trying to use the following keywords: pinning sites, domain walls, regular, repeating, greater, density.



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Hinge Point Question

One magnet has its coercivity based on magneto-crystalline anisotropy, of which the easy direction to magnetisation is known, and another magnet has its coercivity based on domain pinning. Which of the two will be 'easier' to magnetise? Think about the process of magnetisation to saturation with domain wall growth to a single domain.

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Alloys

An alloy is a metal that is made of two or more elements. The alloying elements (at least one of them being metal) are first melted and are mixed as liquid solution. As they cool from liquid to solid; they then form a solid solution. Below are some examples of common alloys:

Alloy	Elements
Brass	Copper and Zinc
Bronze	Copper and Tin
Steel	Iron and Carbon (under 2 weight %)
Stainless Steel	Iron, Carbon, Chromium, Manganese, Molybdenum, Nitrogen, Sulphur (and sometimes more depending on the type of stainless steel and it's intended use!)

The addition of other elements to form the metal alloy will change the material properties. For example, copper by itself is quite easy to shape and form, but the addition of tin to makes bronze which is a lot stronger to the point it was used as tooling and weapons in ancient civilisations.

Rare-Earth Permanent Magnet alloys

In the 1970s, certain rare-earth elements were found to have a very beneficial effects to both the magnetisation and coercivity when alloyed with certain ferromagnetic elements. This gave rise to a new class of permanent magnet materials called the rare-earth permanent magnets and benefited a lot of industries including energy, computer, automotive, audio and music and medical.

Nd-Fe-B

Neodymium-Iron-Boron (**Nd-Fe-B**) was developed in the 1980s and still are the most powerful permanent magnets available. The addition of Nd (and B in very small amounts) has the effect of increasing the magnetisation, but also the coercivity. This is done by changing the crystal structure of iron from cubic to tetragonal. As such, the coercivity of Nd-Fe-B is based on **magneto-crystalline anisotropy** and so a lot of development has been focused around making these magnets without defects or irregularities.

While Nd-Fe-B magnets are very strong and difficult to demagnetise at room temperature, they are very sensitive to temperature change so their magnetic properties can vary significantly with temperature. At around 200°C Nd-Fe-B is about 30% as effective as it is at room temperature. This is problematic for certain applications such as electric motors, where the temperatures run around 160°C.

Another rare earth element called Dysprosium (Dy) can be added to help Nd-Fe-B coercivity at higher temperatures. However, Dy is very expensive, so there is a lot of research on-going looking at how to be efficient and use as little Dy as possible, while

also increasing the operating temperature of Nd-Fe-B magnets. Nd-Fe-B will also corrode very easily, so if used at high temperature or in hazardous conditions it will need to be coated in a protective material.

Activity 4

What type of coercivity mechanism is characteristic of Nd-Fe-B permanent magnets?
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What are the two rare-earth elements used in Nd-Fe-B permanent magnets?
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What temperature is the typical operational limit for Nd-Fe-B permanent magnets?
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Sm-Co

Samarium-Cobalt (Sm-Co) type permanent magnets were the first commercially viable rare-earth permanent magnets developed in the 1970s. $SmCo_5$ was the first developed and at the time had the largest magneto-crystalline anisotropy of any magnet. These types of rare-earth permanent magnets have been developed further such that the most used alloy of this type is now comprised of $Sm_2(Co, Fe, Cu, Zr)_{17}$. These additional alloying elements help to create a very effective **domain pinning** within the magnet. Nanoscale islands of Sm, Co and Fe are surrounded by Sm, Co and Cu which act to trap domains and prevent demagnetisation. Figure 11 shows this regular structure, which if produced uniformly throughout the magnet, makes for very large coercivities.

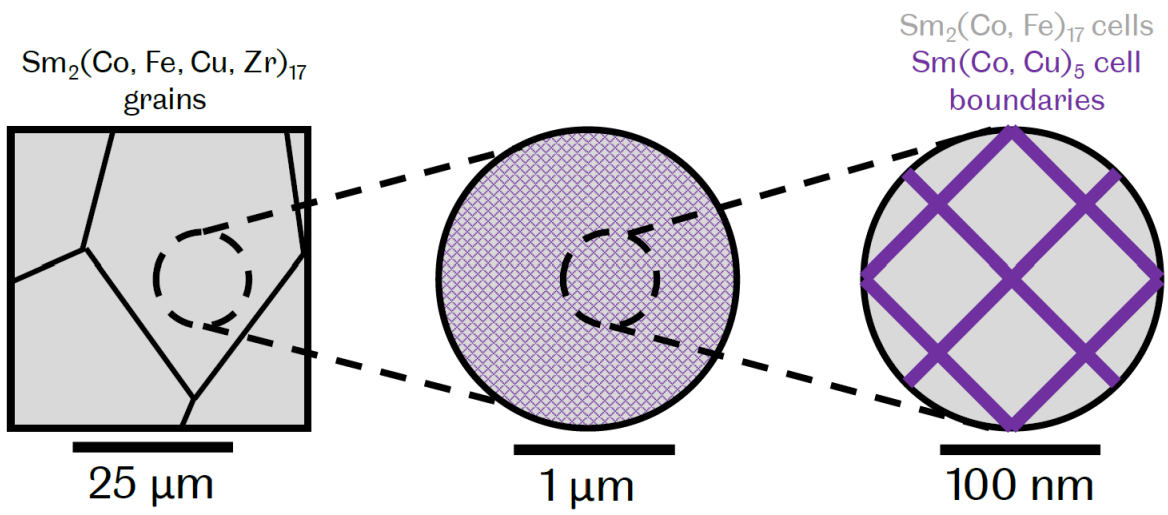

Figure 11 – Nanoscale domain pinning structure of $Sm_2(Co, Fe, Cu, Zr)_{17}$ permanent magnets

Sm-Co type permanent magnets have lower magnetisation and coercivity compared to Nd-Fe-B magnets at room temperature. However, Sm-Co type magnets are much more stable with changing temperature and are the superior magnet above 200°C. As such, a lot of the research for Sm-Co type permanent magnets is around further developing their capabilities at high temperatures applications (up to and even beyond 400°C), such as in aircraft, high-performance motor, military, and the space industries. Sm-Co type magnets are also much more resistant to corrosion, so again are used in the most challenging environments.

PhD research: Layered Sm-Co magnets

The rare-earth permanent magnets I researched during my PhD were $Sm_2(Co, Fe, Cu, Zr)_{17}$. I investigated how to make them by using a new method (explained in tutorial five) but also investigating how to add layers of additional materials would assist their performance at higher temperature. Normally, thin layers of insulating material is added to rare-earth permanent magnets for usage at high temperatures. To do this they slice the magnet up, coat the surfaces and then bond the magnet back together. As you can imagine, this is a time consuming, expensive, and wasteful process (lots of magnet material is lost during the process). My PhD looked at adding these layers during the initial manufacture, removing the need for additional processing.

Activity 5

What is the rare-earth element in Sm-Co type magnets?

……

……

What is the coercivity mechanism of $Sm_2(Co, Fe, Cu, Zr)_{17}$ permanent magnets

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Homework

A power recovery system for an F1 motor car will use rare-earth permanent magnets within it. The more powerful the rare-earth permanent magnet the more effective the power recovery system will be. However, the operating temperature will spike during operation, and on average will be around 200°C. State which rare-earth permanent magnet you would recommend and why? Make your argument around the performance of the power recovery system, the stability of the magnet and magnetic properties at high temperature

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Tutorial 4 – The rare-earth element crisis

What is the Purpose of Tutorial 4?

- Students can describe the main causes of the rare-earth element crisis of 2011/12
- Students can summarize and communicate key information
- Students will be able to debate good and bad sources of information

Starter activity

1. What is an alloy?

……..

2. Give an example of an alloy

……..

3. What is the coercivity mechanism for Sm-Co type permanent magnets?

……..

4. What is the coercivity mechanism for Nd-Fe-B type permanent magnets?

……..

Where do the rare-earth elements come from?

In tutorial 1, we looked at the Lanthanide group in the periodic table of elements. These elements, of which we are most interested in **Samarium, Neodymium and Dysprosium**, are more commonly known as the **rare-earth elements**. However, this is a misnomer as they aren't as rare as their name suggests – in terms of how abundant they are in the earth's crust some of them are about as abundant as copper. However, finding large deposits is difficult. Once large enough deposits are found, separating the elements from their ores is

not easy, as they are often found with radioactive elements, and the separation process produces a slew of toxic pollutants.

There are abundant reserves all around the world, but the largest reserves are located in China, Brazil, Vietnam, and Russia.

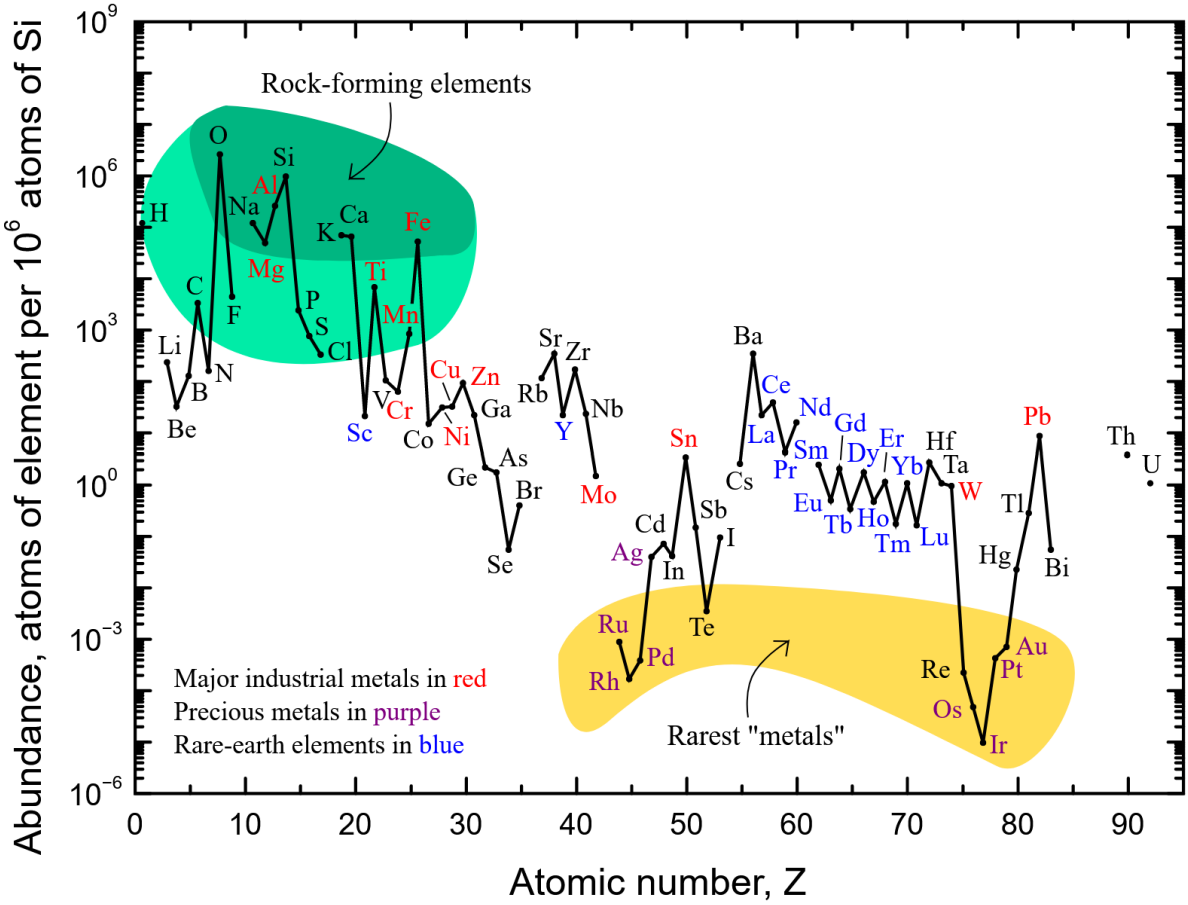

Figure 12 – Number of atoms found in the Earth's crust relative to Si for elements of the periodic table

Activity 1

Take 30 seconds to look at the Figure 12. Name some elements that are as common as the rare earth elements (blue) and some that are rarer.

Based on this information, as well as where the majority of rare-earth reserves are estimated to be, do you think the label rare-earths is appropriate? Explain why?

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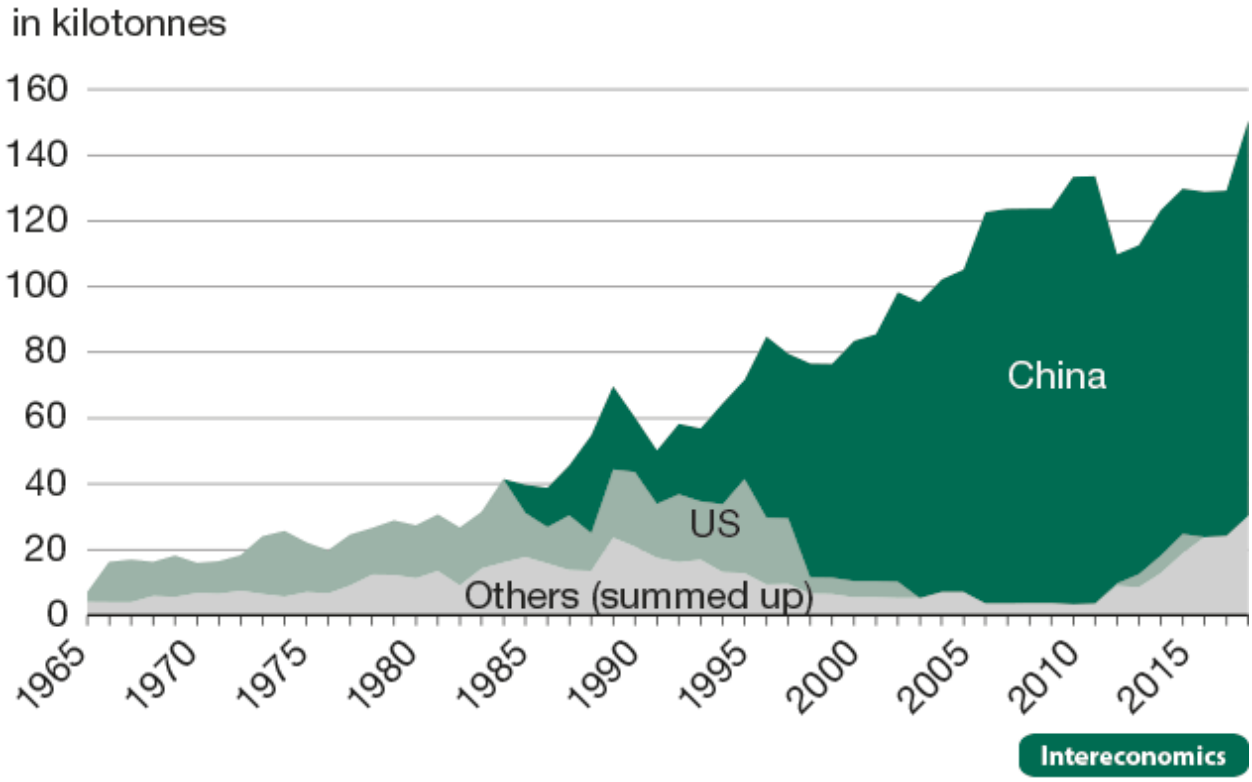

Figure 13 – Rare-earth element production by volume (data taken from US

Up until the mid-1980s, the USA accounted for most of the rare-earth mining and production. However, from around the year 2000 onwards around 90% of rare-earths ores mined today are in China.

In 2010, China reduced their export quotas by 40% (i.e., how much can be exported) and set strict and expensive tariffs (i.e., additional costs on exports) on the rare-earth elements, including Samarium, Neodymium and Dysprosium. China argued these were necessary to protect the environment (as rare-earth mining in China is very damaging to the environment), however critics had said this was national protectionism.

The resultant effect was enormous price increases for these critical elements, as shown in Figure 14. This made companies and countries who manufactured or used rare-earth permanent magnets to question if we can reduce our reliance on China for these critical elements.

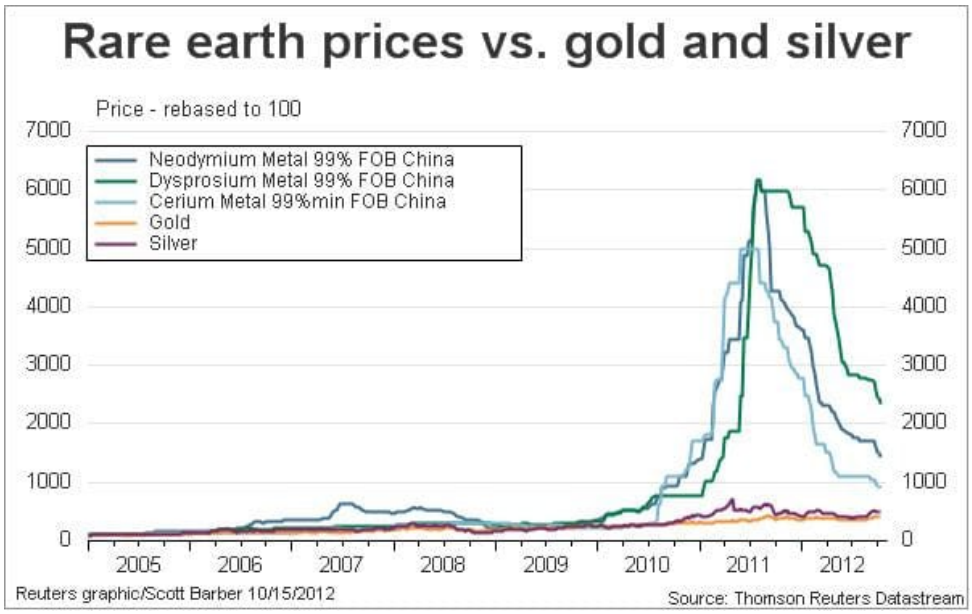

Figure 14 – Price spiking of Neodymium and Dysprosium during the rare-earth crisis

Activity 2

Have a think about the following question for a minute and then share your thoughts with the person next to you.

Question:

What ways could you suggest for the manufacturers and users of rare-earth permanent magnets try to reduce their reliance on China as a source for the rare-earth elements? Think about where they could come from instead or how their use could be reduced? Think about some things we do with other scarce or precious metals/materials/resources.

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Rare earths into magnets

The rare-earth elements have a unique arrangement of their electrons that, when alloyed with the ferromagnetic elements iron, cobalt, and nickel, it helps to produce very effective permanent magnets. Since their discoveries in the 1970s and 1980s respectively, the Sm-Co type and Nd-Fe-B type rare-earth permanent magnets have not been bettered.

Major applications of rare earth elements	Market share in %	Products
Permanent magnets	30	Electric vehicles, wind turbines, hard disk drives
Metal alloys	18	Batteries, hydrogen absorption alloys
Catalysts	18	Fluid catalytic cracking, automotive catalysts
Polishing	14	Polishing powders for monitors, optics
Glass	6	UV-protection, laser applications
Ceramics	5	Ceramic capacitors, dental ceramics
Phosphors	4	Energy-efficient lighting (e.g. LEDs), displays
Others	5	Fertilisers, etc.

The rare-earth crisis prompted a lot of research into rare-earth permanent magnets. Most areas of research are looking at ways to reduce the amounts of rare-earth elements used so they are not wasted. Alternatively, there is a lot of interest in whether the rare-earth elements can be recovered and recycled.

We are going to look at some sections of journal articles on-going research into rare-earth permanent magnets. Try to categorise the type of research (e.g., new material development, improvement of a current material, recycling, etc.).

Activity 3

What headings are typically used in scientific journals?

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Most reliable bodies of work are peer reviewed. What does this mean?

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When another piece of work is talked about, or a statement is made, what do you notice about what follows this? Why is this important?

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Homework

Read the highlighted sections in the journal papers. These will give you additional information on rare-earth permanent magnets and the research themed around reducing reliance on the rare-earth elements. Pay careful attention to the style and structure of the writing.

Use the following to make notes, write any questions you may have, and/or reflect on the highlighted sections – Was the research themes interesting? Was the style of writing easy or difficult to understand?

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Tutorial 5 – 'Powder'-ful magnets

What is the Purpose of Tutorial 5?

- How rare-earth permanent magnets are usually made
- An overview of the spark plasma sintering process
- A discussion as how spark plasma sintering was used, and future uses identified from my PhD research

Starter activity

1. Name the change of state of a solid to a liquid?
   .....
2. What do we call the specific temperature at which this change of state occurs?
   .....
3. Name a type of rare-earth permanent magnet
   .....
4. What is an alloy?
   .....
5. Which country mines and produces around 80% of all rare-earth elements
   .....

Most rare-earth permanent magnets are made by a process called **sintering**. Sintering is a process that an object is heated up and it is made denser and tougher. An example of this is when clay is put in a kiln and heated. Powder sintering is when powders are heated in a mould to form a single, solid object.

It is important to note that the temperature at which sintering takes place is *below* the melting temperature/point of the material. This means this process takes place while the material is solid.

Rare-earth permanent magnets are usually sintered as powders. The powders are pre-alloyed, which means they are powdered versions of their alloys (e.g., Sm-Co is turned into powders, rather than sintered as individual powders of Sm and Co). During sintering, the powders fuse together, increasing the density and take the shape of the mould. The process usually takes a few hours to complete.

Hinge point question:

Think for 30 seconds, then talk with the person next to you for a minute. Be prepared to share your answer to the following:

Why do think it is beneficial for magnetic powders to be pre-alloyed before sintering?

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The general benefits to sintering are that lower temperatures are used than for casting (which is when the alloys are melted together). There is also more control over the shapes of objects than can be made.

For making permanent magnets, the main benefit for making permanent magnets this way is that we can apply a strong magnetic before to the powders (while in the mould but before they are sintered), which will rotate the powders. If you think of each powder as a tiny magnet, then with a strong magnetic field applied, the magnetic moments of each of the powders will be aligned to the direction of the magnetic field. If the powders are then immediately sintered, the resulting magnet will have very little irregularity, and this is key to making powerful permanent magnets.

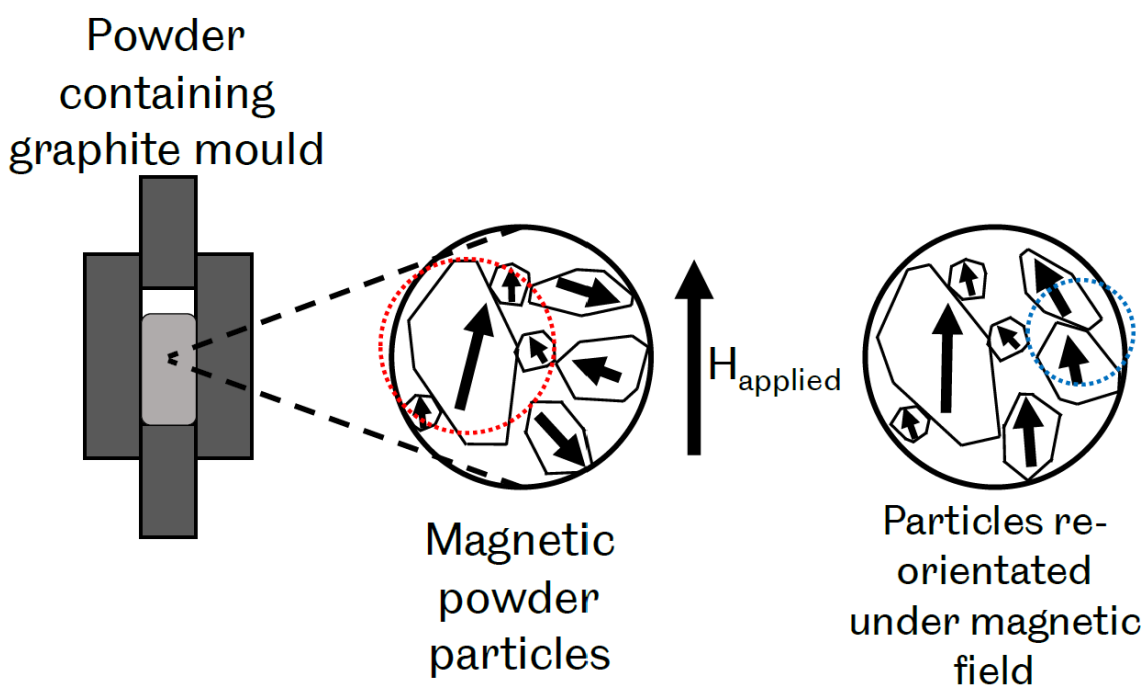
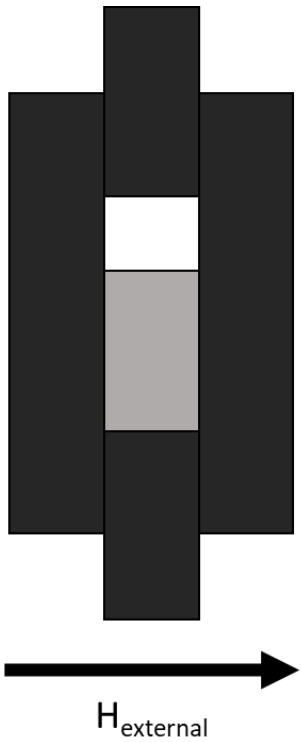


Figure 15 – How powders of permanent magnets can be rotated to align with a magnetic field before sintering

Activity 1

1. On the following example, draw an arrow on the powder to show the alignment of the magnetic powders due to the applied magnetic field.



2. Is the temperature for sintering above or below the melting point of an alloy?

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3. Approximately, how long does conventional sintering take for rare-earth permanent magnets?

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4. Describe why you think it is important for the coercivity that the magnetic powders are aligned before sintering? Try to include reference to magneto-crystalline anisotropy

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This is beneficial as different shaped magnets can be made this way. The sintering process will be different for Nd-Fe-B and Sm-Co type magnets, with the sintering temperature, time, and conditions specific to the different materials. Over the last 30 years, the 'recipes' used for sintering have been refined to make the highest quality magnets that are optimised to their coercivity mechanisms.

Field-Assisted Sintering Technique (FAST)

Conventional sintering relies on in-direct heating – a bit like an oven where there is a heating element, but the heat is transferred to the alloy by convection of gases. It's simple, but not particularly efficient. Heating rates are slow, and sintering takes hours.

This can be problematic for Nd-Fe-B and Sm-Co magnets because longer time spent at higher temperatures allows the material structure to change. Small regions of the magnet can start to rearrange their atoms, or defects within the material can 'grow'. Coercivity mechanisms for rare-earth permanent magnets are very much based on the magnet being uniform and controlled, so small regions of irregularity can greatly affect their coercivities.

For my PhD I used a relatively new piece of technology, appropriately named Field-Assisted Sintering Technique (FAST) to rapidly sinter powders in minutes.

It works by applying both force (pressure) and heat directly to the powders in a mould. The heat is generated by sending over 10,000 amps of electrical current through the mould/die (and powders if also electrically conductive) – this what the Field part is referencing in the FAST acronym. Combining these two effects means in only takes minutes rather than hours to go from loose powders to full dense materials.

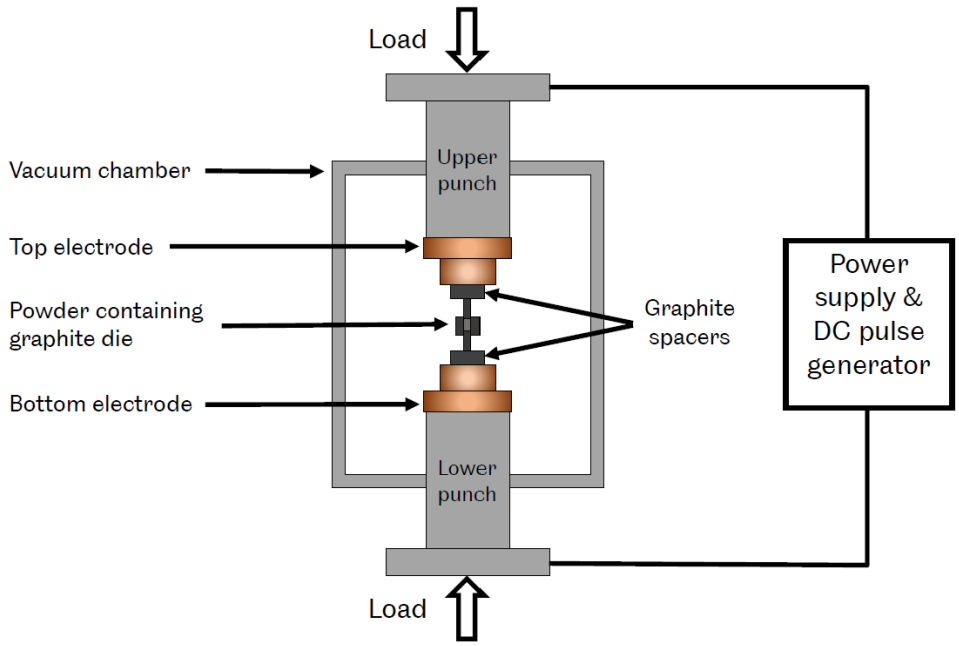

Figure 16 – Schematic of the FAST technology

One of the benefits of rapid sintering is there is little time for material change to occur while at the high sintering temperatures. In theory, this means for the rare-earth permanent magnets that they would be less irregular, which is beneficial to their coercivity mechanisms and magnetic properties. If the magnets are made better, they will require less rare-earth elements and that is one way to reduce our usage of the rare-earth elements in a future electrified society.

One drawback of the process is that the size of the magnets produced are small. The magnets I made were 20 mm in diameter and one at a time. The technology is being developed, with new machines able to make samples up to 800 mm in diameter, or several smaller samples at the same time.

Activity 2

1. How many amps of current are passed through the mould to heat the powders?

   .....

2. What two effects are combined to rapidly sinter the powders?

   .....

3. What diameter were the magnets I made using the FAST process during my PhD?

   .....

Design of Experiments

Every material and alloy will have an 'ideal' sintering temperature. For the FAST process it is no different. When exploring but there are several other variables to consider, such as pressure, heating/pressure rate, hold time, etc. to ensure the whole process is optimised for the quality of the rare-earth permanent magnet.

Part of my PhD was to look at Sm-Co type permanent magnets and try to identify the best parameters for sintering using FAST. To get started, I used scientific journals to first see what other researchers had done for Sm-Co type by other sintering techniques – this gave me an idea of the type of temperatures, pressures, times, etc. to explore around. I would choose one variable (e.g., sintering temperature) to be my independent variable, which would change, while I controlled the other variables.

I would make several samples at selected minimum and maximum values (e.g., minimum sintering temperature 800°C, maximum sintering temperature 1150°C). My dependent variable to measure would be the density and magnetic properties of the permanent magnets.

I would then choose another variable to be the independent variable (e.g., sintering pressure), while controlling the other variables. I would repeat this method to make dozens of samples – fortunately the FAST process is relatively quick!

This method of exploring variables by design is called **Design of Experiments** and is used to identify which variable has the biggest influence on an experiment.

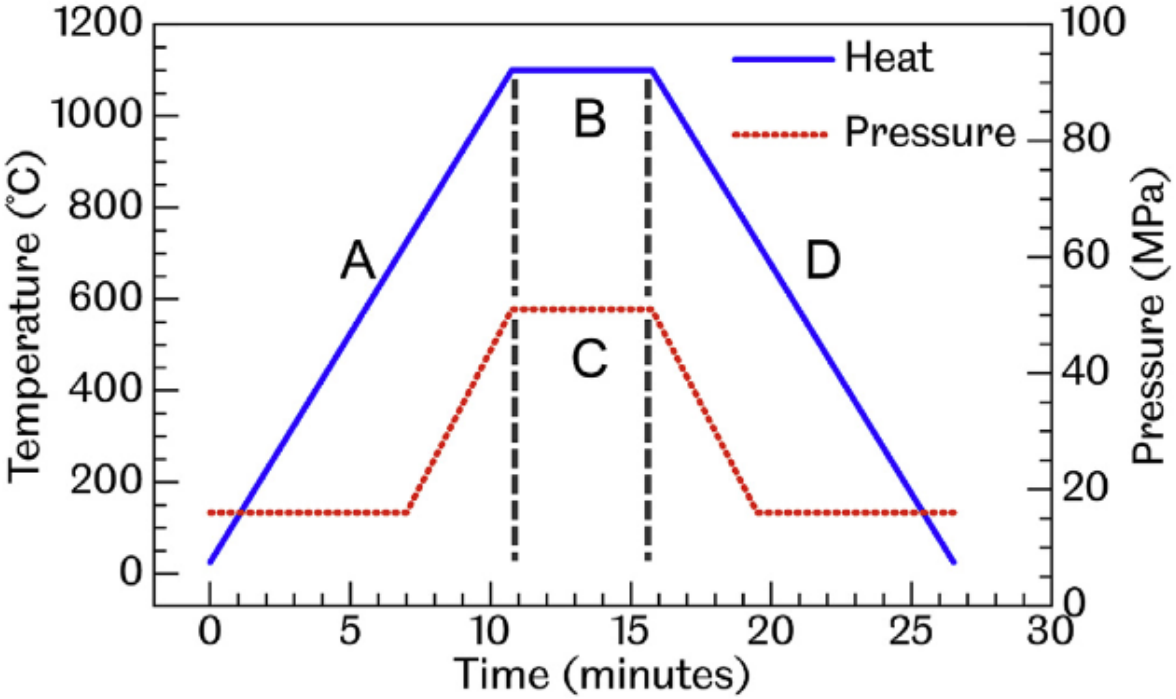

Figure 17 – Example FAST recipe the produced fully dense Sm-Co magnets

Final assignment

Question:

Explain how the FAST process can be used to make rare-earth permanent magnets for use in future electric powered aircraft?

Details of the assignment:

You are helping to write an application (2000 words ± 10%) for funding for a research project on rare-earth permanent magnets that could be used in future electric power-systems in aircraft, in which the expected operating temperatures for the REPMs will be above 150 °C.

The project theme will be around making the REPMs using the FAST process. The theme of the project should centre around the growing demand for electric motors and power systems, which use REPM, but that there is uncertainty on how and where rare-earth elements are mined and supplied. Therefore, there is an emphasis to 'do more with less', especially with the heavy rare earth elements such as dysprosium, which are added to help with high temperature performance in Nd-Fe-B magnets

You can pick between Nd-Fe-B or Sm-Co as your REPM, but you are welcome to be creative as you like with what you would like to investigate.

All proposals will be marked and graded per the mark scheme. However, this will also be a competition for the best proposal winning 'funding', with some additional prizes for the second and third best proposal. Therefore, while I am happy for you guys to help each other out, each proposal should be unique.

Some potential research ideas are:

Investigating FAST with pre-alloyed powders of Nd-Fe-B 'coated' in Dy, so as little is wasted compared to adding it as separate powders.

$Sm_2(Co, Fe, Cu, Zr)_{17}$ magnets with additional Co for high temperature applications made by the FAST process (you could investigate varying the amount of Co or the FAST processing parameters for a particular composition).

Investigating recycled Nd-Fe-B or Sm-Co powders by the FAST process. Recycled Nd-Fe-B and Sm-Co permanent magnets are broken down into powders again and re-used. Are the quality of magnets affected by recycling? How many times can the materials be recycled?

Success criteria – how to structure your assignment and what to include:

You have been asked to write the main pitch of the project proposal, which will need to include:

- An **introduction section** which introduces the problem and (brief) summary of what you think can be done to solve this – introduce your project!

- A **theory section** which will initially explain what permanent magnets are and their key properties (i.e., remanence, coercivity and energy product). You are encouraged to use graphs to aid the reader with these concepts.

- A **review section** which will introduce and give a summary of the rare-earth permanent magnet your research project is focussed on (Nd-Fe-B type and/or Sm-Co type).

    - You should also explain briefly how sintered magnets are usually made.
    - Develop on the problems introduced in the introduction by explaining where rare-earth elements come from and why they are very important. You will need to think critically and communicate your thoughts on the issue.

- A **method section** which will introduce and explain how the FAST process will be used to make new REPMs.

    - Use the information you have learned on the course to justify the REPM (NdFeB-type, SmCo-type, or both) you have chosen for research and explain what you plan to study using the FAST process for future REPMs for use at high temperature. As this is a research proposal you will want to sell the importance of the work.

- A conclusion section summarising the project proposal; what it intends to do with the type of REPM you have identified and why this is important with respect to reducing dependence on critical rare-earth elements and the use of REPMs in future electric powered aircraft

<u>Tips</u>

It is encouraged to do your research before you start writing your proposal pitch. It may also help to put together a plan before you start writing.

You will be provided with some articles with highlighted sections to help you with researching for your proposal pitch. You are encouraged to do your own research on the different topics, using the internet to access scientific websites and news articles on the relevant topics.

When including what you have researched into your proposal pitch, make sure you reference your information to include your sources of information. In your text you will

be expected to comment on the information and your thoughts on the reliability of the source(s). When including figures, make sure they are numbered and have caption text below the image (see examples in this booklet). If a figure is included, make sure it is referenced and mentioned in the text. Referencing style: Harvard (Author Name, YEAR) or using a numbering system[1]	
In this assignment, show me that you **understand**: • The theory behind permanent magnets (i.e., what makes them permanent) • What are the rare-earth elements and why are they a critical resource? • How rare-earth permanent magnets are usually made and how a processing technology such as FAST could be applied to make future permanent magnets	Show me that you **are able to**: • Explain scientific concepts (e.g., for permanent magnets why they are permanent with reference to key magnetic properties) and apply these concepts correctly in text • Critically assess and evaluate information you have researched, and form your own opinion • Summarise and communicate important knowledge – word limit is 2000 words ± 10%, so make it all count!

Tutorial 6 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on your final assignment
- To respond to the feedback from your Uni Pathways teacher
- To write targets for improvement on your final assignment

Final assignment feedback from your Uni Pathways Teacher

(Remember to look at the mark scheme to help you understand what you have done well so far, and how you can do even better in your final assignment)

Here are three things that my Uni Pathways Teacher thought I did well in my draft assignment
•   •   •

Here are three things that my Uni Pathways Teacher thinks that I could do to get a higher mark in my final assignment
•   •

•

Tasks from my Uni Pathways Teacher to do during the feedback tutorial to help me improve
•   •   •
My response:

Actions I will take to improve my final assignment after this tutorial…
•   •   •

Hand in date for my final assignment:	

Tutorial 7 – Final tutorial

What is the Purpose of Tutorial 7?

- To receive feedback and a grade on your final assignment.
- To reflect on the programme including what you enjoyed and what was challenging.
- To ask any questions you may have about university.

Final assignment feedback from my Uni Pathways Teacher

Final mark:	University style grade:
Feedback: Here are three things that my Uni Pathways teacher thought I did well in my final assignment • • •	

Here are three things that my Uni Pathways teacher thinks I should remember for when I am doing this kind of study in the future
• • •

University

What questions do you still have about University after taking part in Uni Pathways?
• • •

Reflecting on Uni Pathways

What did you most enjoy about Uni Pathways?
• • •

What did you find challenging about the programme?	How did you overcome these challenges?
• • •	• • •

Appendix 1 – Referencing correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?

A reference is just a note in your assignment which says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

When should you use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important to thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

1. **A marker in your assignment**: After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].
2. **Bibliography**: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used, and include as much information as you have about the reference. The list below gives what should be included for different sources.

    a. **Websites** – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].

    E.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].

    b. **Books** – Author, date published, title of book (in italics), pages where the information came from.

    E.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.

    c. **Articles** – Author, 'title of the article' (with quotation marks), *where the article comes from* (newspaper, journal etc.), date of the article.

    E.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

Notes

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