Project 3

Evaluating a scientific model

Building a mass spectrometer

- Themed lesson guide for teachers
- Teacher's project guide
- Class project instructions
- Student project portfolio

This project is extracted from Analytical Chemistry in Ireland
More projects and resources available from https://rsc.li/3P00Lfl

THEMED LESSON GUIDE FOR TEACHERS

Building a mass spectrometer

Focus: evaluating a model. Two–three lesson plan

3

Task

Building and using a model of a mass spectrometer and evaluating its utility.

Background

Mass spectrometry is a key technique in almost every laboratory analysis – this is profiled in the careers and industries stories. This project seeks to introduce students to the 'scientific model' by way of a model mass spectrometer, instilling an understanding of how it works and the type of data it generates, showcasing the use of models in general. To complete the project, students must engage with the data in a manner fitting of a scientific investigation, with the focus being evaluation.

Syllabus link

On completion of the project students will be familiar with:

- use of the mass spectrometer in determining relative atomic mass;
- calculating relative atomic mass from abundances of isotopes;
- fundamental processes that occur in a mass spectrometer – vaporisation of substance, production of positive ions, acceleration, separation, detection (mathematical treatment excluded).

Learning objectives

On completion of the project students will:

- have a basic understanding of how a mass spectrometer works;
- understand the scientific method, in particular the aspects of scientific modelling;
- be able to calculate the relative atomic abundance of different isotopes from graphical data.

Pre-planning

- Ideally, students will have completed the previous projects and gained a solid understanding of the scientific method, accuracy and precision, drawing graphs and have a basic understanding of spectroscopy.
- Prepare bags with three–five different types of coins (with different weights), a total of nine–15, so enough for three trials each. Different-sized washers could be used as an alternative.

General equipment

- Ramp – door stops are ideal
- Two blocks – jenga pieces are ideal
- A hairdryer
- Metre ruler
- Coins
- Balance
- The **teacher's project guide** has a deflection graph – one needed per group (to be printed A3)

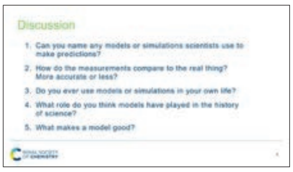
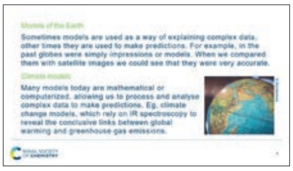
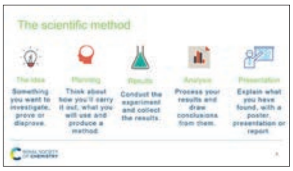
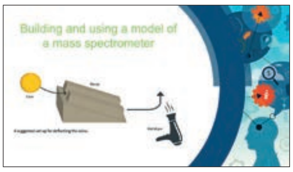
Additional resources

- For use with the suggested lesson plan PowerPoints, the **teacher's project guide**, the **class project instructions** and the **student project portfolio**.
- Visit **edu.rsc.org/resources/analysis** for information and resources for teaching about spectroscopy.
- Professional development course on scientific models and theories **rsc.org/cpd/resource/RES00001448/developing-and-using-models**

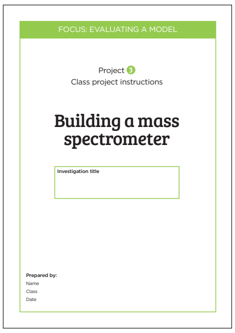
Model of mass spectrometer

This activity has been adapted from Rosie Research's *Making a Mass Spectrometer* **rosieresearch.com/making-mass-spectrometer**, which includes a video of the set-up.

BUILDING A MASS SPECTROMETER: LESSON ONE
Planning the project and carrying out the investigation

STAGE/PURPOSE	RUNNING NOTES	
Engage Get students interested in planning an investigation and how they would do it. Introduce them to some of the vocabulary.		Display slide 2 shows the question, what is the purpose of a scientific model?
		Slide 3 suggested answers: **1** Weather, climate change, particle models **2** It depends on the equipment usually and the input. **3** Video games, algorithms, weather forecasts **4** Notable ones include the solar system, the shape of the Earth **5** Robustness, reliability, track record of predictions
Real world and careers link Get students interested in how this links to their career aspirations and industry in Ireland.		Display slide 4 shows how this is relevant to the real world. An interesting article to challenge higher level students and those who want to know more about the modelling: T R Anderson, E Hawkins, P D Jones, *Endeavour*, **40**, 2016, 178. DOI: 10.1016/j.endeavour.2016.07.002.
		Display slide 5 shows a condensed personalised version of two careers stories.
Scientific method This section allows teachers to introduce key concepts for undertaking the scientific method.		Display slide 6 shows the key stages of the scientific method which students should be aware of throughout their projects, relating what they are doing to each of the key concepts.
Project instructions and investigation Students should be encouraged to play around with the equipment before deciding on a method and collecting results.		Display slide 7 **1** Put students in groups and give each group a copy of the **class project instruction** sheets. **2** Then give each student an individual blank **student project portfolio**. **3** Allow them then to plan and investigate which method they will choose.

BUILDING A MASS SPECTROMETER: LESSON TWO
Analysing and evaluating

STAGE/PURPOSE	RUNNING NOTES
Building a model This stage will allow students to explore a scientific model and also engage with the knowledge in the curriculum (how a mass spectrometer operates).	It's ideal to provide the graph paper at the start of this session, after the students have experimented with a number of different methods. → The **class project instructions** contain comprehensive help with how to collect results and conduct the analysis.  FOCUS: EVALUATING A MODEL Project 3 Class project instructions Building a mass spectrometer Investigation title Prepared by: Name Class Date
Probe The students gain first-hand understanding of how models generate results.	Students should be guided to understand that the model seeks to prove or demonstrate how coins can be separated by their variability in mass, and that deviation from these results points to a lack of robustness in methodology. This hopefully infers an understanding that models, and the results they generate, are subject to the rigorousness of the planning.
Analysis conclusion	This section allows teachers to draw attention to the difference in the model and the key concepts for undertaking of the scientific method.
Evaluation of the model Including learning the differences by focusing on what a mass spectrometer actually measures.	This involves answering some applied questions which will extend their understanding of the mass spectrometer and thus will extend their ability to evaluate.
Extension task	An extension task for this section is included in the research section at the end of the **class project instructions**. It is not part of the project as it is not required for the Leaving Certificate specification but could challenge higher lever students.

Project 3

Teacher's project guide

Building a mass spectrometer

Building and using a model of a mass spectrometer

Planning sheet

Why are you doing this investigation?

What do you want to find out?

We are investigating whether you can separate out coins based on their weight.

How?

Through the design of a method which exploits the differences in this variable (mass of the coin), by applying force which distinguishes them.

Why?

To explore the concept of a scientific model, while gaining an appreciation for the robustness of method to give accurate data.

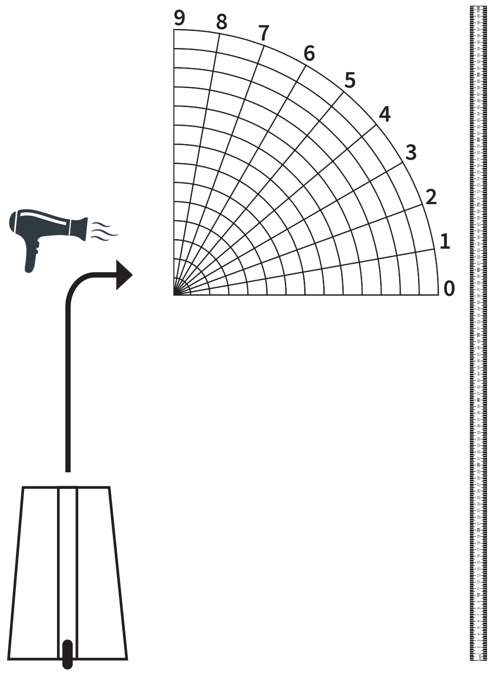
Suggested method

A suggested set-up is outlined here, and an A3 sheet of deflection angles is included. A metre ruler makes a good stopping point for the coins and provides an alternative metric for the distance travelled, and can be combined with the angle by the use of string.

However, it could be observed that more convoluted steps will confer a less robust method.

Students should be encouraged first to try and work out how to measure the deflections. Most distances and variations are acceptable, so they should be encouraged to find what generates the best results for accuracy and precision. For example, too close to the hairdryer causes the coins to be blown across the page rather than to roll.

Students could be made aware that each coin represents an isotope of the same element.



Variables

Students should be encouraged to identify their own variables and design for how they will obtain the most accurate results.

Make sure that students are aware that consistency with their execution of the method is required to get accurate results. This includes placing the hairdryer and the ramp in the same place each time, and also considering the force with which they release the coins each time.

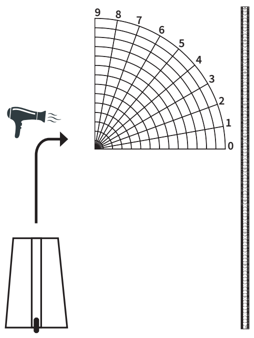
Independent – the mass of the coin

Dependent – the angle of deflection

Control – the power of the hairdryer, coin release force, height of ramp

BUILDING A MASS SPECTROMETER
Results

Raw data



Results could be collected with the angle graph or using a metre ruler to gauge relative distances.

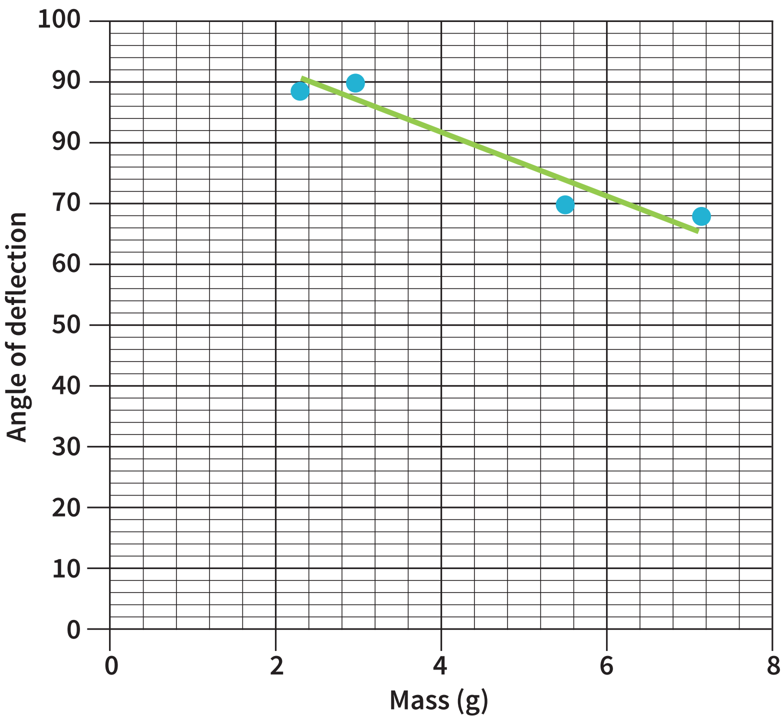
Mass (g)	Average angle of deflection
2.3	90.0
	89.0
	89.0
3	91.0
	90.5
	88.0
3.6	70.0
	69.0
	71.0
7.1	69.0
	68.0
	66.0

Averaged results table

Mass (g)	Average angle of deflection
2.3	89
3	90
5.5	70
7.1	68

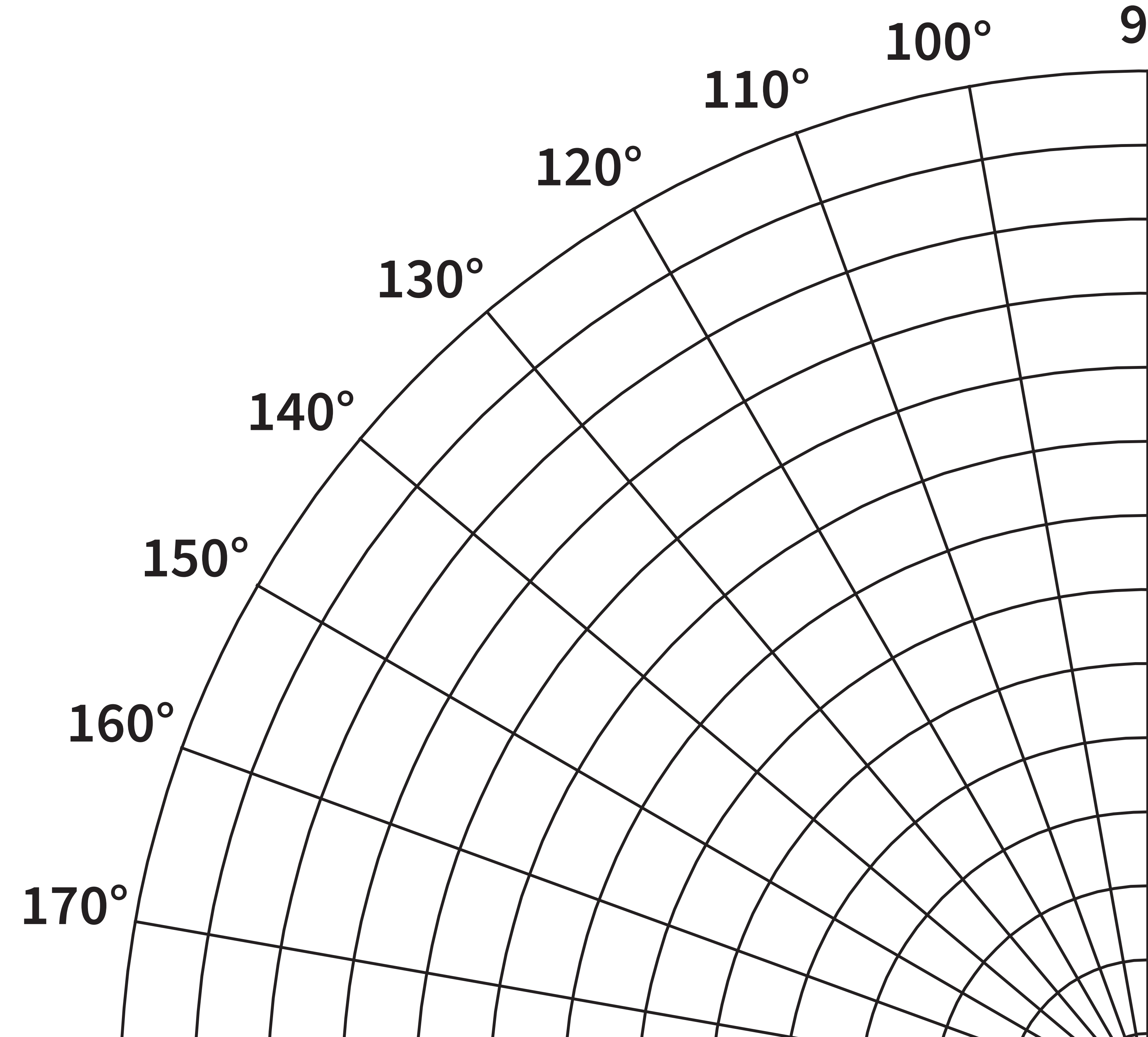
Graph

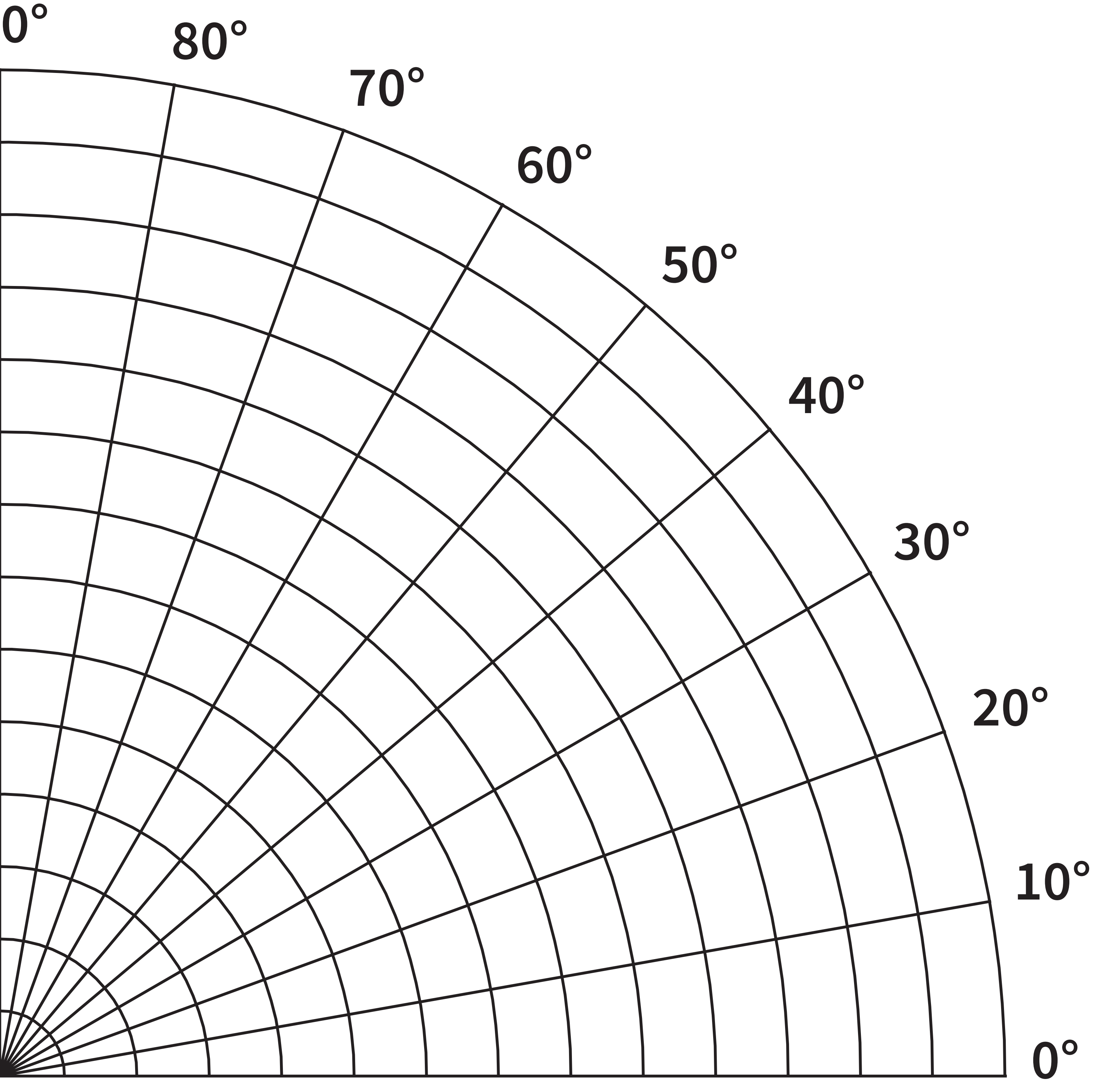
The following graph provides a representation of the results for four different coins, allowing for a more conclusive data set and hence a line of best fit to illuminate the general trend, ie that as the mass increases the angle of deflection decreases. This observation is not important for the knowledge of mass spec but serves to represent a key feature of how it works, by the deflection column.



Students should be encouraged to peer mark their graphs using the sheet in their group guide.

Deflection graph template




0°
80°
70°
60°
50°
40°
30°
20°
10°
0°

Analysis and conclusion

Graph analysis

Describe the relationship that has been established between the independent and dependent variables and link this back to the theory if possible.

Checklist for analysing the graph

1 Make a statement describing what the graph shows, or the relationship between the two variables, eg 'As the mass increases, the angle of deflection decreases.'

2 Use the results, usually two as evidence, eg 'When the mass was 2.3 the deflection was 89 degrees. When the mass was twice this size the angle of deflection was …'

HL 3 Link this to the model explaining what this model represents, eg 'These results would reflect what is to be expected, a larger mass leads to a higher degree of deflection therefore …'

3

Conclusion

How could you improve your results next time?

For example, what would you change about your method, or the day/location/the amount of time taken to get accurate results? Hint! Think about the following:

- uniform circumference of the coins
- a way to remove wind resistance

Or interestingly, what would happen if you had a greater discrepancies between the sizes of the coins?

Here we want to point out the parallels between the difficulties in obtaining significantly different deflection results and the problems scientists face with minute particles in the real-world. This is why advanced mass spectrometry techniques that measure the mass coupled with the charge (m/z ratio) are significant, they have increased sensitivity as they allow for a wider variability in the results.

Make a concluding statement linking back to your hypothesis, suggesting whether your results confirmed or denied that, eg 'My results confirm that as the mass increased the angle of deflection increased, this works the same way as in a mass spectrometer suggesting that the model was relevant or accurate as a demonstration.'

How does the model of a mass spectrometer compare to an actual instrument?

- It accelerates coins using a force (in a mass spectrometer this is an electric field, in the DIY spectrometer, there is ramp to introduce the force of gravity).
- It uses a secondary force to change the path of the sample (in a mass spectrometer this is a magnetic field where deflection changes based on the mass and charge of the ions, in the model mass spectrometer, this is a force of the hairdryer that changes based on cross-section and mass of the coin).
- It separates objects based on mass (in a mass spectrometer this can be isotopes in a carbon sample like ^{12}C and ^{14}C and in the DIY mass spectrometer this is the type of coin).

Project 3

Class project instructions

Building a mass spectrometer

Investigation title

Prepared by:

Name

Class

Date

STUDENT INSTRUCTION SHEET ONE
Building and using a model of a mass spectrometer

Background

Mass spectrometry (MS) is a very useful analytical technique that takes advantage of the mass to charge ratio (m/z) in a sample to determine its identity. The technique is about 1000 times more sensitive than infrared or nuclear magnetic resonance analysis. Extremely small samples (a few nanograms) can be analysed using MS.

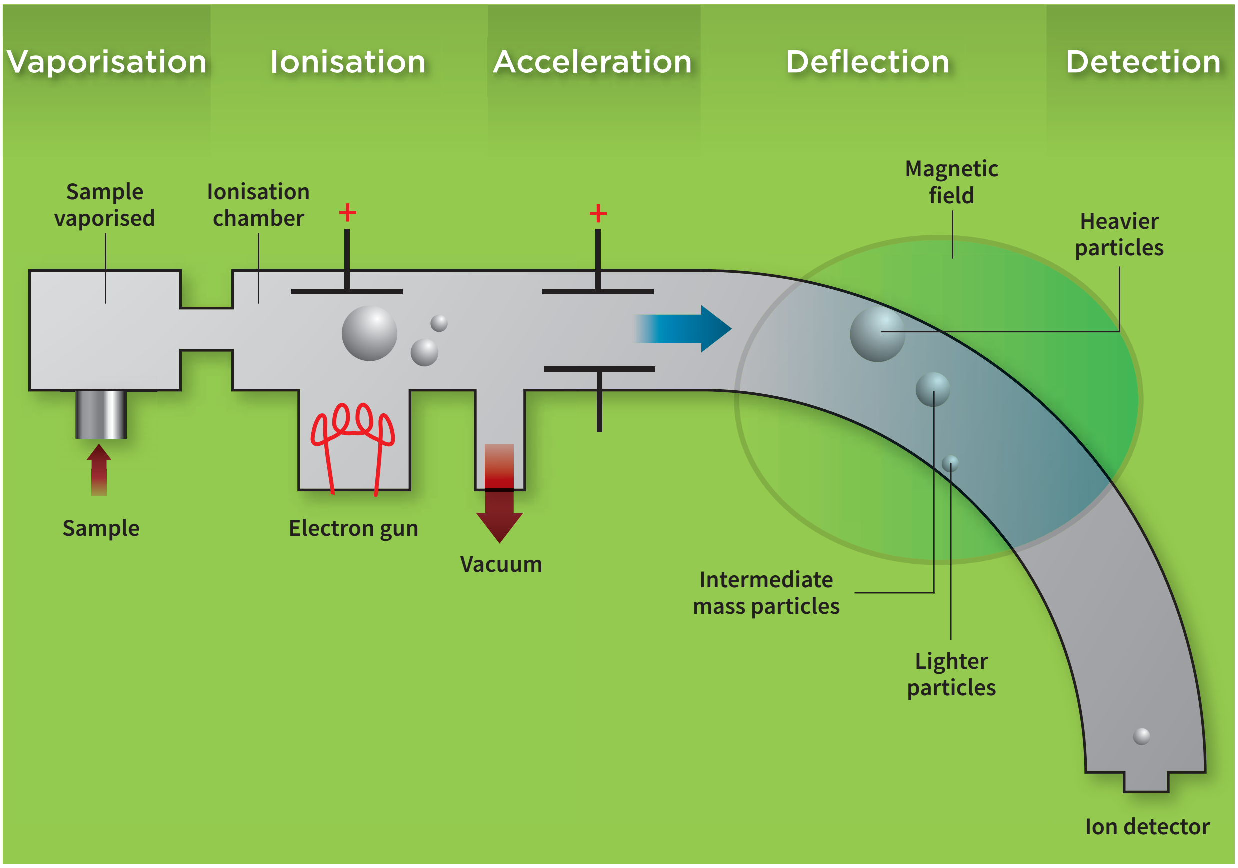


Diagram depicting the main principles of MS

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It takes the particles through the process outlined below. For more details, including an interactive simulation, follow the link **edu.rsc.org/resources/mass-spectrometry-ms/11332.article**

How it works

MS uses quite sophisticated equipment and techniques to separate samples. First they are **vaporised** and then **ionised**, which will give them a charge. Then they are **accelerated** down the chamber, which contains a magnetic field designed to influence the charge on the particles. The chamber is also quite long and curved to allow the samples to be **separated** by their mass and ability to be deflected.

Your task

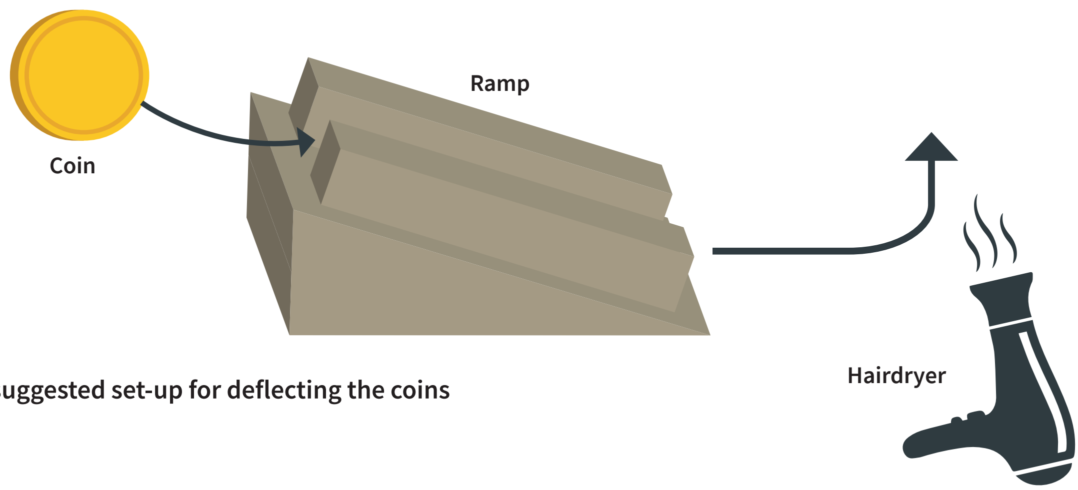
Your task is to create a model mass spectrometer, the best that you can! What will make it the best is how well it separates the bag of coins your teacher will give you.

You should design it to separate them by mass, using the same techniques as a mass spectrometer, ie some way of deflecting them and then measuring this deflection. The recommended set-up is outlined below, but you should be as creative as possible in your method.

Keep in mind that the best scientific methods are often the most robust, ie are resistant to errors, and can be completed a number of times and still generate the same results.

Your teacher will give you a bag containing at least two different types of coins.

Construct your own set-up as shown below.



A suggested set-up for deflecting the coins

Consider how your model of a mass spectrometer compares to an actual instrument.

- It accelerates the sample using a force (acceleration)
- It uses a secondary force to change the path of the sample (deflection)
- It separates objects based on mass (separation)

Think about how you could measure the deflection of the coins.

BUILDING A MASS SPECTROMETER
Planning sheet

Why are you doing this investigation?

What do you want to find out? This could be some type of hypothesis or idea you want to prove or disprove, or a way to explain a complex process.

Include any inspiration for undertaking the project, eg the work of other scientists (particularly anything from the careers stories), or things in the media that might have motivated your interest in this topic.

What do you think you might discover or find? This should link to the focus of research and analysis, and how your results will prove or disprove your hypothesis or idea.

Deciding your method

Your equipment should give you an idea of how to set up your method – try to focus on achieving the most repeatable results.

Variables

What are your project variables, including control variables?

Are there any control variables that you will not be able to control, and what impact do you think this will have on your results?

Model

For the focus of the evaluation, you should seek to make your model represent a key feature of how the mass spectrometer works, aiming for a model that does one thing well rather than many things less accurately.

3

Include a photograph or a diagram of your equipment set-up

BUILDING A MASS SPECTROMETER
Results

Models are particularly well suited to qualitative evaluations, eg how it was both like and unlike the real simulation.

Raw data

This should be a table of results you collected, without any processing. Careful! This model seeks to demonstrate something we already know to be true, and when collecting results, you should discard those trials where there was clearly a physical cause, such as the coin wobbled, or it went over a bump in the floor. If there are consistencies with this, it points to your method needing to be changed, eg the coin with a dent in it continually veered left, so this coin should be removed from the sample.

Averaged results table

You should average your trials – usually you will have about three. This means add them all together and divide by three (if you carried out three trials).

For quantitative data, analysis involves collecting numerical values, using this to carry out calculations or presenting the numerical values in a graph to establish a relationship between independent and dependent variables or to find an unknown value.

Graph

Graphs should only be drawn from averaged results.

Draw your graph by hand or on Excel and paste it in the box below.

Affix graph here

Marking criteria for the graph

- Axis drawn using a pencil and a ruler.
- Axis labelled with correct headings and includes units.
- Appropriate scale used.
- Points plotted correctly.
- Line of best fit drawn.

Analysis and evaluation

Describe the relationship that has been established between the independent and dependent variables and link this back to the theory if possible.

Checklist for analysing the graph

1 **Make a statement describing what the graph shows or the relationship between the two variables**, eg 'As × increases, y decreases because …'

2 **Use the results, usually two as evidence**, eg 'When the mass of the coin was two grams, the coin was deflected by × degrees. When the mass of the coin was four grams, the coin was deflected by 2x degrees'.

HL 3 Link this to the theory explaining why this relationship exists, state whether the hypothesis or question posed at the beginning of the investigation is correct, eg 'These results would reflect what is to be expected, a greater mass corresponds to a higher degree of deflection, therefore …'

Conclusion and evaluation

How could you improve your results next time? For example what would you change about your method to get more accurate results?

Make a concluding statement linking back to your hypothesis, suggesting if your results confirmed or denied that. Also include what you have learned from the project and any suggestions you may have for proving or disproving the method.

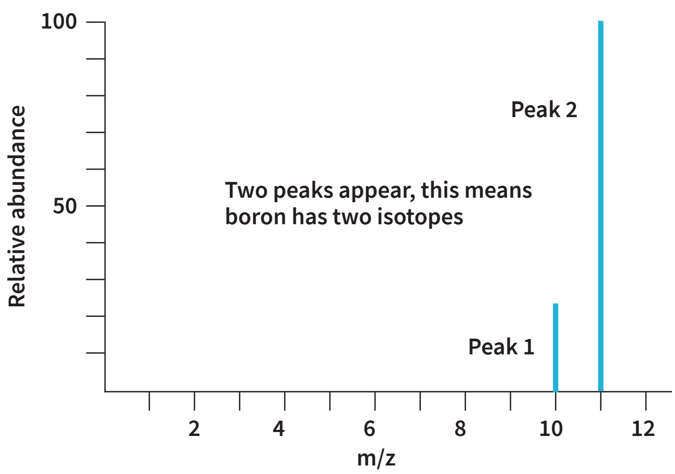
List the key ways your model differs from a real mass spectrometer. Why was a ramp used, what is this analogous to in an actual mass spectrometer? What did the hair dryer represent? Why were different sized coins used?

Research

Mass spectrometers in industry are used in a variety of ways and with a number of different techniques. In the careers stories section, you will see that they are often used to identify substances.

Luckily, you don't have to interpret these graphs but you have to be familiar with how some of the simpler ones work, such as how the relative atomic mass of an element is calculated from the relative abundance of its isotopes.

All that means is imagining back to your bag of coins – an element can exist in a number of different forms called isotopes (or coins). If you know the number of different coins and the total mass of them then you could calculate an average for a single coin that is the relative atomic mass or Ar, which is what the following graph represents.



Graph shows the mass spectrum produced for a sample of boron. See chemguide.co.uk/analysis/masspec/elements.html

Calculation

To calculate the relative atomic mass of boron (as shown on the periodic table):

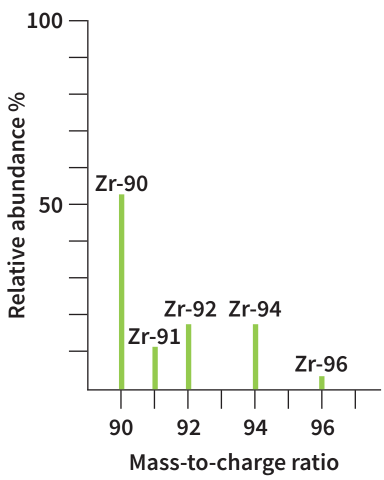
STEP ONE Take the mass to charge ratio (m/z) and multiply it by the relative abundance of the isotope. Calculate this for all isotopes detected and add together.

1 [11 (m/z) × 100 (relative abundance of isotope 1)] + [10 (m/z) × 23 (relative abundance of isotope 2) = 1330.

STEP TWO Then divide this by the total relative abundance to get the weighted average for one boron atom.

2 1330/123 (combined relative abundance of isotope 1 and 2) = 10.8

The peaks in the graph show the relative abundance of the two most common naturally occurring isotopes of boron and its Ar reflects their distribution between 10 and 11.



Challenge

The relative abundance of zirconium is shown on the left. Using this graph, calculate the relative atomic mass using % abundance.

Hint! It works the same way as mass but using percentage instead.

Graph shows mass spectrum of zirconium

FOCUS: EVALUATING A MODEL

Project 3

Student project portfolio

Building a mass spectrometer

Project title

Prepared by:

Name

Class

Date

Planning sheet

Why are you doing this investigation?

Deciding your method

Variables

Model

Include a photograph or a diagram of your equipment set-up

3

Results

Raw data

Averaged results table

Graph

Affix graph here

Marking criteria for the graph

- Axis drawn using a pencil and a ruler.
- Axis labelled with correct headings and includes units.
- An appropriate scale was used.
- Points plotted correctly.
- Line of best fit drawn.

Analysis and evaluation

Analysis

Conclusion and evaluation

Your answer for the challenge question

3