Group 4
Internal Assessment
Student Guide

Name……………………………………………

Introduction to Internal assessment

The internal assessment (IA) is worth 20% of the final IB grade in chemistry and physics. The performance in the internal assessment in SL and HL is marked against assessment criteria with a total mark of 24.
The IA is one scientific investigation taking about 10 hours of class time. It is recommended that the final report should be 6 to 12 pages long with a maximum word count of 2000 words. It should be noted that excessively long IA reports will be penalized in the communication criterion.
The entire practical programme of work will take a minimum of 40 hours for SL and 60 hours for HL. Included in this time allocation are 10 hours for the group 4 project and 10 hours for the completion of the internal assessment task as well as the prescribed practicals and other practical activities.

Internal assessment criteria

The breakdown of the five assessment criteria is as follows:

Personal engagement	Exploration	Analysis	Evaluation	Communication	Total
2 (8%)	6 (25%)	6 (25%)	6 (25%)	4 (17%)	24 (100%)

Personal engagement

This criterion assesses the extent to which the student engages with the exploration and makes it their own. Personal engagement may be recognized in different attributes and skills. These could include addressing personal interests or showing evidence of independent thinking, creativity or initiative in the designing, implementation or presentation of the investigation.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1	The evidence of personal engagement with the exploration is limited with little independent thinking, initiative or creativity. The justification given for choosing the research question and/or the topic under investigation does not demonstrate personal significance, interest or curiosity. There is little evidence of personal input and initiative in the designing, implementation or presentation of the investigation.
2	The evidence of personal engagement with the exploration is clear with significant independent thinking, initiative or creativity. The justification given for choosing the research question and/or the topic under investigation demonstrates personal significance, interest or curiosity. There is evidence of personal input and initiative in the designing, implementation or presentation of the investigation.

Tips for students:

- Your topic should have a personal significance.
- You should be able to show personal input in designing the experiment.
- The outcome of the experiment should be unknown.

Exploration

This criterion assesses the extent to which the student establishes the scientific context for the work, states a clear and focused research question and uses concepts and techniques appropriate to the Diploma Programme level. Where appropriate, this criterion also assesses awareness of safety, environmental, and ethical considerations.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	The topic of the investigation is identified and a research question of some relevance is **stated but it is not focused**. The background information provided for the investigation is **superficial** or of limited relevance and does not aid the understanding of the context of the investigation. The methodology of the investigation is only appropriate to address the research question to a very limited extent since it takes into consideration few of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of limited awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation***.
3-4	The topic of the investigation is identified and a relevant but not fully focused research question is described. The background information provided for the investigation is mainly appropriate and relevant and aids the understanding of the context of the investigation. The methodology of the investigation is mainly appropriate to address the research question but has limitations since it takes into consideration only some of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of some awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation.***
5-6	The topic of the investigation is identified and a relevant and fully focused research question is clearly described. The background information provided for the investigation is entirely appropriate and relevant and enhances the understanding of the context of the investigation. The methodology of the investigation is highly appropriate to address the research question because it takes into consideration all, or nearly all, of the significant factors that may influence the relevance, reliability and sufficiency of the collected data. The report shows evidence of full awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation**.*

Tips for students:

- The background information should describe and explain the theory related to your topic, specifically the research question.

Research question: be specific…

- How does the (change in independent variable) affect the (dependent variable)?

Variables:

- Independent variable – what will be changed (at least five changes of the independent variable)
- Dependent variable (what will be measured and how)
- Control variables (what will stay the same in each trial)
- State precisely **in the method** how you will *vary* the independent variable
- State **in the method** how you are going to measure or observe the dependent variable

Control variables	How it will be controlled in the method
Temperature of solutions	Record the temperature of the solution at regular intervals

Method for Collecting Data

- Ensure that your method enables sufficient relevant data to be collected
- Take into account that you are trying to collect precise and reliable data to be able to address your research question
- Give accurate and concise details about the apparatus and materials used
- Includes all reagents with concentrations (where applicable)

  0.100 mol dm^{-3} $NaOH_{(aq)}$

  20.0g Zn powder
- Describes details of apparatus:

  Glassware (volumetric pipette 25.00 cm^3 ± 0.04 cm^3)

  Power supplies (D.C. voltmeter, 0 to 10 V)
- Draw a detailed diagram of apparatus
- Describe a method that will allow you or another person carry out your experiment
- Indicate how many trials will be made

Analysis

This criterion assesses the extent to which the student's report provides evidence that the student has selected, recorded, processed and interpreted the data in ways that are relevant to the research question and can support a conclusion.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	The report includes insufficient relevant raw data to support a valid conclusion to the research question. Some basic data processing is carried out but is either too inaccurate or too insufficient to lead to a valid conclusion. The report shows evidence of little consideration of the impact of measurement uncertainty on the analysis. The processed data is incorrectly or insufficiently interpreted so that the conclusion is invalid or very incomplete.
3-4	The report includes relevant but incomplete quantitative and qualitative raw data that could support a simple or partially valid conclusion to the research question. Appropriate and sufficient data processing is carried out that could lead to a broadly valid conclusion but there are significant inaccuracies and inconsistencies in the processing. The report shows evidence of some consideration of the impact of measurement uncertainty on the analysis. The processed data is interpreted so that a broadly valid but incomplete or limited conclusion to the research question can be deduced.
5-6	The report includes sufficient relevant quantitative and qualitative raw data that could support a detailed and valid conclusion to the research question. Appropriate and sufficient data processing is carried out with the accuracy required to enable a conclusion to the research question to be drawn that is fully consistent with the experimental data. The report shows evidence of full and appropriate consideration of the impact of measurement uncertainty on the analysis. The processed data is correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced.

Tips for students:

- Record ALL relevant data and observations using a table
- Include quantitative data (*e.g,* measurements of temperature, mass, volume, absorbance, pressure – all with the appropriate **units**)
- Include qualitative observations before and after the experiment. (*e.g.* "the final color at the endpoint was a faint pink", "during the reaction, the bromine water changed from being bright yellow to colorless").
- Within tables of quantitative data, write the **units and uncertainty** in the column heading.
- Significant digits in the data and the uncertainty in the data must be consistent
- Use the same number of decimal places for your raw data
- Always process and show your results mathematically in some way (e.g. use averages or calculations with appropriate formula to process your results)

Trial	**Mass of X before heating (±0.01g)**	**Mass of X after heating (±0.01g)**	**Change in mass (±0.02g)**
1	1.09	1.15	0.06
2	1.08	1.16	0.08
3	1.10	1.15	0.05

Average = (0.06+0.08+0.05) ÷ 3 = 0.06g (uncertainties will be dealt with later)

- Express your calculated quantities with the proper number of significant figures
- Include descriptions of what you are calculating and why
- Plot your data in a graph (if applicable)
- Consider the uncertainties and errors in your processed data
- You need to propagate the uncertainties in percentage form
- Include headings or title for calculations, tables and graphs
- Graphs should have appropriate scales, labelled axes with units, and accurately plotted data points with a suitable best-fit line or curve (not a scatter graph with data-point to data-point connecting lines)
- Include uncertainty bars where significant
- Draw lines of minimum and maximum gradients
- Determine the uncertainty in the best straight-line gradient
- Present all the stages of your data processing so that final result can be followed easily
- Make sure that someone else could understand exactly what your data means.
- **Be especially careful with decimal places and significant figures.**

Evaluation

This criterion assesses the extent to which the student's report provides evidence of evaluation of the investigation and the results with regard to the research question and the accepted scientific context.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	A conclusion is outlined which is not relevant to the research question or is not supported by the data presented. The conclusion makes superficial comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are outlined but are restricted to an account of the practical or procedural issues faced. The student has outlined very few realistic and relevant suggestions for the improvement and extension of the investigation.
3-4	A conclusion is described which is relevant to the research question and supported by the data presented. A conclusion is described which makes some relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are described and provide evidence of some awareness of the methodological issues* involved in establishing the conclusion. The student has described some realistic and relevant suggestions for the improvement and extension of the investigation.
5-6	A detailed conclusion is described and justified which is entirely relevant to the research question and fully supported by the data presented. A conclusion is correctly described and justified through relevant comparison to the accepted scientific context. Strengths and weaknesses of the investigation, such as limitations of the data and sources of error, are discussed and provide evidence of a clear understanding of the methodological issues* involved in establishing the conclusion. The student has discussed realistic and relevant suggestions for the improvement and extension of the investigation.

Tips for students

Conclusion

- The conclusion should refer any trends in the data
- Your findings should be compared to published data
- Weaknesses in the experimental method should be identified and discussed
- Errors could be classified as random or systematic
- Improvements and extension to the investigation are suggested and discussed
- Use detailed scientific knowledge to explain a valid conclusion given the evidence available from your results.
- When measuring an already known and accepted value of a physical quantity, compare the experimental value with the textbook or literature value. Be sure to reference the literature used.
- Calculate the percentage error of your final result:

$$\%\ \text{error} = \frac{(experimental) - (theoretical)}{(theoretical)} \times 100$$

- A negative percentage error indicates that the experimental value is lower than the theoretical value.
- A positive percentage error indicates that the experimental value is higher than the theoretical value.
- Discuss whether systematic error or random errors were encountered.

Evaluation

- Identify random and systematic errors.
- State any assumptions that were made which may affect the result.
- Comment on the limitations of the method chosen.
- Identify any weaknesses and explain how significant the weaknesses are.
- Include comments about the precision and accuracy of the measurements
- Suggestions should be based on the weaknesses and limitations mentioned
- You should suggest how to reduce random error, remove systematic error and/or obtain greater control of variables.
- Suggestions should deal with issues of precision, accuracy and reproducibility of the results.
- Don’t list irrelevant suggestions – I should have concentrated more, we should have worked together as a team, we should have prepared more….

Weaknesses	**Improvements**
1. number each weakness 2.	1. relate the improvement to the numbered weakness 2.

Communication

This criterion assesses whether the investigation is presented and reported in a way that supports effective communication of the focus, process and outcomes.

Mark	Descriptor
0	The student's report does not reach a standard described by the descriptors below.
1-2	The presentation of the investigation is unclear, making it difficult to understand the focus, process and outcomes. The report is not well structured and is unclear: the necessary information on focus, process and outcomes is missing or is presented in an incoherent or disorganized way. The understanding of the focus, process and outcomes of the investigation is obscured by the presence of inappropriate or irrelevant information. There are many errors in the use of subject specific terminology and conventions.
3-4	The presentation of the investigation is clear. Any errors do not hamper understanding of the focus, process and outcomes. The report is well structured and clear: the necessary information on focus, process and outcomes is present and presented in a coherent way. The report is relevant and concise thereby facilitating a ready understanding of the focus, process and outcomes of the investigation. The use of subject specific terminology and conventions is appropriate and correct. Any errors do not hamper understanding.

Tips for students:

- Graphs should be labelled correctly
- Tables should have headings
- Sources should cited using an appropriate format
- Make sure that all measurements have units and are recorded with the correct number of significant figures or decimal places.
- Ensure that all sources (tables, figures, etc) have been referenced using an appropriate system.

*For example, incorrect/missing labelling of graphs, tables, images; use of units, decimal places. For issues of referencing and citations refer to the "Academic honesty" section.

Laboratory safety

The science laboratory and the chemicals in it are potentially extremely hazardous and safe practice and a high level of awareness of potential risks must be maintained consistently at all times. You must ensure that you understand and follow the general rules covering practical work in the science laboratories which are displayed prominently in the laboratory. Chemistry poses particular problems of safety since in addition to scientific apparatus you will come into contact with many different chemicals, some of which pose a health risk. In each practical you will find that particular safety problems have been highlighted, however it is good practice to treat all chemicals with care. Use minimum quantities in well ventilated spaces, always replace stoppers on bottles after use and clear up any spillages immediately. Look at the label on the bottle or container and make sure you are familiar with the hazard warning and safety signs, the most important of which are shown at the end of this introduction. When carrying out practical work you **must** always wear one of the aprons provided and you **must** wear safety goggles or a face mask.

General Guidelines

1. Conduct yourself in a responsible manner at all times in the laboratory.
2. Follow all written and verbal instructions carefully. If you do not understand a direction or part of a procedure, ask the instructor before proceeding.
3. Never work alone. No student may work in the laboratory without an instructor present…**EVER!**
4. When first entering a science room, do not touch any equipment, chemicals, or other materials in the laboratory area until you are instructed to do so.
5. Do not eat food, drink beverages, or chew gum in the laboratory. Do not use laboratory glassware or drawers as containers for food or beverages.
6. **Always wear your safety goggles, you will be told when you can remove them.**
7. Perform only those experiments authorized by the instructor. Never do anything in the laboratory that is not called for in the laboratory procedures or by your instructor. Carefully follow all instructions, both written and oral. Unauthorized experiments are prohibited.
8. Be prepared for your work in the laboratory. Read all procedures thoroughly before entering the laboratory. Never fool around in the laboratory. Horseplay, practical jokes, and pranks are dangerous and prohibited.
9. Observe good housekeeping practices. Work areas should be kept clean and tidy at all times. Bring only your laboratory book to the work area. Other materials (books, purses, backpacks, etc.) should be stored in the classroom, or on the side benches.
10. Keep aisles clear. Push your chair under the table when not in use.

11. Know the locations and operating procedures of the fire extinguisher. Know where the fire alarm and the exits are located.
12. Always work in a well-ventilated area. Use the fume hood when working with volatile substances or poisonous vapors. Never place your head into the fume hood.
13. Be alert and proceed with caution at all times in the laboratory. Notify the instructor immediately of any unsafe conditions you observe.
14. Dispose of all chemical waste properly. Never mix chemicals in sink drains. Sinks are to be used only for water and those solutions designated by the instructor. Solid chemicals, metals, matches, filter paper, and all other insoluble materials are to be disposed of in the proper waste containers, not in the sink. Check the label of all waste containers twice before adding your chemical waste to the container.
15. Labels and equipment instructions must be read carefully before use. Set up and use the prescribed apparatus as directed in the laboratory instructions or by your instructor.
16. Keep hands away from face, eyes, mouth and body while using chemicals or preserved specimens. Wash your hands with soap and water after performing all experiments. Clean and wipe dry all work surfaces (including the sink) and apparatus at the end of the experiment. Return all equipment clean and in working order to the proper storage area.
17. Experiments must be personally monitored at all times. Do not wander around the room, distract other students, or interfere with the laboratory experiments of others.
18. Students are **never** permitted in the science storage rooms or preparation areas unless given specific permission by their instructor.
19. Know what to do if there is a fire drill, during a laboratory period; containers must be closed, gas valves turned off, fume hoods turned off, and any electrical equipment turned off.
20. If there is an earthquake, turn off the gas immediately. Try to be under a bench that does not have chemicals on it!
21. Any time you are in the laboratory, you will wear safety goggles. There will be no exceptions to this rule! Only remove the goggles when you are instructed to do so.
22. Contact lenses should not be worn in the laboratory unless you have permission from your instructor.
23. Dress properly during a laboratory activity. Long hair must be tied back and ties should be taken off. Shoes must be worn properly.
24. Lab aprons have been provided for your use and should be worn during laboratory activities.

25. Report any accident (spill, breakage, etc.) or injury (cut, burn, etc.) to the instructor immediately, no matter how trivial it may appear.
26. If you or your lab partners are hurt, immediately yell out to get the instructor's attention.
27. If a chemical should splash in your eye(s) or on your skin, immediately flush with running water from the tap for at least **20 minutes.** Notify the instructor immediately.
28. If you are using a mercury thermometer and there is a spill, notify the instructor immediately **mercury must not be touched!**

Handling Chemicals

29. All chemicals in the laboratory are to be considered dangerous. Do not touch, taste, or smell any chemicals unless specifically instructed to do so. The proper technique for smelling chemical fumes will be demonstrated to you.
30. Check the label on chemical bottles twice before removing any of the contents. Take only as much chemical as you need. Never return unused chemicals to their original containers.
31. Never use mouth suction to fill a pipette. Use a rubber bulb or pipette pump.
32. When transferring reagents from one container to another, hold the containers away from your body.
33. Acids must be handled with extreme care. You will be shown the proper method for diluting strong acids***. Always add acid to water***, swirl or stir the solution and be careful of the heat produced, particularly with sulfuric acid.
34. Handle flammable hazardous liquids over a pan to contain spills. Never dispense flammable liquids anywhere near an open flame or source of heat.
35. Never remove chemicals or other materials from the laboratory area.
36. Take great care when transferring acids and other chemicals from one part of the laboratory to another. Hold them securely and walk carefully.
37. Carry glass tubing (or burettes), especially long pieces, in a vertical position to minimize the likelihood of breakage and injury.
38. Fill wash bottles **only** with distilled water and use only as intended, e.g., rinsing glassware and equipment, or adding water to a container.
39. When removing an electrical plug from its socket, grasp the plug, not the electrical cord. Hands must be completely dry before touching an electrical switch, plug, or outlet.
40. Examine glassware before each use. **Never** use chipped or cracked glassware. Never use dirty glassware.
41. Report damaged electrical equipment immediately. Look for things such as frayed cords, exposed wires, and loose connections. Do not use damaged electrical equipment.

42. If you do not understand how to use a piece of equipment, **ask** the instructor for help.
43. Do not immerse hot glassware in cold water; it may shatter.

Heating Substances

44. Exercise extreme caution when using a gas burner. Take care that hair, clothing and hands are a safe distance from the flame at all times. Do not put any substance into the flame unless specifically instructed to do so. Never reach over an exposed flame. Light gas (or alcohol) burners only as instructed by the teacher.
45. Never leave a lit burner unattended. Never leave anything that is being heated or is visibly reacting unattended. Always turn the burner or hot plate off when not in use.
46. You will be instructed in the proper method of heating and boiling liquids in test tubes. Do not point the open end of a test tube being heated at yourself or anyone else.
47. Heated metals and glass remain very hot for a long time. They should be set aside to cool and picked up with caution. Use tongs or heat-protective gloves if necessary.
48. Never look into a container that is being heated.
49. Do not place hot apparatus directly on the laboratory desk. Always use an insulating pad. Allow plenty of time for hot apparatus to cool before touching it.

Errors and uncertainties

Random and systematic errors

Systematic errors occur because of poor experimental design or procedure. They cannot be reduced by repeat trials. Systematic errors will cause all data to be either too high or too low.

Examples of systematic errors include:

- measuring the volume of water from the top of the meniscus rather than on the bottom which results in volumes being too high
- overshooting the volume of liquid delivered in a titration
- heat losses in an exothermic reaction
- mass balance not calibrated correctly (or any electronic equipment)
- Sticking or leaking gas syringes.
- Calibration errors in pH meters.

Random errors can be caused by readability of the measuring instrument, due to the precision limitations of the measurement device. The lead to measurable values being inconsistent when repeated measures are taken. Random errors can be reduced by having repeat trials and using precise measuring equipment (using volumetric pipettes rather than measuring cylinders).

Examples of random errors include:

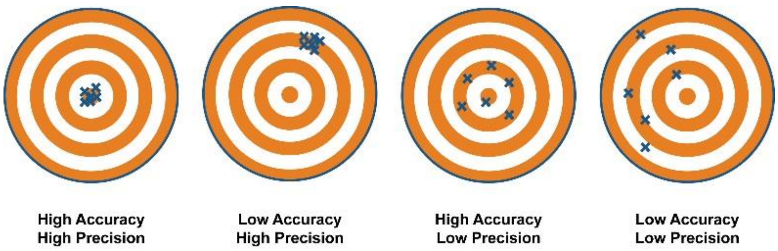
- Effects of changes in the surroundings such as temperature variations of wind currents
- Lack of data
- Using imprecise measuring equipment (such as using a beaker to measure volumes of liquids)

Accuracy and precision

The accuracy of a measurement refers to its closeness to the true value – the smaller the systematic error, the greater the accuracy.

Precision refers to how well experimental values agree with each other (how reproducible the measurement is) – the smaller the random error, the greater the precision.

These terms consider only measured or estimated data. Pure numbers like exact counts or numerically defined numbers have infinite precision and accuracy.



Significant figures

The number of **significant figures** in a numerical result is an indication of the accepted error in a number. In counting the number of significant figures the problem is the digit zero (0). There are five rules used in counting the number of significant figures in a number

1. All non-zero digits are significant,

e.g., 12.3 has three significant figures and 549 has three significant figures.

2. Zeros between non-zero digits are significant,

e.g., 1.03 has three significant figures and 4023 has four significant figures.

3. Zeros at the end of a number are significant,

For numbers with decimal points, zeros to the right of a non- zero digit are significant. E.g., 2.00 has three significant figures, but 0.050 has two (the 5 & 0 in the second and third decimal places).

4. Zeros to the left of the first non-zero digit are not significant, e.g., 0.84 has two significant figures: eight and four. The zero is termed a placeholder, meaning the zero is not part of the measurement, i.e., it is not significant.

5. Zeros at the end of a number without a decimal point are ambiguous,

e.g., 80 may have two significant figures or it may have one – the eight – with the zero being a place holder. Only the person who carried out the measurement would know. The ambiguity can be removed by reporting such numbers in scientific or standard notation. Writing 80 as 8×10^1 means that only one significant figure is present, while writing it as 8.0×10^1 means that two significant figures are present.

6. Many physical constants, have a very large number of digits, e.g., the speed of light in a vacuum, c (299 792 458 m s^{-1}) (assume infinite)

7. Mathematical constants, e.g., a number such as pi (π) has an infinite number of digits

8. Logarithms can only retain in their mantissa the same number of significant figures as there are in the number whose logarithm you are taking.

ROUNDING OFF

Sometimes it is necessary **to round off,** to give the correct number of significant figures.

1. A digit of 5 or larger rounds up.

2. A digit smaller than 5 rounds down.

- For example, rounding 13.654 to three significant figures gives 13.7 (the 4 is ignored, the 5 rounds up).
- For example, rounding 13.246 to three significant figures gives 13.2 (the 6 is ignored, the 4 rounds down).

Calculating uncertainties

During an experiment there will be a number of uncertainties which will have to be considered to give the overall uncertainty. This is known as the **propagation of uncertainties.**

Adding or subtraction measured quantities with uncertainties

When adding or subtracting values, add the absolute uncertainties	Initial temp. = 34.5 ± 0.5 °C Final Temp. = 45.2 ± 0.5 °C ΔT= 45.2 **-** 34.5 =10.7°C (± 0.5 + 0.5 = ± 0.1°C) ΔT should be reported as 10.7 ± 0.1°C

Multiplying or dividing measured quantities with uncertainties

If uncertainties are to be multiplied or divided, then percentage uncertainties have to be used (to take into account that the physical quantities will have different units). **The maximum percentage uncertainty is the sum of the percentage uncertainties for each** of the individual quantities.

When multiplying or dividing add the percentage uncertainties	Mass = 9.24 ± 0.01g Volume = 14.1 ± 0.5 cm^3
a Make calculations	Density = mass ÷ volume Density = 9.24 ÷ 14.1 = 0.655 g cm^{-3}
b Convert absolute uncertainties to percentage uncertainties (absolute ÷ measurement) x 100	Mass: (0.01 ÷ 9.24) × 100 = 0.1% Volume: (0.5 ÷ 14.1) × 100 = 4%
c Add percentage uncertainties	(0.1+ 4) = 4.1% Density = 0.655 gcm^{-3} ± 4%
d Convert total uncertainty back to absolute uncertainty	0.655 × (4/100) = 0.0262 Density = 0.655 ± 0.026 g/cm^3

Note:

Percentage uncertainites should be reported to one significant figure.

Absolute uncertainities should be reported to the same precision at the final answer.

Half range method

- Used to calculate the uncertainties when taking the average of a set of data.
- Subtract the highest value from the lowest value and then divide by 2.

Precision and Uncertainties for Common Lab Equipment

Precision is this context is the number of decimal places that the apparatus is able to measure to.

For example, a measuring cylinder can usually measure to 1 d.p, and a volumetric pipette to 2.dp. Therefore, the volumetric pipette is more precise than the measuring cylinder.

Type of equipment	Uncertainty
Electronic mass balance	±0.01g
Glass beakers	± half smallest scale division
Measuring cylinders	± half smallest scale division
50 cm^3 burette	± 0.05cm^3 (record to 2 d.p)
5 cm^3 volumetric pipette	± 0.01 cm^3
10 cm^3 volumetric pipette	± 0.02 cm^3
20 cm^3 volumetric pipette	± 0.05 cm^3
100 cm^3 volumetric flask	± 0.08 cm^3
200 cm^3 volumetric flask	± 0.1 cm^3
Alcohol thermometer	± 0.5 ^oC

Precision and Uncertainties for Vernier probes

Probe	Uncertainty

Worked example

In an experiment to measure the enthalpy change of a reaction the following measurements were made:

Trial	Initial temperature ±0.5°C	Highest temperature ±0.5°C	Change in temperature ±1°C
1	18.5	26.0	6.5
2	18.5	25.5	7.0
3	18.5	26.5	8.0

Volume of water in calorimeter = 50.0 ± 0.5 cm^3

1) Use the half range method to calculate the uncertainty of the average values:

Calculate average: $\frac{(6.5+7.0+8.0)}{3} =$ 7.2 °C

Half range method: (highest – lowest) ÷ 2

(8.0 – 6.5) ÷ 2 = 0.8 °C

Average change in temperature = 7.2 ± 0.8 °C

2) Calculate enthalpy change:

Density of water = 1 gcm^{-3}

Specific heat capacity of water = 4.18 J g^{-1} $°C^{-1}$

q=mcΔT

q = 50.00 g × 4.18 × 7.2 = 1504.8 J

The temperature change was the **least** precise measurement (two significant figures) so the final value should be quoted to this precision.

q = 1.5 × 10^3 J

3) Propagate uncertainties:

Uncertainty in temperature (already calculated) ± 0.8 °C

Convert to percentage uncertainty:

$\frac{0.8}{7.2}$ × 100 = 11 %

Uncertainty in volume of water ±0.5cm^3

Convert to percentage uncertainty:

$\frac{0.5}{50.0}$ × 100 = 1 %

Add together percentage uncertainties: (1+11) = 12 %

q = 1.5 × 10^3 J ± 12 %

Convert back to absolute uncertainty:

$\frac{12}{100}$ × 1500 = 180 J **Final answer: q = 1.5 × 10^3 ± 180 J**

Table of SI units

Quantity	Name	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	degrees Celsius	^{o}C
absolute temperature	kelvin	K
volume	cubic meter	m^3
volume	decimeter	dm^3
amount of substance	mole	mol
concentration	moles per decimeter	$moldm^{-3}$
frequency	hertz	Hz
force	newton	N
pressure	pascal	Pa
energy, work, quantity of heat	joule	J
power	watt	W
electrical resistance	ohm	Ω
luminous intensity	candela	cd
luminous flux	lumen	lm
electric charge	coulomb	C
electric potential difference / electromotive force	volt	V
capacitance	farad	F
magnetic flux	weber	Wb
magnetic flux density	telsa	T
inductance	henry	H

Conversions factors

1 m^3 = 1000 dm^3

1 dm^3 = 1000 cm^3

SI derived units

Quantity	Name	Symbol
Plane Angle	radian	rad
Solid Angle	steradian	sr

SI derived units whose names and symbols include SI derived units with special names and symbols

Quantity	Name	Symbol
Dynamic Viscosity	pascal second	Pa·s
Moment of Force	newton meter	N·m
Surface Tension	newton per meter	N/m
Heat Flux Density, Irradiance	watt per square meter	W/m^2
Heat Capacity, Entropy	joule per kelvin	J/K
Specific Heat Capacity,Specific Entropy*	joule per kilogram kelvin	J/(kg·K)
Thermal Conductivity	watt per meter kelvin	W/(m·K)
Permittivity	farad per meter	F/m
Permeability	henry per meter	H/m

*Also called weight entropy.

Units outside the SI but accepted for use with SI

Name	Symbol	Value in SI Units
Minute (Time)	min	1min=60s
Hour	h	1h=60min=3,600s
Day	d	1d=24h=86,400s
Degree	°	$1° = (\pi/180)$rad
Minute (Angle)	′	$1′ = (1/60)° = (\pi/10{,}800)$rad
Second (Angle)	″	$1″ = (1/60)′ = (\pi/648{,}000)$rad
Liter	ℓ	$1\ \ell = 1dm^3 = 10^{-3}m^3$
Ton	t	$1t = 10^3kg$

SI prefixes

Factor	Name	Symbol
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hector	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a