IB PHYSICS
PSOW GUIDANCE
NOTES
**Internal assessed coursework**

The internally assessed (but externally moderated) coursework component of the IB is worth 24% of the final assessment awarded by the IB. The practical scheme of work – PSOW – acts as a summary of all the investigative activities carried out by the student.

High level students are required to spend 60 hours and standard level students 40 hours spread over the two year program. [This includes the 10 hours that will be spent on the Group 4 Project.]

**Submitting labs for assessment**

‘Teachers can give general advice to students on a first draft of their work for internal assessment. However, constant drafting and redrafting is not allowed and the next version handed to the teacher after the first draft must be the final one. This is marked by the teacher using the internal assessment criteria.’

**In assessing student work using the internal assessment criteria, teachers should only mark and annotate the final draft.**

Physics diploma Guide 2007 p19
Laboratory write ups tend to vary from one educational establishment to the other, but a general pattern is found by comparing different laboratory reports, generally the expected format is one of:

**Title, Date and name of experimenter:** This needs no explanation.

**Aim:** This section should **define** the purpose of the investigation

**Hypothesis:** **formulate a testable hypothesis** and **explain** the hypothesis using scientific reasoning.

**Apparatus:** Usually a list of apparatus and a schematic showing how the apparatus fits together.

**Method:** identifies the relevant variables (dependent, independent, control) and explains how to manipulate them.

**Results:** Typically the results are given in a table and then as a graph where appropriate with error bars.

**Conclusion:** Put here what it is you have found. This may just be a statement of a numerical value, or a simple statement that relates your results to your hypothesis.

**Evaluation:** **evaluate** the method commenting on its **reliability** and/or **validity**, suggesting improvements to the method and making suggestions for further inquiry when relevant.

**Reliability:** Refers to measurement of the data. This depends upon the selection of the measuring instrument, the precision and accuracy of the measurements, errors associated with the measurement, the size of the sample, the sampling techniques used, the number of readings.

**Validity:** Refers to the success of the method at measuring what the investigator wishes to measure. This includes factors such as the choice of the measuring instrument and whether this measures what it is supposed to measure, the conditions of the experiment, and variable manipulation (fair testing).

*You are not constrained to use this format but it is one which has become familiar to many experimentalists as it does follow a logical path. Whatever format you prefer to use, make sure it can be followed easily by somebody who is not conversant with your work!*
Assessment criteria

There are five assessment criteria which are used to assess the work of both higher and standard level candidates.

Design (D)

Data collection and processing (DCP)

Conclusion and evaluation (CE)

Manipulative skills (MS)

Personal skills (PS) – assessed on Group 4 project only.

The performance for both high level and standard level is judged against these assessment criteria, each consisting of achievement levels 0 to 6. There is no difference in the assessment between standard level and high level.

The next few pages outline the assessment criteria and give some guidance of how to ensure your lab report meets the higher levels of each criterion.
Assessment Criteria

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”).

### Design

<table>
<thead>
<tr>
<th>Levels/marks</th>
<th>Aspect 1</th>
<th>Aspect 2</th>
<th>Aspect 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete/2</td>
<td>Defining the problem and selecting variables</td>
<td>Controlling variables</td>
<td>Developing a method for collection of data</td>
</tr>
<tr>
<td></td>
<td>Formulates a focused problem/research question and identifies the relevant variables.</td>
<td>Designs a method for the effective control of the variables.</td>
<td>Develops a method that allows for the collection of sufficient relevant data.</td>
</tr>
<tr>
<td>Partial/1</td>
<td>Formulates a problem/research question that is incomplete or identifies only some relevant variables.</td>
<td>Designs a method that makes some attempt to control the variables.</td>
<td>Develops a method that allows for the collection of insufficient relevant data.</td>
</tr>
<tr>
<td>Not at all/0</td>
<td>Does not identify a problem/research question and does not identify any relevant variables.</td>
<td>Designs a method that does not control the variables.</td>
<td>Develops a method that does not allow for any relevant data to be collected.</td>
</tr>
</tbody>
</table>

#### Aspect 1: defining the problem and selecting variables

Variables are factors that can be measured and/or controlled. Independent variables are those that are manipulated, and the result of this manipulation leads to the measurement of the dependent variable. A controlled variable is one that should be held constant so as not to obscure the effect of the independent variable on the dependent variable.

The variables need to be explicitly identified by the student as the dependent (measured); independent (manipulated) and controlled variables (constants). Relevant variables are those that can reasonably be expected to affect the outcome. For example, in the investigation of the bouncing ball, the drop height would be the independent variable and the rebound height would be the dependent variable. Controlled variables would include using the same ball and the same surface for all measurements.

#### Aspect 2: controlling variables

“Control of variables” refers to the manipulation of the independent variable and the attempt to maintain the controlled variables at a constant value. The method should include explicit reference to how the control of variables is achieved. If the control of variables is not practically possible, some effort should be made to monitor the variables.
Aspect 3: developing a method for collection of data

The definition of “sufficient relevant data” depends on the context. The planned investigation should anticipate the collection of sufficient data so that the aim or research question can be suitably addressed and an evaluation of the reliability of the data can be made.

The collection of sufficient relevant data usually implies repeating measurements. For example, to find the period of a pendulum, the time for a number of oscillations is measured in order to find the time for one oscillation. Measuring the time for just one oscillation for a given pendulum length would not earn a “complete”. Or, for example, measuring the time for a ball to roll a given distance down an inclined plane can be repeated a number of times and then an average time can be determined.

The data range and the amount of data in that range are also important. For example, in the pendulum experiment, a length range of 10 cm to 100 cm might be used, but measuring the period for only three points within that range would not be appropriate. Similarly, measuring the period for 10 data points in a range from 80 cm to 90 cm would also be inappropriate.
Data collection and processing

<table>
<thead>
<tr>
<th>Levels/marks</th>
<th>Aspect 1</th>
<th>Aspect 2</th>
<th>Aspect 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recording raw data</td>
<td>Processing raw data</td>
<td>Presenting processed data</td>
</tr>
<tr>
<td><strong>Complete/2</strong></td>
<td>Records appropriate quantitative and associated qualitative raw data, including units and uncertainties where relevant.</td>
<td>Processes the quantitative raw data correctly.</td>
<td>Presents processed data appropriately and, where relevant, includes errors and uncertainties.</td>
</tr>
<tr>
<td><strong>Partial/1</strong></td>
<td>Records appropriate quantitative and associated qualitative raw data, but with some mistakes or omissions.</td>
<td>Processes quantitative raw data, but with some mistakes and/or omissions.</td>
<td>Presents processed data appropriately, but with some mistakes and/or omissions.</td>
</tr>
<tr>
<td><strong>Not at all/0</strong></td>
<td>Does not record any appropriate quantitative raw data or raw data is incomprehensible.</td>
<td>No processing of quantitative raw data is carried out or major mistakes are made in processing.</td>
<td>Presents processed data inappropriately or incomprehensibly.</td>
</tr>
</tbody>
</table>

When data collection is carried out in groups, the actual recording and processing of data should be independently undertaken if this criterion is to be assessed.

**Aspect 1: recording raw data**

Raw data is the actual data measured. This may include associated qualitative data. It is permissible to convert handwritten raw data into word-processed form. The term ‘quantitative data’ refers to numerical measurements of the variables associated with the investigation. Associated qualitative data are considered to be those observations that would enhance the interpretation of results.

Uncertainties are associated with all raw data and an attempt should always be made to quantify uncertainties. For example, when students say there is an uncertainty in a stopwatch measurement because of reaction time, they must estimate the magnitude of the uncertainty. Within tables of quantitative data, columns should be clearly annotated with a heading, units and an indication of the uncertainty of measurement. The uncertainty need not be the same as the manufacturer’s stated precision of the measuring device used. Significant digits in the data and the uncertainty in the data must be consistent.

This applies to all measuring devices, for example, digital meters, stopwatches, and so on. The number of significant digits should reflect the precision of the measurement.

There should be no variation in the precision of raw data. For example, the same number of decimal places should be used. For data derived from processing raw data (for example, means), the level of precision should be consistent with that of the raw data.

Students should not be told how to record the raw data. For example, they should not be given a preformatted table with any columns, headings, units or uncertainties.
Aspect 2: processing raw data

Data processing involves, for example, combining and manipulating raw data to determine the value of a physical quantity (such as adding, subtracting, squaring, dividing), and taking the average of several measurements and transforming data into a form suitable for graphical representation. It might be that the data is already in a form suitable for graphical presentation, for example, light absorbance readings plotted against time readings. If the raw data is represented in this way and a best-fit line graph is drawn and the gradient determined, then the raw data has been processed. Plotting raw data (without a graph line) does not constitute processing data.

The recording and processing of data may be shown in one table provided they are clearly distinguishable.

Most processed data will result in the drawing of a graph showing the relationship between the independent and dependent variables.

Aspect 3: presenting processed data

When data is processed, the uncertainties associated with the data must also be considered. If the data is combined and manipulated to determine the value of a physical quantity (for example, specific heat capacity), then the uncertainties in the data must be propagated (see sub-topic 1.2). Calculating the percentage difference between the measured value and the literature value does not constitute error analysis. The uncertainties associated with the raw data must be taken into account.

Graphs need to have appropriate scales, labelled axes with units, and accurately plotted data points with a suitable best-fit line or curve (not a scattergraph with data-point to data-point connecting lines).

In order to fulfill aspect 3 completely, students should include a treatment of uncertainties and errors with their processed data.

The complete fulfillment of aspect 3 requires the students to:

- include uncertainty bars where significant
- explain where uncertainties are not significant
- draw lines of minimum and maximum gradients
- determine the uncertainty in the best straight-line gradient.
Conclusion and evaluation

<table>
<thead>
<tr>
<th>Levels/marks</th>
<th>Aspect 1</th>
<th>Aspect 2</th>
<th>Aspect 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concluding</td>
<td>Evaluating procedure(s)</td>
<td>Improving the investigation</td>
</tr>
<tr>
<td>Complete/2</td>
<td>States a conclusion, with justification, based on a reasonable interpretation of the data.</td>
<td>Evaluates weaknesses and limitations.</td>
<td>Suggests realistic improvements in respect of identified weaknesses and limitations.</td>
</tr>
<tr>
<td>Partial/1</td>
<td>States a conclusion based on a reasonable interpretation of the data.</td>
<td>Identifies some weaknesses and limitations, but the evaluation is weak or missing.</td>
<td>Suggests only superficial improvements.</td>
</tr>
<tr>
<td>Not at all/0</td>
<td>States no conclusion or the conclusion is based on an unreasonable interpretation of the data.</td>
<td>Identifies irrelevant weaknesses and limitations.</td>
<td>Suggests unrealistic improvements.</td>
</tr>
</tbody>
</table>

Aspect 1: concluding

Conclusions that are supported by the data are acceptable even if they appear to contradict accepted theories. However, the conclusion must take into account any systematic or random errors and uncertainties. A percentage error should be compared with the total estimated random error as derived from the propagation of uncertainties.

In justifying their conclusion, students should discuss whether systematic error or further random errors were encountered. The direction of any systematic errors should be appreciated. Analysis may include comparisons of different graphs or descriptions of trends shown in graphs. The explanation should contain observations, trends, or patterns revealed by the data.

When measuring an already known and accepted value of a physical quantity, students should draw a conclusion as to their confidence in their result by comparing the experimental value with the textbook or literature value. The literature consulted should be fully referenced.

Aspect 2: evaluating procedure(s)

The design and method of the investigation must be commented upon as well as the quality of the data. The student must not only list the weaknesses but must also appreciate how significant the weaknesses are. Comments about the precision and accuracy of the measurements are relevant here. When evaluating the procedure used, the student should specifically look at the processes, use of equipment and management of time.

Aspect 3: improving the investigation

Suggestions for improvement should be based on the weaknesses and limitations identified in aspect 2. Modifications to the experimental techniques and the data range can be addressed here. The modifications should address issues of precision, accuracy and reproducibility of the results. Students should suggest how to reduce random error, remove systematic error and/or obtain greater control of variables. The modifications proposed should be realistic and clearly specified. It is not sufficient to state generally that more precise equipment should be used.
Manipulative skills (assessed summatively)

This criterion addresses objective 5.

<table>
<thead>
<tr>
<th>Levels/marks</th>
<th>Aspect 1</th>
<th>Aspect 2</th>
<th>Aspect 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Following instructions*</td>
<td>Carrying out techniques</td>
<td>Working safely</td>
</tr>
<tr>
<td>Complete/2</td>
<td>Follows instructions accurately, adapting to new circumstances (seeking assistance when required).</td>
<td>Competent and methodical in the use of a range of techniques and equipment.</td>
<td>Pays attention to safety issues.</td>
</tr>
<tr>
<td>Partial/1</td>
<td>Follows instructions but requires assistance.</td>
<td>Usually competent and methodical in the use of a range of techniques and equipment.</td>
<td>Usually pays attention to safety issues.</td>
</tr>
<tr>
<td>Not at all/0</td>
<td>Rarely follows instructions or requires constant supervision.</td>
<td>Rarely competent and methodical in the use of a range of techniques and equipment.</td>
<td>Rarely pays attention to safety issues.</td>
</tr>
</tbody>
</table>

**Aspect 1: following instructions**

Indications of manipulative ability are the amount of assistance required in assembling equipment, the orderliness of carrying out the procedure(s) and the ability to follow the instructions accurately. The adherence to safe working practices should be apparent in all aspects of practical activities.

A wide range of complex tasks should be included in the scheme of work.

**Aspect 2: carrying out techniques**

It is expected that students will be exposed to a variety of different investigations during the course that enables them to experience a variety of experimental situations.

**Aspect 3: working safely**

The student's approach to safety during investigations in the laboratory or in the field must be assessed. Nevertheless, the teacher must not put students in situations of unacceptable risk.

The teacher should judge what is acceptable and legal under local regulations and with the facilities available. See the “Safety” section in this guide under “Guidance and authenticity”.
Interpreting the Relevant Assessment Criteria

Data Collection (Aspect 1)

The data collected in Table 1 is from an Ohm's law experiment. The candidate designed the data table, and the raw data is correctly recorded, including units and uncertainties. The level of achievement for aspect 1 of data collection is complete.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>DC (aspect 1) = complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>Current</td>
</tr>
<tr>
<td>$\pm \Delta V = \pm 0.02 \text{ V}$</td>
<td>$\pm \Delta I = \pm 0.2 \text{ A}$</td>
</tr>
<tr>
<td>1.03</td>
<td>0.5</td>
</tr>
<tr>
<td>3.35</td>
<td>1.2</td>
</tr>
<tr>
<td>5.18</td>
<td>2.1</td>
</tr>
<tr>
<td>7.20</td>
<td>2.7</td>
</tr>
<tr>
<td>8.75</td>
<td>3.5</td>
</tr>
<tr>
<td>9.88</td>
<td>3.7</td>
</tr>
<tr>
<td>10.32</td>
<td>4.1</td>
</tr>
</tbody>
</table>

In Table 2, the same data is recorded in a less than complete manner. Uncertainties are significant here, and should have been included. The level of achievement for aspect 1 of data collection is partial.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>DC (aspect 1) = partial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (V)</td>
<td>Current (A)</td>
</tr>
<tr>
<td>1.03</td>
<td>0.5</td>
</tr>
<tr>
<td>3.35</td>
<td>1.2</td>
</tr>
<tr>
<td>5.18</td>
<td>2.1</td>
</tr>
<tr>
<td>7.20</td>
<td>2.7</td>
</tr>
<tr>
<td>8.75</td>
<td>3.5</td>
</tr>
<tr>
<td>9.88</td>
<td>3.7</td>
</tr>
<tr>
<td>10.32</td>
<td>4.1</td>
</tr>
</tbody>
</table>
In Table 3, the same data is recorded in an inconsistent manner. Significant digits and uncertainties are not appreciated, and units are not given. However, the level of achievement for aspect 1 of *data collection* is still **partial**.

<table>
<thead>
<tr>
<th></th>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.5</td>
<td></td>
</tr>
<tr>
<td>3.4</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>5.2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>7.2</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>8.8</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>9.9</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

In Table 4, the candidate directly graphs the data and does not make a permanent record of it. The candidate fails to meet any of the requirements for aspect 1 of *data collection*, and the level of achievement is **not at all**.

<table>
<thead>
<tr>
<th></th>
<th>Voltage and current measurements were entered directly into the computer-graphing program.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DC (aspect 1) = <strong>not at all</strong></td>
</tr>
</tbody>
</table>
Data Processing and Presentation (Aspect 2)

Figure 1 is a graph of the previous Ohm’s law data, where only the current has a significant uncertainty. The computer drew the uncertainty bars based on the candidate entering the correct information, which in this case was ±0.2 A for each current value. This graph is appropriate for standard level candidates. The level of achievement for a standard level candidate for aspect 2 of *data processing and presentation* is **complete**. If this graph were to be presented by a higher level candidate, then the level of achievement for aspect 2 of *data processing and presentation* would only be **partial**.

**Figure 1**

*DPP (aspect 2) = complete (at standard level)*

![Graph of Voltage against Current](image)

Figure 2 is the same as Figure 1, but for higher level candidates. Here, minimum and maximum slopes are drawn on the uncertainty bars, and the range of experimentally acceptable values of resistance can be calculated from these extreme slopes. The level of achievement for aspect 2 of *data processing and presentation* is **complete**.
Figure 2
DPP (aspect 2) = complete (higher level only)

Figure 3 also uses the same Ohm’s law data as above, but the candidate does not include the relevant uncertainty bars. The level of achievement for aspect 2 of data processing and presentation is partial.

Figure 3
DPP (aspect 2) = partial
In Figure 4, the uncertainty bars are omitted, and the candidate fails to draw a best straight line. Although the axes are named, the units are missing. The level of achievement for aspect 2 of *data processing and presentation* is **not at all**.

**Figure 4**

DPP (aspect 2) = not at all

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**Taking uncertainties into account**

**Conclusion and Evaluation (Aspects 1 and 2)**

When attempting to measure an already known and accepted value of a physical quantity, such as the charge of an electron, the wavelength of a laser light, or the free-fall acceleration rate due to gravity, candidates can make two types of comment:

1. **The error in the measurement can be expressed by comparing the experimental value with the textbook value.**
   Perhaps a candidate measured gravity as $g_{\text{exp}} = 9.5 \pm 0.2 \, \text{m s}^{-2}$ and the accepted value is $g_{\text{acc}} = 9.81 \pm 0.01 \, \text{m s}^{-2}$. The error (a measure of accuracy, not precision) is a little more than 3% off the accepted value. This sounds good but, in fact, the experimental uncertainty only allows a confidence range between 9.3 m s$^{-2}$ and 9.7 m s$^{-2}$.

2. **The experimental results fail to meet the accepted value** (a more relevant comment).
   The experimental range does not include the accepted value. The experimental value has an uncertainty of only about 2%. A critical candidate would appreciate that they must have missed something here. There must be more uncertainty and/or errors than acknowledged.
CRITERIA CHECK LIST

[use this to check you have fulfilled all the requirements for each aspect of your labs]

CRITERION: DESIGN

DESIGN ASPECT ONE: Define problem and select variables

- Have you formulated a clear and focused problem or research question based on the teacher’s prompt? This should be an investigation into the relationship or function between two variables.

- What is your dependent variable? Even if the teacher’s prompt gives you is the dependent variable you should identify it.

- What have you decided to be your independent variable? Make sure your terms are well defined. Don’t say “the size of the crater” but rather “the depth of the crater as measured from the normal sand level”.

- Identify relevant controlled variables. Be sure to use the terms dependent, independent and controlled when talking about the variables.

DESIGN ASPECT TWO: Controlling variables

- Design a method for the effective control of the variables. Be sure to discuss each of the controlled variables as well the independent variable.

- Your method should include a list of materials and equipment.

- A sketch is often helpful in explaining your ideas.

- Details of how you plan to take measurements are important. Don’t just say “I’ll measure the time” but mention the timing device, what you will look for, issues of reaction time or parallax, etc.

DESIGN ASPECT THREE: Developing a method for collection of data

- You should discuss the amount of data you plan to take. This includes the number of data points and a discussion on the range and limits of this data.

- Also, your method should include repeated measurements, using an average for the given data point.
CRITERION: DATA COLLECTION & PROCESSING

DCP ASPECT ONE: Recording raw data

- Record raw data in a table that is easy to understand. Be sure to include the name of quantity, its symbol, its units and uncertainty.
- Comment on any qualitative aspects relevant to the data. There may be none.

DCP ASPECT TWO: Processing raw data

- Processing data includes things that taking an average of several repeated measurements, converting units, multiplying or dividing or other mathematical manipulations.
- Show one example of your processing by writing the equation, explaining the quantities, and showing a sample calculation.
- Process any uncertainties from the raw data correctly to the calculated data. When finding the average, you take the range and divide by two. You use absolute uncertainties when adding or subtracting, and percentage of uncertainties when multiply or dividing, squaring, etc. When processing non-linear function you may want to take minimum and maximum values for the calculated range.

DCP ASPECT THREE: Presenting processed data

- Present processed or raw data in an appropriate graph. The graph should have a title, quantities and units for both axes. Unless there is a good reason, the graph should start at the zero origin value.
- Data points on graphs should include uncertainty bars for one of the axes only.
- Construct the best-fit line, a straight line if the function is linear. Determine the equation of the best-fit curve or the gradient of the best-straight line.
- If you have a linear graph then construct minimum and maximum gradients on your graph by using the uncertainty bar extremes for the first and last data points. Use these gradients to determine the uncertainty in your best-straight line graph.
CRITERION: CONCLUSION & EVALUATION

CE ASPECT ONE: Concluding

- Do you clearly state a conclusion based on a reasonable interpretation of your data?
- Does your conclusion offer more than just a restatement of the graph? You need to explain and justify what you discovered, including the scope and limit of your results.
- If relevant, comment about random and systematic errors in your data, and comment about any x-axis or y-axis intercepts. What, if anything, is the physical meaning of the intercept? What, if anything, is the physical meaning of the systematic shift?

CE ASPECT TWO: Evaluating procedure(s)

- Carefully look at your procedure or method. Identify any limitations or weaknesses.
- Comment on the overall quality of your data. Precision and accuracy are relevant here.
- Consider the equipment used, methods followed, as well as time management.
- Have you sufficiently controlled the relevant variables?

CE ASPECT THREE: Improving the investigation

- Consider the evaluation from above (CE aspect 2) and address the important issues.
- Make sure suggestions or improvements are realistic, detailed and significant.
- Make qualitative and quantitative evaluative statements if possible.
- What about the range and number of your data? Would changing this help?
- Precision, accuracy and reproducibility may be relevant when talking about improvements.
- Is it possible to have greater control of your variables?