

IB HL & AP CHEMISTRY
Internal Assessment
STUDENT GUIDE

INTERNAL ASSESSMENT (IA)

Introduction

The Internal Assessment (IA) consists of an interdisciplinary project, a mixture of short- and long-term investigations (such as practical's and subject-specific projects). Student work is internally assessed by the teacher and externally moderated by the IBO. The performance in IA is judged against assessment criteria each consisting of achievement levels 0–3.

IA Time Allocation

Higher level students are required to spend 60 hours, on practical activities (excluding time spent writing up work). These times include 10 to 15 hours for the group 4 project. Only 2–3 hours of investigative work can be carried out after the deadline for submission of work to the moderator and still be counted in the total hours for the practical scheme of work.

Criteria and Aspects

There are five assessment criteria that are used to assess the work of both SL and HL students.



Design—D



Data collection and processing—DCP



Conclusion and evaluation—CE



Manipulative skills—MS



Personal skills—PS

The first three criteria—design (D), data collection and processing (DCP) and conclusion and evaluation (CE)—are each assessed twice. Manipulative skills (MS) are assessed summatively over the whole course and the assessment should be based on a wide range of manipulative skills. Personal skills (PS) are assessed once only and this should be during the group 4 project. Each of the assessment criteria can be separated into three **aspects** as shown in the following sections. Descriptions are provided to indicate what is expected in order to meet the requirements of a given aspect **completely (c)** and **partially (p)**. A description is also given for circumstances in which the requirements are not satisfied, **not at all (n)**. A “**complete**” is awarded 2 marks, a “**partial**” 1 mark and a “**not at all**” 0 marks. The maximum mark for each criterion is 6 (representing three “completes”).



$$D \times 2 = 12$$



$$DCP \times 2 = 12$$



$$CE \times 2 = 12$$



$$MS \times 1 = 6$$



$$PS \times 1 = 6$$

This makes a total mark out of 48.

The marks for each of the criteria are added together to determine the final mark out of 48 for the IA component. This is then scaled at IBCA to give a total out of 24%.

Laboratory Experiment Grading Rubric

Name _____ Block _____ Date: _____ Hours: _____

Title of Experiment: _____ Topic _____

Assessment Criteria to be Graded			
MS	DCP	CE	D
X			

Manipulative Skills				
	Complete/2	Partial/1	Not at all/0	Earned
Following instructions	Follows instructions accurately, adapting to new circumstances (seeking assistance when required).	Follows instructions but requires assistance.	Rarely follows instructions or requires constant supervision.	
Carrying out techniques	Competent and methodical in the use of a range of techniques and equipment.	Usually competent and methodical in the use of a range of techniques and equipment.	Rarely competent and methodical in the use of a range of techniques and equipment.	
Working safely	Pays attention to safety issues.	Usually pays attention to safety issues.	Rarely pays attention to safety issues.	
Suggested Improvements				

Data Collection and Processing				
	Complete/2	Partial/1	Not at all/0	Earned
Recording raw data	Records appropriate quantitative and associated qualitative raw data, including units and uncertainties where relevant.	Records appropriate quantitative and associated qualitative raw data, but with some mistakes or omissions.	Does not record any appropriate quantitative raw data or raw data is incomprehensible.	
Processing raw data	Processes the quantitative raw data correctly.	Processes quantitative raw data, but with some mistakes and/or omissions.	No processing of quantitative raw data is carried out or major mistakes are made in processing.	
Presenting processed data	Presents processed data appropriately and, where relevant, includes errors and uncertainties.	Presents processed data appropriately, but with some mistakes and/or omissions.	Presents processed data inappropriately or incomprehensibly.	
Suggested Improvements				

Conclusion and Evaluation				
	Complete/2	Partial/1	Not at all/0	Earned
Concluding	States a conclusion, with justification, based on a reasonable interpretation of the data.	States a conclusion based on a reasonable interpretation of the data.	States no conclusion or the conclusion is based on an unreasonable interpretation of the data.	
Evaluating procedure(s)	Evaluates weaknesses and limitations.	Identifies some weaknesses and limitations, but the evaluation is weak or missing.	Identifies irrelevant weaknesses and limitations.	
Improving the investigation	Suggests realistic improvements in respect of identified weaknesses and limitations.	Suggests only superficial improvements.	Suggests unrealistic improvements.	
Suggested Improvements				

Design				
	Complete/2	Partial/1	Not at all/0	Earned
Defining the problem and selecting variables	Formulates a focused problem/research question and identifies the relevant variables.	Formulates a problem/research question that is incomplete or identifies only some relevant variables.	Does not identify a problem/research question and does not identify any relevant variables.	
Controlling variables	Designs a method for the effective control of the variables.	Designs a method that makes some attempt to control the variables.	Designs a method that does not control the variables.	
Developing a method for collection of data	Develops a method that allows for the collection of sufficient relevant data.	Develops a method that allows for the collection of insufficient relevant data.	Develops a method that does not allow for any relevant data to be collected.	
Suggested Improvements				

$$\frac{\text{earned points}}{\text{total possible points}} \times 20 = \text{points} = \underline{\hspace{2cm}} \text{ assessment criteria points}$$

Neat and Correct Format = 5 points	
Laboratory Notes = 5 points	
Data Collection & Processing = 10 points	
Conclusion and Evaluation = 10 points	
Assessment Criteria = 20 points	
TOTAL	

Typed Laboratory Report Format

Typed Report essentials

(Top-left)

- Name
- Topic

(Top-right)

- Date(month/ day/ year)
- Number of Hours

(

Title

- Center on line after heading
- Descriptive and original

I. Introduction

- Research Question / Problem statement
- Hypothesis
- Variables

II. Procedures & Materials

- Materials/ Apparatus
- Procedure
- Diagram of set-up

III. Data Collection and Presentation

- Observations
- Data Table

IV. Data Processing and Presentation

- Calculations
- Graphs
- Diagrams

V. Conclusion and Evaluation

- Conclusion
- Compare results to the literature
- Evaluation of procedure
- Weaknesses and realistic suggestion to improve experiment

Jane Smith Stoichiometry	February 2, 2008 2 hours
HYDRATES	
I. Introduction	
II. Procedure and Materials	
III. Data Collection	
IV. Data Processing:	
V. Conclusion and Evaluation:	

Title the sections I through V in your report.

DATA COLLECTION

Aspects	Comments
<p><i>Records appropriate raw data (qualitative and/or quantitative), including units and uncertainties where necessary.</i></p>	<ul style="list-style-type: none"> • Record ALL relevant data and observations • Include quantitative data (<i>e.g.</i>, measurements of temperature, mass, volume, absorbance, pressure – all with the appropriate units) • Include qualitative observations (<i>e.g.</i> “the final color at the endpoint was a faint pink”, “during the reaction, the bromine water changed from being a bright yellow to solution of no color”). • Report any changes in procedure or unusual conditions. • All data recorded should be to the greatest possible number of significant figures that the accuracy of the equipment allows. • Consider uncertainties and errors in your measurements and deal with it properly (<i>See Appendix A</i>)
<p><i>Presents raw data clearly, allowing for easy interpretation</i></p>	<ul style="list-style-type: none"> • Make sure that someone else could understand exactly what your data means. • Do not include deductions/ interpretations/inferences, although you may find it easier to present deductions and interpretations alongside the observations. • Your presentation should be methodical and logical. • All tables and graphs should be clearly identified and labeled.

DATA PROCESSING AND PRESENTATION

Aspects	Comments
<i>Processes the data correctly</i>	<ul style="list-style-type: none"> • Always process and show your results mathematically in some way (e.g. use averages or calculations with appropriate formula to process your results) • Include analysis of any errors (<i>See Notes on Appendix A</i>) which have been stated in your data collection. • Convert tabulated data into a graphical form. • Convert drawings into diagrams
<i>Presents processed data appropriately, helping interpretation and, where relevant, takes into account errors and uncertainties</i>	<ul style="list-style-type: none"> • Quality of layout should be orderly and easy to follow • Use of proper scientific conventions in tables, graphs, etc • Label appropriate bar charts, histograms, pie charts or line graphs (using lines of best fit whenever relevant).

TIPS AND SUGGESTIONS FOR WRITING UP DATA COLLECTION AND PROCESSING

- **The integrity of raw data is important from a scientific standpoint and from an ethical standpoint! You must follow these procedures when recording data:**
 - Raw data and observations will always be recorded in a bound laboratory notebook.
 - Data will be recorded in blue or black ink, not pencil. Errors can be lined out.
 - Your instructor may require you to obtain his initials on your data sheets prior to leaving the lab.
- **Your lab report must be accompanied by the original hand-written data sheets that you recorded in your laboratory notebook when it is turned in to be graded.**

DATA COLLECTION

- There are two aspects to Data Collection. You must collect and record raw data accurately. But equally important—you must present the raw data so the reader can easily interpret it. This means it must be organized and legible.
- The best way to collect and present data is by using Data Tables. If Data Collection is being assessed in a lab activity, your teacher will normally require you to make a data table before you begin the lab. You might use one Table, or more than one.
- Give an identifying title to each Data Table.
- Qualitative observations are just as important as quantitative measurements! Make sure you take note of and record the physical characteristics of substances or solutions involved in the reactions, their color changes, the evolution of a gas, whether something got hot or cold, etc. Organize these qualitative observations in a separate Data Table
- A measurement without units is meaningless! Make sure you include them: g, cm, mL, kPa, etc. If you show the units in a column heading of a Data Table, you do not have to write them again after each number in the table.
- All measurements have uncertainties and you must indicate them in your Data Tables. **This is best done by paying attention to significant digits, and by using the “plus-or-minus” (+/-) notation.** Examples:
 - Mass of a penny on a centigram balance: 3.12 g (+/- 0.01 g)

- Temperature using a typical lab thermometer: 25.5 °C (+/- 0.2 °C)
- Just as for units, in a column of data you can show the uncertainty in the column heading and then you don't have to keep re-writing it for every measurement in the table.
- The precision (+ or -) of common laboratory equipment is shown in a table near the back of this handbook.

DATA PROCESSING:

This is the part of the report in which you take your raw data and transform it into results that answer (hopefully!) your research question. Here you will show the calculations that give you a numerical result. Or it may involve making a graph of some type to show a trend or a relationship. It might involve both of these. But just as in Data Collection, there are two important aspects: processing the data correctly, and also presenting the processed data effectively and legibly so the reader can clearly see the results.

Calculations of Results

- You will often have to show calculations. Use plenty of room; make sure they are clear and legible.
- To make your calculations easy to follow, precede each calculation with a phrase that states what you are doing. (For example: "Calculate the molarity of the solution:", then show the actual calculation). Show the units and the formulas of substances in all calculations.
- Pay attention to significant digits! Don't lose accuracy by carelessly rounding off.
- Identical, repetitive calculations do not have to be repeated. Show one sample calculation (labeling it as such) and then you don't have to repeat it for all the trials but only show the results obtained.
- When calculating an average value from repeated trials, don't average the raw data. Instead, calculate a result from each trial. Then average the end results from each trial to get your final experimental average.

Experimental Errors and Uncertainties

- When the objective of the lab is to obtain a numerical result, you must also compare your experimental result with the literature value and determine the percent error. You then must analyze whether the error is due to random error alone, or whether systematic error in your experiment was also present. This process is called error analysis.

PRESENTATION OF RESULTS CRITERIA:

- Easy to follow and understand
- Comprehensive
- Appropriate to the nature of the results.
- Consider summarizing results in a table.
- Graph may be useful, especially for several values of continuous variables.
 - ❖ Show title and axes, using standard notation
 - ❖ Use an appropriate size (larger rather than smaller)
 - ❖ Use an appropriate scale (the origin may not need to be included)
 - ❖ Indicate points clearly
 - ❖ Show relationship by fitting points to line or smooth curve
 - ❖ Line graphs may show the degree of uncertainty in plotted points by using error bars.

Presentation of Results

- There are many ways to present and display results. Tables and line graphs are used very often in science. But in some situations, other techniques might also be good. Consider the use of bar charts, pie graphs, or histograms.
- Graphs must be done on graph paper—either hand-drawn or done with computer assistance. In all cases, the axes of graphs must be clearly labeled with the variable and the units used. Additionally, each graph must have a title that states what the graph depicts. (Examples: Rate of reaction vs. Concentration of Reactant; Pressure vs. Volume of Carbon Dioxide).

Your teacher will give you further instructions on graphing techniques.

CONCLUSION and EVALUATION

Aspects	Comments
<i>Gives a valid conclusion based on the correct interpretation of the results, with an explanation where appropriate, compares results with literature values</i>	<ul style="list-style-type: none">• This is where you draw conclusions about the experiment as it relates to your aim and hypothesis• Use detailed scientific knowledge to explain a valid conclusion given the evidence available from your results.• Compare your results with information from books or other sources and indicate the reference• Try to identify trends or patterns in the results to backup your conclusion.• Explain how your results support or don't support your original hypothesis if appropriate.• Calculate percentage error (See Appendix A)
<i>Evaluates procedure(s) and results including limitations and errors</i>	<ul style="list-style-type: none">• Explain how the equipment might you used and/or the school environments have limited the accuracy of your results.• State how the weaknesses in your method might have contributed to incorrect results.• Clearly state if the systematic errors are larger or smaller than the random errors and if the experimental result is within the random errors range. (See Appendix A)• Identify all the main systematic errors and if possible give some evidence for them. (Do not give trivial errors as this indicates that you are not evaluating the procedure).
<i>Identifies weaknesses and states realistic suggestions to improve the investigation</i>	<ul style="list-style-type: none">• Include improvements could you make to your plan to overcome the weaknesses you have identified• State what further investigations would you suggest to test your conclusions or even extend the inquiry

TIPS AND SUGGESTIONS FOR WRITING THE CONCLUSIONS/EVALUATION

Conclusions

You will draw a conclusion from your results, and state whether or not your conclusions support your hypothesis. Your conclusion(s) should be clearly related to the research question and the purpose of the experiment. Interpret your results. You must also provide a brief explanation as to how you came to this conclusion from your results. (In other words, sum up the evidence) Describe and explain the theory behind calculations that were performed on the data.

If a numerical value or result is the object of the lab, you must compare it with the literature value and if possible, calculate a percent error.

- Draw conclusions from your results; don't just restate results.
- Use actual data (e.g. chemical formula, name of unknown, etc.) from your experiment to defend your conclusion.
- Conclusions should be clearly related to the research question and purpose of lab.
- Explain how your conclusions follow from the results.
- Compare with literature or accepted value or reasonable value where possible.
- Calculate percent error where comparison is possible

Limitations to Conclusions

- Considering how large is the errors or uncertainties in your results, how confident are you in the results? Are they fairly conclusive, or are other interpretations/results possible?
- Effect of Error
 - Was your value too low? What errors contributed to making it low?
 - Was your value too high? What errors contributed to making it too high?
 - Which error, of those listed, was the most significant?
 - Are your results reliable, given the errors listed? Justify this.
 - Estimate the magnitude of errors if possible

Limitations of the Experimental Procedure

- Identify and discuss significant errors and limitations that could have affected the outcome of your experiment. Were there important variables that were not controlled? Were there flaws in the procedure you chose which could affect the results? Are measurements and observations reliable? Is precision unknown because of lack of repeated trials?
- Your emphasis in this section should be on systematic errors, not the random errors that always occur in reading instruments and taking measurements. You must identify the source of error and if possible, state how it probably affected your results.

Acceptable Example: "Because the simple calorimeter we used was made from a tin can, some heat was lost to the surroundings—metals conduct heat well. Therefore, the value we obtained for the heat gained by the water in the calorimeter was lower than it should have been."

Unacceptable Examples: "The test tubes weren't clean" "Human Error"

Limitations of procedures

- Are there flaws in the procedures which could affect the results?
- Are important variables not controlled?
- Are measurements and observations reliable?
- Is precision unknown because of lack of replication?
- Analyze possible sources of error
- Distinguish systematic and random error
- Main emphasis should be on possible systematic errors
- Indicate the direction and magnitude of the effects on the final result

- Compare direction and magnitude of possible errors with the observed error.
- Sources of error such as “spills” should have been noted in observations.

Limitations of conclusions

- Are tests conclusive? Are other interpretations possible?
- Take account of magnitudes of errors and uncertainties in considering the reliabilities and limitations of conclusions.

Suggestions for Improvement

Suggest improvements or fixes for the weaknesses you identified in the previous section. These suggestions should be realistic, keeping in mind the type of equipment normally found in high school or college general chemistry labs. Suggestions should focus on specific pieces of equipment or techniques you used. (Vague comments such as “We should have worked more carefully” or “I should have been given a better calorimeter” won't cut it! For identified weaknesses, suggest improvements

- Suggestions should be realistic, not involving unavailable equipment...
- Suggestions should be specific (not “more careful work”)
- Proposed changes may do any or all of the following
- Eliminate or reduce errors
- Improve control of variables
- Reduce approximations
- Provide other procedures for better measurements.
- State if modifications are unnecessary or impossible (standard procedures used...)

DESIGN:

Aspects	Comments
Formulates a focused problem/research question and identifies the relevant variables.	<ul style="list-style-type: none"> • Expect an open-ended problem from the teacher • Use the title "research question" • Do not just repeat the teacher's title • Indicate what specific aspect of the general problem you will be investigating
	<ul style="list-style-type: none"> • Hypothesis is a testable statement that predicts the relationship of the independent and dependent variables. • It should be specific and detailed using scientific knowledge. • This should be quantitative if you're hypothesis calls for it. (<i>For higher level, you may be expected to go into quantitative details</i>) • Usually in the form "if y is done, then z will occur" • It should be as long as is needed.
Designs a method for the effective control of the variables.	<ul style="list-style-type: none"> • Independent variable- is the variable <u>that you change</u> • Dependent variable- is the variable that responds to what you have already changed • Controlled variables- are the variables that remain the same, the things that you fix in order to maintain a fair test.

Example

Poor hypothesis: The concentration of reactant will affect the rate of reaction

Better hypothesis: If the concentration of the reactant, HCl (aq) is doubled from 0.5 M to 1.0 M, then the rate of pressure increase in an Erlenmeyer Flask containing the reaction mixture HCl (aq) and CaCO₃ (s), will also double.

Example

Poor research question: What factors affect rates of reaction?

Better research question: Are heterogeneous catalysts as effective as homogeneous catalysts in the decomposition of 6 % hydrogen peroxide?

DESIGN

Aspects	Comments
Controlling variables Develops a method that allows for the collection of sufficient relevant data.	<ul style="list-style-type: none">• Include a comprehensive list of everything that you use- apparatus, chemicals, reagents etc.• Your list must include units, uncertainty, sizes and accurate concentrations• Draw a detailed diagram of any setup
	<ul style="list-style-type: none">• Write the details of a procedure in chronological order – number list or paragraph form.• State precisely how you will <u>vary</u> the independent variable• State how you are going to measure or observe the dependent variable• Indicate how many replicates will be made.• It is also important to outline why one approach is taken versus another, if appropriate
	<ul style="list-style-type: none">• State clearly and exactly what you will do so that any other student could follow your plan• State what number and range of measurements you will use• Include how many different and suitable readings you need• Take into account the fact that you are trying to collect precise and reliable data

Treatment of Error and Uncertainty in Chemistry Measurements / How to do Error Analysis—a self-teaching guide

1. In science, we are always seeking to better understand the world around us. We do this by designing and carrying out experiments according to the scientific method. And in these experiments, we are often concerned with measuring something—coming up with a numerical value for some property or behavior we observe. Eventually, if we can interpret and make sense of all these measurements, we might propose a scientific law that allows us to predict the values in future cases without actually having to conduct the experiment each time.

2. But it takes work and effort, often trial and error, to design good experiments. And even in a well-designed experiment, it is impossible to make absolutely perfect measurements. There are **two types of error or uncertainty** that will always limit the precision and the accuracy of our results. The two types are called **random error** and **systematic error**.

1. Random errors

- related in taking measurements on imperfect tools (balances, cylinders, etc)
- can be estimated and the degree of error can be calculated.
- are related to insufficiently controlled variations in experimental conditions
- Affect precision, but not accuracy
- Cannot be eliminated

2. Systematic error

- Usually are related to improper experimental design or adjustment of experimental apparatus.
- Sometime related to a particular method.
- These errors systematically distort the observations.
- do not affect precision, and can, in theory, be eliminated.

Examples:

- Sticking or leaking gas syringes.
- Calibration errors in pH meters.
- Stop clock running low.
- Changes in external influences such as temperature and atmospheric pressure affect the measurement of gas volumes, etc.
- Personal errors such as reading scales incorrectly.
- Unaccounted heat loss.
- Liquids evaporating.

USING 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 ($299\,792\,458\text{ m s}^{-1}$). (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).

WORKED EXAMPLE

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

$$\text{mass of water} = 58.000 \pm 0.0005 \text{ g}$$

$$\text{temperature change of water} = 12.5 \pm 0.05^\circ\text{C}$$

Heat released = mass of water \times specific heat capacity of water \times change in temperature

$$= 58.000 \text{ g} \times 4.184 \text{ J g}^{-1}\text{C}^{-1} \times 12.5^\circ\text{C} = 3033.4 \text{ J}$$

The temperature change was the **least** precise measurement (three significant figures) so the result cannot be expressed as having more than three significant figures. Therefore the answer is 3030 J or, better still, $3.03 \times 10^3 \text{ J}$ and **not** 3033.4 J.

It is unacceptable to report values with more significant figures than indicated by the associated uncertainty. For example, in $8.37 \pm 0.2 \text{ cm}$ the seven has no meaning and the length should be reported as $8.3 \pm 0.2 \text{ cm}$.

TREATMENT OF UNCERTAINTIES IN CALCULATIONS

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**.

1. ADDING OR SUBTRACTING MEASURED QUANTITIES WITH ASSOCIATED UNCERTAINTIES

The maximum absolute uncertainty is the sum of the individual uncertainties

Dealing with uncertainties when one value is being subtracted from another

WORKED EXAMPLE

If the values of two temperatures are $36.3 \pm 0.1^\circ\text{C}$ and $56.3 \pm 0.1^\circ\text{C}$, find the difference.

We first subtract the nominal values ($56.3 - 36.3$) = 20.0°C .

Then, the absolute uncertainties are 0.1 and 0.1, so we add these, $(0.1 + 0.1) = 0.2$.

The final answer is $20.0 \pm 0.2^\circ\text{C}$.

Dealing with uncertainties when one value is being added to another

WORKED EXAMPLE

If the values of two temperatures are $36.3 \pm 0.1^\circ\text{C}$ and $56.3 \pm 0.3^\circ\text{C}$, find the sum.

We first add the nominal values ($56.3 + 36.3$) = 92.6°C .

The absolute uncertainties are 0.3 and 0.1, so we add these, $0.3 + 0.1 = 0.4$.

The final answer is $92.6 \pm 0.4^\circ\text{C}$.

The rule for both examples above is to add absolute uncertainties.

2. MULTIPLYING OR DIVIDING MEASURED QUANTITIES WITH ASSOCIATED 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.**

WORKED EXAMPLE

If we want to calculate the power developed during an energy change of 44.01 ± 0.05 J, and the time over which it occurred, namely 2.10 ± 0.05 s, we :

1. take each of the uncertainties,
2. divide it by the given value, and then,
3. multiply by 100 to obtain a percentage.

In this case, for 44.01 ± 0.05 J we have: $\frac{0.05}{44.01} \times 100 = 0.11\%$

For 2.10 ± 0.05 s we have: $\frac{0.05}{2.10} \times 100 = 2.38\%$

The two percentage uncertainties are then added: $(0.11\% + 2.38\%) = 2.49\%$

So, $\frac{(44.01 \pm 0.05) \text{ J}}{(2.10 \pm 0.05) \text{ s}} = \frac{44.01}{2.10} \pm 2.49\% = 20.96 \text{ J s}^{-1} \pm 2.49$

Now, we determine 2.49% of 20.96: $20.96 \times \frac{2.49}{100} = 0.52$

So, our final answer is, $20.96 \pm 0.52 \text{ J s}^{-1}$ or $(20.96 \pm 0.52) \text{ J s}^{-1}$.

Note that the relative uncertainty must be converted back into an absolute uncertainty:

i.e., $21 \text{ J s}^{-1} \pm 2.5\% = \pm 0.52$, but to one significant digit i.e. ± 0.5 since uncertainties are themselves approximate and are not given to more than one significant figure.

Therefore $\frac{(44.01 \pm 0.05) \text{ J}}{(2.10 \pm 0.05) \text{ s}} = 21.0 \pm 0.5 \text{ J s}^{-1}$

The rule is to convert the absolute uncertainties to percentage uncertainties, then convert them back to an absolute uncertainty after the calculation.

WORKED EXAMPLE (THERMOCHEMISTRY)

The heat capacity of a copper can is $50 \pm 1 \text{ J K}^{-1}$ and in an experiment a temperature rise of $4.0 \pm 0.2 \text{ }^\circ\text{C}$ is obtained.

The uncertainty in the heat capacity is $\pm 1 \text{ J K}^{-1}$, in **percentage terms** = $\frac{1}{50} \times 100 = 2 \%$

The percentage uncertainty in the temperature reading is $\frac{0.2}{4.0} \times 100 = 5 \%$

So, the **maximum percentage uncertainty** is $(2\% + 5\%) = 7\%$

Now, heat energy released = heat capacity of copper can \times temperature rise
= $(50 \times 4.0) \text{ J} \pm 7\% = 200 \pm 7\% = (200 \pm 14) \text{ J}$

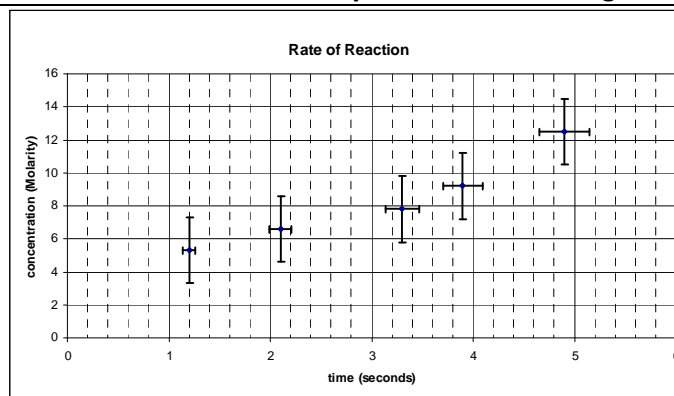
(Note, 7% of 200 is 14.)

The answer is best expressed in scientific notation: $(2.0 \pm 0.14) \times 10^2 \text{ J} = (2.0 \pm 0.1) \times 10^2 \text{ J}$

BASIC RULES FOR PROPAGATION OF UNCERTAINTIES

	<i>Rule</i>	<i>Example</i>
1	When adding or subtracting uncertain values, add the absolute uncertainties	Initial temp. = $34.50^\circ\text{C} (\pm 0.05)$ Final Temp. = $45.21^\circ\text{C} (\pm 0.05)$ $\Delta T = 45.21 - 34.5 = 10.71^\circ\text{C}$ $(\pm 0.05 + 0.05 = \pm 0.1^\circ\text{C})$ ΔT should be reported as $10.7 \pm 0.1^\circ\text{C}$
2	When multiplying or dividing add the percentage uncertainties	Mass = $9.24 \text{ g} (\pm 0.005\text{g})$ Volume = $14.1\text{cm}^3 (\pm 0.05\text{cm}^3)$
	a Make calculations	Density = $9.24/14.1 = 0.655 \text{ g/cm}^3$
	b Convert absolute uncertainties to percentage/fractional/relative uncertainties	Mass: $0.005/9.24 \times 100 = 0.054\%$ Vol: $0.05/14.1 \times 100 = 0.35 \%$
	c Add percentage uncertainties	$0.054 + 0.35 = 0.40 \%$ Density = $0.655 \text{ g/cm}^3 (\pm 0.40\%)$
d Convert total uncertainty back to absolute uncertainty	$0.655 * 0.4/100 = 0.00262$ Density = $0.655 \pm 0.003 \text{ g/cm}^3$	
3	Multiplying or dividing by a pure (whole) number: <ul style="list-style-type: none">multiply or divide the uncertainty by that number.	$4.95 \pm 0.05 \times 10 = 49.5 \pm 0.5$

4	Powers: <ul style="list-style-type: none"> When raising to the n^{th} power, multiply the % uncertainty by n. When extracting the n^{th} root, divide the % uncertainty by n. 	$(4.3 \pm .5 \text{ cm})^3 = 4.3^3 \pm (.5/4.3)*3$ $= 79.5 \text{ cm}^3 (\pm 0.349\%)$ $= 79.5 \pm 0.3 \text{ cm}^3$
5	Graphing Graphing is an excellent way to average a range of values. When a range of values is plotted each point should have error bars drawn on it. The size of the bar is calculated from the uncertainty due to random errors. Any line that is drawn should be within the error bars of each point. If it is not possible to draw a line of “best” fit within the error bars then the systematic errors are greater than the random errors .	



Precision and Uncertainties for Common Lab Equipment

When you record a scientific measurement, the last digit that you record is understood to have some uncertainty, and to be your best estimate. When reading non-electronic devices such as rulers, thermometers, and glassware, the general rule of thumb is to "read between the lines"! *This means that you can estimate one more digit or decimal place than the device is marked.* But this rule does NOT APPLY to electronic equipment (such as a balance or electronic thermometer) which gives you a direct digital readout. For these digital devices, your teacher will provide you the precision of the instrument.

The following uncertainties apply to careful measurements made by a trained observer:

Length (common metric rulers): ± 0.01 cm (or 0.1 mm)

Mass (electronic balances): always \pm one unit in the last digit. This means that a common centigram balance is ± 0.01 grams; a milligram balance ± 0.001 grams.

Volumetric Glassware

- 10 mL graduated cylinder: ± 0.02 mL (always record to 2 decimal places)
- 25 mL graduated cylinder: ± 0.1 mL (always record to 1 decimal places)
- 100 mL graduated cylinder: ± 0.5 mL (always record to 1 decimal place)
- 500 mL graduated cylinder: ± 5 mL
- 50 mL buret: ± 0.02 mL (always record to 2 decimal places)
- 10 mL graduated pipet: ± 0.01 mL (always record to 2 decimal places)
- Fixed volume pipets (glass): $\pm 0.2\%$ of the capacity (Ex: 25 mL = ± 0.05 mL)

Beakers and Flasks: Approximately 5% of the capacity. (But of course, you would never use one of these to measure a precise amount of liquid, would you?)

Thermometer

- (alcohol or mercury): ± 0.2 °C
- TI CBL temperature probe: ± 0.1 °C

pH Measurements

- pH paper: ± 1 pH unit (pH paper gives a "quick and dirty" estimate)
- TI CBL pH probe: ± 0.1 pH units (even though it reads out to 0.01).

pressure

- TI CBL pressure probe: ± 2 kPa (even though it may read out to decimal places)

GROUP 4 PROJECT

The Group IV Project is to emphasize interdisciplinary cooperation and the **processes** involved in scientific investigation rather than the **products** of such investigation. A scientific investigation requires that a problem should be identified. An answer (hypothesis) is proposed and research takes place to test the validity of the hypothesis. Scientific research should be methodical and logical.

INTERDISCIPLINARY

All the sciences are involved (i.e. all the IB students)

All will be working on the same theme.

All will be investigating the same problem from different perspectives.

TEAM WORK

You will be working as part of a team of 3 to 4 students. This means that your personal skills will be tested.

Personal Skills Group 4 Project				
	Complete/2	Partial/1	Not at all/0	Earned
Self-motivation and perseverance	Approaches the project with self-motivation and follows it through to completion.	Completes the project but sometimes lacks self-motivation.	Lacks perseverance and motivation.	
Working within a team	Collaborates and communicates in a group situation and integrates the views of others.	Exchanges some views but requires guidance to collaborate with others.	Makes little or no attempt to collaborate in a group situation.	
Self-reflection	Shows a thorough awareness of their own strengths and weaknesses and gives thoughtful consideration to their learning experience.	Shows limited awareness of their own strengths and weaknesses and gives some consideration to their learning experience.	Shows no awareness of their own strengths and weaknesses and gives no consideration to their learning experience.	

WHAT KIND OF PROBLEM?

The choice of problem to investigate should have moral, ethical, social, economic or environmental implications. It should be a problem which provides enough scope for all the different science groups.

WHAT KIND OF PROJECT?

The project will be selected by the students. It is your idea.

Needless to say the teachers will be on-hand to give advice concerning feasibility in terms of time and materials, safety and ethics.

The project may have a hands-on practical action phase or one involving purely theoretical aspects. It could be undertaken in a wide range of ways.

- Designing and carrying out a laboratory investigation or fieldwork.
- Carrying out a comparative study (experimental or otherwise) in collaboration with another school.
- Collating, manipulating and analyzing data from other sources, such as scientific journals, environmental organizations, science and technology industries and government reports.
- Designing and using a model or simulation.
- Contributing to a long-term project organized by the school.

The planning stage will be completed the first year of IB, the topic will be decided upon, and provisional discussion in individual subjects will take place at the end of the first year. Students will tackle the project and would be ready to start work early in the second year.

PROJECT STAGES

The 10 hours allocated to the group 4 project, which are part of the teaching time set aside for IA.

Planning:

You will be required to turn a proposal at the completion of this stage. This stage will be completed at the end of your first year in IB science.

This stage is crucial to the whole exercise and you will be given time after the AP and IB test in May to work in your groups to formulate a research question and hypothesis and to research your topic. In researching your topic you need to determine what is known about your topic and your research question. Your group will need to develop a research plan and submit a formal proposal. •

After selecting a topic or issue, the activities to be carried out must be clearly defined before moving from the planning stage to the action and evaluation stages.

WHAT IS A PROPOSAL?

A proposal for a project always precedes the actual project action phase. In a proposal one outlines three things:

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- The nature of the project
- What is presently known about this topic
- A research plan

Use the internet or library resources to identify who has done research into this or related areas and what their findings were. This does not have to be very long but should demonstrate that you have taken the time to inform yourself about the area of science you plan to operate in. Make sure that you record the references and attach them to your research.

Action:

Early during your second year of IB science, a day will be set aside for the action stage of your project. There should be collaboration during the action stage; findings of investigations should be shared with other students within your group. During this stage, in any practically based activity, it is important to pay attention to safety, ethical and environmental considerations.

Evaluation:

The emphasis during this stage is on students sharing their findings, both successes and failures, with other students.

Sources:

<http://occ.ibo.org> Chemistry Guide, Internal Assessment

<http://occ.ibo.org> Chemistry Resource by Ruth Sanderson

<http://occ.ibo.org> Chemistry Resource by Julie Sykes

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<http://dbhs.wvusd.k12.ca.us/webdocs/SigFigs/SigFigRules.html>

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