# Boids of a Feather

## Key Stage 4 Programme

Pupil Name

Handbook Designed by Dr Papavassiliou

# Timetable and Assignment Submission

## Timetable – Tutorials

| Tutorial | Date | Time | Location |
|---|---|---|---|
| 1 | 12/12/2018 | 2pm | King's College London |
| 2 | wb 7/1/2019 | 3pm | Chobham Academy |
| 3 | wb 14/1/2019 | 3pm | Chobham Academy |
| 4 | wb 21/1/2019 | 3pm | Chobham Academy |
| 5 | wb 28/1/2019 | 3pm | Chobham Academy |
| 6 (Feedback) | wb 11/2/2019 | 3pm | Chobham Academy |
| 7 (Feedback) | wb 18/3/2019 | 3pm | Chobham Academy |

## Timetable – Homework Assignments

| Homework Assignment | Description | Due Date |
|---|---|---|
| Tutorial 1 | Active matter behaviour (500 words) | |
| Tutorial 2 | Vicsek model questions | |
| Tutorial 3 | Table and plot of order in Vicsek model | |
| Tutorial 4 | Symmetries and phases in the Vicsek model | |
| Tutorial 5 | Phase behaviour in active matter (2000 words) | |

## Assignment Submission – Lateness and Plagiarism

| Lateness | |
|---|---|
| Submission after deadline | 10 marks deducted |
| **Plagiarism** | |
| Some plagiarism | 10 marks deducted |
| Moderate plagiarism | 20 marks deducted |
| Extreme plagiarism | Automatic fail |

# Uni Pathways – Pupil Feedback Report

| Grade | Marks | Guidance |
|---|---|---|
| 1st | 70+ | |
| 2:1 | 60-69 | |
| 2:2 | 50-59 | |
| 3rd | 40-49 | |
| Working towards a pass | 0-39 | |
| 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 | Dr Papavassiliou | | |
| Title of Assignment | Boids of a Feather | | |
| Name of Pupil | | | |
| Name of School | Chobham Academy | | |
| 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 - | |
|---|---|
| What you did in relation to this Key Learning Priority | How you could improve in the future |
| **Learning Feedback Comment 2 –** | |
| What you did in relation to this Key Learning Priority | How you could improve in the future |
| **Learning Feedback Comment 3 –** | |
| 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

How do birds fly together in flocks? As far as we know, they can't communicate as humans would to organise themselves. However, a flock of birds appears to be very well organised: the birds are flying (more or less) in the same direction, the flock itself has sharp edges, and flocks can be huge (numbering in the tens or even hundreds of thousands of individual birds).

The behaviour of large systems of moving and interacting organisms is termed *collective motion*, and is seen in many different types of animals: fish form schools, ants form colonies, locusts form swarms, whales form pods, humans form societies…In fact, flocking behaviour and collective motion is also seen in organisms as simple as bacteria or single cells, and even in non-living particles (such as rice being vibrated on a plate).

The aim of these tutorials is to look at some of the very recent science attempting to explain and understand this collective motion, called the science of *active matter*. The fact that this behaviour is common to such a variety of systems, despite the obvious differences in the actual organisms or objects, suggests that it might be a universal feature of collections of moving objects.

In exploring these we will uncover some surprising links to *statistical mechanics*: the science of matter, and one of the most active and productive branches of physics to emerge in recent decades. We will find changes of state in active matter systems, which shed light on the more familiar changes of state between solids, liquids and gases. We will make use of a common technique in physics research, *computer simulation*: a sort of cartoon version of reality which allows us to carry out experiments that would otherwise be impossible or impractical.

The first half of this course will be more practical: following an introduction to systems showing collective motion we will explore them using a computer simulation of one of the most famous models in this field, the Vicsek model.

The second half will look at some of the important theoretical concepts needed to understand statistical mechanics. In particular we will need to understand what *symmetry* means in physics – while this is probably a familiar word already, here it has a precise definition which is worth studying in detail. Symmetry is arguably one of the most central ideas in theoretical physics, appearing in nuclear physics, particle physics, statistical mechanics and the physics of matter (to name but a few).

Each tutorial will be followed by homework. This builds on the material we will cover in the tutorials and is an essential part of the course. Finally you will produce a university-style assignment, which will bring together all the concepts covered within the course. You will receive a grade and feedback as you would at university.

# Mark Scheme

| Skills | 1st (70-100) | 2:1 (60-69) | 2:2 (50-59) |
|---|---|---|---|
| Knowledge and Understanding | • All content included is relevant to the general topic and to the specific question/title<br><br>• Good understanding of all the relevant topics.<br><br>• Scientific terms are defined and used accurately throughout<br><br>• Clear justification on how the content included is related to the specific issues that are the focus of the assignment | • Most of the content included is relevant to the general topic and to the specific question/title<br><br>• Good understanding of most the relevant topics<br><br>• Scientific terms are used accurately but not always clearly defined.<br><br>• Adequate justification on how the content included is related to the specific issues that are the focus of the assignment | • Some of the content included is relevant to the general topic and to the specific question/title<br><br>• Good understanding on some of the relevant topics but occasional confusion on others.<br><br>• Scientific terms are used mostly accurately with occasional confusion and often not defined.<br><br>• Some justification on how the content included is related to the specific issues that are the focus of the assignment |
| Critical Evaluation/ Problem solving | • Moved beyond description to an assessment of the value or significance of what is described<br><br>• Evaluative points are consistently explicit/systematic/reasoned/justified<br><br>• Effective critiques on the reliability of sources provided<br><br>• Consistently demonstrate clear, analytical and logical steps to solving problems | • Mostly description but some assessment of the value or significance of what is described<br><br>• Evaluative points are mostly explicit/systematic/reasoned/justified<br><br>• Some evidence of critiques on the reliability of sources provided<br><br>• Some examples of solving problems but not consistently clear, analytical and logical | • Only description with minimal assessment of the value or significance of what is described<br><br>• Evaluative points are at times explicit/systematic/reasoned/justified<br><br>• Limited evidence of critiques on the reliability of sources provided<br><br>• Demonstrate clear steps to solving problems but not consistently analytical or logical |

| | | | |
|---|---|---|---|
| Structure and Presentation | • Ideas are presented in paragraphs and arranged in a logical structure that is appropriate for the assignment<br><br>• The introduction clearly outlines how the essay/report will deal with the issues<br><br>• The conclusion summarises all the main points clearly and concisely<br><br>• All calculations, formulas and methods are clearly structured, clear to follow and correct<br><br>• Tables and graphs are effectively constructed including appropriate headings, units and scales.<br><br>• All sources are referenced correctly in an agreed format<br><br>• No spelling, grammar or punctuation errors<br><br>• Writing style consistently clear, tone appropriate and easy to follow<br><br>• Accurate and consistent use of technical language and vocabulary | • Ideas are presented in paragraphs and arranged in a structure that is mostly appropriate for the assignment<br><br>• The introduction adequately describes how the essay/report will deal with the issues<br><br>• The conclusion summarises most of the main points clearly<br><br>• Calculations, formulas and methods are mostly structured, clear to follow and correct<br><br>• Most tables and graphs are well constructed<br><br>• Most sources are referenced correctly in an agreed format<br><br>• Minimal spelling, grammar or punctuation errors<br><br>• Writing style mostly clear, tone appropriate and easy to follow<br><br>• Some attempts of using technical language and vocab alary, but not always accurate | • Ideas are presented in paragraphs and arranged in a structure<br><br>• The introduction mentions how the essay/report will deal with the issues<br><br>• The conclusion summarises some of the main points clearly<br><br>• Calculations, formulas and methods are not always structured, clear to follow and correct.<br><br>• Some tables and graphs are well constructed but contains some errors<br><br>• Some sources are referenced correctly in the agreed format with occasional errors<br><br>• Some spelling, grammar or punctuation errors<br><br>• Writing style moderately clear, tone appropriate and easy to follow<br><br>• Use of simple language and vocabulary effectively but struggles to use technical language |

# Glossary

This space should be used to note key words and terms. These will be pointed out when they come up in the tutorials. If you need more space there is another glossary on page 34.

| Word | Definition | Example/In a sentence |
|---|---|---|
| | | |
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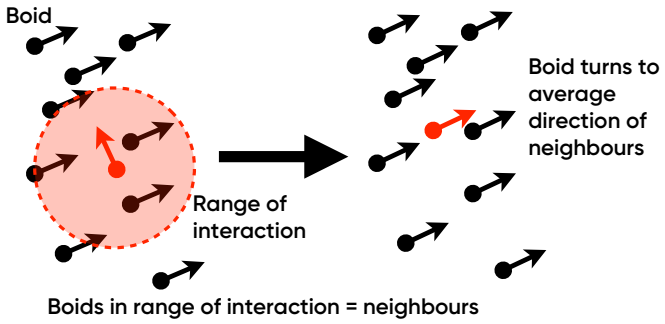
# Knowledge Organiser
# The Vicsek model

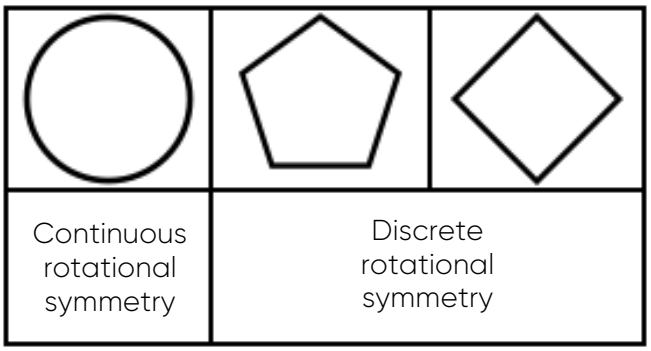
Computer simulations can be very useful to investigate how accurate a model is. A famous simulation of flocking behaviour of **boids** (simulated birds) is the Vicsek model. Here, boids turn to fly in the same average direction as their neighbours.



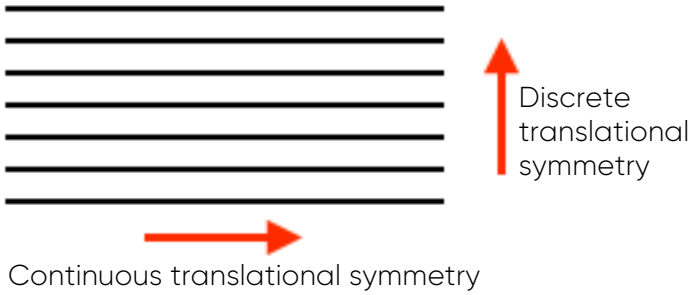

# Symmetries

In physics, a **symmetry** is a geometric operation (such as translation, rotation or reflection) which leaves a system unchanged. A **continuous symmetry** can be a smooth action, while a **discrete symmetry** must be taken in steps.

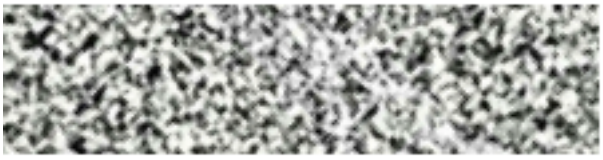
## Rotational symmetry




## Translational symmetry



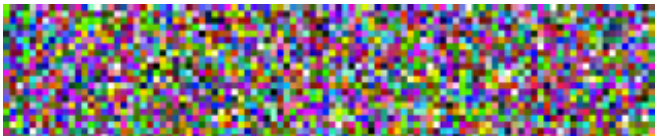

## Symmetry in randomness



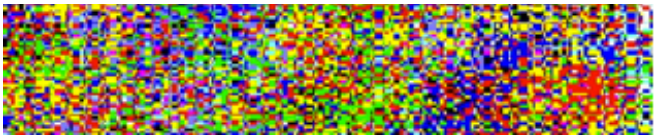
This random pattern is highly **symmetric** because the probability of finding black is the same everywhere

# Order and disorder

Regions of a system with high randomness are called **disordered**, while regions with low randomness are called **ordered**. Order can be **local** (different in different regions of the system) or **global** (the same everywhere), and is measured with an **order parameter**.



**Disorder** (random colouring)



**Local order** (same colour over small distances)

**Global order** (same colour everywhere)

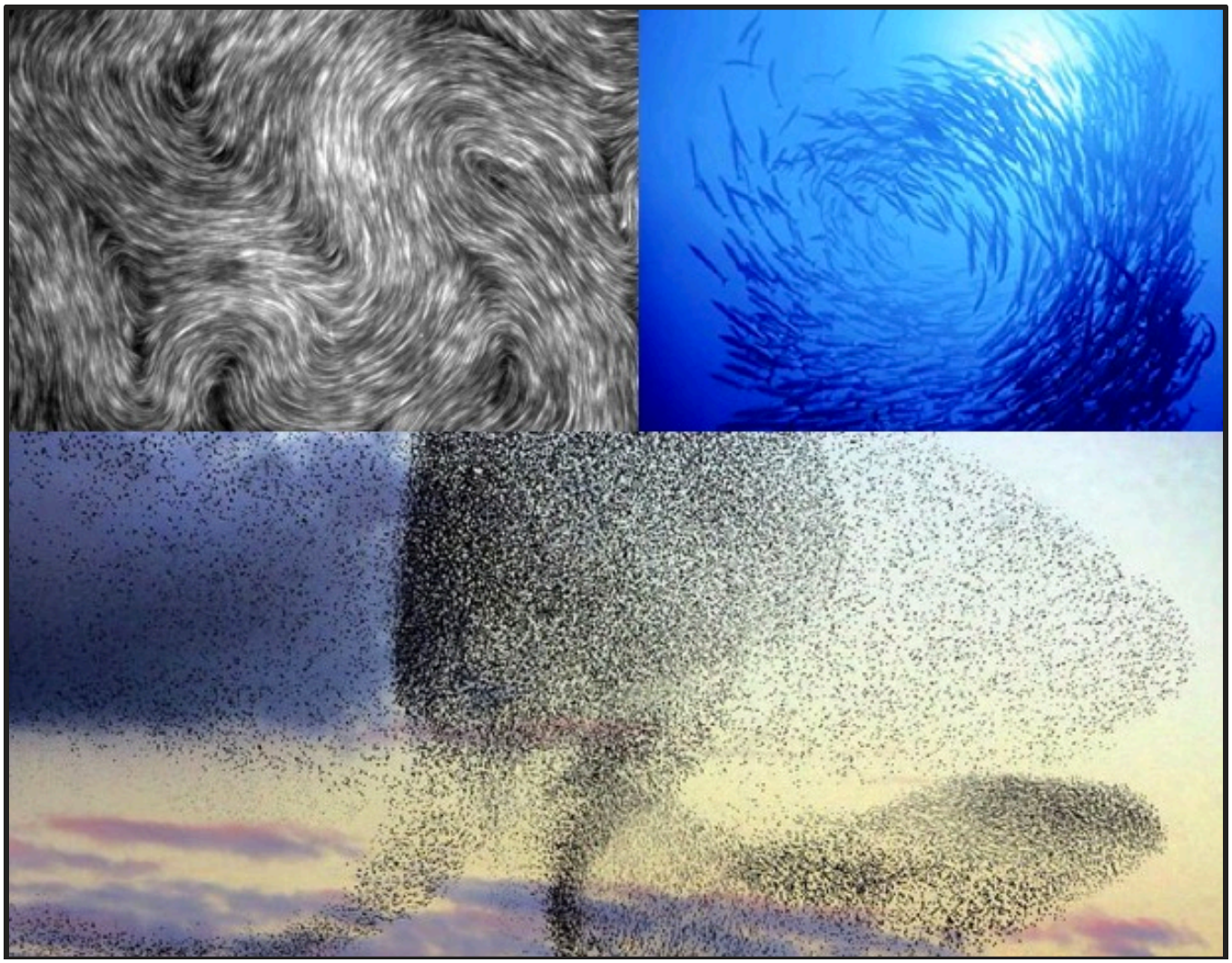
# Phase transitions

The scientific name for a **change of state** is a **phase transition.** Phase transitions are marked by

- A change in **physical properties**
- A change in **microscopic structure** (and, often, a change in **symmetry**)
- A change in the value of the **order parameter**

Some examples of phase transitions: ice melting, water boiling, jelly setting, ironing creases out of fabric.

# Tutorial 1 – Collective Behaviour in Active Matter



## Tutorial Aims

- To understand the terms *active matter*, *collective behaviour* and *interactions*
- To know some of the interactions by which collective behaviour may arise

## Activity 1

You should see a video and a demonstration in front of you. Write down 3 features these systems have in common, and 3 differences.

| Similarities | Differences |
|---|---|
| | |
| | |
| | |

## Flocking models

Craig Reynolds (1987) simulated very realistic flocking by making a computer model with only three features:

1. Collision avoidance
2. Velocity matching
3. Cohesion

The (in)famous wildebeest stampede from Disney's The Lion King (1995) used Craig Reynolds's algorithm

## Lecture & Discussion – Living and non-living active matter

Fill out the table below with details of the separation, alignment and cohesion mechanisms in the active systems discussed in the lecture. If you need more space use the Notes section at the end of this tutorial.

| System | Separation | Alignment | Cohesion |
|---|---|---|---|
| Flock of birds | | | |
| Bacterial swarm | | | |
| Vibrated rice grains | | | |

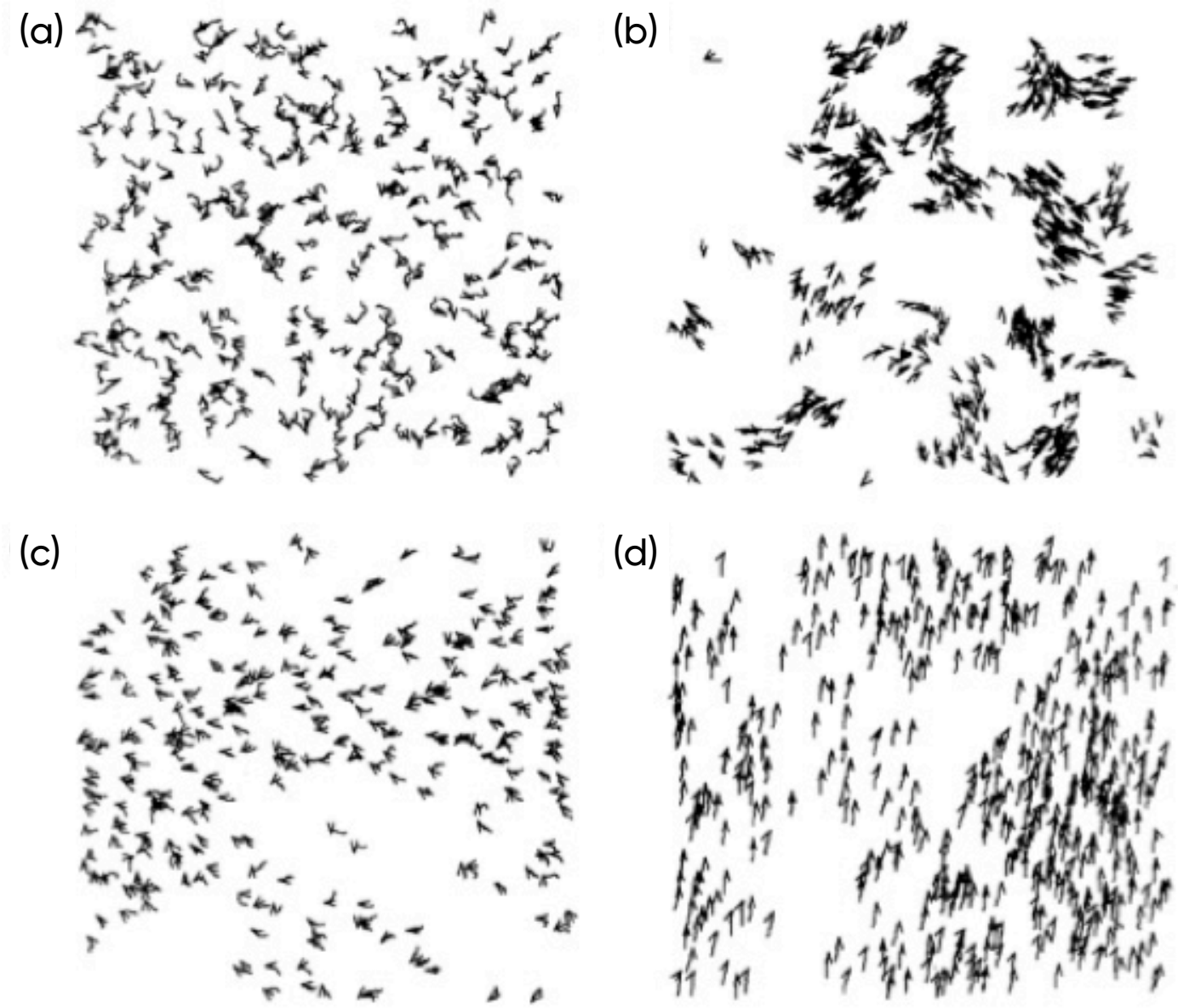
# Homework – Baseline Assessment

1. Write a short essay (around 500 words) introducing active matter.
   A good essay will:
   - Discuss what types of systems are considered to be active matter and give examples
   - Give some examples of collective behaviour and explain why they are interesting for scientists
   - Name and explain at least 3 different interactions that give rise to this behaviour, and give examples of systems with these interactions
   - Use key words learnt in this tutorial
   - Use correct spelling, punctuation and grammar
   - Reference appropriately

2. Draw a sketch of the arrangement of molecules in a solid, a liquid and a gas
   Describe the arrangement of molecules in each.
   Explain how this affects the physical properties of the material.

# Tutorial 1 Notes

# Tutorial 2 – The Vicsek Model (Theory)




## What is the Purpose of Tutorial 2?

- To learn what the Vicsek model is

## How can we simulate a flock of birds?

We can use a simulation. Let's start with a number of flying objects (we shall call them 'boids'). These boids have a head and a tail, and fly at a *fixed speed*. They also fly through each other (i.e. we ignore physical contact). In other words, this is the simplest flock of boids we can think of.

What does this flock look like?

We need *interactions* to keep the flock together. What form could these be? What do you think happens in nature?

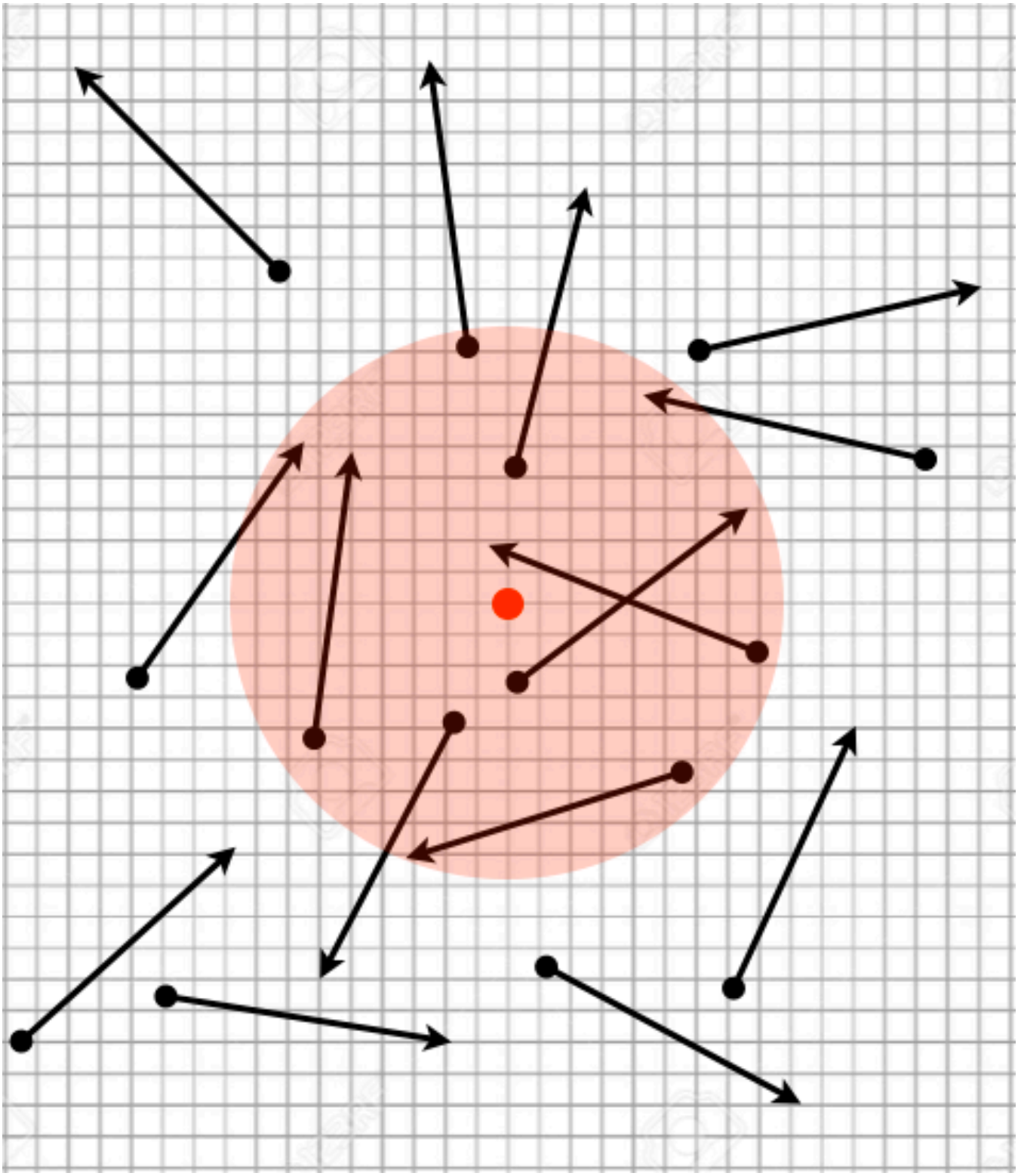
## Reorientation

The interaction rule used in the Vicsek model (Tamás Vicsek, 1995) is:

"boids look at their neighbours and try to fly in their average direction"

## Activity 1

Draw an arrow pointing in the average direction of the nearest neighbours of this boid. You will need a protractor.



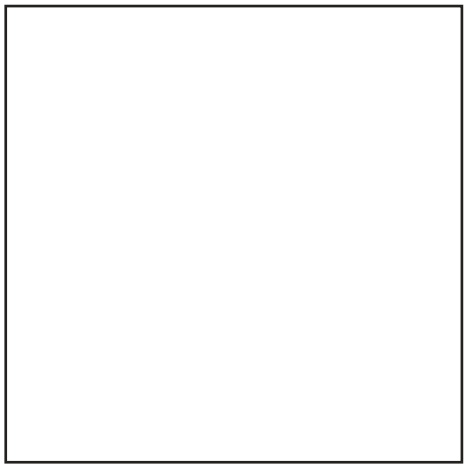
## Noise

In fact our boids are not perfect at reorienting themselves, and occasionally make mistakes. We introduce another rule:

## Activity 2

1. If the average direction of a boid's neighbours is 45° and the noise is 15°, what are the maximum and minimum angles the boid could point in?
2. What is the probability that its direction will be between 40° and 50°?
3. If the average direction of a boid's neighbours is 285° and the noise is 94°, what are the maximum and minimum angles the boid could point in?
4. What happens if the strength of the noise is 0°?
5. What happens if the strength of the noise is 180°?

## Periodic boundary conditions



# Homework

1. How many variables are there in the Vicsek model? What are they?
2. What do you think will happen to the flock if the strength of the noise is high?
3. What do you think will happen to the flock if the strength of the noise is low?
4. What do you think would happen without period boundary conditions?
5. CHALLENGE: Many researchers have experimented with simulations using alternative interaction rules. Can you think of any? Can you predict any advantages or disadvantages of these alternative rules?

# Tutorial 3 – The Vicsek Model (Simulation)

## What is the Purpose of Tutorial 3?

- To explore the Vicsek model using a computer simulation

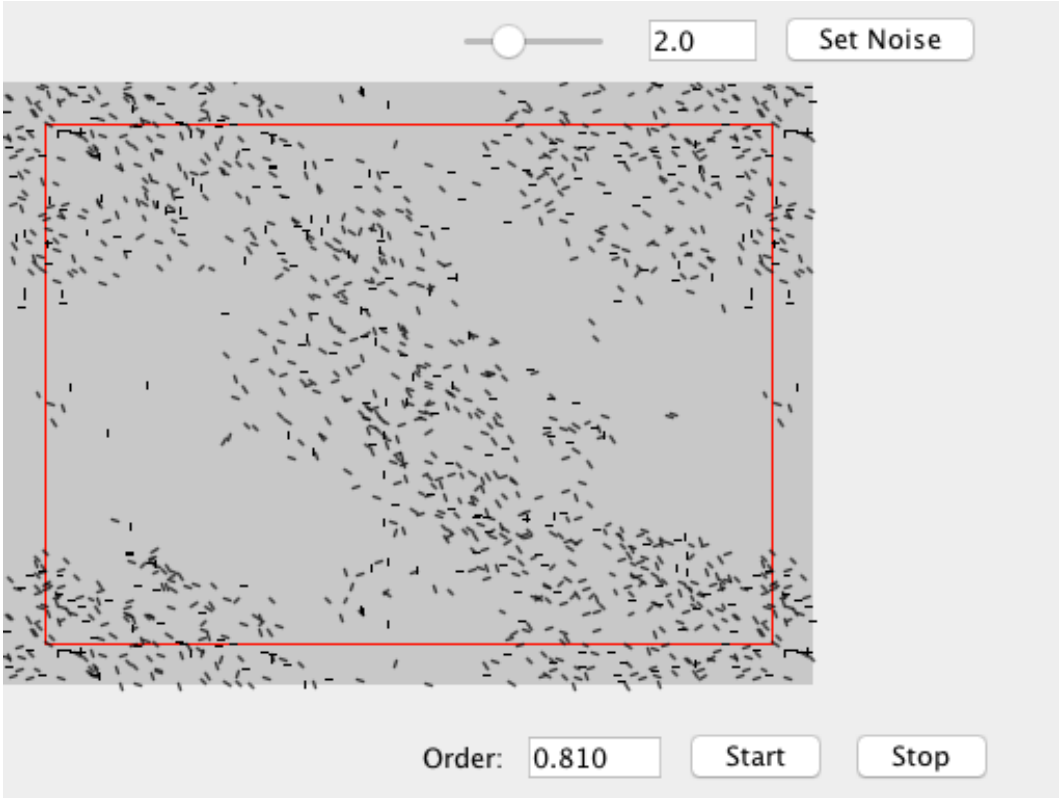
## Lecture – Simulating the Vicsek model

Listen carefully to the lecture on implementing a simulation of the Vicsek model and annotate the code below:

```
#INITIALISING

set number of boids (N)

set size of box

set initial positions of boids

set initial directions of boids (x)

set interaction range (r)

set size of step (step)

set strength of noise (n)

#CALCULATING

while i<N:
      look at other boids, find distance to boid i

      ignore all boids with distance > r

      neighbours = what is left

      a = average_direction(neighbours)

      x = n*random_number(-1,1) + a

      update position by step in direction x

      if new position is out of box:

            apply periodic boundary conditions

      change i to i+1
```

## Activity 2

Go to https://www.stthomas.edu/physics/research/computation/vicsek/ (IMPORTANT: this will not work in recent versions of Google Chrome, so use a different browser if possible. Java must be installed and enabled). This is an interactive Vicsek model with 1000 boids, and gives you the option to adjust the noise. At the bottom of the screen a number is shown called 'order' (we will see what this means later).




Describe what happens when the noise is 0, 1, 3 and 6. Write 2 sentences for each: what do you see? What value does the order take?

## How does the order vary with the noise?

You should have found that by varying the noise the order changes, and that low noise leads to high order while high noise leads to low order.

We will now try to find the relationship between noise and order in a more precise way by taking some measurements, just as we would in an experiment, and drawing a graph.

### Method

1. Calculate the noise in degrees. To do this, multiply the value of noise in the first column by 28.65, round to the nearest degree, and fill out the second column in the table.
2. Start the simulation.
3. Type the value of noise in the box and click 'Set Noise'.
4. Wait 5 seconds for the simulation to settle.
5. Press 'Stop', write down the value of the order, then start the simulation again.
6. Wait another 5 seconds, press 'Stop', and take another measurement.
7. Repeat from step 2 until the table is filled.
8. Calculate the average order for each value of the noise.

| Noise | Noise (°) | Order | | | Average order |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | |
| 0.0 | 0 | 1.000 | 1.000 | 1.000 | 1.000 |
| 0.5 | 14 | 0.985 | 0.986 | 0.986 | |
| 1.0 | | | | | |
| 1.5 | | | | | |
| 2.0 | | | | | |
| 2.5 | | | | | |
| 3.0 | | | | | |
| 3.5 | | | | | |
| 4.0 | | | | | |
| 4.5 | | | | | |
| 5.0 | | | | | |
| 5.5 | | | | | |
| 6.0 | | | | | |

## Homework

You will produce a plot of the results you have obtained from the simulation on graph paper.

1. The independent variable will go on the x-axis
2. The dependent variable will go on the y-axis
3. Use your **range** of values of the order for each value of the noise to draw **error bars**.
4. **In pencil**, draw a curve of best fit and use it to estimate the value of noise for which the order is 0.5.

Remember that graphs should have a clear title, axes should be labelled and data points should be marked with x.

This graph will be needed for your final assignment so make sure you do not lose it!

# Tutorial 3 Notes

# Tutorial 4 – Symmetry

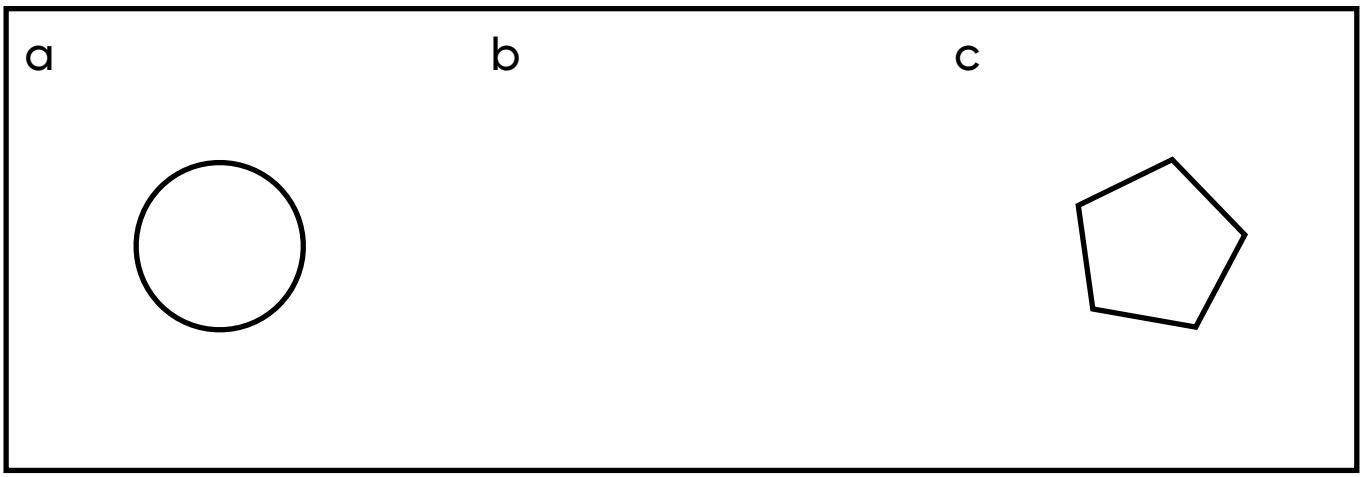
## What is the Purpose of Tutorial 4?

- To understand that *symmetry* in physics has a different meaning to what we are used to from maths lessons
- To identify different types of symmetry, and apply this understanding to familiar states of matter

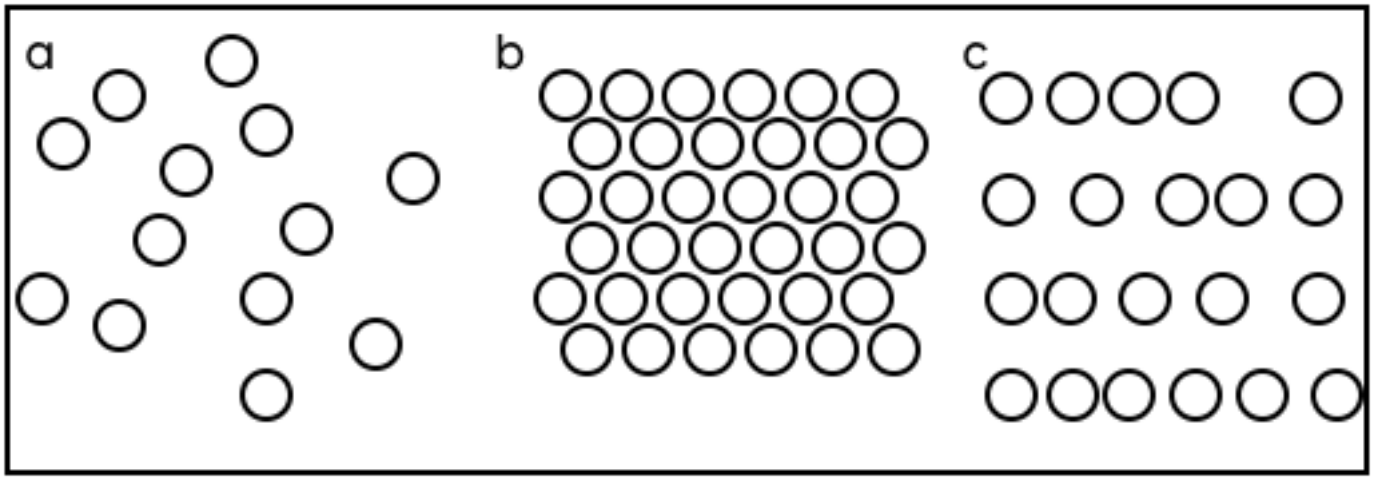
## Activity 1

## Definition of symmetry

## Which picture is most symmetric? Why?



Which picture is most symmetric? What types of symmetry can we see?



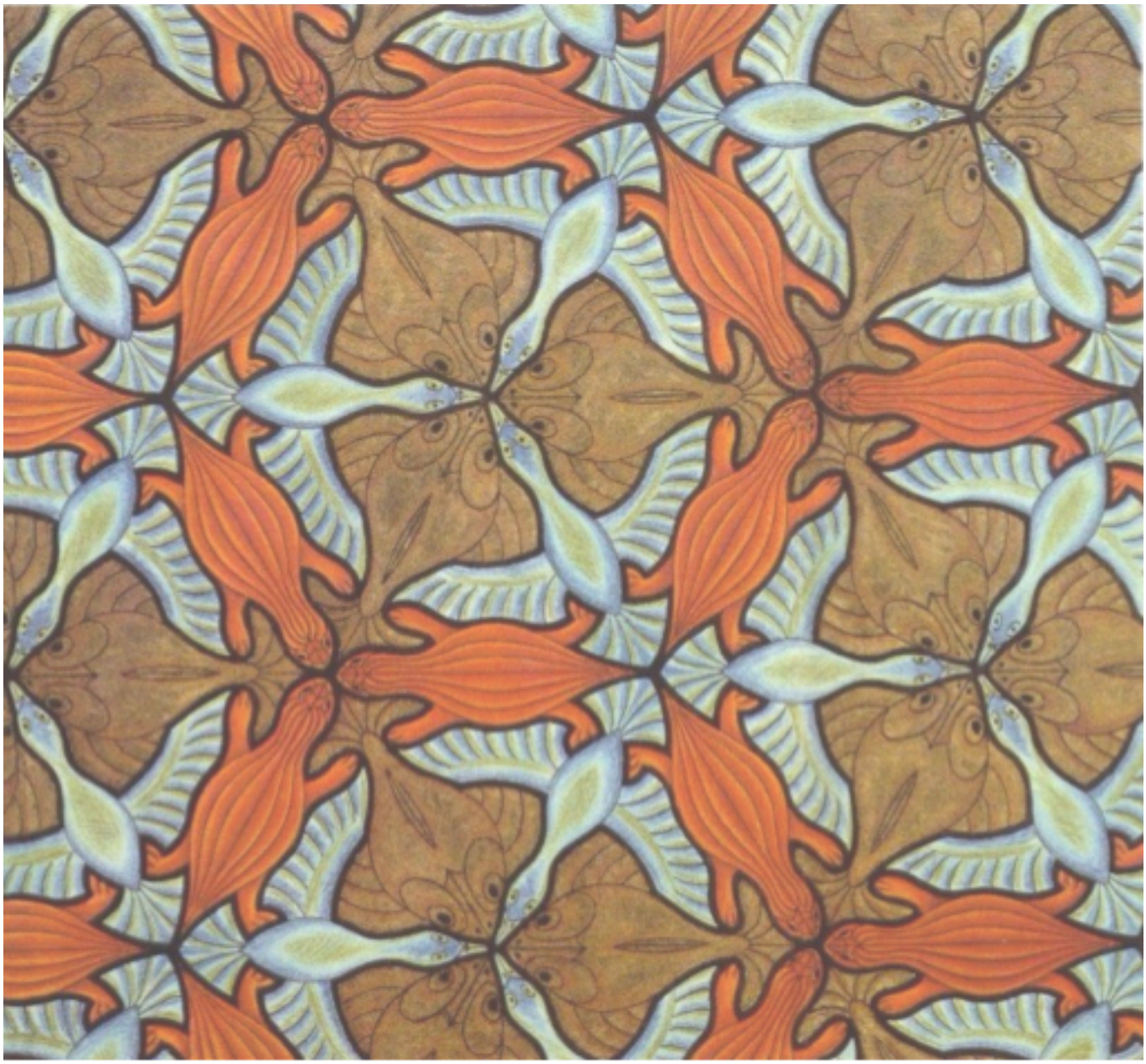

## Lecture: types of symmetry

Fill out the table below based on information in the lecture on types of symmetry. You will be given writing time. If you need more space you can write on the 'Notes' section at the end of this tutorial.

| Symmetry | Definition |
|---|---|
| Translational | |
| Rotational | |
| Mirror | |
| Scale invariance | |
| Continuous | |
| Discrete | |
| Time | |

## Activity 2

Identify as many symmetries as possible in this painting by M. C. Escher. State whether these symmetries are discrete or continuous, and if they are discrete explain in what way (e.g. "Discrete rotational symmetry of order 2 about the points marked x" or "discrete translational symmetry in the direction shown by the arrow, repeating every 4cm"). You may draw on the picture if you need to.



# Homework

For each of the four pictures in the figure at the start of Lesson 2 (page 13):

1. Describe the symmetries seen and whether the symmetry is local or global
2. Which picture is the most symmetric? Which picture is the least symmetric?
3. Did you see similar behaviour in your own investigation of the Vicsek model (Homework 3), and if so what was the value of the order parameter for each?

You should write no more than 200 words.

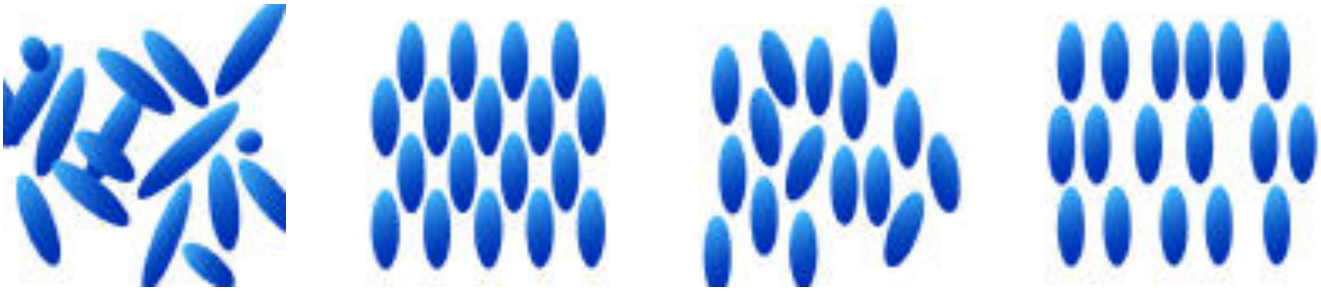
# Tutorial 4 Notes

# Tutorial 5 – Phase Transitions

## What is the Purpose of Tutorial 5?

- To understand that some phase transitions can be understood as *spontaneous symmetry breaking*
- To appreciate that an *order parameter* can be used to identify a phase transition

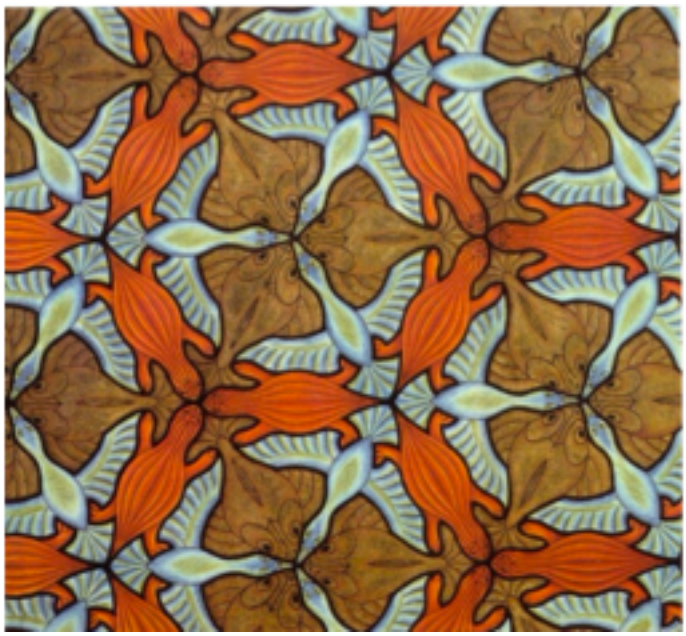
## Activity 1: In pairs, arrange these 4 phases in order of increasing symmetry:

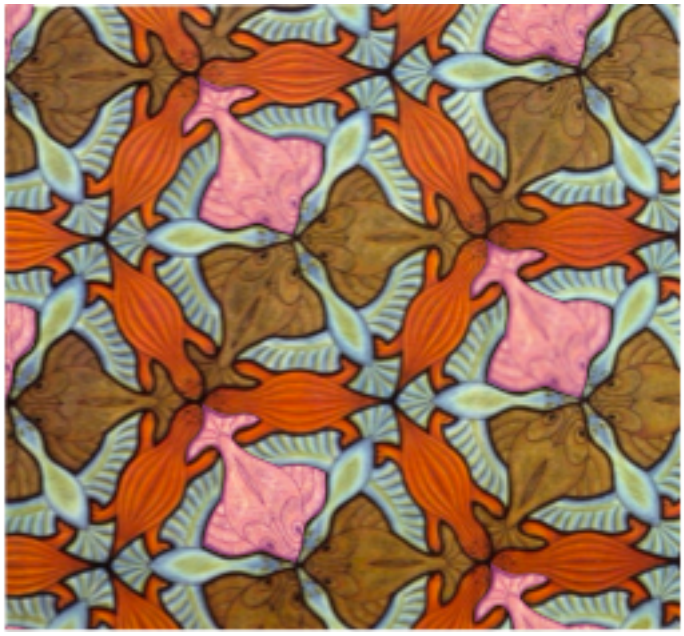


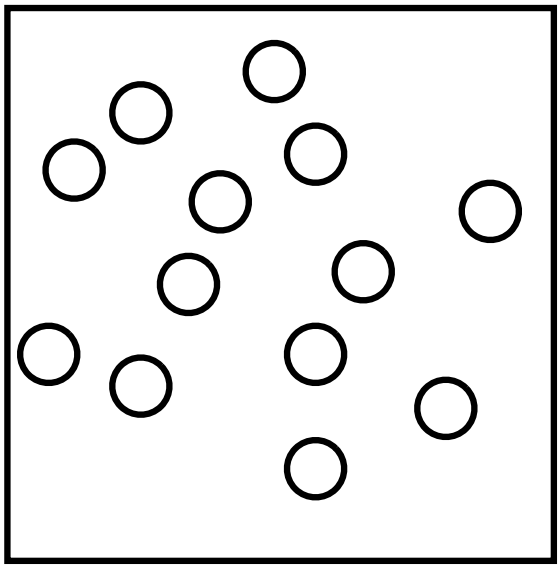
a b c d

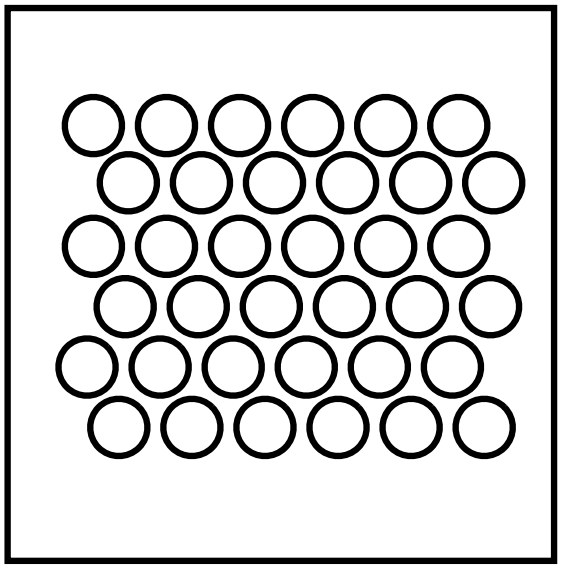
These pictures represent molecules in a liquid crystal, and each picture is a different phase. This variety of phases with different physical behaviour (especially in how light interacts with the liquid crystal) allows liquid crystals to be used to make screens for TVs and other devices (LCD).

## Activity 2: What symmetries have been broken in these pairs of pictures?









Each of these pairs of pictures can be thought of as showing two different phases, with the phase transition marked by a change of symmetry.

## Order parameter

Phases can be distinguished by an **order parameter:** a number which can be calculated from the microscopic picture of matter, which has a value of 1 in the ordered phase and 0 in the disordered phase.

For example in the first picture above, an order parameter could be defined as:

"Start with 0. For each person walking to the right add 1, for each person walking to the left subtract 1. Then divide by the number of people in the picture and, if the result is negative, remove the minus sign."

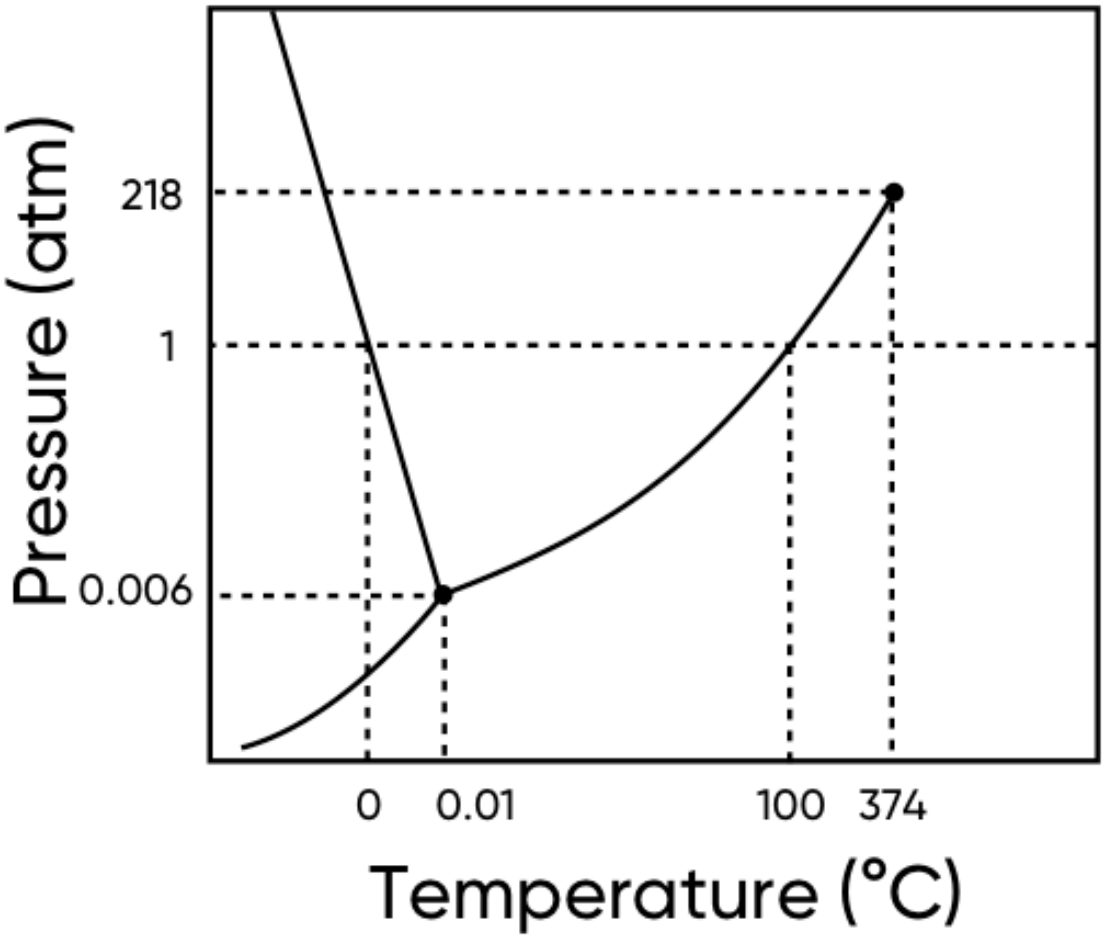
## Activity 3

Using the definition of the order parameter given above, calculate the order parameter for each picture of people crossing the road and show that there must be a phase transition between the two.

**Challenge**: can you think of how to calculate an order parameter for the Vicsek model?

## Lecture: phase diagrams and phase transitions

The figure below is the phase diagram for water. Listen carefully to the lecture and annotate the phase diagram. Take notes in the Notes section. Any important points will be emphasised.



# Tutorial 5 Notes

# Final Assignment

To conclude this course you have a choice of two final assignments.

**Either:**

- An essay (around 2000 words)

**Or**

- A poster (with at least 1000 words of text)

Your final assignment should be entitled

**"Phase transitions in active matter"**

## Success criteria

A good assignment will:

- Contain an introduction to active matter and flocking. This could be based on your first homework.
- Explain what the Vicsek model is, its rules, and the range of behaviour seen, and the relevance to real systems. Discuss any possible problems with the Vicsek model and how they may be overcome.
- Discuss the phase transition in the Vicsek model, and explain how it comes about.
- Explain what is meant by *symmetry* in physics.
- Relate the Vicsek phase transition to the solid-liquid transition (melting/freezing) and the liquid-gas transition (boiling/condensing). What is similar? What is different?
- Include a conclusion: what insight have you gained from studying the Vicsek model? Are there any questions that remain unanswered? In what direction could this project continue?
- Be appropriately referenced (see Appendix 1).
- Include relevant figures with informative labels (if appropriate) and captions, which are referenced within the text (e.g. "This may be seen in figure 2").
- Use key words learnt through the course correctly.
- Have good spelling, punctuation and grammar throughout.

The mark scheme on pages 6-7 will also help you structure your work.

Good luck!

# 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 enjoyed and what was challenging.

## Final assignment feedback

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

| My target for future work is… |
|---|
| |

# Tutorial 7 – Feedback tutorial

## What is the Purpose of Tutorial 7?

- 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 enjoyed 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? |
| --- |
| • <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 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 – Glossary (continued)

This space should be used to note key words. These will be pointed out when they come up in the tutorials.

| Word | Definition | Example/In a sentence |
|---|---|---|
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# Notes

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# Boids of a Feather

## Key Stage 4 Programme

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