Daniel Slosberg

The Science IA: Earning Full Marks on HL or SL Science Lab Reports

Ideal for the INTERNATIONAL BACCALAUREATE DIPLOMA

2014-22 Edition

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by Daniel Durwood Slosberg

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Dedications

To Monica, Selena, and Rebecca, who all made time for Daddy to write this book.

To Maggie Koong, who graciously waived clause 13 in my contract to allow me to write the 2007-15 edition of this book while teaching at Victoria Shanghai Academy.

To my students who inspired me to write this book.

To Alan Ng and Jen Whitehair who pointed out differences in how the raw data in appendices were treated between biology, chemistry, and physics.

To my fellow teachers who critiqued what I have written and made it better.

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The IB occasionally modifies its requirements between syllabus updates. If you spot something which is now out of date, please let me know so that I can update all electronic versions of this book and ensure that any new printed copies have the correction incorporated. It is helpful if you include the document and page number where you saw the discrepancy.

-Daniel D. Slosberg
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The Science IA
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Chapter 1 - Personal Engagement - 2 Marks

These first two marks are all about making this project your own. You have been studying your elected science for some time now, and it is time for you to design an experiment of your own to answer some question which you may have. Now certainly it is true that there are many good experiments written up and available online, but the very first criterion is designed to ensure you are not simply following a pre-made script.

The good news is that how you make the project your own is entirely up to you. As long as you demonstrate that you are personally engaged with the exploration, you can earn your first two marks. There are several ways to do this.

Strand 1: Personal Engagement

The first is by showing significant independent thinking. You can research a particular experiment online and find two or three ways of running it (which you document in your introduction with footnotes), and then you decide to run the experiment in a different way. It is important that you demonstrate these differences to your grader (whether that is your teacher or the moderator), by explaining how your lab is different from the labs you read about and by explaining your reasons for making these changes. Remember that the rubric is looking for significant independent thinking, so just changing the brand of pH paper you use is not going to be sufficient.

The second way to show personal engagement is by showing initiative. Being the first in class to approach the teacher with an idea for your exploration, finding materials on your own instead of relying on the lab assistant to get everything you require, and coming in at recess or after school are all ways to take initiative. While your teacher may see these behaviors, remember that the moderator is not at your school and doesn't know anything more than you have told them. Be sure to mention in your paper what you have done that was above and beyond the teacher's requirements.

The third way to show personal engagement is through your creativity. This may be visually displaying your data in an unusual way--a graph that is not simply x-axis and y-axis. This may be through your method or lab setup--feel free to include photos showing how you did your lab to demonstrate this. It could also be analyzing your data in an unusual way to show a particular pattern that a standard analysis may have missed.

Strand 2: Research Question

The research question is a central part of your investigation. What do you want to know at the end of your experiment that you don't know now? As you consider the best question to undertake, you want to think about what you find interesting. It may be a topic you are curious about, or it may be something which is personally significant to you. In any case, you want to document why the research question you have chosen is meaningful to you.

Make a list right now of 3-5 topics in the syllabus which are interesting to you. If you need some inspiration, please check the list of labs included in your course for biology, chemistry, or physics. Don't worry, at the bottom of each list is a link back to this strand. Remember that if you choose one of the prescribed practicals, you will need to show significant extension to earn your personal engagement marks.[1]

In addition to an investigation in where you are collecting data in the science lab, consider investigations using a mathematical model, computer simulation, or database.[2] In physics, for instance, the extrasolar database now has nearly 3,000 planets[3] whose properties you can easily analyze.

Next to each prospective topic, write down ways that these particular topics are connected to your personal life--things that you could bring out in your introduction to show that you are personally engaged with the topic. Using your personal engagement angle as inspiration, narrow down 2-3 of the topics into preliminary research questions.

Strand 3: Design, Implementation, and Presentation

The final strand in personal engagement is looking at your own personal input and initiative in designing, implementing, and presenting your investigation. What design decisions did you make differently from experiments you have done before or read about in books or online? How did you implement your methodology? Did you have to solve problems of limited resources in an unusual or creative way? How have you presented your report in your own style unique to you? Keep these questions in mind as you move on to designing your experiment in chapter 2.

[1]Physics Subject Reports, May 2016, pg. 2: "A required investigation could be a starting point for an IA, although the teacher needs to be careful doing this."
[2]Physics Subject Reports, May 2016, pg. 2: "A surprisingly low number of investigations were mathematical models, computer simulations and database investigations."
[3]Exoplanet Data Explorer: 2,951 confirmed exoplanets and 5,454 exoplanets including Kepler candidates as of October 16, 2016.

Chapter 2 - Exploration - 6 Marks

The exploration criteria is concerned with two major sections in your lab report: your introduction and your procedure. The first two strands deal with the introduction. Strand 1 requires you to identify and focus your research question, and then to describe it clearly. Strand 2 requires you to research background information and present your research as context for your experiment. The last two strands deal with your procedure. Strand 3 is about the procedure itself and requires you to design a method which is highly appropriate to your question, which controls all important variables, and which ensures sufficient data for reliable results. Strand 4 looks at safety from 3 perspectives: yourself (is the lab safe for you and your classmates), your subjects (the ethics of your experiment), and your community (the environment).

On some labs, especially early in the two year course, your teacher may have given you a lab design they want you to follow. On other labs, you may do research on the internet or in books which essentially tells you how to design your lab. Your IA is different from these because in your IA you need to design the lab yourself.

Strand 2: Background Research

From chapter 1, you should already have 2-3 preliminary personally interesting research questions at this point. Spend half an hour in the library researching each of these questions. You will be working on your IA in the lab for 10 hours, so it is well worth an hour in the library making sure your investigation will be both interesting and fruitful. At the end of your time in the library, you should be able to narrow down your inquiry to a single question which you are excited to investigate in the lab over the coming weeks. It is now time to check with your teacher and your lab assistant to make certain the lab is appropriate and that you will be able to acquire all the materials you need prior to the start of the in class investigation time.

Once you have confirmed that your lab is a go, begin writing your introduction, laying out all the research you have learned from your trip to the library. As you add information, be sure to create footnotes citing the source of your material. It is important to do this while you are writing and not to try to go back and do it at the end because you may find at the end that you have forgotten which reference gave you that vital piece of information and then you will waste a lot of time searching for it again. At this stage, if it is easier, you can just jot down the title of the book and the page number or the name of the website and the date so that you have the critical information at hand. Later, you can clean up these footnotes and get them into the proper format for your school.

Once you have written down all the information from your research (and added all your sources to your bibliography), spend some time editing what you have written for context. Ask yourself: Does this piece of information directly lay the groundwork for my investigation? If not, delete it. Does this section enhance the reader's understanding of the context of my investigation? If not delete it. As you will read in the chapter on communication, one of the goals of this project is for you to learn to write concisely. In the introduction, that conciseness is shown by sticking to the topic at hand.[1]

Strand 1: Research Question

Now that you have laid out the prior research about your investigation for the reader and yourself, it is time to focus your research question. If you haven't done so already, you should brainstorm as many variables affecting your investigation as possible. Then consider which will you change and which will you keep the same.

Let's take an example: say your preliminary research question is "How fast does hot chocolate cool?" You start to list variables: brand of hot chocolate, amount of chocolate added, amount of water added, temperature hot chocolate is initially raised to, type of milk (whole, 2%, skim, etc.), amount of milk, ambient temperature, material of the container holding the hot chocolate, surface area:volume ratio, time to cool to a specific temperature, etc. You can then choose two variables you would like to investigate to get a more focused research question: How does the ambient temperature affect the time it takes for 250 mL of Nestle hot chocolate in a metal cylindrical cup with a radius of 5cm prepared according to the directions and with 10 mL whole milk added to cool from 70°C to 30°C in a room with no breeze?

Your teacher has only scheduled 10 hours of time in the lab for you to solve this question. Narrowing your topic is important so that you don't wind up with something incredibly broad like "rank all mammals according to their speed in completing a maze." It would take years for you to get access to all the mammal species on planet Earth and to design appropriate and comparable mazes for them to run (a maze appropriate for a rat will likely not be appropriate for a blue whale). A more focused topic such as "How do the hazel dormouse (*muscardinus avellanarius*), Eurasian harvest mouse (*micromys minutus*), deer mouse (*peromyscus maniculatus*), and wood mouse (*apodemus sylvaticus*) compare in speed when running our school's mouse maze after 1 hour of practice runs?"[2] is much more achievable.

The key here is thinking about not just what you want to know, but what you can find out in a limited amount of time. Try to estimate how long each trial will take you, how many trials you will need for each condition, and then how many conditions you have time to test. Remember to leave a bit of leeway in case something goes wrong.

Once you know how many conditions you can test (whether that is how many mice, how many acids, or how many planets), you can start to think strategically about which conditions are most important to test. If you find it difficult to choose a good cross section of conditions knowing how few conditions you can actually test, it may be that your research question is too broad. Instead of thinking about all acids, narrow your question down to monoprotic acids, or even just to monocarboxylic acids, or even further still.

Eventually, you should have a topic with a single, focused research question[3] for your investigation. While you have already been thinking about it, now it is time to write down...

Strand 3: Your Procedure

Now that you have your focused research question, you need to figure out a way to control as many of the other variables as you possibly can, and as well as you possibly can. Go back to your brainstormed list of variables, and turn it into a list or table showing each variable and how it has been controlled. For instance:

Amount of Milk - After preparing 250 mL of hot chocolate, 10 mL of whole milk will be carefully measured and added each time. This ensures that the liquid being cooled is the same in each test run.

or

Variables Controlled	
Amount of Milk	After preparing 250 mL of hot chocolate, 10 mL of whole milk will be carefully measured and added each time. This ensures that the liquid being cooled is the same in each test run.

Table 2.1 - Controlling your variables using tables to clearly indicate how each variable is controlled.

Frequently, there is more than one way to control each variable. For instance:

Amount of Milk - Although only 100 mL of hot chocolate will be cooled in each trial, when I prepare the hot chocolate I will mix 1 L of hot chocolate with 100 mL of milk and then pour out 100 mL into each of my beakers after the hot chocolate has been stirred for 10 minutes while boiling on the hot plate. This ensures that each cooling beaker has the same proportion of chocolate to milk and since there is the same amount of liquid in each cooling beaker, there is the same amount of milk in each as well.

While there are different ways to control each variable, some may be better than others, so to get full marks on this aspect, you want to make sure you control each variable in the best way possible. If you feel you cannot completely control a variable, it is OK to say what you have done to try to control it and how well you feel it is controlled.

Once you have controlled your variables, you want to consider how many trials you need to run in order to get reliable data. Reliable data should be both precise and accurate: that is to say the data should give you the same value each time you run the experiment, and that value should be close to the true value.

accuracy

When we talk about accuracy, we are talking about closeness to the true value. The human body is incredibly accurate in matching caloric intake with caloric output. Even Jon Minnoch, the world's heaviest man, who had a peak weight of 635 kg or 1400 pounds,[4] ate less than 320 extra calories (intake - output) per day.[5] Assuming he died at that weight, that's just half an extra chocolate bar per day (Cadbury Dairy Milk Oreo 120g chocolate bar is 336 calories for half the bar), but actually he weighed just over 362 kg or 798 pounds[6] when he died, so over his lifetime his average excess consumption was only about 250 calories per day or roughly 10% of the 2500 calories required per day.[7] (For comparison, a typical Snickers bar (51g) is 247 calories.) And this is for the most obese man in the world. For someone weighing 200 pounds at 100 years old, the error is less than 20 calories (i.e. less than 1%). This shows how incredibly accurate the human body is over the course of a lifetime. The day to day swings in both consumption and exercise, however, are quite a different matter--think about how much you eat on Thanksgiving day, or how much you expend running a marathon. We can say the human body is therefore accurate, but not precise.

precision
: When we talk about the precision of a measurement, we are talking about how close together multiple measurements are to each other. In the example of the half full cup, the data set may have been accurate, but it was anything but precise. The measured values were as far apart as they possibly could be. An example of an extremely precise measurement would be a stopped (broken) clock. It always measures the same time, so it is perfectly precise, but the accuracy is +/- 12 hours.

A well designed experiment ensures that measurements will be both accurate and precise.

More data is often better, but you are constrained to 10 hours of laboratory time, so just saying you need more data at the end as an improvement in your evaluation shows either a lack of planning--which hurts your exploration marks because you haven't designed for sufficient data--or a lack of efficiency in the lab--which hurts your personal engagement marks because it shows a lack of initiative--neither of which you want.

You really want to plan out in the early stages how long each trial will take you and how you want to allocate time between more trials per condition and more conditions tested. At the same time, you want to consider a sufficient number of conditions so that your overall result is reliable.

In determining how many trials you should do, you should consider how you will evaluate the precision of your experiment. If you only measure a value once, you may have a particularly high value or a particularly low value and never discover that this was an outlier. If you measure the same value 100 times, you will have a very good understanding of the precision of that measurement, but it will also take a long time. In the end, you will want to balance the amount of time something will take with the added precision you will get by doing it extra times.

For something like timing a pendulum swing, where the error in measurement is your reaction time hitting the start and stop buttons--and these errors get added for the total error of one swing, but they get divided by the number of swings--it makes sense to allow the pendulum to swing back and forth 10 or 15 times. It does not take the pendulum very long to swing back and forth one extra time, and watching two swings vs. one swing cuts the error in half for just an extra second or two of lab time. In fact, you could measure 20 oscillations under 10 sets of conditions which would give you a very good feel for the precision of your final values while also providing a broad range on conditions.

Now let's take an in depth look at a more complicated example: the hot chocolate question above--How does the ambient temperature affect the time it takes for 250 mL of Nestle hot chocolate in a metal cylindrical cup with a radius of 5cm prepared according to the directions and with 10 mL whole milk added to cool from 70°C to 30°C in a room with no breeze?--and look at the trade off between number of trials per condition and number of conditions. It would be relatively easy to come into the lab each day, take the temperature of the lab, and run 6 trials during the course of that practical period. On Monday it might be 23.0°C, so you could run 6 trials at 23.0°C. On Tuesday it might be 23.4°C, so you could run 6 trials at 23.4°C. By the end of the lab time, you have run the experiment 60 times with 6 trials at each temperature and at 10 (hopefully different) temperatures. Is this reliable? Well, you certainly have a very good idea of how long hot chocolate takes to cool at room temperature by the end. Is it sufficient however? All of your temperatures are likely to be between 21°C and 25°C, so you have a very narrow range.

Shifting to doing the lab outside with the same protocol will give you a wider range of temperatures, although unless your lab time is spread throughout the seasons it is unlikely to be too wide, so perhaps between 10°C and 30°C. That's a much wider range of temperatures and improves your experiment considerably with relatively little extra work (just moving the equipment outside) so you can probably keep 5 trials a day (depending on how far "outside" is from the classroom) instead of 6. Still, the increase in sufficiency more than makes up for a small decrease in reliability.

Now let's try a different setup. You have a cylindrical donut around the hot chocolate mug (or beaker) which you fill with water of different temperatures (boiling and freezing and nothing). On the day there is nothing in the donut, you can get your 6 trials done fairly easily as there is little setup. On the days you are working with freezing water, you have to add the ice to the water in the donut and then wait for the air temperature between the donut and the hot chocolate mug to cool down and level off. You may only get 2 measurements that day, so you will need to run that temperature--that condition--on three different days. The boiling water condition is even more time consuming because it takes a long time to boil the water and it is difficult to keep water in the donut at that constant high temperature. If you can only get one measurement per day, it would take you six days to gather that data. So now in your 10 days, you have only gathered data at 3 different temperatures, but still have 6 trials at each temperature. Is this experiment better or worse than the previous one?

Certainly your line of best fit will be more accurate since the data are spread out considerably further than in the first experimental design, but you still can't see the shape of that curve very well, so you would not know if it was really non-linear.

So how can we get more temperatures? One way is to decrease the number of trials we run at each temperature. If we aim for an ambient temperature of 0°C, 20°C, 40°C, 60°C, 80°C, and 100°C, we will have 6 different conditions. That will show us the shape of the curve quite nicely, but how many trials can we run at each temperature? Probably only 2 trials would be possible at each temperature. This is a large increase in sufficiency and a large decrease in reliability. Whether the tradeoff is worth it may depend on your personal engagement--are you a math student who really cares about the shape of the curve because that is what you are interested in, or are you a skier who really cares about temperatures close to freezing?

If we want to modify the experiment one more time to improve the methodology still further, that skier could choose temperatures more highly appropriate to their situation and look at 0°C, 5°C, 10°C, 15°C, 20°C and 25°C. This is still 6 conditions, but the conditions are much more appropriate to address the research question as a skier might modify it. In addition, several of those temperatures are probably achievable either in the lab or outdoors on various days during the experiment and so 5 trials could be run quite easily on a single day (and if the temperature is actually 16°C outside instead of the planned 15°C, you can still use the data point as long as you note the actual temperature). On days when the weather does not cooperate, cold baths (or the classroom heater--as long as you adjust it at the start of the previous period) could be used to get an appropriate indoor temperature and 5 trials may take 2 days for those temperatures. Assuming we can get 3 temperatures naturally in a single day and 3 temperatures need two days to artificially get the appropriate temperature, you have spent 9 days collecting data and have one lesson left over in case something goes wrong.

As you can see, it is important that you go through this process of designing your experiment, thinking about the implications, and then redesigning it. If you wait until after you have collected your data to realize during your analysis that you have made a mistake in designing your experiment, you will be spending many a day during recess or after school in the lab wishing you had planned more thoroughly ahead of time.

Once you think your procedure is set and sound (and before you set foot in the lab), show it to your teacher or to a friend to get a second opinion. Make sure it really addresses the question you have asked (or change the question so that it does). Make sure you are controlling as many variables as you can. Make sure the data you plan to collect are relevant to your question, will be reliable because you have repeated your trials enough times, and will have been taken under a sufficient number of different experimental conditions to allow you to really understand the situation.[8]

Strand 4: Safety

There are some labs where safety is pretty simple (it is difficult to injure anyone creating an HR diagram from data you found on the internet), but other labs where you need to consider the implications very carefully and perhaps decide to do a different experiment. (While you may be curious as to the LD50 of caffeine, is killing 50/100 mice by forcing them to drink so much coke it literally kills them worth it for one lab report? Probably not, and besides it contravenes the "Guidelines for the Use of Animals in IB World Schools."[9])

The first thing you want to consider is your personal safety and that of your classmates around you. In biology, are you working with animals that could get away from you and hurt someone? Are you using sharp instruments in a dissection? In chemistry, should that reaction be done in a fume hood? Have you minimized the distances you need to transport liquids to minimize the possibility of spills? In physics, are you working with anything hot--either radioactively hot or with a high temperature--or sharp? What are you doing that could possibly hurt those around you?

The second thing you want to consider is the ethics of what you are doing. This shows up most commonly in biology when you are doing any sort of experiment that involves animals or humans. With animals, you need to consider whether what you are doing hurts the animal in any way. Understanding acid rain is a noble cause, but is killing fish in a fishtank fair to those fish? With people, you need to consider what risks your participants will be undertaking and you need to ask them for informed consent after telling them about the risks.

The final thing to consider is the environment. What's going to happen to the chemicals you are using? Will they be disposed of safely or will they enter the water supply? What's going to happen to the hillside if you roll large boulders down it to test gravitational acceleration? Will it destroy some of the plantlife? What will happen to the mix of mosquitos outdoors if you genetically modify some and then they escape? (Even if you are careful, those around you may not be. While Warwick Kerr carefully fitted the hives in his breeding experiment with queen excluders, another beekeeper removed them allowing killer bees to infiltrate the Americas.[10])

Make sure that any experiment you do is safe (or as safe as possible) for yourself and your classmates, the subjects of your experiment, and the larger community before you begin.[11] If you have any questions as to what may be safe, see your teacher before you begin.

[1]"Exploration," *Biology Guide*, Feb 2014, pg. 156; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 144: "The background information provided for the investigation is entirely appropriate and relevant and enhances the understanding of the context of the investigation."

[2]Shazza, "Mouse Species Guide," Sep 2016: valuable information on various mouse species.

[3]"Exploration," *Biology Guide*, Feb 2014, pg. 156; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 144: "The topic of the investigation is identified and a relevant and fully focused research question is clearly described."

[4]Guinness, 2006.

[5]Wishnofsky, 1958, pg. 546: assuming a protein/glycoen equilibrium

value of 3500 calories per pound.

[6] Guinness, 2006.

[7] Wishnofsky, 1958, pg. 543.

[8] "Exploration," *Biology Guide*, Feb 2014, pg. 156; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 144: "The methodology of the investigation is highly appropriate to address the research question because it takes into consideration all, or nearly all, of the significant factors that may influence the relevance, reliability and sufficiency of the collected data."

[9] "Guidelines for the Use of Animals in IB World Schools," Sep 2016, pg. 2: "experiments that administer drugs or medicines or manipulate the environment or diet beyond that which can be regarded as humane is unacceptable in IB schools."

[10] Dave Langston, "Africanized Honey Bees: Historical Perspective," Sep 2016.

[11] "Exploration," *Biology Guide*, Feb 2014, pg. 156; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 144: "The report shows evidence of full awareness of the significant safety, ethical or environmental issues that are relevant to the methodology of the investigation."

Chapter 3 - Analysis - 6 Marks

This criterion is all about how you treat the data you actually collected, and in particular it deals with how you deal with both the uncertainties inherent in your raw data and the uncertainties which are discovered upon analysis. All data has uncertainties in both accuracy and precision. The final strand then focuses on the correct interpretation of the uncertain data to allow a valid and detailed conclusion to be drawn.[1] (Note that the actual conclusion doesn't matter for the analysis criteria--the conclusion will be judged in the evaluation criteria--it just has to be possible to draw the correct conclusion.)

Because a quarter of your grade is based on how you treat data, you want to make sure you get as much data as you can from your time in the lab. Use a lab notebook. Write down the date each time you come into the lab and write down everything you notice that could affect your experiment: the temperature in the room, the amount of sunlight, how long it takes the Bunsen burner to boil the water, what color the solution is before and after distillation. All of your control variables values should be recorded. Anytime you have a few minutes to spare, look around and observe your experiment and write down what you see, what you hear, what you smell, or what you feel. The more you write down during the experiment, the more you will have to draw from as you analyze your data.

While you are working on your internal assessment in the lab, each day when you get home you should write up the data you collected on that day. This will help you catch issues early so you can rerun parts of the lab if you discover you didn't do something correctly. It will also let you see if something interesting is happening. For instance, if you find the density of water at -3°C, 0°C, 3°C, and 6°C, you may notice something odd is happening and choose to find the density at 4°C, 5°C, and 9°C in the lab the next day. If you did that, you would find that the density of water peaks at 4°C[2]--something you wouldn't have found out if you had just continued measuring at 3°C intervals.

Strand 1: Raw Data

In order to grade your analysis of your data, the first thing a grader--whether it is your teacher or the moderator--needs to see is your raw data. You must include this in some form whether it is a graph, a table, a list, or described in paragraphs. Qualitative data should accompany the quantitative data and controlled variable values should not be neglected. If you have a large quantity of data--unless you are taking biology[3]--it can be appropriate to include this in an appendix (where it doesn't affect your page count). If the complete data set is found in the appendix, a graph of the data should be in the body of your paper to satisfy the requirement that raw data be included because moderators do not need to read the appendices.[4]

Sometimes, if you have gathered a lot of data (for instance with a data logger), it is really the data you derive which is important. In these cases, you can treat the derived data as your raw data and then process it further. The original raw data does not need to be included in these instances.[5]

Make it easy for your grader to find your data by including a section in your report titled "Data Analysis" with subsections titled "Raw Data" and "Processed Data."

Two key terms in the strand 1 descriptor are sufficient and relevant.[6] Sufficient means you need enough data to be able to draw conclusions. Relevant means you only want to include data that impacts on your research question. Temperature is relevant if you are measuring cooling rates, but not if you are measuring force required to break a wooden plank.

The next key terms are quantitative and qualitative. Quantitative data is anything involving numbers. Once you have designed your procedure, you can create tables in your lab notebook to ensure you capture all the relevant quantitative data you designed the experiment to capture. During the experiment, you may think of other quantitative data you wish to record and you could measure and record that data on the facing page. It is important with quantitative data that you include uncertainties associated with each number. Uncertainties will be discussed in further depth in strand 3 below, but remember there are both uncertainties inherent with your equipment (which you can frequently look up or ask the lab technician for) and uncertainties inherent with your procedure. Both should be recorded in your lab notebook.

Qualitative data is anything for which a number is either unknown or inappropriate. For instance, you may be taking data over several days, but on day three the air conditioner is broken and you feel extremely hot working in the lab. You may not think it is relevant to your experiment on that day, but it is good to record this data because when you look back at your results you may find it has an impact. A simple statement in your lab book saying "It is very hot today." is a qualitative way of describing this information. Of course you could also take out a thermometer and measure the temperature which would turn the data back into quantitative data. Similarly, might notice that when you mix two chemicals together you get a green liquid. As you continue stirring them, the liquid may turn blue, and then red, and then green again. A simple statement as to the color of the liquid is a qualitative way to capture this data. Once again, if you want to make it quantitative, you can get out a spectroscope and measure the wavelength(s) of light which make up that shade of green.

It is not just the data about your independent and dependent variables which are important. You should also include information about your control variables.[7] This data helps the moderator understand the context of your experiment and can help explain an unexpected outcome.

The final three key words are support, detailed, and valid.[8] You data needs to be able to support a conclusion which is both detailed and valid. As you get to hours 7 or 8 in the lab, you should start to see what the results of your lab will be as you work on your report at night between laboratory sessions. Start thinking about what your conclusion will be and ask yourself, do I have enough data to support this conclusion. As you read through chapter 4, you will see that a good conclusion has limitations, but the more of those limitations you can remove by taking more data, the better. Think about how you can best use the last few hours of lab time to gather the most important data to support your conclusion even if it means changing your initial plan somewhat.

Your conclusion must be detailed, which means you need to have enough data to support that level of detail. If you are graphing the data, do you have a smooth curve, or is it jagged in some way. If it is jagged, one question you might ask is whether the function is really jagged or whether that data point is merely an outlier due to problems you had conducting the experiment. One way to check is to look at data points on either side. Think about the density of water, for instance. Initially, the density is increasing until 3°C, and then it decreases at 6°C. Is the dip at 6°C real, or is it a problem with your measurement of that data point. By taking measurements at 4°C, 5°C, and 9°C you could see that a) there really is a maximum--not at 3°C but at 4°C, and b) the decreasing trend continues past 6°C. This gives you an increased level of detail that your original plan to take measurements every 3°C would not have given you--no matter how carefully you made your measurements.

Finally, your conclusion must be accurate. This means ensuring your data is both precise (when you conduct three trials, how close are your values to each other), and accurate (were you careful in your procedure so that your values are the true ones, or did you have systematic errors which moved all your trials in a particular direction).

Strand 2: Accuracy of Processed Data

Once you have your data, you will need to process that data in some way. If you have done multiple trials, you may need to average the results. You will also have a chance at this point to evaluate the precision of your measurements. A quick way to find a rough estimate for the precision of your experiment is to take the highest and lowest values, subtract them, and divide by two. If you have a lot of measurements, a better way is to find the standard deviation of your measurements and to say that the actual value is likely to be within two standard deviations of the mean.

Having done this, you need to compare the precision of your measurements with the accuracy of the measurements. Remember the stopped clock. Just because every measurement is identical doesn't mean you have no uncertainty. Just because an electronic sensor gives you 15 significant figures doesn't mean they are all meaningful. As a general rule of thumb, you can take the larger of the two uncertainties (this works well if one is large and one is small, if both uncertainties are about the same size, the actual uncertainty will be somewhat larger).

Of course if you are investigating something involving a complicated equation, you need to propagate your errors properly. If you are multiplying two measured quantities together, for instance, you will need to find their percentage error and then convert that back to an absolute error at the end.

Another way of processing data is by presenting it in a graphical form, especially if you are finding a line of best fit or a constant of proportionality.

Remember data should be plotted accurately on both the x- and y-axes, and that you should have both vertical and horizontal error bars. Think back to the hot chocolate experiment. You intended the ambient temperature to be 0°C, 5°C, 10°C, 15°C, 20°C, and 25°C; but you were using the temperature inside the classroom and outside the school to get some of those temperatures. Even if you set the air conditioner to exactly 20°C, the temperature around your hot chocolate might be a little higher or a little lower (say 20.3°C). When we take weather into account, the closest mother nature might provide to 10°C might be 11.1°C. The x-coordinates you should be plotting are therefore 11.1°C and 20.3°C, not 10°C and 20°C. The errors, however are those of your thermometer (+/- 0.1°C), not the distance from your intended temperature.

Remember that if you are finding a line of maximum slope or a line of minimum slope, you want to be careful to hit all of your data points within your error bars. In other words, if you carefully make a box around each data point such that the sides of your box just touch the outside of your error bars, any line representing your data should enter each and every box.

It is important in all your processing that you check your work for accuracy--both your manipulation of the actual data and the propagation of the error. The key here is to do enough data processing accurately so that you can make a conclusion which addresses your research question which is fully consistent with your raw data.[9]

Strand 3: Measurement Uncertainty

When we initially record our data, we know something about its accuracy from the documentation that comes with our equipment. We may have a stopwatch that shows hundredths of a second, for instance, and so the manufacturer of that stopwatch is implying that each measurement is accurate to +/- 0.005 seconds. Now if you are pressing the stop button with your hand, you can do a mini experiment to see what your reaction time is. Press start and then press stop as fast as you can. The time you see is the fastest your hand could react. While the stopwatch may be accurate as a device to +/- 0.005 seconds, the stopwatch being held by your hand is likely to have a worse accuracy.

It is important to remember when recording your data that both your dependent and your independent variables will have uncertainties dealing with the accuracy of your equipment. Unless you are dealing with discrete quantities like the number of chicken eggs cracked into a beaker (which you are likely to know exactly), chances are both variables should have a +/- attached to them.

While students tend to understand that they must measure the independent variable, they frequently forget that the dependent variable should be measured as well. I think many students feel that since the procedure says they need 100mg of copper, and they measured 100 mg, that the mass of that copper is actually 100mg. If you put that copper on a more sensitive balance, you may find that the actual amount is somewhat more or less than intended (perhaps 100.45 mg). That measured value then has uncertainty due to the sensitivity of the balance as well.

Similarly, in chemistry, if you are dropping in 5 mL of a chemical into a solution, you should write down how much of the chemical was in the burette before and after you added the chemical. Subtracting those two numbers (and adding their uncertainties) should give you 5 mL, but in my experience if there is an error, too much was added more frequently than too little (as students who added too little will try to add a little more, but students who added too much have no recourse). When you are plotting, say, pH vs. volume of acid added on a graph, you want to graph the actual volume added, not volume you intended to add. Yes, measuring carefully will help you be accurate, but being honest about your errors by reporting what actually happened will make your graph and data analysis more accurate despite the measuring error.

In summary, measure both dependent and independent errors; record both the error inherent in the equipment and the error inherent in your procedure; where ever possible, check the accuracy of measured quantities by measuring them in a different way; propagate your errors when you process your data; and display your uncertainties whether you present your final values graphically, in a table, or in the text.[10]

Strand 4: Correct Interpretation

The final strand deals with how you talk about the data you have processed in the text. Ensure that in the paragraphs where you describe your final results, you are interpreting your data correctly.[11]

[1]"Analysis," *Biology Guide*, Feb 2014, pg. 157; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 145: "The processed data is correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced."

[2]J.C. Kotz, P. Treichel, and G.C. Weaver, *Chemistry & Chemical Reactivity*, Thomson Brooks/Cole, 2005, as cited in "Water," Wikipedia, last modified 12 Feb 2016: actual maximum density is 3.98°C or 39.16°F.

[3]Biology Subject Report, May 2016, pg. 7: "Candidates should not add on appendices in addition to a write up of about 12 pages and should not send in excessive quantities of raw data from data loggers (although showing an example of how raw data have been processed will be helpful to the moderator)."

[4]Chemistry Subject Report, May 2016, pg. 7: "Some students did include lengthy appendices in order to circumvent the page limit ruling but this is not an acceptable strategy since examiners do not have to read the appendices so vital marks could have been lost."

[5]Biology Subject Report, May 2016, pg. 4: "A candidate should only present a representative sample of the raw data, for example, when large amounts of data have been collected using data logging. A representative graphical readout revealing how data is derived is acceptable. In this way the derived data becomes the raw data."

[6]"Analysis," *Biology Guide*, Feb 2014, pg. 157; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 145: "The report includes sufficient relevant quantitative and qualitative raw data that could support a detailed and valid conclusion to the research question."

[7]Chemistry Subject Report, May 2016, pg. 4: "Fewer students though also included associated data such as qualitative observations or the data regarding the control variables such as reaction temperatures or reactant amounts. It is this wider data that can provide valuable context for the evaluation of the procedure."

[8]"Analysis," *Biology Guide*, Feb 2014, pg. 157; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 145: "The report includes sufficient relevant quantitative and qualitative raw data that could support a detailed and valid conclusion to the research question."

[9]"Analysis," *Biology Guide*, Feb 2014, pg. 157; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 145: "Appropriate and sufficient data processing is carried out with the accuracy required to enable a conclusion to the research question to be drawn that is fully consistent with the experimental data."

[10]"Analysis," *Biology Guide*, Feb 2014, pg. 157; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 145: "The report shows evidence of full and appropriate consideration of the impact of measurement uncertainty on the analysis."

[11]"Analysis," *Biology Guide*, Feb 2014, pg. 157; *Chemistry Guide*, Feb 2014, pg. 181; *Physics Guide*, Feb 2014, pg. 145: "The processed data is

correctly interpreted so that a completely valid and detailed conclusion to the research question can be deduced."

Chapter 4 - Evaluation - 6 Marks

Your evaluation section is where you present and justify your conclusion, and also where you look for ways to improve your methodology in the event you were to repeat your experiment. This should be in a section of its own in your report, titled either "Evaluation" or "Conclusion."

Creating a Conclusion

It is time now to go back to your original research question. You may even want to restate it at the start of this section: "I began this [laboratory investigation / spreadsheet model / graphical analysis of database information / simulation] hoping to discover ...." In any event, you want to double check that the research question as stated in the abstract, introduction, and conclusion all match in content if not in exact wording.

A good conclusion must directly answer this question,[1] so you should start by considering what your data analysis is telling you about your question. It may be that your data does not give you as complete an answer to your question as you had initially intended--and you can address that in identifying weaknesses and proposing improvements below, but you want to use your data to answer your research question as directly as you can.

Let's take an example: you are looking at the density of solids and liquids close to the freezing point. Your question is to discover whether solids or liquids are more dense. In your data you see copper, iron, gold, and egg white are all denser as solids than as liquids, but that water is denser as a liquid than as a solid. You therefore know that you cannot make a broad statement claiming that all solids are denser than all liquids, but you can say, "For the majority of materials I tested, solids are denser than liquids at the temperatures at which I was able to measure them. The exception was water which was less dense as a solid despite repeated careful measurements." This is still entirely relevant to the research question while remaining fully supported by the data.

For those of you who are curious, I have presented some accepted values for the substances in question below.

Densities of Various Substances as Solids and Liquids

substance	density as solid (g/cc)	density as liquid (g/cc)
copper	9.0 +/- 0.1	8.0 +/- 0.1
iron	7.9 +/- 0.1	7.0 +/- 0.1
gold	19.3 +/- 0.1	17.3 +/- 0.1
egg white	higher	1.0 +/- 0.1

water	0.9 +/- 0.1	1.0 +/- 0.1

Table 4.1: Here are accepted densities of various solids and liquids that might have resulted in the experimental results described in the example above. Data Sources: Copper data from *Wikipedia* last modified 15 Feb 2016, solid density is at room temperature. Iron data from *Wikipedia* last modified 7 Jan 2016, solid density is at room temperature. Gold data from *Wikipedia* last modified 11 Feb 2016, solid density is at room temperature. Liquid egg white density found on this website viewed on 15 Feb 2016, conversion for metric cups can be found here viewed on 15 Feb 2016, and evidence for a higher solid density can be found here viewed on 15 Feb 2016. Water data from *Wikipedia* last modified 12 Feb 2016, liquid density is at 4 degrees Celcius.

A strong conclusion should not just state an answer to the research question, it should be qualified--it should say when this answer is the correct one for the research question and when (due to lack of data or limitations on apparatus) it is unknown whether it is true. Remember that in science, unlike in math, no amount of experimentation can ever prove a theory to be true. A single disagreeing fact can disprove the most established of theories. The orbit of Mercury, for instance, proved that Newtonian gravity was wrong despite the fact that all the other planets and moons seemed to obey Newton's law. If Newton were submitting an IA on gravity, he might say, "For all the large bodies in the solar system except for Mercury, my laws of gravitation appear to apply within the error bars of my observations."

While it is easy to qualify data if you have outlying data points, it is just as important to put limits on your conclusions if all of your data agrees. Just imagine you had only measured copper, iron, and gold; or that you had only looked at Venus, Earth, Mars, Ceres, and Jupiter in terms of gravity. Just because you haven't seen an outlier, doesn't mean one does not exist, so you need to couch your conclusions with that in mind. "Within the limits of my experiment, it appears that objects inside my lab--at least those which I have tested--fall to the floor when dropped from a height so long as nothing is between them and the floor." (Obviously you didn't test a helium balloon, but you have qualified your conclusion by saying "at least those which I have tested.")

Once you feel you have a strong conclusion, you will need to justify it in two different ways: first with your own data, and then with scientific theory.

Strand 1: Justifying with Data

For the first strand--justifying your conclusion with your data--it does not actually matter if your conclusion is correct or not. What matters is that it is detailed and fully supported by your data.[2] (For the second strand, however, your conclusion must be correct[3] to achieve the 5-6 band, so you can't get a level 6 with an incorrect conclusion no matter how much your data supports it.) It is important at this stage to consider every facet of your conclusion and ask yourself the ToK question: How do I know that? If you feel your conclusion has said something you can't find in your data, add a qualifier. Instead of "For all the planets in our solar system ...," you might start off "For all the known planets in our solar system ...." Instead of "For all acids ..." you might say "For all hydrocarbon based acids with four or fewer carbons ..." if that is what you actually tested. Instead of "For all mammals ..." you might say "For the three species of bat that I tested ...."

You want to make certain in describing your reasoning that you give the strongest support possible with your data. It is insufficient, for instance, to merely state that since the line of best fit has a given slope, that slope is the constant of proportionality. You must first show that the relationship is a proportional one by showing that a y-intercept of zero is consistent with your data (that there exists a line going through (0,0) which also goes through each data point (within the error bars)).

Strand 2: Justifying with Theory

You now have a detailed conclusion entirely relevant to your research question which is fully supported by your data. The next step is to justify your conclusion by comparing it to the accepted scientific context. This means heading to the library and researching what other scientists have found and what theories they've come up with. Your textbook is a wonderful starting place, but any information you find there is likely to be out of date. *Science News* is a great way to bring your findings up to date with current research. Their articles are short (the entire magazine is only 16 pages long each week so most articles are less than one page), and they have a great index at the end of each year of the articles that have appeared the year before. arXiv is another great resource for new articles in physics and biology, but the articles there are written for fellow researchers so I would recommend reading just the abstracts at first, and if you find an article to be particularly relevant, only then attack the introduction and conclusion.

Your goal for this strand is to demonstrate to your grader that your conclusion is true given the current state of knowledge for your area of research. For some areas of research, the current state of knowledge is fairly well established (classical mechanics for instance). For other areas, such as the understanding of newly discovered exoplanets, the field is quite new and you may discover something completely new to science which you could publish in a peer reviewed journal. In either case, you want to discuss the theory surrounding your findings and justify why you feel your conclusion is true.

This subsection of your report should contain several footnotes to the different sources you used for learning the theory related to your experiment.

Strand 3: Identifying Weaknesses

While it is fine to start out discussing what you feel you did well in your experiment, the focus of this strand is on honing in on your weaknesses to understand how you could have improved your experiment. What limitations were there on your data? What were your sources of error or uncertainty? Some uncertainty is needed in any measurement, but as you write you should start thinking about how you could have reduced the magnitude of your uncertainties (see Strand 4). What was good or bad about the method that you used for collecting data?

When you are looking at the limitations of your data, it is insufficient to say "I should have collected more data." No one expects you, in 10 hours, to collect data on every element of the periodic table, for instance. You will necessarily be collecting a sampling of data and you want to look at how issues of sampling affected your results. Did you have equal numbers of male and female animals in your experiment, for instance? Did you use an equal number of acids and bases with pH's more or less evenly spread out from 1 to 14? Was the coefficient of friction and size really the same on the various balls of different masses that you used?

When you are discussing the sources of error in your experiment, you should evaluate how much uncertainty each weakness contributed to your experiment. Simply stating that there was "human error" may be true but is insufficient. If you say it was hard to hit the stopwatch at exactly the peak of a swing, try to estimate how early or how late you may have been. The more you can quantify your uncertainties, the more you can focus later in your improvements on the ones which really matter.

Finally look at your actual method. If you measured the density of a metal at room temperature instead of 1,000°C, that made your measurements a lot more practical to obtain, but you then have to consider how a change in temperature affects the density of a solid. Similarly, how might an air conditioner, kicking on unexpectedly in the middle of your experiment, have affected the results?

Strand 4: Proposing Improvements

It is generally good form for the improvements to address the weaknesses you described above, and some students will make a table which shows the weaknesses and improvements side by side. For it to be a good improvement, it must both help the experiment (be relevant) and be accomplishable with the materials at your school (be realistic).

Shutting the windows before a simulation where dice rolling simulates radioactive decay is unlikely to actually change the results. Ensuring that none of the dice is loaded is much more likely to be relevant to your experiment.

Stating that you will steal an atomic clock to get more precise timing data is not realistic. Recording a video of the experiment with your phone so you can replay it frame by frame, however, will allow you to analyze the timing data much more precisely with equipment you have at hand.

[1]"Internal Assessment Details: Evaluation," *Biology Guide*, Feb 2014, pg. 157-8; *Chemistry Guide*, Feb 2014, pg. 182; *Physics Guide*, Feb 2014, pg. 146: The conclusion is "1-2: ...not relevant...; 3-4: ...relevant...; 5-6: ... entirely relevant..." to the research question.
[2]"Internal Assessment Details: Evaluation," *Biology Guide*, Feb 2014, pg. 158; *Chemistry Guide*, Feb 2014, pg. 182; *Physics Guide*, Feb 2014, pg. 146: "5-6: A detailed conclusion is described and justified which is entirely relevant to the research question and fully supported by the data presented."
[3]"Internal Assessment Details: Evaluation," *Biology Guide*, Feb 2014, pg. 158; *Chemistry Guide*, Feb 2014, pg. 182; *Physics Guide*, Feb 2014, pg. 146: "5-6: A conclusion is correctly described and justified through relevant comparison to the accepted scientific context."

Chapter 5 - Communication - 4 Marks

Your entire IA should be between 6 and 12 pages starting from the first page of your introduction and ending with the last page of your conclusion. If you write more than 12 pages, you will be penalized in communication because you have not written concisely.[1] You do not need to count your title page, abstract, table of contents, appendices, or bibliography in your page count. Please note that biology IA's are not allowed to have a separate title page, a full page table of contents,[2] or appendices,[3] and that for chemistry[4] and physics IA's moderators are not required to read your appendices so anything which is critical to your paper does not belong in an appendix.

Your title page and abstract should not have page numbers so that the first page of your introduction should be page 1. On most word processing programs, you can do this by having your introduction be the beginning of a new section. Make sure your headers and footers do not match the previous section (if "Match Previous Section" is checked, then any changes you make to the introduction will also be made to the title page and you will wind up with two page 1's). Your appendices and bibliography should have page numbers, however, so you do not need an extra section for them.

Also, remember that it is better to add a table of contents automatically (Insert -> Table of Contents -> Document) rather than creating one on your own. The automatic table of contents will update the page numbers as you work, add sections as soon as you add them in your document (be sure to use "Styles -> Heading" or "Styles -> Heading 2" to add sections and subsections so the table of contents can find them), and generally ensure that everything looks perfect for your final draft. If you create a table of contents on your own, not only is it a lot more work, it generally doesn't look as good and it is very easy in the flurry of last minute changes to forget to check that every page number is up to date.

Take a moment now to check that you have numbered your pages correctly, to ensure that you have fewer than 12 pages (if you are over, try reducing the font size to 9 and doing 1.5 spacing (or even single spacing) instead of double spacing) and more than 6 pages (if you are under, try increasing the font size to 12 and double space the document).

When you have finished checking your work, click here.

Abstract

An abstract is not required for science IA's, but it can be a good way to showcase the marks you have earned in a way which communicates your experiment clearly. Going through the criteria, you can address the rubric, showing that you have earned full marks in each area. For personal engagement, you can state the personal significance, interest, or curiosity which led you to design your experiment; and if you have designed, implemented, or presented your investigation in a particularly unique way you can showcase that as well.[5] For exploration, you can state your focused research question; point to background research you have done (merely mentioning the main points here and not describing it in detail); describe briefly the methods you used stating all significant factors; and addressing any safety, ethical, or environmental issues where relevant.[6] For analysis, you can state the categories of quantitative or qualitative data you collected; summarize the processed data including error bars where appropriate and the uncertainties which led to those error bars; and stating your conclusion with any necessary caveats.[7] For evaluation, you should state in one sentence the justification of your conclusion by your data and in a second sentence the justification of your conclusion based on the scientific principles you have learned. You should also mention strengths and weaknesses in your investigation as well as suggestions for improvement.[8]

By showcasing these key points on focus, process, and outcomes at the very beginning of your writeup, you will highlight for the grader--whether that is your teacher or a moderator--that you have earned all the points you feel you should have earned. In addition, by structuring your abstract in a single page with either four short paragraphs (one per criteria), or in a single long paragraph, you will have shown the grader that you can communicate clearly and hence should earn full marks on communication as well.[9] The final benefit that writing a good abstract provides for you is that if you cannot answer any of the points listed above, you will know that your paper is missing critical material and you can go back and fix those sections. Similarly, your teacher can help to guide you in the weaker areas of your paper without needing to read the entire paper (and hence using up your one and only[10] rough draft).

Strand 1: Error Free

It is time now to proofread your report. Any errors--even a simple typo--which makes it hard to understand the focus, process, or outcome could put your 4 marks in jeopardy, so once you've read through your paper for the last time, give it to your friend and your English teacher to make sure that they can understand it. If they are confused about something, that is probably an area you want to work on to make sure it is more clear and error-free.

Strand 2: Structure

Make sure you have laid out your investigation in a well structured manner. Do you have an Introduction, a Procedure, a Data Analysis section, and an Evaluation or Conclusion? These are sections every grader looks for to give you marks on the criteria. If you have hidden them away without giving them bold section titles, they may be missed.

Now go through page by page. Check that all your footnotes are in the proper format, and that every source which appears in a footnote also appears in the bibliography. You should have many footnotes in your introduction and in the section of your evaluation where you justify your conclusion with theory.

Strand 4: Terminology

Check your language. Make sure you have a clear understanding of all the words you have used. Subject specific terminology must be appropriate and correct. There are no bonus points for using big words, so if you can use simpler words in a clearer way, go ahead and do so.

Strand 3: Concise

Go through your write up one more time looking for anything that is not needed. Is there any background in the introduction which doesn't really give background to your question? Have you given an outline of your procedure which would allow someone to repeat your experiment without repeating yourself or being overly detailed? Does your conclusion stick to points supported by your data? If there is anything which is not needed for your report, take it out.

Finally, after making all of the above changes, it is important to scroll to the back one final time and make sure you aren't over that 12 page limit. If you are, it will cost you points in communication.

[1] Biology Guide, Feb 2014, pg. 153; Chemistry Guide, Feb 2014, pg. 178; Physics Guide, Feb 2014, pg. 142.

[2] Biology Subject Reports, May 2016, pg. 6: "Use of whole pages for titles or contents. These are not necessary."

[3] Biology Subject Report, May 2016, pg. 7: "Candidates should not add on appendices in addition to a write up of about 12 pages."

[4] Chemistry Subject Report, May 2016, pg. 7: "Some students did include lengthy appendices in order to circumvent the page limit ruling but this is not an acceptable strategy since examiners do not have to read the appendices so vital marks could have been lost."

[5] Biology Guide, Feb 2014, pg. 155.

[6] Biology Guide, Feb 2014, pg. 156.

[7] Biology Guide, Feb 2014, pg. 157.

[8] Biology Guide, Feb 2014, pg. 158.

[9] Biology Guide, Feb 2014, pg. 158.

[10] "Guidance and Authenticity," *Biology Guide*, Feb 2014, pg. 148; *Chemistry Guide*, Feb 2014, pg. 173; *Physics Guide*, Feb 2014, pg. 136: "As part of the learning process, teachers should read and give advice to students on one draft of the work. The teacher should provide oral or written advice on how the work could be improved, but not edit the draft. The next version handed to the teacher must be the final version for submission."

Chapter 6 - Closing Remarks

Grade boundaries on IA's, unlike grade boundaries for the external exams, tend to be stable from year to year, so I am providing a table with them below. Of course it is my hope that the only grade you need to know is that full marks gets you a level 7.

IA Grade Boundaries

1	2	3	4	5	6	7
0-3	4-6	7-10	11-13	14-16	17-19	20-24

Table 6.1 - These are the internal assessment grade boundaries.[1]

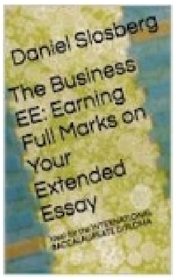
I hope you have found this book useful to you in perfecting your science IA this year. If you found it valuable, please let your friends know about this and other books in the "Earning Full Marks" series, post a link to it on your blog or in IB chat rooms, and give it a 5-star rating on Amazon here (click, then swipe to next page).

If, however, you found it lacking in any way, please let me know how I can improve it for future students by sending me an eMail and I will make the changes and send them out to all the students using the eVersion of this book, as well as to all new purchasers of the paperback version.

Thank you for your support.

[1] Physics Subject Reports, May 2016, pg. 2.

More *Earn Full Marks on Your DP Internal Assessments* Books



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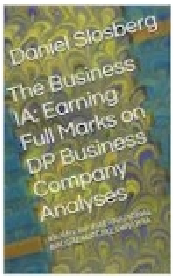

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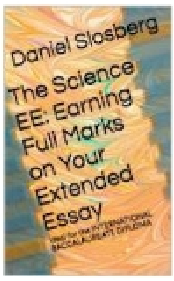

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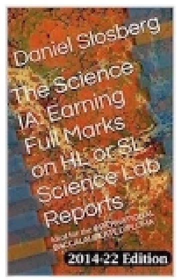

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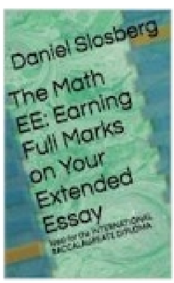

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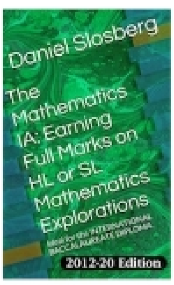

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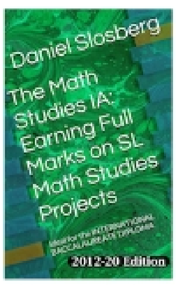

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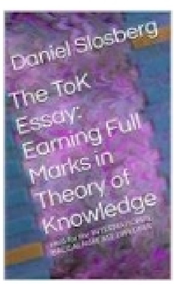

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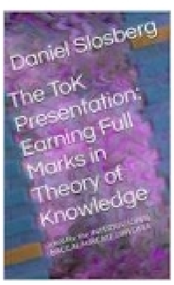

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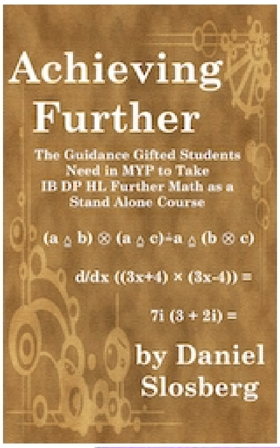
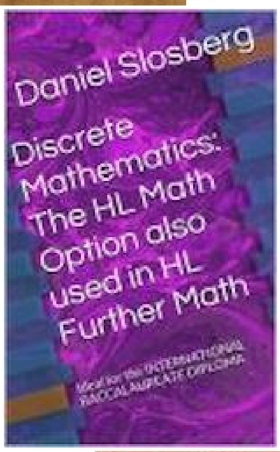
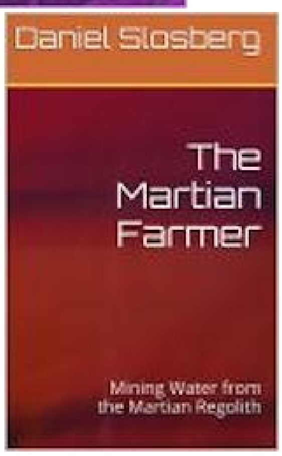
Rainbowdash Publishers LLC is currently seeking teachers and 1st year university students who earned 7's in DP to author books for additional courses, especially in groups 1, 2, 3 and 6. eMail RainbowdashPublishersLLC@umich.edu if you are interested.

Also by Daniel Slosberg







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Biology Labs

Prescribed Practicals

1. Use a light microscope to investigate the structure of cells and tissues, with drawing of cells. Calculation of the magnification of drawings and the actual size of structures and ultrastructures shown in drawings or micrographs. (pg. 30)
2. Estimation of osmolarity in tissues by bathing samples in hypotonic and hypertonic solutions. (pg. 33)
3. Experimental investigation of a factor affecting enzyme activity. (pg. 42)
4. Separation of photosynthetic pigments by chromatograph. (pg. 47)
5. Setting up sealed mesocosms to try to establish sustainability. (pg. 60) Mesocosms can be set up in open tanks, but sealed glass vessels are preferable because entry and exit of matter can be prevented but light can enter and heat can leave. Aquatic systems are likely to be more successful than terrestrial ones. (pg. 60 Guidance)
6. Monitoring of ventilation in humans at rest and after mild and vigorous exercise. (pg. 78) Ventilation can either be monitored by simple observation and simple apparatus or by data logging with a spirometer or chest belt and pressure meter. Ventilation rate and tidal volume should be measured, but

the terms vital capacity and residual volume are not expected. (pg. 79 Guidance)
7. HL-Measurement of transpiration rates using potometers. (pg. 92)

Understandings

1. Temperature, pH and substrate concentration affect the rate of activity of enzymes. (pg. 42)
2. Enzymes can be denatured. (pg. 42)

Applications and Skills

1. Application: Investigation of functions of life in Paramecium and one named photosynthetic unicellular organism. (pg. 30)
2. Skill: Drawing of the ultrastructure of prokaryotic cells based on electron micrographs. (pg. 31)
3. Skill: Drawing of the ultrastructure of eukaryotic cells based on electron micrographs. (pg. 31)
4. Skill: Interpretation of electron micrographs to identify organelles and deduce the function of specialized cells. (pg. 31)
5. Skill: Determination of a mitotic index from a micrograph. (pg. 35)
6. Skill: Use of molecular visualization software to compare cellulose, starch and glycogen. (pg. 39, see also pp. 36 & 40 Aim 7)
7. Skill: Determination of body mass index by calculation or use of a nomogram. (pg. 39)

8. Application: Denaturation of proteins by heat or by deviation of pH from the optimum. (pg. 40)
9. Application: Methods of production of lactose-free milk. (pg. 42)
10. Skill: Design of experiments to test the effect of temperature, pH and substrate concentration on the activity of enzymes. (pg. 42)
11. Application: Use of anaerobic cell respiration in yeasts to produce ethanol and carbon dioxide in baking. (pg. 46)
12. Skill: Analysis of results from experiments involving measurement of respiration rates in germinating seeds or invertebrates using a respirometer. (pg. 46)
13. Skill: Drawing an absorption spectrum for chlorophyll and an action spectrum for photosynthesis. (pg. 47)
14. Skill: Design of experiments to investigate the effect of limiting factors on photosynthesis. (pg. 47)
15. Application: Comparison of the number of genes in humans with other species. (pg. 49)
16. Skill: Use of a database to determine differences in the base sequence of a gene in two species. (pg. 49)
17. Application: Use of karyograms to deduce sex and diagnose Down syndrome in humans. (pg. 52)
18. Skill: Design of an experiment to assess one factor affecting the rooting of stem-cuttings. (pg. 58) A plant species should be chosen for rooting experiments that forms

roots readily in water or a solid medium. (pg. 58 Guidance) The design of a rooting experiment should ideally lead to the experiment actually being carried out by students. (pg. 57 Aim 6)

19. Skill: Testing for association between two species using the chi-squared test with data obtained by quadrat sampling. (pg. 60) To obtain data for the chi-squared test, an ecosystem should be chosen in which one or more factors affecting the distribution of the chosen species varies. Sampling should be based on random numbers. In each quadrat the presence or absence of the chosen species should be recorded. (pg. 60 Guidance)
20. Application: Use of dialysis tubing to model absorption of digested food in the intestine. (pg. 72)
21. Application: Florey and Chain's experiments to test penicillin on bacterial infections in mice. (pg. 76)
22. HL-Skill: Analysis of results of the Hershey and Chase experiment providing evidence that DNA is the genetic material. (pg. 83)
23. HL-Skill: Calculating and plotting rates of reaction from raw experimental results. (pg. 88)
24. HL-Skill: Distinguishing different types of inhibition from graphs at specified substrate concentration. (pg. 88)
25. HL-Application: Calvin's experiment to elucidate the carboxylation of RuBP. (pg.

91)

26. HL-Application: Models of water transport in xylem using simple apparatus including blotting or filter paper, porous pots and capillary tubing. (pg. 92)
27. HL-Skill: Design of an experiment to test hypotheses about the effect of temperature or humidity on transpiration rates. (pg. 92)
28. HL-Skill: Analysis of data from experiments measuring phloem transport rates using aphid stylets and radioactively-labelled carbon dioxide. (pg. 93)
29. HL-Application: Micropropagation of plants using tissue from the shoot apex, nutrient agar gels and growth hormones. (pg. 94)
30. HL-Application: Methods used to induce short-day plants to flower out of season. (pg. 95) Flowering in so-called short-day plants such as chrysanthemums, is stimulated by long nights rather than short days. (pg. 95 Guidance)
31. HL-Skill: Design of experiments to test hypotheses about factors affecting germination. (pg. 95)
32. HL-Skill: Drawing labelled diagrams of the structure of a sarcomere. (pg. 102) Measurement of the length of sarcomeres will require calibration of the eyepiece scale of the microscope. (pg. 103 Guidance)
33. B-Skill: Gram staining of Gram-positive and Gram-negative bacteria. (pg. 120)

34. B-Skill: Experiments showing zone of inhibition of bacterial growth by bactericides in sterile bacterial cultures. (pg. 120)
35. B-Skill: Production of biogas in a small-scale fermenter. (pg. 120)
36. B-HL-Skill: Explore chromosome 21 in databases (for example in Ensembl). (pg. 126)
37. B-HL-Skill: Use of software to align two proteins. (pg. 126)
38. B-HL-Skill: Use of software to construct simple cladograms and phylograms of related organisms using DNA sequences. (pg. 126)

Guidance

1. Osmosis experiments are a useful opportunity to stress the need for accurate mass and volume measurements in scientific experiments. (pg. 33)
2. Preparation of temporary mounts of root squashes is recommended but phases in mitosis can also be viewed using permanent slides. (pg. 35)
3. Egg white or albumin solutions can be used in denaturation experiments. (pg. 41)
4. Lactase can be immobilized in alginate beads and experiments can then be carried out in which the lactose in milk is hydrolysed. (pg. 42)
5. There are many simple respirometers which could be used. Students are expected to

know that an alkali is used to absorb CO_2, so reductions in volume are due to oxygen use. Temperature should be kept constant to avoid volume changes due to temperature fluctuations. (pg. 46)

6. Water free of dissolved carbon dioxide for photosynthesis experiments can be produced by boiling and cooling water. (pg. 48)
7. Paper chromatography can be used to separate photosynthetic pigments but thin layer chromatography gives better results. (pg. 48)
8. At least one plant and one bacterium should be included in the comparison and at least one species with more genes and one with fewer genes than a human. The Genbank® database can be used to search for DNA base sequences. The cytochrome C gene sequence is available for many different organisms and is of particular interest because of its use in reclassifying organisms into three domains. (pg. 50)
9. Preparation of microscope slides showing meiosis is challenging and permanent slides should be available in case no cells in meiosis are visible in temporary mounts. (pg. 54)

Aim 6

1. Dialysis tubing experiments can act as a model of membrane action. (pg. 33)
2. Experiments with potato, beetroot or single-celled algae can be used to investigate

real membranes. (pg. 33)

3. Pasteur's experiment can be repeated using modern apparatus. (pg. 34)
4. Food tests such as the use of iodine to identify starch or Benedict's reagent to identify reducing sugars could be carried out. (pg. 36) Author's Note: This can be done in conjunction with chemistry. See pg. 128 in the chemistry guide.
5. Probes can be used to determine the effect of different factors likely to influence the cooling with water. (pg. 38)
6. Staining root tip squashes and microscope examination of chromosomes is recommended but NOT obligatory. (pg. 51)
7. The design of a rooting experiment should ideally lead to the experiment actually being carried out by students. (pg. 57)
8. It would be best for students to obtain data for the chi-squared test themselves, to give first-hand experience of field work techniques. (pg. 59)
9. A heart dissection is suggested as a means of studying heart structure. (pg. 74)
10. HL: Students could design models to illustrate the stages of DNA replication. (pg. 83)
11. HL: Experiments on enzyme inhibition can be performed. (pg. 88)
12. HL: Hill's method demonstrating electron transfer in chloroplasts by observing DCPIP reduction, immobilization of a culture of an alga such as Scenedesmus in alginate beads and measurement of the rate of photosyn-

thesis by monitoring their effect on hydrogencarbonate indicator are all possible experiments. (pg. 91)

13. HL: Measurement of stomatal apertures and the distribution of stomata using leaf casts, including replicate measurements to enhance reliability, are possible experiments. (pg. 92)
14. HL: Investigations into tropisms could be carried out. (pg. 94)
15. HL: Staining of lily anthers or other tissue containing germ-line cells and microscope examination to observe cells in meiosis are possible activities. (pg. 96)
16. B-HL: Sequence alignment of related proteins such as hemoglobin and myoglobin could be investigated. (pg. 126)
17. C: Factors influencing herbivory could be investigated. (pg. 127)
18. D: Temporary mounts of hepatocytes can be prepared from fresh liver. (pg. 138)

Aim 7

1. ICT can be used for molecular visualization of carbohydrates, lipids and proteins. (pp. 36, 39 (skill), & 40)
2. The use of a database to compare DNA base sequences. (pg. 49)
3. Use of databases to identify gene loci and protein products of genes. (pg. 51)
4. Databases can be used to analyse concentrations of greenhouse gases. (pg. 65)

5. HL: Computer simulations on enzyme action including metabolic inhibition are available. (pg. 88)
6. HL: The introduction of image processing software and digital microscopes increases further the ability to gather more data to ensure reliability. (pg. 92)
7. HL: Use of databases to analyse epidemiological data. (pg. 100)
8. HL: Use of grip strength data loggers to assess muscle fatigue. (pg. 102)
9. HL: Use of animations to visualize contraction. (pg. 102)
10. A-HL: Data logging using an electrocardiogram (ECG) sensor to analyse neuromuscular reflexes. (pg. 113)
11. B: Use of bioinformatics to determine sequences to be modified. (pg. 121)

I believe the above list to be complete. If, however, you find that I have missed any required lab in the Biology Guide, please eMail the name of the lab and the page in the guide where you found it to RainbowdashPublishersLLC@umich.edu and I will update this list for everyone. Thank you.

Return to brainstorming your research question.

Chemistry Required Labs

Prescribed Practicals

1. Obtaining and using experimental data for deriving empirical formulas from reactions involving mass changes. (pg. 34)
2. Use of the experimental method of titration to calculate the concentration of a solution by reference to a standard solution. (TSM)
3. Obtaining and using experimental values to calculate the molar mass of a gas from the ideal gas equation. (TSM)
4. A calorimetry experiment for an enthalpy of reaction should be covered and the results evaluated. (TSM)
5. Investigation of rates of reaction experimentally and evaluation of the results. (pg. 55)
6. Candidates should have experience of acid-base titrations with different indicators. (pg. 59)
7. Students should be familiar with the use of a pH meter and universal indicator. (pg. 60)
8. Performance of laboratory experiments involving a typical voltaic cell using two metal/metal-ion half-cells. (pg. 65)
9. Construction of 3-D models (real or virtual) of organic molecules. (pg. 68)
10. HL: Perform lab experiments which could include single replacement reactions in aqueous solutions. (pg. 84) (NOTE: TSM does

not indicate this is limited to HL students.)

Applications and Skills

1. Calculation of the enthalpy changes from known bond enthalpy values and comparison of these to experimentally measured values. (pg. 53)
2. Deduction of the Brønsted–Lowry acid and base in a chemical reaction. (pg. 58)
3. Deduction of the conjugate acid or conjugate base in a chemical reaction. (pg. 58)
4. Most acids have observable characteristic chemical reactions with reactive metals, metal oxides, metal hydroxides, hydrogen carbonates and carbonates. (pg. 59)
5. Salt and water are produced in exothermic neutralization reactions. (pg. 59)
6. The Winkler Method can be used to measure biochemical oxygen demand (BOD), used as a measure of the degree of pollution in a water sample. (pg. 63)
7. Application of the Winkler Method to calculate BOD. (pg. 64)
8. Construction and annotation of both types of electrochemical cells. (pg. 65)
9. Identification of different classes: alkanes, alkenes, alkynes, halogenoalkanes, alcohols, ethers, aldehydes, ketones, esters, carboxylic acids, amines, amides, nitriles and arenes. (pg. 68)
10. Identification of typical functional groups in molecules eg phenyl, hydroxyl, car-

bonyl, carboxyl, carboxamide, aldehyde, ester, ether, amine, nitrile, alkyl, alkenyl and alkynyl. (pg. 68)

11. Mass spectrometry (MS), proton nuclear magnetic resonance spectroscopy (^{1}H NMR) and infrared spectroscopy (IR) are techniques that can be used to help identify compounds and to determine their structure. (pg. 75)
12. HL: The oxidation states of vanadium and manganese, for example, could be investigated experimentally. (pg. 78)
13. HL: Transition metals could be analyzed using redox titrations. (pg. 78)
14. HL: Perform lab experiments which could include single replacement reactions in aqueous solutions. (pg. 84)
15. HL: Deduction of the rate expression for an equation from experimental data and solving problems involving the rate expression. (pg. 86)
16. HL: When aqueous solutions are electrolysed, water can be oxidized to oxygen at the anode and reduced to hydrogen at the cathode. (pg. 95)
17. HL: Perform lab experiments that could include single replacement reactions in aqueous solutions. (pg. 96)
18. B-HL: Amino acids and proteins can act as buffers in solution. (pg. 132)
19. B-HL: Investigation of pigments through paper and thin layer chromatography. (pg. 137)

Guidance

1. The operation of the mass spectrometer is not required. (pg. 38)
2. Consider reactions in aqueous solution and combustion reactions. (pg. 50)
3. Heat losses to the environment and the heat capacity of the calorimeter in experiments should be considered, but the use of a bomb calorimeter is not required. (pg. 51)
4. HL: Any experiment which allows students to vary concentrations to see the effect upon the rate and hence determine a rate equation is appropriate. Consider concentration–time and rate–concentration graphs. (pg. 87)

Utilization

1. Refrigeration and how it is related to the changes of state. (pg. 32) Author's Note: Electric cooling blocks make tabletop "as you watch it" experiments possible.
2. Freeze-drying of foods. (pg. 32)
3. Ionic liquids are efficient solvents and electrolytes used in electric power sources and green industrial processes. (pg. 44)
4. Determining energy content of important substances in food and fuels. (pg. 50)
5. HL: Electroplating. (pg. 95)
6. HL: Rusting of metals. (pg. 95)
7. B-HL: The purplish-red colour of meat is

largely due to the presence of myoglobin. The change in colour to brown on cooking occurs as the iron ion becomes oxidized to Fe^{3+}. (pg. 136)

Aim 6

1. Experiments could include percent mass of hydrates, burning of magnesium or calculating Avogadro's number. (pg. 35)
2. Experimental design could include excess and limiting reactants. Experiments could include gravimetric determination by precipitation of an insoluble salt. (pg. 37)
3. Emission spectra could be observed using discharge tubes of different gases and a spectroscope. Flame tests could be used to study spectra. (pg. 41)
4. Be able to recognize physical samples or images of common elements. (pg. 42)
5. Experiment with chemical trends directly in the laboratory or through the use of teacher demonstrations. (pg. 43)
6. The use of transition metal ions as catalysts could be investigated. (pg. 43)
7. Students could investigate compounds based on their bond type and properties or obtain sodium chloride by solar evaporation. (pg. 44)
8. Experiments could include calculating enthalpy changes from given experimental data (energy content of food, enthalpy of melting of ice or the enthalpy change of

simple reactions in aqueous solution). (pg. 50)

9. Experiments could include Hess's Law labs. (pg. 52)
10. Experiments could be enthalpy of combustion of propane or butane. (pg. 53)
11. Investigate the rate of a reaction with and without a catalyst. (pg. 55)
12. Experiments could include investigating rates by changing concentration of a reactant or temperature. (pg. 55)
13. Le Châtelier's principle can be investigated qualitatively by looking at pressure, concentration and temperature changes on different equilibrium systems. (pg. 57)
14. The evidence for [the] properties [of acids and bases] could be based on a student's experimental experiences. (pg. 59)
15. An acid–base titration could be monitored with an indicator or a pH probe. (pg. 60)
16. Students should have experimental experience of working qualitatively with both strong and weak acids and bases. Examples to include: H_2SO_4 (aq), HCl (aq), HNO_3 (aq), NaOH (aq), NH_3 (aq). (pg. 61)
17. The effects of acid rain on different construction materials could be quantitatively investigated. (pg. 62) Author's Note: The pH of local rain and snow packs can be measured and discussed--perhaps in conjunction with the environmental science class.
18. Experiments could include demonstrating the activity series, redox titrations and

using the Winkler Method to measure BOD. (pg. 64)

19. Construction of a typical voltaic cell using two metal/metal-ion half-cells. (pg. 65) Author's Note: This can be done in conjunction with physics. See pg. 58 in the physics guide.
20. Electrolysis experiments could include that of a molten salt. A video could also be used to show some of these electrolytic processes. (pg. 65)
21. Either use model kits or suitable computer-generated molecular graphics programmes to construct three-dimensional models of a wide range of organic molecules. (pg. 68)
22. Experiments could include distillation to separate liquids or the use of a rotary evaporator to remove a solvent from a mixture. (pg. 68)
23. Experiments could include distinguishing between alkanes and alkenes, preparing soap and the use of gravity filtration, filtration under vacuum (using a Buchner flask), purification including recrystallization, reflux and distillation, melting point determination and extraction. (pg. 70)
24. The distinction and different roles of Class A and Class B glassware could be explored. (pg. 72)
25. HL: The oxidation states of vanadium and manganese, for example, could be investigated experimentally. Transition metals

could be analysed using redox titrations. (pg. 78)

26. HL: The colours of a range of complex ions, of elements such as Cr, Fe, Co, Ni and Cu could be investigated. (pg. 79)
27. HL: A possible experiment is to calculate either the enthalpy of crystallization of water or the heat capacity of water when a cube of ice is added to hot water. (pg. 84)
28. HL: Experiments investigating endothermic and exothermic processes could be run numerous times to compare reliability of repetitive data and compare to theoretical values. (pg. 85)
29. HL: Experiments could include those involving the collection of temperature readings to obtain sufficient data for a graph. (pg. 88)
30. HL: The equilibrium constant for an esterification reaction and other reactions could be experimentally investigated. (pg. 90)
31. HL: Transition metal complexes could be experimentally explored. (pg. 91)
32. HL: The properties of strong and weak acids could be investigated experimentally. (pg. 92)
33. HL: Experiments could include investigation of pH curves, determination of the pKa of a weak acid, preparation and investigation of a buffer solution and the determination of the pKa of an indicator. (pg. 93)
34. HL: Three-dimensional visualization of or-

ganic compounds using molecular models could be covered. (pg. 97)

35. HL: A range of experiments of organic synthetic reactions exploring various types of reactions and functional group interconversions could be done. Core techniques of organic chemistry could include reflux, distillation, filtration, purification (including chromatographic techniques), separations and extractions. (pg. 98)
36. HL: Synthesis (or reaction) in the laboratory of an example of a widely used drug or medicine (eg aspirin [see option D pg. 159]) or a household product (eg fading of tomato ketchup—electrophilic addition reaction of bromine). (pg. 98)
37. HL: Multiple stage organic synthetic route series of experiments (up to a maximum of four stages). (pg. 100)
38. HL: Experiments could include the synthesis and characterization of an enantiomer (eg (-) menthol) or the resolution of a racemic mixture. (pg. 102)
39. A: Experiments could include investigating the stretching of rubber bands under different chemical environments, or properties of metals, polymers, ceramics, or composites, making thin concrete slabs from various ratios of cement, gravel, and sand and investigating the breaking strength upon drying. (pg. 107)
40. A: Experiments could include calculating the Faraday constant via electrolysis of

aqueous copper sulfate, solving for the concentration of a nickel or copper solution using Beer's law and spectrophotometry. Analysis of alloy composition labs could also be conducted such as colorimetric determination of manganese in a paper clip or gravimetric analysis of silver or copper in a coin. (pg. 108)

41. A: Experiments could include investigating the decomposition of potassium sodium tartrate with cobalt chloride and the decomposition of hydrogen peroxide with manganese (IV) oxide. (pg. 110)
42. A: An ion exchange using zeolite could be explored. (pg. 110)
43. A: Experiments could include investigating a thermotropic liquid crystal and the temperature range which affects these crystals. (pg. 111)
44. A: Physical properties of high and low density polyethene could be investigated or synthesis of a polyester, polyamide or other polymer could be quantitatively performed to measure atom efficiency. (pg. 112)
45. A-HL: Synthesis of nylon could be performed. (pg. 120)
46. A-HL: Experiments could include investigations of K_{sp}. (pg. 121)
47. B: Experiments could involve hydrolysis of a protein, separation and identification of amino acid mixtures by paper chromatography, or gel electrophoresis of proteins

and DNA. (pg. 123)

48. B: Experiments could include the calculation of the iodine number of fats to measure degree of unsaturation, calorimetric experiments on different fats and oils, or the separation of lipids from common food sources using different solvents and a separating funnel. (pg. 126)
49. B: Experiments could include using Benedict's or Fehling's solution tests to distinguish between reducing sugars and non-reducing sugars or using iodine solution to test for the presence of starch. (pg. 128) Author's Note: This can be done in conjunction with biology. See pg. 36 in the biology guide.
50. B: Experiments could include the DCPIP determination of vitamin C levels in foods. (pg. 129)
51. B: Experiments could include the comparison of the breakdown of biodegradable and non-biodegradable plastics in the environment. (pg. 130)
52. B-HL: Experiments could include measuring enzyme activity with changing conditions of temperature, pH and heavy metal ion concentration. (pg. 133)
53. B-HL: Experiments could include DNA extraction from cells and investigation of its physical properties, and model building exercises of DNA structure, including the specific base pairings between a purine and a pyrimidine. (pg. 135)

54. B-HL: Experiments could include the extraction and isolation of pigments from plant sources using solvents and separating funnel or the use of anthocyanins as pH indicators. (pg. 137)
55. C: The energy density of different fuels could be investigated experimentally. (pg. 141)
56. C: Possible experiments include fractional distillation and catalytic cracking reactions. (pg. 142)
57. C: Experiments could include those involving photosynthesis, fermentation and transesterification. (pg. 146)
58. C: The equilibrium between aqueous and gaseous carbon dioxide could be experimentally investigated. (pg. 148)
59. C-HL: The factors that affect the voltage of a cell and the lead–acid battery could be investigated experimentally. (pg. 150)
60. C-HL: Students could build an inexpensive dye-sensitized solar cell and investigate their photovoltaic properties. (pg. 154)
61. D: The properties of DSSCs can be best investigated using data loggers. (pg. 159)
62. D: Experiments could include titrations to test the effectiveness of various antacids. (pg. 161)

Aim 7

1. Data loggers can be used to measure mass changes during reactions. (pg. 35)

2. Data loggers can be used to measure temperature, pressure and volume changes in reactions or to determine the value of the gas constant, R. (pg. 37)
3. Simulations of Rutherford’s gold foil experiment can be undertaken. (pg. 39) Author's Note: Local universities may permit students to use their linear accelerator to reproduce Rutherford's experiment. This is a good joint field trip with physics.
4. Periodic trends can be studied with the use of computer databases. (pg. 43)
5. Computer simulation could be used to observe crystal lattice structures. (pg. 44)
6. Computer simulations could be used to model VSEPR structures. (pg. 46)
7. Computer simulations could be used to show intermolecular forces interactions. (pg. 48)
8. Computer simulations could be used to view examples of metallic bonding. (pg. 49)
9. Use of databases to analyse the energy content of food. (pg. 50)
10. Use of data loggers to record temperature changes. (pg. 50, 52, 53 & 84)
11. Use simulations to show how molecular collisions are affected by change of macroscopic properties such as temperature, pressure and concentration. (pg. 55)
12. Animations and simulations can be used to illustrate the concept of dynamic equilibrium. (pg. 57)
13. Students could use data loggers to investi-

gate the strength of acid and bases. (pg. 61)

14. Graph-plotting software may be used, including the use of spreadsheets and the derivation of best-fit lines and gradients. (pg. 74)
15. Spectral databases could be used here. (pg. 76)
16. HL: Databases could be used for compiling graphs of trends in ionization energies and simulations are available for the Davisson-Germer electron diffraction experiment. (pg. 77)
17. HL: Complex ions could be investigated using a spectrometer data logger. (pg. 79)
18. HL: Computer simulations can be used to model structures predicted by VSEPR theory. (pg. 82)
19. HL: Computer simulations could be used to model hybrid orbitals. (pg. 83)
20. HL: Use of databases to source accepted values. (pg. 84)
21. HL: Use of databases to research hypothetical reactions capable of generating free energy. (pg. 85)
22. HL: Databases, data loggers and other ICT applications can be used to research proposed mechanisms for lab work performed and to carry out virtual experiments to investigate factors which influence rate equations. (pg. 86)
23. HL: Use of simulations and virtual experiments to study effect of temperature and steric factors on rates of reaction. (pg. 88)

24. HL: Graphing calculators can be employed to easily input and analyse data for E a and frequency factor values. (pg. 88)
25. HL: The concept of a dynamic equilibrium can be illustrated with computer animations. (pg. 90)
26. HL: Animations can be used to distinguish between the different acid–base theories. (pg. 91)
27. HL: Data logging, databases, spreadsheets and simulations can all be used. For example, the equivalence point could be determined by using a conductivity probe or a temperature probe. (pg. 93)
28. HL: Spectral databases can be used here. (pg. 105)
29. A: Animations involving ICP could be used. (pg. 109)
30. A: Simulations and virtual experiments could be used to investigate semiconductors. (pg. 109)
31. A: Virtual experiments and simulations involving nanoparticles as catalysts could be done here. (pg. 110)
32. A: Computer animations could be used to investigate thermotropic liquid crystals. (pg. 111)
33. A: Animations, simulations, and videos of nanotube manufacture and uses should be used. (pg. 115)
34. A: Database of RIC codes and IR spectra can be used. (pg. 116)
35. A-HL: Animations and simulations would

be very useful to explain superconductivity and X-ray crystallography. (pg. 118)

36. B: Data logging experiments involving absorption/concentration studies for protein content using the Biuret reagent. (pg. 123)
37. B: Simulations can be used for gel electrophoresis. (p. 124)
38. B-HL: Data-logging experiments with temperature or pH probes to investigate enzyme activity under different conditions; or computer modelling of enzyme–substrate interactions. (pg. 133)
39. B-HL: Databases exist of genetic sequences from different organisms. (pg. 135)
40. B-HL: Use of data loggers for collecting absorption data. (pg. 137)
41. C: Databases of energy statistics on a global and national scale can be explored here. (pg. 141)
42. C: Databases of energy statistics on a global and national scale can be explored here. (pg. 142)
43. C: Many online calculators are available to calculate carbon footprints. (pg. 142)
44. C: Computer animations and simulations of radioactive decay, and nuclear fusion and fission reactions. (pg. 144)
45. C: Computer modelling is a powerful tool by which knowledge can be gained about the greenhouse effect. (pg. 149)
46. C-HL: Computer animations and simulations of radioactive decay, and nuclear fusion and fission reactions. (pg. 153)

47. C-HL: The properties of DSSCs can be best investigated using data loggers. (pg. 154)
48. D: Use computer animations for the investigation of 3-D visualizations of drugs and receptor sites. (pg. 160)
49. D-HL: Computer databases with spectroscopy data could be used to confirm the identity of newly synthesized molecules. (pg. 166)

I believe the above list to be complete. If, however, you find that I have missed any required lab in the Chemistry Guide, please eMail the name of the lab and the page in the guide where you found it to RainbowdashPublishersLLC@umich.edu and I will update this list for everyone. Thank you.

Return to brainstorming your research question.

Physics Labs

Prescribed Practicals

Applications and Skills

ple harmonic motion examples. (pg. 46) Graphs describing simple harmonic motion should include displacement-time, velocity-time, acceleration-time and acceleration-displacement. (pg. 47)

3. Investigating combinations of resistors in parallel and series circuits. (pg. 56)
4. Investigating practical electric cells (both primary and secondary). (pg. 58)
5. Describing the Rutherford-Geiger-Marsden experiment that led to the discovery of the nucleus. (pg. 66)
6. HL: Investigating combinations of capacitors in series or parallel circuits. (pg. 88)
7. HL: Discussing the photoelectric effect experiment and explaining which features of the experiment cannot be explained by the classical wave theory of light. (pg. 91)
8. HL: While not in the physics guide as an experiment, Rutherford's gold foil experiment is frequently doable at local universities and simulations of it are in the chemistry guide (pg. 39). It can make a good joint field trip.
9. HL: Discussing experimental evidence for matter waves, including an experiment in which the wave nature of electrons is evident. (pg. 91)
10. HL: Explaining the methods for measuring short and long half-lives. (pg. 92)
11. C: Investigating the optical compound microscope experimentally. (pg. 114)
12. C: Investigating the performance of a simple optical astronomical refracting telescope

experimentally. (pg. 115)

13. D: Sketching and interpreting HR diagrams. (pg. 122)

Guidance

1. Methods of polarization will be restricted to the use of polarizing filters and reflection from a non-metallic plane surface. (pg. 49)
2. Students should have the opportunity to observe diffraction and interference patterns arising from more than one type of wave. (pg. 51)

Utilization

1. Pressure gauges, barometers and manometers are a good way to present aspects of this sub-topic. (pg. 42)
2. Many systems can approximate simple harmonic motion: mass on a spring, fluid in U-tube, models of icebergs oscillating vertically in the ocean, and motion of a sphere rolling in a concave mirror. (pg. 47)
3. Students studying music should be encouraged to bring their own experiences of this art form to the physics classroom. (pg. 52)
4. The chemistry of electric cells. (pg. 58) Author's Note: This can be done in conjunction with chemistry. See pg. 65 in the chemistry guide.

Aim 3

1. Students are able to both physically observe and qualitatively measure the locations of nodes and antinodes, following the investigative techniques of early scientists and musicians. (pg. 53)

Aim 6

Experiments could include (but are not limited to)...

1. determination of g, estimating speed using travel timetables, analyzing projectile motion, and investigating motion through a fluid. (pg. 35)
2. verification of Newton's second law; investigating forces in equilibrium; determination of the effects of friction. (pg. 37)
3. relationship of kinetic and gravitational potential energy for a falling mass; power and efficiency of mechanical objects; comparison of different situations involving elastic potential energy. (pg. 39)
4. analysis of collisions with respect to energy transfer; impulse investigations to determine velocity, force, time, or mass; determinations of amount of transformed energy in inelastic collisions. (pg. 41)
5. transfer of energy due to temperature difference; calorimetric investigations; energy involved in phase changes. (pg. 43)
6. verification of gas laws; calculation of the Avogadro constant; virtual investigation of

gas law parameters not possible within a school laboratory setting. (pg. 44)

7. mass on a spring; simple pendulum; motion on a curved air track, (pg. 47) with further extensions for HL students. (pg. 73)
8. speed of waves in different media; detection of electromagnetic waves from various sources; use of echo methods (or similar) for determining wave speed, wavelength, distance, or medium elasticity and/or density. (pg. 48)
9. observation of polarization under different conditions, including the use of microwaves; superposition of waves; representation of wave types using physical models (eg slinky demonstrations). (pg. 49)
10. determination of refractive index and application of Snell's law; determining conditions under which total internal reflection may occur; examination of diffraction patterns through apertures and around obstacles; investigation of the double-slit experiment. (pg. 51)
11. observation of standing wave patterns in physical objects (eg slinky springs); prediction of harmonic locations in an air tube in water; determining the frequency of tuning forks; observing or measuring vibrating violin/guitar strings. (pg. 53)
12. demonstrations showing the effect of an electric field (eg using semolina); simulations involving the placement of one or more point charges and determining the re-

sultant field. (pg. 55)

13. use of a hot-wire ammeter as an historically important device; comparison of resistivity of a variety of conductors such as a wire at constant temperature, a filament lamp, or a graphite pencil; determination of thickness of a pencil mark on paper; investigation of ohmic and non-ohmic conductor characteristics; using a resistive wire wound and taped around the reservoir of a thermometer to relate wire resistance to current in the wire and temperature of wire. (pg. 57)
14. investigation of simple electrolytic cells using various materials for the cathode, anode and electrolyte; software-based investigations of electrical cell design; comparison of the life expectancy of various batteries. (pg. 58) Author's Note: This can be done in conjunction with chemistry. See pg. 65 in the chemistry guide.
15. mass on a string; observation and quantification of loop-the-loop experiences; friction of a mass on a turntable. (pg. 60)
16. the scattering angle of alpha particles as a function of the aiming error, or the minimum distance of approach as a function of the initial kinetic energy of the alpha particle. (pg. 66)
17. simulations of energy exchange in the Earth surface-atmosphere system. (pg. 71)
18. HL: investigation of simple or torsional pendulums; measuring the vibrations of a

tuning fork. (pg. 73)

19. HL: iterating force laws numerically. (details on pg. 73)
20. HL: use of diffraction gratings in spectroscopes; analysis of thin soap films; sound wave and microwave interference pattern analysis. (pg. 76)
21. HL: spectral data and images of receding galaxies are available from professional astronomical observatories for analysis. (pg. 79)
22. HL: construction and observation of the adjustments made in very large electricity distribution systems are best carried out using computer-modeling software and websites. (pg. 86)
23. HL: investigating basic RC circuits; using a capacitor in a bridge circuit; examining other types of capacitors; verifying time constant. (pg. 88)
24. HL: the photoelectric effect can be investigated using LEDs. (pg. 91) Author's Note: a very good simulation of the photoelectric effect can also be found here.
25. B-HL: observation of sand on a vibrating surface of varying frequencies; investigation of the effect of increasing damping on an oscillating system, such as a tuning fork; observing the use of a driving frequency on forced oscillations. (pg. 111)
26. C: magnification determination using an optical bench; investigating real and virtual images formed by lenses; observing

aberrations. (pg. 112)

27. C & D: Local amateur or professional astronomical organizations can be useful for arranging demonstrations of the night sky. (pg. 115 & 120)
28. D: software-based analysis is available for students to participate in astrophysics research. (pg. 122)

Aim 7

1. Technology has allowed for more accurate and precise measurements of motion, including video analysis of real-life projectiles and modelling/simulations of terminal velocity. (pg. 35)
2. Technology has allowed for more accurate and precise measurements of force and momentum, including video analysis of real-life collisions and modelling/simulations of molecular collisions. (pg. 41)
3. IT skills can be used to model the simple harmonic motion defining equation; this gives valuable insight into the meaning of the equation itself. (pg. 47)
4. Use of computer modelling enables students to observe wave motion in three dimensions as well as being able to more accurately adjust wave characteristics in superposition demonstrations. (pg. 49)
5. Use of computer simulations would enable students to measure microscopic interactions that are typically very difficult in a

school laboratory situation. (pg. 55)

6. There are many software and online options for constructing simple and complex circuits quickly to investigate the effect of using different components within a circuit. (pg. 57)
7. Computer-based simulations enable the visualization of electromagnetic fields in three-dimensional space. (pg. 59)
8. Technology has allowed for more accurate and precise measurements of circular motion, including data loggers for force measurements and video analysis of objects moving in circular motion. (pg. 60)
9. HL: The observation of simple harmonic motion and the variables affected can be easily followed in computer simulations. (pg. 73)
10. HL: Computer simulations of the Doppler effect allow students to visualize complex and mostly unobservable situations. (pg. 79)
11. B: Technology has allowed for computer simulations that accurately model the complicated outcomes of actions on bodies. (pg. 104)
12. B-HL: The complexity of fluid dynamics makes it an ideal topic to be visualized through computer software. (pg. 109)
13. B-HL: To investigate the use of resonance in electrical circuits, atoms/molecules, or with radio/television communications is best achieved through software modeling exam-

ples. (pg. 111)

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About the Author

Daniel Slosberg has always loved science, from the time when he was six year old and got his first chemistry kit and promptly set up shop in his parents photography lab, to the time when he was eight and wasn't satisfied with his first electronics kit but wanted to keep going back to Radio Shack to get more parts to incorporate. At university he built a computer from transistors in his dorm room--only shorting out the electricity for the entire dorm once in the process--and then he went to Germany to study solar physics, quantum physics, and particle physics. He returned to the US to study general relativity and more quantum mechanics before he graduated, and in graduate school he first published a paper on extracting water from Martian soil and then he worked on the pickup ion data from the Cassini spacecraft.

Daniel started teaching in 1995. Astronomy at first, and then physics, math, computer programming, architecture and various other courses to the present day. He has taught both HL & SL Mathematics since 2004 starting in Centennial High School in Corona, CA and continuing in Hong Kong, China since 2007 where he has been teaching MYP and DP Math and Physics at Victoria Shanghai Academy (in Hong Kong, not Shanghai). It is his hope that this short book will allow both his own students and students all over the globe to achieve greater success in writing their scientific investigations so that they will be under less stress when they write their external examinations.

The future, however, is why Daniel writes. He feels every young person requires a strong foundation in science, not for its own sake, but to be used throughout life. He hopes the students reading this book will enjoy the science in their investigations and more importantly will apply scientific thinking and experimentation usefully in their daily lives long after they have graduated from the diploma program. Personally, Daniel will use his scientific training to figure out how to live on Mars. You can find more of his writings in the Proceedings of the Mars Society and on Amazon, the Nook, and iBooks.