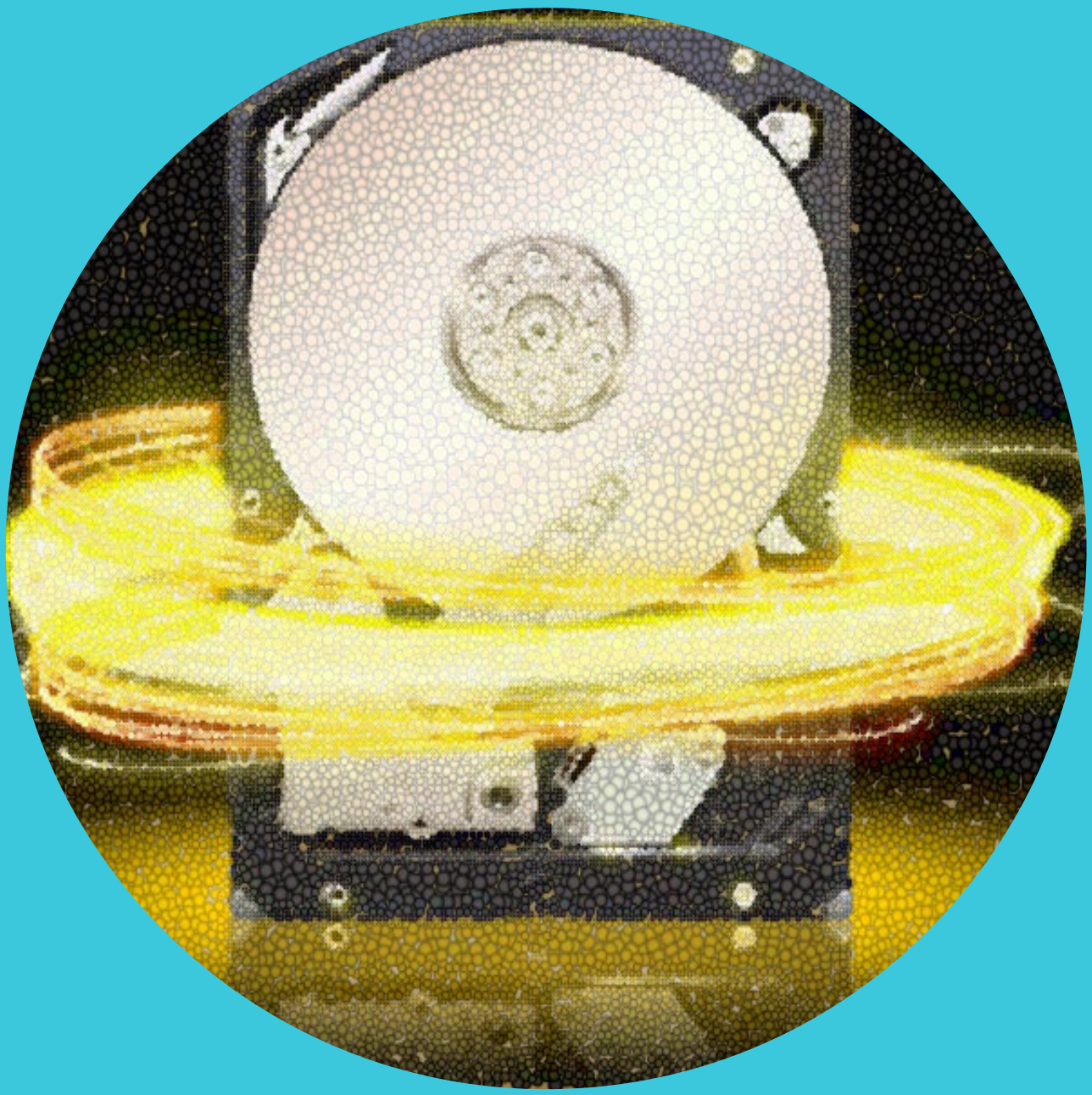
Researchers in Schools



What is so attractive about magnetism?

Key Stage 4 Programme

Pupil Name	
Coursebook Designed by	Dr. B Dutson

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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		
Tutorial 2		
Tutorial 3		
Tutorial 4		
Tutorial 5		

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

Humans have always captured information. The primitive cavemen initially achieved this through cave paintings and storytelling. The ability to store more, detailed information was made possible when paper was invented in China around 100AD. For over a millennium, books remained the main source of information storage but in the past 100 years we have advanced the technology of data storage with digital electronics. In the modern world we have unprecedented computing power, wireless technology, the internet and mobile communication. Data is becoming one of the great currencies of the world: search histories, online purchases, the latest TikTok video craze, digital photographs. Each day on Earth we generate 500 million tweets, 294 billion emails, 4 million gigabytes of Facebook data, 65 billion WhatsApp messages and 720,000 hours of new content is added daily on YouTube.

There are many technologies for digitally storing data, such as magnetic storage (Hard Disk Drive), optical discs (CD, DVD, Blu-Ray) and semiconductor memories (Solid State Device, flash drive). Each type of memory is more useful to specific applications, for example optical storage is mostly used for movies, software and gaming, while magnetic data storage remains the dominant technology for high-capacity information storage, including personal computers and data servers.

During this course, we will delve further into magnetic data storage. Specifically covering:

- Basic magnetism and electromagnetism.
- How data is stored on magnet hard disk drive.
- The limitations of increasing the amount of data stored on a hard disk.
- A variety of methods to stabilise the data.
- How nanoparticles can be used to advance the technology.

At the end of the course, you should be able to not only understand the underlying principles of magnetism and magnetic data storage, but also be able to critically assess the importance, both scientifically and economically, of increasing the capacity for information storage.

Uni Pathways Mark Scheme 2021

	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.	Beginning to analyse scientific evidence, arguments, and reasoning.	The grammar, spelling, style, and structure of the work need improving in order

	Does not yet apply this knowledge to build and support scientific arguments and explanations.	Describes evidence and arguments, while not yet evaluating them.	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

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…

Subject Vocabulary

Word	Definition	In a sentence	I can put it into my own sentence…
Anisotropy	The quality of exhibiting properties with different values when measured along axes in different directions.	Materials with large anisotropy are harder to write magnetic data to, but are more stable.	
Annealing	Annealing is a heat treatment that alters the physical, and sometimes chemical, properties of a material.	High temperature annealing changes the crystal structure of the iron platinum nanoparticles.	
Anti-ferromagnetically coupled media	This term covers when the data is stored on the magnetic hard disk in the plane of the disk, i.e. left to right, right to left, but there is also another magnetic layer underneath, which mirrors the magnetization of the data layer to stabilize the data.	Longitudinal recording media can be stabilised by using antiferromagnetically coupled media.	
Areal density	Areal density is a measure of the amount of information in a particular space or area, specifically the number of 'bits' of data stored on a disc.	A hard disk with a large areal density can store a lot of information, also known as data density.	
Binary data	A type of information that is represented in the binary numerical system, traditionally labelled as 0 or 1.	Information is stored on a hard disk as binary data.	
Bit of data	A single unit of data, i.e. 1 or 0, stored	The binary data that I save is stored on a bit.	
Computer hard drive	An electromechanical data storage device.	I save my word document to the local computer hard drive.	
Electromagnetism	The property of attracting certain metals with a magnetic field that is produced by a current of electricity	The electric motor was moving because of the force of electromagnetism	

Heat assisted magnetic recording	This term covers when the magnetic layer is made of a magnetically more stable material, so a localized heat is applied when writing the data.	Heat assisted magnetic recording can be used to increase data density on a hard disk.	
Induced magnet	An object that only becomes a magnet when it is placed in a magnetic field	The door closed again when the induced magnet door stop was turned off	
Longitudinal recording media	This term covers when the data is stored on the magnetic hard disk in the plane of the disk, i.e. left to right, right to left	The first hard disks were made of longitudinal recording media.	
Magnetic domains	A magnetic domain is a region within a magnetic material in which the magnetisation is in a uniform direction.	The magnetic fields of atoms are grouped together and aligned in a magnetic domain.	
Magnetic field	A region around a magnetic material or a moving electric charge within which the force of magnetism acts.	The magnetic field affects certain metals to produce a force	
Magnetic field lines	A visual tool to represent a magnetic field.	The magnetic field line shows the line of similar magnetic field that flows from the north pole to the south pole	
Magnetic hard disk	A storage device that uses a magnetization process to write, rewrite and access data.	The computer hard drive has a magnetic hard disk in it.	
Magnetism	The property of attracting certain metals: the attracting property of a magnet	A compass uses magnetism to help me to find my way	
Moore's Law	A scientific principle that states that the computing power speed of computers will double every 2 years.	The rapid increase in data capacity over the last 50 years can be related to Moore's law.	

Non-contact force	A natural power or effect that can change the speed or direction of something without directly touching it	The magnets attracted each other through a non-contact force when they were held near each other.	
Permanent magnet	An object made from a material that is magnetized and creates its own persistent magnetic field.	On my fridge there is a permanent magnet that stays there all the time	
Perpendicular recording media	This term covers when the data is stored on the magnetic hard disk at right angles to the plane of the disk, i.e. up to down, down to up.	Modern hard disks use perpendicular recording media to increase the data density.	
Pole	Two opposite points at each end of an object. In magnetism, the two opposite points on the surface of a magnet at which magnetic fields are the strongest.	Magnetic field lines flow from the north pole to the south pole	
Self-organised magnetic arrays	A regular pattern of magnetic particles that forms naturally.	Nanoparticles can be chemically synthesised to create self-organised magnetic arrays.	

Tutorial 1 – Where on Earth can we see magnetism?

Figure 1: The Aurora Borealis.

What is the Purpose of Tutorial 1?

- Identify the key properties of magnetism.
- Explain the characteristics of an electromagnet.
- Identify where magnets are found in our lives.

How is the Earth like a magnet?

Discuss with a partner and make a note of any properties of a magnet that you can think of? Together, see if you can think of any similarities to things in the world around us?

Magnetic properties	**Earth Example**
Iron is a magnetic material	The Earth's core contains molten iron.

The Earth's magnetic field is the same as that of a big bar magnet with the south pole at the top of the planet, near Greenland currently. Lines of force go from magnetic north to south. The earth rotates around the geographic poles.

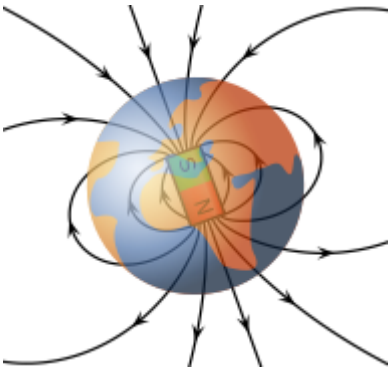
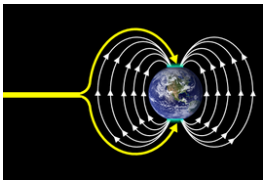


Figure 2: A representation of the Earth's magnetic field.

What do you think is the link between the Earth as a magnet and the Aurora Borealis?



Fun fact: The Earth's magnetic field keeps flipping. About 500,000 years ago the magnetic north pole was actually the south pole.

Basic Magnetism – Attractive or Repulsive?

With a magnet, you can make something move without even touching it!

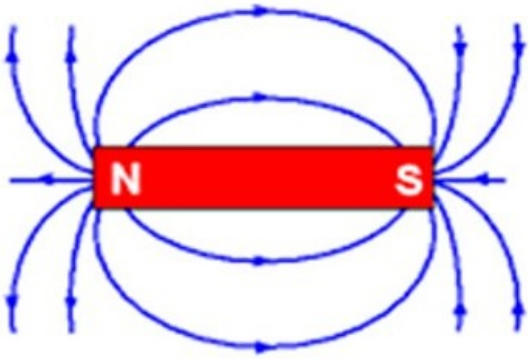


Figure 3: A bar magnet and representation of the magnetic field lines.

A magnet has a north pole and south pole, as typically shown by N and S in diagrams. The poles of a magnet are the places where the magnetic forces are the strongest. When two magnets are brought close together they exert a force on each other. Two like poles repel each other, whereas two unlike poles attract each other. Attraction and repulsion between two magnetic poles are examples of a non-contact force, i.e. a push or pull that acts on an object due to the interaction with another object that is physically separated.

North poles repel North poles
South poles repel South poles
North poles attract South poles

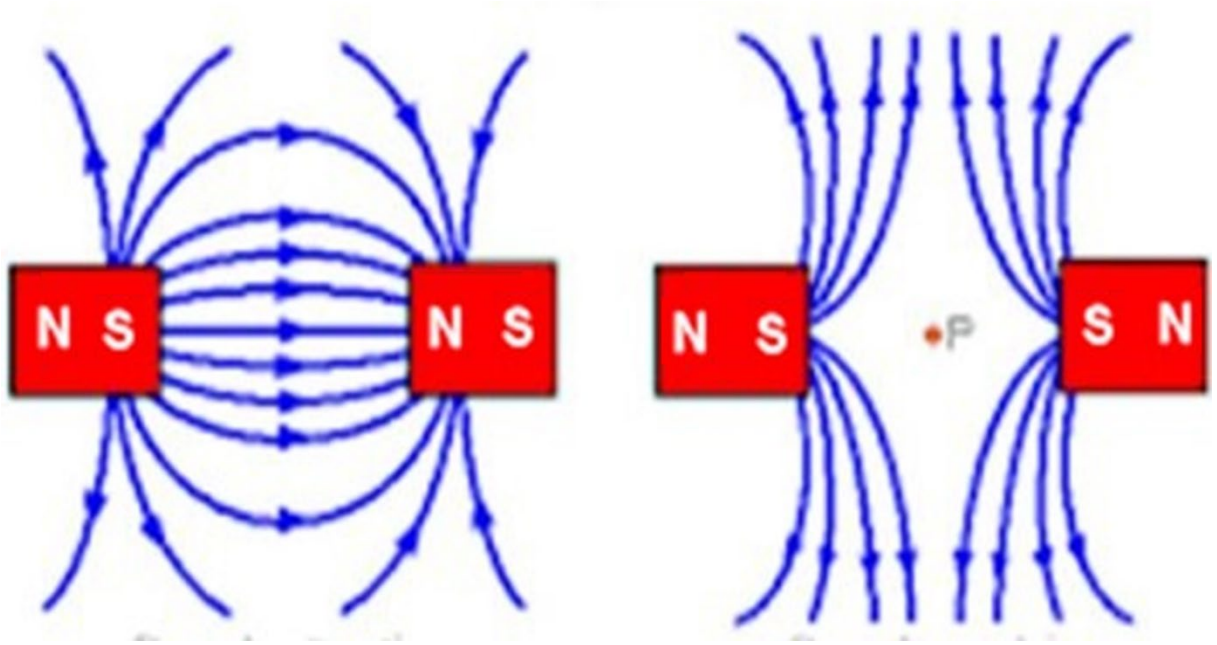


Figure 4: A representation of the magnetic field lines from two magnets attracting and repelling.

A permanent magnet produces its own magnetic field, whereas an induced magnet is a material that becomes a magnet when it is placed in a magnetic field. Induced magnetism always causes a force of attraction. When removed from the magnetic field an induced magnet loses most/all of its magnetism quickly.

The region around a magnet where a force acts on another magnet or on a magnetic material, such as iron, steel, cobalt and nickel, is called a magnetic field. The force between a magnet and a magnetic field is always one of attraction. The strength of the magnetic field depends on the distance from the magnet. The field is strongest at the poles of the magnet.

The direction of the magnetic field at any point is given by the direction of the force that would act on another north pole placed at that point. The direction of the magnetic field line is from the north (seeking) pole to the south (seeking) pole of the magnet. A magnetic compass contains a small bar magnet, which points in the direction of the Earth's magnetic field.

You can find the shape of a magnetic field in two ways, by using a plotting compass or iron fillings. The needles of a compass lines up with the magnetic field, as do the iron filings. You can draw magnetic field lines to represent the field. The lines go from the north pole to the south pole of the magnet, with arrows pointing from north to south. If the magnetic field lines are closer together this shows that the magnetic field is stronger.

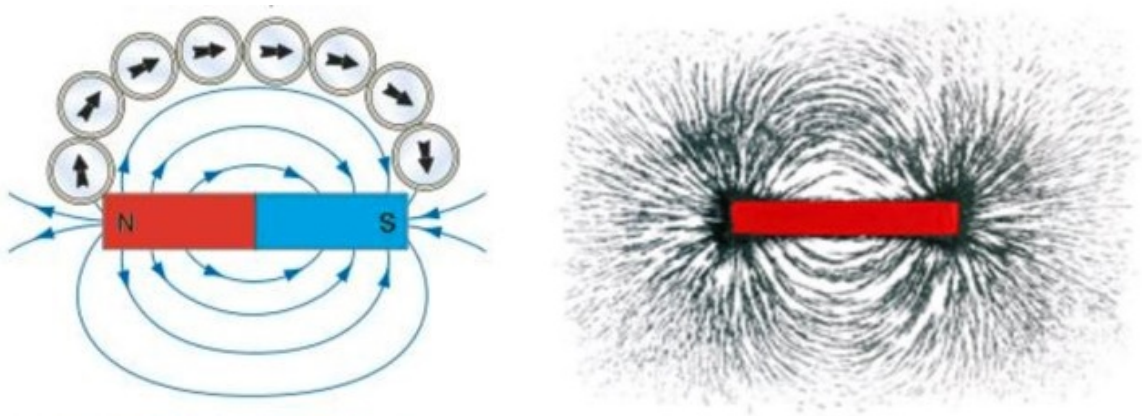


Figure 5: The magnetic field lines represented by compasses (left) and iron filings (right).

Quick Knowledge Check

Fill in the blanks using the following terms

cobalt repel poles seeking attract south magnetic apart

All magnets have two _ _ _ _ _ : one north - _ _ _ _ _ _ _ pole and one _ _ _ _ _ - seeking pole.

Opposite poles will _ _ _ _ _ _ _ each other.

Like poles will _ _ _ _ _ each other: they will push each other _ _ _ _ _ .

Magnets will also attract pieces of _ _ _ _ _ _ _ _ metals: iron, nickel and _ _ _ _ _ _.

Magnets - True or False?

Decide if the following statements are true or false.

1. All metals are magnetic TRUE/FALSE
2. All magnets have a south pole and a north pole TRUE/FALSE
3. The Earth has its own magnetic field TRUE/FALSE
4. If you place two south poles together they will attract each other TRUE/FALSE
5. The needle of a compass is a magnet which lines up with the Earth's magnetic field TRUE/FALSE
6. The Earth has a magnetic field because it's iron core acts like a giant magnet TRUE/FALSE
7. North poles attract iron and south poles repel it TRUE/FALSE
8. Iron and steel are the only magnetic metals TRUE/FALSE
9. You can separate iron and copper using a magnet TRUE/FALSE
10. Magnets can pick up 2p coins because copper is magnetic TRUE/FALSE

In the space below, draw a bar magnet and label the key features such as the poles and potential magnetic field lines:

Electromagnetism

When a current flows through a conducting wire a magnetic field is produced around the wire. The strength of the magnetic field depends on the current through the wire and the distance from the wire. Shaping a wire into multiple coils increases the strength of the magnetic field created by a current through the wire. The magnetic field inside the coils is strong and uniform.

The magnetic field around coils of wire has a similar shape to that of a bar magnet. Adding an iron core increases the strength of the magnetic field in a coil of wires. An electromagnet is a coil of wires with an iron core.

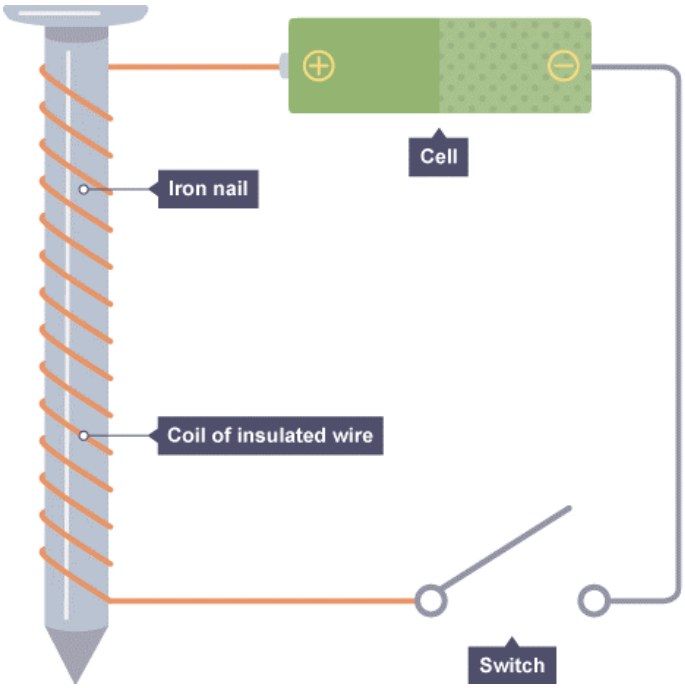


Figure 6: A schematic diagram of an electromagnet.

What Happens When…

Fill in the blanks using the following terms

weaker	magnetic	increases	stops
decreases	starts	stronger	non-magnetic

When there are fewer coils of wire on an electromagnet, the magnetic field is _____

An iron core inside the coils makes the magnetic field strength _____

Increasing the current through the wire, _____ the magnetic field strength

When the current is switched off, the magnetic field _____

An electromagnetic can be used to separate rubbish for recycling because iron is _____ and aluminium is _____

Where do we see Magnets in the world around us?

Note down any examples of Magnets in the world around us – think about where they might be found at home or in life.

Object	**What does the magnet do?**
Fridge magnet	A magnet with a decoration that sticks to the door of your fridge to look pretty or trap an important piece of paper

Figure 7: Example uses of magnets.

Baseline Assignment – What use are magnets in my life?

Think of where you come across magnets in your day-to-day life. Write an article (approximately 500 words) about magnetism. Your article should include:

- A brief description of a magnet, including the key properties.
- How magnets are useful in our everyday lives.
- Include a description of an example of magnets in life, such as fridge magnets, Earth's magnetic field, electromagnets, magnetic levitation, Magnetic Resonance Imaging (MRI).

Any references and sources of information should be properly referenced.

Tutorial 2 – How to store your data magnetically

Figure 8: Visual binary representation.

What is the Purpose of Tutorial 2?

- Describe how binary information can be stored in a magnetic material
- Produce a correctly labelled and reference diagram identifying the key features of magnetic data storage

Binary Solo

Watch the YouTube video of The Flight of the Conchords doing their 'BINARY SOLO'
https://www.youtube.com/watch?v=CTjolEUj00g

Figure 9: Binary solo.

Capture your response to the video in this box below. It can be a drawing or words or your own binary art!

Binary Data

Computers use binary - the digits 0 and 1 - to store data. A binary digit, or bit, is the smallest unit of data in computing. It is represented by a 0 or a 1. Binary numbers are made up of binary digits (bits), for example the binary number 1001. The circuits in a computer's processor are made up of billions of tiny switches that are activated by the electronic signals it receives. The digits 1 and 0 used in binary reflect the on and off states of the switch. All software, music, documents, and any other information that is processed by a computer, is stored using binary.

Is it binary or not?
Draw a tick ✓ next to the information that can be classed as binary data and a cross ✗ next to information which is not binary.

☑ 1 or 0	☐ pH scale	☐ Up and down	☐ Left or right
☐ Yes or no	☐ True or false	☐ north and south poles	☐ Equator
☐ A scale of 1 to 10	☐ pounds and pence	☐ Alphabet	☐ Tick/cross

Definition of binary data…	What you should remember…
Binary data is information whose unit can take on only two possible states, traditionally labelled as 0 and 1 in accordance with the binary numeral system and Boolean algebra.	Any information can be translated into 1 or 0 for storage, and then translated back from 1 and 0 into your data again

Find the famous phrase

Using the binary look-up table below, translate this binary information back into the famous phrase:

A = 100 0001	H = 100 1000	O = 100 1111	V = 101 0110
B = 100 0010	I = 100 1001	P = 101 0000	W =101 0111
C = 100 0011	J = 100 1010	Q = 101 0001	X = 101 1000
D = 100 0100	K = 100 1011	R = 101 1010	Y = 101 1001
E = 100 0101	L = 100 1100	S = 101 0011	Z = 101 1010
F = 100 0110	M = 100 1101	T = 101 0100	
G = 100 0111	N = 100 1110	U = 101 0101	

1.

1001001	=	I
1001000_1000001_1010110_1000101	=	have
1000001	=	a
1000100_10101010_1000101_1000001_1001101	=	dream

2.

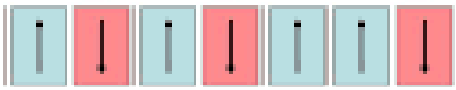
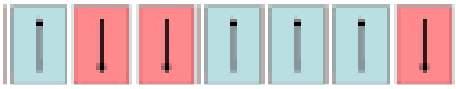
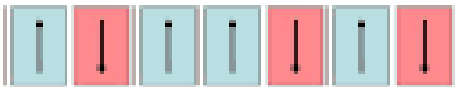
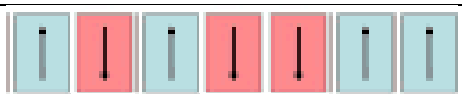
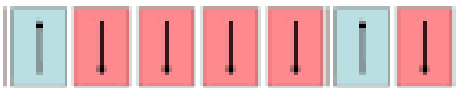
1000010_1000101	=
1001011_1001001_1001110_1000100	=

3.

1011001_1001111_1010101	=
1000001_1011010_1000101	=
1000001	=
1010100_1001111_1011001	=

Now please write your own message in code for a partner to solve.

Write the Binary from the magnetic data below

Magnetic Orientations	Binary	Meaning
	1010110	V
		
		
		
		

Computers and Magnetic Data Storage

Figure 10: Computers of the past, present and (maybe) future.

Think about parts of a computer. Make a list below of anything you recognise that belong to a computer…

e.g. mouse

The main parts of a computer include;

- the central processing unit (CPU) which are like the brains of the system.
- the motherboard which is the main board of the computer that all components are connected to.
- the short term, fast, working memory also known as random access memory (RAM).
- the longer term, storage memory, also known as secondary storage device (SSD).
- the operating system, i.e. the software that controls the hardware components.

There are many technologies that can be used for the secondary storage device, such as magnetic storage (Hard Disk Drive), optical discs (CD, DVD, Blu-Ray) and semiconductor memories (Solid State Device, flash drive). Each type of memory is more useful to specific applications, for example optical storage is mostly used for movies, software and gaming, while magnetic data storage remains the dominant technology for high-capacity information storage, including personal computers and data servers.

Figure 11: An example magnetic hard disk drive.

Definition of hard disk drive…	What you should remember…
An electromechanical data storage device that stores and retrieves binary data using magnetic storage on a platter coated with magnetic material. The platters are paired with magnetic heads that read and write data to the platter surface.	A disk, a bit like a magnetic CD, that a small magnet (called the read/write head) flies over to align the magnetic orientation of a section to store data.

The current magnetic recording technology stores the information in longitudinal orientation, i.e. with the magnetic moment lying in the plane of the disk. A magnetic field is created in the write-head, and the subsequent magnetic "fringing" field is applied over a small region of the disk. This then becomes the 'bit'. The known direction of the field aligns the magnetic moment within that bit, as a '1' or a '0' depending on its orientation. Thus, the information is

stored in the magnetic layer of the disc, so the magnetic properties of this layer are essential to the possible data density.

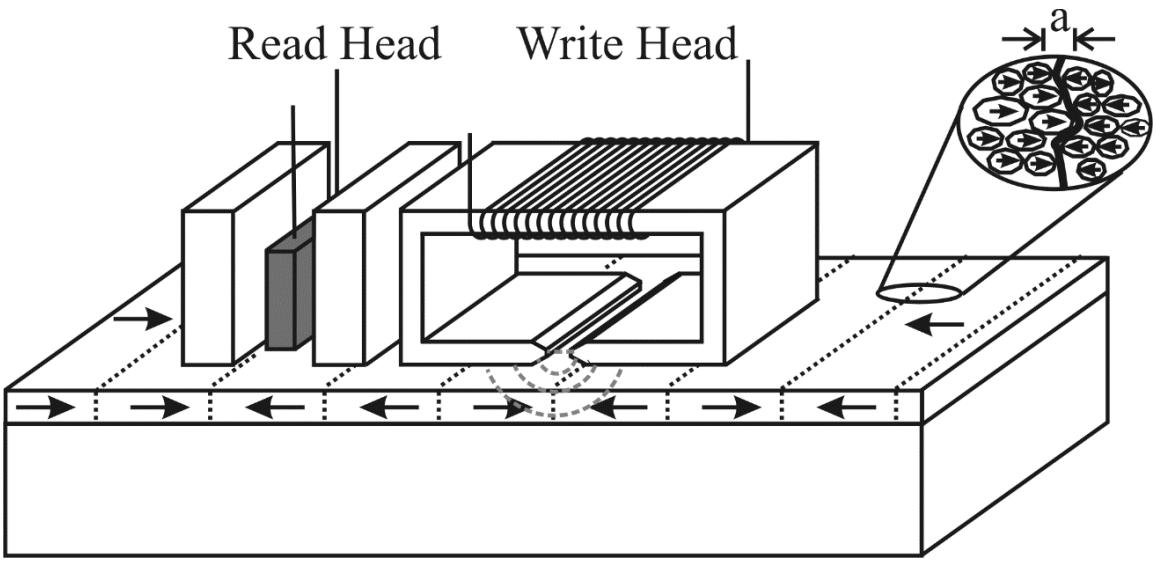


Figure 12: The recording principles of longitudinal recording media.

Each bit consists of many grains within the media and the transition between each bit is never a straight line. Hence there is always a certain distance between neighbouring bits that limits the data density. This is known as the transition parameter, a, which should be kept to a minimum to maximise the data density.

The first magnetic hard disks were simple cobalt (Co) based alloys, which have since evolved into very complex alloy multi-layer films. All aspects have been systematically improved, through careful choice of the various components, such as the substrate, underlayers, overcoats and lubricants. Below is a schematic diagram of a typical longitudinal film. The substrate is usually made of an aluminium magnetism (AlMg) alloy or a glass ceramic because they have a smooth surface, which allows the head to fly closer to the disk, giving better recording properties. The underlayers, such as nickel phosphorous (NiP), are chosen specifically to control the grain size distribution and the crystallographic texture of the recording layer. The magnetic layer is typically based on a cobalt chromium platinum (CoCrPt) alloy, containing 70-80% Co, 12-20% Cr and 4-8% Pt. Additives are frequently included to enhance certain qualities, such as boron (B) and tantalum (Ta) to improve the noise characteristics. The overcoats are typically a very thin diamond-like carbon layer to protect the head and the media from any accidental contact. Then, the last layer of lubricant reduces the friction and wear on the disk.

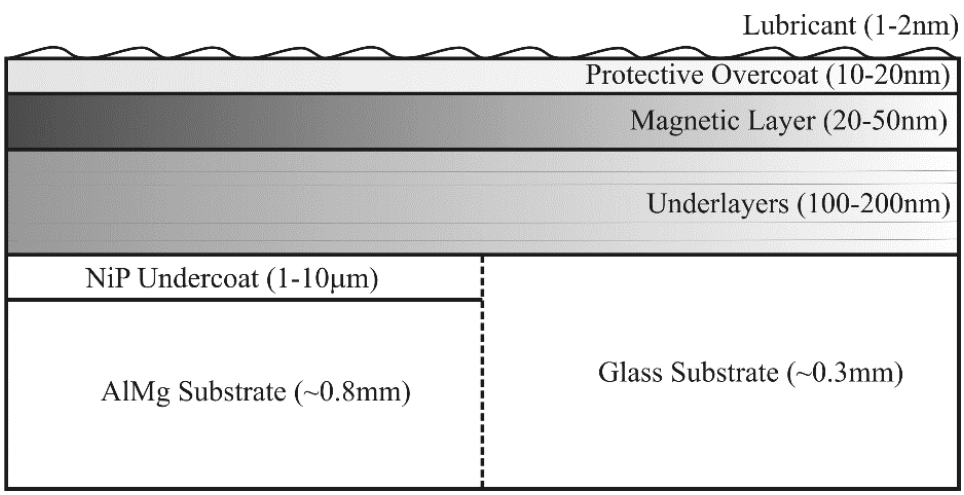
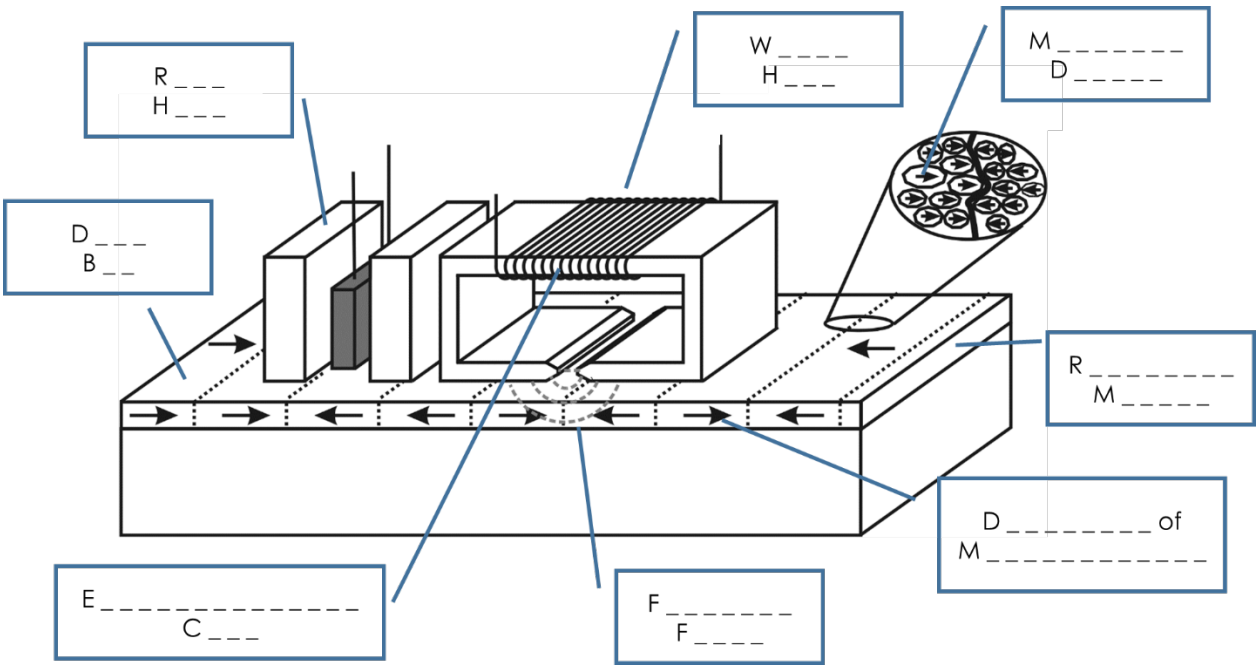


Figure 13: Example layers of a longitudinal recording magnetic hard disk.

Fill in the missing labels and give a brief description of what each part does.



Label	**Brief description**
Read head	Reads the direction of the magnetisation below so that it can be translated from a 1 or 0 to retrieve the data
Write Head	
Fringing field	
Direction of magnetisation	
Magnetic domain	
Data Bit	
Electromagnetic coil	
Recording medium	

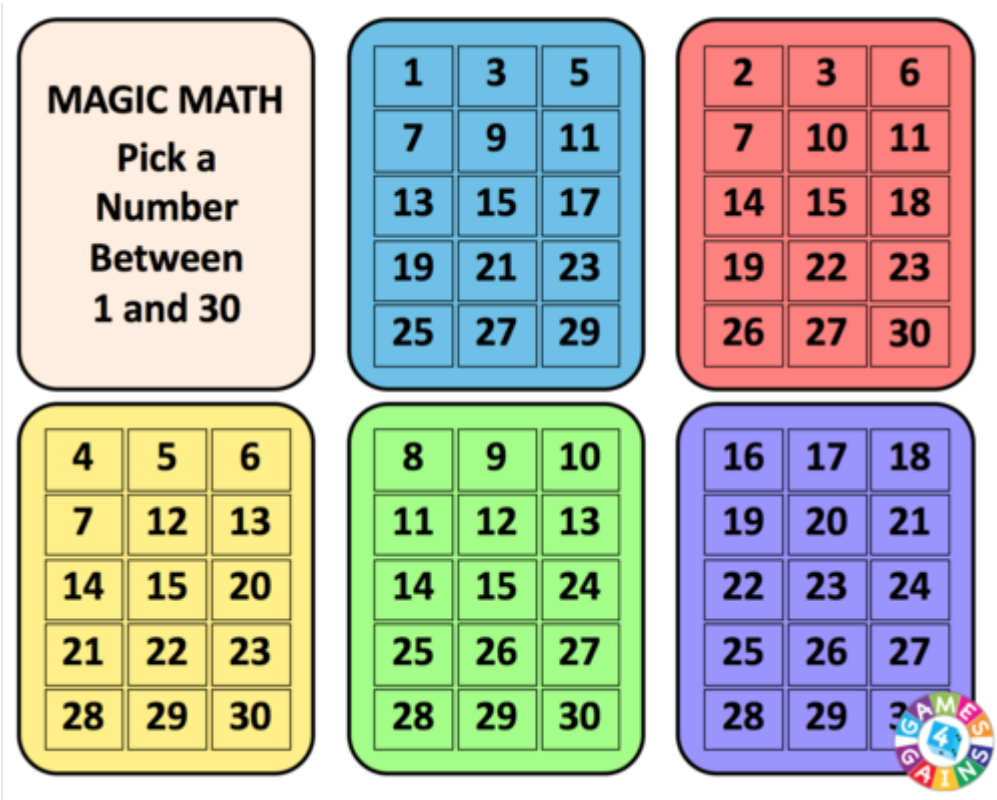
Home Learning Assignment – How are Magnetic Hard Disks and the 'Cloud' related?

Research how magnetic hard drives are used now that we have 'cloud' storage?

Please use your research skills, google, Wikipedia, etc, to investigate this relationship. Then please write 2 or 3 bullet points on the relationship between magnetic hard drives and the 'cloud'.

- _____
- _____
- _____

A bit of binary magic – try it on your family…



Tutorial 3 – Data Density

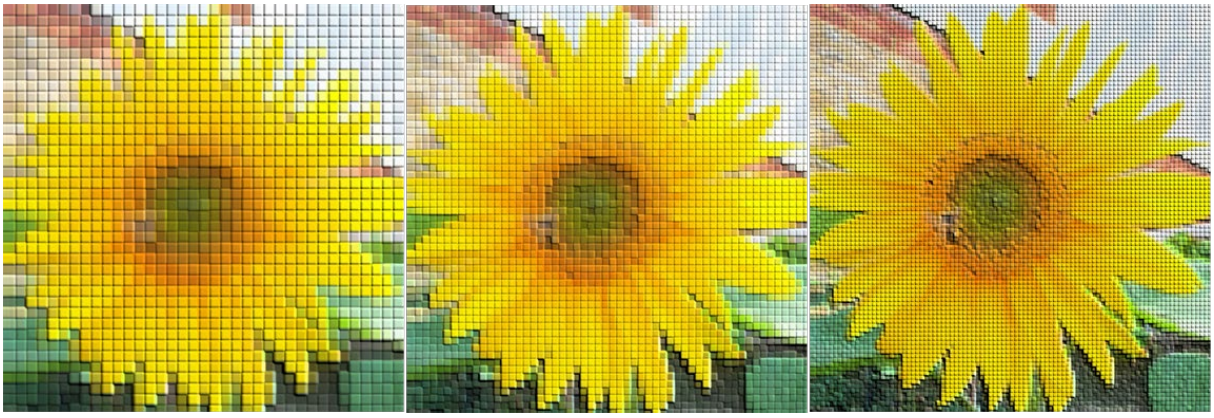


Figure 14: Sunflower at a variety of densities of data on the photograph.

What is the Purpose of Tutorial 3?

- Review the benefit of increasing the data density on a magnetic hard disk.
- Identify at least two main limitations to continually increasing the density of data.

How Big?

International System of Units (SI) prefixes are used to form multiples of SI units. They are used to avoid very large or very small numeric values. The prefix attaches directly to the name of a unit, and a prefix symbol attaches directly to the symbol for a unit.

Figure 15: Visual representation of an atom.

For example, an atom has a radius of approximately 0.0000000001 metres. It is easy to get lost in zeros, so it is useful to use scientific notation, 1×10^{-10} m. It is even easier to get rid of the complicated notation and add a scientific prefix, 0.1nm.

Watch this youtube video on the scales of the physical world… 'the cosmic eye'.

https://youtu.be/8Are9dDbW24

Scientific prefix	Notation	Multiplying factor	Scientific notation
yotta	Y	1 000 000 000 000 000 000 000 000	10^{24}
zetta	Z	1 000 000 000 000 000 000 000	10^{21}
exa	E	1 000 000 000 000 000 000	10^{18}
peta	P	1 000 000 000 000 000	10^{15}
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^{9}
mega	M	1 000 000	10^{6}
kilo	k	1 000	10^{3}
hecto	H	100	10^{2}
deca	da	10	10^{1}
		1	
deci	de	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	µ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pico	p	0.000 000 000 001	10^{-12}
femto	f	0.000 000 000 000 001	10^{-15}
atto	a	0.000 000 000 000 000 001	10^{-18}
zepto	z	0.000 000 000 000 000 000 001	10^{-21}

Using the table of scientific prefixes above, find the ratio between these units;

Unit A		Unit B		Ratio A : B
km	1000	m	1	1000 : 1
mg	0.001	kg	1000	1 : 1 000 000
ml	0.001	Ml	1 000 000	
s	1	ps	0.000 000 000 001	
cm	10	mm	0.001	

How Dense?

Density "quality of being very close or compact", from the Latin 'densus' meaning "thick, dense". In science it is the mass of matter per unit of bulk, which can be expressed with the equation:

$$\rho = density = \frac{mass}{volume} = \frac{m}{V}$$

Density, ρ, has the standard unit of kg/m^3, because it is the mass, m, in kg divided by the volume, V, in m^3. Use this equation to fill in the gaps in the table below:

Material	Mass (any unit)	Mass (in kg)	Volume (any unit)	Volume (in m^3)	Density (in kg/m^3)
Water	1.00g	1x10^{-3} kg	1cm^3	1x10^{-6} m^3	1000 kg/m^3
Wood	0.50g	5x10^{-4} kg	1 cm^3	1x10^{-6} m^3	
Iron	8.00g		1 cm^3		
Gold			20 cm^3		20,000 kg/m^3
Silver	10g				10,000 kg/m^3
Petrol			1m^3		800 kg/m^3

Now please order the materials from most to least dense.

Most Dense – Gold →

→ Least Dense - Wood

Data Density

Data density can be thought of as a measure of how much information can be stored in a specific amount of storage space. For example, you can think of this like the population density in a big city versus the population of those living outside city limits in the country. The number of people per square kilometer or mile is significantly higher in the city than in the country. Data density can be thought of in the same fashion.

In computing, this is given the name areal density. It is a measure of the quantity of information bits that can be stored on a given length of track, area of surface, or in a given volume of a computer storage medium. Generally, higher density is more desirable, for it allows more data to be stored in the same physical space.

In your own words, please write your own definition of the relation between density and data density.

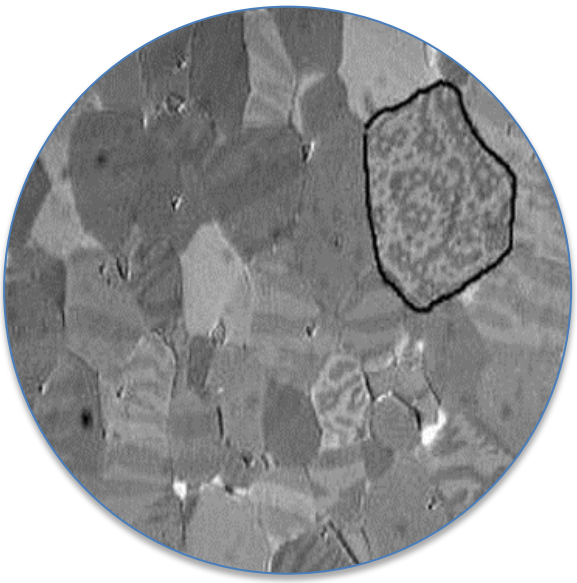


Figure 16: Example structure of a magnetic material, the black outline indicates one 'grain'.

Hard disk drives store data in the magnetic polarisation of small patches of the surface coating on a disk. The maximum density is limited by the size of the magnetic particles in the surface, as well as the size of the "head" used to read and write the data.

Fill in the 3 hard disks below with different 'densities' of data.

Lowest Density	Medium Density	Highest Density

If you want a challenge – see if you can calculate the data density that you have drawn for your highest density hard disk. (The circles are 5cm in diameter).

In 1956 the first hard drive, the IBM 350, had an areal density of 3 Mbit/m^2. Since then, the increase in density has matched Moore's Law, reaching 1550 Tbit/m^2 in 2014.

Moore's Law

Moore's Law, which was formulated around 1970, stated that computer processing units (CPU) speeds will double every two years.

Plot a graph of data that doubles every 2 years.

Time (years)	Data (number)
0	1
2	2
4	4
6	8
8	16
10	32
12	64
14	128
16	256

In your own words, describe the shape of the graph:

Industry players

In 2015, Seagate introduced a hard drive with a density of 2080 Tbit/m^2, more than 600 million times that of the IBM 350. It is expected that current recording technology can "feasibly" scale to at least 7750 Tbit/m^2 in the near future. New technologies like heat-assisted magnetic recording (HAMR) and microwave-assisted magnetic recording (MAMR) are under development and are expected to allow increases in magnetic data density to continue.

Write a mind map of problems that threaten magnetic data storage.

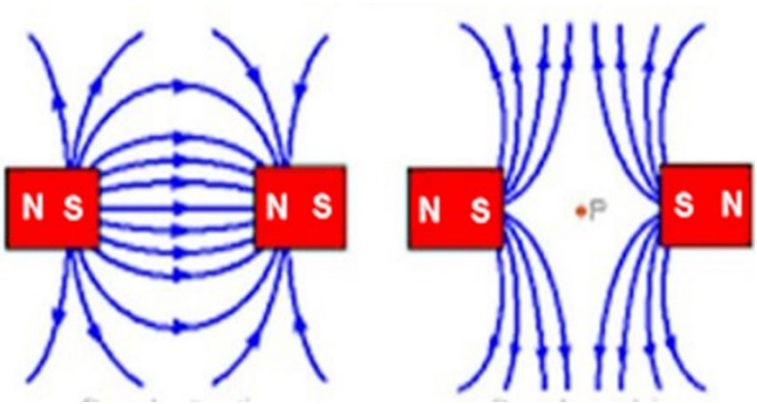
Corrupt data

Write a definition of stability. Feel free to include a descriptive example of what something stable or unstable would be like.

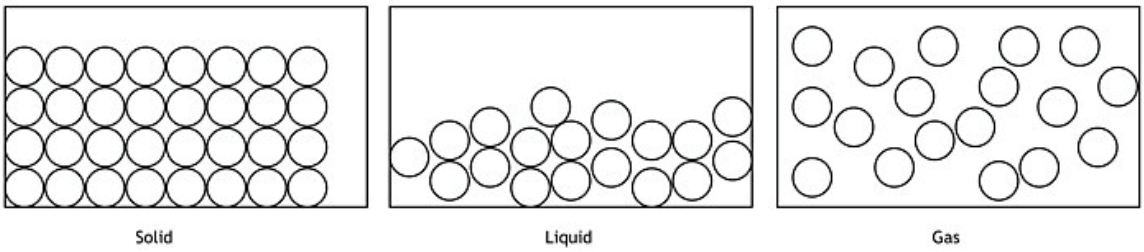
Stable	Unstable	What does this mean for magnetically stored data?

Magnetic and Thermal Stability

What happens when you try to bring two magnets together? Draw the lines of force on each diagram…



What happens when you heat an object?
https://www.bbc.co.uk/bitesize/topics/z9r4jxs/articles/zqpv7p3#zr6hxbk1



Magnetism doesn't become a gas with increasing temperature, but it can much more easily change its direction of magnetisation.

The drive for increasing data density requires that the magnetic domain grain size incrementally decreases, but at each step stability is forfeited. Thermal fluctuations increase the possibility of the magnetic moment spontaneously switching, by breaching the energy barrier to reversal. The energy barrier is proportional to the volume, so the probability of reversal is greater for smaller grain sizes.

The obvious solution is to increase the anisotropy of the material to compensate for a decrease in volume. Alternative modes of recording have been proposed to extend the density past 155000 Gbit/m^2, such as perpendicular media, heat assisted magnetic recording, and self-organised magnetic recording, each discussed in the following tutorials.

Home Learning Assignment

In your own words, write 3 paragraphs on Moore's Law and how information stored on computer hard disks have changed since the first hard disk was made in 1956.

Tutorial 4 – For added stability

Figure 17: A wooden Jenga tower.

What is the Purpose of Tutorial 4?

- Students will identify the characteristics of longitudinal recording media (LRM) and perpendicular recording media (PRM).
- Students will compare the benefits and limitations of LRM and PRM.

Can we add training wheels?

Figure 18: A child's bike with stabilisers.

In your own words, please write your own definition of stability and think of examples of how we stabilise everyday objects.

Instability	How we stabilise…
Bicycle	Training wheels
Cathedral	Buttress
Tent	
3-tiered cake	
Lego	
Jelly	

What can we do to stabilise the magnetic layer on a hard disk drive?

Antiferromagnetically coupled media

Antiferromagnetically coupled media (AFC) has an additional magnetic layer stabilising the top magnetic recording layer. These two ferromagnetic layers are separated by approximately 0.8nm of Ruthenium, which couples the two layers antiferromagnetically. This additional layer and subsequent coupling gives added stability to the grains.

The self-demagnetising field arises due to the return field from each magnetic bit, which adds an extra field that increases the probability of spontaneous reversal. It is dependent on the shape of the bit, because the shape changes as the data density increases. The bit-to-bit demagnetising field arises when neighbouring bits have opposite orientation. The bits would prefer to lie in the same orientation, hence there is an extra force required to orient the moment. This force increases as the bits get smaller and closer, destabilising the information.

Magnetism Name	Diagram	Description
ferromagnetism	↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑↑	Magnetic moments are aligned in the same direction
antiferromagnetism	↓↑↓↑↓↑↓↑↓↑↓↑↓↑↓↑↓↑↓↑	Magnetic moments are aligned alternatively in opposite directions. The net magnetic moment is zero.
paramagnetism	↓↑↓↓↓↑↓↑↑↑↓↓↑↓↑↓↑↑↑↓	Randomly aligned magnetic moments, but will align in an applied magnetic field
diamagnetism	↓↑↓↓↓↑↓↑↑↑↓↓↑↓↑↓↑↑↑↓	Randomly aligned magnetic moments, but will align weakly in the opposite direction of an applied magnetic field

Magnetic domains
Hysteresis curves of different types of magnetism… let us draw them together.

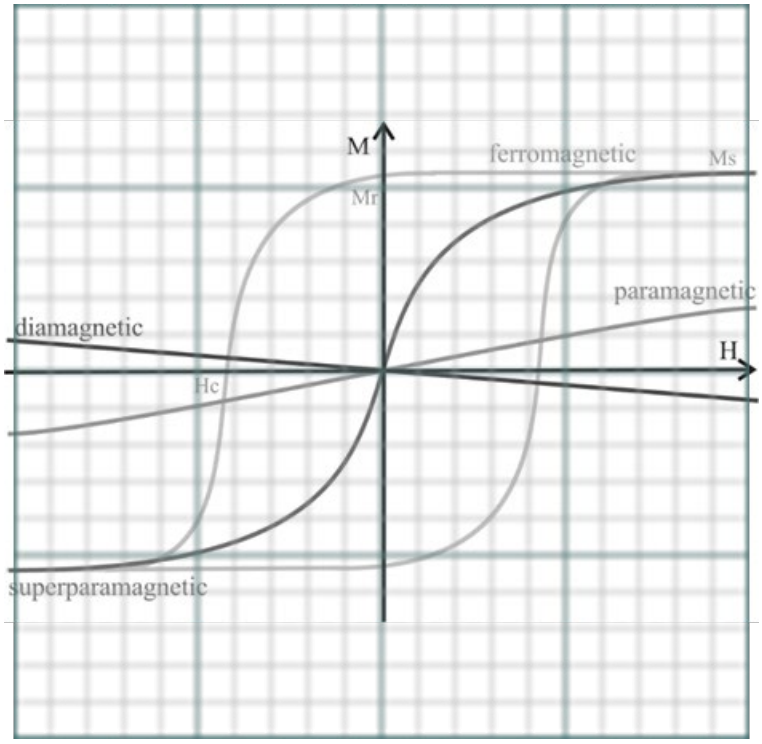


Figure 19: Magnetic properties of different types of magnetisation.

Increasing Stability with volume not area

Calculate the volume of the each 'bit' of data for various surface areas of 'bit', i.e. 1cm, 3cm, 10cm, for various depth of 'bit', i.e. 1µm, 1mm, 1cm. Please be very mindful of the units!).

Area of Bit	Depth of Bit	Area x Depth	Volume of Bit
$1cm^2$	1µm	$1cm^2 \times 1\mu m = 1\times10^{-4}\ m^2 \times 1\times10^{-6}\ m$	$= 1\times10^{-24}\ m^3$
$1cm^2$	1mm	$1cm^2 \times 1mm = 1\times10^{-4}\ m^2 \times 1\times10^{-3}\ m$	$= 1 \times 10^{-12}\ m^3$
$1cm^2$	1cm	$1cm^2 \times 1cm = 1\times10^{-4}\ m^2 \times 1\times10^{-2}\ m$	$= 1 \times 10^{-8}\ m^3$
$2cm^2$	1µm		
$2cm^2$	1mm		
$2cm^2$	1cm		
$3cm^2$	1µm		
$3cm^2$	1mm		
$3cm^2$	1cm		

Make notes on your observations of the information the impact of increasing the depth of the 'bit' on the volume of the bit.

Perpendicular Recording Media

Direction	Relative direction	Label	What does that mean to you
Up - down	In out of paper	perpendicular	
Left - right	Along paper	longitudinal	

Perpendicular media, as implied, store the information perpendicular to the plane of the disc, i.e. the magnetic domains are oriented with the magnetisation normal to the plane of the medium. Many advantages arise by changing the orientation of the information, for example;

- As the surface area of the grains decrease in size, the depth of the grain can be increased, essentially sustaining the volume of the bit (i.e. volume = area x depth).
- The materials used can have a much higher anisotropy and hence a larger energy barrier to reversal, giving added thermal stability for smaller grain volumes.

Thus, the rate of decrease of the grain volume is impeded significantly compared to longitudinal media.

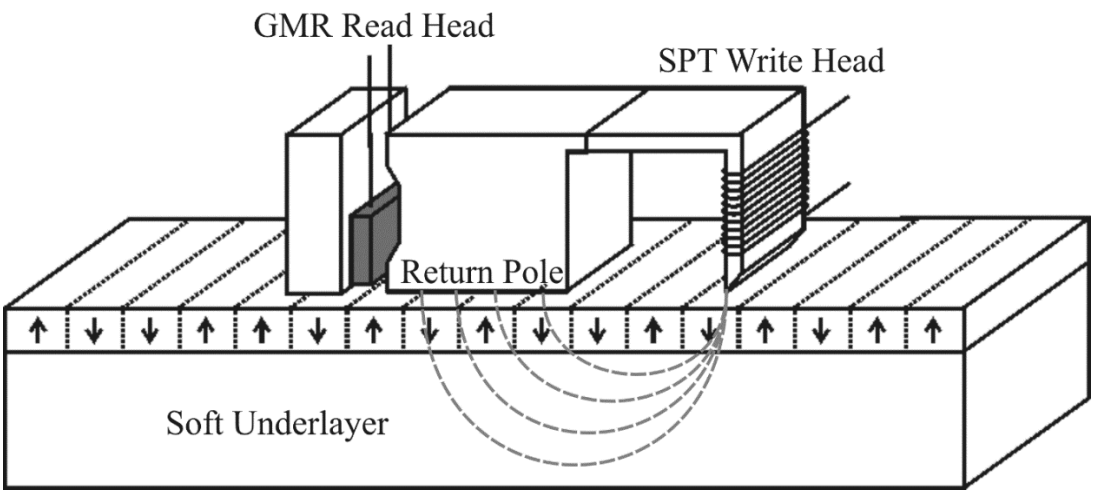


Figure 20: The recording principles of perpendicular recording media.

The two main features to note are the single pole tip (SPT) and the soft underlayer (SUL). The STP is used to create a large field in a single narrow pole to write data to the media rather than using the fringing field. An image of the SPT is made in the SUL, and the field is then returned to a much wider return pole. The return pole is designed to be large enough that the field doesn't interfere downtrack of the written data. If the return field is too large, the data density is limited due to the additional erasure problems created.

In perpendicular media, the bit-to-bit demagnetising field assists the stability of perpendicular materials. The perpendicular bits are stabilised by flux closure. The bit-to-bit demagnetising field has the opposite effect on longitudinal media, because the return flux of each longitudinal bit acts to destabilise the system. This flux closure within perpendicular media allows much higher densities because of the enhanced stability in the system.

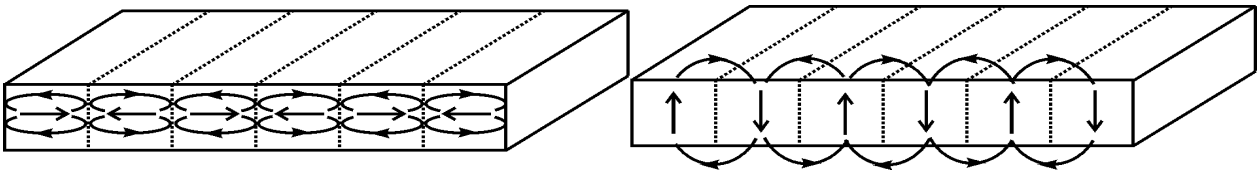
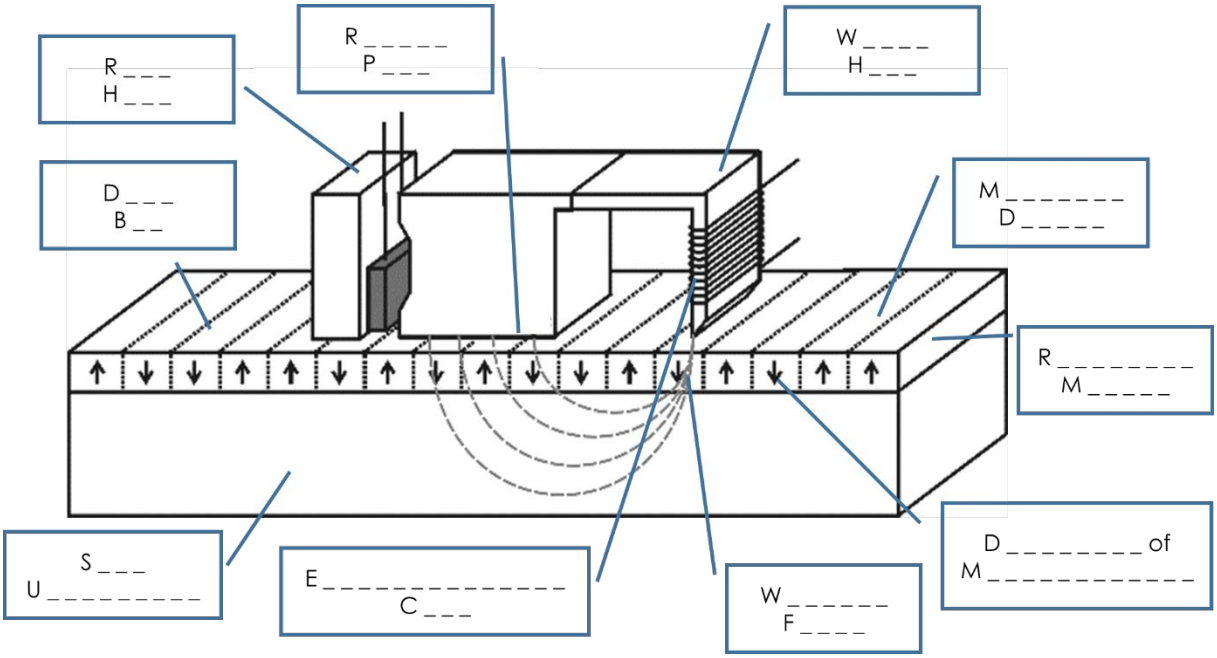


Figure 21: Schematic diagram of the magnetic return field in longitudinal and perpendicular magnetic media.

Can we still use the same technology?

Describe the key parts of Perpendicular Recording method and label these key features.

Label	**Brief description**
Read head	Reads the direction of the magnetisation below so that it can be translated from a 1 or 0 to retrieve the data
Write Head	
Return pole	
Writing field	
Direction of magnetisation	
Magnetic domain	
Data Bit	
Electromagnetic coil	
Recording medium	
Soft Underlayer	



Make a note of the similarities and difference between longitudinal and perpendicular recording methods.

Similarities	**Differences**
Layer of magnetic recording media	Soft underlayer in PRM to allow return field.
	Ring vs monopole inductive write element

Make a note of the benefits and problems of perpendicular recording methods.

Pros	**Cons**
Similar technology	Extra layers required
Increased volume without changing surface area	

Heat Assisted Magnetic Recording

Once the volume is increased with the use of perpendicular technology, materials with high magnetic anisotropy, i.e. highly magnetic in one direction, can be considered to continue to extend the data density in magnetic recording media. The anisotropy stabilises smaller grain sizes against the thermal stability limit. Unfortunately, this additional stability also requires a greater magnetic field to change the direction of the magnetisation, i.e. an extremely large write-field is required to write data on high anisotropy media. Heat assisted magnetic recording (HAMR) has been suggested as a possible means to overcome this writing problem.

HAMR exploits the temperature dependence of magneto-crystalline anisotropy, because localised heating of the media temporarily lowers the field. This reduces the field required to change the magnetic orientation and hence a smaller write-field is needed. The medium must then be cooled rapidly to store the data. Such advances in recording technology requires considerable change to the write head, to include a local heat source such as a laser.

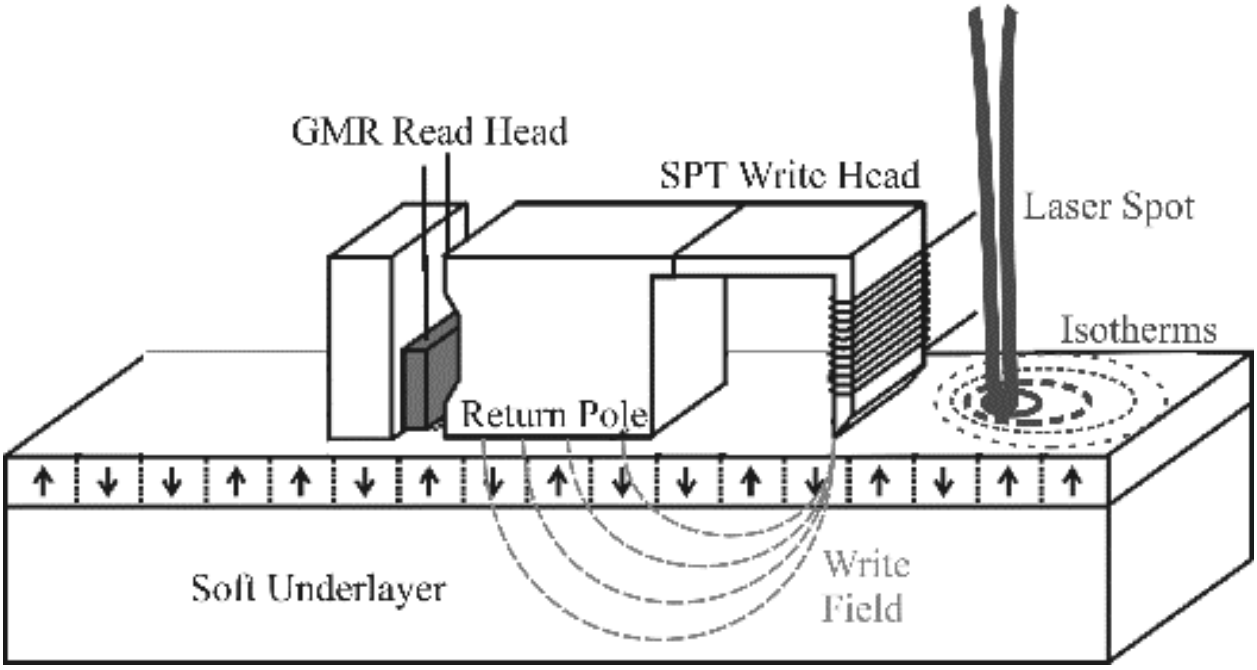


Figure 22: The recording principles of heat assisted magnetic recording.

Malleability

A 'malleable' substance is one that is 'capable of being stretched or bent into different shapes', for example a malleable metal. It can also be used to describe the capability of being easily changed or influenced, for example malleable young minds.

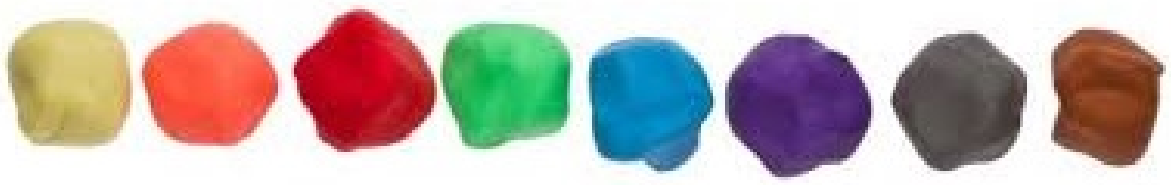


Figure 23: Plasticine balls

Let us use the comparison of plasticine;

- Take a lump of plasticine and roll it into a sphere.
- Initially, it is difficult to mould.
- As the warmth from your hands heats the plasticine, it becomes easier to mould!

In your own words, please describe how the plasticine becomes easier to handle as it warms up. Then, using your experience, apply this to the context of using heat to make it easier to alter the direction of magnetisation on a hard disk.

Molding plasticine…	Heat Assisted Magnetic Recording…

Home Learning

Investigate the latest magnetic recording hard disk drive available to buy. Make an A4 size poster/advert for the product - summarise the density, cost and technology involved

Tutorial 5 – Itty Bitty

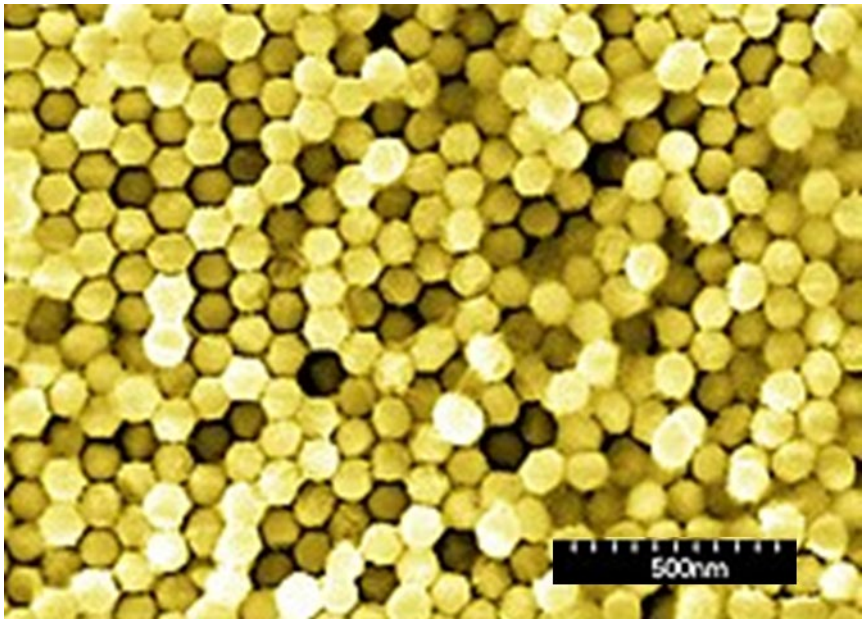


Figure 24: Gold nanoparticles

What is the Purpose of Tutorial 5?

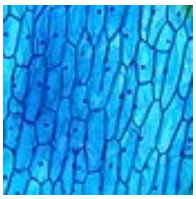
- Students will explain the benefits of nanoparticles over a continuous layer of magnetic material for data storage.
- Students will conclude three main factors that make a good magnetic storage material.

Nanoparticle or Megaparticle?

Definition of a nanoparticle…	What does this mean to you…
A particle of matter that is between 1 and 100 nanometres (nm) in diameter. Their small size drives very different physical or chemical properties.	

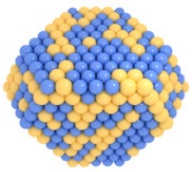
Nanoparticle or not?

Nanoparticle or Not?
Not – it's Mars



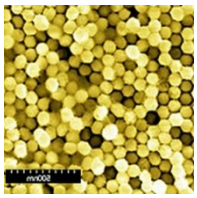
Nanoparticle or Not?

Nanoparticle or Not?

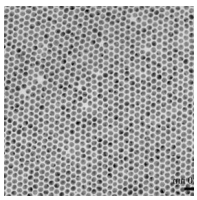


Nanoparticle or Not?

Nanoparticle or Not?



Nanoparticle or Not?



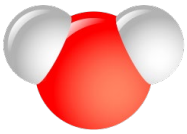
Nanoparticle or Not?

Nanoparticle or Not?

Nanoparticle or Not?

Nanoparticle or Not?

Nanoparticle or Not?



Nanoparticle or Not?

NanoParticles vs Continuous Media

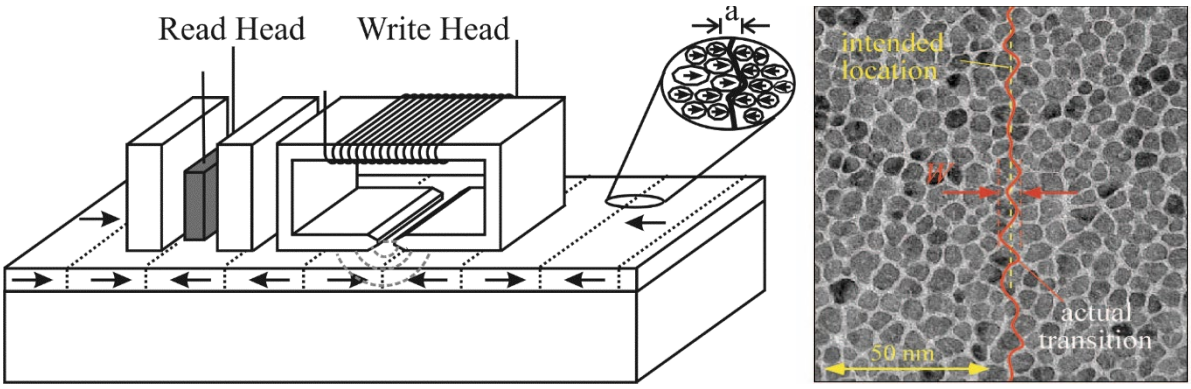


Figure 25: The recording principles of longitudinal recording media, and an image of the grain structure of the recording material showing the transition parameter, a.

Each bit consists of many grains within the media and the transition between each bit is never a straight line. Hence there is always a certain distance between neighbouring bits that limits the data density. This is known as the transition parameter, a, which should be kept to a minimum to maximise the data density.

This transition parameter, a, should become irrelevant for nanoparticles, as it is hoped that they would produce a regular array of evenly spaced isolated islands. Ideally, each nanoparticle island would contain one bit of data rather than a number, collectively forming the bit. Thus, the transition parameter would be pared down to the separation between each particle, which could be readily controlled.

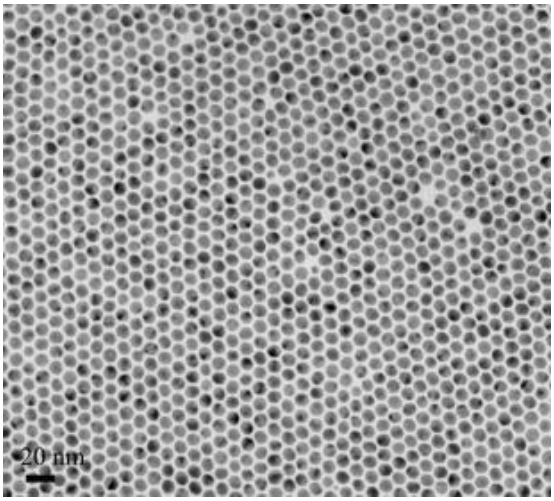


Figure 26: An self-organised array of FePt nanoparticles.

Write two benefits of an array of nanoparticles rather than one continuous layer.

Chemically synthesised nanoparticles

The material iron platinum (FePt) has one of the largest anisotropies, magnetic barrier to reversal, possible and hence, even with very small particles, is less susceptible to the fundamental thermal limit. The minimum stable diameter for FePt is only 3nm due to this very large anisotropy. Thus it is an ideal candidate for high-density magnetic recording because a small grain volume can be used.

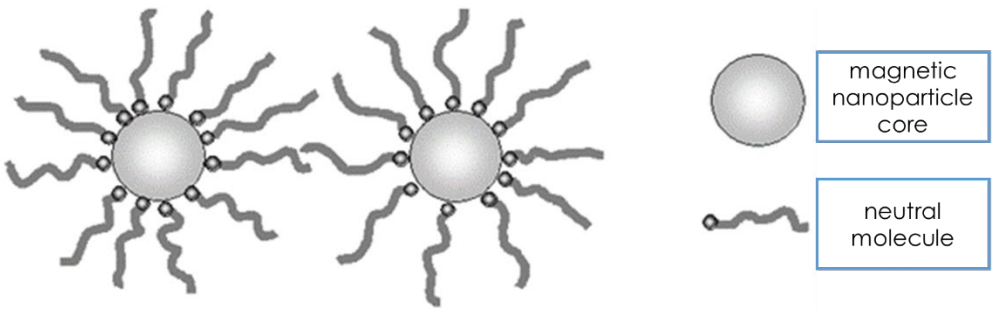


Figure 27: A schematic diagram of chemically synthesised magnetic nanoparticles.

FePt nanoparticles can be chemical synthesised. This involves one or more compounds, known as reactants, experiencing a transformation when subjected to certain conditions. This requires mixing the reactants in a reaction vessel, such as a chemical reactor or a simple round-bottom flask, followed by some form of processing or purification procedure to isolate

the final product. FePt nanoparticles have been successfully chemically synthesised into resultant particles consisting of a small metal core of FePt surrounded by neutral molecules that bond to the core. The surrounding neutral molecule is important because it stabilises the magnetic particle and prevents the particles from clumping together. These nanoparticles are then dispersed in a fluid, such as ethanol. This sample fluid is then deposited onto a surface, where the solvent (i.e. carrying fluid) is left to evaporate, leaving the nanoparticles to settle into a self-organised array.

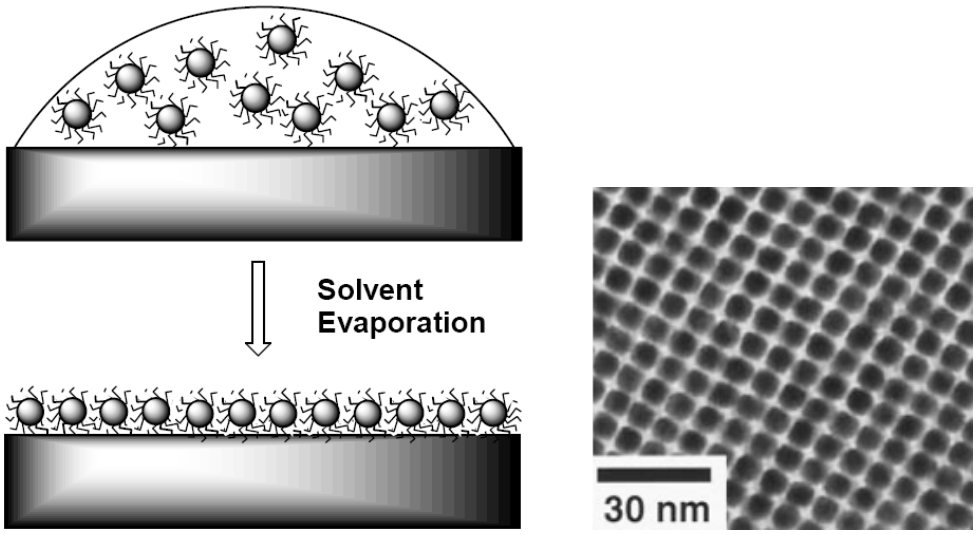
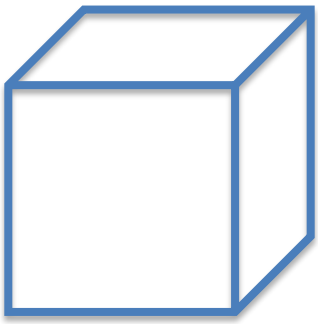
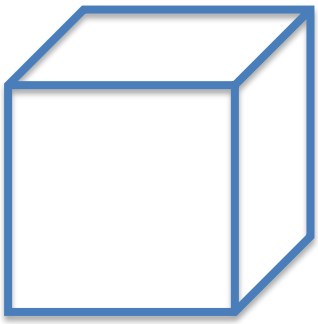
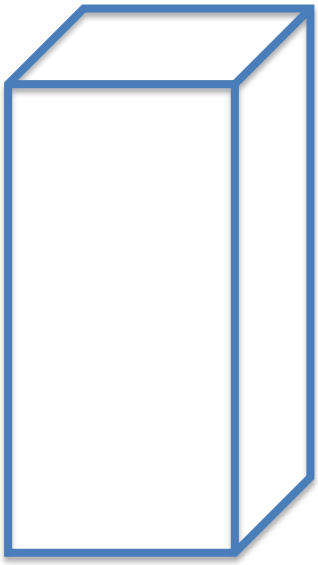


Figure 28: A schematic diagram of the method of depositing nanoparticles into a self-organised pattern.

The resultant nanoparticles have a chemically disordered chemical crystallography structure. They are face centred cubic (fcc), which has a low anisotropy. By heating the nanoparticles to very high temperature, greater than 500°C, the atoms within the nanoparticle organise into layers. This produces a high anisotropy, face centred tetragonal (fct) structure within the nanoparticle. Let's draw the some crystallographic structures together to demonstrate cubic, face centred cubic and face centred tetragonal.

Cubic structure (such as NaCl)	As synthesised (cubic) FePt (FCC)	Annealed Face centred tetragonal FePt
		

Looking at the crystallographic diagrams that we have drawn above, it is not a large leap to see how the face centred tetragonal FePt particles have a much larger 'magneto-crystalline' anisotropy than the face centred cubic FePt particles. Particularly if you recall a definition of magnetic anisotropy as…

Definition of magnetic anisotropy…	What you can think…
The property that confers a preferred direction of the spin of a system which may not be aligned with an external magnetic field.	Property of have a preferential axis. If the nanoparticle is long and thin, with the magnetisation along the long axis, it takes a lot of energy (large field) to change direction.

Self-Organised Arrays

Draw a regular array of nanoparticles in two different arrays – triangular and square array.

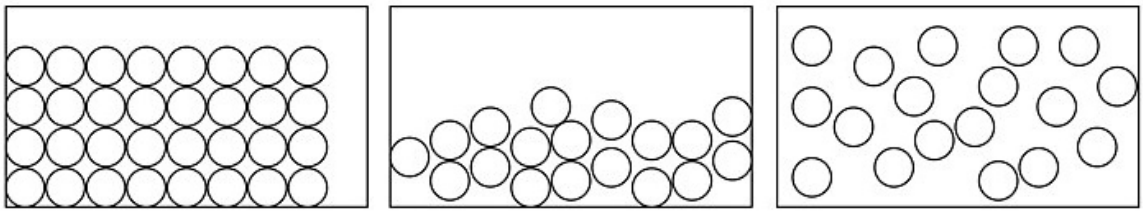
Triangular regular pattern	Square regular pattern

What happens to the regular array when high temperature annealed?

Figure 29: Examples of loss of structure as chocolate is heated.

Sorting activity

Look at the series of 3 pictures below. Write order pattern into order of most to least ordered.



Most ordered Least ordered

Self-Organised Magnetic Arrays – Pros and Cons

Summarise our discussions on self-organised magnetic FePt nanoparticle arrays into the table below.

Pros	**Cons**
High anisotropy	Different manufacturing technology
Thermally stable	

Overview of everything learned so far

Let's draw a mind map of information…

Think about the factors that have been discussed and the reasons why they are important. For example, the storage material cannot be too expensive because there are many alternatives for data storage, such as solid state devices, so it needs to be competitive and good value.

Final Assignment –What makes a good magnetic storage material?

Details of the assignment:

Your task is to write a 2000 (+/- 10%) word essay describing the key features that are required for a good magnetic storage media, demonstrating understanding of:

- How data is stored on a magnetic hard disk.
- What factors limit the stability of the stored data and the ability to continue increasing data density?
- What material properties are optimal for alternative storage media?
- Discuss the pros and cons of example types of future of magnetic data storage.
- Draw conclusions of good magnetic materials for data storage, referencing the pros and cons outlined.

Any references and sources of information should be properly referenced.

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

In your essay, please include:

- An introduction to magnetism, including magnetic poles, field lines and forces.
- A brief extension of magnetism to electromagnetism.
- Identify examples of magnets in real life, such as fridge magnets, etc.
- A description of the basics of magnetic data storage.
- An overview of how magnetic materials can be used as magnetic data storage.
- A brief history of the growth in storage capacity and subsequent challenges and solutions.
- An overview of different methods for magnetically storing data, including Longitudinal recording media (LRM), antiferromagnetically coupled recording media (AFM), perpendicular recording media (PRM), heat-assisted recording media (HAMR) and self-organised magnetic arrays (SOMA).
- A summary of the similarities and differences between the suggested methods for magnetic material specification.
- A brief description of an ideal magnetic material for data storage.
- A conclusion summarising your definition of a good magnetic material for storage media, supporting evidence for why you think this, and the future directions of data storage.

Your document should be structured using appropriate subheadings, including introduction and conclusion. Include diagrams when they help explain your point. These must be labelled or commented on in the text.

Extra reading and research is encouraged. Search for information about the magnetic data storage on the internet and look out for news articles and scientific websites. Make sure to comment on the reliability of these sources and reference them as stated below.

In this assignment, show me that you **understand**:

- Basic principles of magnetism
- Magnetic data storage
- Magnetic hard disk technology
- Modern material advancements

Show me that you **are able to**:

- Have a high level of topic knowledge and understanding
- Give evidence and references to support facts
- Understand commercial benefits of technological advancement

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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