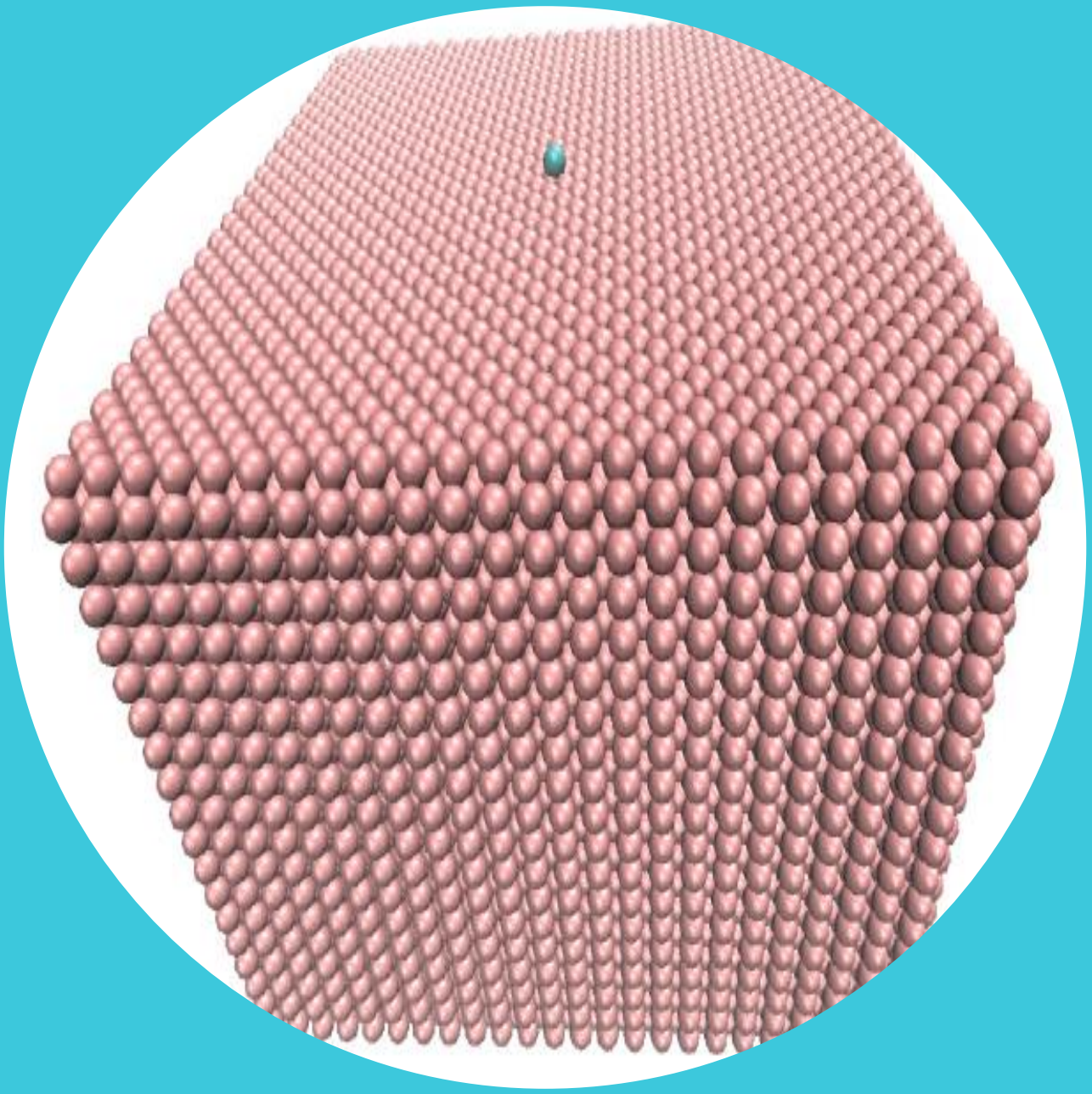
Researchers in Schools



# Hopping Mad

## Key Stage 4 Programme

Pupil Name

Coursebook Designed by Dr Peter Townsend

# Contents

Uni Pathways launch event ..... 4
Timetable and Assignment Submission ..... 8
Timetable – Tutorials ..... 8
Timetable – Homework Assignments ..... 8
Assignment Submission – Lateness and Plagiarism ..... 8
Course Rationale ..... 9
Uni Pathways Mark Scheme 2020 – science-based assignments ..... 10
Mark scheme for problem-based baseline assignment ..... 11
Mark scheme for problem-based final assignment ..... 12
Baseline Assignment (problem-set): Pupil Feedback Report ..... 13
Final Assignment (problem-set): Pupil Feedback Report ..... 14
Subject Vocabulary ..... 15
Tutorial 1 – Introduction to Surfaces ..... 17
What is the Purpose of Tutorial 1? ..... 17
Key vocabulary for Tutorial 1 ..... 17
HOMEWORK 1: BASELINE ASSIGNMENT ..... 21
Tutorial 2 – Introduction to Crystals ..... 23
What is the Purpose of Tutorial 2? ..... 23
Key vocabulary for Tutorial 2 ..... 23
Tutorial 2 Summary Quiz ..... 27
Homework 2: transformations ..... 27
Tutorial 3 – Crystal surfaces ..... 29
What is the Purpose of Tutorial 3? ..... 29
Key vocabulary for Tutorial 3 ..... 29
Tutorial 3 Summary Quiz ..... 32
Homework 3: special sites ..... 33
Tutorial 4 – Adsorption and Diffusion ..... 35
What is the Purpose of Tutorial 4? ..... 35
Key vocabulary for Tutorial 4 ..... 35
Tutorial 4 Summary Quiz ..... 38
Homework 4: the rules of probability ..... 39
Tutorial 5 – Diffusion by Random Jumps ..... 40
What is the Purpose of Tutorial 5? ..... 40
Key vocabulary for Tutorial 5 ..... 40
Tutorial 5 Summary Quiz ..... 42
HOMEWORK 5: FINAL ASSIGNMENT ..... 43
Tutorial 6 – Feedback tutorial ..... 46
What is the Purpose of Tutorial 6? ..... 46
Final assignment feedback from your Uni Pathways Teacher ..... 46
Tutorial 7 – Final tutorial ..... 48
Appendix 1 – Referencing correctly ..... 50
How do I reference? ..... 51

Notes ..... 52

# Uni Pathways launch event

Welcome to Uni Pathways! We are delighted to be able to launch the Uni Pathways programme with you. We hope that you are ready to embark on your Uni Pathways journey and that you enjoy the video.
You will be asked to pause the video at times to complete some work in this workbook, so make sure you have a pen / pencil to hand when you start the video.

By the end of the video, you will have

- Learnt about what studying at university means
- Learnt about some of the skills that you will develop during Uni Pathways
- Heard from pupils who have participated in Uni Pathways or The Scholars Programme (which is the same programme!)
- Heard from current university students talking about what life is like at university

If you are in school your teacher will play the video. If you are at home and logged in to a session with your teacher, your teacher will play the video and show it to you. If you are participating independently your teacher will email you the link to the video or the video file. There are opportunities for you to answer some questions, and you will be told when to pause the video to answer them.

**Introduction to Uni Pathways**

1. Write down what you think a supra-activity is

_____
_____
_____

2. Independent learning is

_____
_____
_____

3. Write down in your own words what resilience means, and come up with a different example to the one mentioned in the PowerPoint.

_____
_____
_____
_____

4. Why do you think analysis and evaluation skills are useful in your academic career? _____
_____
_____
_____
_____
_____

5. Why do you think analysis and evaluation skills are useful in life in general? _____
_____
_____
_____

6. What are the different types of learning that university students do?

**Pupils' experience of Uni Pathways**
You will now watch some pupils talk about their experience of learning a PhD topic and producing a final assignment. Some may refer to The Scholars Programme rather than Uni Pathways. As you heard in the introduction PowerPoint, The Scholars Programme is a very similar programme to Uni Pathways. Listen carefully and then respond to the questions below. Be prepared to share some of your responses with your peers.

1. How did the pupils describe talking about writing a long essay for their final assignment?

2. Write down something that one of the pupils mentioned was particularly interesting in their course.

3. What were some challenges that the pupils met?

**Virtual campus tours**
You will now go on a virtual tour of some universities! Once you have seen some of the university campuses, respond to the questions below.
Note down something that you liked out of any of the campus tours you saw. It may be a particular building, space, city etc.

1. Were there any similarities between the different university campuses? If so, what are the similarities?

2. If you had to pick one of those universities to go and visit in person, which one would it be and why?

3. Note down some of the societies that you could join at different universities

**Meet university students!**
You are about to virtually meet or hear from some current university students.
If you are virtually meeting them, think about what questions you would like to ask the students, share your questions with a partner and note those questions down in the space below.

If you are not meeting them but watching some videos that they have made, use the space below to note down what else you would like to find out about university. You can then ask your teacher during Uni Pathways tutorials!

**Reflection**
Congratulations on completing the launch of the Uni Pathways programme. Before you go, take some time to reflect on what you have learnt by answering the following questions:

1. Are there any aspects of university style learning that you would look forward to? If so, what are they?

2. What challenges do you think students face when learning at university? How would you try to overcome these challenges?

3. What skills do you hope to develop during your Uni Pathways course?

4. What part of Uni Pathways seems the most challenging for you?

5. What are you most looking forward to about Uni Pathways?

# Timetable and Assignment Submission

## Timetable – Tutorials

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

## Timetable – Homework Assignments

| Homework Assignment | Description | Due Date |
|---|---|---|
| Tutorial 1 | Baseline Assignment | |
| Tutorial 2 | Transformations | |
| Tutorial 3 | Special sites | |
| Tutorial 4 | Rules of probability | |
| Tutorial 5 | Final Assignment | |

## Assignment Submission – Lateness and Plagiarism

| **Lateness** | |
|---|---|
| Submission after midnight on due date | 10 marks deducted |
| **Plagiarism** | |
| Some plagiarism | 10 marks deducted |
| Moderate plagiarism | 20 marks deducted |
| Extreme plagiarism | Automatic fail |

## Course Rationale

Surfaces are everywhere in our lives. Some surfaces are of great use to humanity because of their effects on chemical reactions, for example allowing toxic gases to be removed from car exhaust fumes. Other surfaces can be used as templates to grow extremely thin materials that can be applied in electronics. Diffusion is a key process, when two or more atoms on a surface have to move around to meet each other in order to react. In general, diffusion refers to a spreading out over time, but the details of how it happens at a surface depend entirely on what the surface is and what is doing the diffusing. In modern surface science, the structure of surfaces and processes such as surface diffusion are studied at the level of individual atoms.

In this course you will build on concepts you have studied in Physics, Chemistry and Maths. You will learn about how atoms are arranged in crystals, the patterns produced when crystals are cut to expose a surface, and what happens when a crystal surface undergoes a chemical reaction with a gas. You will investigate the connection between randomness, probability and diffusion by carrying out a numerical experiment using an interactive computer simulation.

## Uni Pathways Mark Scheme 2020 – science-based assignments

| | 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.<br>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.<br>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.<br>The writing style is appropriate; scientific language and key scientific terms are used accurately and effectively to support the arguments and explanations made.<br>There are no, or very few, errors in spelling or grammar.<br>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.<br>Knowledge is used to build and support effective scientific arguments and explanations. | Analyses relevant scientific evidence, arguments, and reasoning.<br>Identifies and critically evaluates relevant scientific arguments and evidence, deciding on their credibility and strength, drawing reasonable conclusions.<br>Shows some understanding of the relative value of evidence and arguments. | The work is well-structured.<br>The writing style is appropriate; scientific language and key terms are used correctly.<br>There are few errors in spelling or grammar.<br>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.<br>Beginning to apply this knowledge to build and support effective scientific arguments and explanations. | Identifies and uses basic scientific evidence, arguments, and reasoning.<br>Showing some understanding of the quality of scientific arguments and evidence.<br>Not yet showing understanding of the relative value of evidence and arguments. | The work has some structure.<br>The writing style can sometimes be informal; occasionally scientific language and key terms are not used when it would be appropriate to do so.<br>There are some errors in grammar and spelling do not get in the way of communicating the content.<br>Referencing has some consistency; matching the style taught in the course<br>Limited use of tables and graphs. |
| 3rd | Shows a developing understanding of key concepts and scientific methods, with some misconceptions.<br>Does not yet apply this knowledge to build and support scientific arguments and explanations. | Beginning to analyse scientific evidence, arguments, and reasoning.<br>Describes evidence and arguments, while not yet evaluating them. | The grammar, spelling, style, and structure of the work need improving in order to communicate ideas to the reader.<br>Scientific language, key terms and references are not always used correctly.<br>Limited, or no use of tables and graphs. |

## Mark scheme for problem-based baseline assignment

| | Subject Knowledge | Critical Thinking | Written Communication |
|---|---|---|---|
| **Q1** | Accepted answer is compared in suitable units. | Plausible explanation given for any discrepancy with the accepted answer. Source of the accepted answer is quoted. | Working should be shown and explained in words, as well as any numerical operations. |
| **Q2** | The particle diagram shows that a solid keeps its shape, and that the particles are regularly arranged. | The way in which the phrase 'pure element' is represented in the diagram should be discussed. | The explanation of the diagram's main features makes it clear how each feature of the diagram relates to real physical properties of the solid. |
| **Q3** | Understanding of the terms 'clean' and 'flat' must be evident from the answer. | Conclusions are justified in a way that is consistent with the definitions involved. | Any additional terminology from extra reading is used correctly. |
| **Q4** | Graphs have the correct value and gradient at the origin, and have the correct shape. | Inverse relationship between square and square root is related to the graph shapes. | Graph axes are perpendicular and straight. Axes are labelled. |
| **Q5** | Either after answering Question 1 of the baseline assignment, or using other resources, a reasonable estimate is given for the distance between atoms. | Connection is made between the separation of atoms in the pattern, circumference and diameter of a circle. | In addition to any numerical working, calculations are also explained in words. |

## Mark scheme for problem-based final assignment

| | Subject Knowledge | Critical Thinking | Written Communication |
|---|---|---|---|
| **Q1** | Diagram should clearly illustrate the meaning of the term 'square lattice'. Calculation should show understanding of the unit 'Angstrom' | Answer should show that the concept of 'per square metre' was interpreted correctly. | Calculation should include explanations in words of why each step is taken, not just a sequence of number of operations. Diagram should be drawn neatly using a ruler for any straight edges. |
| **Q2** | Diagrams should clearly show the difference between amorphous and crystalline materials. | The relevant key word definitions (crystalline, amorphous) should be clearly consistent with the diagrams drawn to illustrate them. | The best answers will draw on additional key words from the course that can be used to express the distinction between crystalline and amorphous materials. |
| **Q3** | The relevant rule(s) of probability are identified and applied. The answer implicitly or explicitly shows an understanding of the term 'square lattice'. | In both (a) and (b), it should be made clear how many different paths there are between the initial and final location on the lattice. | Terminology related to probability such as 'independent' is used correctly. The diagrams drawn genuinely assist in communicating the method. Suitable diagrams could include tree diagrams, tables or pictures of the path(s) taken on the lattice. |
| **Q4** | The distinction between finding the mean of data then the square, versus squaring the data and then taking the mean, should be evident throughout. | Evidence of progress towards the general results, such as trial and improvement, or use of prior knowledge about square numbers. | The numerical calculations are methodically laid out, for example in (neat) tables. The remaining answers should be set out in full sentences, so that it is completely unambiguous which answers refer to which part of the question. |
| **Q5** | Idea of the *rmsd* from tutorial 5 is explained with reference to multiple independent computational experiments (repeats). Newton's laws of motion, or equivalent statements in KS3 language about forces, are related to the conditions under which a gas particle is 'ballistic'. | Answer to part (f) should pay close attention to the relationship between number of steps, length of step and distance travelled, and similarly between the rate of events, the time elapsed, and the number of events that occur in that time. | Graph in part (b) should include straight, labelled perpendicular axes. The axes should meet at the origin (0,0). The range of the *n* axis should be as instructed in the question. The values on the vertical axis (rmsd) should be consistent with the equation given. The relationship should be represented with a smooth curve on the graph. |

# Baseline Assignment (problem-set): 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* |
| | |
| | |

| Problem Set | |
|---|---|
| *Comment* | *mark* |
| | |

## Final Assignment (problem-set): 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

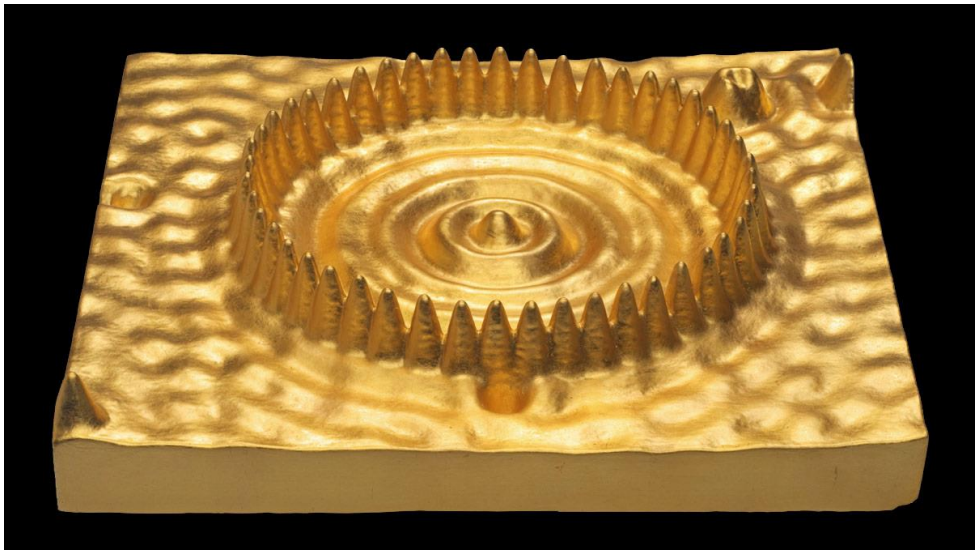
| Subject knowledge | |
|---|---|
| | *mark* |
| | |
| | |
| **Critical thinking** | |
| | *mark* |
| | |
| | |
| **Written communication** | |
| | *mark* |
| | |
| | |
| **Problem Set** | |
| *Comment* | *mark* |
| | |

## Subject Vocabulary

| Word | Definition | In a sentence |
|---|---|---|
| Surface (n) | The boundary of a solid object, where it meets a gas or empty space. | The surface of an object is often its most interesting part! |
| Flat (adj)<br>[of a surface] | Not curved, and not rough. All at one height, without bumps, lumps, scratches or ridges.<br>Visibly (optically) flat: a surface that gives a clear mirror-like reflection.<br>Atomically flat: as flat as a surface can ever be, given that matter is not homogeneous but made of atoms. | The surface of the CD looked flat, but when I looked at it under a microscope I saw it was covered in tiny scratches.<br><br>"The surface was repeatedly bombarded with argon ions and heated to 400 degrees C, until it was clean and flat" |
| Clean (adj)<br>[of a surface] | (In this course) The opposite of covered. The surface consists of just the material making up the solid whose surface we're talking about. A clean surface is free from the obvious everyday kinds of dirt (grease, grime, dust, oil, soil). It is also free from any substance other than the one the solid is made from.<br><br>For example, a copper surface is clean if the surface layer consists of copper atoms only, with not a single water molecule, oxygen atom or literally anything other than copper. | Any surface in the room around you will not be clean, because it is covered in at least one layer of gas molecules from the atmosphere. |
| Particle (n) | An individual component of matter that is so small that its size is unimportant, and so unlikely to decompose into smaller items that it can be considered as indivisible. | The particles of hydrogen gas are hydrogen molecules. The particles of metallic copper are copper atoms. To predict the future of the solar system, entire planets can be modelled as particles! |
| Crystal (n)<br>Crystalline (adj) | In a crystalline solid, the atoms are regularly arranged. A chunk of matter in which the regular arrangement is unbroken is called a crystal. | The seawater evaporated, leaving behind salt crystals. |
| Amorphous (adj) | (Everyday) Having no particular clear form.<br>(In materials science) The atomic structure does not have a repeating unit. The opposite of crystalline. | Sodium chloride is a crystal because the atoms are arranged in a repeating pattern. But window glass is amorphous. |
| Nanometre(n) | 1/1000000000 of a metre, or 10-9m in standard form.<br>Symbol is 'nm'. Equal to 10 Angstrom, or 10 Å. | Most viruses are about 100 nanometres in diameter, which is tiny. |
| Angstrom (unit)<br>[ Å ] | One tenth of a nanometre.<br>1/10000000000 of a metre, or 10-10 m in standard form. Symbol is Å. | A human hair is about a million Angstroms in diameter. But the space between atoms in solid copper is only about 2.5 Angstrom. |

| | | |
|---|---|---|
| Adsorb (v) | To stick to a surface. (Adsorb on, adsorb to, adsorb at).<br>(Process: adsorption).<br>Not to be confused with: absorb. | Water is *absorbed* by a sponge, but molecules of a gas *adsorb* on a surface. |
| Adsorption site (n) | A particular type of environment on a surface where an atom or molecule can absorb. Generally, important (named) adsorption sites have some relationship with symmetry, e.g. lines of symmetry pass through them, or the lattice has a rotation symmetry about the point. | Dimples in an egg carton are analogous to adsorption sites on a surface. |
| Random (adj) | Having an uncertain or unpredictable outcome. | "Are we supposed to get homework on Mondays or Wednesdays?"<br>" I don't know. So far it's been totally random!" |
| Statistic (n) | A single number that summarizes a set of numbers or data. | "80% of all statistics are made up." |
| Root mean square (n) [rms]<br><br>Root mean square displacement [rmsd] | Mean square: the statistic calculated by squaring each member of a data set, adding all the squares together, and dividing by the number of items in the data set.<br>Root mean square [rms]: the square root of the mean square. | The root mean square speed of air molecules at room temperature is about 500 metres per second. |
| Hop (n)<br>Jump (n)<br>Hop (v)<br>Jump (v) | Interchangeable terms. A hop or jump occurs when a particle adsorbed at one adsorption site moves rapidly to another adsorption site, spending very little time in between. | The atom hopped from a hollow site to the neighbouring hollow site.<br>I jumped from one raft to the next. I didn't put my feet down in between, or I would have fallen in the water. |
| Jump diffusion (n) | Diffusion in which particles spend essentially all their time at a particular type of adsorption site. A movie showing sequential snapshots of the surface would almost always show all the diffusing atoms fixed at a preferred site, but they are generally at different sites in different frames. You would hardly ever see a frame where an atom is caught in the act of hopping from one site to another. | Hydrogen atoms on Cu(001) do jump diffusion because they are strongly attracted to hollow sites, but pollen particles in water do continuous diffusion because liquid water has no fixed adsorption sites. |

# Tutorial 1 – Introduction to Surfaces



By Julian Voss-Andreae - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=17273241

## What is the Purpose of Tutorial 1?

1. I can define what is meant by a *surface*
2. I can contrast *clean* vs *covered* surfaces, and *flat* vs *rough* surfaces.
3. I can relate the study of clean flat surfaces to the concept of a *control variable*
4. **Baseline Assignment** on the topic of heterogeneous catalysis

## Key vocabulary for Tutorial 1

***Quick starter!*** Match the vocabulary to its definition. More detailed definitions are given in the vocabulary list for the whole workbook.

| | |
|---|---|
| Surface | Free from dirt, dust, grime; free from any chemical impurity |
| Flat | Possessing lumps, bumps and scratches, no matter how small |
| Clean | Free from lumps, bumps and scratches (even very tiny ones!) |
| Rough | Boundary of a solid object |

## Activity 1: initial thoughts about surfaces

Write your thoughts in the blank spaces provided.

- what is a surface?

- can you think of any *examples* of a surface?

- what are some *properties* of a surface?

- what are surfaces *good for*?

## Activity 2: mirrors (Year 7 revision)

How do mirrors work? Draw a diagram to explain why you can see an object clearly reflected from a mirror, but not from a brick wall. Clue: a surface will only act as a good mirror if it is flat enough.

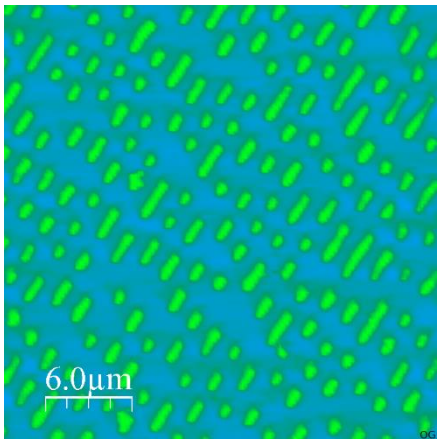
If you're really stuck, we can find help at Bitesize !

This is a picture of a **hinge**, like on a door. Whenever you see this picture, the idea is to get through the imaginary door by answering a question that checks your understanding. If you can't get through the door, we need to go back again to get the key!

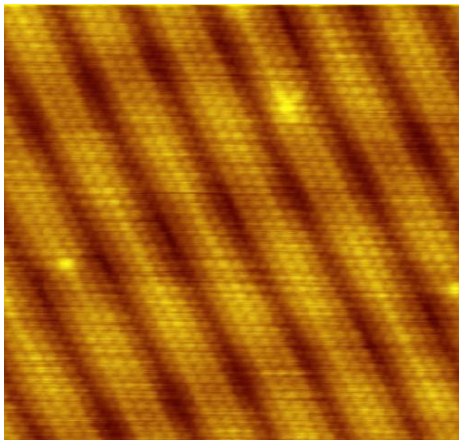
Today's ***hinge question*** is: as defined in today's Tutorial what's the opposite of a flat surface?

## Going deeper: how flat is flat?

The image of a CD's surface shown below was produced using a type of microscope that measures the repulsion between a surface and a sharp tip. Even though a CD surface is mirror-like, it is not *perfectly* flat: it is covered in features that store the data on the CD. There is no such thing as perfectly flat! In this course we are interested in surfaces much flatter than the surface of the CD. On the right is an image of a small portion of a *very* flat surface, so flat that the atomic pattern repeats itself perfectly across the image. The image was produced using another type of microscope, the Scanning Tunnelling Microscope. The ripples across the image are caused by tiny variations in height that make the extremely flat surface slightly more stable.




A



B

**A**: Atomic Force Microscope image of a CD surface. By Olivier G84 — Microscopie AFM, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=6844204
**B**: Scanning Tunneling Microscope image of a clean gold surface. By Erwinrossen - en:File:Atomic_resolution_Au100.JPG, see upload log, Public Domain, https://commons.wikimedia.org/w/index.php?curid=1790142

## Activity 3: control variables

Throughout your Science education you have studied Working Scientifically, including how to classify different variables in an experiment as independent, dependent and control variables. An independent variable is one that you can choose the value of in advance; a dependent variable is one that changes when the independent variable changes, but you don't know in advance how the dependent variable is going to change. A control variable is something else in the experiment that could affect the dependent variable, so the control variable needs to be kept constant.

For example, in an experiment to find out how the height from which I drop a ball affects the time it takes to hit the ground, the independent variable is the height, the dependent variable is the time, and control variables include (say) the temperature of the air, the wind speed, and using the same or an equivalent ball each time.

Repeat the exercise for an experiment to determine how the extension of a spring depends on the amount of force applied to stretch it.

*Independent variable:*
*Dependent variable:*
*Control variable(s):*

To make experiments in surface science well controlled, comparable and *reproducible* between different laboratories across the world, it is important to know "how clean and flat was the surface?". Atoms on rough and dirty surfaces might get stuck in place, whereas on a clean flat surface they are free to move long distances.

### Activity 4: catalysts – homework primer

Write down what you understand by the word *catalyst* in Chemistry.

*Catalyst (Chemistry):*

## Tutorial 1 Summary Quiz

1. What is meant by a flat surface?
2. What is meant by a control variable?
3. Why is it important to use flat surfaces in surface science experiments?

# HOMEWORK 1: BASELINE ASSIGNMENT

To mirror your final assignment, your baseline assignment is in two equally-weighted halves: a set of mathematical problems (Part I), and an extended answer question (Part II). The need to engage with both types of activity within the same topic area reflects the nature of scientific research. You are advised to spend a similar amount of time on both Parts, as they are worth equal credit.

**Part I: problem set [25 marks] (you must show working for full credit)**

1) Use the Scanning Tunneling Microscope image of a gold surface in Tutorial 1 to estimate the closest distance between gold atoms in solid gold. The whole image represents a square area of the surface, of side length 10nm. Give your answer in units of nm. Use other resources to find out the accepted answer for the atomic spacing in solid gold, and comment on any difference between your answer and the accepted answer. **[5]**

2) A solid object, made of a pure element, is placed inside a box. Draw the arrangement of the atoms in the solid, explaining carefully why you have drawn the particles the way you have. **[5]**

3) Use the definitions in Tutorial 1, and any other reading or resources, to give reasoned answers to the following questions. Your reasoning is more important than your yes/no answers.

(a) Is it possible for a surface to be clean if it is not flat?

(b) Is it possible for a surface to be flat if it is not clean? **[Total for question: 6]**

4) Sketch graphs of the relationships $y = x$, $y = x^2$, and $y = \sqrt{x}$ . Describe how and why the shapes of the second and third graph are related. There is no need to use graph paper. You should draw and label your own axes. The third (square root) graph will become very relevant in Tutorial 5. **[6]**

5) Using what you know about the size of atoms, estimate the diameter of the 'quantum corral' image at the top of Tutorial 1, in which each lump on the surface is an individual atom. **[4]**

**Part II: essay [25 marks]**

**! Important !** When you first read the essay title, do not panic. Read the full task description before starting. The task is broken down further for you, if you keep reading.

*Write an essay on*
"***Chemical reactions of gases, catalysed by solid surfaces***." (essay title)

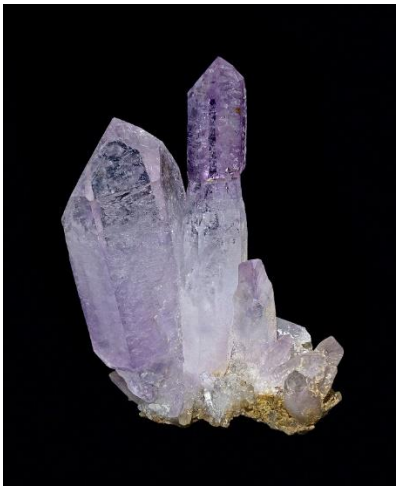
Include a discussion of the following chemical reactions, including why the reaction is important for the environment or society, and how the reaction relates to the field of surface science.
(a) $N_2+H_2 \rightarrow NH_3$ , known as the *Haber-Bosch process.*
(b) $CO+O_2 \rightarrow CO_2$ . which occurs in *catalytic converters* in cars.

Your word limit is 500 words, plus or minus 10%. Your work should include a reference list, which does not contribute to the word count. Refer to the section towards the end of this workbook about correct referencing.

The essay is an opportunity to demonstrate, practice and develop your skills in scientific communication and in searching and referencing sources of information. However, you should try to relate information you find out to information you already know, and to any concepts or vocabulary covered in the Tutorial. The following prompts will help you to include and organise relevant information that you find.

- Generally speaking, what is the point of a *catalyst*? What does the term mean?
- In each reaction, are the products desirable, or are the reactants undesirable, or both? What is desirable or undesirable about the products and reactants?
- Are the equations for the reactions balanced? If not, can you balance them?
- Which surfaces (i.e. which metals) are used to catalyse the two reactions above?
- Is there any advantage or disadvantages to the surfaces being extremely flat, or being rough?
- Does the temperature of the surfaces matter, and why? Does that have any practical implications?
- Does it matter if the surfaces are clean? There is a concept in catalysis called 'catalyst poisoning' – how does that relate to the concept of a clean surface in the tutorial, and is it a problem for either of the above two reactions?

# Tutorial 2 – Introduction to Crystals

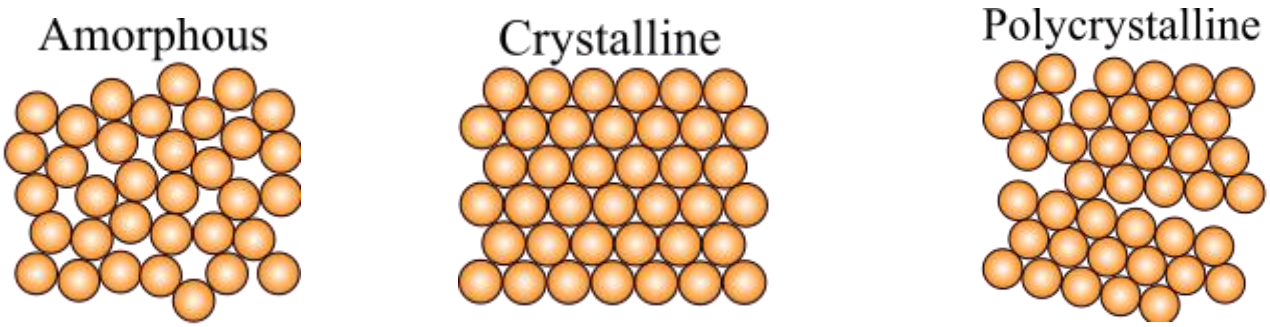


By Didier Descouens - Own work, CC BY-SA 4.0, commons.wikimedia.org/w/index.php?curid=6911957

## What is the Purpose of Tutorial 2?

1. I can define the terms amorphous, crystalline and polycrystalline
2. I can distinguish between the atomic structure of solids, the microstructure, and the visible appearance
3. I can use nanometres and Angstroms as units of length and distance.

## Key vocabulary for Tutorial 2



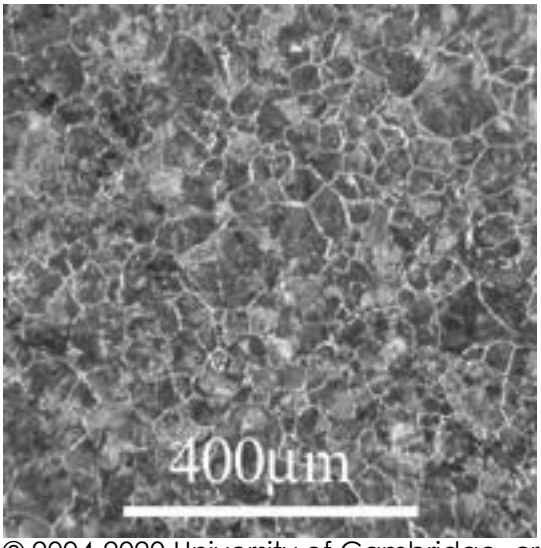

Adapted from Crystalline_or_amorphous.svg, CC BY-SA 3.0, By Sbyrnes321 - https://commons.wikimedia.org/w/index.php?curid=17439392

***Quick starter!*** Match each term to its definition, using the images above to help you. More detailed definitions are given in the vocabulary list for the whole workbook.

| | |
|---|---|
| Crystalline | A solid whose atoms are arranged in an irregular pattern |
| Amorphous | A tenth of a millionth of a thousandth of a metre |
| Nanometre | A solid whose atoms are arranged in a regular pattern |
| Angstrom | A solid made up of lots of small crystals jumbled together |
| Polycrystalline | A millionth of a thousandth of a metre |

## Activity 1: polycrystalline copper

We watched a video of copper sulfate crystals forming from a solution of copper sulfate in water. You will do a similar experiment as a Required Practical ('Making Salts') in Chemistry. The image below shows an iron alloy viewed through an optical microscope. The alloy solidified from a liquid. What is the connection between the video we watched, and the image here?




Explanation:

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Although the example shown here is an iron alloy, all metals that solidified from a liquid will tend to form the same kind of polycrystalline structure, unless great care is taken to allow only one crystal to form.

## Activity 2: single crystals

Look at the images below. For each one: is it a single crystal? Do you have any way of knowing, or is it just a guess?

A Turbine blade B "Crystal glass" C Silicon ingot D Cubic zirconia

A: Institute of Making.
B: By Paolo Neo - Public Domain, commons.wikimedia.org/w/index.php?curid=24926188
C: By user Saperaud~commonswiki, CC BY-SA 3.0, commons.wikimedia.org/w/index.php?curid=314282
D: By Gregory Phillips - CC BY-SA 3.0, commons.wikimedia.org/w/index.php?curid=350064

After seeing the answers – what can you conclude about crystals and the shape of objects? Is there a definite relationship between the shape of the object and whether or not the object is a crystal?

## Activity 3: crystalline or amorphous

In your regular Science lessons you have met the idea of particle diagrams for solids, liquids and gases, but you never worried about crystalline or amorphous solids! Using what you already knew about the properties of solids and liquids, and what you now know about amorphous and crystalline solids: draw particle diagrams for a crystalline solid, a liquid, and an amorphous solid in the boxes below.

Crystalline solid Liquid Amorphous solid

Remember the **hinge**?
Today's hinge question is: describe the difference between a crystalline solid and an amorphous solid, in your own words.

## Activity 4: nanometres and Angstroms

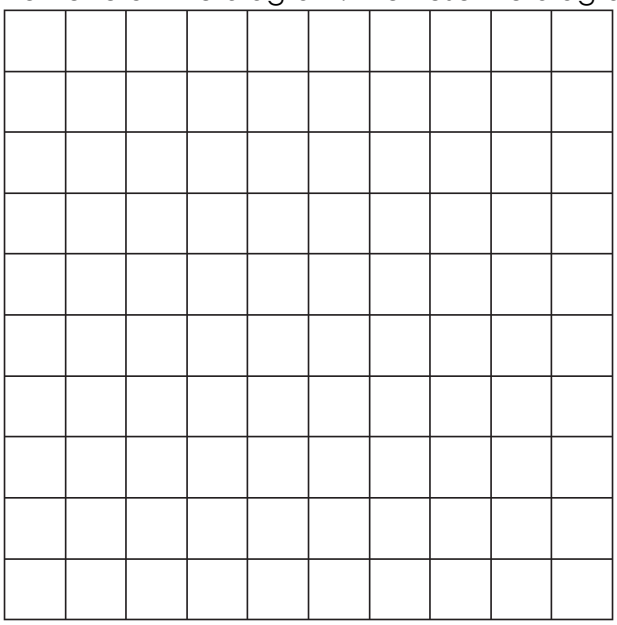
The *nanometre* (nm) is one thousandth of one thousandth of one millimetre.
You might have come across the micrometre (μm) when you studied microscopy in Biology.
The nanometre is one thousandth of a micrometre.
One *Angstrom* (A) is one tenth of a nanometre.
Units of *area* include the square mm, the square cm, the square nm and the square A.

(a) Work out how many *nanometres* there are in one *metre*. Show your working and write your answer in *standard form*.

(b) How many square mm are there in a square cm?

(c) How many square Angstrom are there in one square nanometre?

[Hint: Assuming that one small square on the following diagram is one Angstrom, label one Angstrom and one nanometre on the diagram. Then use the diagram to help you answer the question!]



## Tutorial 2 Summary Quiz

1. How are crystalline and amorphous solids different to each other?

2. Most everyday metal objects are polycrystalline. What does *polycrystalline* mean?

3. A human hair is 0.1 mm thick. How thick is the hair in Angstroms?

## Homework 2: transformations

We are going to think some more about how to describe crystal order.

In Maths (Geometry), you have studied *transformations* and their effect on geometrical shapes (like, for example, squares). Some transformations leave particular shapes unchanged, for example a square rotated about its centre by 90 degrees is indistinguishable from the original square, as indicated in the Figure below.

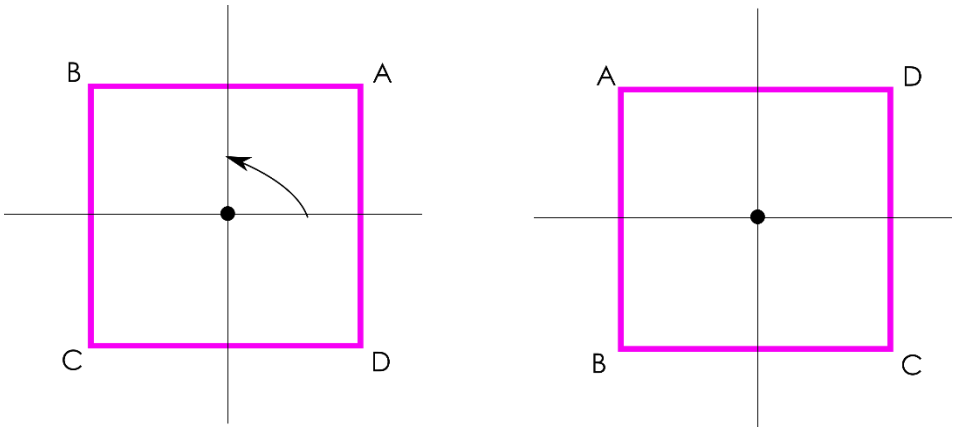



Figure: *rotation* of a square by 90 degrees about its centre produces another square that lies exactly on top of the original.

A *translation* is a geometrical transformation in which an entire object is moved in space without rotation. A square translated by any amount is *distinguishable* from the original square: you can tell the difference between the original and final square.

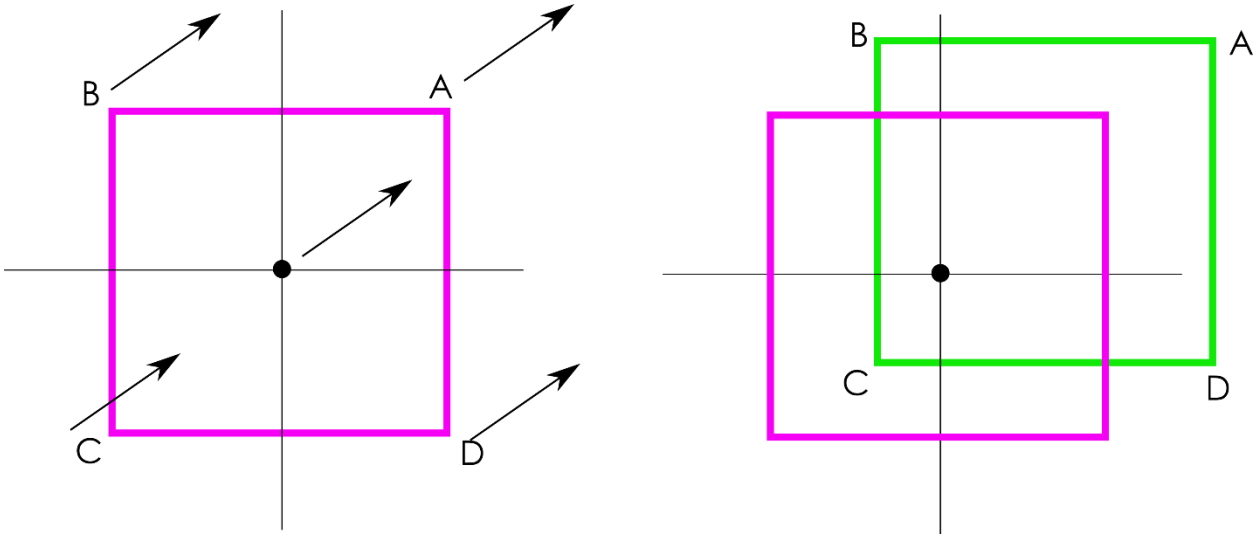



Figure: *translation* of a square produces a square that is displaced from the original: one does not lie on top of the other.

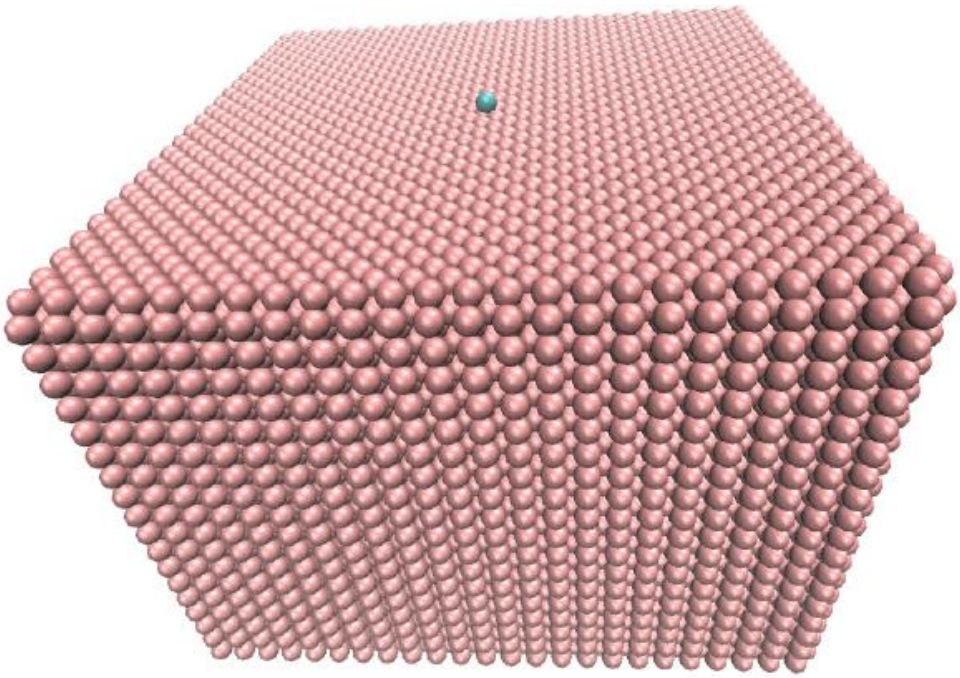
*Task:* Is there such a thing as an object that is unchanged by translations? How does your answer relate to the definition of *crystalline* in this Tutorial? Draw a diagram to represent your answer. You are welcome to use any resources available to help you answer, and especially welcome to reference any sources you use!

You can do the homework on a separate sheet and stick it into the workbook below, so you have a free choice over how much space to use!

## Success criteria for Homework 2

**Vacuum (U)** Homework missing, or no serious attempt.
**Plastic (3)** Your answer clearly shows that you understand what the word *translation* means, in the context of maths / geometry / shape and space, and includes a diagram.
**Bronze (2.2)** Your answer also gives a persuasive reason or argument for concluding 'yes' or 'no' to the first part of the task.
**Silver (2.1)** Your answer also discusses the connection between your conclusion and the concept of a *crystalline* material.
**Gold (1)** Your answer is also supported by a correctly referenced source. See the Appendix on referencing sources for guidance.

# Tutorial 3 – Crystal surfaces



## What is the Purpose of Tutorial 3?

1. Draw and describe how atoms are arranged in a face-centred cubic crystal structure such as that of copper.
2. Define the terms translation, lattice and motif
3. Identify the smallest repeating unit of the surface of a face centred cubic crystal cut along the (001) plane.

## Key vocabulary for Tutorial 3

***Quick starter!*** Match each term to its definition. More detailed definitions are given in the vocabulary list for the whole workbook.

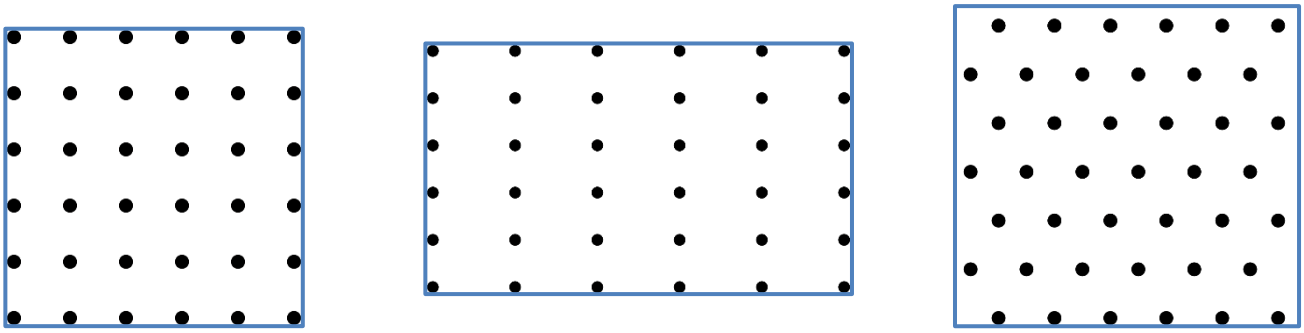
| | |
|---|---|
| Translation | A type of geometrical transformation: moving sideways without rotation |
| Lattice | Structure in which the repeating unit is a cube, but every cube has atoms at the corners and at the centres of the faces. |
| Motif | An infinitely repeating set of points |
| Face-centred cubic | The pattern placed at every lattice point to form a crystal. Like the flower that gets repeated in a wallpaper pattern. |

## Activity 1: the structure of crystals

Here is a description of what a crystal is (we studied it last time):
"A crystalline atomic structure is a *regular arrangement* of atomic positions, made up of a basic unit that repeats itself throughout all space."

From that description, what do we still **not** know about the arrangement of atoms in a specific material (say, the metal copper)? Use the hints below if you feel stuck.

*Hint 1*: the images below all show a repeating pattern. What is the same about each one, and what is different?



*Hint 2*: the images below both show a repeating pattern. What is the same about each one, and what is different?

A

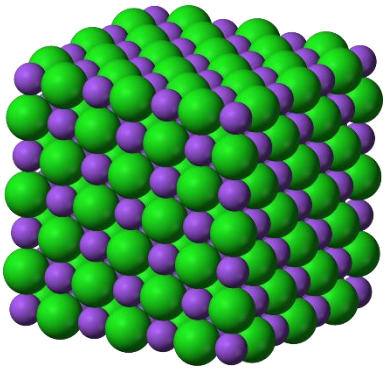
B

A: Daisy wallpaper. By William Morris - Planet Art CD of royalty-free PD images William Morris: Selected Works, Public Domain, commons.wikimedia.org/w/index.php?curid=2440405
B: Snakeshead design. By William Morris - https://clevelandart.org/art/1937.695, CC0, commons.wikimedia.org/w/index.php?curid=76008788

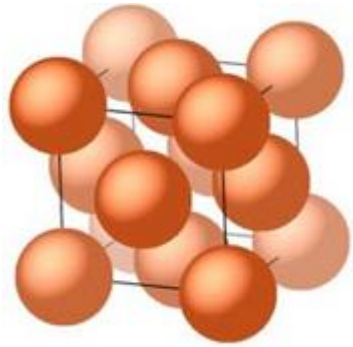
## Activity 2: equivalent atoms

Some crystalline materials are drawn below. Is every atom in the crystal equivalent? If not, why not? What is different about different atoms in the structure?

A



B



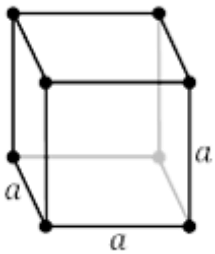
C

A: diamond.
B: sodium chloride. By user Benjah-bmm27 - Own work, Public Domain, commons.wikimedia.org/w/index.php?curid=702423
C: copper. From lecture notes at the University of Western Ontario by Dr L. Goncharova

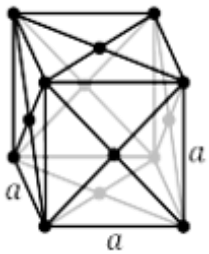
## Activity 3: crystal structure of copper

Look at the lattices drawn below. A lattice is a mathematical construct, not an object in the real world. The crystal structure consists of atoms, not mathematical points. However, in crystalline copper the crystal structure is built up by placing a single copper atom at every point in a lattice, so the lattice and the crystal structure look alike. By comparison, the daisy wallpaper you saw in Activity 1 is much more complicated than its underlying lattice! Copper is a relatively simple case because copper is an element, containing only one type of atom, and all the atoms in the structure are equivalent.

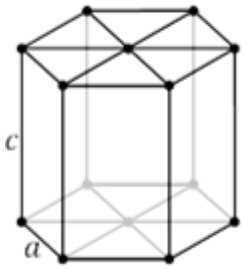
Which lattice shown below corresponds to the crystal structure of copper? You might like to look again at the structure of copper shown in Activity 2.




Simple cubic




Face-centred cubic




Hexagonal

The **hinge** is back!
Today's hinge question is: if I want to know how atoms are arranged in a crystal, I need to know the *lattice* type, and ***what else***?

## Activity 4: crystal surface

**Definition:** the (001) face of a cubic structure is the face viewed 'from the z direction', as shown in the slides. The notation we use to talk about a particular surface is the chemical formula of the crystal, followed by three integers enclosed in parentheses, like Cu(001).

(a) In the box on the left, sketch how the atoms are arranged on the clean Cu(001) surface.
(b) In the box on the right, draw the smallest repeating unit (think wallpaper!)
(c) If the length of a cube edge of the original face centred cubic structure was 3.61Å, how long is an edge of the repeating unit on the surface?

(a)

(b)

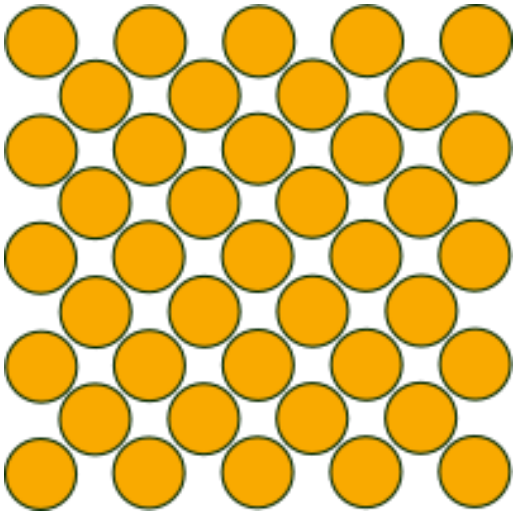
Length of one edge of the smallest repeating unit: _____

## Tutorial 3 Summary Quiz

1. Describe the connection between a *lattice*, a *motif* and a crystal.

2. In a crystal of copper, what is the motif?

## Homework 3: special sites



Above is a diagram of how the atoms are arranged on the Cu(001) surface. Only atoms in the top (outermost) layer are shown. The surface is 'in the place of the paper', i.e. if you put your pen through the paper, that represents going into the solid crystal. Each orange circle represents a copper atom. Read the following definitions, then write the letters T, B and H on the diagram to indicate the different types of *adsorption site*. Then answer the questions below. Reference one source to support any of your answers.

**Definitions:**
A top site (T) is directly above a copper atom.
A bridge site (B) is half way between two nearest-neighbour copper atoms
A hollow site (H) is equally far from four copper atoms

**Questions:**

1. (a) Are all top sites equivalent to each other? If not, why not?

   (b) Are all bridge sites equivalent to each other? If not, why not?

   (c) Are all hollow sites equivalent to each other? If not, why not?

2. Other than the description above, can you name any other *special properties* of each site? Think about possible *lines of mirror symmetry*, for example, or anything else you notice. [A line of mirror symmetry is a line about which the diagram lies perfectly on top of its own reflection.]

Special properties of top sites:

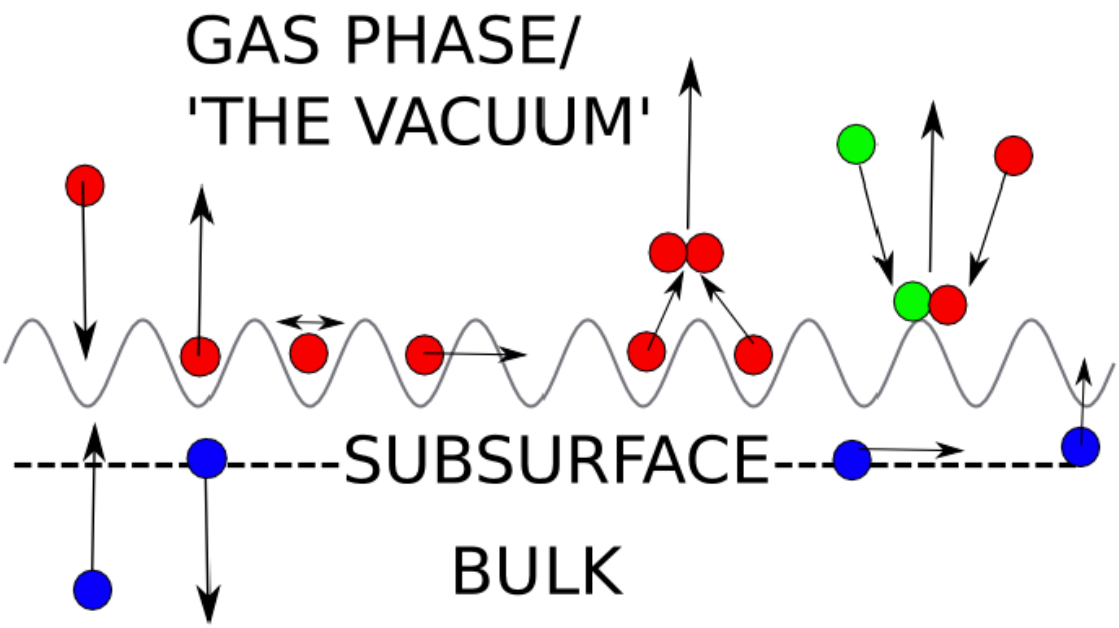
Special properties of bridge sites:

Special properties of hollow sites:

## Success criteria for Homework 3

**Vacuum (U)** Homework missing, or no serious attempt.
**Plastic (3)** Letters T, B and H placed on the diagram. Yes/no answers attempted and at least one type of site considered in Question 2.
**Bronze (2.2)** Letters T, B and H indicated in the correct place on the diagram. Yes/no answers correct and correct statements about lines of symmetry are made about each site in Question 2.
**Silver (2.1)** Answer also gives a correct justification to the 'If not, why not' part where relevant. At least one type of symmetry *other than* mirror lines are considered for Question 2.
**Gold (1)** Your answer is also supported by a correctly referenced source. Your answer makes it clear what information is taken from the source. See the Appendix on referencing sources for guidance.

## Tutorial 4 – Adsorption and Diffusion




### What is the Purpose of Tutorial 4?

1. Define the terms *absorption*, *adsorption* and *diffusion*
2. Calculate the probability of independent events (AND), and of outcomes that can occur in more than one way (OR)
3. Describe the role of randomness in diffusion

### Key vocabulary for Tutorial 4

***Quick starter!*** Match each term to its definition. More detailed definitions are given in the vocabulary list for the whole workbook.

| | |
|---|---|
| Absorption | Spreading out. |
| Adsorption | When something sticks to a surface. |
| Diffusion | When a liquid or gas goes into a solid, like water into a sponge. |
| Adsorption sites | The special places on a crystal surface where *adsorbed* atoms like to sit. |

## Activity 1: diffusion

What do you understand by the word *diffusion* from your regular Science lessons? Why is diffusion important? Think, pair and share!

## Activity 2: PhET simulation

PhET is a website created by the University of Colorado, which has interactive simulations designed to help students learn topics in Physics and Chemistry. Navigate to the PhET simulation,
https://phet.colorado.edu/sims/html/diffusion/latest/diffusion_en.html
which is a *two dimensional* simulation and therefore great for thinking about surfaces!

Spend a few minutes playing with the simulation. See what happens when you add a scale bar (no surprise!) and try out the stopwatch feature. How can you make the particles move faster or slower? Is there a limit to how many particles you can fit in the simulation? What happens when you remove the partition?

***Bonus question: the mass of gases. The default mass of the gas particles, in atomic mass units, is 28. What gases could that represent in real life?***

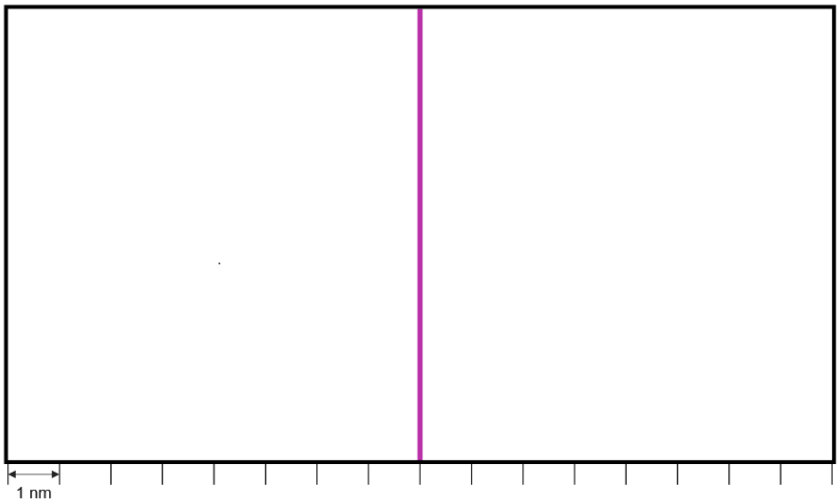
You can't escape the **hinge**.
Today's hinge question is: if a particle in the PhET simulation is at the centre of the box to begin with, and I run the simulation all day long, where will it be at the end of the day?

## Activity 3: diffusion as the spread of probability

Suppose the gases are fully mixed, in the sense that both gases are spread out over the whole box. Even so, the gas particles are still mixing with each other. The continuous mixing of the particles is the same process that led to diffusion of one gas into the other when the partition was removed. How can we quantify that process when there is just one type of gas present? Let's put together an answer in two stages.

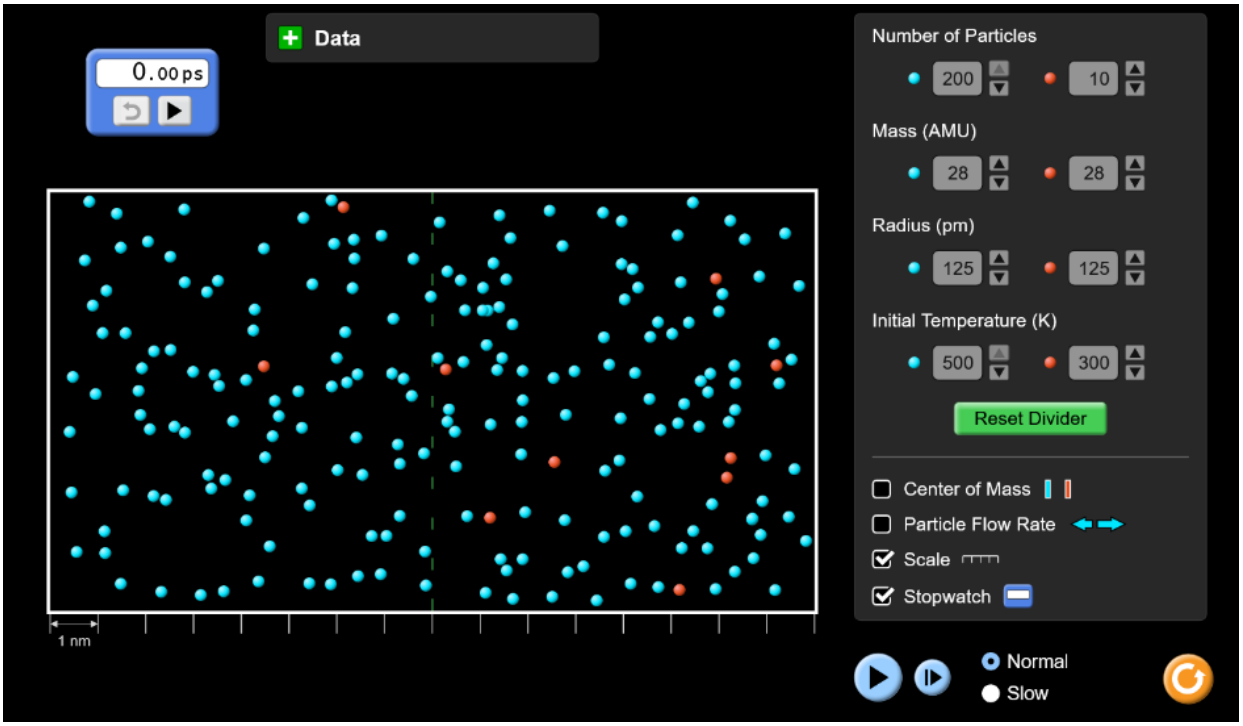
**Stage 1: focus on a single particle**

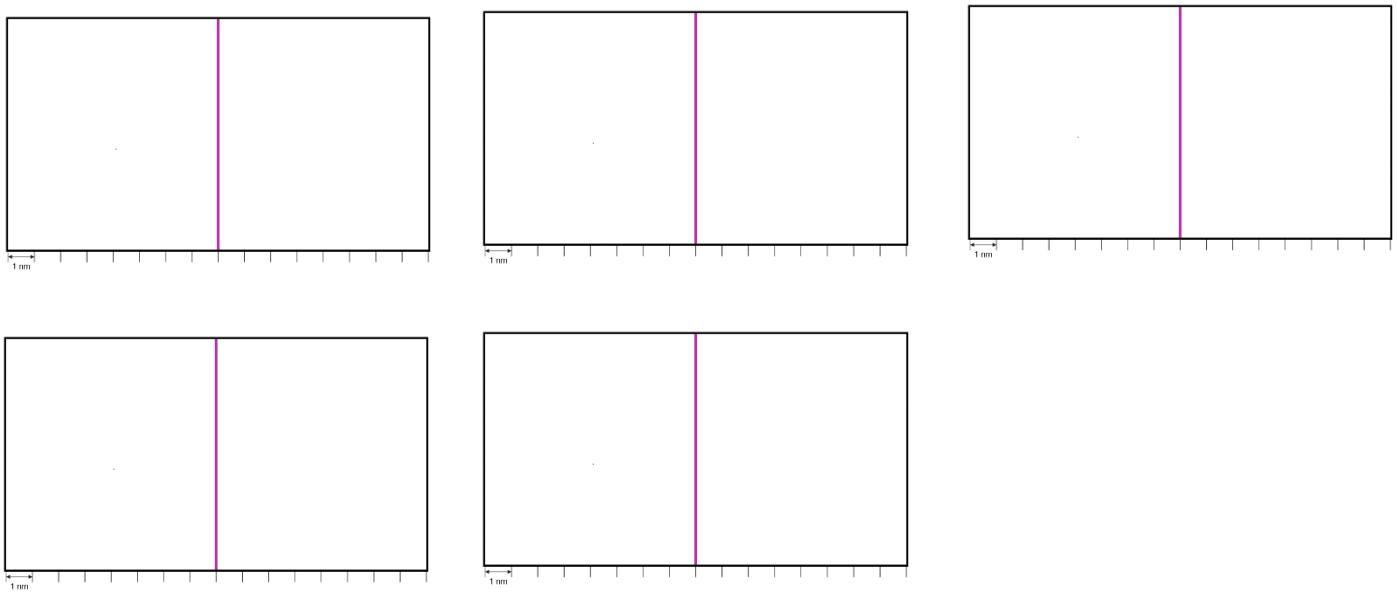
Sketch the trajectory of a single particle ('where it goes'). We will do this by pausing the simulation every two 'picoseconds'. Fortunately, the simuation has a built-in stopwatch that slows down time, so we can see the 'picoseconds' elapsing! Draw a dot to show where the chosen particle is located each time the simulation is paused. Draw your sequence of dots and crosses in the box below, and join them together with arrows to show the particle's journey. **NB.** To make your life easier, the box shown is the same as the box in the PhET simulation, with the colours inverted.. Notice the '1 nanometre' scale bar in the corner!




**Stage 2: rinse and repeat**

If you were to repeat the exercise many times, you could get reliable *statistics* and *probabilities* relating to diffusion. We will do more of that in Tutorial 5. However, it is often valuable to work out some *rules of thumb* before using Maths. Conduct the simulation we just tried five times, using the simulation conditions shown in the snapshot with 200 blue particles and 10 red particles. Each time you restart the simulation, wait until the gases are mixed and a red particle is roughly in the middle of the box, as shown below. Follow that red particle's trajectory until it reaches an edge of the box. After sketching five trajectories (one per box), answer the questions below.






Questions:

1. Does the particle always get further from its starting point?

2. Does the particle generally get further from its starting point?

3. Does the particle always take the same amount of time to reach the edge of the box?

## Tutorial 4 Summary Quiz

1. How are *ab*sorption and *ab*sorption different?

2. What does it mean for a substance like a gas to diffuse?

3. What does it mean for a *single particle* to diffuse?

## Homework 4: the rules of probability

Probability describes how likely an event is, on a scale from 0 (impossible) to 1 (certain).

**Definition:** A *fair coin* is a coin which, when thrown, has an equal probability of returning heads or tails. A *standard die* is a six-faced die with an equal probability of throwing a 1,2,3,4,5 or 6.

**Questions (show your working!)**

1. Under what conditions does the probability of a set of events add up to 1? Give your answer in plain English (i.e. in your own words) first, then use the technical term. Regardless of whether you knew the technical term or not, provide a reference to a source that explains the meaning of the technical term.

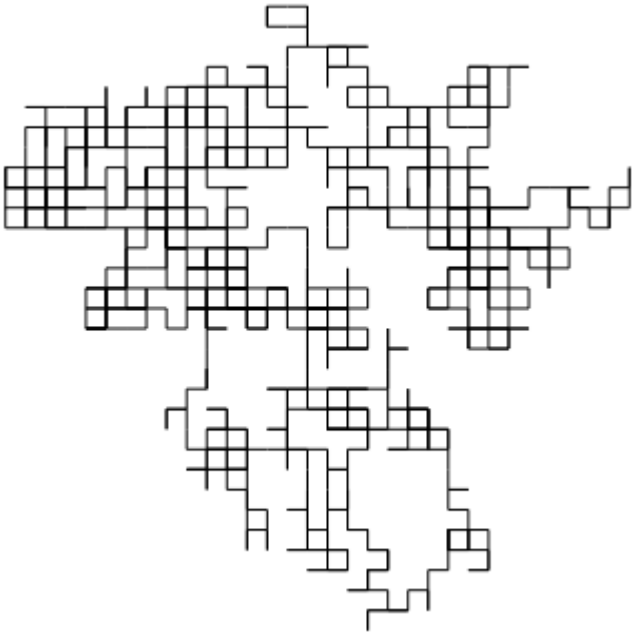
2. I throw a fair coin twice. What is the probability of throwing two heads? Show your working clearly and illustrate your working with any relevant diagram.

3. I throw a fair coin and then a standard die. What is the probability of throwing heads and then a 6?

## Success criteria for Homework 4

**Vacuum (U)** Homework missing, or no serious attempt.
**Plastic (3)** The condition for probabilities adding to 1 is given correctly in either plain English or as a technical term.
**Bronze (2.2)** Numerical answers given but no working, or working given but cannot be followed.
**Silver (2.1)** Numerical answers correct, and working can be followed. The answer to Question 1 is supported by a correctly referenced source.
**Gold (1)** Working for questions 2 and 3 is correct, methodical, easily followed and includes tree diagrams or tables.

# Tutorial 5 – Diffusion by Random Jumps



## What is the Purpose of Tutorial 5?

1. I can interpret the rules of probability to calculate the probability of independent events, and of outcomes that can occur in multiple ways
2. I can calculate statistics from a collection of data, including the mean, mean square and root-mean-square
3. I can interpret computer simulations that use random numbers, to learn about the diffusion of particles on solid surfaces by *jumps*
4. Introduce the Final Assignment and equip you to produce your *formative* submission.

## Key vocabulary for Tutorial 5

*Jump diffusion, random, mean, root-mean-square*

***Quick starter!*** Match each term to its definition. More detailed definitions are given in the vocabulary list for the whole workbook.

| | |
|---|---|
| Jump diffusion | Add up a set of numbers, and divide by the number of numbers |
| Random | Unpredictable; governed by probability |
| Mean | Starting from a set of numbers: square every number, add the squares together, divide by the number of numbers and then take the square root of the result |
| Root mean square | Diffusion that takes place when an atom stays at one adsorption site for a long time, then hops quickly to another, then waits a long time, then hops to another, … |

## Activity 1: random walk simulation

Navigate to https://demonstrations.wolfram.com/LatticeRandomWalkIn2D/
As a result of Tutorial 2, you now know what is meant by the word 'lattice' in the page title. Wolfram is a company who write software used by scientists, engineers, financial modellers and in other fields. We are going to use a free online demonstration that illustrates *jump diffusion,* but they refer to it as a *random walk*.

Play with the simulation for a few minutes, and read the one-line description on the web page. Answer the following questions:

1. Where does the random walk start?

2. What does the word 'randomly' mean, in the simulation description?

3. What does the 'new random walk' slider do?

The **hinge** is back for one last question.
Today's hinge question is: describe what happens to the random walk as the number of random steps increases. Focus on the *distance* between the starting point and ending point of the path.

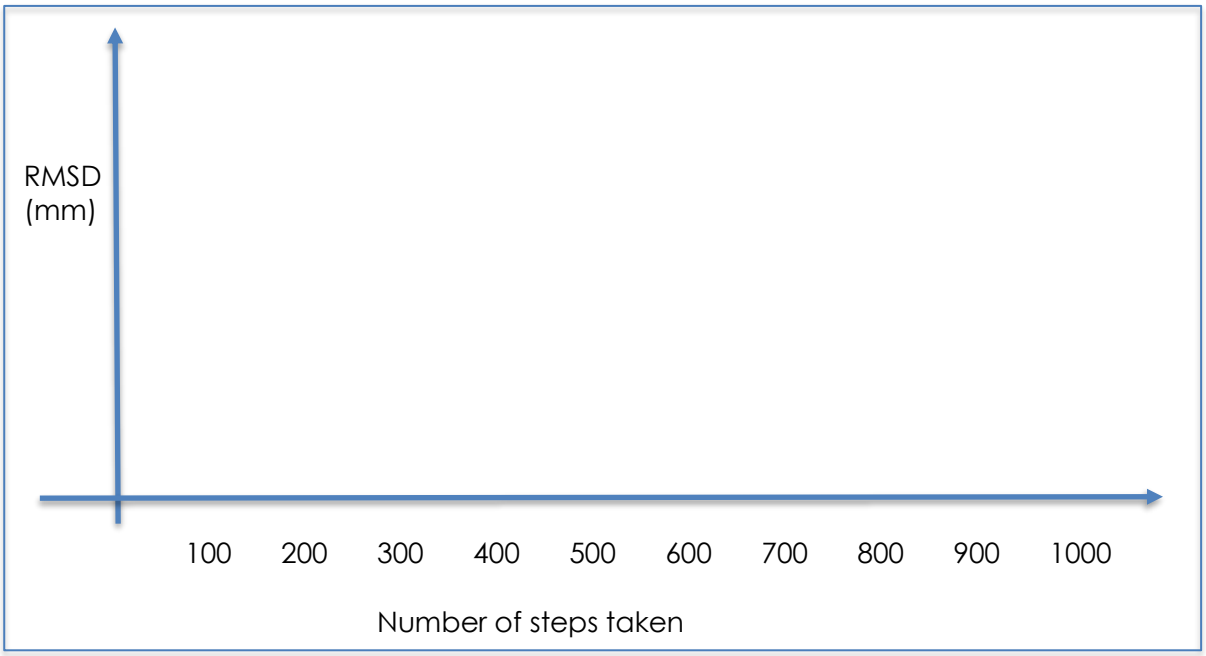
## Activity 2: statistics - numbers that summarise

Turn off the 'shrink to fit' option. Select 1000 as the maximum number of steps, and click the 'steps taken' slider through its ten settings add 100 more steps and note where the trajectory ends. Each time 200 steps are added, measure the distance from the centre of the simulation (in mm on the screen is fine, using a physical plastic ruler). Write your answer in the $D_1$ (distance of first simulation) column. When you have finished the column, move the slider for 'new random walk' to its next setting. Repeat the exercise and write in columns $D_2$ and $D_3$.

The final column of the table is the mean of the three 'D squared' columns. The mean of the square of a set of distances is known as the 'mean square distance'. The column to the right of the msd is the rmsd, defined as the square root of the msd. Rmsd stands for *root mean square distance*.

| Steps taken | $D_1$ (mm) | $D_1{}^2$ | $D_2$ (mm) | $D_2^2$ | $D_3$ (mm) | $D_3^2$ | Mean (msd) | Rmsd |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 200 | | | | | | | | |
| 400 | | | | | | | | |
| 600 | | | | | | | | |
| 800 | | | | | | | | |
| 1000 | | | | | | | | |

We have just conducted a kind of experiment on a computer (some would call it a computational experiment). As in real-life experiments, it is useful to plot our findings as a graph. In the box below, **draw** a set of axes using pencil and a ruler, where the horizontal ('x') axis is the number of steps taken, and the vertical ('y') axis is the root mean square distance between the start and end of the trajectory. You should notice that the curve keeps on getting higher, but its rate of increase slows down. The mathematical description of the graph is revisited in the Final Assignment.




## Tutorial 5 Summary Quiz

1. What is a random walk?

2. In the context of a random walk, what does the term 'mean square disiplacement' refer to?

3. What happens to the mean square displacement of a particle during a random walk?

# HOMEWORK 5: FINAL ASSIGNMENT

Your final assessment is in two equally-weighted halves: a set of mathematical problems using concepts from the course (Part I), and an extended answer question (Part II). The need to engage with both types of activity within the same topic area reflects the nature of scientific research. You are advised to spend a similar amount of time on both Parts, as they are worth equal credit.

## Part I: problem set [50 marks]

You must show your working to receive full credit for a correct answer. You can score good marks for correct working even if the final answer is incorrect.

1) The atoms making up the surface layer of a crystal form a *square lattice* (see **Tutorials 3 and 5**). The smallest repeating unit is a square of side length 2.70Å. Draw a diagram of the surface layer, indicating the side length on the diagram. How many atoms per square metre are in the that layer? **[5]**

2) Draw the arrangement of atoms at the surface of a crystalline material, and at the surface of an amorphous material (see **Tutorial 2**). State and explain which diagram is which. You should aim to use additional key vocabulary from the course in your explanations. One of the diagrams is constructed out of a repeating unit: indicate the repeating unit on the relevant diagram. **[10]**

3) This question is about steps taken in a random walk (**Tutorial 5**) and the probability of different outcomes (**Homework 4**). In part (a) and (b) below, use one or more diagrams to support your explanations.

(a) I am standing on a lattice site of a square lattice, and I hold a standard six-sided die. In the event that I roll a 1,2,3 or 4 I move left, right, up or down respectively, otherwise I stay put. After rolling twice (and moving accordingly), how likely am I to be at my original location? Explain your working carefully. **[5]**

(b) In a random walk simulation on a square lattice (Tutorial 5), a particle starts at the origin and undergoes ten random jumps. The side length of one square is one unit. What is the probability that the particle ends up a distance of ten units from the origin? **[5]**

4) This question is about the statistic known as the *root mean* square, as seen in **Tutorial 5**. Throughout part (b), even if you are unsure about your final answers, you should show your attempts and communicate your strategy or thought process.

(a) Consider the data {-10,-7,-2,1,5,9}. For the given data, find the mean of the square (*mos*) and the square of the mean (*som*) **[3]**

(b) What is the minimum value of the *mos*, and what is the minimum possible value of the *som*? For each minimum value, give an example of a data set where the *mos* (or *som*) has that minimum value. Finally, work out a general rule for when a data set will have a *som* equal to its *mos*. **[7]**

5) The root mean square distance (rmsd) moved by a particle jump-diffusing on a square lattice of side length 1 is given by

$$rmsd = \sqrt{2n}\ ,$$

where $n$ is the number of steps of the random walk. (We explored the random walk simulation in **Tutorial 5**.)

(a) Explain the meaning of the term 'root mean square distance', with reference to the idea of simulating several trajectories independently.

(b) Draw a graph showing clearly how *rmsd* depends on $n$. Your graph should represent *n* from *n=0* up to *n=10000*. The horizontal axis of the graph should be the *n* axis. You are not required to calculate the *rmsd* explicitly for all values of *n*, but you should include at least one point where the co-ordinates of the point are labelled on the graph, besides (0,0). Be sure to refer to the Final Assignment success criteria for what makes a good graph. Overall, the graph should look a little like the one completed in **Tutorial 5**, but not exactly the same – bonus marks if you can explain why.

(c) Write down an equation expressing how the mean square distance (*msd*) depends on *n*.

(d) A particle moving away from the origin at a fixed speed is known as a *ballistic particle*, and has a root mean square deviation of 'speed times time', that is *rmsd* = *vt* . Find the time *T* at which the *msd* of the diffusing particle in part (a) is equal to the *msd* of the ballistic particle.

(e) ***Synthesis***. Using what you know (or can find out) about Newton's laws and using what we saw in the PhET simulation, describe the conditions under which a particle in a gas will undergo ballistic motion away from its starting point, at least for a short period of time.

(f) ***Simulation vs. real world.*** Instead of simulating a random walk on a square with a side length of one unit, I simulate a particle hopping on the square lattice formed by the top sites of an fcc(001) surface, with side length $a$. The jumps occur at a rate of $\Gamma$ per unit time. How does the rmsd depend on $a$ and $\Gamma$?

**[Total for question: 15]**

## Part II: essay [50 marks, 1000 words]

Write an essay on

'***Jump diffusion on crystalline surfaces***' ( essay title ).

Your answer should include a clear explanation of what the topic of the essay means, and also the following elements:

- How jump diffusion is distinct from continuous diffusion, and the conditions in which jump diffusion will occur on surfaces. Continuous diffusion was simulated in Tutorial 4, and jump diffusion was simulated in **Tutorial 5**. To relate the simulation in Tutorial 5 to real surfaces, you will want to refer to **Tutorials 2-3** about how the atoms are arranged in crystals and at the surfaces of crystals.

- Why diffusion on surfaces is relevant to modern technology or industry, with specific examples where relevant. (Relevant industries might include chemicals or electronics). Key search terms that could help you find out about relevant applications include *heterogeneous catalysis* (see **Tutorial 1**), *diffusion-limited chemical reactions, self-assembled monolayers, two-dimensional materials, chemical vapour deposition and molecular beam epitaxy*. You are *not* required to explain all those terms, but you should try to link your area(s) of focus carefully to the title of the essay.

- An account of one experimental method that can be used to study jump diffusion on surfaces. How does the method work, what is measured, and what are the challenges and limitations of the method? We saw in **Tutorial 1** an image produced by a type of microscope that can resolve individual atoms. The same device can be used to study jump diffusion. You are welcome to use that example, or a different one.

*Additional information*

- Your essay should include your name, the date, the essay title, page numbers, and a section at the end entitled 'References'.

- You will be graded on your ability to present information in a logical and structured way, to use the terminology of the field correctly, and to reference sources of information appropriately. To score high marks you will need to search for sources of information beyond the course workbook. You should cite your sources in-text, as well as at the end of the essay, to indicate which information is attributed to a particular source.

- You are welcome and encouraged to include Tables, Graphs and Figures in your answer. You should include captions with any Table, Graph or Figure, but captions will not count towards the word limit. Spelling and grammar are important and contribute to the overall mark.

## 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 |
|---|
| • <br><br>• <br><br>• |

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

| Tasks from my Uni Pathways Teacher to do during the feedback tutorial to help me improve |
| --- |
| • <br><br>• <br><br>• |
| My response: |

| Actions I will take to improve my final assignment after this tutorial… |
| --- |
| • <br><br>• <br><br>• |

| 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<br>•<br>•<br>• | |

| 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 |
|---|
| •<br>•<br>• |

**University**

| What questions do you still have about University after taking part in Uni Pathways? |
| --- |
| • <br>• <br>• |

**Reflecting on Uni Pathways**

| What did you most enjoy about Uni Pathways? |
| --- |
| • <br>• <br>• |

| What did you find challenging about the programme? | How did you overcome these challenges? |
| --- | --- |
| • <br>• <br>• | • <br>• <br>• |

## 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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