

INTERNATIONAL ADVANCED LEVEL

PHYSICS

PRACTICAL GUIDE

TEACHER

Pearson Edexcel International Advanced Subsidiary in Physics (XPH11)

Pearson Edexcel International Advanced Level in Physics (YPH11)

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KY Introduction

This guide is designed to:

1. support you and your students through all elements of practical work in the new International Advanced Subsidiary and International Advanced Level specification. Although it will address assessment arrangements, its focus is to ensure good quality practical work is at the heart of teaching and learning in the subject,
2. explain how practical skills can be developed throughout the course using both core practicals and other specification content.

The over-arching aim of the specification is to help learners progress from being INTERNATIONAL GCSE/GCSE students towards becoming ready for the next stage of their development, whether that be university or the workplace. To some extent this can be through developing skills such as non-routine problem solving and ICT literacy but also by personal skills in communication, adaptability and self-management. In terms of practical work, the aim is for students to become capable of thinking independently. Part of this is developing confidence in their own competence to challenge accepted practice and ask 'How do I know that?', whilst thinking about the science behind the observations. This may be exhibited by working towards thinking independently in planning and evaluating for themselves the outcome of practical work.

Over the course of the IAL, students will develop a range of skills in practical work which will vary from the acquisition of specific practical techniques in a range of experiments (such as the use of ICT to analyse motion or the design and construction of electric circuits), through to the development of some investigative techniques requiring some independent thinking (such as how best to investigate the effect of a force).

At one level, practical work undertaken by students can be simple, perhaps focusing on making straightforward measurements (such as CP8: *Measuring the e.m.f. and internal resistance of a cell*), whereas other practical experiences may be truly experimental (such as CP13: *Determining the specific latent heat of a phase change*).

Experimental activity in Physics involves the collection of quantitative data and this provides opportunities for the development of mathematical skills, which are also required as part of the specification (see *Appendix 6* of the specification).

There is a students' guide designed to be used alongside this teacher resource, which is written to explain the new requirements to your students in a straightforward way and to provide exercises to allow them to develop their skills. You will find the suggested answers to these exercises included in this teachers' guide.

Practical assessment – the whole picture

At first glance, the specification contains a number of references to practical work – both in terms of delivery and assessment – so it might be helpful, at the start of this Guide, to see what these are, and how they relate to each other. This is particularly important because, as a teacher of the subject, you will naturally want to focus most closely on what is best for your students in terms of skills development and examination preparation.

The most obvious place to start is with Units 3 and 6 in the specification, as these cover the practical skills which will be assessed in the written examinations for these units. Completing the core practicals will enable students to practise these skills.

In terms of the assessment of practical skills within written examinations, the most informative guide probably comes from looking at the questions in the sample assessment materials. These questions should be easy to spot: they are present in each paper the students will sit. Knowledge and understanding of the core practicals will be assessed in the relevant unit paper, for example Core Practical 1 will be assessed in the Unit 1 paper.

How do the core practicals cover practical skills?

So, as long as you follow the program of core practicals, you will automatically cover all of the standard techniques and apparatus the students are expected to know and reproduce in their examinations. In addition, these practicals encourage students to practise the skills outlined in Units 3 and 6.

It should be noted here that students will be expected to apply the skills and techniques they have learned to practicals other than the core practicals, particularly in Units 3 and 6. Students who do well in these units are often those that have carried out a range of practicals so you should aim to complete more than just the core practicals.

How flexible are the core practicals?

The core practicals are part of the specification and the students are expected to know them for the examinations. By completing these the students become more competent and confident with the techniques and apparatus they are expected to know. Students can use different methods and techniques to those stated, for example, in Core Practical 11 they may measure the discharge of a capacitor using a voltmeter and timer. However, they will still need to know and understand the methods stated in the core practicals.

We'd also recommend that you did other practical work as well as the practicals that we specify. These need not include expensive pieces of apparatus. Any practical work that your students attempt – not just the core practicals – will develop their practical competency.

Addressing 'investigative approaches'

To help support you, we have provided practical worksheets for each of our core practical activities. These worksheets are available for teachers, technicians and students.

Competent practical work does include the ability to follow instructions correctly. However, competency should also include the ability to be more independent and to think about planning an experiment or investigation.

So, for some of the core practicals, it would be a good idea to ask students to research and plan an experiment before issuing them with the worksheet; or to research and plan a similar experiment before undertaking the core practical activity.

What's the overall message for practical assessment?

- do all the core practicals as a minimum – do more if possible
- ensure that students keep records of the practical work they do
- practise exam questions containing practical skills

Assessment of practical skills

Practical skills will be assessed in all of the written question papers.

Assessment of practical skills in written examinations

There are likely to be questions all of the six IAL papers that test knowledge and understanding of practical work. Success in these questions will come more naturally if practical work is carried out on a regular basis and students have a thorough understanding of practical techniques. Therefore, students should conduct additional experiments to the core practical activities.

Units 1, 2, 4 and 5

There are four written papers for IAL (two for IAS) that test knowledge and understanding of Physics.

IAS Unit 1: 1h 30mins. This paper tests Mechanics and Materials.

IAS Unit 2: 1h 30mins. This paper tests Waves and Electricity.

IA2 Unit 4: 1h 45mins. This paper tests Further Mechanics, Fields and Particles.

IA2 Unit 5: 1h 45mins. This paper tests Thermodynamics, Radiation, Oscillations and Cosmology.

These will contain questions which test knowledge and understanding of the topics listed above but they can be presented in many different forms which are linked to practical skills e.g. topic questions may well contain data tables or graphs which students might be asked to interpret and explain - in which case, they will need to use the skills they have developed throughout the whole course. There may also be questions directly linked to the relevant core practical activities, in particular the Physics behind the practical.

Units 3 and 6: Practical Physics I and II

The papers for these units focus entirely the understanding of experimental methods. These will draw on the students' experience of experimental methods and, in particular, will draw on their experience of the core practicals. In general, the Physics contained in these papers will be based on the IAS content for the Unit 3 paper, or the IA2 content for the Unit 6 paper. Where the Physics content may be unfamiliar there will be enough information in the question to help you answer it.

Both of these papers are 1h 20mins in length and will test the ability to plan an experiment, comment on measurements, and process data in both familiar and unfamiliar contexts. The details for what students are expected to do for each unit are given in the specification.

When planning an experiment, students will be expected to be able to consider risk management and the select appropriate apparatus and methods, with reasons. They may also be given the results of an experiment which may be completed, either by reading scales or giving appropriate units, or criticise the results and suggest how they could be improved.

Processing data will involve using significant figures appropriately in calculations and plotting graphs. For Unit 6 students will need to be able to form a straight-line graph from non-linear data, for example by calculating logs. In analysing outcomes and drawing valid conclusions, they should

critically consider methods and data, including assessing measurement uncertainties and errors. Appendix 10: *Uncertainties and practical work* in the specification provides more guidance on this.

Preparing students for questions assessing practical understanding

There are many suitable examples in the papers set on earlier specifications, in particular unit 3 and 6, that could be used be set to students preparing for this type of question.

The most obvious place to look for practical questions is the Sample Assessment Materials (SAMs) produced for the new specification

Sample questions

This is the part of a question that deals with data handling and analysis, the context is that of a light bulb whose input power and output light intensity have been measured.

Question 1

Values of power P and the corresponding light intensity I are shown in the table below.

$I/\text{W m}^{-2}$	P/W		
1900	20.47		
740	13.09		
425	11.09		
220	8.29		
123	6.37		
76	5.45		

It is suggested that I and P are related by

$$I = kP^x$$

where k and x are constants.

- (a) Show that a graph of $\ln I$ against $\ln P$ should be a straight line. (2)
- (b) Use the grid opposite to plot a graph of $\ln I$ against $\ln P$. Use the column(s) in the table for your processed data. (5)
- (c) Use your graph to determine a value for x . (2)

Mark scheme for Question 1

- (a) $\ln I = x \ln P + \ln k$ (1)
Compares with $y = mx + c$ **and** states that gradient m is constant (1)
- (b) Graph should have the following features. One mark each.
- \ln values correct and consistently to 3 or 4 SF
 - Axes correct and labelled
 - Scales
 - Plots
 - Line of Best Fit
- (c) Big triangle – at least half the plotted length (1)
 x within range 2.38–2.48 **and** with no unit (1)

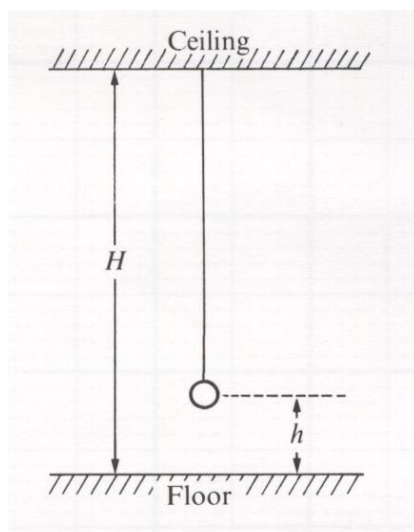
Commentary on Question 1

- (a) The use of logarithms is a standard piece of mathematics that is widely used – see Appendix 6 C.3.11, candidates usually score the first mark but often forget that the equation only gives a straight line if the gradient m is a constant.
- (b) Graph work forms a large part of *Appendix 6* and it is a vital skill for a physicist. Here there are 5 marks for calculating data and plotting a graph. The way these are awarded is standard and details are given at the front of the mark scheme for this unit.
- (c) There are then two further marks for measuring the gradient (C.3.4) and applying the answer to the question.

(Question taken from IAL Unit WPH06/01 June 2015)

Question 2

A student has been asked to determine the height H of a ceiling, using a simple pendulum as shown below.



The student measures the distance h from the floor to the centre of the pendulum bob. He determines values for the time period T for different values of h .

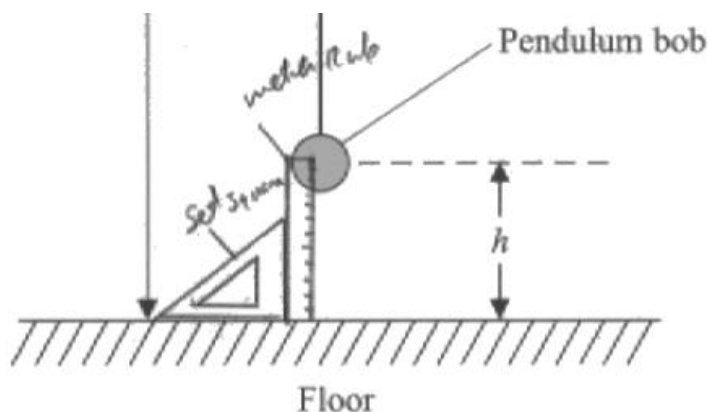
- (a) Describe how he should use a metre rule to measure h . You may add to the diagram if you wish. (3)
- (b) Describe what the student should do to make his values for T as accurate as possible. (3)

Mark scheme for Question 2

- | | |
|--|-----|
| (a) Metre rule used | (1) |
| Rule shown vertical | (1) |
| Suitable method for measuring to centre – either by vertical tangent or by difference method | (1) |
| (b) Measure $10T$ and divide by 10 | (1) |
| Find mean of repeats | (1) |
| Use timing marker in centre of swing Or allow swings to settle before timing | (1) |

Commentary on Question 2

- (a) Note that this question is set in the familiar context of the simple pendulum but it is used in a manner that the candidate may well not have met. The question would have been made easier if candidates had been directed to use a set square as well but most candidates appreciated the need for one. This is a good example of an answer scoring the first two marks.



The candidate labels the metre rule and shows it clearly vertical but ducks the issue of how to measure to the centre of mass of the bob.

- (b) The techniques for timing an oscillation are well known but they must be applied correctly to the context of the question. Note that the question also implicitly expects some knowledge of physics.

(Question taken from IAL Unit WPH06/01 June 2014)

Question 3

In this question the candidate has already been given repeated readings and been asked to calculate a mean value (C.1.2) and a percentage uncertainty (C.0.3 & C.1.5). They now use their value for the volume.

The mass of the microscope slide is recorded as 4.82 g with an uncertainty of 0.03 g

- (a) Calculate a value for the density of the slide. (2)
- (b) Estimate the percentage uncertainty in your value for the density.
You may assume the uncertainty in the measurement for the width is negligible. (2)
- (c) The student researched the density of different types of glass and found a value for 'Crown glass' of $2600 \pm 100 \text{ kg m}^{-3}$.
Use this information to decide if the slide is made from Crown glass. (2)

Mark scheme for Question 3

- (a) Density = 2.46 g cm^{-3} or 2460 kg m^{-3} (1)
calculation correct (1)
to 3 SF with appropriate unit (1)
Example of calculation
 $(4.82 \div (7.58 \times 2.58 \times 0.100)) = 2.46 \text{ g cm}^{-3}$
- (b) Calculates %U for mass (1)
Adds to both their answers for (b) (1)
Example of calculation
 $(3 \div 482) \times 100 + 2.13 = 2.75\%$
- (c) Calculates range of values in density using %U (allow ecf) (1)
Makes comment based on overlap of values (1)
- Or** finds %D in values, calculates %U in book value (1)
and compares percentages (1)
Example of calculation
 $2460 \times 1.0275 = 2528 \text{ kg m}^{-3}$
 $(2600 - 100 = 2500, 2528 > 2500)$
Ranges overlap so it could be Crown glass.
Allow ecf on their values.

Commentary on Question 3

- (a) The calculation is fairly easy but since the data is to 3 significant figures (SF) the answer must be to 3 SF (C.1.1) and with units appropriate to the candidate's values (C.0.1).
- (b) The overall uncertainty is calculated (C.0.3)...
- (c) ...and then used to draw a conclusion about the material from which the microscope slide is made.

(Question taken from IAL Unit WPH06/01 January 2015)

Using core practicals to teach skills

The most important principle which will be reiterated throughout this guide is the idea of developing skills. Whilst students are expected to have some knowledge of the techniques and procedures they encounter throughout the course, recalling small details is the simplest part of what is required.

Developing skills implies that there is significant progression in terms of independent thinking and understanding of the underlying science behind what they are undertaking.

One of the aims of practical work is to ground the theory in real physical situations that students can measure for themselves and another is to encourage students to develop confidence in their approach to apparatus. The empirical nature of the subject is a good guide to progress.

The introduction of new skills and the development of existing ones will take time and since some of them apply only to topics likely to be taught in IA2 record keeping will also help to ensure smooth progress from INTERNATIONAL GCSE/GCSE to A level.

It is not the intention that the list of core practicals represents the only practical work a student should undertake through the course, neither is it a 'perfect' example of experimentation or even the 'right' way to do it. Students will encounter a wider range of instrumentation and techniques that will need to be introduced as it arises; much of this comes at the start of the course and an introductory 'measurement circus' can be an effective way of introducing students to new instruments, the techniques required and the effective use of uncertainties.

Progression

As students' confidence increases so does the complexity of even the simplest experiments of the later topics. The core practicals fit into the Scheme of Work and provide a skeleton on which can be hung a full development of the skilful use of instruments. It is this development which should go alongside an increasing depth of scientific awareness and the willingness to think independently about how a practical investigation might be successfully achieved. Students should be encouraged to write their own plans and decide their own course of action – as well as analysing and evaluating their outcomes. By taking ownership of their practical work their appreciation of its place and their enjoyment in doing it are likely to increase.

Students are likely to achieve this more successfully if they have clear aims and objectives and while these can be more open-ended as the course progresses it is important that they appreciate the end point for which they are aiming. Each of the core practical activities should have some guidance (ensuring aims and objectives are established) and this should become less prescriptive as the student progresses through the course. As the students develop their skills and their understanding of physics so it will become more obvious to them how the theory and the practical are inseparable. This is the route to a practical mastery which is the aim of the course.

Planning practical lessons

The difficulty with practical work in physics is having enough equipment at the same time, these constraints are also determined by class size and timetabling. The core practicals have been selected principally for coverage of the techniques and skills students are expected to know but the practical guide is written with these constraints in mind.

It is possible for each of the core practicals to be completed in a one hour lesson and often a large part of the report can be written in that time as well. The equipment suggested is designed to be low cost where possible however many centres will be able to provide further equipment if they have it available. The core practicals provide the framework for the practical activity, it is not necessary to do that activity in any particular format.

It is probably a good idea to have covered the theory behind a practical before the students attempt the work and like any other lesson, students are only engaged when they see clear aims and objectives which are relevant to their course.

Some of the experiments require apparatus that centres will have plenty of, for example the e.m.f. and internal resistance of a cell (CP8) or the latent heat determination (CP13) – if you use ice! Other practicals require apparatus that many centres will have in limited numbers, such as oscilloscopes and Boyle's law. The emphasis is on the students carrying out the techniques listed and not merely seeing someone else do them. One solution to this problem is to have a 'practical circus' where the students rotate around a number of practicals. This has the disadvantage of being very slow and rather remote from the theory lesson concerning the work but it might work for part of the specification. Grouping together practicals that can be done by a few students at a time is another way. There are a number of options for centres to offer their students the opportunity of doing the practical work.

It will be most important to have a scheme of practical work and a planned timetable for that scheme so it can sit alongside the theory lessons and the number of students in each class will affect that planning. You will want to keep a record of the students' practical work and if it can be planned in advance then the students can contribute to the success of the programme.

Developing maths skills through core practicals

Full details of the mathematical skills requirements can be found in *Appendix 6* of the specification along with exemplification of each assessment objective.

Almost all of the skills are to be examined at level 2.

A minimum of 40% of the marks awarded both at IAS and at IAL are for mathematical skills.

Mathematical skills will be expected in all papers

This marks only a small change in the mathematics requirements from the old specification and in practice teachers should experience little change. The principal change is that there is a minimum number of marks on each paper dedicated to mathematical skills. These marks are not for maths by itself but rather for the application of maths to physics in the same way as it was for the old specification.

The other change is that these skills are clearly laid out in *Appendix 6* and as such will be a feature of the examination papers. The skills fall under the headings C.0 Arithmetical computation, C.1 Handling data, C.2 Algebra, C.3 Graphs, C.4 Geometry and trigonometry.

Clearly all these skills can be rehearsed through practical work and the mapping document gives more detail. The practical work thus gives the students more opportunities to develop their mathematical skills and for them to appreciate further the way in which mathematics contribute to the language of physics.

What is meant by level 2 mathematics?

Level 2 mathematics is of the standard of higher tier INTERNATIONAL GCSE/GCSE. The definition of level 2 can be affected by the context in which it is applied. For instance, where there is a great deal of structure or 'scaffolding' then the demand is lower and may not be level 2. Simply providing a formula and a list of data which is carefully defined would involve only simple substitution and be unlikely to meet level 2. However, selecting which data to apply and which formula to use would meet it. A good practical example would be requiring a student to draw a graph and then use the gradient to calculate the internal resistance of a cell.

It should be noted that the sections in *Appendix 6* shown in bold refer to mathematics that is not at level 2. These are principally exponentials and logarithms, and also \sin^2 and \cos^2 functions. These refer to work that is likely to be done in Year 13.

Many students will be taking an A level in mathematics alongside their physics and these students should find little difficulty in grasping the concepts; the difficulty arises in applying their mathematics in the service of their physics. This requires an understanding of the mathematics that is often beyond the INTERNATIONAL GCSE/GCSE student and it also means that their ability in their use of INTERNATIONAL GCSE/GCSE maths needs to be at a relatively high level. Students not taking maths beyond INTERNATIONAL GCSE/GCSE will probably need some reinforcement work to develop and maintain their understanding at a sufficiently high level. Time must also be given for teaching the Year 13 sections of *Appendix 6*.

Specifically, there will be a great deal of numerical computation, data handling and graph work in the scheme of practical work – this develops sections 0, 1 and 3 of *Appendix 6*. The algebra section (1) covers the foundations of the way theory is used in practical analysis and section 4 develops that foundation.

Mathematical skills

Further detail on these is given in the *Guide to Mathematical Skills* but the table below gives some guidance on how these skills are employed in the Core Practicals and other practical situations.

Skill Code	Nature of skill	Core Practicals requiring this skill	Notes
C0.1	Units	All	All physical measurements will have a unit. It is important that the correct form of that is used in calculations e.g. a measurement made in centimetres must be converted to metres. Units are also a feature of graphical work C3.1–4.
C0.2	Recognise and use expressions in decimal and standard form	All (particularly 2, 3, 6, 11)	Opportunities to use these occur in all practicals especially when changing units.
C0.3	Use of ratios and percentages	1, 2, 4, 5, 7, 9, 11, 12, 13, 14, 16 and where percentage uncertainties are used	When considering uncertainties it is necessary to express them as a percentage of the measurement. Further details of how to handle uncertainty in determining physical quantities from measurements can be found in <i>Appendix 10</i> of the specification.
C0.4	Estimate results	All	This may be done whenever convenient, but gas law graphs (CP 14) offer a good opportunity.
C0.5	Use of calculator for powers, exponential and logarithmic functions	1, 3, 7, 11, 12, 15, 16	Most of the practicals require some 'number crunching' but the use of powers, exponents and logarithms is as shown. Note that exponents and logarithms are not included in Level 2 mathematics and will need teaching separately, so time should be added to the Scheme of Work.
C0.6	Use of calculator for trigonometrical, functions	6, 10	Use of trig functions will depend on the exact nature of the work done by the candidate but it is expected that these will occur somewhere in these two practicals.
C1.1	Use of significant figures	All	All instruments have a finite resolution and thus a limit to the number of significant figures (SF) that can be used in quoting the measured value.
C1.2	Finding mean values	1, 2, 5, 6, 7, 9, 15, 16,	Whenever possible, readings should be repeated and a mean value found. There are some experiments where repeating the method is either not possible – e.g. in CP 14 because some of the oil adheres to the tube – or it is unlikely that the same values of the independent variable can be found exactly.

Skill Code	Nature of skill	Core Practicals requiring this skill	Notes
C1.3	Understand simple probability		There are few practical opportunities for this unless carrying out the dice simulation for radioactive decay.
C1.4	Make order of magnitude calculations		These do not occur in the Core Practicals.
C1.5	Uncertainties	1, 2, 4, 5, 7, 9, 11, 12, 13, 14, 16	All measurements have an associated uncertainty and A level physicists are expected to note an uncertainty in every reading they take. It will not be useful to combine these rigorously in every practical but candidates should demonstrate that they can do so routinely.
C2.1	Understand the use of mathematical symbols	All	» and « are often not used in practical physics, otherwise these occur throughout.
C2.2	Change the subject of an equation	2, 3, 6, (8), 13, 16	This is likely to occur when students plot a graph with axes that are not suggested by the standard equation e.g. in the speed of sound experiment where frequency and wavelength are measured but one will need to be inverted in order to get the speed as the gradient. A level candidates should not find this demanding.
C2.3	Substituting into an equation using units	All	This is largely a combination of what has gone before and is a feature of every experiment that has a mathematical model describing the behaviour.
C2.4	Solve algebraic equations		This is not a feature of practical work.
C2.5	Use logarithms with quantities that range over several orders of magnitude	11, 12, 15	This is for Year 13 work only.
C3.1- C3.4	Use of graphs	All except 6, 10, 12 & 13	Most of the practicals require a graph to determine a value for the outcome and an uncertainty. CP6 and CP13 are 'single shot' experiments since it is difficult to find a variable. CP10 and CP12 are more investigations or a design exercise. It is expected that A level candidates are quite at home with graphical methods. Graphical work will be part of the written question papers.

Skill Code	Nature of skill	Core Practicals requiring this skill	Notes
C3.5	Calculate rate of change from a linear graph		This will be a feature of the written papers.
C3.6	Use a tangent to a curve to calculate rate of change		This will be a feature of the written papers.
C3.7	Distinguish between instantaneous and average rate of change		This will be a feature of the written papers.
C3.8	Understand the physical significance of the area under a graph		This will be a feature of the written papers.
C3.9	Apply the concepts of calculus in graphical work		
C3.10	Interpret logarithmic plots	11, 12, 15	The mathematics associated with this is beyond Level 2 and may require special teaching. Since the resulting line should be straight the gradient calculations are not demanding but use of scales and units can be, especially if the value of the intercept is required.
C3.11	Test variations using log graphs	11, 12, 15	The mathematics associated with this is beyond Level 2 and may require special teaching. This is to test a relationship and should not be found demanding.
C3.12	Sketch mathematical relationships	14	Sketches should have labelled axes but no scale, the line of best fit should be carefully drawn, steady and thin.
C4.1, 2 & 5	Use sine and cosine in 2 D representations	10	In order to determine whether momentum has been conserved in 2 dimensions the analysis of diagrams will be done.
C4.1	Use angles in regular structures	10	2D vector diagrams.
C4.2	Represent 2D & 3D structures	All except 8, 11 and 13	Diagrams for the arrangement of apparatus is a skill many candidates could improve.
C4.3	Areas and volumes	2, 3 and 7	

Skill Code	Nature of skill	Core Practicals requiring this skill	Notes
C4.4	Use Pythagoras' theorem	10	Calculation of energies in elastic collisions.
C4.5	Use sin and cosine functions	6 and 10	
C4.6	Use of small angles approximations		This occurs in many practical situations but not the core practicals – see practical guide.
C4.7	Degrees and radians	6, (10)	This does not occur in a practical context but it does in the supporting theory.

The implication of this is clear. There needs to be specific learning opportunities integrated into the course which provide reinforcement and training in these mathematical areas if students are to develop confident practical mastery and enable them to perform to the best of their ability in the terminal examinations.

Practical activities offer an excellent framework for this as they provide all the required elements within an applied setting which has been shown to be much more effective than a purely theoretical approach. It is probably appropriate to include here some illustration of some aspects of *Appendix 6*.

Graphs

Generally, physicists are interested in seeing data as a straight line and will manipulate their data in accordance with the mathematical model they are using in order to get a straight-line graph. The following is the guidance shown on current mark schemes for the marking of graphs and this will apply to the papers of the new specification.

A mark given for axes requires both axes to be labelled with quantities and units, and drawn the correct way round.

Sometimes a separate mark will be given for units for each axis if the units are complex. This will be indicated on the mark scheme.

A mark given for choosing a scale requires that the chosen scale allows all points to be plotted and spreads the plotted points over more than half of each axis. The scale should be sensible, i.e. in 1, 2 or 5 and their multiples of 10. Awkward scale e.g. multiples of 3, 4, 7 etc., should not be used and do not get given any credit.

Points should be plotted to within 1 mm or half a small square.

For the best fit line mark there must be a thin continuous line which is the best-fit line for the candidate's results.

Additionally

If V is to be plotted against I the V goes on the y axis and I goes on the x axis – so we plot y against x .

The best-fit line should have an even number of plots above and below the line, and outliers should be ringed to show they have not been used in the drawing the line.

Graphs should be drawn using a pencil – HB is fine as it is neither too faint nor too thick. Candidates can use a pen but mistakes are usually permanent and the lines tend to be too thick.

Graph drawing by hand is a skill that physicists are expected to have and students should develop this skill through practice. It is often very convenient to use ICT when the data needs processing and then drawing as a graph. Once a student has developed a mastery of drawing by hand they should develop the skills of using Excel or a similar programme for processing data and producing a graph.

The use of error bars on a graph enables an uncertainty to be gauged which is based on the data. Error bars and uncertainties are not covered by the specification and will not be examined.

Significant figures

As a rule of thumb, the recorded measurement must match the resolution of the instrument, i.e. the recorded value should always be that showing on the instrument. The number of significant figures (sf) to be used can vary. For example, a metre rule has a resolution of 1 mm, so measurements are usually to 3 sf so you may record a value of 15.2 cm. But if the range of readings is below 100 mm then only 2 sf are available hence you may record a value of 9.4 cm.

Similarly, electronic metres usually have 4 digits in their display. On a voltmeter set to the 2 V range, values above 1 V show 4 sf, e.g. 1.039 V, and below 1 V values are shown to 3 sf, e.g. 0.915. Both are correct in their context and would be recorded as they are shown on the display. In some measurements the least significant figure can sometimes vary quite wildly. In this case the sf might only be 2 or 3 so the number of sf quoted depends on the measurement as well as the instrument.

When recording the time for 10 oscillations it might be that $10T = 14.58$ s, then we say $T = 1.458$ s. We have gained the extra resolution by timing 10 oscillations – the value of T is still quoted to 4 sf even though we have gained 1 decimal place. Recent examiner's reports show that some candidates may tabulate T^2 to 2 sf, e.g. 0.48, because they measured T to 2 decimal places. Generally, it is the number of significant figures that is significant!

When taking a mean this should be to the same number of sf as the data. We would expect 3 sf to be used in plotting data and in measuring gradients and in further calculations.

When using measurements in further calculations the number of sf of the final answer should be no more than the fewest of the sf in the data. Thus 45 N acting over an area of 3.459 mm² gives a pressure of 13 N mm⁻² and not 13.0 or 13.01 N mm⁻². The number of sf can often be increased when dealing with single digit temperature rises.

Mapping core practicals for mathematics skills development

This grid shows how the core practicals can be used to develop mathematical skills (*Appendix 6*) within Physics; and also suggests which CPAC statements could be tested on each.

Core Practical Activity	Appendix 6
1. Determine the acceleration of a freely-falling object	0.1, 0.3, 0.5, 1.1, 1.2, 1.5, 2.3, 3.1-4
2. Use a falling-ball method to determine the viscosity of a liquid	0.1, 0.2, 0.3, 1.1, 11.2, 1.5, 2.3, 4.3
3. Determine the Young modulus of a material	0.1, 0.2, 1.1, 2.2, 2.3, 3.1-4
4. Determine the speed of sound in air using a 2-beam oscilloscope, signal generator, speaker and microphone	0.1, 0.3, 1.1, 1.5, 2.3
5. Investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire	0.1, 0.3, 1.1, 1.2, 1.5, 2.3, 3.1-4
6. Determine the wavelength of light from a laser or other light source using a diffraction grating	0.1, 0.2, 0.6, 1.1, 1.2, 2.2, 2.3, 4.1, 4.5
7. Determine the electrical resistivity of a material	0.1, 0.3, 1.1, 1.5, 2.3, 3.1-4, 4.3
8. Determine the e.m.f. and internal resistance of an electrical cell	0.1, 1.1, 2.3, 3.1-4
9. Investigate the relationship between the force exerted on an object and its change of momentum	0.1, 0.3, 1.1, 1.5, 3.1-4
10. Use ICT to analyse collisions between small spheres, e.g. ball bearings on a table top	0.1, 0.6, 1.1, 2.3, 4.1, 4.4, 4.5
11. Use an oscilloscope or data logger to display and analyse the potential difference (p.d.) across a capacitor as it charges and discharges through a resistor	0.1, 0.2, 0.3, 0.5, 1.1, 1.5, 2.3, 2.5, 3.1-4, 3.10, 3.11
12. Calibrate a thermistor in a potential divider circuit as a thermostat	0.1, 0.3, 0.5, 1.1, 1.5, 2.3, 2.5, 3.1-4, 3.10, 3.11
13. Determine the specific latent heat of a phase change	0.1, 0.3, 1.1, 1.5, 2.2, 2.3,
14. Investigate the relationship between pressure and volume of a gas at fixed temperature	0.1, 0.3, 1.1, 1.5, 2.3, 3.1-4, 3.12
15. Investigate the absorption of gamma radiation by lead	0.1, 0.5, 1.1, 1.2, 1.3, 2.3, 2.5, 3.1-4, 3.10, 3.11
16. Determine the value of an unknown mass using the resonant frequencies of the oscillation of known masses	0.1, 0.3, 0.5, 1.1, 1.2, 1.5, 2.2, 2.3, 3.1-4

Teaching approaches to core practicals

The 16 core practicals should be used to allow students to develop their practical techniques and skills, and to rehearse their mathematical skills.

It is expected that the students will carry out other practicals that also allow these techniques and skills to be introduced and practised, but it is essential that the core practicals are given priority and emphasis. The intention is that any practical work is short and sharp and does not take up any more time than is strictly necessary. As the students improve their skills each practical should occupy less time.

Practical skills and core practicals

Units 3 and 6 in the Specification lists the practical skills that a student should acquire during the IAL course, and these will be assessed through the written examinations. By completing all 16 core practicals students should be able to develop the skills to the level expected in the examinations.

Choosing the Core Practical

The Core Practical focus attention on practical activities that provide students with the opportunities to develop their skills in accordance with the demands of the specification. How a centre chooses to use these opportunities is very dependent on the available resources of time, space and apparatus and it depends too on the abilities of the students.

The Core Practical, as set out in the guide, have a recommended method. It is recommended that you follow the method suggested, but as your students develop their skills the practicals can become more investigative. For example if you find your students capable of setting up electric circuits then CP7, 8, 11 and 12 could be adapted to allow them to design their own. Similarly, many of the IA2 practicals, such as the capacitor (CP11) or thermistor (CP12), generate data that is more usefully plotted using ICT. You can tailor the practicals to the needs of your students and there are additional suggestions in what follows.

Commentary on the Core Practicals

1. Determine the acceleration of a freely falling object

This experiment is a good one to do early in the course as it builds on the suvat equation familiar from INTERNATIONAL GCSE/GCSE and can be investigative in style.

This practical is one that we have been doing for a long time and the traditional method is to drop a ball on to a trap door and use a timer to record the time of fall and a ruler to measure the distance fallen. This works well and is one your students will feel confident with.

An alternative method is to drop something like a whiteboard pen through a light gate. If you can drop the object down a glass or Perspex tube there is less difficulty detecting it pass through the light gate – you position the light gate outside the tube. By moving the light gate up the tube you reduce the distance it falls. Some software will record the speed if you programme in the length of the dropped object otherwise you simply record the time for which the sensor is obscured and calculate the speed yourself. Alternatively a timing ball works well too! There are plenty of YouTube clips showing this practical. If you are having difficulty with the light gate try reducing the ambient light, high light levels are likely to swamp the gate sensor.

This is a good experiment to get your students going with uncertainties and they have a definite value to compare to their answer by calculating a range of values or percentage difference. Offering students a choice of methods will start their path towards mastery of practical physics and use of investigative techniques. It might be interesting to have two groups of students trying using the two methods separately to see if one method produces different results in any way.

2. Use a falling ball method to determine the viscosity of a liquid

This practical measures the balance between the forces on an object falling in a resistive medium, and the students often have difficulty identifying all three.

The practical difficulties with this are to obtain a tube large enough for the sphere to fall without interference from the side wall. You can use the Perspex tubes from CP1 if you have them, and block one end with a bung. A strong magnet can be used to retrieve the balls from the bottom of the tube. Washing-up liquid makes a very good medium and it is a good idea to have some glycerol to hand and one tube of water to show that it is too quick to measure.

Different students might have different liquids and some should use different diameters. Achieving concordant results can be difficult and the students should be encouraged to think of ways of addressing this. The resulting uncertainties can be discussed when pooling their results.

3. Determine the Young modulus of a material

This is a standard experiment found in most good textbooks and since it involves stretching a wire under tension students should make reference in their report to the safety of their procedure. Students' lab books should be showing a sense of routine about safety, method and analysis as each develops their own style.

The extension of the wire is small as is the diameter so careful measurements are needed. It is important to get a long stretch of wire in order to get a measurable extension but the diameter should not be too thin or the wire will creep.

The graph will also show some non-linearity. They might research their work by looking up a value for the Young modulus and estimating the range of their readings to get a good graph.

Alternative methods can be employed. One such uses engineer's beam theory and a beam, such as a metre rule, is deflected by a load and the equation linking load and deflection includes the Young modulus. They will also need to use Vernier calipers and micrometers to measure the beam. Another allows a cantilever to be oscillated by a mass on the end, the equation linking period of oscillation and mass includes the Young modulus.

4. Determine the speed of sound in air

This is a standard experiment also found in most good textbooks but it will require quite a degree of skill to get all the apparatus working together.

Additionally this is probably the first time the students have used an oscilloscope so it is probably a good idea for them to have done some preparatory work displaying waveforms and just seeing what the controls do. This is best done after they have spent some time on waves as well so that they are really displaying what they understand and the investigative element is in getting the apparatus to work together rather than concern about waves too much – although the concept of phase is quite difficult this will do much to help them with that.

5. Investigate the effects of length, tension and mass per unit length on the frequency of a vibrating string or wire

This experiment has 3 variables to test and so is another that makes a very good investigation and the sheets in the guide take this approach. The students might write a plan out of class and come to the lesson ready to carry it out so clearly the theory will have to be done thoroughly first. Because it is more open ended than some of these practicals students will need to keep a complete record of all that they do from the plan onwards.

It is unlikely that centres will have enough vibration transducers for a class set so if all students are to do this at the same time a vertical alternative is possible. A wire is hung vertically with slotted masses at the bottom, an alternating current is passed down the wire, leads attached with crocodile clips, an a magnetic field is placed at the centre – either a horseshoe magnet or pole faced magnets on a yoke. This removes frequency as a variable since it is 50 Hz, unless frequency generators are available. This makes a good alternative and students can still make measurements of standing waves by varying the mass on the wire. There will be no variable to control but students could still plan for frequency as a variable.

Safety should feature in all reports but this one has it as a feature since there are wires under tension and hanging masses. The data can be processed using ICT as there is a non-linear relation in the variables.

6. Determine the wavelength of light from a laser or other source using a diffraction grating

This is the only core practical to use a laser but of course you can use one in a different experiment – determining the refractive index of a material. This practical also requires the understanding of angles which is one of the mathematical requirements (C4.5) so it is quite helpful if the students carry this out.

The practical session for each student need only be quite short since setting up the grating in front of the laser and taking the measurements need only take a few minutes each once the equipment is in place.

The laser is now deemed less harmful than was once the case but there are still safety procedures that need to be observed which the students could research before the class. Certainly, there should be reference in the report to how the safety procedures were followed whilst doing the work.

A long tape, such as is used in athletics, might be more useful for measuring the distance between maxima but the resolution of the metre rule might make it preferable. The students might address this in their report.

This is not really an investigative practical so a list of instructions is best.

7. Determine the electrical resistivity of a material

Students should quickly see how this experiment will work and after a short demonstration you can use this as a planning exercise. They might compare the two meter method with one using an ohmmeter. Otherwise students can follow the instructions but either way they will generate some data. They can look up the result they should get and practise referencing their sources properly. If they use an ohmmeter this is not really complex enough. If they use the 2 meter method they can select their ranges but one or two 1.5 V cells should be enough to generate results.

This is a good exercise in uncertainties and there will probably be a systematic error due to resistance in the contacts – with the wire and in the plugs and leads – and the graph may well miss the origin whilst being straight. They might also draw two lines of fit and estimate the uncertainty in their final value.

8. Determine the e.m.f. and internal resistance of a cell

This is a more complex experiment and students might be capable of designing their own circuits, if not then following the instructions is perfectly acceptable. There is a wide variety of methods for this practical and they should be encouraged to think of 2 (slightly) different methods. The methods depend on whether the independent variable is the resistance or the current. If you do not know the external resistance you can use a 2 meter method and the analysis is less complex too.

A 1.5 V cell is ideal but probably will have an internal resistance too low to make a difference and so a resistor can be connected externally – this has the advantage that students can measure it separately and see how close their graphical method is. This experiment begins to raise the awareness of safety and safety of the apparatus is almost as important as personal safety. Most of the experiments in most school physics laboratories are inherently safe so it helps to encourage the students to think about the apparatus as well. It is perfectly acceptable to conclude there is no hazard and so no precaution is necessary but they should provide a reason for saying this.

This would be a good experiment to ask the students to plot a proper graph using ICT.

9. Investigate the relationship between the force on an object and its change of momentum

This is another broad practical that can be tackled in a number of ways and so it a good one for the students to use to develop their planning skills. The safety issues are more to do with management of apparatus and working with other people in the area rather than any particular hazard although there will be suspended masses.

Centres can use an air track but it is more likely that the bulk of the students will use trolleys and timers or light gates. The apparatus used will depend on the local constraints of class size, laboratory space and amount of equipment available.

10. Use ICT to analyse collisions between small spheres e.g. ball bearings on a table top

This practical is one where the students can be free to plan and carry out the work but they will need clear guidelines about the outcome expected.

They are expected to use software to analyse video clips of ball bearings colliding, the software will enable them to take measurements of velocities and angles. Weighing the ball bearings will enable them to perform momentum calculations and show that momentum is conserved in 2 dimensions. Energies might remain as an extension activity but with ball bearings there should be little loss of energy.

Using rulers or similar as a guide the collisions might be made repeatable so that change in one variable become possible. A plan will certainly help them focus on the outcome and as part of their development they should be able to write a plan they can follow.

The software is freely available from the internet, one such is called Tracker and is available as a free download from Open Source Physics at

<http://www.opensourcephysics.org/items/detail.cfm?ID=7365>

The programme has many formats and downloading takes little time and requires little space – you might need help from IT support to install it on machines in your centre. A recording of the motion on a phone can introduce difficulties with the computer holding the software and it might be easier to use a 'proper' camera. In practice it is not the recording that is the significant aspect but the analysis of the motion and it might prove more efficient to record some suitable collisions and make these available to students – however there is nothing like analysing your own data. Familiarity with this programme is essential and it might be helpful if it was used to analyse momentum in one dimension in IAS. We hope the students will enjoy using software as an analytical tool which they are easily able to continue to do at home.

11. Use an oscilloscope or data logger to display and analyse the potential difference (p.d.) across a capacitor as it charges and discharges through resistor

This is a well tried practical that appears in a number of guises and here we use it to develop use of the oscilloscope. In the first case the students use it as a d.c. voltmeter and in the second they use a frequency generator with square wave output and show the capacitor discharging many times each second. Adjusting the value of the resistor in circuit changes the shape of the discharge and they can take measurements to support the relationship they tested in the first part. They should use estimates of their uncertainties to support their conclusion.

Although the oscilloscope has low resolution when reading off the screen, the technique of using the laptimer facility and recording the time to fall to a pre-determined p.d. works well, especially if repeats are taken.

It is probably best that students are given a list of instructions to follow to guide them with the particular oscilloscope they will use. The safety aspects are best covered by observation and what the candidate says about the polarity of the capacitor. The sheet in the guide gives some instructions that might be helpful and some component values but these can both be adapted locally. The students can either follow or design the circuit themselves. It depends how well they are progressing as an investigator.

12. Calibrate a thermistor in a potential divider circuit as a thermostat

The students should find this practical very comprehensible and so should be able to concentrate on their practical technique and results. This should be a good investigation to show what they can do as competent physicists.

Students can research temperature scales, although not on the specification it is good physics that applies to this practical and makes sense of the briefing.

The apparatus should provide few worries and the usual risk assessment should be written by the student even though it is not a feature of this practical. Students should, by this stage of the course, be able to investigate the resistance of a thermistor with temperature and make sense of the result. They then design a circuit and test their design and since this is IAS theory it should also provide useful revision.

The key to accurate results is their management of the temperature of the actual thermistor – thermal equilibrium is required. They can compare the reading on the thermometer of the temperature of the water with the reading on their thermostat. Percentage difference comparison with their percentage uncertainties should give an indication of their success.

13. Determine the specific latent heat of a phase change

This is a straightforward practical as written, however good technique is required if a reasonable value is expected. Insulating the beaker will improve the result.

The hazards are slight with this equipment and again students should remark on this and state why. There might well be some confusion with units.

Since the outcome is a well defined value they can determine a percentage difference and consider their uncertainties in response to the questions to the sheet.

14. Investigate the relationship between pressure and volume of a gas at a fixed temperature

This practical tests their abilities to follow a set of instructions and to think about the consequences of their actions before they make them. Specifically, the oil will cling to the sides of the tube so repeats are not possible and they must ensure that the temperature of the gas remains constant.

Apparatus will be an issue here but to enable all students to take measurements a simple syringe can be compressed using a series of masses paced on top of a syringe held in a retort stand. Students will need to measure the diameter of the tube in order to determine the area and hence the pressure. There might be a systematic error in volume measurement depending on how the end is sealed; this can be investigated using a measuring cylinder or similar.

Using the initial volume it might be possible to estimate the number of molecules in the gas and derive a value for the ideal gas constant. Their uncertainties will be of use in their conclusion.

15. Investigate the absorption of gamma rays by lead

The activity offers the opportunity to use ionising radiation and detectors. This could be based on naturally occurring radiation, and Radioactive Mineral Specimens can be stored without licence and are very inexpensive. There are also radioactive kits that comprise enough equipment to carry out a good range of practicals on sources.

The experiment described in the guide is suitable for a gamma source and can be done by a number of students together. In order to gain a 'practical mastery' of radioactive sources it is recommended that students identify a variety of sources by an absorption process and carry out other simple activities including obtaining a background count – these sources need only be a mineral or similar.

Students can research the rules governing use of sources and become familiar with the hazards involved in using sources. A risk assessment could include the procedures they adopt in handling the materials. Since the decay process is a random one any results they take should show some use of uncertainties in forming any conclusion.

16. Determine the value of an unknown mass using the resonant frequencies of the oscillation of known masses

This practical is intended to provide students with a final investigation that they can use to demonstrate their investigative skills to best effect. Given a spring and some known masses they are to determine the mass of an unknown mass and evaluate their result and their method.

The extent to which they follow instructions depends on their ability to investigate. It might be that they write a plan and follow their own plan in doing the work or that they are given some intermediate help. Their ability to evaluate their outcome will tell a great deal about their investigative abilities. Specifically, they can plot their results using ICT or a graph can be drawn by hand. The apparatus is not complex and the physics of oscillating systems should be familiar to students so they can concentrate on the investigative process.

Research and referencing

Students need to understand how scientific advances are communicated and reviewed. The process of peer-review, citations and attention to detail needed to present scientific papers should be understood, as should the role of scientific journals, conferences and the international nature of research. Evidence revealed by research might 'support the idea that' but is not described as 'proving'. Objective scientific language is cautious and often conditional and this needs to be reflected in students' own practical recording.

Students might start by asking what is already known. This might simply be to look up the accepted value, for example the resistivity of the wire you are investigating. They might also consider the instruments they are using. They probably will have little choice about what to use, but they could find out what the manufacturer thinks is the resolution and likely accuracy of their instrument, for example an Ohmmeter on its 200 Ω range.

The student might also research a method. There might be several ways of doing this practical work but some of them are likely to require apparatus that is not available at school. How can they use the best ideas for their own use?

Students are quite likely to use their textbook as a source for research and they will find that sometimes the ideas are presented in a simplified form. They might use Wikipedia and should be aware that this is peer-reviewed and not necessarily an expert source. All the Core Practicals might provide the opportunity for research, particularly 7 for instrumentation and 8 for method, 2 for topic and 4 for accepted final value. 9, 10 and 12 provide good opportunities in IA2.

Independent objective research needs to be developed to incorporate this approach. The internet is a wonderful resource but is often approached in a scientifically naive manner. Valid scientific information can be extracted easily but it is rarely found on an anonymous question and answer site and even the first few pages of a Google search might be looked at with caution. In contrast Wikipedia is often carefully referenced or flagged where further corroboration of details are required so perhaps less caution might be allowed. Certainly students should get used to recording the URL for every site from which information has been extracted and the date of access should be included, it will help if some brief description of the author could be given as this is not always obvious from the URL. In this way it is possible to avoid plagiarism.

Independent thinking and practical investigations

It is highly desirable that students are challenged to think more critically about a practical procedure from the start of the IAL course. It is vital that they realise that what has served them well at INTERNATIONAL GCSE/GCSE needs to be developed to achieve the same success later.

Planning is a forward step away from INTERNATIONAL GCSE/GCSE and at root this means deciding for yourself what you will do. Your research has probably given you plenty to think about and so it is more a question of sifting through to find what will work for you.

Drawing a conclusion will depend on the detail of the aims and objectives of their work on a particular activity. Most of the Core Practicals are expected to use a graphical method and all should combine uncertainties in a quantitative way. The conclusion should be clearly stated and related to the original aims with reference to the supporting evidence. Successful practical work is that which has clearly defined aims and objectives and teachers should ensure that this is always the case.

The learner should have as an aim an outcome which is either numerical or descriptive as in confirming a mathematical model so that they are able to drive towards a conclusion. The conclusion is that of the investigator, even if they are showing their data supports a suggestion they have been given and they should support their conclusion with evidence from their work.

Whilst most students are not comfortable with uncertainty and often simply want to learn the 'right' answer, this approach, rather than simply being presented with a worksheet, is vital if we are to show students what we mean by progression to advanced level.

Independent thinking and evaluation

An objective discussion and reflection on the reliability and validity of their findings provides crucial evidence of a student's independent thinking and practical competence.

The student's ability to do this convincingly whilst basing it on evidence is the mark of a student who has progressed a long way from INTERNATIONAL GCSE/GCSE.

In evaluating the apparatus they might consider whether the use of IT is justified, if used, or whether it might improve the work. For example do the light gates in Core Practical 1 improve the readings and if so in what way – they might consider the repeatability and reproducibility of the readings. They might also consider whether different apparatus would have made the readings easier and more repeatable and they might consider the contribution of the instruments to the uncertainty in the result.

Evaluation of their method might touch on their research, how close were they to the accepted value and do other people get 'better' results in some way.

They should look critically at their results, perhaps the graph is an excellent straight line, might they have taken more or fewer readings. Is there any evidence of a systematic error?

They should evaluate the numerical aspects of their outcome by considering uncertainties. These come from the spread of repeated readings and might be influenced by the resolution of the instruments. These measuring uncertainties could then be shown on the graph as error bars where there can be more than one line of best fit in order to determine the uncertainty in the gradient – or the deviation from the mathematical model. Where the outcome is a known value such as the speed of sound in air or g – or indeed something that has been researched – then the percentage difference between the student's value and the accepted value is useful, it can be compared with the overall percentage uncertainty to strengthen its validity. This numerical work is an essential part of evaluation.

In evaluating the whole students might consider what they have learned by doing the work and whether they would do the same thing again or, by thinking independently, adapt their ideas. Finally, do they believe what they have found?

Students need to appreciate that in a perfect investigation where all variables are accurately controlled then any repeats should be identical. When this is not the case then the size of these differences can provide useful information. All of this will provide good evidence for any judgements on the reliability of the findings.

In summary the practical work is part of the overall assessment of physics and in such a practical subject it is at the core, after all, if you cannot measure it is it physics at all?

Student records

You will need to make a decision about what format you will require your students to keep records of their practical work. Possible formats include:

- a lab book. This has some advantages, mostly in being a 'working document' where students can write notes on procedures, as well as take down data, sketch rough graphs and so on.
- a folder of practical work. In some ways similar to the lab book, but having the advantage of being able to store worksheets and other stimulus material alongside the practical notes.
- integrating practical notes into students' main folder.

Whichever format you decide works best for you, and your students, it is important that the method of collecting and recording the practical work that students do meets the following requirements:

- be a useful revision aid for students at the end of their course
- allow students to record evidence in a variety of formats, such as diagrams / drawings, tables, graphs and so on. This would also include space for any data analysis or evaluation.

Answers to Student Guide Questions

Question A

Top pan balance for mass – it has the range to weigh both

Micrometer to measure the thickness – its resolution is very small

Vernier calipers to measure the block – a micrometer will be too small and it has a better resolution than a metre rule.

Note that for IAL, if approximate sizes are given in the question the justification should include a calculation of the expected percentage uncertainty.

Question B

Close the jaws of the micrometer and check for a zero error. Fold the foil in half as many times as possible, say 5 times for 32 thicknesses, measure the thickness of the folded foil several times and take a mean. Divide the mean by 32.

Question C

The 0.77 mm reading is an anomaly and should be ignored. The mean of the remaining 4 readings is 0.2725 mm but the data is to 2 significant figures so the mean should be to the same and so 0.27 mm is the best value from the readings.

Question D:

Mathematical Model	x-axis	y-axis	gradient	intercept
$I = I_0 \exp(b/T)$	$1/T$	$\ln I$	b	$\ln I_0$
$T = f^2 \lambda^2 \mu$	f^2	T	$\lambda^2 \mu$	0

Question E

$100 \times (1.32 - 1.17) \div 1.17 = 13\%$ The powers of ten are the same and so cancel

Question F

(i) $v = 2d \div t = 0.668 \text{ m} \div 0.92 \text{ s} = 0.73 \text{ m s}^{-1}$

(ii) %U in $d = 100 \times 0.2 \div 33.4 = 0.6\%$

%U in $t = 100 \times 0.03 \div 0.92 = 3.3\%$

%U in $v = 0.6\% + 3.3\% = 3.9\%$

Question G

Mean value & Uncertainty: Width = $28.9 \pm 0.6 \text{ mm}$

Thickness = $5.99 \pm 0.5 \text{ mm}$

(i) Volume = $0.0289 \text{ m} \times 0.00599 \text{ m} \times 1.000 \text{ m} = 1.73 \times 10^{-4} \text{ m}^3$

So Density = mass \div volume = $0.1064 \text{ kg} \div 1.73 \times 10^{-4} \text{ m}^3 = 615 \text{ kg m}^{-3}$

(ii) %U = $100 \times (0.6 \div 28.9 + 0.5 \div 5.99) = 100 \times (0.0208 + 0.0835) = 10.4\%$

We assume the uncertainties in mass and length will be very small

So uncertainty in density = $615 \times 0.104 = 64 \text{ kg m}^{-3}$

Question H

(i) $\rho = RA \div l = 1.15 \, \Omega \times \pi (0.559 \times 10^{-3} \, \text{m})^2 \div (4 \times 0.600 \, \text{m}) = 4.71 \times 10^{-7} \, \Omega \, \text{m}$

(ii) %U in $R = 100 \times 0.02 \div 1.15 = 1.7\%$

%U in $d = 100 \times 0.010 \div 0.559 = 1.8\%$

%U in $l = 100 \times 0.003 \div 0.600 = 0.5\%$

%U in $\rho = 1.7 + (2 \times 1.8) + 0.5 = 5.8\%$

(iii) The upper limit for the measurement is $4.71 \times 10^{-7} \times (1 + 5.8\%) = 4.98 \times 10^{-7} \, \Omega \, \text{m}$

Since the accepted value is less than the upper limit it is likely that the measurement is valid.
So the student's experiment was a good one and likely to produce the true value for that sample of metal

Answers to Core Practical Questions

- (a) $s = ut + \frac{1}{2}at^2$ where $u = 0$ so $a = 2s \div t^2$
 $a = 2 \times 1.200 \div 0.50^2 = 9.6 \text{ m s}^{-2}$ and $a = 2 \times 0.900 \div 0.43^2 = 9.73 \text{ m s}^{-2}$
Mean value = 9.67 m s^{-2} or 9.7 m s^{-2} since the time is to 2 SF

(b) There are only two values for the independent variable which means a graph cannot be plotted. There is no sign of repeats having been taken. The resolution of the height measurement is to $\pm 1 \text{ mm}$ which is good, a tape measure must have been used for the reading greater than 1 m. The times are to only 2 SF thus reducing the resolution of the answer. The two values for acceleration have a percentage difference of 1.3% meaning they are precise.
- (a) As the temperature rises the molecules increase in speed in their random thermal motion. Viscosity is caused in part by the forces of attraction between the molecules. The reduction in viscosity can be explained in part by the fact that if the molecules are close to each other for less time the effect of the attractive force will be less.

(b) The oil coats the metal surfaces and keeps them apart – lubrication – because liquids are incompressible. As the surfaces slide past each other the viscosity causes a drag force opposing the motion. This drag force reduces at higher temperatures and the engine turns more freely.
- (a) $E = Fl \div Ax$ the gradient of the force extension graph is $F \div x = m$
So $E = ml \div A = 12 \times 10^3 \text{ N m}^{-1} \times 1.300 \text{ m} \times 4 \div (\pi \times (0.315 \times 10^{-3} \text{ m})^2)$
 $E = 2.00 \times 10^{11} \text{ N m}^{-2}$

(b) It acts as a control for any effects not accounted for. For example, the support for the wire might sag, so both wires sag. The temperature might change so both wires change length.

(c) It shows up anomalies that can be ignored. In this experiment a straight-line graph indicates that the wire has not yielded nor lost proportionality. The line of best fit effectively takes an average of the readings.
- (a) The x -axis is a time axis and so distance from one peak to the next peak represents the periodic time of the frequency generator.

(b) Since the scale is made larger the display, which takes the same time as before, becomes smaller so the peaks get closer together.

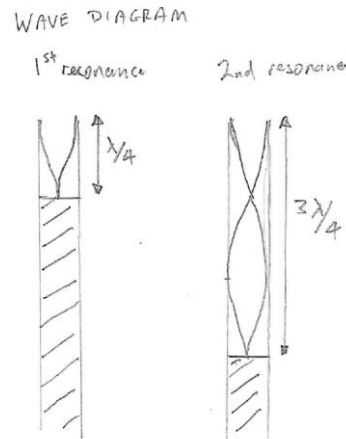
(c) As you get further from the microphone the sound is quieter and so the amplitude gets smaller.

(d) It avoids any effect that might be caused by resonance, such as a poor response from the microphone at a certain frequency. It always helps to take a range of readings to spot anomalies and detect trends. In this case the speed should not vary with frequency.

5. (a) The string is heavier and it will take more force to move it, so it will respond more slowly and the speed of the waves on the string will be slower. At the same frequencies the wavelength will be shorter.

Considering the maths the speed c is given by $c^2 = f^2 \lambda^2 = T \div \mu$, so a larger value for μ gives a smaller value for c .

(b)



The difference between the two resonating lengths is $3\lambda \div 4 - \lambda \div 4 = \lambda \div 2$. Diagrams are a very good way to help answer many physics questions so always include one if you can.

6. The mathematical model for the angle θ at which maxima are seen is $\sin \theta = n\lambda \div d$ where d is the distance between adjacent slits on the grating and n is an integer. The experiment involves measuring the angle θ . This is done by measuring the distance between the grating and the wall and the distance along the wall between maxima. As the distance between grating and wall increases so does the distance between maxima. Measuring a larger distance with the same instrument – in this case a metre rule – will reduce the percentage uncertainty caused by the resolution of the instrument.

7. (a) $\rho = RA \div l = 1.28 \times 10^6 \Omega \times (0.020 \text{ m} \times 0.0005 \text{ m}) \div 0.020 \text{ m} = 640 \Omega \text{ m}$
- (b) The resistance of a semiconductor is very much higher than a similar sized piece of metal – as the name suggests. This is because there are fewer charge carriers available to carry a current.
- (c) Replace the two numbers 0.020 mm in the equation above with 0.015 mm and they cancel out again so the answer is still 1.28 M Ω .
- (d) If the connection to the silicon is made in the centre of the face the current will spread out and not all the silicon will have the same current in it. It will be better to attach metal plates along the face of the slice so that the current flow is even across the slice and all the silicon is used.
8. (a) $E = V + Ir$ so the terminal p.d. is $V = E - Ir$. Since E is 12 V we can work out the terminal p.d. as $12 - 150r$. So if $r = 0.05 \Omega$ then $Ir = 7.5 \text{ V}$ (the lost volts) and the output p.d. is 5.5 V. This means the starter motor only has 5.5 V to operate and not 12 V. If $r = 0.06 \Omega$ then $Ir = 9.0 \text{ V}$ and we are down to 3.0 V for the starter motor. 0.05 Ω is very, very low.
- (b) If the connections have any resistance this has the same effect as the internal resistance of the battery and the starter motor 'sees' even more lost volts.
- (c) The wires must be short – the battery is close to the starter motor – and very thick. They must be made from a very conductor and the connections must have a large area of contact.

9. The mass hanging on the hanger is providing the force that will change the momentum of the trolley. The mass of the whole system, trolley string and hanger, must remain the same so that when we measure the velocity we can calculate the momentum and it is the whole system that is gaining momentum.
10. This is an excellent opportunity to use digital equipment to analyse a relatively complex occurrence. Measuring velocity using Tracker is reasonably easy but the angles will prove a little more demanding. Again, this is an investigation so you decide exactly what you will do to investigate momentum in two dimensions. You might like to carry out some work with striking stationary golf balls or kicking footballs. If you can measure the initial velocity and the duration of the impact from the video clip you can calculate the force if you know the mass of the ball.
11. (a) The circuit is as drawn on the student sheet but with the voltmeter replaced by a voltage sensor which should be shown connected to a data logger. This need not be shown connected to a computer.
- (b) Charging slowly – advantages are that the logger records both variables, potential difference and time, with a high frequency so you get more readings. The resolution of the potential difference reading may be much smaller.
- Charging quickly – the same advantages as above and the display doesn't flicker as the oscilloscope is likely to do.
- Disadvantage – both oscilloscope and data logger are more expensive than a voltmeter and stopwatch, but you get what you pay for and you cannot observe the quick charging circuit with a voltmeter. The datalogger can deal with high frequency signals.
12. For this research question the students might look at the resistance of a resistor, the e.m.f of a thermocouple or perhaps the volume of a gas. An optical pyrometer might be the choice for high temperatures.
13. (a) The plan should include a power supply, voltmeter and ammeter, and timer. A Joulemeter is a good alternative. A top pan balance will also be needed, as will a second beaker. A circuit diagram should be drawn if the Joulemeter is not being used.
- Method**
- Weigh the dry beaker and place the second beaker under the condenser.
- Turn on the power supply and allow the water in the upper chamber to boil.
- Ensure that cold water is flowing through the condenser.
- When there is a steady flow of condensate, place the dry beaker under the condenser and start the clock/reset the Joulemeter.
- After a reasonable amount of water has fallen into the beaker, stop the clock/Joulemeter and remove the beaker.
- Weigh the beaker and calculate the mass of water boiled off and calculate the energy supplied
- (b) The water boils at a fixed temperature so its temperature does not need to be measured.
14. (a) The amount of gas is determined by the number of molecules N . This must be kept constant so that there are only two variables changing.
- (b) Any apparatus that will work is acceptable. The key point is how to keep the pressure constant. Marks would be awarded for the diagram and the means of varying and measuring the temperature, how the volume will be measured and a precaution for accuracy

such as to ensure the temperature of the gas is the same as that of the thermometer. A graph of volume against temperature should be a straight line but they should discuss which temperature they will use with regard to their graph.

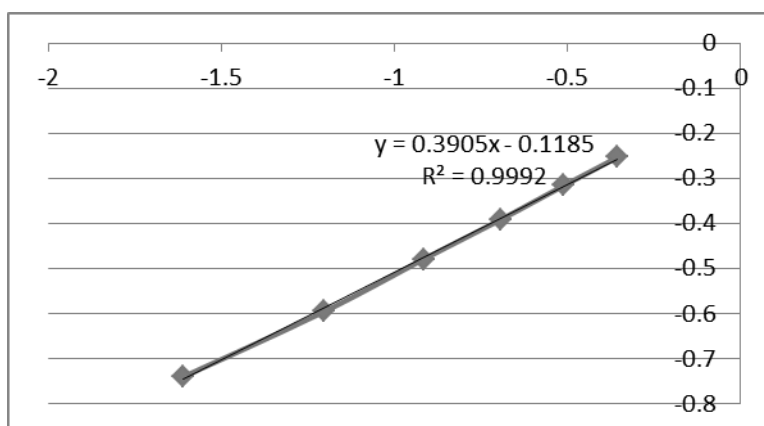
15. At high frequencies electromagnetic radiation can be thought of as particles, so the radiation consists of gamma particles, or photons. We know that $E = hf$ so the higher the frequency the higher the energy of the photons and so more lead will be required to stop the same number. For a higher frequency the half thickness will be higher.

16. (a) $T = 2\pi\left(\frac{m}{k}\right)^{\frac{1}{2}}$

becomes

$$\ln T = 0.5 \ln m + \ln(2\pi(k)^{\frac{1}{2}})$$

which is similar to $y = mx + c$ so the log graph should have a gradient of 0.5. The Excel version of the graph is



And it is clear that the bottom point is anomalous. On removing that the gradient is 0.39 which is disappointingly small.

- (b) The fact that the bottom plot is anomalous might be explained by suggesting that since the extension is small – just over 2 cm – it is possible that the oscillation was not simple harmonic with the spring closing up. Also the period is very small so counting 10 oscillations in under 4 seconds is likely to be difficult. There seems little explanation for the poor value for the gradient.