The Internal Assessment

The Internal Assessment (IA) in Physics is a scientific investigation that contributes 20% to your final grade at both standard and higher level. View the IA as a discrete piece of work that has a definite beginning and end, measured in days (not weeks or months). There is no point starting your IA midway in your first year and finishing it midway in the second. The allotted time for the IA is 10 hours. It is highly recommended that you do not have more than two weeks between starting the investigation and writing the first draft. Once you receive comments from your teacher on your first draft, finish the assessment within a week.

Choosing a topic

The topics that will have the greatest chance for success are those that have research questions of the type 'How does y depend on x?' For example:

1 How does the period T of a simple pendulum depend on the angle θ from which it is released?

2 How does the rebound height H of a basketball depend on the pressure P of air in the ball?

3 How does the damping coefficient b depend on the area A of a piece of cardboard attached to an oscillating mass?

4 How does the dominant frequency f of the sound made by a ping-pong ball hitting the floor depend on the height H from which it is dropped?

5 How does the diameter D of the crater formed by a ball bearing falling on balsa wood depend on the height H from which the ball is released?

6 How does the maximum height H reached by a water rocket depend on the mass M of water in the rocket?

7 How does the time T to empty a funnel filled with granular material depend on the diameter D of the opening of the funnel in the diagram?

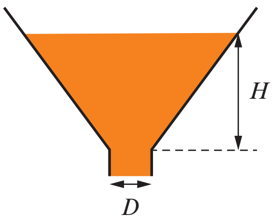

Figure 1.1

Or, for fixed density and diameter, how does the time to empty, T, depend on the amount of material in the funnel measured through the height H?

8 How does the displacement d of a horizontal, plastic ruler clamped at both ends depend on the mass M placed at the middle of the ruler in the diagram?

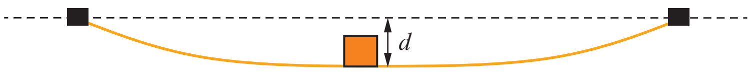

Figure 1.2

9 How does the displacement d of a horizontal rod clamped at one end depend on the mass M placed at the free end of the rod? How does the displacement d of a horizontal rod clamped at one end depend on the distance x from the left end where a mass M is placed? How does the displacement d of a horizontal rod clamped at one end depend on the length L of the rod when a mass M placed at the free end of the rod? Investigate the oscillations of this system.

10 How does the deflection d of a cantilever depend on the mass M attached at the free end in the diagram? How does it depend on the distance x from the clamped end when the mass is attached there? How does the period of oscillations T depend on M or x?

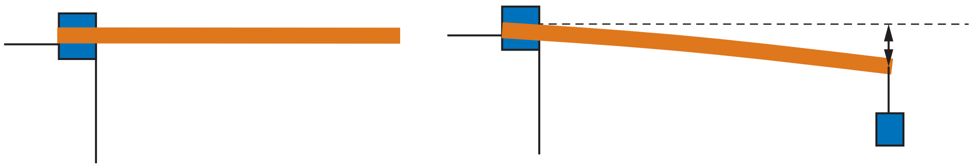

Figure 1.3

11 How does the frequency f of the first harmonic on a string depend on the radius r of the string?

12 How does the frequency f of the first harmonic in a closed-open pipe depend on the diameter d of the pipe?

13 How does $\frac{\Delta T}{\Delta t}$ (the rate of change of temperature of water cooling) depend on $T - T_{\text{room}}$?

14 How does the period T of small angle oscillations of a ball of radius r that rolls without slipping inside a fixed hemispherical bowl depend on r as shown in the diagram?

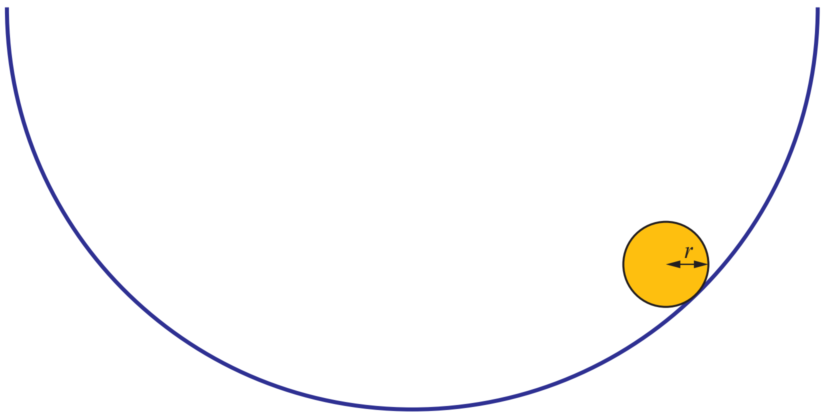

Figure 1.4

15. A fuse wire of diameter D is included in a circuit as shown in the diagram, and the current is slowly increased. How does the current I that melts the wire depend on the diameter D?

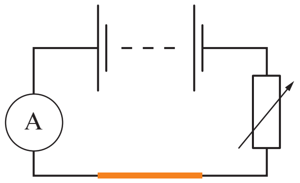

Figure 1.5

16 A vertical burette is filled with water. How does the length L of the water column depend on time t as the burette empties?

17 A bifilar pendulum consists of a horizontal rod supported by two strings as shown in the diagram. How does the period T of oscillations in a horizontal plane depend on d? (This can be extended to include nonparallel strings or unequal strings.)

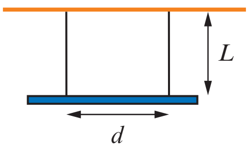

Figure 1.6

18 How does the temperature θ depend on the distance x from the surface of boiling water in the diagram?

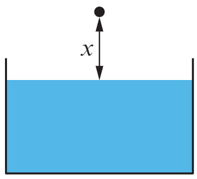

Figure 1.7

19 How does the period of oscillations T depend on the number of turns N of a vertical slinky?

20 The two magnets are placed above each other so they attract as shown in the diagram. The top magnet is allowed to oscillate with small amplitude. How does the period of oscillations T depend on x?

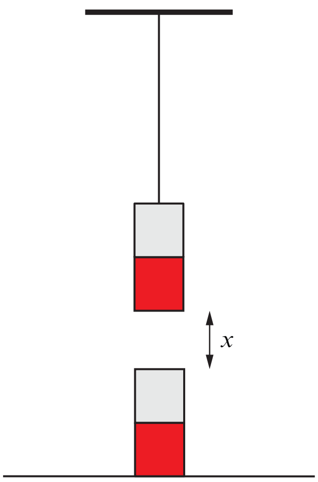

Figure 1.8

For research questions such as the ones above – and hundreds more like them – you must ask the following questions:

a Do I have the *materials* I need to conduct my experiment?

b Do I have the *equipment* that will allow me to measure the variables involved?

c Can I measure my variables with a *reasonable* level of *precision*?

d Will I be able to collect *lots* of *reliable* data in a *reasonable* amount of time?

e What are the variables that must be controlled during the experiment, and *am I able to control them*?

f Is the *theory* behind my experiment something that *I can understand* with what I already know or possibly understand with a bit of extra research?

For the majority of the examples listed previously, the answer to all the questions would be 'yes' for most students around the world: this type of question is what you should be aiming for. Questions relating to the accelerated expansion of the Universe, the nature of dark energy, properties of black holes, gravitational waves, and string theory are fascinating questions and the topic of current research by professional physicists, but they are inappropriate for a high school investigation. But you could be brilliant, so there are exceptions to every rule!

Interests and hobbies

Personal interests and hobbies can help you to select a topic. For example, if you are an amateur astronomer with a telescope, you could measure the distance to a star, such as δ Cephei by obtaining the star's light curve. Or you could use a database to get information on masses and radii of white dwarf stars and then, by deducing the relation between mass and radius, predict the Chandrasekhar limit. Or you could determine the maximum and minimum radius of a pulsating star when it enters the instability region of the HR diagram. You will need to get, from a database, the variation with time of the apparent brightness, colour index and radial velocity of the star. Do some research into the method devised by A. Wesselink and apply the method to the star you chose.

Sport is another hobby that may help you develop ideas for an IA. One popular topic is projectile motion (range, maximum height, effect of air resistance and so on). But before you start, you must find a reliable method to launch projectiles with the same speed and the same angle. Similarly, you could investigate how the angle a long jump athlete makes with the horizontal affects range, and what angle gives the maximum range. But first you must solve the problem of how you will make sure the athlete jumps with the same speed and how you will measure the angle.

Mock assessments

It may be helpful to perform a *mock IA*. Choose one from the previous list for the whole class to do. Then, you can compare and discuss each other's reports; this will give you lots of ideas to improve your own and prepare you for the real thing.

Complex investigations

There will be some investigations where the answers to the six previously stated questions are not 'yes'. Consider a rubber band that you stretch by a fixed amount and you then let fly horizontally. Change the temperature of the rubber band. How does temperature affect the range? The theory behind this is complicated. You have to think about how to measure the temperature of the band and how reliable that measurement will be. Similarly, some students have tried–with varying degrees of success–to investigate how temperature affects the spring constant of a spring.

You may consider choosing a topic that requires measurement of a specific property, such as the viscosity or surface tension of a liquid, or the Young modulus of a wire. These are not straightforward and may require specialized equipment. You may also measure the width of a fine wire or a human hair using interference and diffraction.

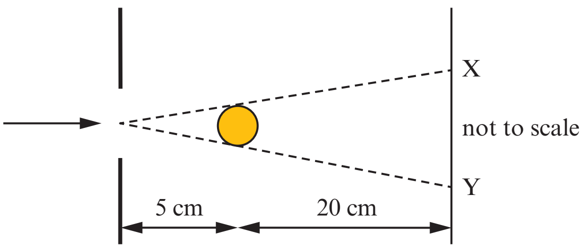

Figure 1.9

There will be interference fringes between X and Y, the separation of which depends on the diameter of the wire as shown in the diagram; the diameter plays the role of the separation of the two slits in Young's experiment. You must understand the theory behind this and make wise choices of the instruments that need to be used to measure the various distances involved. And you must know the wavelength of light used.

You may also use the resonance method in a tube to measure the speed of sound, taking into account the end correction as shown in the diagram. If you can find a way to change and measure the temperature of the air in the tube, then you will have determined the variation of the speed of sound with temperature. Can you investigate the dependence of the end correction on the diameter of the tube?

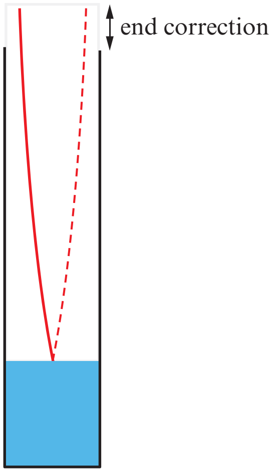

Figure 1.10

Adding a 'complication'

No experiment is 'too simple' for an IA. But you should avoid experiments that form part of your practical program–such as determining *g* using a simple pendulum, measuring the specific heat capacity of a metal, or measuring the internal resistance of a cell–unless you introduce something extra that would not normally be done in the practical program. For example, when measuring the specific heat capacity of a metal, you could include a cooling correction. This would require analyzing a graph like this as shown in the diagram.

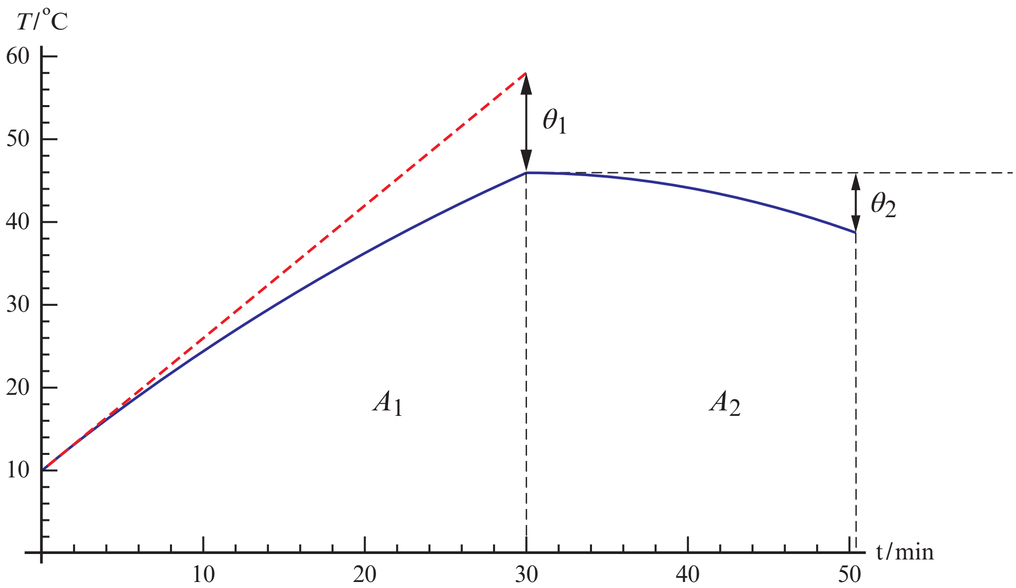

Figure 1.11

The solid is heated for 30 min and then allowed to cool for another 20 min. The temperature drops by θ_2 due to cooling. The objective is to determine the additional temperature θ_1 the solid would have obtained had there been no losses of energy. It can be shown that $\theta_1 = \frac{A_1}{A_2}\theta_2$ where A_1 and A_2 are the areas shown. So, in calculations,

θ_1 must be added to the maximum temperature reached by the solid. A 'complication' of this kind (something that shows you have taken the *extra step* to produce a more accurate result) is enough to make *any* experiment suitable for an IA.

Make a hypothesis

It is good to make a *hypothesis* related to the research question. You are trying to find how y is related to x. Does the theory behind your experiment allow you to *predict* what that relationship is? In most cases, theory can predict the relationship. For example, the dependence of a simple pendulum on initial angular displacement θ is $T \approx T_0\left(1+\frac{\theta^2}{16}\right)$ where $T_0 = 2\pi\sqrt{\frac{L}{g}}$. So you are not randomly trying to find any relationship between T and θ. You know that a graph of T against θ^2 will give a straight line, and the gradient of the expected straight line is something you can check; it is $\frac{T_0}{16}$. In other cases, theory may go part of the way and only predict part of the relationship. For example, the emptying time T of a funnel is related to the funnel diameter d through $T \propto d^{-\frac{5}{2}}$. We do not know what the constant of proportionality is, but again we are guided to expect a straight line graph when T is plotted against $d^{-\frac{5}{2}}$. Getting a straight line verifies the hypothesis, but the gradient is not something we can use here since we do not know what the proportionality constant is.

Final report

You are now going to write the final report on your investigation.

You should know how your report will be graded. The investigation will be graded against four criteria (each contributing 25% to the IA grade). These are:

Research design: The investigation includes a focused research question in a narrow and well-defined context. The method to collect data that are relevant and sufficient in addressing the research question is clearly described. The description of how data are collected is sufficiently clear and precise so that the investigation could be reproduced by someone else. Control variables must be clearly identified, and there is a discussion of how they are being controlled. Information is presented without repetitions and unnecessary statements.

Data analysis: The collected data must be presented in a clear and precise manner with evidence of a realistic consideration of uncertainties. Data must be processed in a way that allows the research question to be addressed. There must be clear and transparent information about how the data are being processed. The data must have realistic number of significant figures consistent with uncertainties. Graphs must be properly labelled, with appropriate units.

Conclusion: The conclusion of the investigation must be clearly, precisely and accurately stated in a way that allows the research question to be answered. Whenever appropriate, a comparison of the conclusion with published scientific literature must be made with clear references to traceable sources.

Evaluation: The investigation must include a discussion of any weaknesses or limitations of the method used. Suggestions of improvements must be realistic and meaningful. In some ways a non-perfect IA has a higher chance of a better grade than a 'perfect' one. By perfect we mean an IA where the error bars are negligibly small, the line of best fit goes through every single point, and the measured quantity agrees perfectly with the accepted value. In this case you will have very little to say under the evaluation criterion!

Even though these are the 'official' criteria against which your investigation will be graded, you must bear in mind that the examiner will be positively influenced by a report that is clear, non-repetitive, coherent, logical, clearly presented with nice graphs and tidy tables of data, and with a satisfactory treatment of uncertainties using proper scientific terminology and notation.

Dos and Don'ts

Before starting your report, consider these dos and don'ts:

1. Do not use * for the multiplication sign; use × instead.
2. Do not use 5.3 × 10^2 or 5.3E2 for powers; use 5.3×10^2.
3. Do not write $a = F/m$; use an equation editor and write $a = \frac{F}{m}$.
4. Use italics for variables.

5 Use roman for units.

6 Leave space in between different units; in other words, write m $\mathrm{s^{-1}}$ for velocity, not $\mathrm{ms^{-1}}$, which means inverse millisecond.

7 Quote results as, for example, $L = (24.3 \pm 0.1)$ cm, which means $L = \left(\underbrace{24.3}_{\text{mean value}} \pm \underbrace{0.1}_{\text{uncertainty}}\right)$ cm.

8 Do not write $L = (24.3 \pm 0.05)$ cm or $L = (24 \pm 0.1)$ cm; the uncertainty determines the number of decimal places in the mean value.

9 Justify why the uncertainty in a quantity is the one you stated. If you used a stopwatch to measure time, you cannot quote an uncertainty of ±0.01 s just because the stopwatch has this precision; what about your reaction time in starting and stopping the stopwatch, which is greater than 0.01 s?

10 Give a specific example of how you propagated an uncertainty in a calculated quantity. For example, if $T = (1.81 \pm 0.01)$ s and you want to use T^2: $T^2 = 3.27610\ \mathrm{s^2}$; $\frac{\Delta T^2}{3.27610} = 2 \times \frac{\Delta T}{T} = 2 \times \frac{0.01}{1.81} \Rightarrow \Delta T^2 = 0.0362 \approx 0.04$. Hence we quote $T^2 = (3.28 \pm 0.04)\ \mathrm{s^2}$. You only have to do this once in your report. Or, if you need $\frac{1}{T}$: $\frac{1}{T} = 0.552486\ \mathrm{s^{-1}}$ and $\frac{\Delta(T^{-1})}{0.552486} = |-1|\frac{\Delta T}{T} = \frac{0.01}{1.81} \Rightarrow \Delta(T^{-1}) = 0.003$ so that $\frac{1}{T} = (0.552 \pm 0.003)\ \mathrm{s^{-1}}$.

11 Tables must include units and uncertainties. Uncertainty decides the number of decimal places to be used. Keep uncertainties to one significant figure unless you have done a significant amount of statistical analysis that might justify two significant figures.

L/cm ± 0.1 cm	*T*/s ± 0.01 s
94.3	1.95
102.6	2.03

12 Values in tables should be in ascending order for the independent variable.

13 Graphs must have labelled axes with appropriate units.

14 Choose units so that numbers on the axes are not too small or too big.

15 Graphs should have a reasonable size, but bigger is better than smaller.

16 Your graph should cover as much as possible of the area of your graph paper as shown in the diagram.

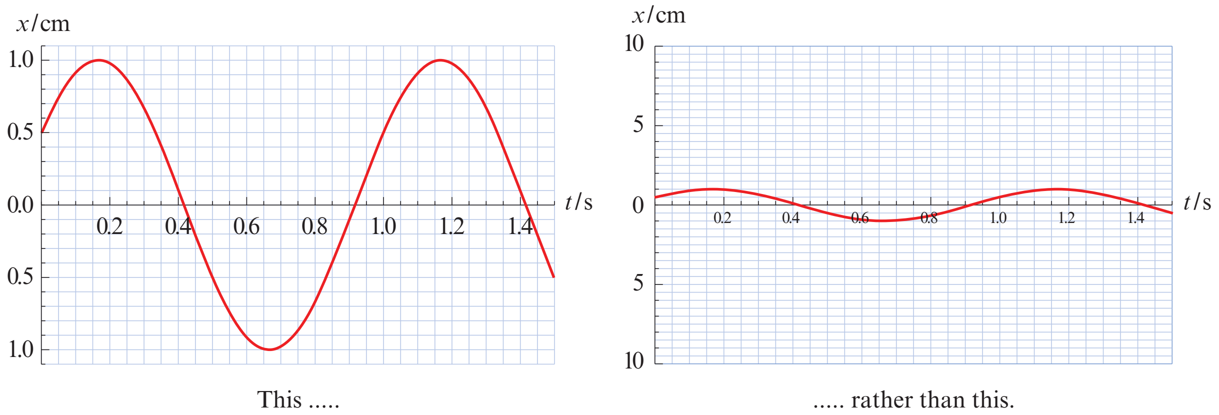

Figure 1.12

17 Every table and figure must be labelled and referred to in the text.

18 Devise methods of measurement that will minimize uncertainties: measure ten periods and divide by ten rather than just one period; measure the width of 50 sheets of paper and divide by 50 to find the thickness of a single sheet of paper.

For example, suppose you measure the time for ten oscillations electronically with a precision of, say, 0.1 s. Each measurement is repeated three times.

Time for ten oscillations/s ±0.1 s			Average/s ±0.1 s	Period/s ±0.01 s
Trial 1	Trial 2	Trial 3		
18.4	18.6	18.6	18.5	1.85

The uncertainty in each measurement and in the average is ±0.1 s, and so these values are recorded to one decimal place. The period is the average divided by ten, and so the uncertainty is ±0.01 s, which is why the period is recorded to two decimal places. You may want to make a comment that by measuring time electronically your reaction time does not enter the measurement.

Suppose you need to measure the diameter of a wire using a micrometer as shown in the diagram. A good practice would be to measure the diameter at ten *different points along the length* of the wire and then take an average; we don't know if the diameter of the wire is constant. Even better, the wire should be rotated a bit every time you take a measurement just in case the wire does not have a circular cross sectional area everywhere.

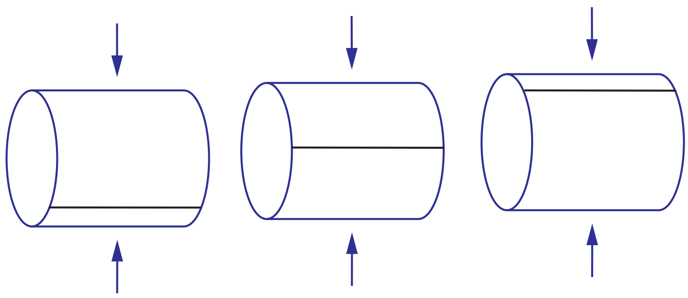

Figure 1.13

19 Look for systematic uncertainties in your methodology and try to correct for them. Always check for zero errors. For example, if the zero error of a micrometer is –0.15 mm and a length reading is 8.56 mm, the corrected reading would be 8.56 + 0.15 = 8.71 mm.

Suppose you are investigating Newton's second law: you want to verify that the acceleration is proportional to the net force. You might consider an experiment like the following:

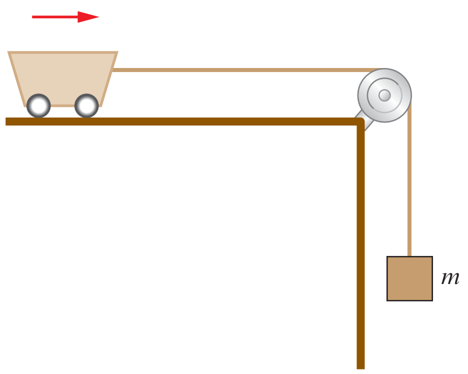

Figure 1.14

The cart has mass M, and the weight attached to the vertical string has mass m. You will measure the acceleration of the system for various values of m. Newton's second law implies

$$mg - f = (m + M)a$$

$$a = \frac{mg}{m + M} - \frac{f}{m + M}$$

where f is the frictional force. You would like to plot acceleration versus the net force (mg) and expect to get a straight line though the origin. The first thing you notice is the presence of the frictional force, which means that your graph will not go through the origin. This is a systematic error. The second thing is that the graph *will not* be a straight line since m also appears in the denominator. It would have been a *better experimental design* if you instead had weights in the cart and one by one you removed them from the cart and placed them at the end of the hanging string. If you did this, the mass $m + M$ would always have the same value, and now a graph of acceleration versus mg would be a straight line, an unambiguous situation rather than a messy curve. In other words, the design of the experiment and the methodology of data collection should, as much as possible, make for a clean and unambiguous analysis of the data.

20 Identify the control variables in your experiment and describe clearly *how* they are controlled.

21 If changing the value of the variable x does not result in an appreciable change in the value of y, you may have to rethink your topic. You should also rethink your topic if different trials give very different measurements for the same value of the independent variable.

22 Choose variables that are quantifiable by a number. If you used filters, do not refer to them by colour but by the wavelength they transmit. Generally, avoid variables that cannot be quantified.

23 Do not repeat information.

24 Do not include irrelevant or unnecessary information.

25 Do not mention irrelevant variables; the position of the moon has nothing to do with your investigation unless you are investigating tides.

26 Do not include terms you do not understand and cannot explain.

27 Do not include statements such as ‘Ever since I was a little child …’, ‘All my life I have been fascinated by …’, ‘I am truly passionate about investigating …’, ‘I remember my grandfather saying …’, ‘My investigation agrees with theory perfectly within experimental error’.

28 Do not include photographs of yourself in the lab.

29 Refer to yourself as ‘we’ rather than ‘I’, but this is a question of style.

30 Do not make statements like ‘it can easily be shown that this follows from …’. Show that it follows.

31 Use proper scientific language and terms. Do not say ‘the ball left the kicker’s foot with a large force’. It left with a high speed.

32 If you use statements such ‘at low density’, ‘at high temperature’, and so on, you must be prepared to face the question ‘low and high relative to what?’

33 Include a *brief* part on the theory relevant to your experiment, especially that which relates to your research question or hypothesis.

34 Include error bars in your graphs.

35 Give equations of lines of best fit to the appropriate number of significant figures and include correct units.

36 Lines of best fit must go through *all* error bars, ideally.

37 Getting a computer to fit a high degree polynomial to your data points and seeing a perfect agreement is not impressive. Why should a fifth degree polynomial fit your data?

38 Try to linearize your data so that you get a straight line graph (if at all possible). A straight line is unambiguous, a curve could be anything.

39 If a straight line of best fit cannot be obtained, a curve will do just as well. There is no requirement that the line of best fit should be straight. The most interesting experiments do not have straight lines of best fit.

40 There is no point stating the gradient of a straight line graph unless the gradient means something.

41 If the gradient of a straight line graph is necessary, state it along with its uncertainty and units.

42 If the vertical or horizontal intercept of a graph is necessary, state it along with its uncertainty and units.

43 Draw a smooth curve through your points; do not join them with zigzag lines.

44 Saying that if you had ‘better’ equipment you would do a better job will not gain you points under the evaluation criterion. Saying that you should have waited longer in between measurements of temperature of a gas so that equilibrium would be reached, would. In an experiment with oil drops falling at terminal speed, saying you needed a better method to measure terminal speed is meaningless. Saying that some oil drops were too big and the Stokes formula for the drag force might not apply to them would be meaningful. In an experiment in which granular material leaves a funnel, you want to measure the time it takes for the funnel to empty. You used a stopwatch to measure the time. An improvement would be to use a force sensor attached to the funnel. As the funnel empties, the force sensor reading decreases. You can use this to get a better estimate of the time, and by plotting the reading versus time you can check if you get a straight line. If you do, it means that the flow rate is constant, something you did not know before.

45 If your investigation involved finding the value of a physical constant, compare your value with the accepted value. State the error and try to explain the difference.

46 It could very well be the case that your conclusion does not verify your hypothesis. There is nothing necessarily wrong with this. It is possible that you neglected something, an assumption you made in reaching your hypothesis may not be valid or perhaps some variable that you thought you were controlling was actually not kept constant. You may have to take some more data, re-evaluate your methodology or refine how you reached your hypothesis in the first place.

47 In physics many laws are power laws. For example,

Motion with constant acceleration and zero initial speed: $s \propto t^2$ and $v \propto \sqrt{s}$

Stefan-Boltzmann law: $P \propto T^4$

Kepler's third law: $T \propto R^{\frac{3}{2}}$

Pendulum period: $T \propto \sqrt{L}$

It would be nice to have an idea of what a possible power relation might be in play for your experiment. In most cases you can find the answer in the books and the literature. But in some cases it might be difficult. Take the funnel again that is being emptied. How does the flow rate (mass per unit time) Q depend on the diameter, d, of the opening? Many times you can find the answer to such questions by dimensional analysis. We would expect the acceleration of gravity to play a role as well as the density of the material in addition to the diameter. Thus, letting $Q \propto \rho^{\alpha} g^{\beta} d^{\gamma}$ we find

$$\frac{\text{kg}}{\text{s}} = \left(\frac{\text{kg}}{\text{m}^3}\right)^{\alpha} \left(\frac{\text{m}}{\text{s}^2}\right)^{\beta} \text{m}^{\gamma} = \text{kg}^{\alpha}\ \text{s}^{-2\beta}\ \text{m}^{-3\alpha+\beta+\gamma}$$

This implies $\alpha = 1$, $\beta = \frac{1}{2}$ and $\gamma = \frac{5}{2}$, and hence $Q = \frac{M}{T} \propto \rho\sqrt{g}\,d^{\frac{5}{2}}$. For fixed density we have $T \propto d^{-\frac{5}{2}}$. We have a definite prediction for the dependence of the time to empty on d which we can now investigate. Or, for fixed diameter you may want to vary the density and see if $Q \propto \rho$.

You should try to make a simple model of the situation described in your experiment whenever possible. Consider the problem of the current that melts a wire (investigation 15 given previously): what can theory tell us to expect? A simple model says: $mc\frac{d\theta}{dt} = RI^2 -$ losses. Assuming that losses are due to *convection only*, we have (the curved surface area of the wire is πdL)

$$mc\frac{d\theta}{dt} = \underbrace{RI^2}_{\text{power in}} - \underbrace{h(\pi dL)(\theta - \theta_0)}_{\text{power lost}}$$

where h is the convective coefficient. At the melting point, $\frac{d\theta}{dt} = 0$ and so $RI^2 = h(\pi dL)(\theta_m - \theta_0)$ where θ_m and θ_0 are the melting and room temperatures, respectively. This gives (recall $R = \rho\frac{L}{A} = \rho\frac{4L}{\pi d^2}$):

$$\rho\frac{4L}{\pi d^2}I^2 = h(\pi dL)(\theta_m - \theta_0) \Rightarrow I^2 = \left(\frac{h\pi^2}{4\rho}(\theta_m - \theta_0)\right)d^3$$

and so $I \propto d^{3/2}$ is the prediction of this simple model. Is this what you are getting? Most likely the exponent of the diameter d will be less than 1.5. What has gone wrong? Is the constant h really a constant? Is the resistivity ρ constant? Is convection the only method of heat loss? Can we correct for these?

48 Power laws are investigated graphically by log plots: if $y \propto x^n$ it means that $y = cx^n$ and so $\log y = \log c + n\log x$. So a power law will be revealed as a straight line graph of $\log y$ against $\log x$ with n as the gradient.

49 Reference all sources from which you obtained information that is not universally well known. So you do not have to refer to Newton if you used $F = ma$.

50 Use a *simple* referencing system, listing all your references separately at the end of the report rather than in footnotes. For example:

… We will use the result, derived in **[5]**, that that the strong interaction beta function is given by $\beta = -(11 - \frac{n_f}{6})\frac{\alpha^2}{2\pi}$. …

References

[5] D. J. Gross and F. Wilczek, Ultraviolet Behavior of Nonabelian Gauge Theories, Phys. Rev. Lett. **30**, (1973) 1343–1346.

H. David Politzer, Reliable Perturbative Results for Strong Interactions? Phys. Rev. Lett. **30**, (1973) 1346–1349.