Week 1

# Science Inquiry Skills

Quantitative Data:

Numerical data; specific amount

Qualitative Data:

Non-numerical data; descriptive data

Model:

Is an aid to understanding. But a model is not the same as the thing itself. A model is a model. The thing to which a model refers is the thing to which it refers.

**Fundamental Units**

| Fundamental Quantities | SI Unit | Symbol |
|---|---|---|
| Length | meter | m |
| Mass | kilogram | kg |
| Time | second | s |
| Electric current | Ampere | A |
| Temperature | Kelvin | K |
| Amount of subtance | mol | mol |
| Luminous Intensity | candela | cd |

**Prefixes:**

| Multiple | Prefix | Symbol | Multiple | Prefix | Symbol |
|---|---|---|---|---|---|
| $10^{18}$ | exa | E | $10^{-2}$ | centi | c |
| $10^{15}$ | peta | P | $10^{-3}$ | milli | m |
| $10^{12}$ | tera | T | $10^{-6}$ | micro | μ |
| $10^{9}$ | giga | G | $10^{-9}$ | nano | n |
| $10^{6}$ | mega | M | $10^{-12}$ | pico | p |
| $10^{3}$ | kilo | k | $10^{-15}$ | femto | f |

| | |
|---|---|
| millimetre (mm) equal to $10^{-3}$m | megawatt (MW) equal to $10^{6}$W |
| centimetre (cm) equal to $10^{-2}$m | kilogram (kg) equal to $10^{3}$g |
| kilometre (km) equal to $10^{3}$m | gigajoule (GJ) equal to $10^{9}$J |

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**Accuracy:**

refers to the closeness of a measured value to a standard or known value

**Precision:**

The limitations of the tool

**Uncertainty:**

Estimate of the range of values within which the 'true value' of a measurement or derived quantity lies

**True Value:**

The exact value of a measurand; the 'true value' is an ideal that can never be known with certainty

**Relative an Percentage Uncertainty:**

Relative and percentage uncertainties are usually given to 2 significant figures. They have no units because they are the ratio of the absolute uncertainty in the measurement.

$$\text{Relative uncertainty} = \frac{\text{uncertainty}}{\text{value}}$$

$$\text{Percentage uncertainty} = \frac{\text{uncertainty}}{\text{value}} \times \frac{100}{1}\%$$

**Proportional Error:**

It is the difference between a measurement and an accepted value, expressed as a fraction of the accepted value.

$$\text{Proportional error} = \frac{|\text{measured value} - \text{accepted value}|}{\text{accepted value}}$$

**Percentage Error:**

Is the ratio of the magnitude of the proportional difference between an accepted value and a measurement result, expressed as a percentage.

$$\%\ \text{error} = \frac{|\text{measured value} - \text{accepted value}|}{\text{accepted value}} \times \frac{100}{1}\%$$

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Example:

A manufacturer gives the wavelength of a light as $(671 \pm 5) \times 10^{-9}$ m. A student measured the wavelength to be $(660 \pm 9) \times 10^{-9}$ m.

**a** Does the student's measurement result fit within the accepted value measurement result? Sketch a graph of range of indication values versus reading to show any differences between the measurement results. (5 marks)

**b** Calculate the percentage error in the student's measurement result. (2 marks)

| Answers | Logic | |
|---|---|---|
| **a** The two measurement results overlap in the region $(666–669) \times 10^{-9}$ m. | Identify the overlap. | 1 mark |
| | Label the horizontal axis and mark the correct overlap values. | 4 marks |

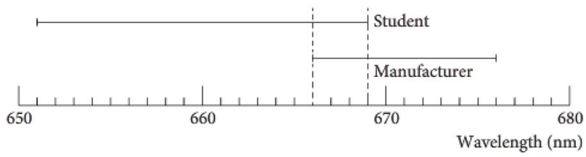


Figure 12.6 Overlap of measurement results for manufacturer's accepted value and student measurement result

**b** $$\% \text{ error} = \frac{|\text{measured value} - \text{accepted value}|}{\text{accepted value}} \times \frac{100}{1}\%$$

Substitute the correct values into the formula. — 1 mark

$$\Rightarrow \% \text{ error} = \frac{|660\text{ m} - 671\text{ m}| \times 10^{-9}}{671 \times 10^{-9}\text{ m}} \times \frac{100}{1}\%$$

$$\Rightarrow \% \text{ error} = \frac{11}{671} \times \frac{100}{1}\%$$

$$\Rightarrow \% \text{ error} = 1.6\%$$

Calculate the answer. — 1 mark

As both measurements incorporate the region in which the 'true value' may be meaningfully said to exist, this figure is of little relevance. This is why the BIPM does not define percentage error.

**Adding and Subtracting Uncertainties:**

1. Add or subtract the 2 values
2. Add the individual uncertainties to fin the uncertainty in the sum or difference
3. Claim the best estimate only as far as the sum of uncertainties will allow; that I, the place value of the first digit of the sum of the uncertainties.

**Rule: $(A \pm \Delta A) - (B \pm \Delta B) = (A - B) \pm (\Delta A + \Delta B)$ $(A \pm \Delta A) + (B \pm \Delta B) = (A + B) \pm (\Delta A + \Delta B)$**

e.g.

$$(17.23 \pm 0.02) + (5.1 \pm 0.4)$$

Add the best estimates of the value: $17.23 + 5.1 = 22.33$
Add the uncertainties for each value: $0.02 + 0.4 = 0.42$

The answer could be given as $22.33 \pm 0.42$, but the result becomes uncertain at the first decimal place in the uncertainty, 4 in 0.42. Hence, the best estimate, with uncertainty, of the sum is $22.3 \pm 0.4$.

**-When there is no uncertainty given in a data point**

i. The last decimal place in each number is regarded as the first uncertain figure
ii. Then the result must have no decimal places than the number with the least decimal places
iii. The addition or subtraction is performed with the numbers as given
iv. Then rounded up from 5 or down from 4

e.g.

$$\begin{array}{r} 32.2187 \\ +\ 126.3 \\ +\ 3.132 \\ \hline 161.6507 \end{array}$$

This is rounded up (0.65 to 0.7) to 161.7 because the number 126.3 is given to only one decimal place.

$$\begin{array}{r} 3052.3 \\ -\ 235 \\ \hline 2817.3 \end{array}$$

This is rounded down (0.3 to 0) to 2817 because the number 235 is given to the nearest whole number.

**Multiplying an Subtracting Raw Data:**

i. Perform using the best estimate values
ii. Add the individual relative or percentage uncertainties to find the relative or percentage uncertainty in the product or quotient
iii. To find the value for the uncertainty, the percentage or proportional uncertainty is used.

**Rule: (A ± εA) / (B ± εB)**

**= (A / B) ± (εA + εB) (A ± εA) x (B ± εB)**

**= (A x B) ± (εA + εB)**

e.g.

$$(50.6 \pm 0.8) \times (123.63 \pm 0.91)$$

Multiply the best estimates: $50.6 \times 123.63$

$$= 6255.678$$

Find the percentage uncertainties for each number:

$$= \frac{0.8}{50.6} \times \frac{100}{1}\% \quad \text{and} \quad = \frac{0.91}{123.63} \times \frac{100}{1}\%$$

$$= 1.581\% \qquad\qquad = 0.736\%$$

Add the percentage uncertainties:

$$= 1.58\% + 0.736\%$$
$$= 2.371\%$$
$$= 2.3\% \text{ by convention}$$

The product can be given as (6255.68 ± 2.3)%, but this hides a problem. The product has far more significant figures than the individual raw data numbers from which it was calculated. That is, the derived quantity is claimed to be more accurate than the raw data from which it was derived! That cannot be.

Let us look at the actual value of the uncertainty:

$$2.3\% \text{ of } 6255.68 = 143.88$$

The result could now be reported, inaccurately, as (6255.68 ± 143.88). The result, 6255.68, is shown to be uncertain in the hundreds column. Using standard form to express the significant figures, the result should now be written, correctly, as:

$$(6.2 \pm 0.1) \times 10^3$$

As long as the raw data measures what is intended, this is an accurate and precise statement of the derived quantity. Notice, however, that the derived quantity has 2 significant figures. This is less than the number of significant figures in the number with the least significant figures, namely 50.6 (3 significant figures). The number of significant figures in a derived quantity is always equal to or less than the number of significant figures in the least precise piece of raw data. In experiments, physicists try to ensure that uncertainties in the raw data do not accumulate to the point where derived quantities become meaningless. This takes high-level thinking, planning and effort.