Student Guide for Internal Assessment in Physics

For examinations starting in 2009

The aim of this booklet is to help the student perform and write up IB physics lab reports, get the most out of the Group Four Project and efficiently produce a practical based Extended Essay. It should also be of interest to physics teachers who are new to the IB or those on a small budget, as ideas that work come with time and suitable experiments fortunately do not always need big spending.

This booklet is not intended to be read from beginning to end in some sort of chronological order. Physics teachers usually start by already giving clear instructions for experiments so students begin collecting and processing data before they plan their own experiments. It is suggested that the student follows the order taken by the class teacher and if the class teacher's style or requirements differ from those of this booklet, then the student should always do as the class teacher requests! Similarly, this book should not be used in isolation, but in conjunction with the IB Physics Syllabus (which the class teacher should supply), as it contains much useful information that is not reproduced here.

This guide is aimed at helping students in the coursework areas: planning, data collection and processing, conclusion and evaluation. There is also advice given in the other skills of manipulation (for you clumsy types!) and personal areas of independent and co-operative work for you shy or overbearing pupils. There then follows a brief look at other related topics such as doing a physics Extended Essay as well as the Group Four Project. There is a mention of the new requirement of ICT in some experiments and the need for awareness on the international aspect of science and as well as the social, ethical and environmental dimensions of what we do as scientists. Each section starts with a paraphrasing of the IB internal criteria and aspects. Then follows more detailed advice as to how to achieve complete scores in each skill, including clear examples of good and bad work, with 'hands on' tasks where the student fills in the table or draws the graph-the best way to learn! At the end of the book are more exercises (with answers) to help improve techniques.

I would like to thank Jacek Latkowski for proof reading and for David Russell for having faith in me to get this project done and to Ashby Merson Davies for his prior work on the biology book on which the style of this one is modelled. Lastly I would like to thank my own students for allowing me to use them to find the best ideas (through trial and lots of error!). Some students are now reaching the magical 48 out of 48 in the coursework-surely the best indication of success for student, teacher and booklet.

Any constructive comments are welcome and should be sent to OSC

Hugh Duncan

Contents

General guidelines on recording lab reports

The IB expects each student to keep a log book of all experiments performed. Some teachers prefer a book in which all lab work is written, others prefer labs written separately on loose leaves and stored in a folder. Students should follow the preference of their teacher. Personally, I have students write labs on separate sheets, stapled together with a common front cover and stored in a filing cabinet in the prep room for safe keeping (loose sheets are easier to Xerox than log books, when sending them off- as long as they are standard A4 size without holes!). If a log book is lost (by the student or the teacher) *all* the coursework is lost, but if one lab report is misplaced out of a total of say 40 experiments, it is no great loss. Plus, collecting in 16 lab reports of a few sheets to correct from each class is less to carry around than 16 thick practical books! A front cover allows the lab work to be collated much more efficiently, by student, date etc, and a checklist of the scores for the skills on the front cover allows rapid identification of a student's strengths and weaknesses.

In my opinion, it is preferable for students to write up lab reports on a word processor than by hand, but it is by *no* means obligatory. This helps with presentation, especially if the student has poor handwriting (like me!). It also means that students can retain a copy for future reference and this can be useful if the original hard copy ever gets misplaced, or if sending work over the net is allowed. I ask students to print on both sides in order to save trees. Even if a lab report is written on a word processor, it is sometimes useful for diagrams and graphs to be hand drawn. Word processed diagrams can take ages and some apparatus is hard to design on a computer. As for graphs, in written exams the student is still expected to be able to draw them freehand (the data based question in paper two for example), so students should not lose that skill and the graphs should still be hand-drawn from time to time.

Criteria and aspects

There are five skill areas in the coursework: design, data collection, evaluation, manipulation and personal. They are dealt with in detail below. Three possible levels can be achieved in each skill: **complete**, **partial** or **not at all**. The aim of course is to reach a complete in all skills.

A Design

-this skill is concerned with the theoretical and practical sides of planning an experiment.
-most experiments cannot be assessed in this area as the teacher usually gives the student instructions or at least discusses the hypotheses and selects the variables in class as a group.
-most experiments found in books are standard experiments and as the outcome is usually well known already, they are unsuitable for planning.
-therefore students are often given 'open ended' experiments, or topics not found directly on the syllabus.
-planning is split into three sub sections:

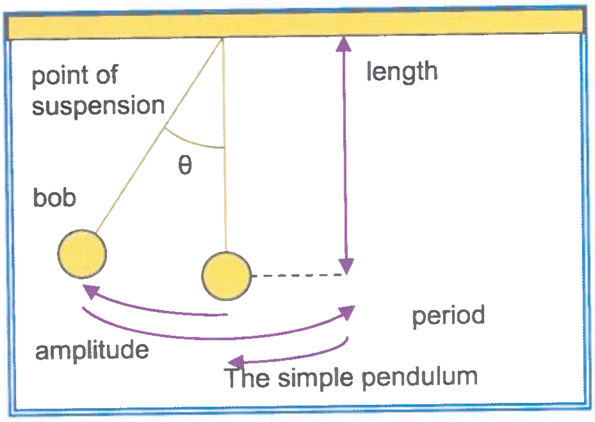
- defining the problem and selecting variables
- controlling variables
- developing a method for collection of data

Aspect 1. Defining the problem and selecting variables

The golden rules for the research question include the following:

-stating only the aim of the experiment in a lab report is *not* enough even for partial credit.
-the problem or research question **must** be included.
-the defining must be focussed and very specific to the problem.
-some background details can also illuminate the problem.

-for example, take *the simple pendulum*.
-this topic is now back on the syllabus so could not be used as planning unless done in advance of the theory. However it does illustrate the idea of planning quite clearly.
-the aim could be '*what factors affect the period of a simple pendulum*?'
-a good start is to explain clearly *what a simple pendulum is*.
A simple pendulum consists of a light inextensible string; one end attached to a point of suspension and fixed to the other end is a mass, called the bob, usually symmetrical in shape and of a dense material such as lead. The length of a pendulum is from the centre of mass (usually the centre of the bob) to the point of suspension. The amplitude of a pendulum is the maximum displacement from its mid position or the maximum angle θ. The period of a pendulum is the time taken for one complete swing-from one extreme displacement to the other and back again. See diagram.



The simple pendulum

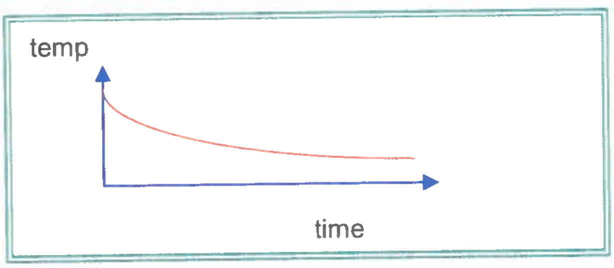
Galileo was the first to notice the time keeping properties of the simple pendulum. In church, he saw a swinging lantern and used his heartbeat as a rough timing device. He found that the period seemed to remain constant, even as the amplitude decreased and from this he designed the first pendulum clock. The aim of this experiment is to find what factors affect the period of a simple pendulum.

-note, this last paragraph involved a bit of background reading-always useful!
-the above is more than enough to obtain a complete in defining the problem.

A hypothesis is no longer required as one of the skills of planning. However, that is not to say it should be ignored completely! Any student considering a university course or career in science should attempt a hypothesis even a simple one. Similarly a student performing an experimentally based Extended Essay should also look at a hypothesis. A brief overview is given below for the motivated student in the Extended Essay section (see page 40)

Selecting variables

There are two types of variables, **dependent** and **independent**.
-the *independent* variable is the one controlled by the experimenter.
-it is set to a certain value by the experimenter.
-the *dependent* variable changes as a result of the *independent* variable.
-for example, *the experimenter may choose to measure the temperature of a cooling beaker of water every minute for ten minutes*.
-in this case *time is the independent variable* as the choice was to select minute intervals.
-the *temperature of the water is the dependent variable* as it depends on when it is read.
-the independent variable is plotted on the x axis, the dependent on the y axis (see below).
-so in this case *the temperature is plotted against time*:



-in some cases, the variables could change roles.
-in the cooling curve, *one could note at what times the temperature falls by five degrees.*
-in this case, *the temperature is the independent variable and time is the dependent variable.*
-sometimes also, one might reverse the axes of the variables and plot the dependent on the x axis and the independent on the y axis.
-this can happen in such cases as a *Hooke's Law spring.*
-*the independent variable is the suspended weight and the extension is the dependent variable.*
-*weight is plotted against extension as the area under the graph is the energy stored.*

The golden rules for variable selection include the following:

> -when planning, first list **all** the possible variables, whether dependent or independent.
> -discuss the importance of each variable and eliminate those considered negligible
> -select, say the three most likely to affect the variable.
> -each factor should be discussed and its likely affect should be assessed.
> -any reasoning must be given either way for accepting or rejecting a possible variable.

-for example, consider *the pendulum* again. *The possible factors that might affect the period could be: length of pendulum, amplitude of swing, mass of bob and air resistance.*

-length of pendulum is expected to be a major factor on the period of a pendulum. This comes from personal experience of swinging ropes and pendulum clocks. The longer the pendulum, the longer the period is predicted. From a vector point of view, when a long pendulum is pulled to one side, then released, most of its motion will be horizontal where no forces are involved, while vertical motion will be very small, hence only a small component of gravity acts.
-amplitude might have an effect on the period. On the one hand, greater amplitude means a greater distance for the pendulum to cover, so it could take longer to complete a period at greater amplitude. However, greater amplitude would also mean that there would be more of a component due to gravity, hence a greater accn so less time. Consider the extreme case when a pendulum bob starts with the string horizontal. It will have the full component of gravity pulling it down. Perhaps the two effects cancel out so amplitude has no effect. Plus Galileo's first observations suggest it has no effect.
*-mass of bob might change the period. A greater mass m will have a greater force on it. This suggests a heavier bob will have a shorter period. However the accn, a, due to gravity is the same for all masses so this suggests mass will **not** change period. Newton's second law says F = ma and as the force F increases with mass, then accn will be constant so mass will **not** change the period.*
-air resistance is likely to change the period. Consider a pendulum swinging in, say oil. The friction with the liquid will slow down the motion of the bob considerably so the period will increase (and might even approach infinity for very thick oil!). Air resistance is much less but is expected to increase period. The cross sectional area of the bob will change the amount of air resistance and this could be done with different material bobs (lead, iron, wood etc), or identical bobs with different area cards attached etc.

-the above discussion is more than enough to earn a complete in selecting variables

2. Controlling variables

Controlling the variables means selecting the appropriate apparatus and designing a method.
-this skill centres on the practical side of planning an experiment.
-it is like the recipe in a cook book, where the amounts. oven settings and utensils are specified for anyone to follow who has not actually seen it done before.
-the student selects the pieces of equipment. their sizes and ranges, explains how the experiment is to be performed and how the data is to be collected.

The golden rules for selecting apparatus are as follows:

> -list the items of apparatus. Be very specific and state the ranges and resolutions of the scales.
> -draw a diagram of the apparatus in use, not as separate items. Use a sharp pencil and rule for straight line work and a compass for circular work. No free hand drawing!
> -diagrams can be drawn using a word processor, but they tend to take a long time.
> -a diagram should be a minimum of half a page and be clearly labelled or have a key.

-for example, in the case of *the simple pendulum*, the list of apparatus would be:
two clamps and a stand
two large rubber stoppers (several cm diameter)
several metres of cotton thread
two 1 metre rules marked in mm
several different sized lead bobs (min 6), e.g. 3g to 100g (such as fishing weights)
digital stop watch to 0.1sec
heavy weight of several kg
triple beam balance or digital balance 0-500g (to nearest 0.1g)
Note the diagram is drawn below.

Designing a method

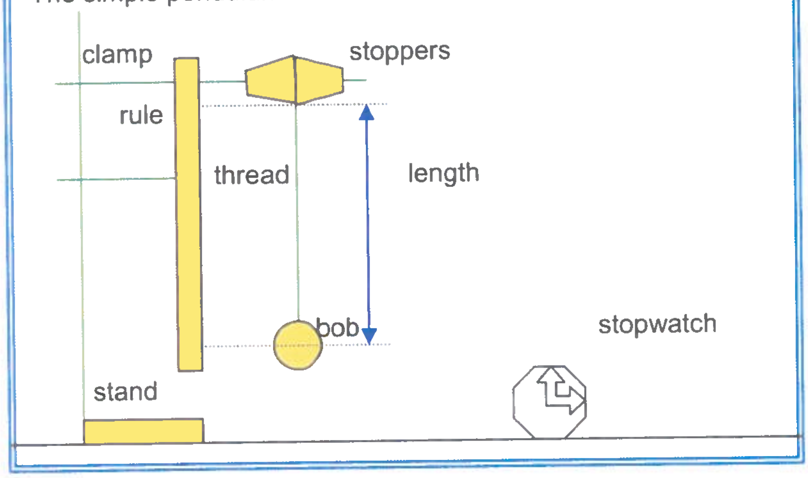
The golden rules for describing a procedure are as follows:

-generally, use short sentences and give the instructions in a chronological order.
-avoid the oversimplified method 'set up as in diagram....'
-explain so that some one who was absent can follow your write up and repeat the experiment.
-avoid ambiguities and vagueness. When specifying a particular piece of apparatus or method, justify why, so it is clear to the reader that you know what you are doing!

-for example in the *simple pendulum experiment where period is being measured with length.*
-take a bob (say 20g) and attach just over a metre length of cotton. There is a hole down the middle of lead fishing weights for such purposes. Clamp the other end of the thread between the two stoppers and set the clamp in the stand so the pendulum hangs vertically over the edge of the table and just in front of the upright of the clamp stand. The upright marks the midpoint of the pendulum swing. Measure the length of the pendulum with the metre rule as demonstrated in the diagram. Place the other ruler horizontally on the desk so that the zero starts below the pendulum when at rest, then pull the bob to one side so that it is above the 20cm mark of the ruler. Release the bob then, after a few swings to ensure it is not going to collide with anything, start counting down 'three, two one with each complete swing and start the watch on zero as it passes the midpoint. Count say 20 complete swings then stop the watch and note the time. Repeat for another 20 swings.

-note this method controls the length of the pendulum by using the stoppers and clamping the string between them. This also makes it easy to change the length. The mass is controlled by having 'ready made' weights (I've found lead fishing weights ideal for pendulum experiments). The amplitude is controlled by using the horizontal ruler close to the pendulum.

The simple pendulum



-the above is more than enough to gain a complete in control of variables

3. Developing a method for the collection of data

This concerns how to make changes for more data and how much to collect. The golden rules for a method to collect sufficient data are as follows;

> -describe clearly how to make one reading.
> -explain how to change the settings to take another *and* further readings.
> -a minimum of six readings should be taken over as wide a range as possible.
> -readings should be repeated to spot mistakes and to reduce errors.
> -include a blank table to show how the data is to be organised.
> -the table should have the headings, with units and suggested errors.

-in the period-length relationship for a simple pendulum, the method might read as follows:
-unclamp the stoppers slightly and increase the pendulum length by say 10cm then reclamp.
-measure the new length, then time 20 periods at least twice ($20T_1$ and $20T_2$).
-repeat this for various lengths from say 50cm up to 100cm.
-this allows a reasonable range without going beyond the length of the metre rule, which would increase errors.
-put the results in a table as below (NB numbers shown as an example):

Table of length and period of a pendulum

Length /cm	$20T_1$/s	$20T_2$/s	Av20T/s	Av T/s
50.0				
60.0				
70.0				
80.0				
90.0				
100.0	39.6	39.8	39.7	1.99
+/- 0.5	+/- 0.2	+/- 0.2	+/- 0.2	+/- 0.01

NB errors and tabulation are discussed in more detail in the data collection page 12.
-the above example is more than enough to gain a complete in developing a method.

Examples

Example 1

Task-you are given 20 different square samples of white cloth material labelled A to T.
-you are then given an unlabelled sample of white material of a similar size which is claimed to be the same material as *one* of the labelled samples.
-without any further teacher help a student should realise they have to design an experiment to identify the sample in more than one independent way.

Defining the problem

It has been the case in forensic science for examples, the fibres found at the scene of the crime have to be matched to the clothes of the suspect or for historical artefacts such as the Shroud of Turin that a small piece of cloth is claimed to have come from the original, or. The Turin Shroud is a length of cloth kept in Turin that is said to be the burial cloth of Christ. Some pieces have been cut off in recorded history and scientists have been asked to find out if any of these supposed relics are indeed from the original shroud or if they are fake. There may be biological methods and chemical methods for comparing two cloths, but the aim of this experiment is to design a method that will distinguish, or match up a piece of unknown cloth with twenty known samples using physical means.

Selecting variables

Physical aspects of a cloth could be characterised by some of the following:

-Colour/reflectiveness-the human eye can distinguish between 2 million different colours as well as the matt/glossy nature of a surface.
-Type of weave-there are many different types of weave from the simplest alternate one thread over-under each other to more complex such as three over, one under (known as three to one herringbone twill).
-Size of weave-each thread will have a characteristic diameter.
-Strength of weave-each weave will have a characteristic breaking strength.
-Feel-human touch can detect the feel of many different surfaces, their roughness/smoothness, heat conducting ability etc, though it is very difficult to quantify.
-Smell-the human nose can detect the smell of some materials, but the difference may be slight as well as being difficult to quantify.
-Sound-connected to feel, the sense of sound and the feeling of 'vibrations' when a cloth is rubbed can be detected by humans. Again, this is a hard observation to quantify.
-Coefficient of friction-assuming nothing has been done to a material to change the value of friction; each material will have a specific coefficient of static/dynamic friction.
-Light transmissibility-identical materials will be equally 'translucent' to light transmission. This lends itself to being measurable with a light meter, but unconformities across a cloth might be large.
-Charging qualities-if untreated, each cloth when rubbed with say Perspex or polythene should have a certain electropositive/negative nature, but with static experiments being notoriously unreliable and affected by the weather this would be unsuitable!
-Density-though the thickness of a material is very small and easily 'squashed', the mass per unit area of cloth is a measurable quantity and each cloth will have its own unique value.
-Ageing of cloth-depending on the age of a cloth or exposure to sunlight and the 'elements', the colour of a white material will yellow. This variable is related to identifying colour.

It has been decided to measure the type of weave, thread concentration (threads/cm) and area density g/cm². There may be other suitable variables, but two of these (density and thread concentration) are very quantifiable and likely to be accurate, being fairly standard quantities from everyday experiences in physics. The type of weave is a useful characteristic that will allow those of the wrong weave to be eliminated straight away, avoiding wasting time. NB the two directions on a cloth are called the weft and warp directions.

Selecting apparatus

-unknown sample plus lettered samples of cloth A to T
-hand lens X7 or X10
-15cm rule marked in mm
-balance 0-10g +/- (0.01g)
-squared paper (mm, 2mm or 5mm)
-sheet of glass at least as large as cloth samples.

Method

-find the mass of a lettered sample (eg A) on the balance.
-repeat and note the average and the difference as the error.
-place the cloth on the squared paper.
-lay on it a sheet of glass to stop anything moving or being knocked.
-find the area of the cloth by counting squares and part squares.
-this might be easier if the cloth and squared paper are photocopied together.
-lay the 15cm rule alongside the cloth sample, so it is parallel to one weave direction.
-observe the cloth and rule with the hand lens.
-count the number of threads in say 5cm.
-it may be necessary to mark the cloth with a permanent marker at the ends of the 5cm and mark every tenth thread so as not to lose count.
-repeat this in a perpendicular direction on the cloth.
-now repeat the above method for all lettered samples and the unknown sample.
-note it may not be possible to identify the warp and weft directions if the edge of the cloth is not included on the sample. This is not too important, but it may mean interchanging the two sets of readings in order to see a match.

Controlling the variables

A suitable table might look like this (the readings are invented):
Length of cloth for counting threads 5.0 +/- 0.1cm

Table of cloth samples and their characteristics.

Sample	Mass/g	Area/cm²	M/A g/cm²	Weft count	thread/cm	Warp count	thread/cm
A	2.37	93.2	0.0254	157		154	
B	1.92	97.5	0.0197	129	25.8	163	32.6
T	3.36	91.6	0.0367	141		141	
?	2.24	101.0	0.0222	127	25.4	164	32.8
Error	+/-0.01	+/-0.1	+/-0.0002	+/-1	+/-0.7	+/-1	+/-0.7

-the data has been manipulated: weft thread (count/cm) = count/length = 127/5.0=25.4 thread/cm %error = 0.1/5 + 1/127 = 2.8% = +/- 0.7 threads/cm.
-the lettered sample that matches most closely to the unknown samples weave pattern thread concentration and density is the one most likely to be made of the same material. In the above example it is B.
-if no sample falls within the errors, then it may mean the unknown sample is not from one of the known ones or the errors have been underestimated.

-the above design would easily score a complete in the three aspects.

Example 2

Task-*How does the diameter of a crater depend on a falling projectile?*

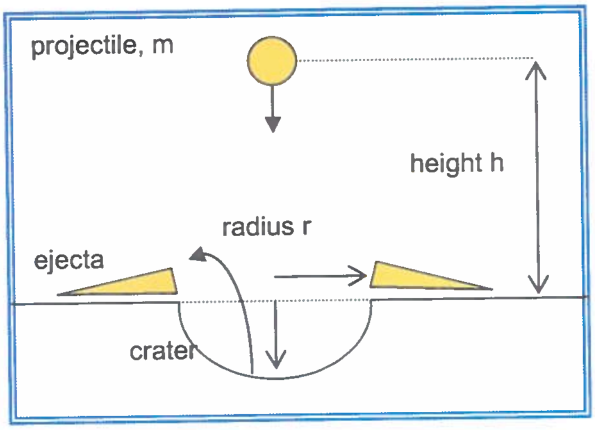
Defining the problem

A crater is a circular depression with a raised rim, formed by the impact of a fast moving projectile. Most of the craters on the Moon, Mars, Mercury and several planetary satellites are believed to be formed by impact. There are even some impact crates on the earth that have survived erosion, such as the famous Meteor Crater in Arizona. When an impacting object strikes a surface, it vaporizes with the energy, the surface acts like liquid (like a drop hitting water), the excavated material forms a raised rim plus an area of ejected material round the crater. The aim is to find out what factors affect the size of the crater. For simplicity, steel ball bearings are to be dropped into a tray of dry sand.

Variables:

-Mass of projectiles-the heavier the projectile, the more energy it will have so the larger the crater.
-Height from which the projectile is dropped/terminal velocity-the greater dropping height, the greater the energy on impact so the greater the crater size.
-Type of surface material-the stronger the surface material, the more energy needed to break up the material, so the smaller the crater.
-Depth of surface material-if the type of surface material changes with depth it can certainly change the crater size. For example, if a weak layer sits on top of a strong layer, it could be that a wide shallow crater is formed. Also if the material is 'wet', the surface tension forces might be larger enough to treat wet sand as stronger than dry sand, giving smaller craters.
-Size of projectile/density of projectile. For lower energy impacts, a large diameter projectile is likely to create a wider, shallower crater, as the large diameter will imprint itself on the sand.
-Air resistance-for low density/large dropping heights, air resistance forces will be large and will reduce the energy put in to excavating the crater, leading to smaller diameter craters.

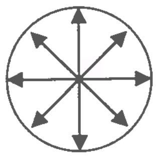
Selecting equipment



plastic tray about 50x50x10cm
sand to fill the tray
selection of steel ball bearings (min 6) 3mm diameter to 25mm (lead shot would also do)
magnet and spirit level.
metre rule(s) in cm or tape measure up to 5m max.
small rule 15cm in mm or callipers.
digital balance up to 100g to 0.1g resolution.
Desk lamp.
Clamp and stand.
Various surfaces, floor, chair, desk, stairwell to accommodate various dropping heights.

Method to control and change variables

-sand is poured into the tray and flattened using the side of a ruler, then checked with the spirit level.
-a ball bearing is selected that is small compared to the depth of sand and expected crater size, but large enough not to be affected too much by air resistance, e.g. 6mm.
-the diameter and mass of the ball are measured.
-a metre rule is set up vertically above the sand using the clamp stand.
-the ball bearing is held at a noted height (e.g. 10cm) and dropped.
-the diameter of the crater formed is measured four times across different diameters.



-the ball is removed using the magnet, the sand smoothed and the process repeated two more times for the same dropping height.
-the dropping height of the ball is then raised to say 20cm and the process repeated.
-this is repeated by approximately doubling the height each time up to 320cm.
(note: dropping heights are not evenly spaced as hypothesis suggests a large change in height needed to give a noticeable change in crater diameter)
-an alternate plan could vary the mass, not the height of the projectile. A set of different sized ball bearings are selected, their diameters and masses are measured, e.g. 1.5mm, 3, 6, 10, 15, 20, 25.
-a fixed dropping height, say 80cm is selected.
-each ball is dropped from this height and the crater diameter measured as above.
-this is repeated two more times for each ball.
A suitable table for varying dropping height would look something like this:

Ball bearing diameter 6.0+/-0.1mm, mass = 1.06+/-0.01g

Table of projectile heights and crater diameters.

Dropping height/m	Dia1,2,3,4/cm	Mean/cm	Dia1'2'3'4'	Mean'	Dia1''2''3''	Mean'''	Mean
0.10	2.3, 2.5, 2.4, 2.1	2.3					
0.20							
0.40							
0.80							
1.60							
3.20							
+/-0.01	+/-0.1	+/-0.1					

Suggested Planning Experiments

NOTE: the IB states that students should not be given a focussed research question. They must work that out for themselves. Students should also not be told the outcome, nor what variables, apparatus or method to use. Nor how much data to collect. However teachers are expected to offer some guidance (eg not just give the student a ball and leave them to think of something, but mention that balls bounce, which is vague enough yet allows a fruitful direction to choose).

1. What factors effect the time of a falling paper cone?
Make a paper cone, hold it up and let go. Observe. Can it be dropped any other way? What is it about the paper that decided how fast it falls?

2. What factors affect the period of a mass on a spring?
This experiment is very similar in style to the simple pendulum experiment. It is on the syllabus as part of simple harmonic motion, but lends itself as a planning exercise if it is performed before the theory. Look at the pendulum plan and try to create a similar approach to this one. Knowledge of Hooke's Law might help.

3. Is there a simple pattern to the rebound height of a rubber ball?
Take a rubber ball, drop it and observe. To what height does it rebound? Is it the same for all surfaces? For all heights? All rubbers? Knowledge of efficiency and coefficients of restitution might help. This plan lends itself to using log graphing techniques.

4. To what height above the rim can a container be 'overfilled' with water?
If you take something like a test tube and once filled to the top, slowly add more water, the water level can be seen to rise above the rim until a point when the surface breaks and the water escapes. A similar observation can be made if water is slowly poured onto a microscope slide. The water builds up in depth until the surface breaks. What height can it reach? What does it depend on (obviously surface tension has something to do with it!).

5. What is the extension pattern of a hanging slinky? (NB a slinky is a wide, loose steel spring, often used as a toy that 'walks' down stairs!). Take a slinky. Hold it vertically and let turn after turn hang down. Is that a geometric or arithmetic progression between the turns? Can you come up with a plan to test the idea? Does it have to obey Hooke's law? Remember the mass of the slinky is not negligible.

6. Is there an inverse square law of force between two bar magnets?
Hold two magnets near each other; feel the force between them. It does change with distance, but how? How can you measure the size of the force? A balance might help.

7. Is there an inverse square law of force between two charged rods?
Hang a charged rod on a thread and approach it with a second charged rod? The hanging rod moves. How can you measure the size of that force and how can you correct for the charge leaking away-a problem for all static experiments! The balance might help here as well.

8. What factors govern the height of a column of floating ring magnets?
Create a pile of repelling floating ring magnets. They are further apart at the top. Is there a pattern? Turn one round so it attracts. How does that mess up the pattern? Is the new pattern predictable?

9. What is the fastest way to empty a bottle of water?
Go on, fill any old bottle with water. Time how long it takes to empty the bottle. Can you empty it a quicker way? Those air bubbles get in the way don't they? Is there an optimum way of getting the water out of the bottle without smashing it to pieces?

10. What causes twinkling?
Draw a small white circle on a black card, illuminate it and walk away. At some distance the white circle starts to scintillate (twinkle). What will affect the twinkling distance? Does it happen when the disc has a fixed angular size?

11. What is the efficiency of 'launching' a rubber band so that it just reaches the ceiling?
Knowing that strain energy put into an elastic band becomes energy of motion then gravitational as it moves up and each can be measured/calculated, it should be possible to find the efficiency of the elastic.

12 Scotch tape.
There are several experiments that could be done with a roll of Scotch tape. For example, what is the breaking force of the tape? What is the sticking power of the sticky side? What static charge does it gain when unwound?

B Data collection and processing

-this involves the skill of accurately recording observed data.
-data could be **qualitative** or **quantitative** using various collection methods.
-qualitative would mean descriptive and not numerical.
eg hot or cold, green in colour, melting etc.
-quantitative means assigning numerical values to observations.
eg, the temperature was 23℃, the wavelength 530nm, it took 25s to melt.
-tabular recording methods of data should be relevant.
-accuracy of the data and the appropriate units are important.
-all collected data must be clearly headed.
There are three subsections to data collection:

- collecting and recording raw data
- processing raw data
- presenting processed data

1. Collecting and recording raw data

The golden rules for data collection are as follows:

-take a minimum of six different readings.
-cover as wide a range as possible.
-repeat readings at least once.
-write down *every single item* of raw data as it happens!
-if working in pairs, each student should *take their own readings*!
-get the set of raw data signed and dated by the teacher as proof.

-six readings is an arbitrary value, but it allows enough data for graph plotting later. More can be taken if time allows. Note this is a *minimum*!
-the greater the range, the more likelihood of seeing any change between the variables.
-repeat more readings if time allows. Repeating allows a checking of the first set of data to see if miscounting or misreading of scales occurred or if a systematic change is occurring. It also allows a better estimate of the errors involved from the spread of data.
-as for recording everything, memory fades and you never know what data might need to be checked later, when a point on a graph is clearly off the line and it might have been misreading the original bad handwriting!
-you cannot guarantee your partner will read the same way as you. Don't let your partner walk off with your data, they may fall ill, lose them and then you will find yourself in deep shifting sands! You won't believe then number of times a student has 'failed' because their partner has the data……

-getting data signed is proof that it was your data and taken during the lesson. It will avoid suspicion of making up readings later on (I know from experience!).

-take the pendulum for example again, where length is varied and period (time for one swing) is found.
-a good range of lengths would be say 40cm to 90cm.This means all readings can be made with one metre rule. Going above 100cm will cause problems of measuring the length with a metre rule, unless there is a longer tape measure.
-the length does not have to be set to a round number such as 50.0cm as time is wasted in trying to get such an exact length. Set it roughly then measure accurately.
-time a large number of swings, e.g. 20 and write it down.
-time again 20 swings and note it down. If they differ by too much, one set could have been miscounted.
-set a new length and repeat the process. If six lengths are being done from 40 to 90cm, then length needs to be changed by about 10cm each time.
-a quick way to change length would be to clamp the string between two rubber stoppers, rather than cutting the length shorter or a new length each time. You might need to go back and check a longer length at the end. Think about these time saving tricks as you are setting up.

Organizing and presenting raw data

The golden rules for raw data presentation are as follows:

-put data in a table.
-use a word processor.
-draw a complete closed box for the table.
-give the table a title.
-have a heading row with the name and unit.
-record the raw data with a consistent number of sig fig.
-have a bottom row for errors, containing the +/- sign.
-for the raw data, the error is estimated.
-errors are only 1 sig fig in the least sig fig of the reading.

-unless there is a better way, use a table. It makes it so much easier to follow what is going on, like having your CD collection in alphabetical order.
-a word processor is neater, easier to make changes and also means a back up copy can be kept on the student's computer should the hard copy ever go missing, or it can be e mailed to an understanding teacher by a conscientious student who might be ill on the hand-in day.
-no open sides to your table. Data tends to drift sideways in a table without edges, if numbers are handwritten.
-refer to the title of the table in the lab report. For example, *the results of the length and timing of twenty swings for the pendulum are shown in Table 1.*
- follow the convention for headings, *for example 'length/cm' 'or mass/g'*. Don't write the units in every row as that crowds the table and wastes time.
- concerning sig fig for example, a centi-second timer might be used for timing a pendulum, but human reaction time means the data cannot be more accurate than 0.1s, so all times should be rounded to the nearest 0.1s. A thermometer may be marked every degree, but it could be possible that with experience a student can read to 0.5 or 0.2 or even 0.1℃ and squeeze an extra significant figure from the observed data.
-estimating errors is a skill that comes with practise. but a glance at the spread of data, or the resolution of the scale helps.

-for example, *the simple pendulum. where the length has been varied and two sets of twenty periods have been timed.*
-give the table a title, even 'Table 1' and refer to it in the write up.
-it could be 'the results of the pendulum's length and timings are shown in Table 1'.
-any constant values can be listed before the table. eg if the pendulum mass is not varied.
-don't forget errors for fixed variables:

pendulum bob mass = 20.3 +/- 0.2g

Table 1

Length /cm	*20T1/s*	*20T2/s*	*Av20T/s*	*Av T/s*
50.0				
60.0				
70.0				
80.0				
90.0				
100.0	*39.6*	*39.8*	*39.7*	*1.99*
+/- 0.5	*+/- 0.2*	*+/- 0.2*	*+/- 0.2*	*+/- 0.01*

Data processing and presentation

-the raw data is turned into a format from which the aim can be assessed.
-this usually involves performing calculations on the data.
-it often includes graphing, finding gradients etc along with error analysis.
-sometimes it may need diagrams, labelling, maps or cross sections.
-all processed data must be clearly headed.

2. Data processing

The golden rules for data processing are as follows:

-explain and show how the data is to be processed. If it is a repetitive process, it need not be done for every single reading, one example should be sufficient.
-include the processed data in the same table as the raw data if this is more efficient
-whether included in the old table or needing a completely new table, the same golden rules apply in having a heading, names, units and consistent sig fig etc as with the raw data table.

-for example in the pendulum experiment, *the period T is found by dividing the time t for the number of swings by the number of swings N*
T = t/N with time in seconds
-the raw data for the time of 20 swings can be processed into the period of the pendulum by adding another column, headed (period/s), avoiding the need to rewrite the table again
-consider another example, *an experiment to measure the density of a microscope slide.*
-suppose the data is as follows:

length l = 7.52 +/- 0.05cm
width w = 2.48 +/- 0.05cm
height h = 0.098 +/- 0.002cm
mass m = 5.03 +/- 0.01g

-the data analysis only needs a calculation: a graph is not necessary.
the density d = m / l x w x h

putting in the numbers d = 5.03 / 7.52 x 2.48 x 0.098 = 2.752 g / cm^3
-now part of the analysis is to calculate the error.

Note: the final calculation of error here is strictly part of aspect 3 (see below), however it is included here for completeness.

The core syllabus explains about errors, but here is a quick summary:

-if $a = b + c$ then $\delta a = \delta b + \delta c$

-if $a = b - c$ then $\delta a = \delta b + \delta c$

-if $a = b.c$ then $\delta a/ a = \delta b/b + \delta c/c$

-if $a = b/c$ then $\delta a/ a = \delta b/b + \delta c/c$

-if $a = b^n$ then $\delta a/ a = n.\delta b/b$

-constants have no error eg $\delta\pi = 0$ or $\delta\pi/\pi = 0$

-if the error calculation is the same for each result, show one example of how it was done.
-state the form of error equation, put the numbers in and show the unrounded answer.
-now round the error to one sig fig only.
-round the analysed data so that the error is in its least sig fig.
-for example, *consider the density of the microscope slide from above*

As $d = m/lwh$ then the error equation is

$\delta d/d = \delta m/m + \delta l/l + \delta w/w + \delta h/h$

putting in the values

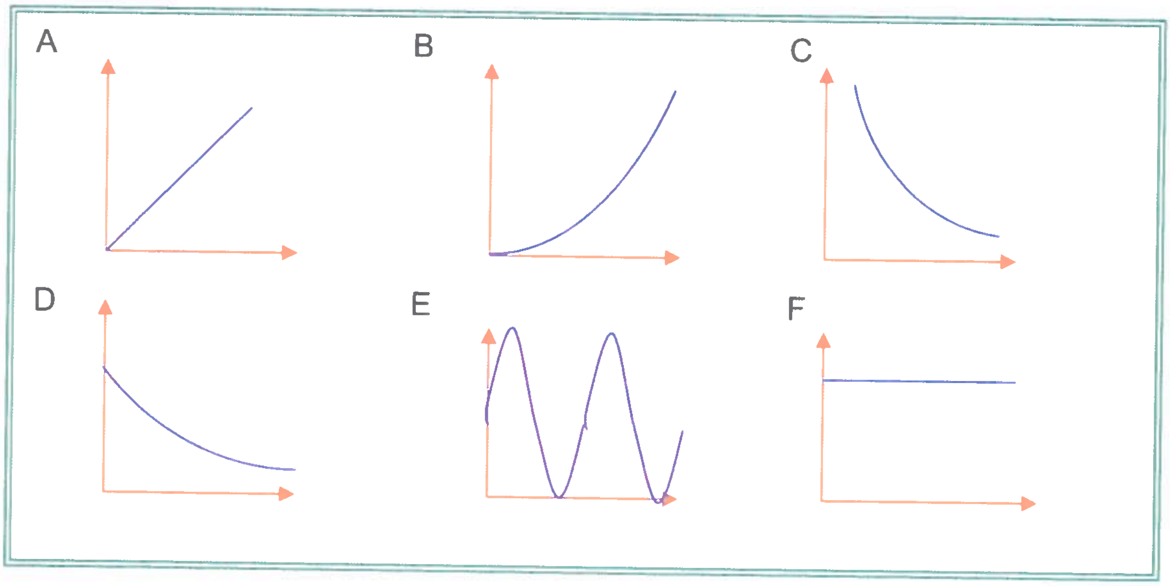
$\delta d / 2.752 = 0.01 / 5.03 + 0.05/7.52 + 0.05/2.48 + 0.002/0.098$

$\delta d = 0.002 + 0.007 + 0.020 + 0.020 = 0.049\ (4.9\%) = 0.134 g/cm^3$

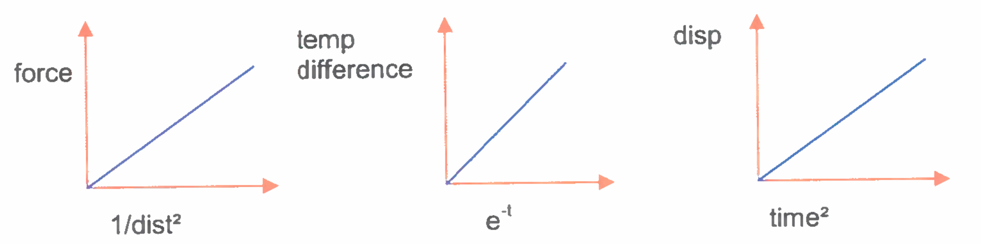
the answer 2.752 +/- 0.134 is not rounded so 0.134 becomes 0.1
so the rounded answer is 2.8 +/- 0.1g/cm^3

3. Presenting processed data

In a case such as the density of a microscope slide, there seems little advantage in trying to put the data in a graph. All that is needed are the steps leading to the density calculation which are clearly displayed, as well as the error analysis. In most experiments though, the data can be better presented in graphical form. A first step is to:
-plot a graph of the dependent variable against the independent. Here are some possibilities:



-A. if it is a straight line, then there is a linear relationship between them. $y \propto x$
-such an example could be the force-extension graph of a spring.
-if not, the shape of the curve might suggest the relation, whether reciprocal, inverse square, or quadratic, exponential.
-B is quadratic so $y \propto x^2$, but could be a higher power x^3 or generally x^n as human eye is not so good.
-such an example could be the cross-sectional area of a ball bearing and its diameter.
-C is reciprocal so $y \propto 1/x$ or similar $1/x^n$ as above.
-such an example could be the pressure and volume of a gas at constant temperature.
-D is exponential decay so $y \propto e^{-x}$.
-such a graph could be the count from a radioactive source with time.
-E is sinusoidal so $y \propto \sin x$.
-this could be the voltage generated with time for a dynamo.
-F shows no relation so y is independent of x.
-this could be the period of a pendulum when varying the mass of the bob.
-from the hypothesis, the expected relationship between the dependent and independent variable is known so a graph of that relationship can be prepared.
-for example, *if the force (change in weight) of a magnet due to a second one depends on the inverse square of the distance between them, then a graph of weight change against 1/dist² should yield a straight line graph (see first graph below).*

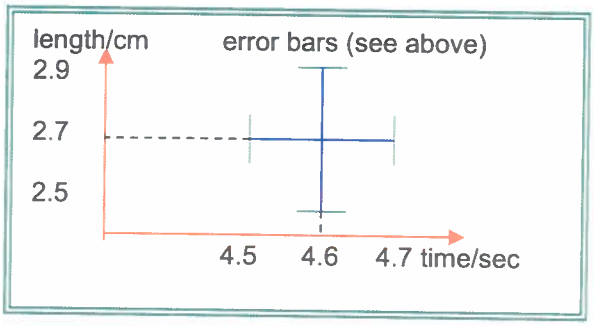


-if the temp difference of a cooling beaker of water is expected to follow an exponential decrease with time, then a graph of temp difference against e to the power of - time (e^{-t}) should also give a straight line. See the middle graph above.
-if the distance travelled depends on time² then a plot of dist v time² gives a straight line (last graph).
-the golden rules for getting a straight graph from an equation are:
-write the full equation with the dependent variable alone on the left (the 'y' side).
-remove all constants and variables that are held constant.
-replace the equals sign with the proportional sign.
-by plotting what's on the left against what's on the right will give a straight line.
-For example, the force between charges is $F = k Q_1 Q_2 /r^2$. If force F and distance r are varied, Q_1, Q_2 and k are constant
$F \propto 1/r^2$ so a plot of F v $1/r^2$ gives a straight line
-another example the displacement $s = ut + \frac{1}{2}at^2$ for a uniformly accelerated object.
-if s and t are varied then u, ½ and a are constant so removing them and the equals sign gives
$s \propto t^2$ so a plot of s v t^2 gives a straight line.
NOTE: I have not used the terminology 'positive (or negative) correlation' as that seems more applicable to biology where there is much more scatter of data and there may be less confidence. However, such mathematical descriptions could be relevant here too.

Error bars

Error bars are the visual representation of the errors on the readings, as plotted on a graph.
-an error bar is a line drawn on a plotted data point that shows the range and therefore maximum and minimum values the reading could have.
-e.g. a time is measured to be 4.6 +/- 0.1s when a length is 2.7 +/- 0.2cm
-the time could be as low as 4.5s or as high as 4.7s, the length from 2.5 to 2.9cm
-the data point is plotted on the graph, length v time with coordinates (4.6, 2.7). See below.

-a vertical line is added to the point and goes from 2.5, up to 2.9.
-the line is usually ended with short horizontal lines to make the limit clear.
-a horizontal line is drawn from 4.5 to 4.7 ending similarly with a short vertical bar at each end.
-this is repeated with all the plotted data points.
-the error bars represent the axes of an oval area inside which the reading lies.
-error bars assist in drawing the line of best fit.
-the best line crosses as many error bars as possible-a minimum of two thirds of them.
-if the mean point has been plotted (see below), then it is a question of turning the ruler about this point until it crosses most error bars.
-in most cases (as with actual errors), bars are all the same size for a given experiment.
-if the % error is constant then error bars grow with the size of the reading.
-sometimes individual errors are different, if readings are known to be taken under different conditions.
-e.g. if a meter has to be replaced with a lower quality one during an experiment then the error bars will be accordingly different.



Mean point

-the mean point of a set of data is the point that has the mean coordinates of all x and y values.
-suppose n data points are taken, (x_1, y_1), (x_2, y_2) ... (x_n, y_n)
-the mean value of x is given by $X = (x_1 + x_2 \ldots. x_n)/n$ and y by $Y = (y_1 + y_2 + \ldots\ldots. y_n)/n$
-if all the readings carry the same accuracy, then the best line *must* pass thorough this point.
-the point (X,Y) is plotted and a ruler is placed on it and turned back and forth to find the best line.
-for the best line there should be as many points above the line as below the line.
-the points above and below must be fairly scattered, i.e. all those above the line should not all be at one end as that would suggest the line could be rotated further to make some of them below the line.
-the line does not have to go through the origin, even if no intercept is expected (there could be a systematic error that has not been taken into account eg friction, forgotten zero error etc).
-calculators can do a least squares fit or 'linear regression'.

Gradient

-when points follow a straight line $y = mx + c$, the gradient and intercept can be found.
-the gradient m (or slope or tangent) is found by drawing a 'slope triangle'.
-two points are chosen on the line which are widely separated (but not on the axes).
-a horizontal line is drawn from the lower point, a vertical dropped from the higher to create a triangle with the line itself being the hypotenuse.
-the vertical side is called the *rise*, the horizontal is called the *run*.
-the gradient is found by calculating the ratio rise to run.
-if the coordinates of the first point are x_1,y_1, the second point x_2, y_2 then the gradient m is given by

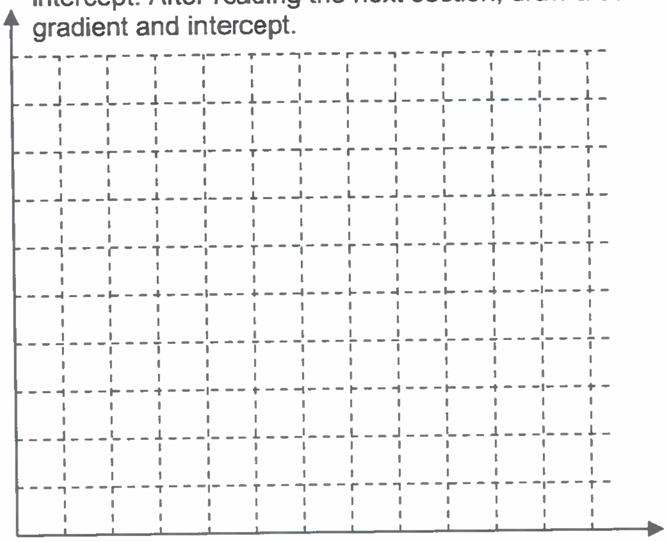
$$m = (y_2 - y_1)/(x_2 - x_1)$$

-show the working out. Usually the gradient has units. These can be found by the ratio of units of y to units of x. Quote them.
-the gradient often represents an important quantity such as gravity or spring constant so make sure you understand what it means.

Intercept

-in the straight line formula y = mx + c, c is the intercept on the y axis.
-this can be found by reading where the line crosses the y axis (ie when x = 0).
-if the x axis does not start at zero then extend the line until it reaches x = 0 or extrapolate.
-the intercept also has units.
-it also usually represents an important quantity such as work function or might be the 'zero' error sought in the experiment. Make sure you understand what it means.

Task-plot a line from the data of mass vs vol, with error bars, measure gradient and intercept. After reading the next section, draw a second best line to find error on gradient and intercept.



Mass/g	Vol/ml
1.9	2.0
3.4	4.0
5.4	6.5
6.9	8.0
7.9	10.0
9.9	12.0
+/- 0.5	+/- 0.5

Answer shown on the next page

Second Best Lines

-it is possible to determine the error on a gradient or intercept in two ways.
-the first involves using the equation of the line and using error analysis
-for example for the simple pendulum, $g = 4\pi^2 L/T^2$ so

$\delta g/g = \delta L/L + 2\delta T/T$

-suppose the value of g found from the gradient is 9.93 m/s²
-taking a middle reading say

L = 0.800 +/- 0.005 m and T = 1.80 +/- 0.02 s

-putting these values into the error equation gives

δg = 2.65% or +/- 0.27 m/s² which rounds to +/- 0.3 m/s²

-the final answer would be rounded to 9.9 +/- 0.3 m/s².
-this first method can be used when the equation of the function is known.
-however, it cannot be used when the exact relation is not known and it is limited as it only uses an approximate value for the errors, those errors from just one of many points on the graph.
-the second method uses all the points on the graph to estimate the error on the gradient and intercept.
-the best line is, as it says, the line that the points are most closely following.
-however, there is a family of lines that could also fit the points, though not as well.
-a second line is drawn (still through the mean point if there is one) that covers at least two thirds of the error bars that is as far from the best line as possible, but can still be considered to fit the points.
-if this second line was to be drawn any further away, it would definitely not fit the points.
-though it is called the second best line, it is in fact the *least* best line.

-this second best line could be the steepest possible or the shallowest possible line.
-the gradient is taken of this second line.
-the difference between the gradient of this line and the best line is the error on the gradient
-for example, if a second line is plotted on the pendulum graph and is found to be 9.42 m/s², then the difference is

9.93 – 9.42 = 0.51 so the answer is g = 9.93 +/- 0.51 which is rounded to

g = 9.9 +/- 0.5 m/s²

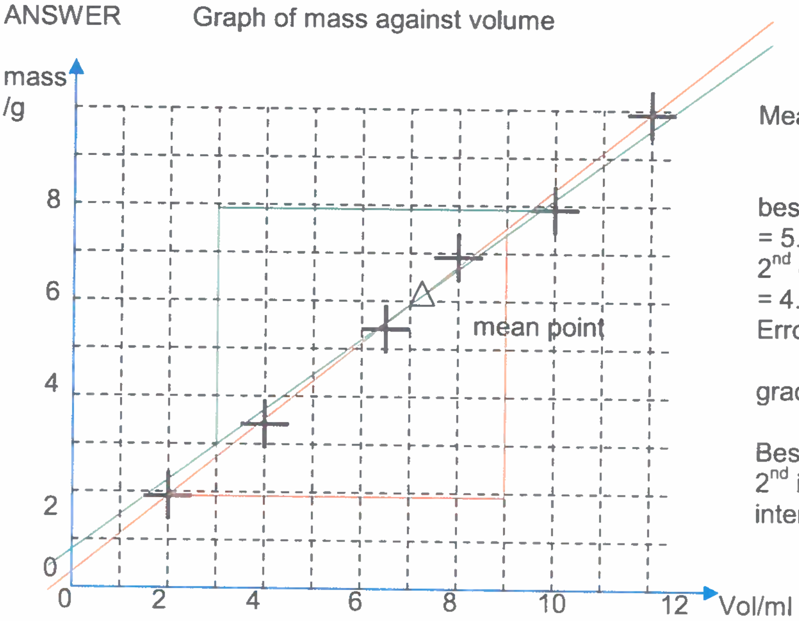
-the same method can be used to find the error in the intercept.
-the intercept is found from the best line.
-the intercept is found from the second best line.
-the error in the intercept is the difference between the best and second best intercepts.
-for example, if the first intercept is c = - 0.016m and the second is -0.0.19m then the error is 0.003m

So c = -0.016 +/- 0.003m

-note this intercept could be a systematic error and one example of its cause in this experiment would be if the student measured the length to the top of the bob and not to the middle, being out by 1.6cm on each length.

Draw a second best line on the previous graph and find the error in the gradient and intercept.

ANSWER Graph of mass against volume



Mean coord Y = 6.0 g
X = 7.1 ml

best grad = 7.6-1.9/9.0-2.0
= 5.7/7.0 = 0.81g/ml
2^{nd} grad = 7.9-3.0/ 9.7-3.0
= 4.9/6.7 = 0.73g/ml
Error = 0.81-0.73 = +/-0.08

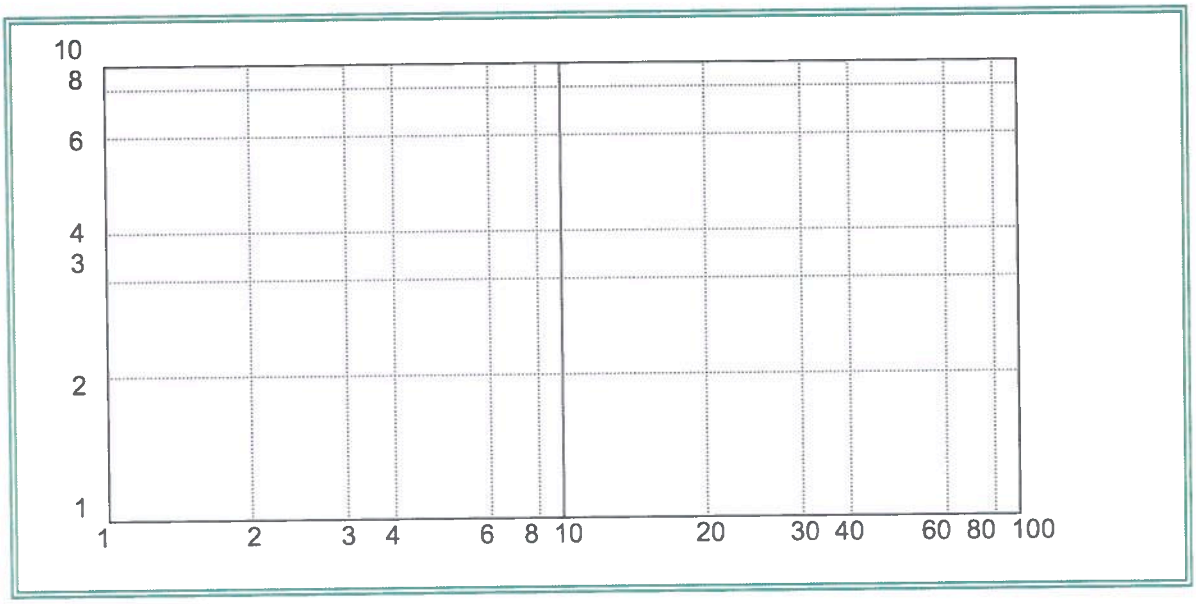
grad = 0.81+/-0.08g/ml

Best intercept = 0.3g
2^{nd} intercept = 0.8g
intercept = 0.3+/-0.5g

NOTE: best line fits can also be done using graphic calculators (regression line analysis)

-if the relationship between the two quantities is not known, but it is a power law of the form $y \propto x^n$ when n is the unknown power, then plotting y and x on log-log graph paper will reveal a straight line. Taking the gradient using *actual* distance on the slope triangle will give the power. If log-log paper is not available then calculating the log values of the two variables and plotting them on ordinary graph paper will also work, it just takes longer.

An example is given below:



Here is some data

mass/g	distance/cm
1	10
3	5
5	4
10	3
30	2
100	1
+/- 10%	+/- 10%

Plot these points on the log-log graph paper above with distance on the y and mass on the x axis. Add the error bars (see above). Draw a best straight line. Draw a slope triangle and measure the gradient by using actual distances (i.e. lengths of the sides of the triangle in cm rather than mass/dist units). It should be close to a round fraction (about -0.5, making the relation dist is prop to 1/√mass)

C Conclusion and evaluation

This skill measures a student's ability to evaluate the results, comparing them to expected or predicted values and to assess the practical problems with the method, suggesting suitable solutions to those problems. This is the section that is most poorly scored by students, mainly due to the discussion lacking detail. Quantity is not a measure of a good conclusion, but it would be hard to do a short one that is perfect and complete. This section is split into three parts:

- drawing conclusions
- evaluating procedures
- improving the investigation

1. Drawing conclusions

The golden rules for drawing conclusions are as follows:

-go back and check what the aim was of the experiment.
-state very clearly what has been found.
-use error analysis to decide on the accuracy of the result.
-compare this result with the expected result.
-a confident result should have a small error and the error range should include the expected result.
-if either or both requirements are missing, then doubt is cast on the accuracy of the results.

-for example, *suppose the accn due to gravity was calculated from a simple pendulum experiment to be 9.8+/-0.2 m/s².*
-*if the accepted value of gravity is 9.83 +/- 0.02m/s² (state your source), then it is clear that the accepted value for gravity falls within the error range of the experimental value and that the experimental value has a small error (0.2 on 9.8 is about a 2% error).*
-*if however, the experimental result had been 9.75+/-0.03 m/s², then the accepted value (9.81-9.85m/s) does not overlap at all with the experimental range 9.72-9.78m/s.*
-*this suggests that the error assigned to the experimental value is too small and/or there is a systematic error.*
-take the example of *the density of a microscope slide*:

The value of the density of the microscope slide found in this experiment was 2.8 +/- 0.1 g/cm³. According to the Phillip Harris Science Equipment Catalogue 2007, their microscope slides are made from silica glass. The Merck Index states that silicon glass has a density between 2.53 and 2.57g/cm³. Taking the experimental error range into account (even the 'unrounded' value of 2.75 +/- 0.14, which is stretching the credibility), it still does not include the accepted value. So either

- *the errors have been underestimated.*
- *there has been a systematic error.*
- *the microscope slide's glass type has been mis-identified.*

The slide looked new and the sides seemed to be 'square' as they fitted into the calliper jaws perfectly (within observational error) and no chips or foreign material were seen on the slide after cleaning. The callipers and micrometer were both checked for zero errors and none was found. The fact that slides are factory made, there are likely to be minor differences from one slide to another. The dimensions suggest the standard slide should be 7.5cm x 2.5cm x 0.1cm, which if this was the case then the density would have come out as 2.67g/cm², closer to and including the expected value within the error range. However, the same callipers had been used previously to measure the diameter of the old French centime coins-made to be exact integer mm values and the results were well within the 0.05cm error quoted.

The laboratory does have a collection of microscope slides and there seem to be batches of slightly different shades of glass, suggesting that perhaps they do not all have the same origin and therefore may not all be made of silica glass. In the section of the Phillip Harris Catalogue for slides, there are special slides made of soda glass and even lead glass, both of which have higher densities than silica glass (2.62 and 2.79 g/cm² respectively from 'Physical Constants by M. Wise P 137), so it is most likely that the slide material was mis-identified.

NOTE, the above discussion is an example, but it should give an idea of the sort of conclusion style that is looked for in order to obtain a complete

2. Evaluating procedures and 3. Improving the investigation

I actually find it more useful if the evaluation of the procedures and results and the improvements of the investigations are treated together. They are effectively complimentary as one deals with 'problems' and the other deals with 'solutions'.

The golden rules for evaluating procedures are as follows:

-list a minimum of four problems encountered in the experiment.
-if you list more problems (e.g. six), then some borderline problems can be ignored and full marks are still possible.
-they must be very specific problems, not general, vague ones.

The golden rules for improving the investigation are as follows:

-for each of the problems mentioned above, suggest a solution.
-the solution should have been applied during the experiment if noticed in time, but could also be as an afterthought.
-the solutions must be precise and not vague at all.
-a problem and its solution can be written in pairs or in a table and a column for each could be drawn.
-it is advisable to suggest, say, six problems and six solutions, in case some are rejected by the examiner, so there are still enough to gain full marks (four good ones should be enough).

-for example, consider the crater experiment from dropping ball bearings into sand.

-problem 1: the ball bearing kept rolling away and getting buried in the sand.
-solution 1: a magnet was used to keep it in place and pull it out of the sand.

-problem 2: the sand needed to be flat to keep the height constant.
-solution 2: the sand was levelled using a set square to drag across the surface. A spirit level was placed on the set square when sitting on the sand to check it was level.

-problem 3: for higher drop heights, the ball bearing hit the bottom of the tray.
-solution 3: using a greater depth of sand would have helped, but there was none left.

-problem 4: the release of the ball bearing involved friction when slipping through the fingers.
-solution 4: a thin sheet of wood was clamped horizontally at the required height and the ball was held in place below the sheet by a magnet placed on the sheet above. When the magnet was quickly raised away from the sheet, the reduced magnetic attraction allowed the ball to fall sharply without friction.

-problem 5: the readings were not very accurate.
-solution 5: be more accurate next time.

-problem 6: the dropping height was difficult to measure with a metre rule as it would sink into the sand.
-solution 6: use a micrometer.

-problem 7: Andrea hogged all the sand and wouldn't let the rest of us have any.
-solution 7: use all the sand in one tray to create the depth required and students take turns dropping the ball bearings.

Some of the above are not good suggestions! Did you spot them? This is why:

1. A real problem-some students kept their ball-bearings in a dish, but nothing beats using a magnet to get the ball out of the sand!

2. Just like the long jump pit! If we wish to measure a vertical height with accuracy, the surface of the sand must be horizontal. This solution would make the distance error no more than a few mm.

3. Another realistic situation. And a realistic solution, but if there's no more sand, then using a deeper but narrower tray might be a suitable compromise.

4. Letting the ball slip through the fingers or even letting it fall off the end of a 'plank' still causes starting errors. The magnet release is a fine remedy. If the ball bearings were not steel, then it would be harder to resolve.

5. Both problem and solution are far too vague: be specific. For example, say what is not accurate about the data-the craters were not very circular, or it was hard to hold the ruler horizontal just above the sand without disturbing the sand. One solution could be: eight diameters of each crater should be

made (instead of four) to reduce the random error, or six craters for each height should be measured rather than three. As for the ruler problem, one could suggest clamping it, or resting the ends on small blocks that are far enough away from the edges of the crater but low enough to reduce parallax between ruler and crater. Or even laying the ruler on the sand next to the crater and taking a digital photograph for measuring later.

6. A good problem but clearly unsuitable solution! One could sit the end of the rule on a thin plastic/card square to spread the weight of the ruler, or in fact push it into the sand until it touches the bottom of the tray and on smoothing the sand flat, note the depth of sand then subtract that from the total height.

7. A good solution but not the best way to word the problem. One should avoid being too emotional or personal in a lab report (can you imagine Einstein writing 'I couldn't measure the time dilation of the relativistic motion because Lorenz wouldn't let me borrow his stop clock'?!). Better to put 'there was insufficient sand for the six groups working in the lab' or possibly 'the trays were too wide for the amount of sand available.

The above problems and solutions on the whole would merit a complete for the aspect.

D Manipulative skills

This is a measure of a student's ability to assemble equipment for a given experiment without help, to follow instructions, follow safety procedures and to do so in an organised fashion. It is now assessed summatively, meaning one overall score for the course rather than the two best lab scores as it used to be. This section is split into three parts;

- following instructions
- carrying out techniques
- working safely

1. Following a variety of instructions

Instructions are the building blocks to performing a successful experiment. They are the logical steps that make up the stages leading to the collection of data and the safe use of the apparatus.
The golden rules about following instructions are:

-follow the instructions *accurately*.
-adapt the method to new circumstances.
-seek help when required.

Instructions can come in various forms, which can include:
-**oral instructions**. The teacher gives instructions via the spoken word.
-**written instructions**. The teacher writes instructions on the board, OHP, or on worksheets. The students could also be asked to read information from a text book.
-**diagrammatic instructions**. The teacher draws diagrams or prints diagrams for the student to follow.
-**photographic instructions**. The teacher gives students access to photographs of the apparatus.
-**demonstrative instructions**. The teacher shows the use of pieces of apparatus 'live' in front of the student, or students watch a video of instructions.
-**audio instructions**. The teacher allows the students to listen to an audiotape.
-**flowchart instructions**. The teacher displays the steps to do an experiment in flowchart form.
-**modelling instructions**. The teacher uses a model of the real apparatus as the real one is either too large or too small.
-**computer program instructions**. The teacher allows the students to interact with a computer simulation of the experiment.

Examples of good and bad practice in following instructions include the following:

-good students will write down the instructions given by the spoken word. If printed instructions are not supplied, the IB expects a record of what is said so they can ascertain what is the student's own work and what was already decided.
-good students also make a copy of instructions written on the board. The best way to do this is to include it on the back of the lab report front cover or in the lab book.
-a bad habit of some students is to write nothing and continually ask their friends or teacher (if the instructions were given orally), or look at the blackboard, until the teacher clears it for other purposes and then the student doesn't know what to do! Either way, they waste time and become less accurate.
-a good student watches carefully when a teacher demonstrates how to use a piece of apparatus, asks questions if allowed to and makes written notes.
-some students are unable to concentrate on listening or even watching instructions and once again they end up disturbing other students or the teacher during their hands-on practical time.
-where instructions are given a day or so in advance, a good student does the appropriate background reading or even asks to have a look at the apparatus if allowed.
-a poor student makes no effort to do anything towards better understanding the instructions.
-a good student looks after instruction sheets and knows where to find them with a moment's notice.
-a poor student loses theirs or has no idea where they have put their instruction sheet! Which are you?

The above list may seem almost too obvious to mention and even an insult to a student's intelligence, but the sad thing is that every year I still get students who choose to avoid doing the basic actions needed for a successful intake of instructions!

2. Carrying out techniques

In this aspect, students are assessed on their ability to carry out and use a range of different techniques and equipment. The golden rules are:

-use a wide range of different equipment.
-use a variety of techniques

Though a metre rule, triple beam balance and stop clock are very versatile, it is important for a student to show that they can make use of other equipment.
Instead of a metre rule use a micrometer, vernier callipers, tape measure or metre wheel.
Instead of a stop clock use a digital stop watch, millisecond timer and light gates, hour glass or water clock (one might want to test the accuracy of Galileo's original experiments to find the equations of motion!)
Instead of a triple beam balance use a digital balance, pan balance, spring balance, inertia balance etc.

The same goes for experiments involving others topics from the syllabus. For example:
Heat-standard liquid-in-glass thermometers can be complimented by digital thermometers, strip thermometers, gas thermometers or resistance thermometers.
Waves-tuning fork and length methods can be varied by using frequency meters, oscilloscopes, stroboscopes and actual distance-time measures.
Electricity-both analogue and digital meters can be used and not only the standard voltmeter and ammeter, but milli-ammeters etc, shunts and multipliers, ohm-meters, multi-meters, ballistic galvanometers, coulomb-meters, the list is almost endless.

It is now obligatory to perform at least one computer controlled experiment. This could be with a data logger or a computer simulation. Performing one experiment is a minimum-doing more would increase experience and success.

It is more difficult to be specific about using a variety of techniques. Some different techniques have been mentioned in the context of designing an experiment. For example, *finding the diameter of a crater formed in sand by a falling steel ball bearing:*
-taking a photo from above with a rule in the picture.
-use vernier callipers and making readings 'live'.

-a lamp can be used to illuminate at a low angle to accentuate the shadows and improve the contrast to get a sharp edge to the crater.
As another example *the period of the pendulum:*
-the usual technique is to let the pendulum swing say from right to left and start timing as the bob passes the midpoint, then stop it after an even number of half swings.
-to eliminate bias, one could also time swings as it goes from left to right, or time an odd number of half swings.
-with suitable technology the timing could be done as the bob cuts a light beam from a light gate connected to a millisecond timer.
-when varying the length of a pendulum, it is usual to set at least half a dozen different lengths and time ten swings for each length, then repeat two or three times for the same length.
-one could instead take times for eighteen different lengths-one set of ten swings each.
-the study of *circular motion is often done with a student spinning a cork on the end of a string that passes through a glass tube with a vertical weight supplying the centripetal force. A student normally has to spin and count rotations and measure the period all at the same time.*
-it might be a good idea to work in pairs: one student concentrates on spinning while the other times and counts, then they swap over.
Another example-*finding the volume of a steel ball bearing*
-diameter could be measured using vernier callipers or a micrometer and then calculated using $V = 4/3\, \pi\, r^3$
-or the volume could be found by displacing water in a measuring cylinder-perhaps using several ball bearings.
-the mass of the ball can be measured and knowing the density of steel, the volume can be found by $V = m / d$.
By using several techniques a better value should be obtained.

The list of techniques is endless and ideas will come with experience. One of the biggest sins committed by students in this area is not fully using their hands-on time efficiently. Once they have taken their minimum of six readings three times over, they treat the rest of the time as a well earned break! No! If time is left over,
-take more readings than the minimum.
-try an alternative technique.
-try and improve the present technique.
-take readings from one setting many times to have a better idea of the random error involved.

The last point can be illustrated with the good old pendulum experiment.
-on one length setting, time ten swings, but then repeat it say a total of ten or twenty times.
-as one set of swings is only likely to take about ten seconds, it is not impossible to do it many times.
-the spread of timings for ten swings will now give a better picture of the randomness of the data.

3. Working safely

The golden rules for safe practice in the lab are as follows:

-apply the normal safety procedures in the lab.
-listen to the teacher for any additional rules of safety.

The most important safety rules are:
-wear safety glasses when using dangerous chemicals, open flames or hot liquids. You only have two eyes to last a life time and partners find them attractive so hold onto them!
-tie long hair/fringes back when using open flames. Hair can ignite and burn in seconds.
-avoid loose, flappy clothing. Catching the end of a piece of apparatus in a sleeve and knocking it over is not only embarrassing but can be lethal.
-avoid showing too much flesh. Garments can act as protection even for a few seconds and if damaged can be replaced, but skin-burns can be permanent and disfiguring.
-do not sit when using open flames or hot liquids. It is impossible to escape quickly from a flame or hot spill when sitting.
-keep the working surface and the surrounding area clear. Clutter causes accidents.
-be aware of what other groups are doing in the vicinity. It's like knowing what the rest of the traffic is doing on a busy road by using rear view and side mirrors.

-do not carry too much equipment in one go. Take your time with repeated trips.
-use apparatus only in a way for which it was designed. Don't use the metre rules as swords, boys!
-do not touch any apparatus without permission. 5000V can be nasty.

The student is expected to be competent in the use of techniques and the equipment. They must also demonstrate a methodical approach.

For example, suppose *a student is finding the latent heat of fusion of ice by electrical method. In this experiment, an immersion heater is placed in a funnel of ice and connected to a power pack, a voltmeter and ammeter are placed in the circuit to measure current and voltage and the amount of ice melted to be collected over a timed interval using a stop watch. The student should:*
-be familiar that an immersion heater should never be left ON when not surrounded by the material to be heated. This can burn out the element.
-connect the voltmeter and ammeter with the correct polarity and not allow the pointers to shoot off either end of the scale as it is likely to cause permanent damage to the instruments.
-know the danger of mixing water and electricity so keep them a suitable distant apart.
-be familiar with checking the meters and balances for zero errors and adjust them accordingly.
-if repeating procedures (e.g. another batch of ice) that they reproduce exactly the techniques used, under the same strict limits of changing only one variable and other similar restrictions.
-also treat the apparatus with the same methodical use, for example use the same heater / ammeter / voltmeter throughout (unless of course that is not possible-i.e. if one breaks).
-should not throw the ice around or slip it down people's necks. Yes it has happened!

E Personal Skills

Personal skills are now only graded during the Group Four Project (see later). However, that does not mean that such skills should be ignored during all the other practical work. For this reason, the section is included here. Personal skills involves working with others. The golden rules of teamwork are:
-recognize the contribution of others.
-expect others to contribute to the experiment.
-expect to make your own contribution to the team.
-encourage the contribution of others, especially reluctant or less confident members, by seeking their input.
This skill concerns the individual and independent aspects of the student. It includes self-motivation and perseverance, working ethically and being concerned about the environmental impact of their investigations. This section is split into three parts;

- self motivation and perserverance
- working within a team
- self-reflection

1. Approaching scientific investigations with self motivation and perseverance

The golden rules for independent skills:

-approach the investigation with self motivation.
-see it through to completion.

-there is nothing worse for a teacher than an able student having absolutely no interest in the work.
-usually a student has chosen to do IB physics and therefore is automatically interested in the subject.
-some have selected it as their least worst science!
-whatever the student's background, coursework is required for every IB subject and it can be approached with a positive attitude and the chance of something positive coming out of it will be increased, or with a negative attitude and end up as a self fulfilled prophecy.
-the fact that a student can gain some 24% of their final grade before they have even set foot in the exam hall should be motivation enough for every student to go for it!

Examples of good and bad personal skills

A class was given the task of studying an aspect of dandelion parachute seeds. A bright group of students selected air currents and used a fan of different blowing speeds to modify the seeds' falling paths. It was a hot afternoon; the task was not being graded as it was a training exercise. The students rushed their readings to finish early and didn't repeat any of their settings. This did not go down well. Like any activity, it can be enjoyed more when approached with a positive attitude

Often students taking repetitive data such as the swinging pendulum cannot wait to end the task. When they finish early, I ask them if they have repeated readings or if they have taken more than the minimum of six readings and they have to be reminded that it is a minimum. I ask them if they have covered a wide enough range. More data can always be taken.

A very bright, assertive girl was working with a very passive boy on the SHC of a metal by method of mixtures. They had the awkward task of somehow lowering a copper cylinder into a beaker of boiling water then transferring it to the beaker of cold water. Due to the smooth shape of the cylinder and the task being hard due to the scalding temperatures, they were unable to secure the block with string as with the other cubic blocks. Time was running out and sadly the girl was ready to give up. She had decided that it was impossible and was put off by the difficulty of the task and the lack of time left. The boy merely followed her lead. The teacher intervened by using thick copper wire to make a more rigid harness.

Working in an ethical manner

In this aspect, a student is expected to pay considerable attention to the authenticity of his/her data. It is one of the aims of the IB. The golden rules are:

-do not plagiarise (that means not copying someone else's work and claiming it as your own).
-give sources of all information gathered.
-do not ignore data because it fails to follow the expected pattern.
-do not invent data in order to allow it to fit perfectly with predictions.

-copying work is not acceptable, whether it is from another student in the class, or the work of a previous student, or an external source.
-if any other person's work is quoted (which is allowed), the source *must* be cited.
-quoting does not mean several pages, but a few sentences, phrases or mathematical values.
-if in doubt, cite the information.

-it is very tempting to ignore points that do not lie on the nice neat straight line graph.
-there are even famous names from physics who have been accused of such practises, Millikan for example. Learn by their mistakes!
-it is far better and more impressive to the examiner to leave such anomalous data in the table and on the graph, and to highlight them and comment about them. Honesty counts more than fixing to get perfect results.
-by being honest the examiner can see that you, the student. have noticed the anomalies and considered why they might be worthy of rejection. Evidence that the student is thinking!

-it is also tempting for students to invent or change values in order that they fit some preconceived idea of what should happen.
-this can be dangerous territory as the assumptions that have been made might be poorly founded or the experiment that has been performed now contains a systematic error that was not anticipated.
-a common example from physics for such inventing is in the very simple experiment of hanging 100g masses on a Newton meter and students often round the answers to 1N. 2N up to 10N exactly as the readings are so close to whole numbers (it should be 9.8N for 1000g).
-density blocks that are made to be exact cm dimensions but in reality maybe 1mm below are often rounded up by students.

Examples of good and bad practice:

One student, who was very bright and understood the underlying concepts behind an experiment, worked backwards, by drawing the expected relationship as a straight line on a graph, then plotted points, then worked out the co ordinates then wrote the table of data as if it had been taken for real! Though the student clearly understands the physics this is still cheating.

Another student who had difficulty working at speed was left to complete the lab during lunch. Instead, he copied some one else's data (he didn't want to give up his free time!) and passed it off as his own. The teacher spotted the identical results when marking the labs. This practice is also unethical.

Paying attention to environmental impact

While this skill is no longer assessed separately, it is important to be included in fulfilling aim 8 of the IB science objectives. This skill concerns trying to minimise the negative impact on the environment when performing the investigation.

The golden rules for minding the environment are:

-think in advance of possible environmental impacts.
-use no more resources than necessary.
-use correct disposal procedures.

-this environmental aspect is an awkward one for physicists.
-it seems more readily applicable to chemistry, and biology with regard to safe disposal of chemicals, taking care of living organisms and respecting habitats.
-there is normally very little to impact the environment in physics experiments, except for perhaps the extreme example of using radioactive substances (normally under strict teacher supervision anyway), but this skill area has to be achieved in order to score a full three points, so, consider the following guidelines that can make a physicist more environmentally friendly:

-dispose or store chemicals safely, as expected in chemistry. There are not many chemicals to worry about in physics, but they could include mercury in the gas law experiments or even in broken thermometers, acid as used in Charles Law and lead acid batteries.
-use rechargeable batteries in circuit kits and sensors and where that is not possible, put the dead batteries in the correct recycling bins.
-use radioactive materials very carefully (usually not handled by students), though potassium can be used for the long half life of K40 and also needs consideration.
-take an energy-conscious approach to the use of electricity-don't leave things on when not in use, wasting an irreplaceable supply, or leave the heating on and then opening the windows to cool down!
-use all school resources sparingly, such as writing paper, or amounts of 'disposable' items, such as paper towels, and don't leave the tap running.
-don't leave Bunsen Burners on when not needed-the Greenhouse Effect is already bad enough as it is!

Examples of good and bad environmental practises

-one of the commonest examples from my experience is the students' use of paper towels. They pull off handfuls from the rolls in the labs, irrespective of the size of the spill to clean up.
-making electric circuits without a switch. This is common as the Morse code type switches are notoriously poor contacts, but without some control, students leave the circuits on and run down batteries.

2. Working within a team

The golden rules for team work include:

-do your share of the work.
-make sure others participate and do their share of the work
-communicate, collaborate and be courteous!

-a team is made up of two or more people working on the same experiment.
-it might be that several individual students have to use the same pieces of apparatus (e.g. a digital balance) and under such circumstances the individuals are effectively part of the same team.
-this idea can also be extended to the use of the whole lab especially when clearing up is concerned!
-the most important aspect of teamwork is **collaboration**. This relies on **communication**.
-in most situations, there is a pecking order among the members of a team, from those with leadership qualities to those shy and timid members and if unchecked, the aggressive ones will easily override the passive ones.
-it is up to the assertive ones to redress this natural imbalance. In fact it is up to every member of the group to aim for and work at collaboration.
-the loudest person is not necessarily the most correct in their ideas.
-the least confident may not have the weakest plan.
-these differences have to be by-passed and true scientific objectivity be taken on board.
-an idea must not automatically be accepted because it has come from a friend.
-likewise, plans should not be rejected if they come from a 'stranger'.
-finally, a team member must recognise the needs of others in order to complete any task.

Though performing an experiment is not the same as a game of football, there are some important overlaps with a team sport. Consider the extreme example of the football player who keeps the ball and never passes it to their own team members. Experience (and game theory) has shown that such a team is less likely to win than one that passes the ball. At the other extreme, there can be players who dread receiving the ball for fear of doing something wrong with it - it happens more in the non-professional, forced team sports found at school. However many reluctant players could have 'hidden' skills or skills that could be nurtured if suitably encouraged and such players. if allowed to bloom and grow in confidence could be much more useful players in future games.

Examples of good and bad teamwork:

-in a group four project (see below) where a student was selected to be 'team leader' as they were thought to have those skills, went off and worked by themselves. No discussion or interaction took place with the rest of the team. This team leader was highly motivated and it would have been better if they had agreed aims and details with the less assertive group members.
-in a gas laws 'circus', two sets of each of the three gas law experiments were set up round the lab and students had to visit each several times during the lesson as the temperature was changing. Though each student was collecting their own data, natural groupings formed from queues waiting for the next temperature. One student quite clearly had no time for those in the same 'group' and read quickly then moved on and in several cases, pushed up the temperature for their own data, thus leaving the next set of students to miss out on lower temperatures. In other groups of students, they synchronised their efforts, so when one apparatus gained thermal equilibrium, the other students were called over to efficiently take their readings, all at the same time or at least in quick succession
-a pair of negative feedback behaviours occurs often in the form of the over passive student who sits back and lets their partner do everything, decide everything and the over-assertive student who is quite happy to take control and not allow their partner any input. Both extremes are not good and both lose out.

Recognising the contributions of others

The golden rules for dealing with team contributions include the following:

-listen to and ask for other team members' ideas.
-take on board the good ideas.
-give credit to team members where due.

Recognising the contribution of others in group work is akin to citing references when quoting sources in an extended essay. But here it means to literally say it out loud! This is where one student identifies and acknowledges what others have done towards the practical. The teacher listens out for these kinds of compliments in order the assess students for this skill. It doesn't mean that you artificially speak out loud 'oh thank you John that was a really good suggestion of yours to use a clamp stand' with all the sincerity of a wooden actor! Say something good if something good has been done. Show a bit of encouragement. It is already what teachers try to do as teachers. as it can inspire people on to

greater success. It doesn't have to be like the cheer leaders in a sports tournament, but the idea of team spirit is the same.
-in a team it is important to expect the views of others.
-if ideas come from only one member or a part of a group then it is not teamwork!
-team members must therefore actively seek the views of others.
-this applies to a practical group from only two students up to a Group Four Project team that could have a dozen or more members.
-in most experiments, there is not a great deal of time available to sit around and discuss the work-it's already hard enough to get through the syllabus!
-if more than a lesson's notice is given for an experiment, then members should get together in breaks or free periods to discuss what has to be done.

Examples of good and bad practice

-in deciding how to measure the conic angle of limpet shells, one boy in a separate group overheard the discussion and suggested using a light to create a shadow of the shells on a wall, the larger outline of the shells being easier to measure than the smaller shells of only a few cm diameter. His idea was taken up then shared round the other groups-credit being verbally given to the originator.
-some mussel shells were so small that filling them with sand and finding the volume of sand was very inaccurate. One student realised the shell could be refilled with sand several times and all attempts poured into the same measuring cylinder so a better average could be found. Another student observed this method, then used it and began claiming that it had been his own idea. This is not fair play.

Exchanging and integrating ideas

In order to fully earn the title of a team, ideas must be exchanged between team members.
Whatever the final task might be, it should have the ideas of all team members integrated into the method. This skill in most people may not be intrinsic and it can be a struggle against the natural 'looking after number one' survival reaction.

The golden rules for exchanging and integrating ideas are much the same as for recognising the contribution of others:

-listen to and take on board other members ideas.
-offer one's own ideas
-combine the best of all ideas, irrespective of their originators.

-this can be a difficult skill to achieve in view of the natural pecking order that manifests itself in any group situation.
-those with strong views must play down their attempt to dominate discussions.
-those willing to let themselves be led and to take a back seat need to push themselves forward.
-the teacher is usually well aware as to which camp each student belongs. so each student has a different emphasis to fulfil.
-the quiet one has to fight against the desire to remain quiet and let themselves drift with the majority. especially if they have good reason to think it is not the best approach.
-similarly. the loud, pushy ones need to deliberately hold back and give the others a chance to voice opinions that might in the long run be better than theirs.

Examples of good and bad practise:

-In the group four cloth experiment (see details below) one student noticed each cloth seemed to have the same width and suggested they might all have been cut from the same original piece. The other groups sensibly listened and agreed to check and they found they were exactly the same width and even fitted together like a jigsaw.

-in the same group four cloth project. one student suggested (before the width observation had been spotted). that the number of threads per cm in each direction on the cloth could be counted and compared for each cloth. No one bothered to take on this idea. which was a shame as it had been this

very technique used on a real cloth identification experiment (the Turin Shroud) and the individual groups lost valuable time from lack of cooperation. The reason the idea was not taken on board was that many considered this particular student too bossy and resented being 'told' what to do.

3. Self-Reflection

This final aspect of personal skills addresses a student's awareness of their own strengths and weaknesses as well as reflecting on the value of the learning experience. The golden rules for successful self-reflection are:

-highlight your strengths
-be honest about your weaknesses
-be objective about the learning

-rightly feel proud of your strengths, whether it's accurate data collection or finding solutions to practical problems or whatever.
-modesty has a place but don't overdo it!
-don't waste time fishing for compliments-as with real fishing you might wait a long time!
-don't bore people with how wonderful you are either (if you are that wonderful you won't need praise from others!)
-don't avoid or hide your weaknesses.
-admit them and consider how you may improve.
-self pity is unhealthy-stop sulking and go do something about it!
-some experimental work may be highly successful and it is quite easy to cope in a winning situation.
-some practicals may be disastrous, complete failures in terms of answering the aim.
-however, more can usually be learned from failures than successes.

Common lab report mistakes

All labs are different but it is clear that students tend to make the same simple mistakes much of the time. These slip-ups and oversights can easily be avoided if a student reads over the teacher's comments on the previous labs and if the student also uses a guide such as this at hand each time a lab report is being written up! But here is a quick list of the commonest mistakes:

- name of student or experiment missing from the front of the lab.
- pages not stapled together or stapled in the wrong order.
- no aim given.
- no title on results table.
- results not fully boxed in a table.
- column headings incomplete or lacking units.
- errors missing or inappropriate errors given.
- data not rounded to be compatible with the errors of one sig fig.
- no calculation example of how the data is manipulated.
- no example of how the manipulated error is calculated.
- graph paper not used for the graph.
- no title on the graph.
- no units on the graph axes.
- a poor scale chosen e.g. 1cm = 7kg.
- graph smaller than half the page.
- data points confined to a small corner of the graph (i.e. origin included when not needed).
- no best line drawn or drawn free hand and without use of mean point.
- no gradient found nor its units determined.
- no second best line drawn nor used and no error on the gradient.
- no intercept calculated, nor second best nor units nor error.
- only the merest comment in the conclusion e.g. 'the lab worked well'.
- no comparison to the expected result given
- a minimum of four specific problems and solutions not offered.

The list above is not exhaustive but should give most of the major omissions made by students when writing lab reports.

Lab Report check list-reminder

In order to assist the writing of lab reports, the following list of questions should be of some value. Any given lab may not need every piece of information mentioned. It is up to the student to make a value judgement on what to use and what to ignore. Most of the report can be word-processed, though the diagram and graph work are preferred free-hand. Similarly, any given lab may not be evaluated in every skill category, but a complete lab should be written (unless otherwise stated) as the practise is useful and it also allows a more thorough revision for data based exam questions.

Have you included a title to your assignment?

Have you stated the aim of the experiment?

Do you need to discuss the background theory at this point?

Is there a diagram of the apparatus?

Is it drawn with a sharp pencil and ruler (or word processed)?

Is it at least half a page and labelled?

Have you clearly described in sufficient detail how the experiment was carried out?

Is it in the correct tense and person?

If the lab involved planning, have you had to modify the procedure?

Are the results clearly tabulated?

Is the table numbered and referred to?

Is the table drawn with a sharp pencil and ruler (or word processed)?

Does it follow the lines of the paper?

Did you include units in the column headings?

Have you assigned an error to your readings in the appropriate part of the column?

Are the readings and errors compatible?

Is there evidence of error calculation where needed?

Is there a graph of the data?

Is it titled or matched with a given table?

Are the axes' units suitably chosen to demonstrate the relationship?

Is it suitable graph paper?

Is it at least half a page?

Is it drawn with a sharp pencil and ruler (or word processed)?

Is it a sensible scale?

Are the axes fully labelled?

Have you plotted points as small crosses or similar?

Have you double-checked your plotting?

Have you included error bars?

If it's a straight line, have you plotted a best fit using the mean (x,y) or similar ?

Have you calculated the slope and intercept?

Have you included their units?

Have you drawn a second line or similar to determine their errors?

Have you compared your findings with the expected to predict relationship/value?

Have you evaluated your findings and your method?

Have you suggested where things went wrong or could be improved?

Have you given credit to any references?

Have you put all the pages in the correct order and stapled them together?

Have you put your name on your work?

If the answer to all the above questions is YES, then you should feel confident in handing in your work.

The Group Four Project

The Group Four Project is an obligatory part of the science coursework for the IB. It consists of a project involving all science disciplines working on the same theme. It is such a varied topic; it cannot be described by simple guidelines. What is most important is what you, the student, contribute to the project, as some of the skill areas are used by the teacher towards your coursework grade. The project is used to test your personal skills A and B and it is the only part of the coursework that is, so it is very important to take it seriously! What follows is a brief overview of the project, followed by some advice that can help get the most out of it and make you a more successful scientist!

Stages

There are three stages to the Group Four Project

- planning
- action
- evaluation

It is expected that students spend 10 hours hands on investigating.

Planning

-every school is different and some may merely give the project topic as decided by the teachers.
-some may allow students to choose their own topic, or at least do so within certain limits.
-whatever the selection process, there is an introductory meeting, where the topic is decided, which is then followed by a brainstorming session, where ideas are shared and discussed.
-often students of different disciplines are mixed together in smaller groups in order to hear the task from different stand points and promote greater interaction.
-while it is fun to work with your best friends, it is as important to be able to work with and get along with others-this happens in the real world, not just in science labs but in every profession.
-whatever topic chosen, the activities must be clearly defined.

As an example of a very successful project (which our school has done twice with a four year gap and likely to be a regular in future), the Group Four Cloth was chosen as the theme (based on the real science research of the Turin Shroud). It was set up along the lines of a 'crime scene investigation'. In the introduction, the students were given a brief background to the science research done on the religious artefact, in order to determine its history. The students were then split up into six mixed groups, each with a carefully selected choice of members to avoid all friends, all gender or any seriously clashing characters. Each group had a leader chosen by the teachers, based on their proven skills in academics, practical and personal areas. Each group was then given a piece of cloth and asked to find out the cloth's history and see how theirs linked with the other cloths. The cloths were covered with all manner of stains, marks, imprints etc, lending themselves to an abundance of studies To start them off each science was given a named task; the chemists to identify the white powder on theirs, the biologists to find and identify any pollen grains in their fibres and the physicists to identify their cloth from some 40 given samples (this aspect you will have met earlier in this booklet). Apart from these tasks, the students had to decide the rest for themselves.

The above project was very structured by the teachers, but is only one of a spectrum of possible projects to do, from the very structured to the very open ended types such as 'how safe is the school environment?'. That is not to say one type is better than others-a variety is good in order to keep the teachers 100% enthusiastic every year!

The definition of activities may depend on just how big the science class is.
-this can be done by individuals for their own specific tasks, or in pairs as is usual lab work.
-this can be done within each discipline or within each working group.
-in the example of the 'Group Four Cloth' above, this happened at every level-first leaders within each group got their separate discipline members to define activities, then leaders got together to compare

notes, then they fed back to their members and modified their tasks in the light of new information. This was to bring a consistency in how data was to be collected so it could be compared like to like.

Action

The action stage is expected to take up at least half of the total hands on time of the project.
-usually the work is spread out over a few weeks, but could be over a longer period (with less meeting times a week) in case there's a need for long incubation times (growing plants, observing corrosion etc).
-some projects may have the action stage on one day, e.g. visiting a dolphinarium to collect the data.
-students should investigate the project from the perspective of their discipline-the biologist should study the biology, the chemistry the chemistry etc but it is not obligatory.
-the important point is that they contribute to the project.
-if a student is doing two IB sciences, they do not have to do two action phases.
-usually a two science student will do one lot of action during one science lesson (e.g. physics) and the other action during the other lesson (e.g. chemistry)
-collaboration is expected during the action process. One group of students may discover something that will help others and vice versa and this part of the project is there to mimic what happens in the real science world where information is shared for the benefit of all.
-this collaboration may be difficult if all action occurs within individual lessons, but students can be encouraged to have meetings, put ideas on a bulletin board, have working lunches or homeroom discussions.
-of course during the action stage, students should follow the previously mentioned guidelines of working ethically and take care of their environment.
-in the Cloth example, team leaders were expected to meet between practical sessions and exchange ideas and state progress. One advantage was that biology and physics were taught at the same time which included every student so most students were working along side each other and interaction was freely possible. Enthusiasm for the project meant that informal discussions were happening all the time and when one student made an important discovery on their cloth, the news was communicated rapidly to see if other clothes shared the same history. It became clear early on that all six cloths had been cut from the same original piece; some had related pollens and when one group observed their cloth under uv light and found fluorescent information, the others tried as well and were also successful.

Evaluation

-the Group Four Project usually ends with a two hour feedback presentation. The form it takes can be decided by the teachers or jointly with the students.
-a common form of evaluation is for the students to present their findings, either to the whole group in the form of a conference or to the whole school in the form of a 'science fair'. Or in fact both.
-in the science fair approach, the students take over the labs (or theatre) and lay out their findings, both the successes and failures and explain to their passing audience what they have done
-it is very important that next year's IB science students get to see the results of a Group Four Project to make them better informed when it's their turn.
-the science fair method allows students to shine and show off what they have achieved, plus making science more accessible to those who see it removed from everyday life. I have seen staff, parents and administration come away appreciating the Group Four in the same way they would enjoy a school play, musical evening, or art display.
-some schools may request written evidence in the form of a lab report.
-this is not a requirement for IB, but may be for the schools own internal grading.
-students are only graded in their personal skills (see above page 26)
-a self assessment form is a useful tool to use at the end of a Group Four Project and I have found students are generally quite honest and objective about their own contributions.

The Group Four Project can satisfy some of the IB aims of
-using information and communication technology.
-raising awareness of ethical, moral, social, environmental and economic aspects of using science.
-highlighting the international dimension of scientific collaboration.

Preparation

This stage is more directed to the teachers but can also involve the students. It looks at the impact the project will have on the normal school schedule.
-students may need to be excused from other lessons.
-non science teachers or outside guests may need to be involved.
-questionnaires may be needed and free access to the photocopier.
-materials may need to be ordered in advance.
-the timing of the project needs to be discussed and decided so as to disrupt the normal school day as little as possible.
-the forms of communication available to coordinate the project most efficiently must be chosen.

Strategies

(a) Considerations

Initially the factors that will decide strategy are:
-the number of IB sciences offered. If for e.g. chemistry is absent, that will modify the project chosen.
-the number of students doing IB. If greater than a limit, then two separate projects may be offered.
-if there is another local IB school which might want to combine resources on a shared project.
-the shape of the school year (trimesters, semesters, school trips etc).

(b) Timing

A balance has to be found as to when the Group Four Project should occur.
-too early in the first year and students have not had enough experience, nor gained enough of the skills, nor the background knowledge.
-too late in the second year and it can interfere with other deadlines such as extended essays, world lit and TOK essays.
-in my experience, the end of the first year seems best for most projects. By then the second year students have sat their IB exams and are out of the way-so will the IGCSE students if the school does that exam (and their teachers free to give more attention to IB first years!). The laboratories are more available. Students have done a full year of IB science and other deadlines like extended essays are not until after the summer vacation.
-some schools introduce the project before the summer vacation so students can plan over the summer then perform it on return.
-some small schools do one project every two years and combine first and second year students to make enough numbers.

(c) Selecting a topic

-the advantage of allowing students to select their own topic is that they are likely to be more enthusiastic.
-however, among the sensible suggestions, there will always be 'the effects of drinking alcohol', 'how dangerous is smoking', 'coffee' and 'energy drinks', where students might see the project as an official way to over indulge in something inappropriate.
-the usual order of events is to start with a survey or brainstorming session, a discussion of the best few topics, followed by a listing of the possible investigations that could be carried out.

(d) Assessing the Investigations

-the project is only used in assessing personal skills as it involves so much possible interaction with very large group and within that framework a student's own commitment.

(e) Participation

-the same standards are applied to higher level and standard level students.
-only whole numbers 0, 1, 2 and 3 can be awarded, no fractions or decimals.
-if a teacher considers a skill falls between two scores, then it is bound to be rounded down.
-it is not necessary to have a perfect performance in a skill area to get a full three points.

The golden rules for success in a Group Four Project:

-get actively involved.
-get an early start on the work.
-plan carefully what you are going to do, don't just turn up without an idea in mind.
-be thorough!
-be honest.

The Extended Essay

-the extended essay is an integral part of the IB Diploma program.
-it is a 4000 word thesis on a topic within one of the IB subjects.
-the theme is in an argument form or is answering a specific question.
-some subjects, like French or mathematics seem to be less popular than others, but physics often generates great interest.
-the sciences do allow the possibility of an experimentally based theme, which is encouraged by examiners.

Should you do an extended essay in physics? Are you interested in physics, fascinated by doing experiments? Are you good at physics? Is there a particular branch of physics that you enjoy? Do you intend to study physics or science at university? Do you intend to follow a career in physics or science? Do you have a willing physics teacher to be your tutor? Do you enjoy constructing devices? If your answer to the majority of the above questions is YES, then perhaps you should do an extended essay in physics!

-first talk to your physics teacher and see if you are both in agreement.
-the teacher could already have several students who have asked to do their extended essay in physics and taking one more could dilute the teacher's help too far.
-the teacher might consider that you have stronger skills elsewhere, or that it is better to chose a discipline closer to your chosen career direction.
-talk to your IB co-ordinator as well (for similar reasons). They often have years of experience and can have an informed opinion of your strengths and weaknesses.
-talk to older students who did a physics extended essay and find out their opinions and experiences.
-the reality may not be what you were expecting (bear in mind the 'standing' of the students that you talk to-try to hear from a range of different people. A lazy student might grumble about how much work is involved, a genius might lead you to think it's going to be easy!).

-if you are still interested, then discuss your favourite ideas with your physics teacher.
-usually the teacher will allow the student an open choice, or may have some ready prepared burning questions that they themselves have wondered about but have never had the time to answer!
-the teacher will also have a feel for certain experimental ideas and might decide that your project is not feasible (too complicated, off subject etc).
-do not be put off by criticism which should be constructive-it could be to stop you wasting time.
-in physics it may be tempting to chose one of those fringe scientific topics, such as telepathy, divining rods or the power of the pyramids.
-these ideas are best avoided until scientific foundations have been confirmed!
-it is also tempting to choose a well established topic like aerodynamics or a fashionable topic like chaos or fractals.
-beware, as such areas are far more complex than they appear on the surface and the maths may be way beyond high school calculus!
-note there are exceptions. See the list below.
-dangerous topics should be avoided such as radioactivity, ultraviolet light etc, unless sufficient safety apparatus or a qualified person is available.
-experiments should be chosen that do not require complex apparatus or constructions that take up too much time.
-remember, the idea is to collect data that can be tested to support (or not) the given hypothesis.

There are four types of extended essay in physics, plus there could be a 'cross-breed' of two or more of them. They are;

1. Experimental-designing and carrying out an experiment, then collecting the data. An example would be the crater experiment given at the start of the book, which actually began as an extended essay and the student came up with the correct power law between projectile energy and crater diameter and supported it with data.

2. Data based-analysing and evaluating data that has been collected by some one else. An example would be to refer to a star catalogue (such as Sky Catalogue 2000), and use the data on all the listed

Cepheid variables to confirm the period luminosity law that is often quoted in books without proof. I have personally found more scatter than ever mentioned.

3. Theoretical-creating a quantitative description of an aspect of physics, using a model and discussing its outcomes and limitations. An example would be to discuss what the equations of relativity would predict if faster than light travel were possible (not for the faint hearted!) or what would happen if a medium with a negative refractive index existed.

4. Survey-a discussion of a topic that is clear and organised and is supported by qualitative analysis. An example would be using volunteers to verify the variation of pitch range with age (see below). It is important to remember that when using students for any survey-based piece of work, it is law in many countries to get their permission in writing first!

-most schools have internal deadlines for the different stages of the essay. Please respect them.
-there are external ones, but the internal ones are imposed to help keep students on track.
-it is surprising just how fast the final deadline creeps up on you!
-keep regular appointments with your teacher. Some teachers pester their students; some leave the students that responsibility.
-either way make the most of your teacher's help. They usually know what they are talking about!
-keep records of such meetings. There should be a healthy number of hours clocked up (about 4 hours, which could come from half hour meetings once a month).

-get an early start on the essay. You might think you will be older and wiser later in the IB course, which is true but you can always modify what's written or repeat readings where possible, but you will find other deadlines such as World Lit, TOK essays, college applications and Group Four Projects all start using up your time.
-guidelines are given to students and should be followed. Don't lose those documents! It happens so often and does not impress your supervisors!
-remember to cite all references; otherwise you could be accused of plagiarism.
-for an experimentally based essay, it is best to follow the general style of a lab report, with obvious modifications to the essay.
-keep a diary of what's done. It could be written up in a diary style so such subheadings as apparatus, method, results, problems and solutions would appear after each practical session.
-as with lab reports, use a word processor where possible.

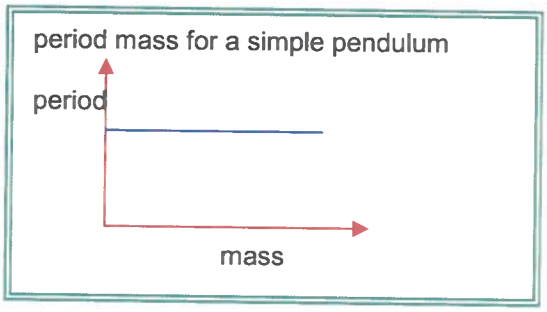
As an additional aid to anyone wanting to do an experimentally based EE, guidelines for designing a hypothesis are given below.

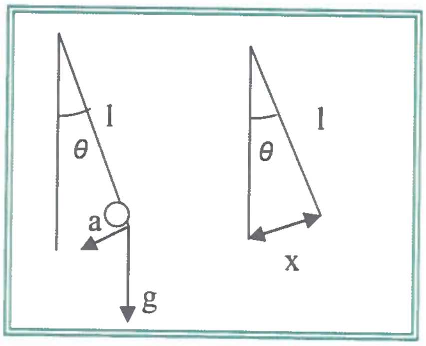
Hypothesis

The golden rules for a hypothesis include the following:

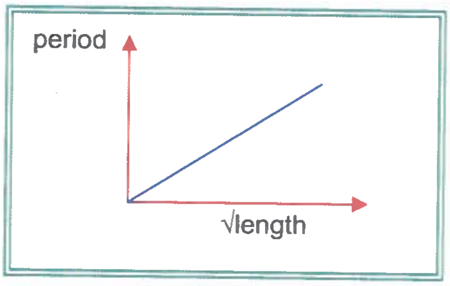
-state the physics principles involved first.
-take each variable and discuss how it will affect the dependent variable.
-suggest a possible relationship as a sentence, proportionality and/or a graph.
-give reasons for the predicted relationship.
-it is often easier to select possible variables *first* and having chosen the most important factors, go back and make predictions. See the next section.

-as an example, consider how *the mass of the pendulum might effect the period (see page 4).*
-hypothesis: from Newton's second law: force = mass x accn. F=ma
-the accn due to gravity is the same for all masses F = mg so g = F/m is constant.
-therefore all masses fall at the same rate. so the period is independent of mass.
-a graph of period against mass will be a horizontal line:





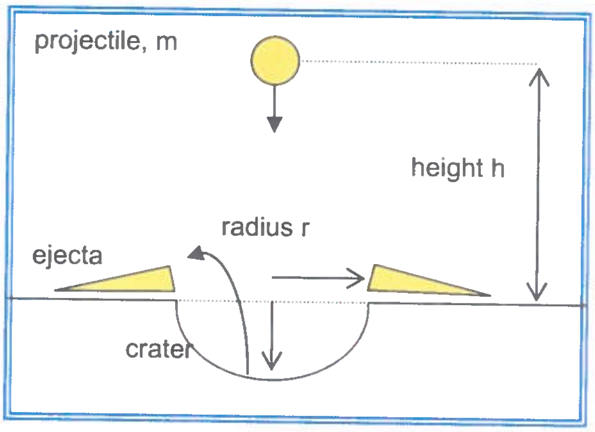
-this hypothesis can be tested.
-consider *how length of a pendulum might affect its period.*
-for a given angle θ, there will be a component of gravity pulling the bob back to the middle
a = g sin θ
θ is given by the ratio x/l (in radians for small angles), so a = g sin (x/l)
for small angles sin = angle so a = gx/l
the greater the length, the smaller the accn so the slower the bob and hence the longer the period.
-as x = ½ a t^2 then t^2 depends on 1/a and a depends on 1/l, so t^2 depends on l
-in other words t depends on the square root of the length.



-note, the theory is actually more complex than this, but even a partially derived hypothesis is better than nothing.

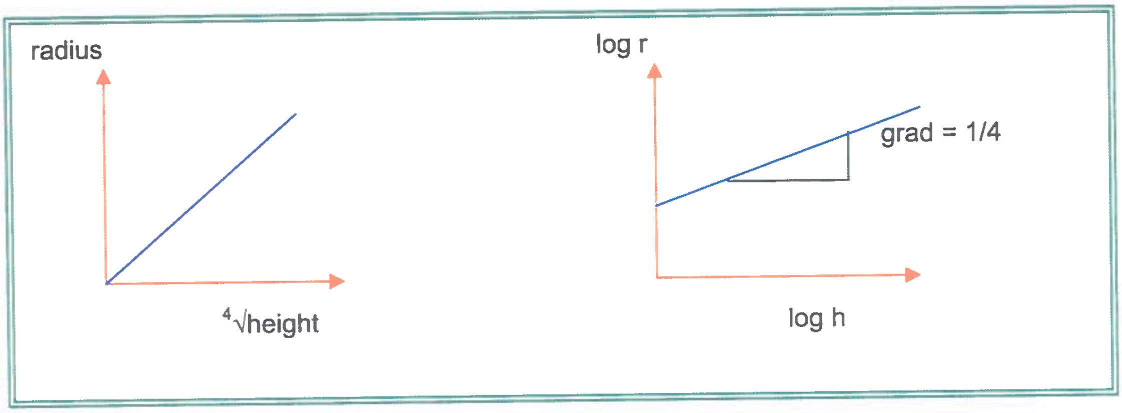
Hypothesis for the cratering experiment *(see page 9)*

It is the energy of the projectile that decides the size of the crater. The potential energy PE of the falling object is turned into kinetic energy KE, then assuming no loss, this becomes the PE of the material excavated from the crater, raising it to the level of the rim of the crater (approximately).



-suppose the height dropped of the projectile mass m is h, PE lost (PE = mgh)
-suppose the crater formed is hemispherical of radius r (even if it isn't, if one assumes the depth of the crater depends on the radius, this idea works. It could be conical or spheroid, as long as the depth depended on the radius.)
-the mass of material raised out of the crater M = ½ x 4/3 π r^3 x density (half as it's a hemisphere)

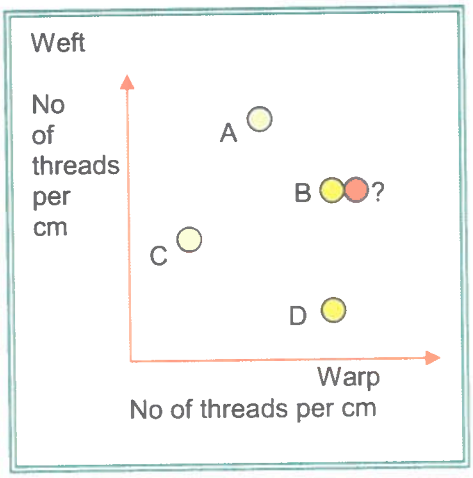
-assuming the material removed is raised by a distance r (even if it isn't, but is raised by a constant fraction of the radius, this still works), then PE = Mgr = 2/3 π r^3 x density x g x r-in other words PE is ∝ to r^4.
-as PE lost by ball is PE gained by crater material, radius to the fourth depends on height dropped.
-therefore the radius depends on the fourth root of the height dropped. r ∝ $\sqrt[4]{h}$
-a graph of log r v log h will have a gradient of ¼.

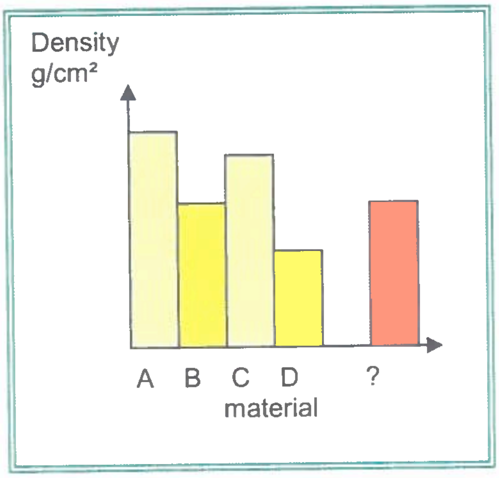


(Note-for a steel ball bearing dropped into sand, the result is actually very close to this value)

Hypothesis for the cloth experiment (see page7)

It is assumed that each sample of material has a characteristic number of threads/cm in each direction horizontally and vertically (technically called the weft and warp directions) and that this is constant across the whole sample. Thus, a graph of weft concentration v warp concentration will show a scatter of points, with the unknown sample coinciding with one of the lettered samples (within errors): in the graph examples below, the unknown material seems to identify with sample B





Assessment criteria

Students are supplied with the assessment criteria for an EE so that there is no misunderstanding as to what should appear in an extended essay. However, it is still surprising just how many students seem not to have referred to these guidelines and the unfortunate supervisor ends up forcing the student to actually open the documents and make the student read them! As the general IB point scoring tables are given to students, they are not reproduced here, but the subject specific categories are, with a clear indication of what is expected:

Criterion J-this category covers the principles of physics. The student must demonstrate an excellent knowledge and understanding of the principles of physics involved. You will not be able to bluff in this

area as the essays are marked by physicists! Neither will you impress the examiner by omission either.

Criterion K-the methods used must be appropriate to physics and relevant to the research question. They must be carefully chosen and competently used. There should be clear evidence of a personal approach by the student.

Criterion L-there must be a thorough analysis of errors in the experiment. This includes the identification of systematic errors and limitations in the model should be accounted for. The quality of sources is confirmed by using secondary sources or checking calculations. Any explanation or agreement / disagreement with the hypothesis must be supported by the analysis.

Here are some two dozen or so suggested topics that could be suitable for an extended essay:

1. Were Martian craters formed in water? Looking at rampart craters on Mars, they look similar to projectiles that have been thrown into something like mud. Try recreating impact craters in wet mud or wet sand, by using catapults or air guns.

2. What is the best form of analysis for Cepheid variable observations? A star such as Delta Cephei with a period of about a week and a large enough variation in brightness can be observed several times a week and over the whole year to amass 100+ observations. The data can be folded into a light curve to see if the period is changing, but what analysis gives the best results, e.g. fixed or moving mean methods?

3. Is there a pattern to scintillation? Draw a set of white discs onto black card and walk away. At some distance they start to scintillate (twinkle). Why? Is size important? Draw black discs on white card. Does the same happen? Is there an underlying relationship? Do all people see the same amount of twinkling?

4. What makes up the background radiation count? Set up a Geiger counter without a source in front of it and it detects the background. Does it vary during the day? The year? Can you design an experiment to find out what contributes to the b/g and how much? As a side line, it might be possible to show the elliptical orbit of the earth by this method-think about it....

5. Can school equipment detect neutrons? If you have some wax, lead, a GM tube and counter plus beryllium or boron, plus a suitably energetic alpha source, then you can recreate the original experiment that first detected neutrons. Can it be done at school?

6. Can school equipment split the copper K alpha line? If your school has the Tel-X-Ometer, then with careful modification, it could be set up to observe X rays with greater resolution, but is it enough to split the K alpha line of the copper source? Could the Compton Effect be observed as well?

7. What is the optimum water to air ratio for a pressurised water rocket to reach maximum height? Pump air into a partly water-filled container through a narrow nozzle and the compressed air will push out the water and lift the rocket into the air. Can you find the best air water mix to raise it to the highest height possible and how does that height compare with theoretical?

8. Does the surface tension of water follow an inverse square law? Take some slightly soapy water such as that used in washing up and drop water drops onto it from a height. Some drops 'float' on the water's surface for several seconds before sinking in-the surface curving under the drop like an elastic sheet under a weight. Drops can be made to orbit one another on this 'potential well' type surface. Can you make an elastic grid surface to mimic that of the meniscus of surface and use water filled balloons on it to represent the floating drops?

9. Is an ooze tube's behaviour predictable? An ooze tube is a container that allows a viscous liquid to fall in a similar way to sand in an hour glass, sold in gadget shops. The falling liquid spirals clockwise or anticlockwise as it falls and air bubbles rise, but everything is disrupted as the bubble breaks and the liquid might change its spiralling direction. Can it be predicted?

10. Is the moon's surface a fractal? A fractal is a surface that is self similar on all scales, so is there a simple relationship between the size of craters and the number of craters of that size? It would mean quadrupling the number of half sized craters. It would need some decent photos of the moon to work from. And what about other cratered bodies? Or how about trying to either model cratering on a computer or actually drop projectiles into sand and see how fractal it is.

11. How good are human estimates? Get some unknown masses and lengths (or distances) and get students to estimate their sizes, and even endure unknown time intervals and get them to estimate those. Even the apparent human skills of 'halving' things ie estimating the middle point of a line are worth researching for bias.

12. What is the complete spectrum of an electric spark? A spark such as that given out by an electric motor is known to give out radio as well as visible light. But is it possible to detect em radiation from any other part of the spectrum from a spark? It would mean the school having access to GM tubes for gamma and X rays, a uv detector, visible, infra red and micro and radio detectors (though even tuning an ordinary radio could work). What causes the radiation and therefore can its spectrum be predicted?

13. Is it easy to make a Lorenz Wheel? According to chaos theory, if water pours into buckets fixed in a Ferris wheel pattern and there are holes in the buckets, then the rate of fall of water decides whether the wheel turns one way, the other, oscillates or performs chaotic motion. Such a device is called a Lorenz wheel. Try making one out of say an old bicycle wheel and plastic basins. Can it work?

14. Catastrophe theory as applied to a stressed beam. Take a metre rule and wedge it between two clamps fixed to a desk, so that the rule bends up in the middle. Note the height in the middle. Now add a force (weights) to the middle and note the displacement. At some force, the rule will suddenly bend downwards. Repeating this for different clamp separations should in theory create a catastrophe graph. If you like the idea, look up the theory.

15. Human sensitivity to pitch. It is often quoted that the normal range of human hearing is between 20-20kHz, but how rigid is that fact and does the upper limit fall with age without exception. Does gender or ethnicity have any bearing? And how easy is it to reproduce the pitch sensitivity graph shown confidently in books? This topic is useful for those studying the biomedical option.

16. Tumbling paper-how does it create lift? Take a rectangle of paper let it fall flat. Now let it fall vertically and it rotates and falls slower. Why? What factors are most relevant? Area? Weight, length/width ratio, and, well, you find out! And how fast does it rotate? And why?

17. A ripple resonance tube. If a resonance tube is set up horizontally with a shallow layer of liquid, then resonance occurs, ripples should appear just as it does with lycopodum powder in a Kundt's tube. Can it be done?

18. A pile of sand. Pour sand slowly onto a flat surface and it seems to take on a conical shape. Does the shape remain the same as the pile grows? What about sugar or any other granular/powdery substance?

19. What is the cause for guitar strings to deviate from the simple inverse frequency length relationship?

Non-practical based extended essays

20. Is school physics literature gender balanced? While this is not a practical based essay, it would allow some statistical analysis of the use of genders in books, e.g. who appears in the photos, what is the gender of the people named in the problems etc. You may be surprised.

21. How would the universe differ if light hydrogen was not stable? This is not a practical based essay either, however, it would allow an interesting look into how stars might form, the Big Bang and lends itself to some theoretical calculations involving nuclear fusion and the composition of the universe. If deuterium was the lightest stable atom, could life evolve?

22. Can the laws of physics be logically consistent if negative mass existed? It could be interesting to explore how the laws of motion, collisions and gravity might change if there was negative mass.

23. Gravity energy levels. The equations of gravity are similar to those of electrostatics and discrete energy levels can be calculated for one mass orbiting another like an electron orbiting a proton, if standing gravity waves existed. Could these be detected?! Could it explain the Bode's Law of planetary orbits in the solar system?

24. How objective is Shroud research? The Shroud of Turin is claimed to be the burial cloth of Christ and a mountain of research has been performed on the material in all scientific disciplines. But is it coloured by the religious beliefs of the researchers? The topic lends itself to some limited experiments.
NOTE, many of the above ideas have been tried out as projects, some even as old A level projects and those that did, all came up with answers (even if the answer was NO!)

CAS work

Physics does lend itself to CAS work in the form of service. If the school is particularly small, then the budget may be limited for a full time lab technician. In my experience, I have found it very useful to have IB physics students working in the labs for many of the non-specialised tasks and this is both helpful to the department and also enriches the students' experiences, especially if they have an interest in working in a lab later in life.

Some of the tasks suitable for CAS students include the following:
-keeping track of the inventory of equipment on the computer.
-sorting out the filing cabinets.
-photocopying or putting booklets together.
-sorting out the apparatus kits.
-unpacking and checking off new equipment.
-repairing broken items including soldering.
-organising the apparatus in the lab.
-washing the glassware.

It is also possible for students to gain creative hours for CAS in science, such as making posters or even designing a piece of apparatus.

Problems (Answers at the back)

1. You are given a roll of Scotch Tape. List the possible planning experiments that could be done with such a simple item (only a phrase for each).

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2. You are given some empty limpet shells (limpet shells are approximately conical in shape without a base, up to about 5cm base diameter, 3cm high). What methods could be used to determine their volume (holding capacity not the volume of the shell material itself) and how could you see if they followed scaling laws (that is large and small are similar shapes)?

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3. You are studying the kinetic energy E of an object of mass m and velocity v. the formula being $E = \frac{1}{2} mv^2$.

a) State what you should plot against what to get a straight line if E and v are the variables, and what would the gradient represent and what would the intercept be if any?

b) Do the same again. but allow m and v to be the variables.

c) The force F between two charged spheres, charges Q and q a distance r apart is given by $F = kQq/r^2$. What would be plotted against what to get a straight line if the variables were r and F. What would the gradient equal?

d) the refractive index n for glass , if the angle of incidence is i and that of refraction is r is given by n = sin i/sin r. If i and r are varied, what should be plotted against what so n is the gradient?

4. Spot the mistakes in the table below by re-tabulating the data in the right hand columns as they should be presented. As background, a ball was timed using a stop watch as it rolled (the ball not the watch!) from rest down various distances on a constant slope, the distance measured by a metre rule marked in cm. Fill in the mean velocity column as well. The data will be used again in question 7.

distance	time	vel = dist/time	dist	time
0.3m	5.55			
0.80m	8.97			
1.1m	10.95			
1.5m	12.23			
2.3m	14			
4.2m	21.04			
+/-2cm	+/-0.01s			

5. Rewrite these answers with their errors, all rounded to the correct number of sig fig:

a) 1.385 +/- 0.24

b) 45.8 +/- 2

c) 198 +/- 0.4

d) 198 +/- 19

6. A field has dimensions 34m by 78m with a metre error on each length. Find the area and error.

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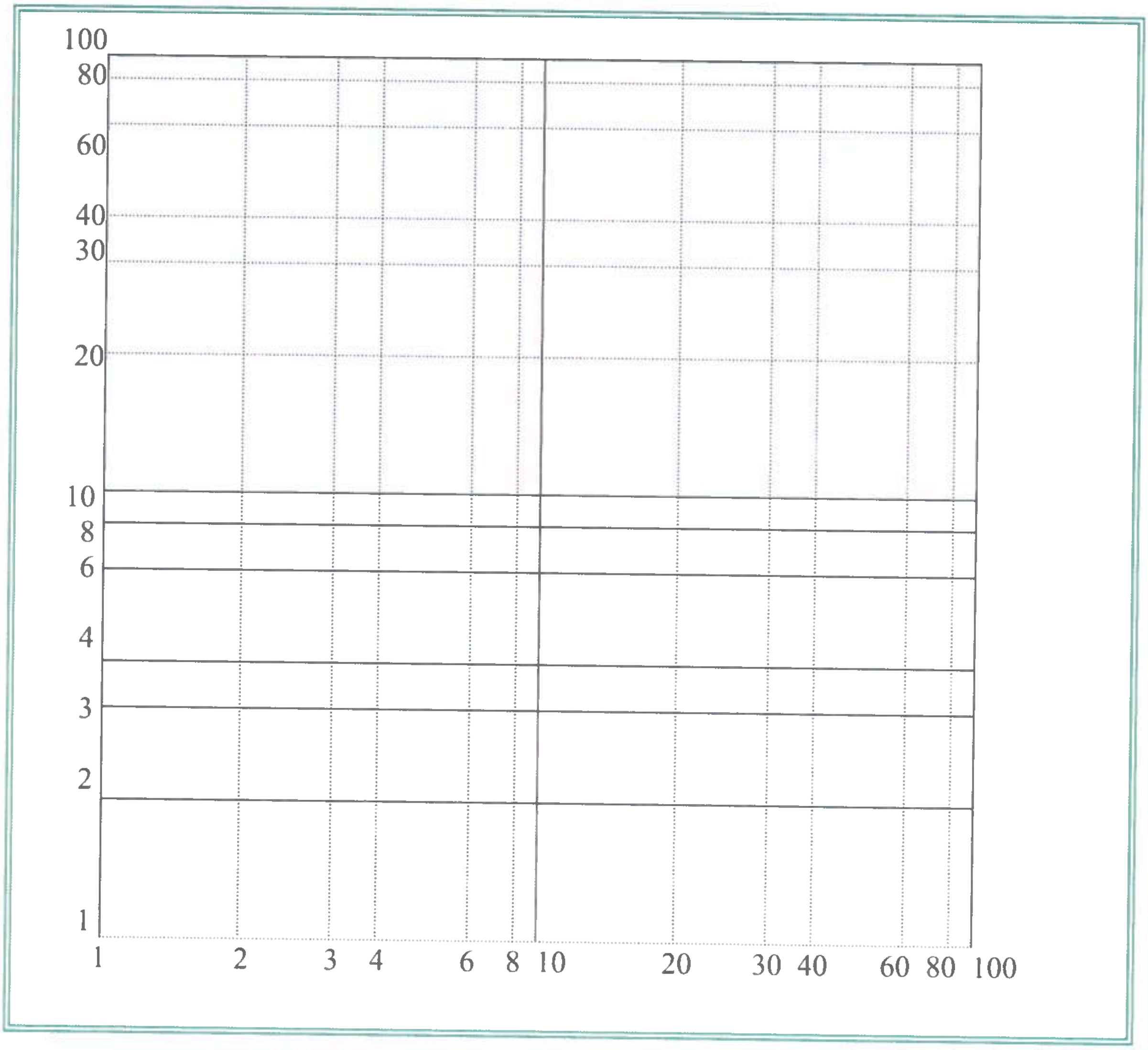
7. (a) Take the data in the table from Q 4 and graph dist v time on the log log paper given below to find the power law. Change the axes scales appropriately.

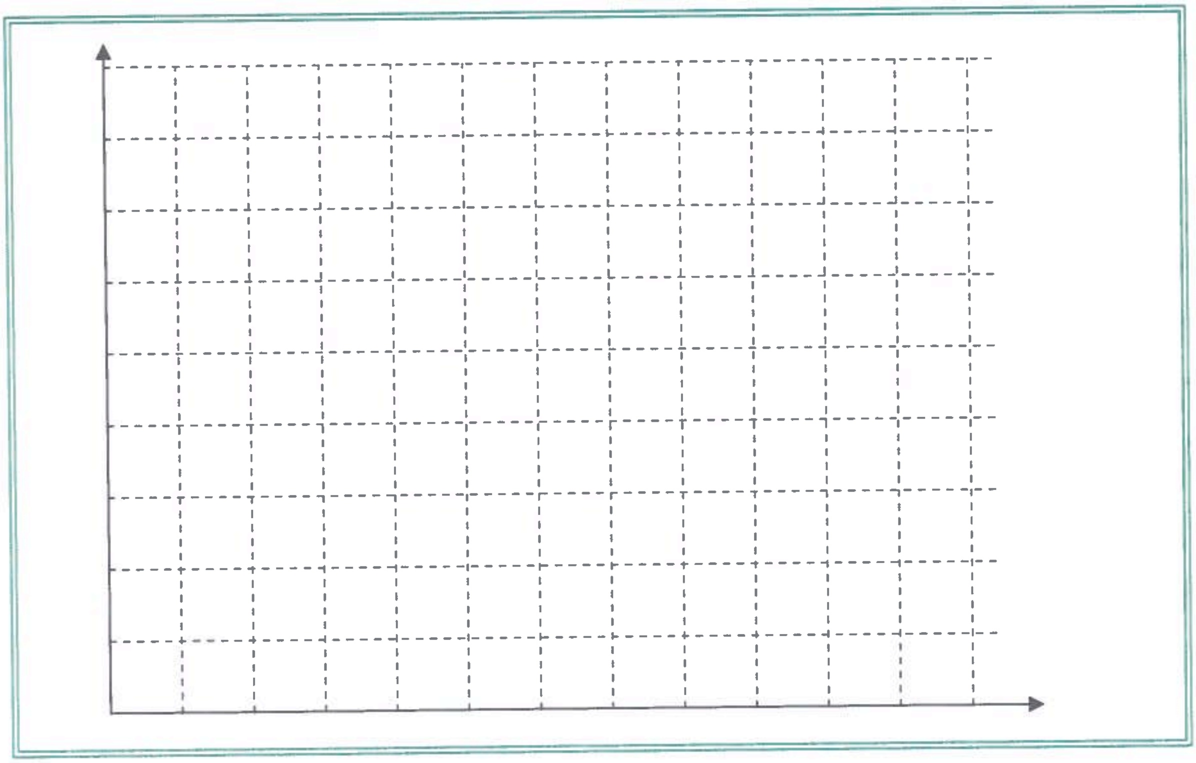
(b) Take the data in the table below and record it as it should be in the right hand columns. Use the same log log paper to find the power law. Use new axes scales top and right of the graph. For your information, the data shows the accn of a trolley using a constant force as the mass is varied. Assume normal lab apparatus was used to make these measurements (balance, ticker timer etc)

Acc/cm/s²	g	.	.
433	104		
215	196		
90.4	403		
56	792		
28.12	1412		
13.7	3188		
+/- 10%	+/-10%		



8. The force between two charged spheres was measured as the distance between them varied. Complete the table by calculating $1/dist^2$ and its error then plot F vs $1/d^2$ on the linear graph given, find the gradient and intercept and the corresponding errors

Dist/m	Force/N	$1/dist^2$ $/m^2$ +/- error
0.042	0.044	
0.075	0.021	
0.095	0.014	
0.100	0.007	
0.120	0.005	
0.170	0.003	
+/- 0.005	+/- 0.001	



9. Consider an experiment to study the factors affecting the time a flat sheet of paper takes to fall to the ground. Derive a formula for the terminal velocity, from the clue that the PE energy lost by the falling paper will be KE energy gained by the column of air it encounters (i.e. that volume of air will end up with the same velocity as the terminal velocity of the falling paper). Or from impulse considerations. NB, hypothesis is not required for the internal assessment, but is part of the extended essay.

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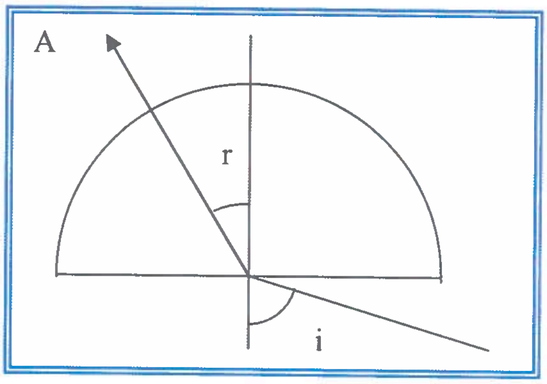
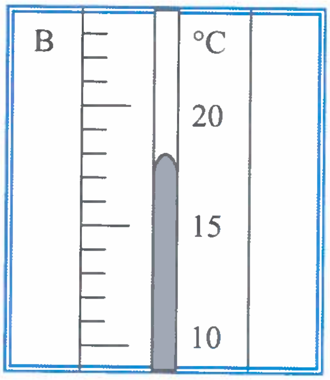
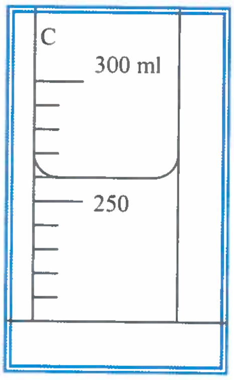
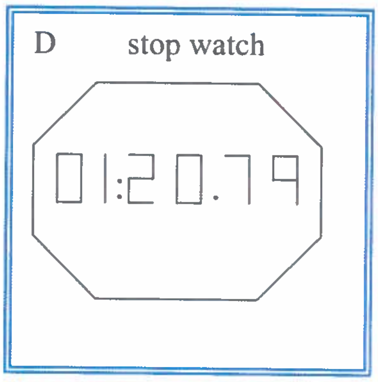
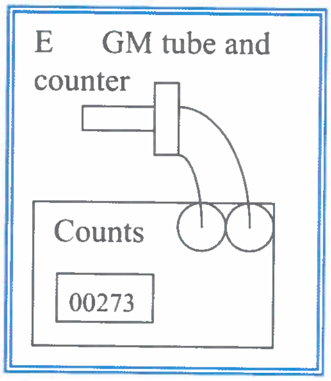
10. Read the following scales and assign errors to the data:

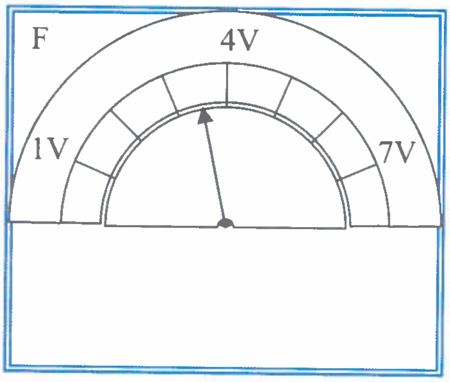












Answers

1. Scotch tape-breaking force. Here are some suggestions:
   - -the force required to snap the tape.
   - -the sticking properties of the sticky side.
   - -what weight can be lifted without becoming unstuck?
   - -the force needed per cm^2.
   - -the effect of temperature on sticking ability.
   - -the static charge gained when the tape is unrolled. There are probably several others.

2. Limpet Shells-calculation of V is not good enough as the space inside is only approximately conical.
   i) The best way is to fill the shell with a material then find the volume of that material (or its mass and use the density of the material to calculate the volume is V = m/d).
   ii) Water can be added or removed using a syringe, hence volume can be found.
   iii) Similarly sand could be used which avoids the problem of drops being left behind and surface tension effects of over filling.
   iv) Even clay/plasticene could be moulded into fit the space, then mass found or even reshaped to a regular shape or using a eureka can.
   v) The limpets could be pushed under water and the air bubbles collected by upward displacement into a burette or similar.

The list of possible ways is quite long!

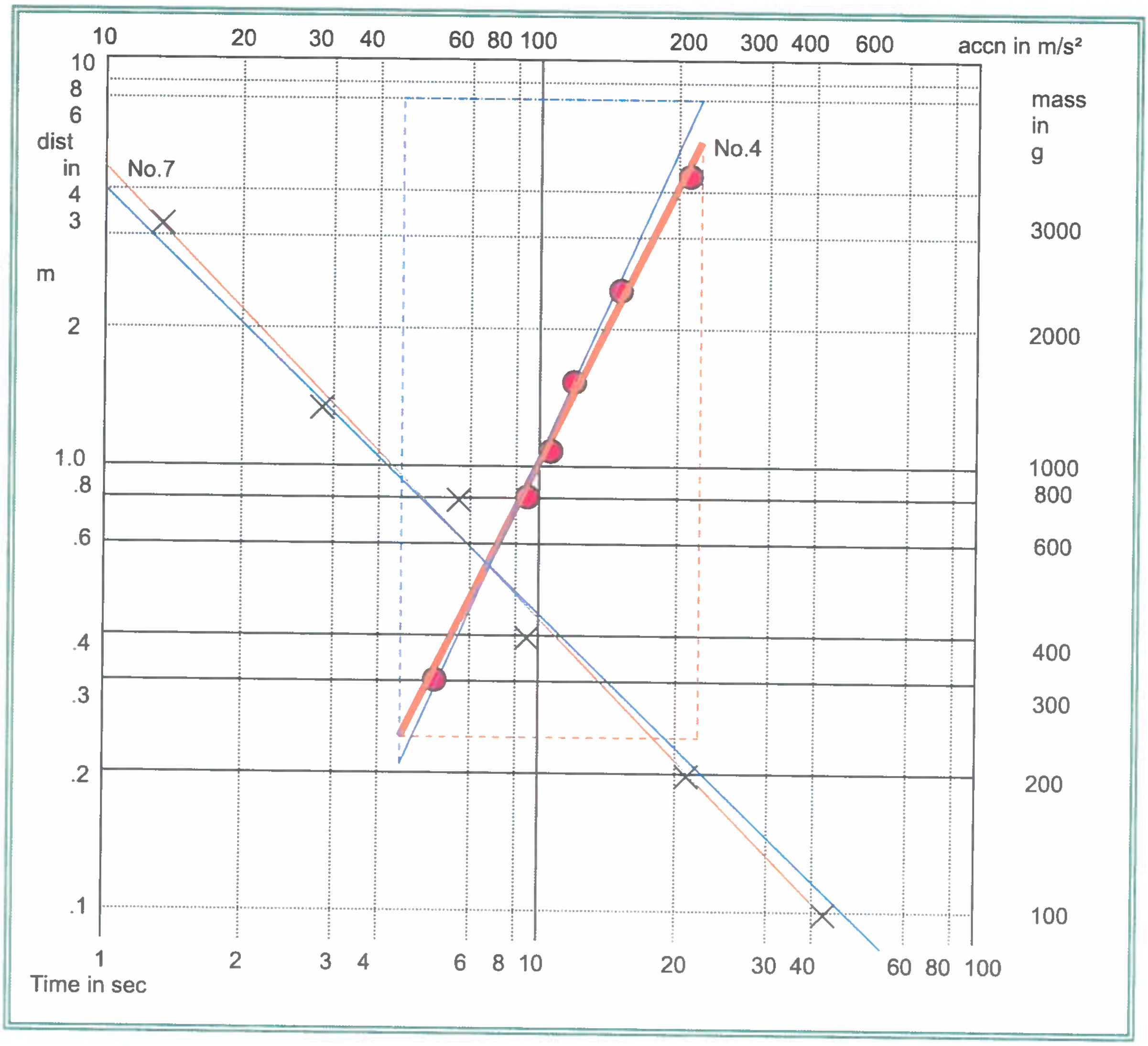
3. Remember to get rid of all constants and end with the dependant variable on the left and the dependent variable on the right of the equation: the proportionality created gives what to plot on the y and x axes, the gradient being the constant that multiplies the x quantity the intercept being the quantity added to the x term:
   a) E against v^2, zero intercept and the gradient m/2
   b) m against $1/v^2$, no intercept, gradient 2E
   c) F against $1/r^2$, no intercept, gradient is kQq
   d) Plot sin i against sin r and the gradient will be n

4. Units of metres should be put in the title column and not with the numbers to avoid crowding. Distance is known to 2cm so each reading should be rounded to 2dp of metres-including significant zeros. Time is in seconds and units should also be put in the title column. A human timing can be no better than 0.1s so all times should be rounded to 1dp of seconds, again including significant zeros. As v = s/t then for errors $\delta v/v = \delta s/s + \delta t/t$ and this varies over the range of readings taken hence individual errors have been assigned.

No.4 (see No.7 below for details)

Dist/m	Time/s	Vel = dist/time ms^{-1}	Acc/ms^{-2}	Mass/g
0.30	5.6	0.054+/-0.005	430	100
0.80	9.0	0.089	220	200
1.10	11.0	0.100+/-0.003	90	400
1.60	12.2	0.123	56	790
2.30	14.0	0.164	28	1400
4.20	21.0	0.200+/-0.002	14	3200
+/-0.02	+/-0.1	Varies	+/- 10%	+/- 10%

Note error bars have not been included for No.4



Gradient, = 9.2cm/4.5cm* = 2.04: 10.2/4.6* = 2.21 diff = 0.17 so grad = 2.0+/-0.2. This makes the power law: (* note the rise and run were taken from the original and may differ in the final print)

dist = k x time$^{2.0+/-0.2}$

or in other words most likely dist ∝ to time² or s ∝ t² which is what was predicted.

5. a) *1.4+/- 0.2* 1.385 +/- 0.24. Remember the steps, error down to 1 sig fig, so 0.24 becomes 0.2 which means the final answer must be rounded to the first decimal place.
b) *46 +/- 2* 45.8 +/- 2. The error is already only 1 sig fig so the answer must be rounded to the units place.
c) *198.0 +/- 0.4* 198 +/- 0.4. The error is already 1sig fig, so the answer must be rounded to the first decimal place.
d) *200 +/- 20* 198 +/- 19. The error must be only 1 sig fig so 19 becomes 20 so the final answer must be rounded to the tens column.

6. area = 2700 +/- 100m²

Area = length x width = 34 x 78 = 2652m²

δarea/area = δlength/length + δwidth/width = 1/34 + 1/78 = 0.030 + 0.013 = 0.043 (4.3%)
4.3% of 2652 = +/-113m² rounds to one fig +/-100m². So 2652 rounds to 2700.

7. See answer No.4 above. As the error is a fixed 10%, then the actual error for each reading increases with size, but take the first reading 433. with a 10% error the error is 43.3, making the results 433+/- 43.3, but errors have only one sig fig so 43.3 becomes 40 so the reading 433 has to be rounded to the tens column ie 430+/-40. All the readings will have to be rounded to two sig fig due to the 10% error. Note the size of the crosses on the graph are about the correct size for the error bars. Gradient1 -11.5/11.2=1.026 grad 2 = 0.973 error = +/-0.05 so power = -1.03+/-0.05 and from Newton II f = ma, so

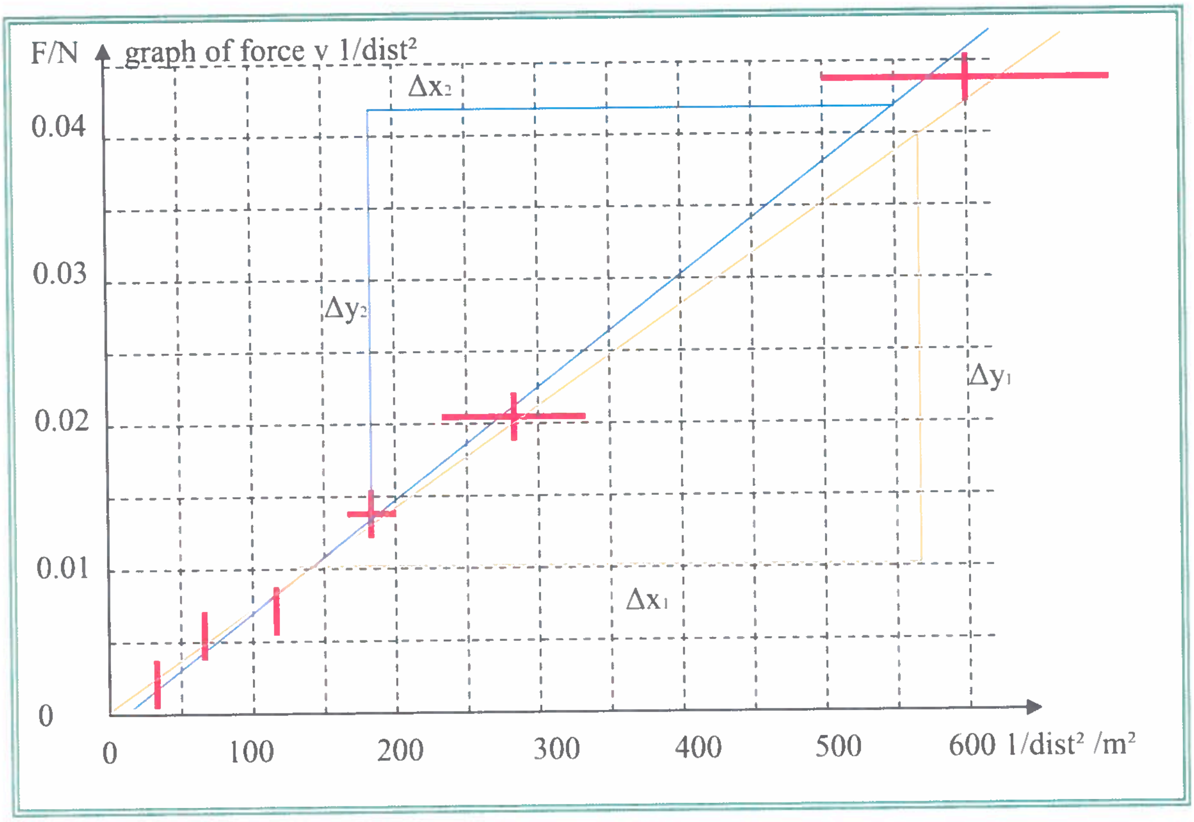
accn = k x $m^{-1.03 +/- 0.05}$

This power was expected.

8. Remember that if a = 1/d² then δa/a = 2.δd/d so the % error in 1/dist² is twice the % error in dist.

Dist/m	Force/N	1/dist² /m² +/- error
0.042	0.044	567 = 600 +/- 100
0.060	0.021	278 = 280 +/- 50
0.075	0.014	177 = 180 +/- 20
0.095	0.007	111 = 110 +/- 10
0.120	0.005	69+/-6
0.170	0.003	35+/-1
+/- 0.005	+/- 0.002	

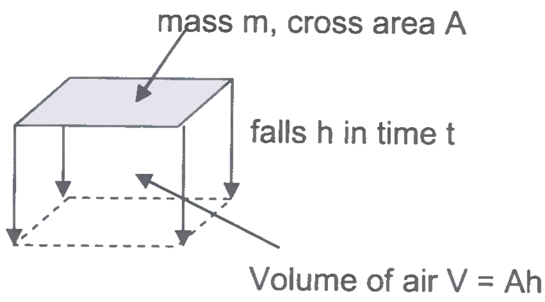
Note not all error bars have been drawn as some are too small on the lower readings, but this should not detract from the process involved.



Gradient1 = 0.040-0.010/565-140 = 0.03/425 = 0.0071 Nm²
Grad2 = 0.042-0.013/550-185 = 0.029/365 = 0.079 so gradient is 0.071+/- 0.007 Nm²
intercept₁ = 0.001N intercept₂ = 0 so intercept is 0.001+/-0.001N

9. If the paper has a mass m and falls a distance h in a time t, its velocity will be v = h/t. The PE it loses will be mgh or energy per sec = mgv

The paper encounters a column of air of height h in time t and if it has a cross-sectional area of A then the volume of air/sec will be Ah/t or Av. If the density of air is d then the mass of air is Avd. The KE gained/sec by this air will be ½ mass/sec v² or ½ Avd v² or ½ Adv^3. This energy gained/sec will be equal to the PE lost/sec so



PE lost/sec by card = KE gained by air/sec at terminal velocity

Mgv = ½ dAh/t.v² (as v = h/t, then)
Mg= ½ dAv²

So v = √(2mg/dA)

10 A. r = 30° and i = 73° +/- 1° if the rays were extended to be as long as the radius of the protractor. A protractor is usually marked every degree, which is the resolution of the scale, not the error but a good guide none the less. And humans are not really any better in measuring angles.

B 18.0℃ +/- 0.2℃ If one goes by the resolution of the sale +/-1° as every degree is marked. It is of course possible to read between the lines and there could be an argument for quoting a larger or smaller error. If this thermometer is being used to take the temp of say a beaker of water then it would be hard to expect the whole beaker to be at exactly 18℃, due to convection or poor stirring, so that error would exceed the resolution of the scale. On the other hand, if one was to measure the temperature difference between two similar temperatures, then one need not know the 'true' temp, only the difference. For example if the min temp is 18℃ exactly on the scale (18.0) and the max is 21.5℃ then the temperature difference 21.5-18.5 could arguably be quoted to better than +/-2℃, i.e. 3.5℃. At best there is probably an error of +/- 0.2℃ on reading the position of the liquid in the thermometer, so the best error for temp diff is likely to be +/- 0.4℃ under these conditions.

C 260 ml +/-5ml from the bottom of the meniscus remember, and 10ml is the resolution of the scale though one could argue that it might be possible to push to +/-5ml, which is halfway between the graduations, though remember air bubbles stuck on the sides or drops stuck on the sides or the surface on which the cylinder sits may not be flat etc would all increase the uncertainty.

D 80.8+/-0.1s 1 min, 20 sec 79/100 of a sec or 80.79s. This should be rounded if a human is timing as we are not better than 0.1s due to our reaction time. The error would be at least maybe double (for starting then stopping the watch). Again there is a case for pushing for a smaller error if it is a timed interval that is 'anticipated' e.g. a pendulum swing and when students have performed the variation of the period of a pendulum with amplitude, with practice they can reduce their timing error down to +/- 0.05s and manage to detect the slight change in period with amplitude.

E 270 +/- 20 counts 273 counts which involves a random error decrease with the root of the reading +/- √273 = 17 so final rounded error is +/- 20.

F 3.6V +/- 0.1 or 0.2V as realistic. True the graduations are not very often so the resolution is only 1V, but the space is large enough to consider it possible to 'read between the lines'. Most skilled students can mentally split a gap into five parts and quote to the nearest fifth; better ones can mentally split a gap into ten equal parts.

THE END