

## Error analysis in chemistry

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A large part of work in studying Chemistry is based on scientific evidence, accumulated through laboratory work. Inherent in all such work are certain assumptions and errors. An essential part of interpreting scientific data is therefore an ability to consider the extent to which a certain result may be compromised by the specific errors present. Broadly the types of error which arise in chemistry experiments are:

### **Systematic errors (determinate)**

- These errors are due to identifiable causes.
- They are likely to give results which are consistently too high or consistently too low
- Sources of systematic errors can usually be identified  
e.g. solubility of a gas when collected over water
- Systematic errors can in principle be eliminated or at least ameliorated by modifications to the experiment

### **Random errors (indeterminate)**

- These errors generally arise from the limit of accuracy of the apparatus.
- They arise from fluctuations that cause about half the measurements to be too high and about half to be too low.
- Sources of random errors cannot always be identified. Possible sources:
  - a) observational e.g. reading burette, judging a colour change
  - b) environmental e.g. convection currents
- Random errors can generally not be ameliorated
- Random errors can be quantified.

The random error is equivalent to the uncertainty in measurement. This is usually given by the manufacturer of the equipment and expressed as  $\pm$  a certain value. If this information is not available, a good guideline is:

- a) for analogue equipment the uncertainty =  $\pm$  half the smallest scale division
- b) for digital equipment the uncertainty =  $\pm$  the smallest measure (the least count)

Note when the uncertainty is recorded, it should be to the same number of decimal places as the measured value. For example a balance reading to 53.457g  $\pm$  0.001

## Propagation of uncertainties

The overall uncertainty arising in an experiment is determined by the manner in which the data values and their associated uncertainties are processed. This is known as propagation of uncertainties through the calculation.

*The principle is that the overall uncertainty is the sum of the absolute uncertainties.*

When values are being added or subtracted, the uncertainties associated with them must be added together:

$$\begin{aligned} \text{e.g. initial temperature} &= 20.1^\circ \text{ C} \quad \pm 0.1 \\ \text{final temperature} &= 27.9^\circ \quad \pm 0.1 \end{aligned}$$

$$\Rightarrow \text{temperature change} = 27.9 - 20.1^\circ \text{ C} = 7.8^\circ \text{ C} \pm 0.2$$

In experiments where values are being multiplied or divided, and / or when there are several measurements made - each with its own uncertainty, the absolute uncertainties must be expressed as percentage uncertainties. These can then be added together, and finally converted back into absolute uncertainties.

$$\begin{aligned} \text{e.g. mass reading} &= 5.456 \text{ g} \pm 0.001 \\ \% \text{ uncertainty} &= 0.001 / 5.456 \times 100 = 0.0183 \% \end{aligned}$$

$$\begin{aligned} \text{temperature reading} &= 27.8^\circ \text{ C} \pm 0.2 \\ \% \text{ uncertainty} &= 0.2 / 27.8 \times 100 = 0.7 \% \end{aligned}$$

$$\Rightarrow \text{total uncertainty} = \text{sum of \% uncertainties} = 0.0183 + 0.7 = 0.72 \%$$

So if the answer is 55.8 J, then the total uncertainty =  $0.72 / 100 \times 55.8 = 0.40 \text{ J}$   
 $\therefore$  final answer = 55.8 J  $\pm 0.4$

## Experimental error

The difference between the experimental and theoretical results.

$$\% \text{ error} = \frac{\text{experimental result} - \text{theoretical result}}{\text{theoretical result}} \times 100$$

When the final uncertainty arising from random errors is calculated, this can then be compared with the experimental error as described above. If the experimental error is larger than the total uncertainty, then random error alone cannot explain the discrepancy and systematic errors must be involved.