

## Unit 6: Practical Skills in Physics II

WPH16 · Issue 3 + Appendix 10 · planning, critique, compounded uncertainties,  
log graphs · sheets 6.1–6.4

## From a reading to a result

### Student A records

Amplitudes only: a table of readings, no result. The data cannot give a decay constant by itself.

### Student B processes

Logarithms, one straight line, gradient and intercept: the readings become a measured decay constant and an initial amplitude.

## Unit 6 adds three new tools

Unit 3 measured well. Unit 6 compounds uncertainties, linearises models and judges conclusions.

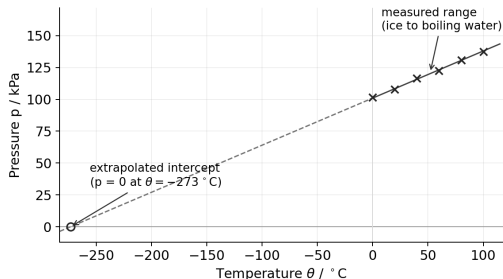
## Choose the graph before the method

- 1 Model** write the predicted relation, e.g.  $P = kX^4$
- 2 Linearise** pick the plot,  $P$  against  $X^4$  or  $\lg P$  against  $\lg X$
- 3 Read off** a straight line through the origin, or gradient 4
- 4 Readings** at least five well-spread settings of the changed quantity

## Four models and their straight-line plots

| Model               | Plot                    | Read off                                  |
|---------------------|-------------------------|-------------------------------------------|
| $V = V_0 e^{-t/RC}$ | $\ln V$ against $t$     | gradient $-1/RC$ ,<br>intercept $\ln V_0$ |
| $P = kX^n$          | $\lg P$ against $\lg X$ | gradient $n$ , intercept<br>$\lg k$       |
| $p = c/V$           | $p$ against $1/V$       | through origin, gradient<br>$c$           |
| $T^2 = (4\pi^2/k)m$ | $T^2$ against $m$       | gradient $4\pi^2/k$                       |

# Plan an extrapolation to absolute zero

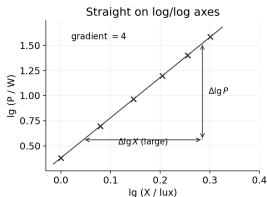
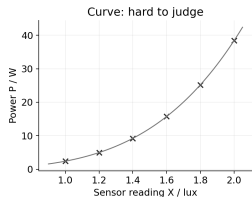


- 1 Range** ice to boiling water bounds the measured temperatures
- 2 Readings** at least five paired pressure and temperature values, stirred and perpendicular
- 3 Graph** best-fit line extended to zero pressure; the intercept estimates  $-273$  °C

## Your turn: plan the bulb power law

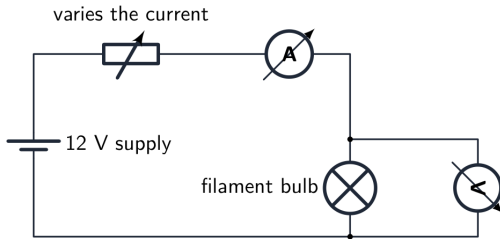
- A sensor reads  $X$  from a bulb; the model is  $P = kX^4$ .
- Name two controls with physical reasons.
- Choose the graph and what proves the model.

# The power-law graph and its controls



- 1 **Controls** distance and alignment fixed; background light removed
- 2 **Data**  $P = IV$  at five or more current settings
- 3 **Graph**  $\lg P$  against  $\lg X$ ; gradient 4 confirms  $P = kX^4$

## Meters belong where the measurement is



- Ammeter in series with the component under test.
- Voltmeter in parallel with that component only.
- A variable resistor in series changes the current.

## Safety and data loggers name their mechanism

| Situation              | Named mechanism                 | Action                                |
|------------------------|---------------------------------|---------------------------------------|
| hot water, heater      | burns on contact                | tongs; clamp the heater               |
| electrolytic capacitor | polarity, rating, stored charge | connect correctly;<br>discharge first |
| data logger probes     | simultaneous pairs, no parallax | better resolution than a thermometer  |

## Record what you can actually judge

A recording resolution finer than your judgement is a fault, not a virtue.

## Time many oscillations, mark the centre

Displace the mass a small distance and release.



Start timing only after several oscillations, at the centre marker.



Time ten oscillations; repeat and record the totals.



Divide the mean total by ten for the period.

## Your turn: criticise this results table

- Readings of 1.1, 1.06, 1.08 s appear in one row.
- A later row holds 2.61 s beside 1.95 and 1.91.
- Find two faults and the honest response to each.

## Decimal places, units and anomalies

- 1 **Fault** 1.1 uses fewer decimal places than its column
- 2 **Fault** 2.61 s breaks its row's pattern, a possible anomaly
- 3 **Response** record to the timer's resolution; flag, check and repeat the anomaly

## Length instruments, with the error named

### Orientations and mean

A real coil is not round. Measuring at several orientations and averaging reduces random variation in the diameter.

### Zero error

A closed-jaw offset shifts every reading the same way. Check it and subtract it, a systematic error that repeating cannot remove.

## Justify an instrument with a calculation

- 1 **Resolution** a micrometer resolves 0.01 mm
- 2 **Uncertainty** one reading of 1.21 mm carries half a division, 0.005 mm
- 3 **Percentage**  $0.005/1.21 = 0.4\%$ , small enough to justify the instrument

$$\text{percentage uncertainty} = \frac{0.005 \text{ mm}}{1.21 \text{ mm}} \times 100\% = 0.4\%$$

## Criticise a graph like an examiner

Point at the actual defect: crowded points, awkward scales, or a curve drawn as a line.

## The building blocks still stand

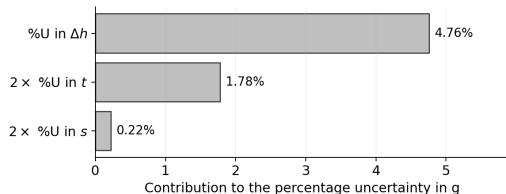
- 1 **Single reading** uncertainty is half the instrument's resolution
- 2 **Repeats** uncertainty is half the range, or the reading furthest from the mean
- 3 **Currency** percentages, quoted to one or two significant figures

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{value}} \times 100\%$$

# The three compounding rules

| Calculation            | Rule               | Example                                |
|------------------------|--------------------|----------------------------------------|
| $A = \pi r^2$          | percentage times 2 | $0.6\% \rightarrow 1.2\%$              |
| $\rho = m/\beta$       | add percentages    | $3 \times 2.1\% + 0.1\% = 6.4\%$       |
| $\Delta h = h_1 - h_2$ | add absolutes      | $\pm 0.5 + \pm 0.5 = \pm 1 \text{ mm}$ |
| $D^2/(2d^2)$           | combine both       | $2 \times \%U(D) + 2 \times \%U(d)$    |

# The ramp measurement of $g$



- The model gives  $g = 14s^2 / (5t^2 \Delta h)$ .
- $s$  squared,  $t$  squared,  $\Delta h$  once:  
add  
 $2 \times \%U(s) + 2 \times \%U(t) + \%U(\Delta h)$ .
- $0.22 + 1.78 + 4.76 = 6.8$  per cent, about 7 per cent.

## Your turn: compound $D$ squared over 2 $d$ squared

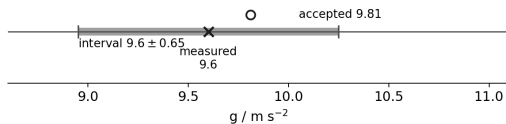
- $D = 59.4 \text{ mm} \pm 0.2 \text{ mm}$  and  $d = 13.9 \text{ mm} \pm 0.1 \text{ mm}$ .
- Show the percentage uncertainty in the term is about 2 per cent.

## Squares double the percentages

- 1 **Diameters**  $0.2/59.4 = 0.34\%$  and  $0.1/13.9 = 0.72\%$
- 2 **Squares** each percentage doubles, and the quotient adds them
- 3 **Result**  $2.1\%$ , quoted to two significant figures

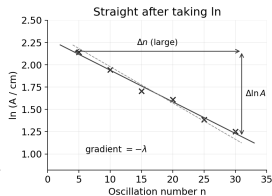
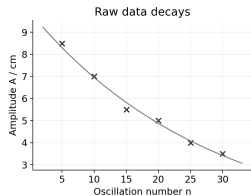
$$\%U\left(\frac{D^2}{2d^2}\right) = 2 \times \frac{0.2}{59.4} \times 100\% + 2 \times \frac{0.1}{13.9} \times 100\% = 2.1\%$$

# Turn the result into a conclusion



- 1 **Interval**  $9.6 \times (1 \pm 0.068) = 8.9$  to  $10.3 \text{ m s}^{-2}$
- 2 **Compare** accepted 9.81 lies inside, so the measurement is accurate
- 3 **Honest** consistency does not prove identity; other values also fall inside

# Straighten an exponential with $\ln$



- Take  $\ln$  of both sides:  $\ln A = \ln A_0 - \lambda n$ .
- Plot  $\ln A$  against  $n$ : gradient minus  $\lambda$ , intercept  $\ln A_0$ .
- The minus sign is the physics, because decay slopes down.

## Convert the line back to physics

- 1 **Gradient**  $\lambda = 0.0355$ , no unit because  $n$  counts oscillations
- 2 **Intercept**  $A_0 = e^{2.295} = 9.9$  cm, the unit the axis carried
- 3 **Discipline** In values to 3 d.p.; gradient from a large triangle on the line

## Your turn: linearise the glass-stack decay

- Light through glass:  $V = A e^{-B w}$ , with thickness  $w$ .
- Explain how  $\ln V$  against  $w$  determines  $B$ .

## Read the model off the line

- 1 **Gradient** the slope of  $\ln V$  against  $w$  is  $-B$
- 2 **Intercept** the intercept is  $\ln A$ , so  $A = e^{\text{intercept}}$
- 3 **Power laws** use  $\lg$  instead; never mix the two bases

$$\ln V = \ln A - Bw \quad \Rightarrow \quad \text{gradient} = -B, \quad \text{intercept} = \ln A$$

## Predict with the line, round the right way

- 1 **Target**  $V/A = 0.60$ , so  $\ln 0.60 = -Bw$
- 2 **Thickness**  $w = \ln 0.60 / (-0.0088 \text{ mm}^{-1}) = 58 \text{ mm}$
- 3 **Round up** 29 filters sit marginally above 60 per cent, so 30 are needed

## When is an extrapolation trustworthy?

An intercept read beyond the data is only as good as the line, so name the reason yours is uncertain.

## Check yourself

- Plan with the graph chosen first; place both meters correctly.
- Judge recording resolution, tables and graphs with named faults.
- Compound for powers, products and differences; find the dominant term.
- Linearise with  $\ln$  and  $\lg$ , convert read-offs, round predictions correctly.