OCR A Level Physics

Your notes

Experimental Design

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Experimental Design

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Experimental Design

- Planning is an essential part of experimental physics
- **Preliminary research** can be very helpful when trying to design an experiment to investigate a particular theory or hypothesis
  - Preliminary means "to come before"
- Researching other **similar studies** or experiments can help with:
  - Posing a hypothesis and confirming the aims of the experiment
  - Choosing the appropriate apparatus
  - Using the correct techniques
  - Identifying variables
  - Controlling other variables
  - Recording and collecting data accurately
  - Processing and presenting data in a useful way
  - Identifying health and safety issues
- The **choice** of apparatus and techniques should be **based on the science** surrounding the issue being investigated
- For example, for measuring the instantaneous velocity of a trolley travelling down a ramp, it is crucial to have:
  - Light gates
  - A trolley
  - A ramp
  - A data logger
  - A metre ruler
- Once the preliminary research has been completed then **preliminary studies** can be conducted to further aid the experimental design
- These studies are very important for:

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  - Identifying additional variables that affect the experiment
  - Finding the best way to control these variables
  - For example, when using Charles' law to determine absolute zero, pressure must be kept constant
- Any experiment conducted without preliminary research or studies is likely to be invalid as the other variables that affect the results in the experiment will not have been identified and controlled

Evaluating an Experimental Method

- Evaluating experimental methods is an important skill for a scientist and is appropriate to meet the expected outcomes of the experiment
- A good way to evaluate an experimental design is by **repeating the experiment** (using the instructions provided) and determining the **reproducibility** of the experiment ie. whether or not **similar results** can be achieved
  - This process is known as **peer review**
- When analysing and criticising the design of an experiment there are several key things to look out for:
  - **Limitations**
  - **Accuracy**
  - **Precision**

Limitations

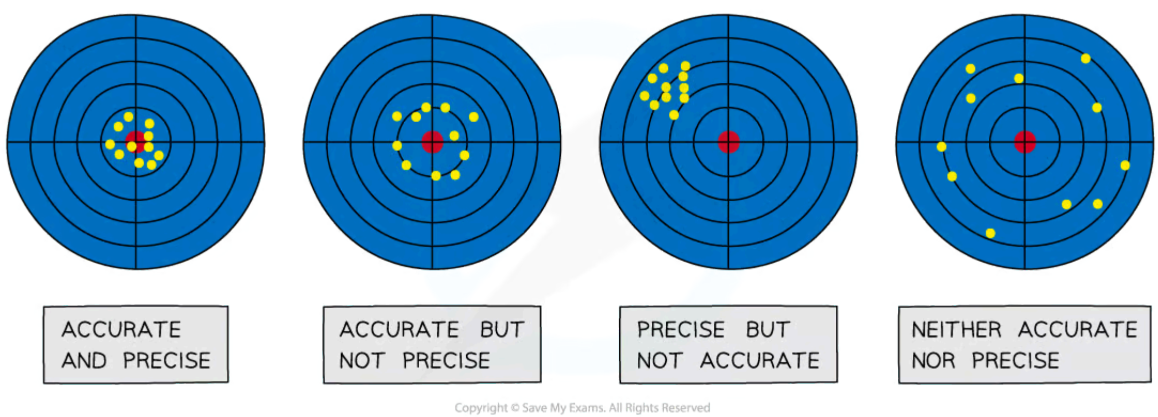
- A limitation is any **design flaw or fault** that affects the accuracy of the experiment
- It is crucial that any limitations within an experiment are **identified and removed/corrected** in order to make the results and findings valid

Accuracy

- Accuracy - how **close** a reading/measurement is to its **true value**
  - Accuracy is affected by the presence of systematic errors
- Experiments should make use of the appropriate methods and equipment to ensure high levels of accuracy when making measurements
- When using measuring equipment, such as when measuring length, equipment with an appropriate measuring scale needs to be used
  - For example, accurately measuring a 5 mm object using a metre ruler would be very difficult
  - A micrometer or vernier callipers would be a much better choice as the measuring scale is of a higher **resolution**

Precision

- Precision - how **similar repeat readings/measurements are to each other**
  - Precision is affected by the presence of random errors
- Experiments are often repeated to ensure the reliability of results
- If the apparatus and measuring equipment in an experiment are not used correctly for each repeat, then there is likely to be a wide range of results
- Individuals conducting the experiment must use the same apparatus in the same way for each repeat of the experiment
- Readings that are tightly clustered together (a small range) are described as precise



The difference between accuracy and precision explained by using a dartboard as a metaphor

- Ideally, the design of an experiment should be **evaluated at the preliminary stage**, this way any corrections or adjustments can be made prior to conducting the actual experiment

Control Variables

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Identifying Control Variables

Types of Variables

- In an experiment, a variable is any factor that could change or be changed
- There are different types of variables within an experiment
  - The **independent variable**: the only variable that should be changed throughout an experiment
  - The **controlled variables**: any other variables that may affect the results of the experiment that need to be controlled or monitored
  - The **dependent variable**: the variable that is measured to determine the outcome of an experiment (the results)
- It is essential that any variable that may affect the outcome of an experiment is controlled in order for the results to be **valid**
- Preliminary research and preliminary studies can be used to identify variables within an experiment and to determine ways of controlling these variables effectively
- The science surrounding the issue / problem being investigated is likely to contain information about different factors or variables that may exist

Identifying Control Variables: An Example – Science Surrounding Ideal Gases

- There are several experiments that can be carried out to investigate the properties of ideal gases
- Factors that can be **changed** include:
  - Temperature
  - Pressure
  - Volume
  - Number of moles of gas
- The **key** point with ideal gas experiments is to ensure that **only one** of these variables is **changed** during a particular experiment
  - This is known as the **independent** variable
- All other variables must be **controlled** (they must stay the **same**)

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- These are known as the **control** variables
- When investigating **Charles' law**:
  - The temperature is varied (**independent** variable)
  - The volume is measured (**dependent** variable)
  - The pressure and number of moles must be kept the same (**control** variables)
- When investigating **Boyle's law**
  - The pressure is varied (**independent** variable)
  - The volume is measured (**dependent** variable)
  - The temperature and number of moles must be kept the same (**control** variables)
- If these control variables are not kept constant, they could **affect the results** of the experiment
  - This would make the results **unreliable**

Refining of Experimental Design

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Refining of Experimental Design

- An important part of experimental physics is being able to identify problems in the experimental design
- Once the problems have been identified, then it is possible to suggest improvements to the procedures and apparatus
- In order to evaluate the procedure, it is important to understand that there is **uncertainty** in every measurement
  - Every instrument is limited by its **resolution**
- Uncertainties are introduced predominantly by the type of apparatus used and the way it is used resulting in
  - **Systematic errors**
  - **Random errors**

Random Error

- Random errors cause unpredictable fluctuations in an instrument's readings as a result of uncontrollable factors, such as environmental conditions
- This affects the **precision** of the measurements taken**,** causing a wider spread of results about the mean value
- To **reduce** random error:
  - **Repeat** measurements several times and calculate an average from them

Systematic Error

- Systematic errors arise from the use of faulty instruments used or from flaws in the experimental method
- This type of error is repeated consistently every time the instrument is used or the method is followed, which affects the **accuracy** of all readings obtained
- To **reduce** systematic errors:
  - Instruments should be **recalibrated**, or different instruments should be used
  - Corrections or adjustments should be made to the technique

Zero Error

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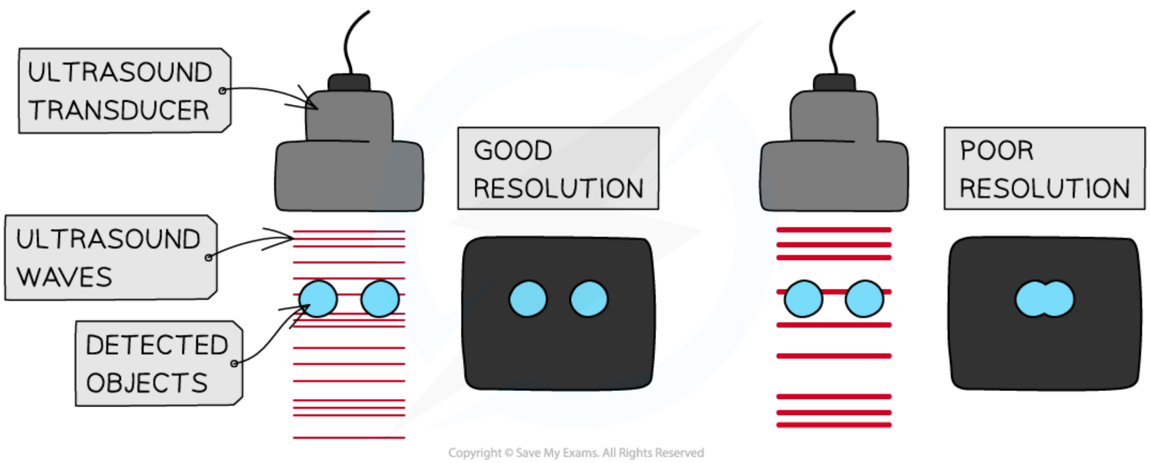
- This is a type of systematic error which occurs when an instrument gives a reading when the **true reading is zero**
- This introduces a fixed error into readings which must be accounted for when the results are recorded

Resolution

- Resolution is the smallest change in the quantity being measured of a measuring instrument that gives a perceptible change in the reading
- For example, the resolution of a wristwatch is 1 s, whereas the resolution of a digital stop-clock is typically 10 ms (0.01 s)
- In imaging, resolution can also be described as the ability to see two structures as two separate structures rather than as one fuzzy entity



Good resolution and poor resolution in an ultrasound scanner. The good image manages to resolve the two objects into two distinct structures whereas the poor image shows one fuzzy entity.

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Investigative Approaches & Methods

- Practical skills are a crucial part of science education
  - These require **investigative** approaches and methods to succeed
- Some of the key skills that demonstrate proficiency in practical work are as follows:
  - Using a range of apparatus / instruments including some ICT, such as a datalogger, an app, or a computer
  - Using apparatus / instruments with confidence and reasonable accuracy
  - Carrying out steps in a practical in the correct order
  - Recording readings whilst still observing the apparatus
  - Being able to 'fine-tune' the apparatus / technique in order to obtain a suitable range of readings
  - Appreciating the importance of independent, dependent and control variables
  - Considering factors that may affect the experiment, so need to be controlled e.g. by using a water bath; or solutions of the same concentration
  - Planning to measure a variable affecting the experiment, such as room temperature, before and after the readings are taken and noting whether it has changed

Examiner Tips and Tricks

Evidence for how you apply investigative approaches and methods to your practical work may come from written work, such as a planning exercise so make sure you keep a well organised practical workbook!Keep in mind, however, this may be ascertained in other ways such as by teachers asking you about control of variable during practical lessons

Using Practical Equipment & Materials

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Using Practical Equipment & Materials

- Choosing the right equipment and knowing how to use it for a physics experiment is crucial
- A list of common apparatus is shown below:

Apparatus	Purpose	Typical Resolution
Metre Rule	To measure the length of an object of moderate length	1 mm
Vernier Calipers	To measure short lengths	0.05 mm
Micrometer Screw Gauge	To measure small values of width, thickness, or diameter	0.001 mm
Top-pan Balance	To measure the mass of an object	0.01 g
Protractor	To measure angles	1°
Stopwatch	To measure periods of time	0.01 s
Thermometer	To measure the temperature of a body	1 °C
Voltmeter	To measure the potential difference across a component	1 mV – 0.1 V
Ammeter	To measure the electric current flowing through a component	1 mA – 0.1 A
Oscilloscope	To display waves and measure their frequencies	1 Hz
Laser	To provide a monochromatic source of light	450–650 nm

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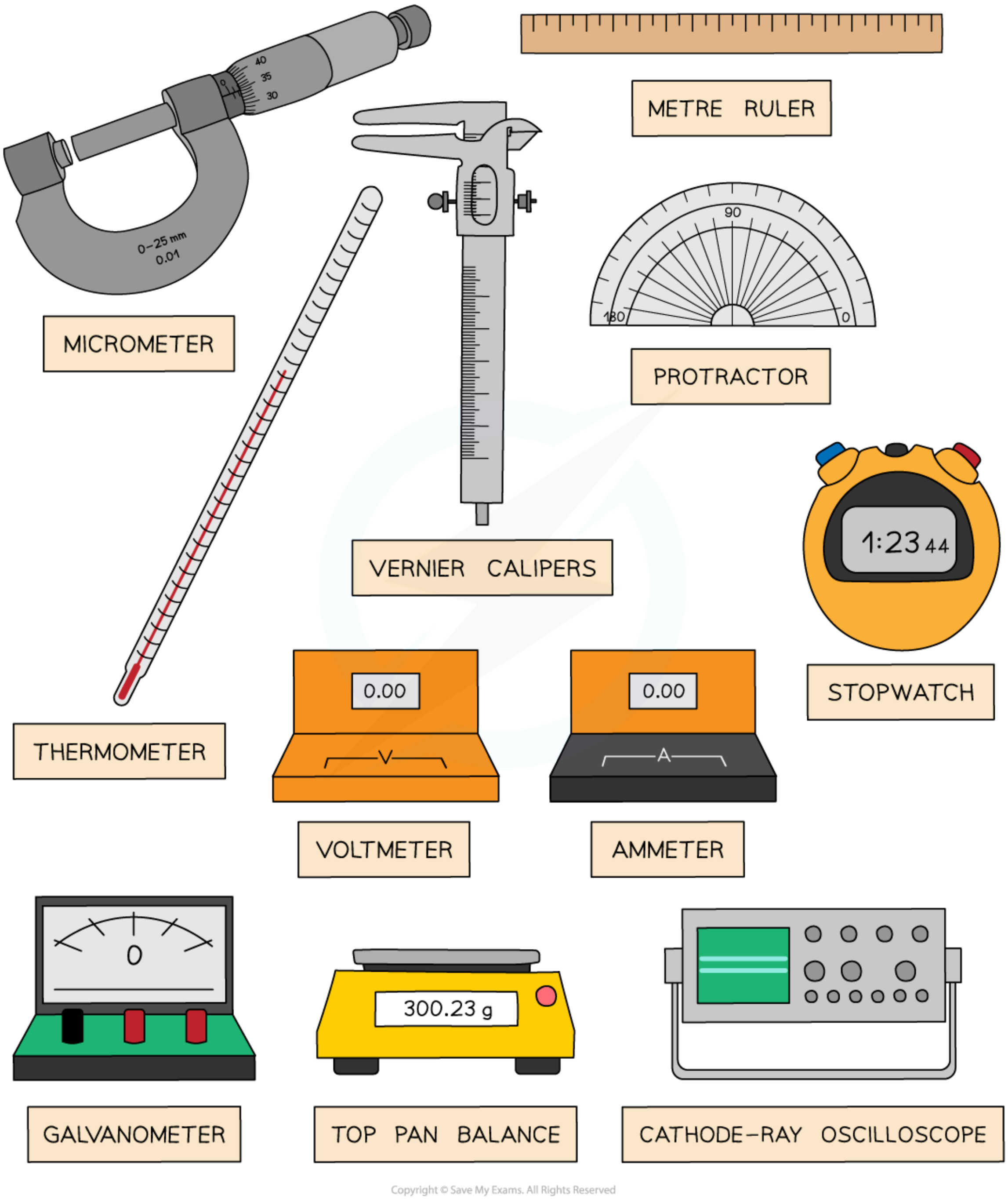

A selection of apparatus commonly used in physics experiments

- When using measuring instruments such as those listed above, it is important to be aware of what each division on a scale represents

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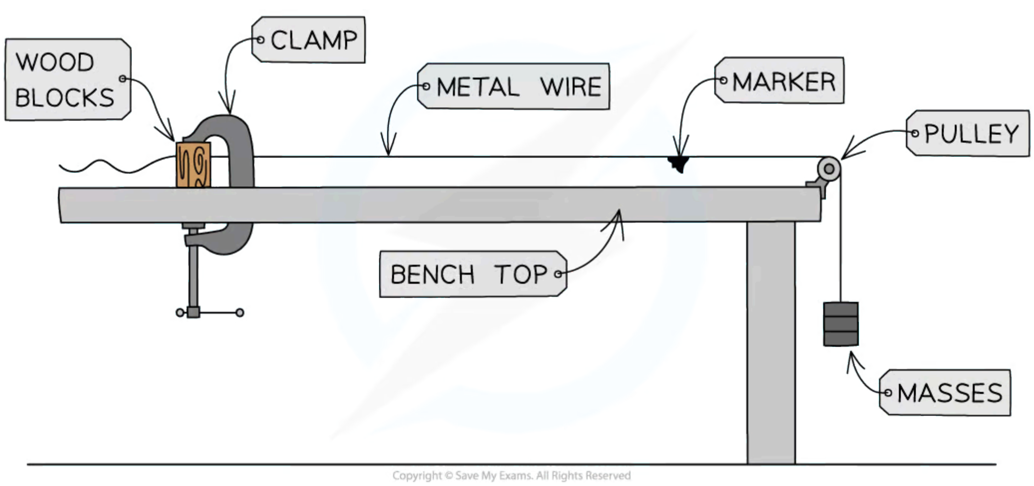
- This is known as the **resolution**
- The resolution is the **smallest** change in the physical quantity being measured that results in a change in the reading given by the measuring instrument
- The smaller the change that can be measured by the instrument, the greater the degree of resolution
- For example, a standard mercury thermometer has a resolution of 1°C whereas a typical digital thermometer will have a resolution of 0.1°C
  - The digital thermometer has a higher resolution than the mercury thermometer

Using Practical Apparatus & Techniques

- When planning and implementing a practical investigation, it is crucial to decide which apparatus is the most suitable for the intended purpose

Worked Example

The diagram below shows one possible method for determining the Young modulus of a metal in the form of a wire.



Describe how you can use this apparatus to determine the Young modulus of the metal. The sections below should be helpful when writing your answers.

- The measurements to be taken.
- The equipment used to take the measurements.
- How you would determine Young modulus from your measurements.

Answer:

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Step 1: State the necessary measurements to be taken

- The **diameter** of the wire
- The **initial length** of the wire
- The **extension** of the wire (final length – initial length)
- The **mass** of the hanging masses or the **weight** applied to the wire

Step 2: State and explain which equipment would be the most suitable

For measuring the diameter of the wire:

- A **micrometer screw gauge** or **vernier callipers**
- Micrometer would be best as this has the highest resolution when measuring small areas

For measuring the original length / extension of the wire:

- A **metre ruler** or a **tape measure**
- The wire has a moderate length which cannot be measured using a vernier scale

For measuring extension:

- **Travelling microscope**
- These are designed for measuring small changes in length

For measuring the mass:

- **Scales** or a **top-pan balance**
- A top-pan balance would be best as this has the higher resolution
- $W = mg$ equation can be used to calculate weight

For measuring the weight directly:

- A **newton-meter**
- This is useful if 'known' weights are used and to check if the quoted masses are accurate

Step 3: Explain how Young's modulus can be determined from these measurements

- Young modulus is equal to the **gradient** of a stress-strain graph (in the linear region)
- Stress is equal to:

$$\text{Tensile stress} = \frac{F}{A}$$

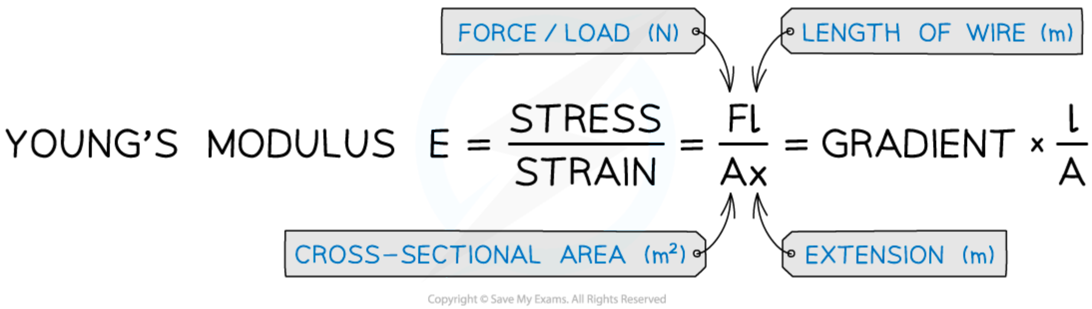
- Strain is equal to:

$$\text{Tensile strain} = \frac{\Delta L}{L}$$

Where:

- F = weight (N)
- A = cross-sectional area of wire (m^2)

- ΔL = extension (m)
- L = original length (m)
- Young's modulus for this metal is then calculated using the following equation:



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Appropriate Units for Measurements

Appropriate Units for Measurements

- It is essential that the correct scientific measurements are used when discussing experiments in physics
- Ensure that the **correct symbols** are used in conjunction with the unit of measurement
    - E.g. m^3 for cubic metres

Units of Measurement Table

Measurement	Base unit	Symbol	Units used
Length	Metre	m	$1000\ m = 1\ km$ $0.01\ m = 1\ cm$ $0.001\ m = 1\ mm$ $0.000001\ m = 1\ \mu m$
Volume	Cubic metre	m^3	$10^9\ m^3 = 1\ km^3$ $0.000001\ m^3 = 1\ cm^3$ $10^{-9}\ m^3 = 1\ mm^3$ $10^{-18}\ m^3 = 1\ \mu m^3$
Volume	Cubic decimetre	dm^3	$0.001\ dm^3 = 1\ cm^3$ $0.000001\ dm^3 = 1\ mm^3$
Area	Square metre	m^2	$10000\ m^2 = 1\ ha$ $0.0001\ m^2 = 1\ cm^2$

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Mass	Kilogram	kg	1000 kg = 1 tonne 0.001 kg = 1 g 0.000001 kg = 1 mg 10^{-9} kg = 1 μg
Time	Second	s	60 s = 1 min 60 min = 1 hour
Pressure	pascal	Pa	1000 Pa = 1 kPa
Energy	joule	J	1000 J = 1 kJ 1000000 J = 1 MJ
Temperature	degrees Celsius	°C	
Amount of substance	mole	mol	0.001 mol = 1 millimole

- Note:
  - cm^3 is the same as millilitre (ml)
  - dm^3 is the same as litre (l)