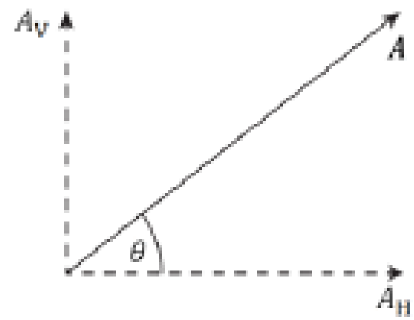
IB PHYSICS
REVIEW
PAPER 3 QUESTION A

Measurements and uncertainties

Sub-topic 1.2 – Uncertainties and errors	Sub-topic 1.3 – Vectors and scalars
If: $y = a \pm b$ then: $\Delta y = \Delta a + \Delta b$ If: $y = \frac{ab}{c}$ then: $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$ If: $y = a^n$ then: $\frac{\Delta y}{y} = \left\lvert n\frac{\Delta a}{a} \right\rvert$	 $A_H = A\cos\theta$ $A_V = A\sin\theta$

Uncertainty and errors

Guidance:

- Analysis of uncertainties will not be expected for trigonometric or logarithmic functions in examinations

Uncertainty and error in measurement

Accuracy is the closeness of agreement between a measured value and a true or accepted value

Precision is the degree of exactness (or refinement) of a measurement (results from limitations of measuring device used).

There are 2 types of errors in measured data: **random and systematic.**

Uncertainty and errors

- **Random**: refer to random fluctuations in the measured data due to:
  - to the recorder, rather than the instrument used for the measurement.
  - the readability of the instrument
  - the effects of something changing in the surroundings between measurements
  - the observer being less than perfect
  - Random errors can be **reduced** by taking many readings and then averaging them.

    A precise experiment has small random error.

Uncertainty and errors

- **Systematic errors** is error due to the instrument being “out of adjustment.” (measurements that are either consistently too large, or too small) can result from:

- poor technique (e.g. carelessness with parallax)

  The observer being less than perfect in the ***same way*** during each measurement.
- zero error of an instrument (e.g. a ruler that has been shortened by wear at the zero end, or a scale that reads a value when nothing is on it);
  Instrument does not read zero when it should
  – to correct for this, the value should be subtracted from every reading)
- an instrument being wrongly calibrated (e.g. every time measurement is measured too large).
- can be detected using **different methods** of measurement.

Uncertainty and errors

Instrument/measurement uncertainty

Analog instrument : ½ of the smallest increment (precision)
Digital instrument : the whole smallest increment

measurement = (best estimate ± uncertainty) unit

Uncertainties are given to 1 significant figure.

Uncertainty and errors

Range of the measurements

$$range = maximum\ value - minimum\ value = x_{max} - x_{min}$$

Absolute uncertainty

$$\Delta \boldsymbol{x} = \frac{range}{2} = \frac{x_{max} - x_{min}}{2}$$

or

$$\Delta x = \left| x_{avg} - x_i \right|_{max}$$

Fractional/relative uncertainty

$$\frac{\Delta x}{x}$$

Percentage uncertainties

$$\frac{\Delta x}{x} 100\%$$

Uncertainty and errors *Propagating uncertainties through calculations*

If data are to be **added** or **subtracted**, **add** the ***absolute*** *uncertainty:*

$$\ell_1 = (3.2 \pm 0.2)m$$

$$\ell_2 = (2.3 \pm 0.1)m$$

$$\ell_1 + \ell_2 = (5.5 \pm 0.3)m$$

$$\ell_1 - \ell_2 = (0.9 \pm 0.3)m$$

If data are to be **multiplied** or **divided**, **add** the ***fractional*** *or* ***percentage*** *uncertainty:*

$$y = \frac{a \cdot b}{c} \qquad \frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$$

$$\ell_1 = (2.3 \pm 0.2)m \qquad \ell_2 = (3.2 \pm 0.1)m$$

$$A = \ell_1 \cdot \ell_2 \qquad \frac{\Delta A}{A} = \frac{\Delta \ell_1}{\ell_1} + \frac{\Delta \ell_2}{\ell_2}$$

$$\Delta A = 7.36(0.087 + 0.031) = 0.868$$

$$\boldsymbol{A = (7.4 \pm 0.9)m}$$

$$B = \frac{\ell_1}{\ell_2} \qquad \frac{\Delta B}{B} = \frac{\Delta \ell_1}{\ell_1} + \frac{\Delta \ell_2}{\ell_2}$$

$$\Delta B = 0.719(0.087 + 0.031) = 0.285$$

$$B = (0.7 \pm 0.3)$$

$$\ell_1 \cdot \ell_2 = 7.36$$

$$\frac{\ell_1}{\ell_2} = 0.719$$

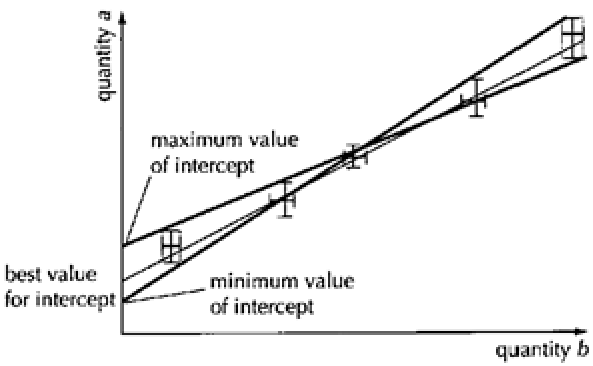
$$\frac{\Delta \ell_1}{\ell_1} = 0.087$$

$$\frac{\Delta \ell_2}{\ell_2} = 0.031$$

WHAT ARE MAX AND MIN LINES and what to do with them?

Remember that most Physics experiments lead to graphical analysis of data. We can use graphs to express and find uncertainties. You must include graphs of your data in aspect 3 in DCP.
Let's say you have found the line of best fit and the slope of this line (linearization)

Therefore, you have found a value of the slope that corresponds to some physical quantity (13.6 eV in previous example which is maximum energy electron can have in H atom: n = 1). Now you must use the **maximum** and **minimum best-fit lines** to determine the final uncertainty in the stated value of the slope of your best-fit line. Here's how:



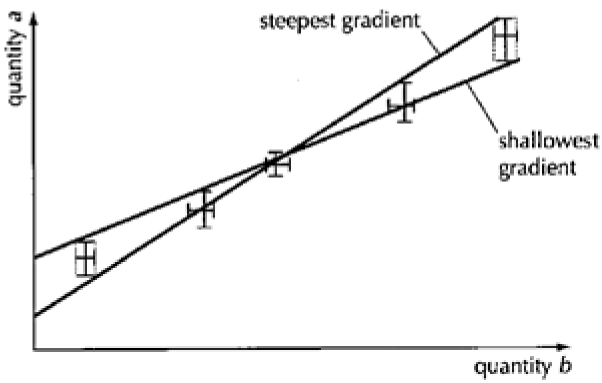
1. Draw a straight line with the **least** slope possible (minimum best-fit line) that connects corners of your first and last error boxes.

2. Draw a straight line with the **greatest** slope possible (maximum best-fit line) that connects corners of your first and last error boxes.

3. Determine the slopes of these two lines.

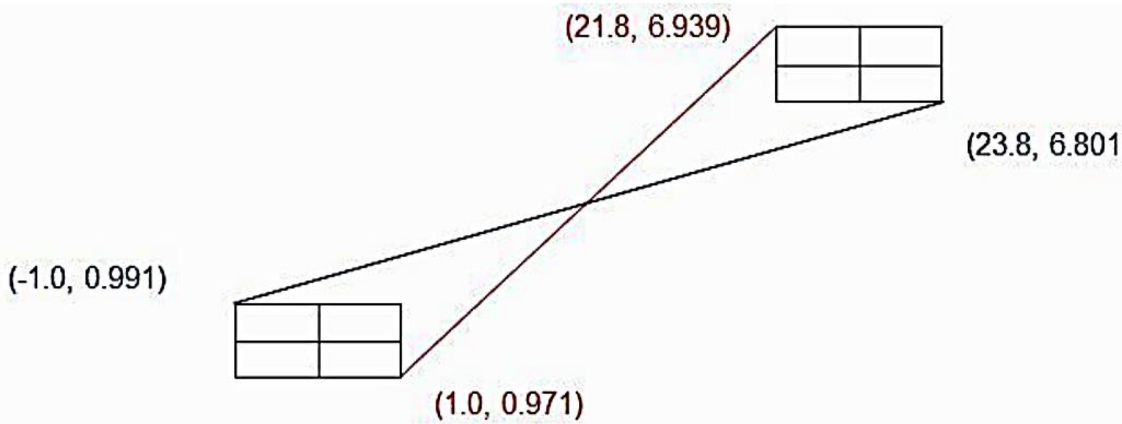
4. Your final uncertainty in the stated value of the slope of your best fit line is:

$$\frac{(\text{max slope} - \text{min slope})}{2}$$



Lines of Best Fit and Max/Min Lines for ‘Graph of Quantity a vs. Quantity b’

Note that by using this technique, you may get max and min lines that do not go through the error boxes of every data point. This is ok and you will not be penalized for it.



Gradient of steep (maximum slope) line $= \dfrac{\Delta y}{\Delta x} = \dfrac{6.939 - 0.971}{21.8 - 1.0} = 0.287 = 0.29$

Gradient of shallow (minimum slope) line $= \dfrac{\Delta y}{\Delta x} = \dfrac{6.801 - 0.991}{23.8 - (-1.0)} = 0.234 = 0.23$