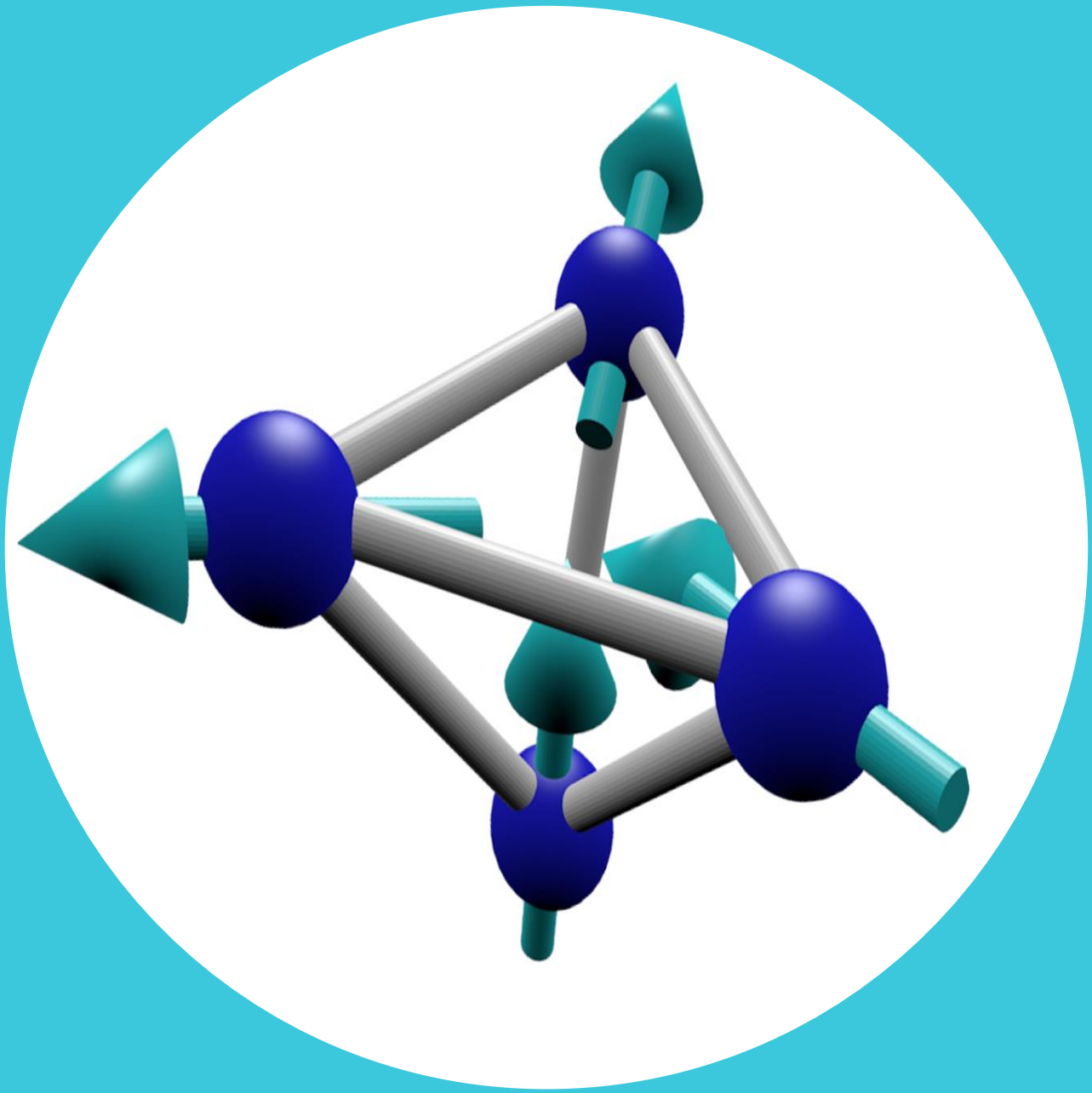

Frustrated Magnets

Key Stage 4 Programme

Pupil Name	Name
Handbook Designed by	Dr Marion Brooks-Bartlett

Timetable and Assignment Submission

Timetable – Tutorials

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

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1	Introduction to Magnetism	
Tutorial 2	Frustrated Magnets	
Tutorial 3	Magnetic monopole behaviour in spin ice	
Tutorial 4	Tools for modelling spin ice	
Tutorial 5	Final Assignment – Write an essay about spin ice	

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight of deadline date	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

The Brilliant Club KS4 Programme – Pupil Feedback Report

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 AS-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

Name of PhD Tutor	Marion Brooks		
Title of Assignment	What has Magnetic Monopoles got to do with Frustrated Magnets?		
Name of Pupil			
Name of School	Harris Academy Orpington		
ORIGINAL MARK / 100		FINAL MARK / 100	
DEDUCTED MARKS		FINAL GRADE	

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

Learning Feedback Comment 1 - *Subject Knowledge*	
What you did in relation to this Key Learning Priority	How you could improve in the future
Learning Feedback Comment 2 – *Critical Thinking*	
What you did in relation to this Key Learning Priority	How you could improve in the future
Learning Feedback Comment 3 – *Written Communication*	
What you did in relation to this Key Learning Priority	How you could improve in the future
Resilience Comment	
How you showed learning resilience during the course	How you could build learning resilience in the future

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Course Rationale

As technology develops, we are seeking more ways to miniaturise devices whilst storing more data. We are needing to write and erase information easily and quickly to storage devices, as well as being assured that the materials used to store that information will be stable enough to withstand changing conditions. However, have we exhausted the use of semiconductor materials that we currently use now? Do we need to look to other alternatives? Maybe to materials that display exotic behaviour that we are not so familiar with?

This course will guide you through the properties and behaviour of one such material known as "frustrated magnets". These magnets consist of a wide range of structures and chemical composition, but one thing they all have in common is that they cannot seem to arrange themselves into magnetic order as the temperature decreases towards absolute zero. This inability makes them truly a frustrated bunch of magnets!

We are going to focus on a class of frustrated magnets known as "Spin Ice" to explain some key concepts. These are materials which rely on the magnetic ability of elements near the bottom of the periodic table (rare earth elements, such as Dysprosium) and whose magnetic structure relates to water ice, the kind of ice that comes out of your freezer. What is also fascinating, is our ability to observe something that resembles a particle never seen before... Magnetic Monopoles!

Mark Scheme Table

	Skills	1st (70-100)	2:1 (60-69)	2:2 (50-59)
Subject knowledge	Knowledge and Understanding	○ All content included is relevant to Frustrated magnets and Magnetic monopoles and hence specific to the title. ○ Good understanding of Frustrated magnetism, monopoles, spintronics and modelling spin systems ○ Scientific terms are defined and used accurately throughout ○ Clear justification and demonstration of how each question is related in the assignment ○ Excellent attempt at challenge question demonstrating critical thinking and use of resources	○ Most of the content included is relevant to Frustrated magnets and Magnetic monopoles and hence specific to the title. ○ Good understanding of Frustrated magnetism and monopoles. ○ Scientific terms are used accurately but not always clearly defined. ○ Adequate justification and demonstration of how each question is related in the assignment ○ Good attempt at challenge question demonstrating critical thinking	○ Some of the content included is relevant to Frustrated magnets and Magnetic monopoles and hence specific to the title. ○ Good understanding on Frustrated magnetism but occasional confusion on others. ○ Scientific terms are used mostly accurately with occasional confusion and often not defined. ○ Some justification and demonstration of how each question is related in the assignment ○ Adequate attempt at challenge question

Critical thinking	Research and Evidence	○ Inclusion of rich sources of research findings, data, quotations or other sourced material as evidence for the claims/ ideas ○ Use evidence/equations to support claims/assertions /ideas, consistently clearly and convincingly ○ Evidence of further reading beyond materials provided which were used in an appropriate context ○ Data provided is effectively analysed and appropriate conclusions are reached	○ Inclusion of adequate sources of research findings, data, quotations or other sourced material as evidence for the claims/ ideas ○ Use evidence/equations to support claims/assertions/ideas, mostly clearly and convincingly ○ Evidence of further reading beyond materials provided ○ Data provided is analysed and the conclusions that are reached are mostly appropriate	○ Inclusion of some sources of research findings, data, quotations or other sourced material as evidence for the claims/ ideas ○ Use evidence/equations to support claims/assertions/ideas, at times clearly and convincingly ○ Limited evidence of further reading beyond materials provided ○ There is an attempt to analyse data provided and draw conclusions
	Developing an Argument	○ A point of view or position in relation to the existence of monopoles and role that frustrated magnets could play in Spintronics is consistently clear ○ Argument/proof exceptionally well-developed and well-justified ○ A position is clearly established in relation to the question, and is developed effectively and consistently throughout the essay ○ Makes links effectively between subjects that have not previously been associated ○ Uses concepts from the tutorials in an unfamiliar context, and does so accurately and confidently.	○ A point of view or position in relation to the existence of monopoles and role that frustrated magnets could play in Spintronics is adequately clear ○ Argument/proof clear and well-developed and position justified ○ A position is established in relation to the question, and is well-developed in most of the essay ○ Some evidence of linking subjects that have not previously been associated ○ Use some concepts from the tutorials in an unfamiliar context, but not always accurate	○ A point of view or position in relation to the existence of monopoles and role that frustrated magnets could play in Spintronics is somewhat clear ○ Argument/proof clear but not well-developed ○ A position is established in relation to the question, and is well-developed in parts of the essay ○ Limited evidence of linking subjects that have not previously been associated ○ Limited use of concepts from the tutorials in other contexts

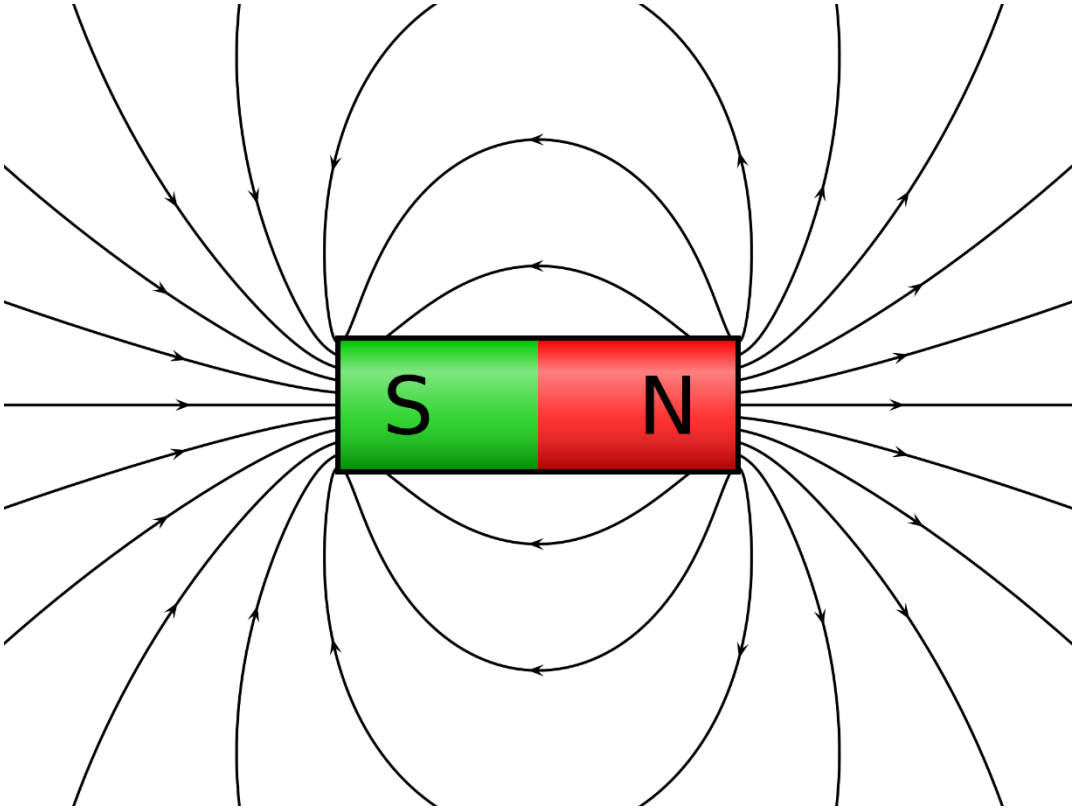
	Critical Evaluation	○ Moved beyond description to an assessment of the value or significance of what is described ○ Evaluative points are consistently justified ○ Effective critiques on the reliability of sources provided	○ Mostly description but some assessment of the value or significance of what is described ○ Evaluative points are mostly justified ○ Some evidence of critiques on the reliability of sources provided	○ Only description with minimal assessment of the value or significance of what is described ○ Evaluative points are at times justified ○ Limited evidence of critiques on the reliability of sources provided
Written communication	Structure and Presentation	○ Ideas are presented in paragraphs and arranged in a logical structure which is according to the questions in the assignment ○ The introduction clearly outlines how the essay/report will deal with the issues ○ The conclusion summarises all the main points clearly and concisely ○ Analysis of data is outlined logically, using correct units and scales. ○ All sources are referenced correctly in the format provided at the end of this booklet	○ Ideas are presented in paragraphs and arranged in a structure that is mostly according to the questions in the assignment ○ The introduction adequately describes how the essay/report will deal with the issues ○ The conclusion summarises most of the main points clearly ○ Analysis of data is mostly outlined logically, using correct units and scales. ○ Most sources are referenced correctly in the format provided at the end of this booklet	○ Ideas are presented in paragraphs and arranged in a structure ○ The introduction mentions how the essay/report will deal with the issues ○ The conclusion summarises some of the main points clearly ○ Analysis of data is outlined. ○ Some sources are referenced correctly in the format provided at the end of this booklet
	Language and Style	○ No spelling, grammar or punctuation errors ○ Writing style consistently clear, appropriate for scientific documents and easy to follow ○ Accurate and consistent use of technical language and vocabulary	○ Minimal spelling, grammar or punctuation errors ○ Writing style mostly clear, appropriate for scientific documents and easy to follow ○ Some attempts of using technical language and vocabulary, but not always accurate	○ Some spelling, grammar or punctuation errors ○ Writing style moderately clear, appropriate for scientific documents and easy to follow ○ Use of simple language and vocabulary effectively but struggles to use technical language

Glossary of Keywords

Word	Definition	In a sentence
Magnetic Moment (Spin)	A quantity that determines the force that the magnet can exert on electric currents. *Think of a bar magnet anytime you see this word.*	The magnetic moment of the electron is -9284.764×10^{-27} J T^{-1}.
Permanent Magnets	Materials which are magnetic all the time and cannot be turned on or off as it can with electromagnets.	Most rare earth elements are permanent magnets.
Spintronics	The magnetic version of electronics. Exploits the spin of an electron rather than the charge	Frustrated magnets are now being considered for use in Spintronics.
Antiferromagnetic interaction	Magnetic moments (spins) align antiparallel to one another	These two spins have an antiferromagnetic interaction
Ferromagnetic interaction	Magnetic moments (spins) align parallel to one another	These two spins have a ferromagnetic interaction
Frustration (geometrical)	When the energy of all pairwise interactions cannot be minimised simultaneously.	The spins are geometrically frustrated in spin ice.
Spin lattice	Where spins are located (reside) in space. For a regular lattice, these spins will be located at particular points in space.	The spin lattice has the kagome structure.
Spin ice	Specific rare earth pyrochlore oxides which have geometrically frustrated spins and obey the ice rules.	Dysprosium Titanate ($Dy_2Ti_2O_7$) is one example of a spin ice.
Ice rules	Two spins in and two spins out of a tetrahedra in the case of spin ice. This idea stems from water ice which has two hydrogens near (covalent) and two hydrogens further away (hydrogen bonds)	Three spins in and one spin out of a tetrahedra disobeys the ice rules.
Degenerate ground state	More than one ground state. More than one arrangement that has the same energy is degenerate. So more than one arrangement with the ground state energy, specifically, indicates a degenerate ground state.	Spin ice has a degenerate ground state. Infact, it is six-fold degenerate because there are six arrangements which have the ground state energy.
Entropy	Is the measure of energy dispersion. Most define this as being the measure of disorder in a system.	A gas has high entropy, whilst a solid has low entropy.
Magnetic monopoles	An isolated magnetic pole. So, a South pole by itself <u>or</u> a North pole by itself.	Real magnetic monopoles have never been observed, only magnetic dipoles - North and South poles.

Coulomb interaction	The interaction between two charges, q_1 and q_2 at a distance r	There is a strong Coulombic interaction between two monopoles close to one another.
Spin flip	When a magnetic moment (spin) changes from its original direction	A spin that was pointing left to right may point right to left after a spin flip.
Dirac string	The trail of spin flips left behind when a monopole in spin ice moves through the lattice	An observable Dirac string can be identified when monopoles move in the spin ice structure.
Magnetricity	The flow of magnetic charge. The magnetic version of electricity.	Monopoles in spin ice demonstrate magnetricity as they flow through the lattice.
Monte Carlo method	A method which uses random sampling in order to converge to a specific desired outcome.	The Monte Carlo method is used to randomly flip spins and evaluate the energy of a spin system in order to find the most favourable arrangement of the spin system under particular conditions.
Correlation	How spins are related to one another.	There is a strong correlation between spins that move together and are dependent on each other.
Neutron scattering	When neutrons are scattered from a sample in order to investigate the lattice structure.	The pyrochlore structure of spin ice was determined by neutron scattering
Magnetic moment equation	$\mu = IA$	μ is the magnetic moment, I is the current and A is the area. This is for a current loop.
Divergence free field equation	$\nabla \cdot B = 0$	One of Maxwell's equations. ∇ is the divergence. $\cdot$ is the dot product and B is the magnetic field. True for magnetic dipole like a bar magnet or the Earth.
Charge at the centre of a tetrahedra	$Q_i = \sum_j M_{ij}$	$M_{ij}$is the direction of the spins j on tetrahedra i, and it has the value +1 or −1. $\sum$ means "sum of…" in this case, sum over all spins j. Q_i is the charge on tetrahedra i. Keep in mind that Q_i is in units of m/a and must be divided by 2.

Tutorial 1 – An introduction to magnetism

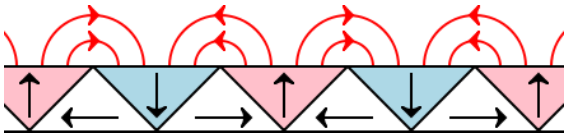
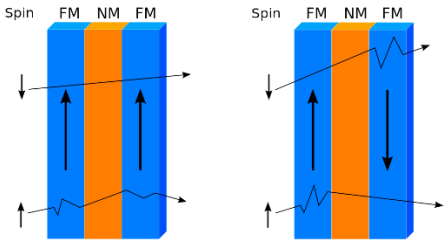
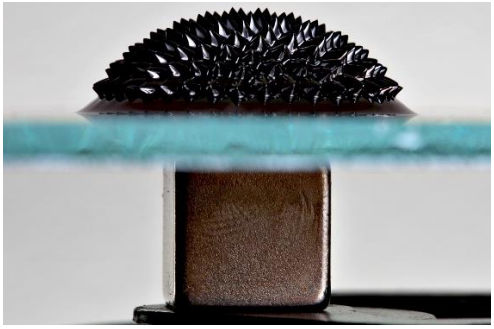
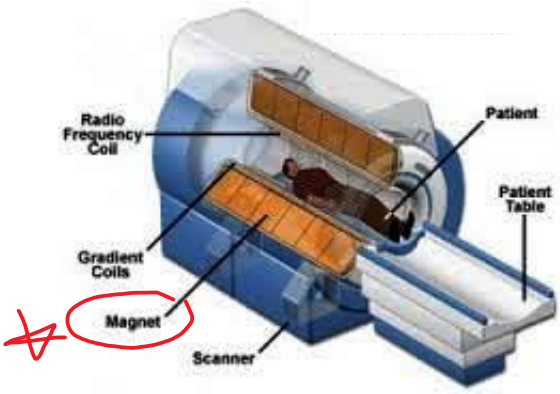
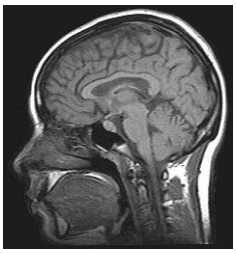
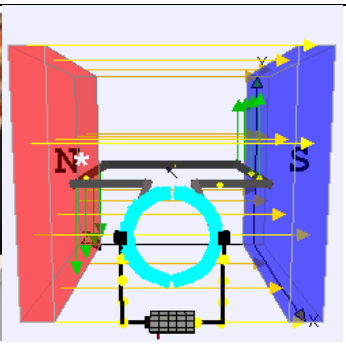


What is the Purpose of Tutorial 1?

- To introduce different types of magnets and their uses.
- An introduction to what magnetism is.
- To understand what makes a material magnetic.

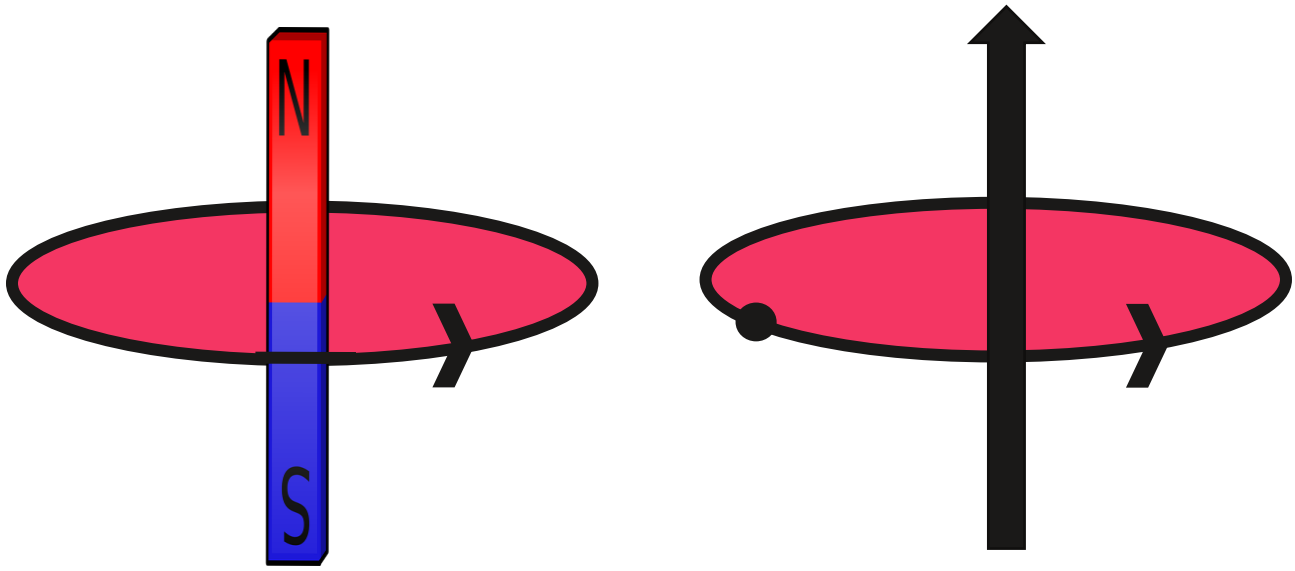
Activity 1: Match the magnet to the use and to the image

Magnets are used all around us for different purposes. Can you match which magnets are used where?

	Magnetic colloid Ferrofluids Used in loudspeakers to remove heat from the voice coil and proposed for magnetic hyperthermia in cancer treatment.
	Superconducting magnets (also electromagnets) Magnetic Resonance Imaging (MRI). Magnetic coils cooled to low temperatures approx..-269 °C. Very low resistance of the material means it can conduct larger currents and produce larger magnetic fields
	Electromagnets. Electric motors. Current carrying wire together with a magnetic field provides a force, and hence, motion of the wire in a rotating manner to produce a motor.
 	Magnetic multilayers. Hard drive disks. Storing information on our computers and using them as external hard drives. Watch this video: https://www.youtube.com/watch?v=wteUW2sL7bc
	Halbach array. Fridge magnet. The magnetic field of the arrays is similar to that of horseshoe magnets.

Activity 2: An introduction to magnetism

Label the diagram on the right using the words listed below.



- Magnetic moment/ Spin
- Electron
- Radius
- Area of current loop

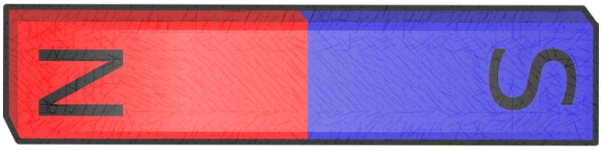
$$\boldsymbol{\mu = IA}$$

The unit of μ is Am^2

A loop of electric current, a bar magnet, an electron, a molecule, and a planet all have magnetic moments. A single magnetic moment has the same field lines as a bar magnet since it is effectively a bar magnet itself. Let's take a look at this.

Magnetic field – Iron filings on a bar magnet

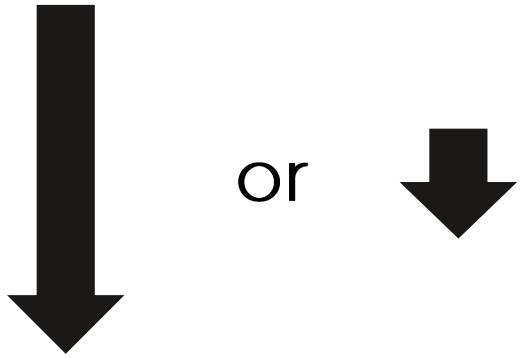
Draw the field lines you observed in the practical on this bar magnet and indicate the directions of the field. Explain what would happen if you were to cut the bar magnet in half. Use the key words: dipole and monopole.

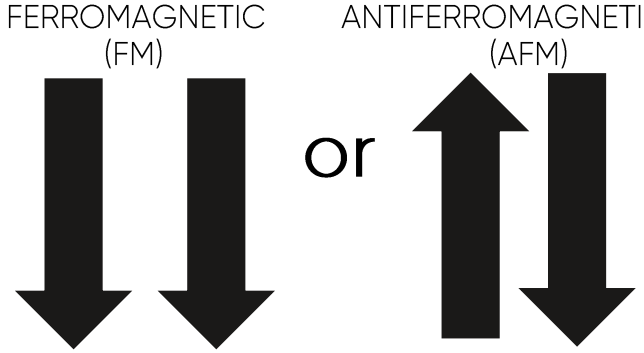


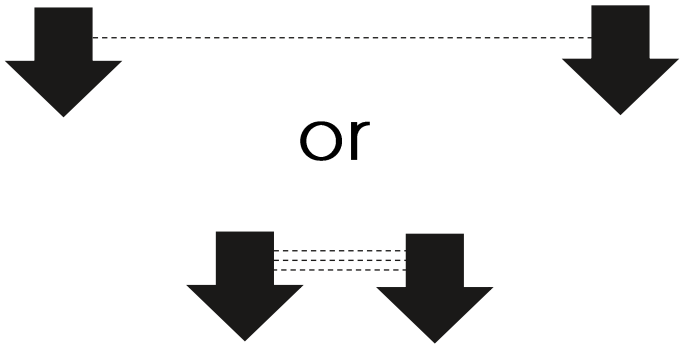
Attract or repel?

Activity 3: What makes a material magnetic?

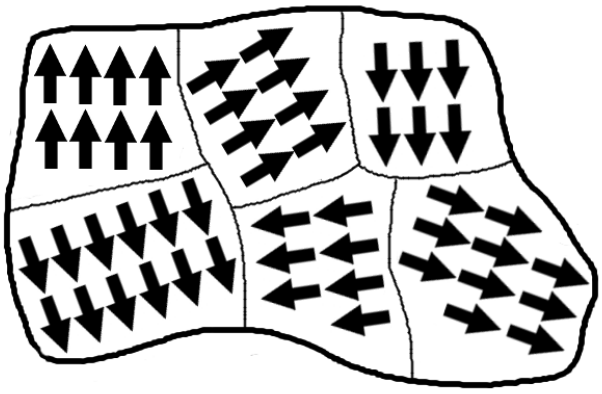
Take notes in the designated area.







DOMAINS



Homework 1: Fundamental theory of magnetism

Baseline test

The homework assignment for the first tutorial is a baseline test to see your initial level of attainment in this subject area. The assignment will test for some or all the subject specific skills that are required later in the final assignment. However, it is shorter than the final assignment and will be an introduction to the subject as well as a challenge. Do not worry too much about doing "well" or "badly" in the baseline test, it accounts for the fact that you may not be too familiar with the subject area. It is designed to help you and your PhD tutor identify where you are at the start of the programme and to help you measure your progress along the way.

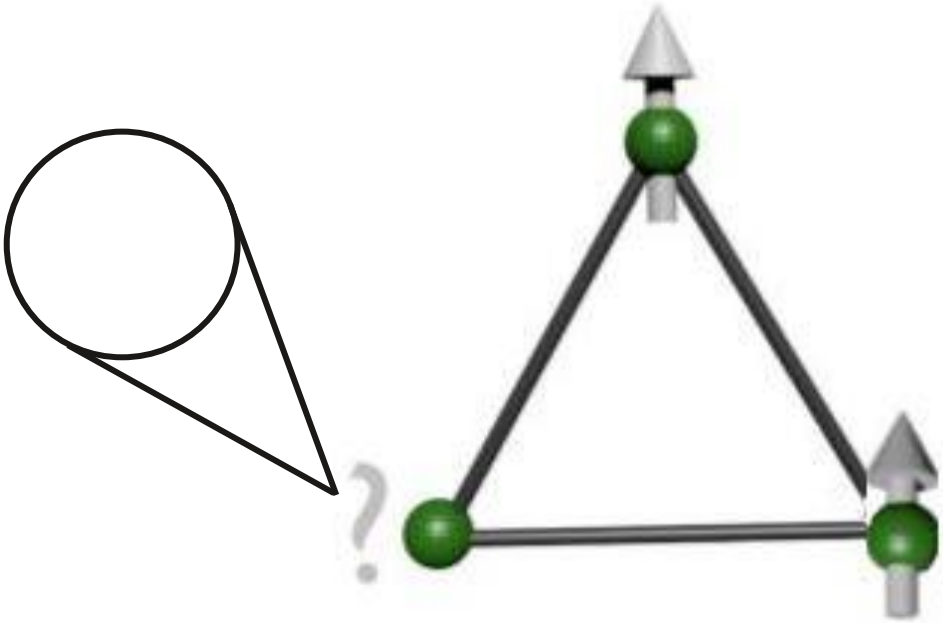
Tutorial 2 – Why are some magnets frustrated?

What is the Purpose of Tutorial 2?

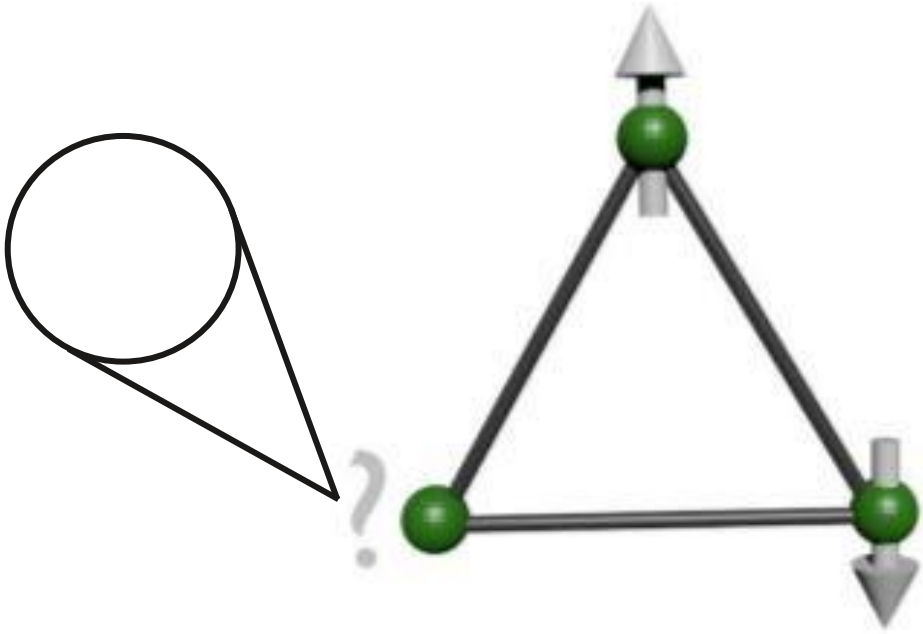
- To learn what frustration is in magnets and when it occurs.
- Spin ice: a key example and how it is related to water ice.

Activity 1: Introduction to frustration

Scenario 1: What would the third spin be if we only wanted ferromagnetic interactions in the system?



Scenario 2: What would the third spin be if we only wanted antiferromagnetic interactions in the system?



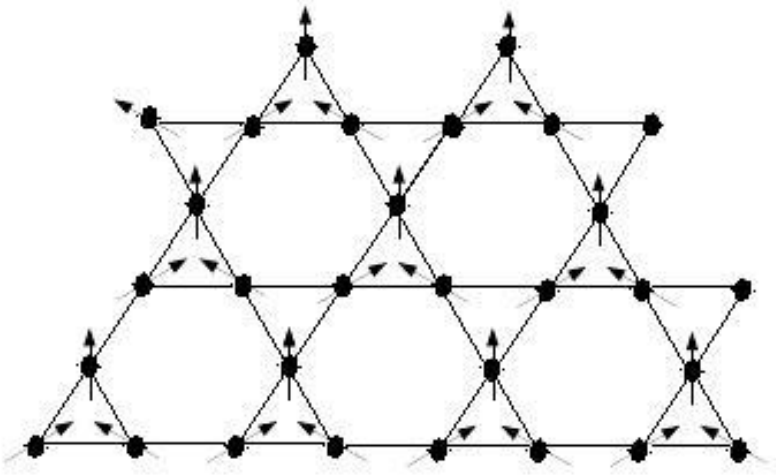
How many interactions in each scenario are satisfied?

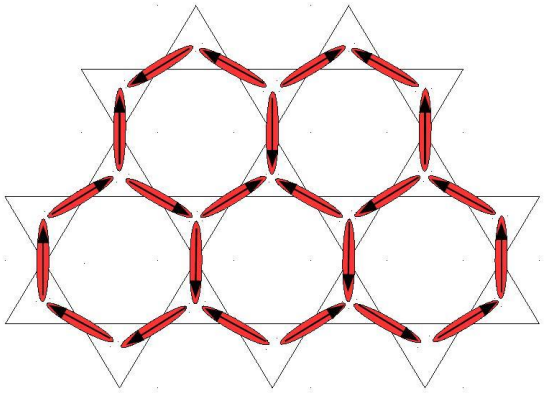
Definition of frustration:
When the e_____ of all p_____ interactions cannot be m_____ simultaneously.

OR IN OTHER WORDS…

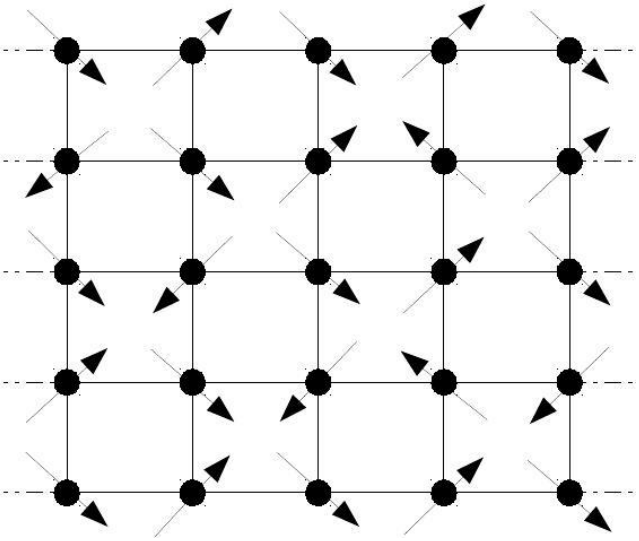
All p_____ interactions cannot be s_____ simultaneously.

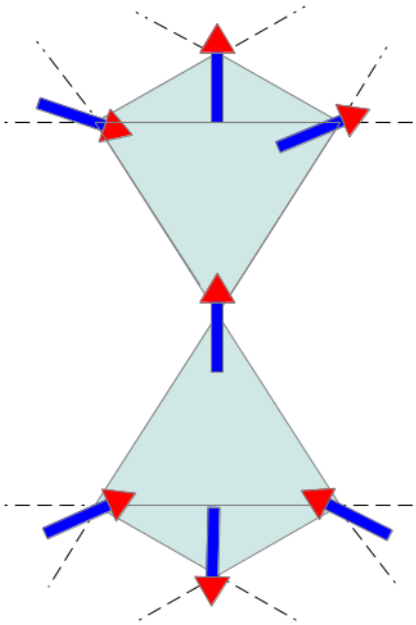
Let's have a look at some complicated examples. Label these lattice types in the space provided (https://physics.aps.org/articles/v5/140).





_____ _____





_____ _____

Activity 2: Spin ice: what is it?

Crystals of spin ice:

*Image: Courtesy of Castelnovo. C, Nature Physics, 2015, **11**, p.99-100.*

Lattice structure of spin ice:

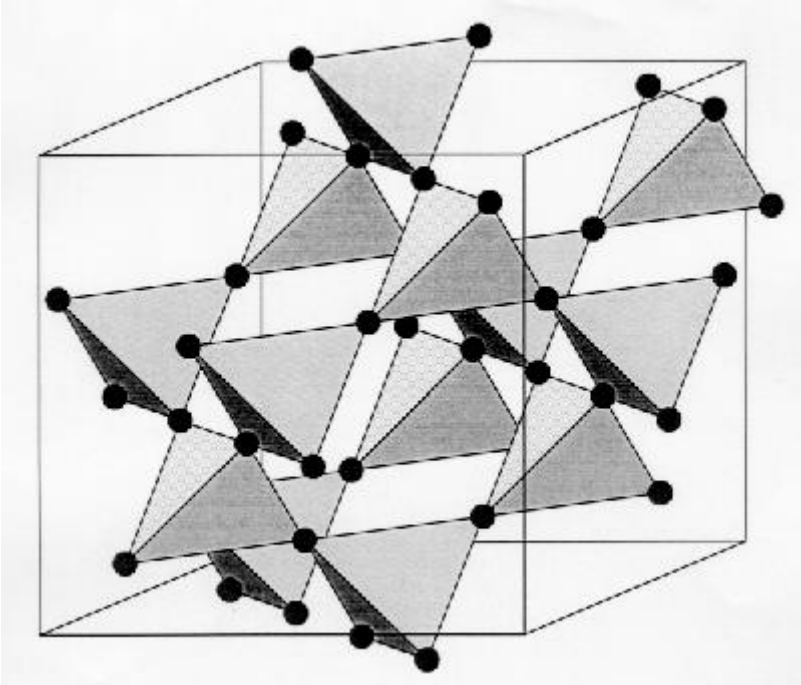


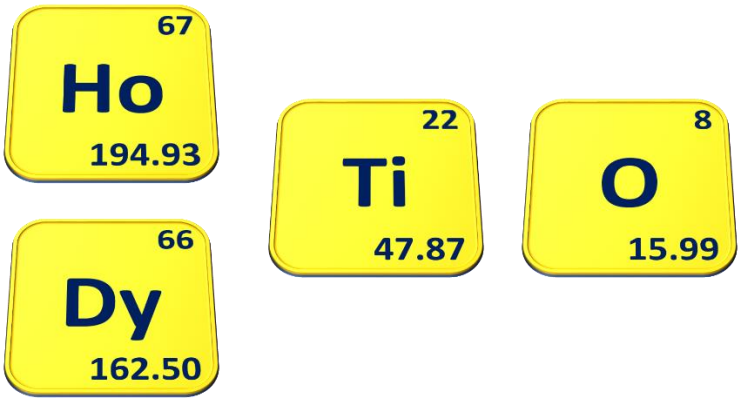
*Image: Courtesy of Moessner, R., Chalker, J. T., Phys. Rev. Lett., 1998, **80**, p.2929.*

What is the main shape in this figure?

What you think it might be	Answer

The pyrochlore structure is made up of

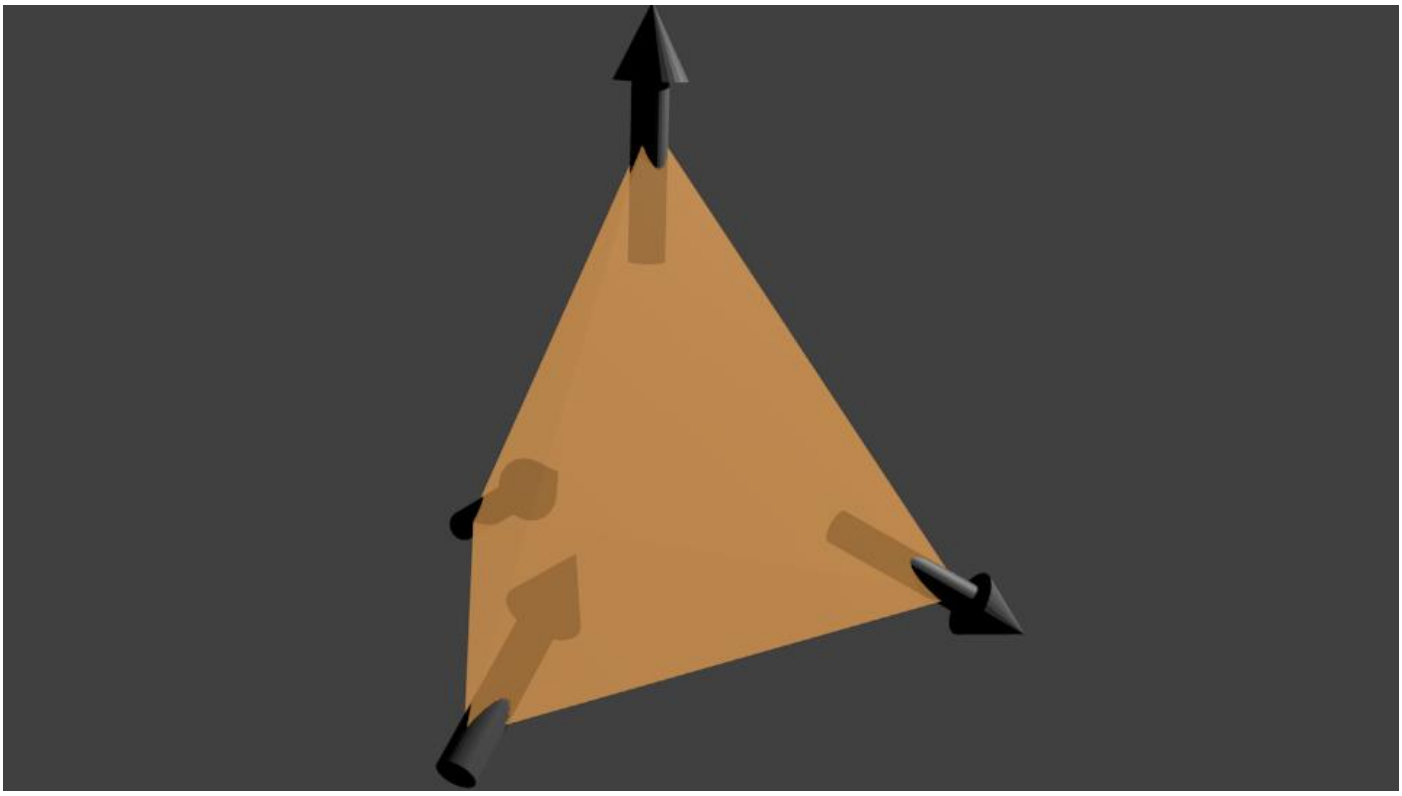
Chemical composition:

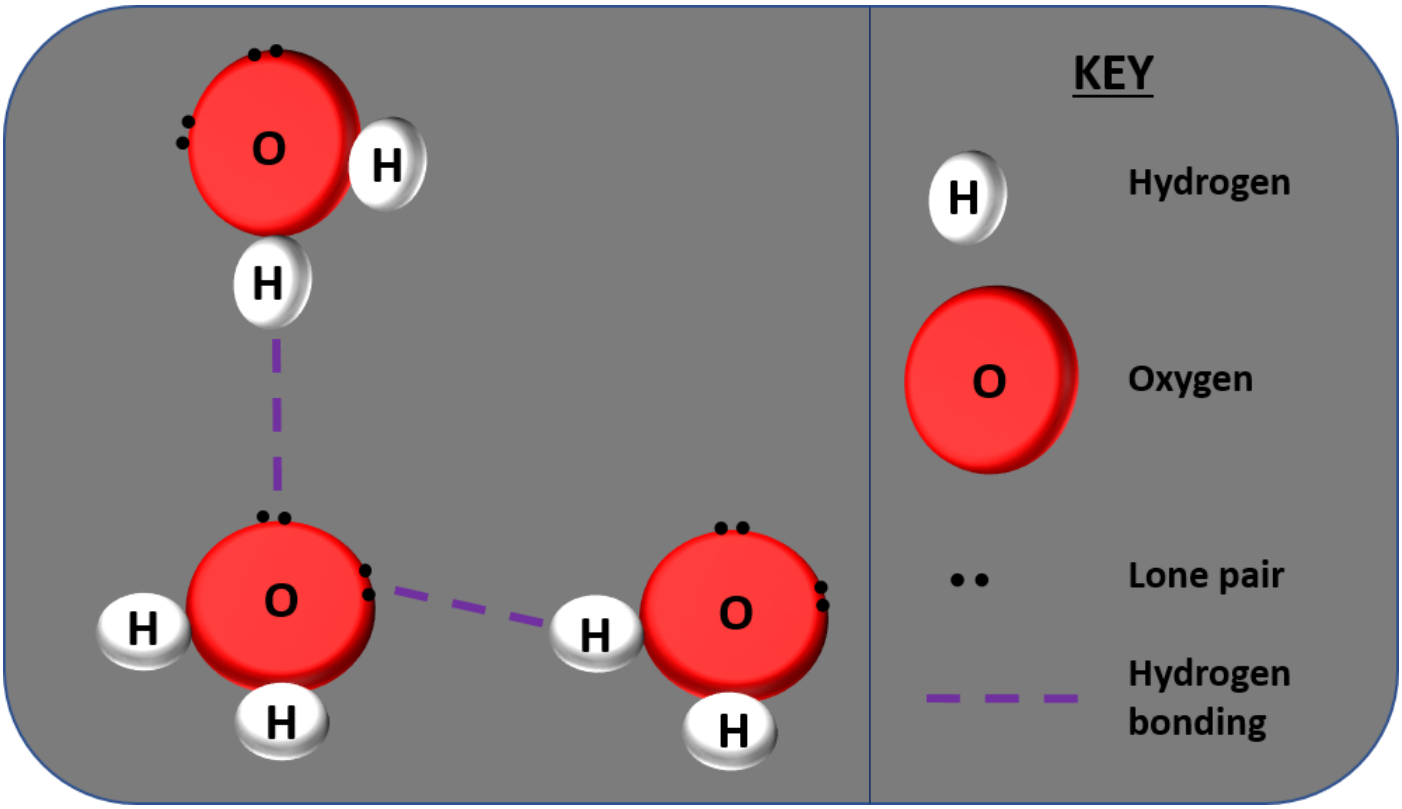


If Ho ions = 3+, Ti ions = 4+ and O ions = 2-, what is the chemical formula for HoTiO / i.e. what is the ratio of Ho ions to Ti and O ions? (CLUE: The overall charge should equal to zero). Use the working space below.

Rare Earth elements:

Spin ice and water ice: Ice rules





What do these two images have in common?

What are the ice rules and how many interactions in spin ice are satisfied in this configuration?

Activity 3: The consequence of frustration in spin ice?

Due to frustration, there is more than one 2-in, 2-out arrangement in spin ice. In fact, there are 6! This arrangement is the most satisfied arrangement of the spins in spin ice. What does this mean for spin ice when the temperature goes down?

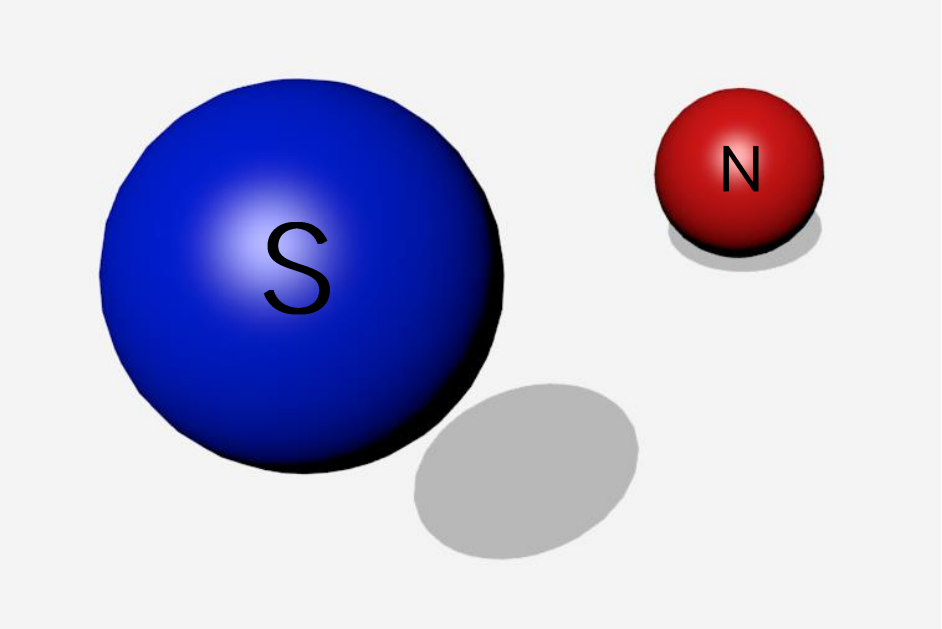
Since spin ice is analogous to water, let's take a look at what happens to water with temperature...

Entropy of water molecules with temperature increase (states of matter)

Homework 2: Frustrated magnets

1. Define geometrical frustration in 2 sentences. Search for one other definition online and define terms you are not familiar with (GOLD).
2. Explain what the ice rules are and draw all six arrangements using the square ice configuration.
3. Draw the Kagome lattice with spins occupied and on top, draw the premedial lattice.
4. Using the square ice configuration, draw at least three spin arrangements that violate the ice rules.

Tutorial 3 – Observing monopoles in spin ice

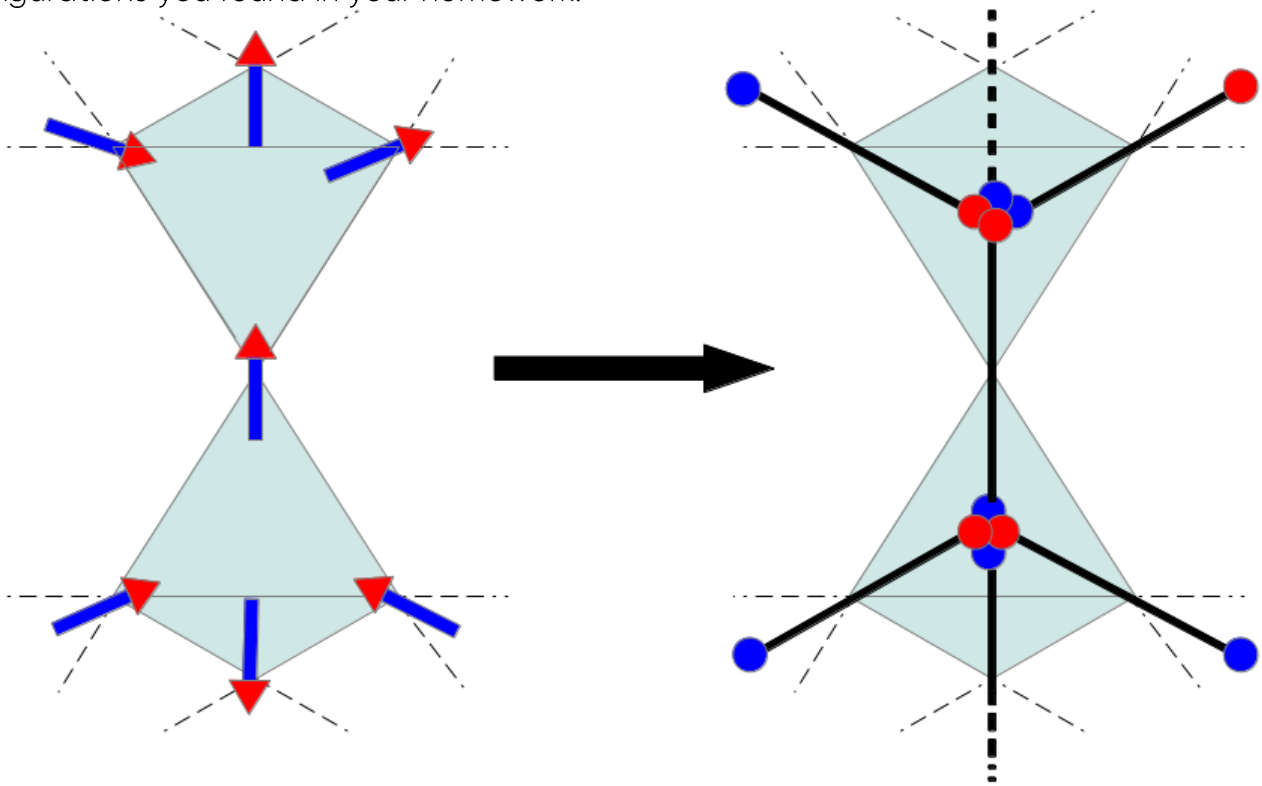


What is the Purpose of Tutorial 3?

- To learn how magnetic monopoles are obtained in spin ice and how they move.
- To understand how real monopoles differ from spin ice monopoles and where we might find them.
- To identify what monopoles could be used for.

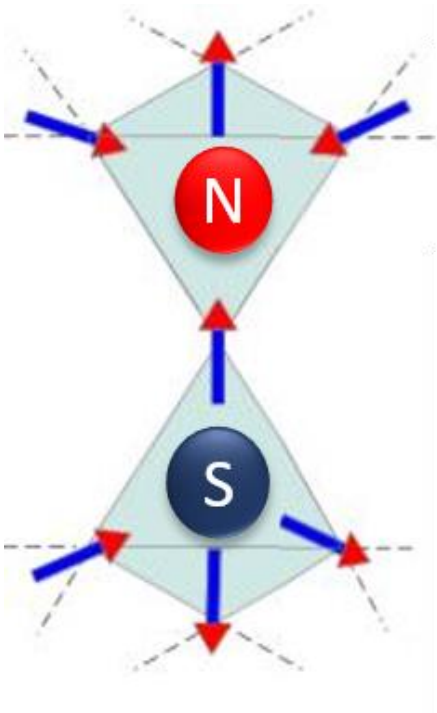
Activity 1: Magnetic monopoles in Spin ice

Magnetic monopoles are observed in Spin ice when the ice rules are violated. Let's see what configurations you found in your homework.



$\nabla \cdot B = 0$ when the ice rules are obeyed.

$Q_i = \sum_j M_{ij}$ tells us the charge of the tetrahedron *i*. The units of Q_i require us to divide the answer by 2.



Circle the methods which you think we use to force the spins to flip in spin ice?

* Magnetic field
* Shaking them
* Electricity
* Programming them
* Sound
* Temperature
* Adding water

How do these monopoles move?

- Let's track the random path of a monopole pair in a small square system.

Fill in the blank spaces using the words below:

When a spin is _____ and causes a violation of the ____ _____, a monopole _____ is _____. These monopoles can separate and move _____ of one another by flipping more spins. This trail of flipped spins is known as a _____ _____. The flow of magnetic charge is known as _____. When a monopole meets another monopole of the _____ charge, this monopole pair is a_____.

---

opposite Dirac pair rules annihilated ice flipped created Magnetricity string independently

Activity 2: Real monopoles: can we ever find them?

The difference between monopoles in spin ice and real monopoles

Monopoles in spin ice do not leave the pyrochlore structure and are still technically connected to one another, but can move quite freely within the structure. To avoid confusion with real monopoles, the monopoles found in spin ice are often referred to as _____ _____.

True or false:

1) Magnetic monopoles in spin ice have an observable string attaching the monopoles
   TRUE FALSE

---

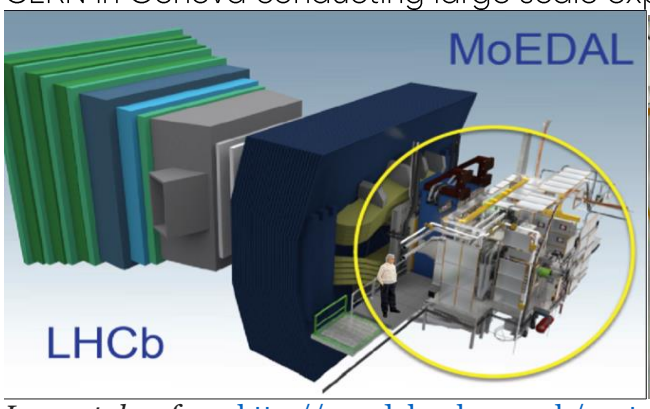
2) Real magnetic monopoles have a non-zero divergence in their magnetic field. So that $\nabla \cdot B \neq 0$
   TRUE FALSE

---

3) The magnitude of the magnetic monopole in spin ice is independent of the material the monopole is in.
   TRUE FALSE

The hunt for real monopoles

- CERN in Geneva conducting large scale experiment to detect monopoles (MoEDAL)



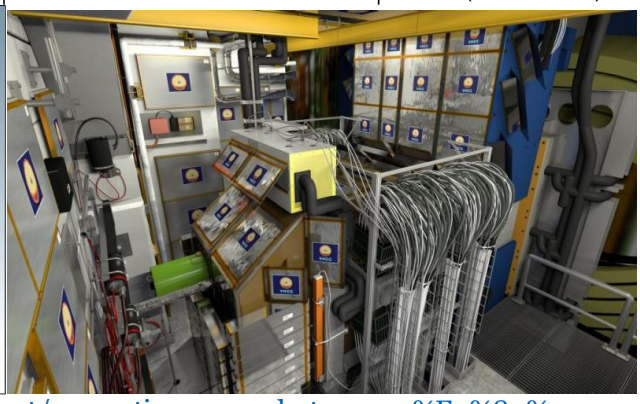


Image taken from http://moedal.web.cern.ch/content/magnetic-monopole-trapper-%E2%80%93-capturing-new-particles, *accessed 31/08/2017*

- Could we find them as Dark Matter?

Activity 3: What could the monopoles in spin ice be used for?

"Spintronics has the potential to significantly increase the amount of information a computer can store and process, because spin gives an electron two fundamental states instead of one - spin up and spin down. This means that information can be stored in arbitrary combinations of these two states, dramatically increasing the amount of information each electron can encode."

Extract taken from https://www.london-nano.com/research-and-facilities/themes/areas/magnetism-and-spintronics, accessed 31/08/2017

Let's watch a few videos to see just how Spintronics works in a HDD:
https://www.youtube.com/watch?v=AdF2uk-EscE – bits and bytes video (0-1.34 m)
https://www.youtube.com/watch?v=f3BNHhfTsvk – reading and writing data (0.40 - 2.25 m)
https://www.youtube.com/watch?v=3owqvmMf6No – hard drive disk moving (0.10 - 1.15 m)

Spintronics goes beyond HDD:
https://www.youtube.com/watch?v=Q0-zTdO-xt8 – Different type of Spintronic. AFM switching memory using electrical current (1.13 m)

Khomskii showed that, besides magnetic charge, there should be an electric dipole attached to each magnetic monopole. This opens new possibilities to study and control such monopoles using an electric field.

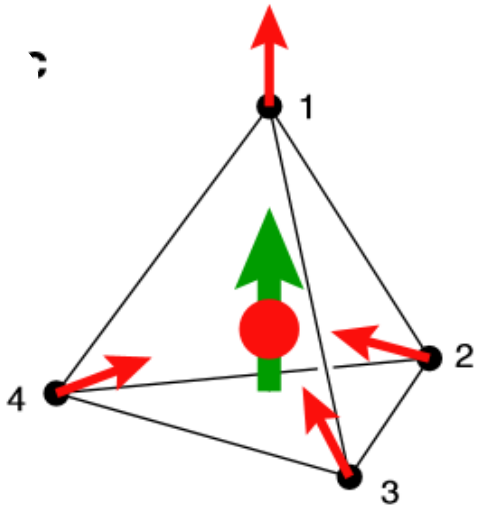
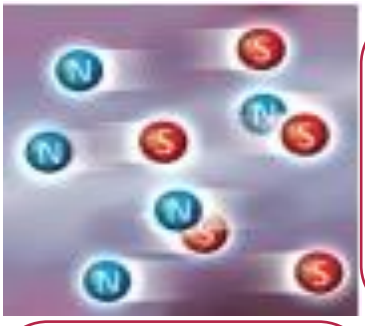


Image: Courtesy of D.I. Khomskii, "Electric dipoles on magnetic monopoles in spin ice", Nat. Comm., 2012, DoI: 10.1038/ncomms1904.

Similar to electrons, which have **electric** c_____ and **magnetic** d_____ (spin), magnetic m_____ in spin i____ will have **magnetic** c_____ and **electric** d_____.

Magnetricity:

What do these numbers represent?

T< 1 K		$Q = 4.266\times10^{-13}$ J T^{-1} m^{-1}
10^{-6} ms^{-1}	~150 s	1.8×10^{3} s^{-1}
5 $\mu_B Å^{-1}$ compared to 1.602×10^{-19} C		B=0.0001 T

Bramwell, S.T. et al. "Measurement of the charge and current of magnetic monopoles in spin ice", Nature, 461, 956–959 (2009).
Giblin, S.R. et al. "Creation and measurement of long-lived magnetic monopole currents in spin ice", Nature Physics, 7, 252–258 (2011).
Bramwell, S.T. et al. "Magnetic monopoles: Magnetricity near the speed of light", Nature Physics, 8, 703–704 (2012).

Thin films of spin ice:

$Ho_2Ti_2O_7$: *D. P. Leusink et. al., "Thin films of the spin ice compound Ho2Ti2O7", APL Materials, 2, 032101, (2014), DOI: 10.1063/1.4867222.*
$Dy_2Ti_2O_7$: *L. Bovo et. al., "Restoration of the third law in spin ice thin films", Nat. Comm., 5, 3439, (2014), DOI: 10.1038/ncomms4439*

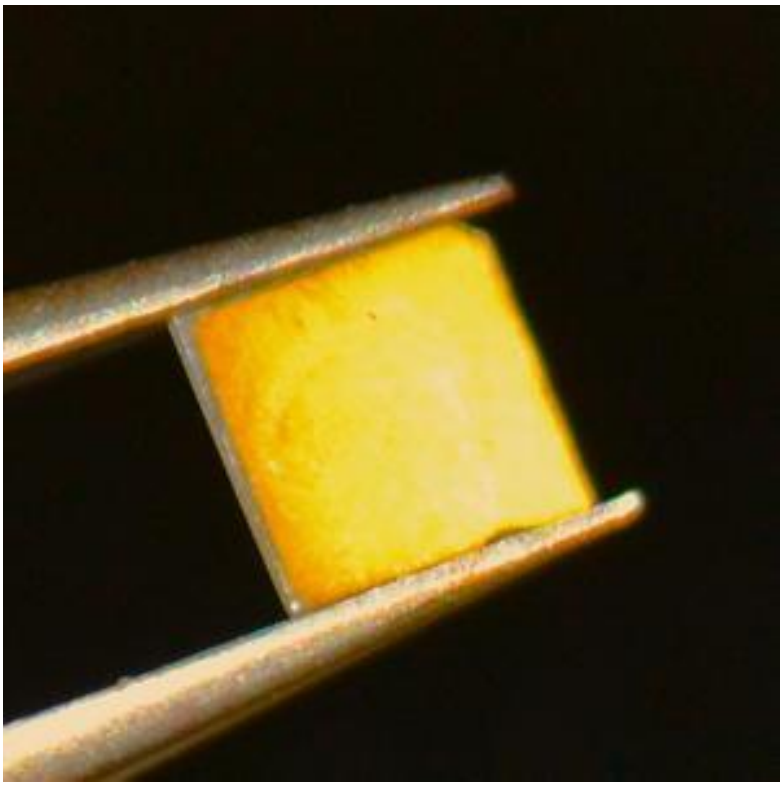


Image: Courtesy of L. Bovo et. al., "First thin films of spin ice reveal cold secrets", www.london-nano.com, accessed 30/08/2017.

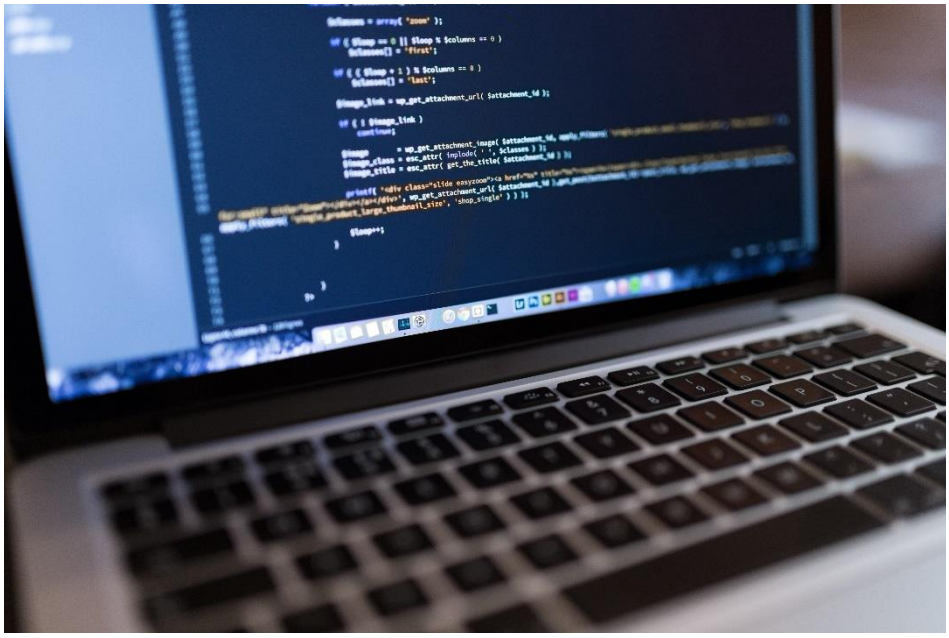
- Spintronics -> nanoscale magnetic sensors & advanced magnetic memories.
- Fundamental effects in electronics demonstrated in magnetic counterparts
- Can electronic signals be coupled to exotic magnetism, e.g. to currents of magnetic monopoles?

Do you think that the spin ice behaviour we observe in the bulk is maintained in the thin film versions? – *(e.g. ice rules, non-zero entropy at T-> 0 K and monopoles)*

Homework 3: Magnetricity in spin ice

- Show a 5-step sequence of spin flips and indicate where magnetic charges are created. You do not need a random number generator but you do need to show the steps and charges formed.
- Read and highlight the extracts about the existence of real monopoles and dark matter and then answer the question provided.
- Explain why you are not using magnetricity to power your household. Provide a brief explanation on magnetricity.
- Challenge: Would you expect the spins and/or charges to be moving in a spin ice system completely filled with monopoles? Explain your answer.

Tutorial 4 – Modelling spin ice



What is the Purpose of Tutorial 4?

- To understand how one would imitate spin systems: The Monte Carlo method.
- To introduce methods that can monitor the movement of spins and monopoles in spin ice.

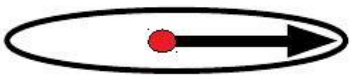
Activity 1: Starting to model a system

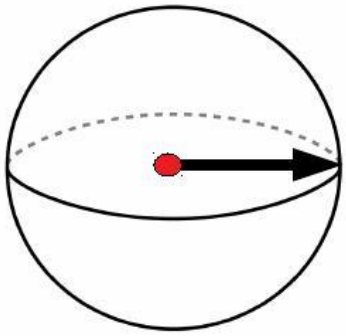
Working in pairs and using the marker pen and a large piece of paper, brainstorm how you would go about deciding this scenario:

> You walk into a classroom (any classroom), how do you decide where to sit? What factors do you consider? The place you decide to sit must satisfy you.

When designing a spin system

Types of spins:





_____ _____ _____

Activity 2: Monte Carlo method

Let's say we do not start in the seated arrangement we would like in our classroom. How do we move to get to our favourite spot?

The Monte Carlo method is a sampling method to help us Scientists find the best arrangement of spins given the external conditions.

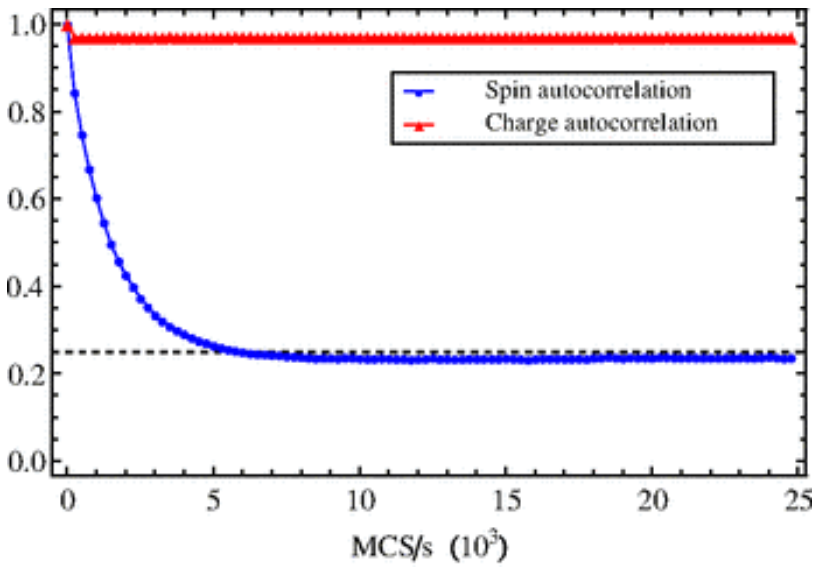
In the space provided, arrange the cards in the order that you think the Monte Carlo steps should go.

Let us try out an interactive simulation of a simple spin system known as the 2d Ising model.
http://mattbierbaum.github.io/ising.js/

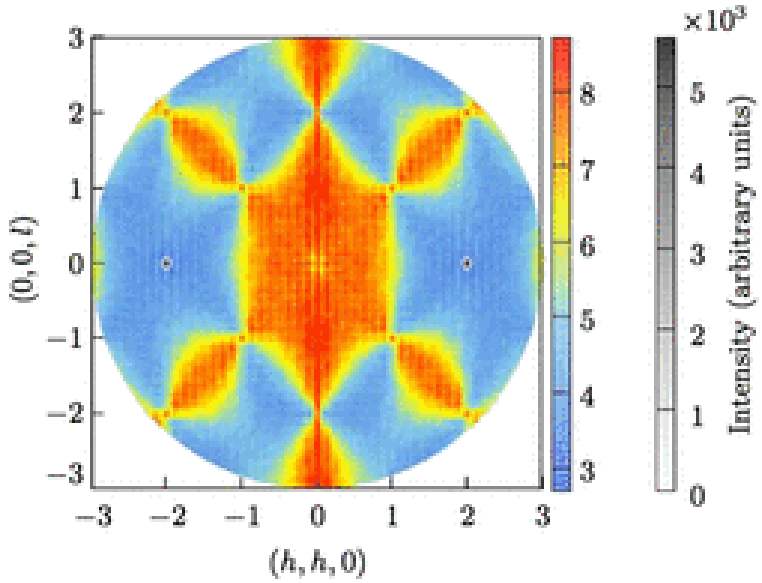
Activity 3: Correlation of spins

You may recall in your homework that I asked whether you thought the charges and/or the spins would move if spin ice were completely filled with monopoles. Well I have the answer and it is indicated by using two methods but measuring a similar thing- the correlation of spins.

Autocorrelation function – key features



Neutron scattering



Homework 4: Classical spin models

- Outline how you may go about finding the most favourable spin arrangement in spin ice for a given temperature. Hint: What do you need to consider when modelling a spin system?
- Label the key features of this M vs T plot and describe the method used to sample this system.

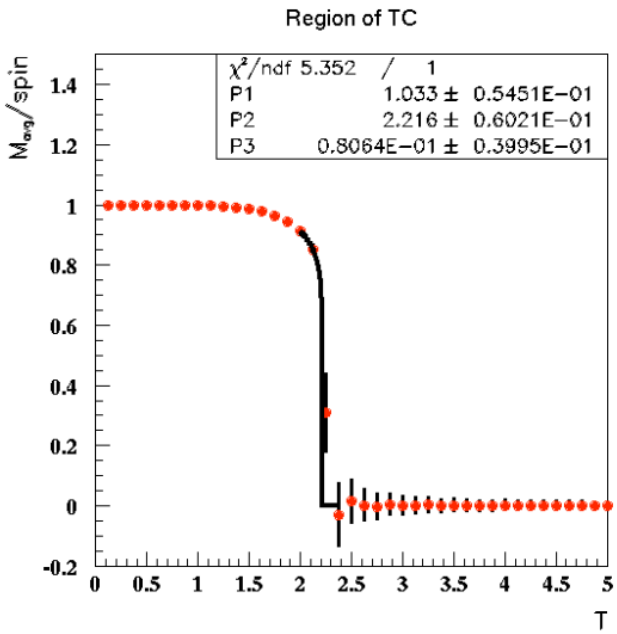
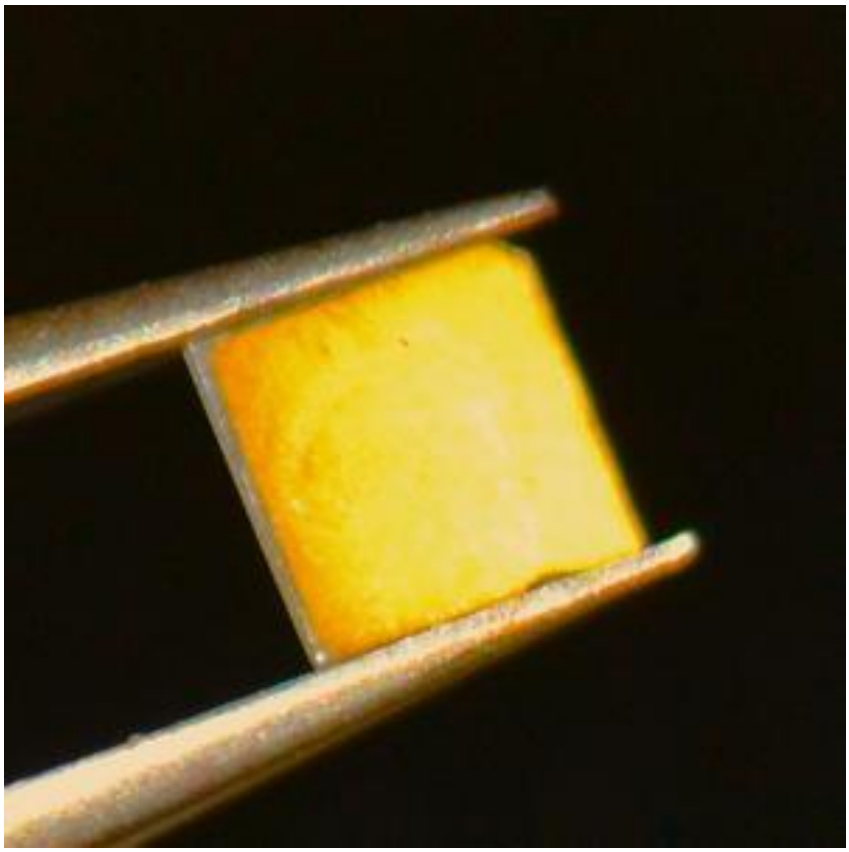


Image: https://www.mpp.mpg.de/~caldwell/ss10/Lecture11.pdf, accessed 24/10/2017.

- Watch this video (https://www.youtube.com/watch?v=0aOpv51Pcdw) on neutron scattering and answer the following ten questions:
    1. What particle is used in neutron scattering?
    2. What happens to neutrons that hit a sample?
    3. When preferred directions of these neutrons are detected, what is the name given to the resulting peaks?
    4. What can be deduced from the patterns found at the detector?
    5. What makes up the background scattering?
    6. Do neutrons have spin?
    7. How do the neutrons cause incoherent nuclear scattering?
    8. Do neutrons which cause incoherent nuclear scattering contribute to Bragg scattering?
    9. What is the name for the spectrometer which can record the spin changes of the neutrons?
    10. What properties can DNS give unique insight into?

Tutorial 5 – A recap



What is the Purpose of Tutorial 5?

- To recap what you have done so far
- To discuss your final assignment and how it should be presented.

Activity 1: Recap exercises

3-minute challenge: you have the pictures of each tutorial and the tutorial title, match these and write a list of all the topics you can remember. There is a prize for the one who gets the topics in the right order and has the longest, *most sensible*, list.

Using one post-it note, write down 3 topics you think you understood the most during this course and on the other post-it note, write down 3 topics you wish you could understand better.

Activity 2: Guidance with the final assignment

- You can use the internet and other sources to help you. However, it must be written in your own words and you must reference the sources you use.
- The assignment should be written so that another student who has not done the project can understand. You therefore should include diagrams.
- You can decide how you would like to structure your writing yourself. The checklist provided will be a useful guide.
- Your work will be marked according to the mark scheme on page 6. You should refer to it as you plan and write.

Final Assignment – Essay

In this assignment, we will be writing an essay on the role that frustrated magnets play in creating magnetic monopoles, how we go about modelling these systems and how we could use them for Spintronics.

The title and question is: "What has magnetic monopoles got to do with frustrated magnets?"

Your essay should include the following points (Please tick the boxes as you complete each point):

- ☐ **Describe** what a Frustrated Magnet is using Spin Ice as an example.
- ☐ **Discuss** the *Ice Rules* and hence how monopoles are obtained.
- ☐ **Explain** why the monopoles in Spin Ice are not real.
- ☐ **Describe** how one would find the most favourable arrangement of a spin system for a given temperature.
- ☐ **Analyse** the data provided and determine the spin and monopole behaviour in the system by explaining the key features.
- ☐ **Discuss** how spin ice is being considered for Spintronics.
- ☐ **Challenge:** What other potential uses could you imagine using frustrated magnets for? Please provide an explanation for each idea.

The essay should be a minimum of 1500 words (not including image captions and references).

Tutorial 6 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on final assignments.
- To share examples of best practice with the other pupils in your group.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyable and what was challenging.

Final assignment feedback

What I did well…	What I could have improved on…
•	•
•	•
•	•

My target for future work is…

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 I 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.

Appendix 2 – Using the VLE

VLE username	
VLE password	

Please remember the following key details…

- You are able to log into the VLE either through the link on our website (www.thebrilliantclub.org) or going directly to the VLE site at (https://portal.thebrilliantclub.org/sign-in).
- Please update your profile with your full name and email address- this will allow you to retrieve forgotten passwords or usernames
- If you forget your login details you can request them to be emailed to you by clicking the link on the VLE home page. (If you are still having problems you can email: schools@thebrilliantclub.org)

What is the VLE?

The VLE is a virtual learning environment for all pupils on Uni Pathways. It is used for:

- messaging your tutor
- submitting homework
- submitting your final assignment
- accessing resources for your tutorials
- finding out more information about university and careers

How should I use the VLE?

The VLE is a professional academic environment in which pupils are able to message their PhD Tutor. Here are a few things to consider:

- Ensure you keep a professional tone in the messages you send to your tutors.
- Ensure you always reply to your tutors in a timely manner.
- Thank your tutor for the effort they are putting in to give you your feedback etc.
- Submit all homework to your tutor on time.

IMPORTANT: Final assignment

- When you submit your final assignment, please remember that you need to do so through the 'My Activities' tab and not as an attachment to a message.

Notes

Notes

Notes

Frustrated Magnets

Key Stage 4 Programme

researchersinschools.org