International Baccalaureate · IB Diploma · Physics · HL

Practical Skills ·

Two parts of the course reward practical skill directly: the scientific investigation (the internal assessment, 20% of the grade) and the data-based questions of Paper 1B. Both mark the same habits – uncertainties carried honestly, a graph that tests a model, and a conclusion that says how far the data support it.

1B

The scientific investigation at a glance

About 10 hours of work, written up in at most 3,000 words, marked out of 24: four criteria of 6 marks each. The word limit includes the text but not the tables, graphs or calculations, so put the working in the data and spend the words on decisions.

Research design – a focused research question naming both variables and the range, the physics behind it, and a method another student could repeat: variables, how each control is held, how many readings, over what range

Data analysis – raw data with uncertainties, processing shown once in full, a graph with error bars and a best-fit line, and the uncertainty carried through to the final result

Conclusion – answers the research question with the numbers, says how well the data fit the model, and compares the result with a published or theoretical value

Evaluation – names the weaknesses that actually affected THIS data set, says which way each one pushed the result, and gives an improvement that a school lab could carry out

A research question that scores reads like a measurement plan: 'How does the period of a mass–spring oscillator depend on the mass, from 0.100 kg to 0.500 kg?' 'Investigating springs' is a topic, not a question.

Choose an investigation whose result you can compare with something: a model ($T \propto \sqrt{m}$), a published constant, or a value from a second method. A conclusion with nothing to compare against has little to say.

Uncertainty in a single reading

Analogue scale – ± half the smallest division for a single reading; a length read at both ends of a ruler is ± one division, because the scale is read twice

Digital display – ± one unit in the last digit displayed, unless the manufacturer states a larger value

Repeated readings – when the repeats scatter more than the scale uncertainty, use half the range: (largest − smallest) ÷ 2. The scatter is then the honest uncertainty, not the scale

Human timing – a stopwatch reads to 0.01 s, but reaction time is about 0.1–0.2 s at each end. Time many oscillations and divide: the uncertainty in one period is then that of the whole timing divided by the number counted

Random error – scatters readings both ways; repeating and averaging reduces its effect on the mean

Systematic error – shifts every reading the same way – a zero error, a slow clock, a heat loss. Repeating cannot find or remove it; it shows up as an intercept where the model predicts none

Accuracy is closeness to the true value; precision is how closely repeats agree. A precise set with a zero error is tightly clustered and wrong.

Propagating uncertainty

These rules are in the data booklet. They give the maximum uncertainty, which is what the course uses.

Sum or difference – if $y = a \pm b$, then $\Delta y = \Delta a + \Delta b$ – ADD the absolute uncertainties. A small difference of two large readings is therefore very uncertain

Product or quotient – if $y = ab/c$, then $\Delta y/y = \Delta a/a + \Delta b/b + \Delta c/c$ – ADD the fractional (or percentage) uncertainties

Power – if $y = a^n$, then $\Delta y/y = |n|\ \Delta a/a$. A squared quantity doubles the percentage uncertainty; a square root halves it

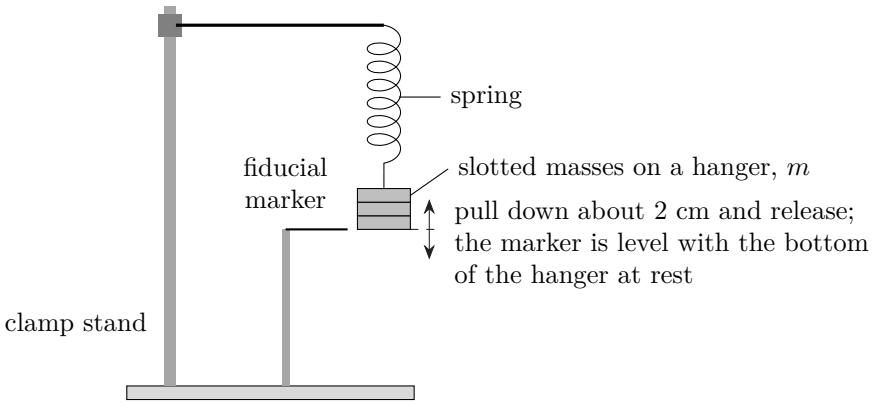
Worked example: $T = 0.773 \pm 0.010$ s, so the percentage uncertainty in T is 1.3% and in T^2 it is 2.6%: $T^2 = 0.598 \pm 0.016\ s^2$.

Round the final uncertainty to one significant figure (two if it starts with 1 is acceptable), then round the value to the same decimal place: 19.94 ± 0.72 N m^{-1} becomes 19.9 ± 0.7 N m^{-1}.

Worked investigation: a mass–spring oscillator :

Research question: how does the period T of a mass–spring oscillator depend on the oscillating mass m, from 0.100 kg to 0.500 kg? Model: $T = 2\pi\sqrt{(m/k)}$, so $T^2 = (4\pi^2/k)\ m$ and a graph of T^2 against m should be a straight line through the origin with gradient $4\pi^2/k$.

Apparatus



Time from the equilibrium position, where the mass moves fastest and the instant of passing is sharpest.

Method

1. Clamp the spring and check the stand is stable; put a G-clamp or a heavy mass on the base.

2. Hang 0.100 kg on the spring and set the fiducial marker level with the bottom of the hanger at rest. Move it each time the mass changes.

3. Pull the mass down about 2 cm and release it. Start timing as it passes the marker, count to ten complete oscillations and stop.

4. Repeat the timing three times; record all three and their mean.

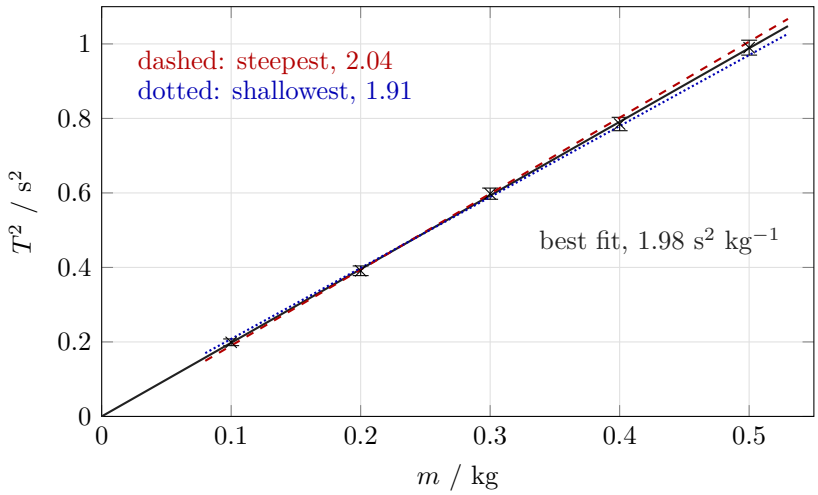
5. Add 0.100 kg at a time up to 0.500 kg and repeat steps 2–4.

6. Keep the spring, the amplitude and the counting point the same throughout; check the spring returns to its original length after unloading, so it was not stretched past its elastic limit.

Results

m / kg	$10T$ / s (mean of 3) ± 0.1	T / s ± 0.01	T^2 / s^2	$\Delta(T^2)$ / s^2
0.100	4.46	0.446	0.199	0.009
0.200	6.25	0.625	0.391	0.013
0.300	7.73	0.773	0.598	0.015
0.400	8.86	0.886	0.785	0.018
0.500	9.95	0.995	0.990	0.020

The ± 0.1 s is half the range of the three timings. Each $\Delta(T^2)$ is $2 \times (\Delta T/T) \times T^2$.



Best-fit line, and the steepest and shallowest lines that still pass through every error bar.

Processing

Gradient = 1.98 s^2 kg^{-1}. Its uncertainty is half the difference between the steepest and shallowest lines: $(2.04 - 1.91) \div 2 = 0.065$, about 0.07 s^2 kg^{-1} or 3.5%.

k = $4\pi^2 \div$ gradient = $39.48 \div 1.98 = 19.9$ N m^{-1}, with the same 3.5%: k = 19.9 ± 0.7 N m^{-1}.

Conclusion

T^2 is proportional to m within the uncertainties: the line passes through every error bar, and the intercept, −0.001 s^2, is zero within them. The data support T = $2\pi\sqrt{(m/k)}$, with k = 19.9 ± 0.7 N m^{-1}. A static test (loading the spring and measuring the extension) would give a second value of k to compare against.

Evaluation

Strength: five masses over a fivefold range, three repeats each, and every point within its error bar of the line.

Weakness – the spring's own mass also oscillates. It adds roughly a third of the spring's mass to m, which would show as a positive intercept on the T^2 axis; here it is too small to see, so a heavier spring would be needed to test it.

Weakness – timing is the largest uncertainty (about 1% in T, 2% in T^2). Improvement: time 20 oscillations, or use a light gate at the equilibrium position with a data logger, which removes reaction time from

both ends of the timing.

Weakness – only five values of m. Improvement: eight or more masses from 0.050 kg, so the line and any curvature at small m are better tested.

Graphs that test a model

Rearrange the model into y = mx + c and plot what makes it straight. A straight line is the only shape you can test by eye and the only one whose gradient and intercept mean something.

Model	Plot	Gradient	Intercept
$T = 2\pi\sqrt{m/k}$	T^2 against m	$4\pi^2/k$	0
$I = \varepsilon/(R+r)$	$1/I$ against R	$1/\varepsilon$	r/ε
$y = kx^n$	$\ln y$ against $\ln x$	n	$\ln k$
$N = N_0 e^{-\lambda t}$	$\ln N$ against t	$-\lambda$	$\ln N_0$
$pV = nRT$ (fixed n, T)	p against $1/V$	nRT	0

Linearising common relationships. The axis labels carry the units: ln(N / counts) has none.

Error bars on a log axis: $\Delta(\ln y) \approx \Delta y / y$, the fractional uncertainty. They are therefore the same size wherever the fractional uncertainty is constant.

Draw one best-fit line with points scattered both sides. Do not join the dots, and do not force the line through the origin; whether it passes through the origin is something the graph tests.

A clear curve in the residuals – points above the line at both ends and below in the middle – means the model is wrong for this range, even if every point is close.

Paper 1B – data-based questions 1B:

Paper 1B puts you in front of someone else's experiment: a method, a table, a graph. The marks are for reading what is there and processing it, not for recalling the topic.

Read the axes before the curve: quantity, unit, power of ten, and whether either axis starts at zero. A gradient read from a false origin is the commonest lost mark.

When asked for a gradient, draw a triangle covering more than half the line and show both points. Give the unit – it is the y-unit over the x-unit.

When asked whether data support a relationship, test the relationship, not the trend: for proportionality, check that the ratio y/x is constant within the uncertainties, or that the line passes through the origin within the error bars.

When asked for an uncertainty, say where it comes from (scale, scatter, or propagation) and show the arithmetic.

When asked to suggest an improvement, tie it to the weakness the data show: a large scatter calls for more repeats; a non-zero intercept calls for finding the systematic error.

Evaluation – what scores and what does not :

Name the weakness, say how it affected the result (bigger, smaller, more scattered), and give an improvement you could actually carry out. All three halves are needed.

'Human error', 'be more careful' and 'use better equipment' name nothing. Say which reading, which error, which instrument: 'use a light gate and data logger in place of the stopwatch, removing the 0.2 s reaction time at each end of the timing'.

‘Repeat more times’ helps only with random error. It does nothing for a zero error, a heat loss or a mis-set marker.

Compare with the accepted value using the uncertainty, not a feeling: a result whose range includes the accepted value agrees with it; one that misses by more than its uncertainty shows a systematic error the method has not accounted for. Then say where that error most likely came from.

Extensions score in the conclusion and evaluation: a second independent variable to test next, a wider range, or a second method for the same quantity.