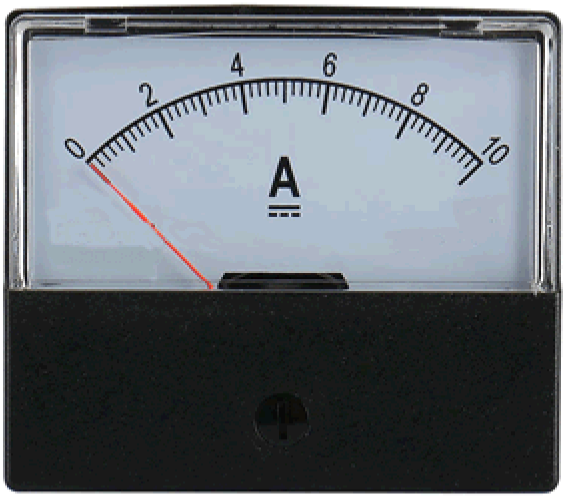
# Instrument resolution





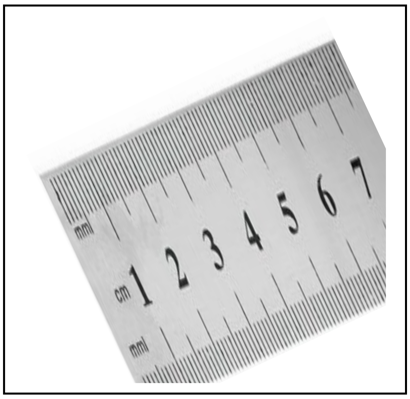

Peter Razos

Before we get into discussing quantitative measurements in chemistry it is important to understand and be familiar with the following terms as they appear in the 2023-2027 VCAA Chemistry study design. When analysing and discussing investigations of a quantitative nature, the following terms require consideration:

- **True value:** The value that would be found if the quantity could be measured perfectly.
- **Accuracy:** A measurement value is considered to be accurate if it is judged to be close to the true value of the quantity being measured. Accuracy is a qualitative term; a measurement value or measurement result may be described, for example, as being 'less accurate' or 'more accurate' when compared with a true value.
- **Precision**: A measure of the repeatability or reproducibility of scientific measurements and refers to how close two or more measurements are to each other. A set of precise measurements will have values very close to the mean value of the measurements. Precision gives no indication of how close the measurements are to the true value and is therefore a separate consideration to accuracy.
- **Measurement result**: Refers to a final result, usually the average of several measurement values. In the (unusual) case where only one value has been measured, then measurement result also applies to that single measurement value.
- **Repeatability:** The closeness of the agreement between the results of successive measurements of the same quantity being measured, carried out under the same conditions of measurement. These conditions include the same observer, the same measurement procedure, the same measuring instrument used under the same conditions, the same location, and replicate measurements on the same or similar objects over a short period of time. Experiments that use subjective human judgement(s) or that involve small sample sizes may yield results that may not be repeatable. Repeatability can be used to evaluate the quality of data in terms of the precision of measurement results. Ideally, measurements should be repeated where possible to produce a measurement result.
- **Reproducibility:** The closeness of the agreement between the results of measurements of the same quantity being measured, carried out under changed conditions of measurement. These changed conditions, involving replicate measurements on the same or similar objects, include a different observer, different method of measurement, different measuring instrument, different location, different conditions of use and different time. The purposes of reproducing experiments include checking of claimed precision and uncovering of any systematic errors that may affect accuracy from one or other experiments/groups. Experiments that use subjective human judgement(s) or that involve small sample sizes or insufficient measurements may also yield results that may not be reproducible. Reproducibility links closely to the accuracy of an experiment. Reproducibility can also be used to evaluate the quality of data in terms of the precision of measurement results.
- **Resolution:** The smallest change in the quantity being measured that causes a perceptible change in the value indicated on the measuring instrument. This has implications for determining the number of decimal places to which a quantity may be quoted. For example, if the measurement scale on a 50 mL burette is at 0.1 mL intervals, the resolution of the burette is said to be 0.1 mL. In a titration, the user must estimate the volume between the two marked intervals on the burette so that the value reported will be to two decimal places. For example, measurement readings of 10.50 mL or 10.55 mL are possible, but a measurement reading of 10.53 mL cannot be claimed. The meniscus of the liquid will either be on the burette line marking, in which case the reading would be 10.50, or it will lie between 10.50 and 10.60, in which case it is measured as 10.55 mL
- **Validity:** A valid experiment investigates what it sets out and/or claims to investigate. Both experimental design and the implementation should be considered when evaluating validity. An experiment and its associated data may not be valid, for example, if the investigation is flawed and controlled variables have been allowed to change. Data may not be valid, for example, if there is observer bias.

**Resolution** of analogue equipment, is the smallest increment on an instrument's scale that can be read directly. In other words, the smallest division marked on the instrument.

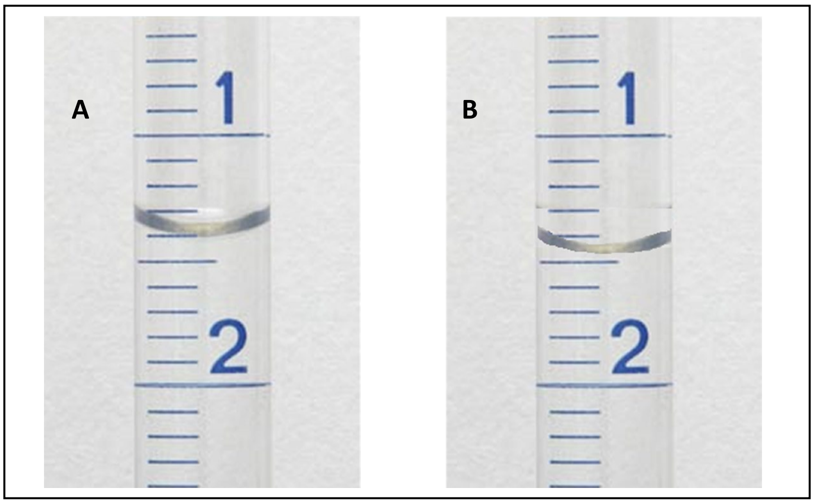
For example, consider the instruments shown below






The ruler has gradations of 1mm hence its resolution is 1mm
The smallest gradation on the burette is 0.1mL hence the resolution is 0.1mL
The smallest gradation on the ammeter is 0.2A. Has the resolution is 0.2A.

This has implications for determining the number of decimal places to which a quantity may be quoted. For example, if the smallest increment on a 50 mL burette scale is 0.1 mL, the resolution of the burette is said to be 0.1 mL. The operator is then free to estimate one more decimal place and record the reading to 2 decimal places. This also increases the significant figures the result is expressed to. The estimate is usually ½ the resolution, in this case, 0.05mL.




For example, measurement reading of burette A, shown above, 1.40 mL. The meniscus is right on the 1.4mL mark and the operator estimates the second decimal place. In this case it is 0, so we can record this as 1.40 mL. Burette B, however, has the meniscus between 1.4 mL and 1.5 mL. In this case the estimation must half way between 1.4 and 1.5 and so it is recorded as 1.45 mL. A reading of 1.46 mL cannot be claimed. The meniscus of the liquid will either be on the burette line marking, in which case the reading would be 1.40, or it will lie between 1.40 and 1.50, in which case it is measured as 1.45 mL.

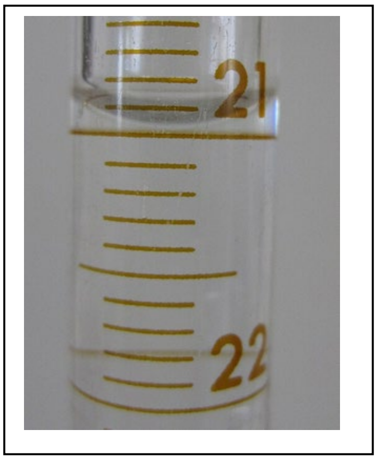
Bellow is a summary of the impact of resolution on uncertainty, validity, accuracy, precision and significant figures.

| Concept | Effect of *High Resolution* | Effect of *Low Resolution* (large increments, fewer decimals) |
|---|---|---|
| **Uncertainty** | Smaller ± uncertainty (analogue: ±½ division; digital: ±1 last digit). | Larger ± uncertainty because each reading is rounded more. |
| **Accuracy** | More accurate: rounding error is reduced (readings closer to true value.) | Less accurate: rounding error larger (readings may be noticeably off the true value.) |
| **Precision** | True precision visible small differences between repeats can be detected. | False precision possible repeated readings may look identical because variation is hidden by rounding. |
| **Validity** | Valid for measuring small quantities or fine changes. | May be invalid if the quantity is smaller than the resolution (instrument cannot resolve the value). |
| **Significant Figures** | Allows more sig. figs to be reported legitimately. | Limits the sig. figs results must be rounded to match the instrument. |

Example 1

What is the correct recorded reading of the burette shown on the right?

*The bottom of the meniscus rests between 20.9 mL and 21.0 mL. Hence the recorded reading should be 10.95  mL. Four significant figures.*




Example 2

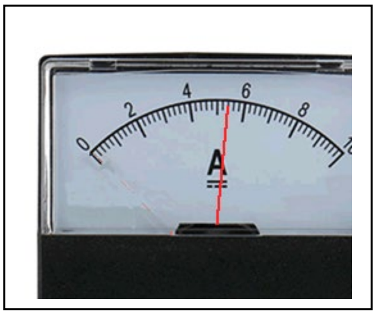
What is the correct recorded reading of the burette shown on the right?

*The bottom of the meniscus rests between 40.00 mL and 40.10 mL. Hence the recorded reading should be 40.05  mL. Four significant figures.*


Example 3

What is the resolution and the correct recorded reading of the ammeter shown on the right?

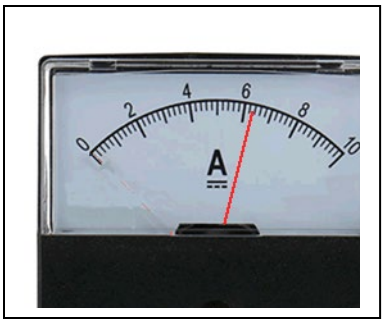
*The smallest gradation on the printed scale is 0.2A. So the resolution is 0.2A. The needle is right on the 5.4 mark. Hence the recorded reading should be 5.4 A.  Two significant figures.*




Example 4

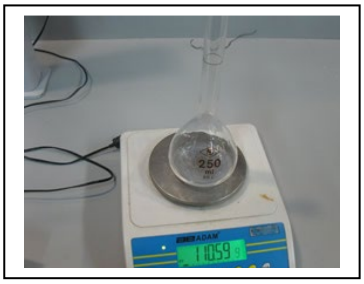
What is the resolution and the correct recorded reading of the ammeter shown on the right?

*The smallest gradation on the printed scale is 0.2 A. So the resolution is 0.2A. The needle is between 6.2 A and 6.4 A. Hence the recorded reading should be 6.3 A. The reading is derived by the operator by reading the scale 6.2 A and estimating a 0.1 (half the resolution) increment between the 6.2 and 6.4. Two significant figures*



When dealing with digital equipment, resolution is the value represented by the smallest change in the last digit on the display. No estimation is possible . The device chooses the decimal place for you.
The electronic scale pictured on the right has a resolution of 0.1g as that is the last digit on the display.


The electronic balance on the right has a higher resolution of 0.001 g, as shown on its display. Because it can detect smaller changes in mass, all readings are recorded to three decimal places. This increases the number of significant figures in each measurement and therefore provides a value in which we can have greater confidence.


Example 5

What is the resolution of the electronic balance shown on the right?

*The last digit is 0.01g hence the resolution of the electronic balance is 0.01g. The reading is given, in this case, to 5 significant figures (110.59g)*

Example 6

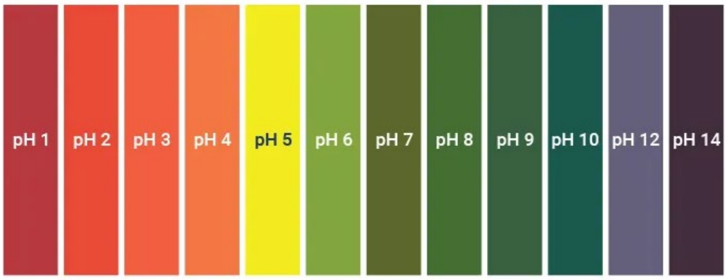
A student needs to measure 0.0115 g of an *unknown powdered sample*.
Two electronic balances are available:

- Balance A, gave the following readings
  Readings - 0.0114 g, 0.0115 g, 0.0116 g
- Balance B, gave the following readings
  Readings - 0.01 g, 0.01 g, 0.01 g

a) What is the resolution of each balance? *Balance A 0.0001g Balance B 0.01g*
b) Which balance appears more precise based on the numbers alone?
*Balance B gives four consistent results of 0.01g so based on numbers alone the results are more precise than balance A.*
c) Which balance actually gives a more valid measurement?
*Balance A gives the valid measurement. Its readings fluctuate slightly around 0.0115 g and its resolution is high enough to detect this mass. In contrast, rounding to two decimal places means that any actual mass between 0.0100 g and 0.0149 g would be recorded as 0.01 g, making Balance B's results appear precise but invalid because they do not represent the true mass of the powder*

# Indicators and pH metres

A pH meter provides a numerical reading, typically with a resolution of 0.01–0.001 pH units, giving much higher precision than an indicator, which can only estimate pH within a wide colour-change range. Indicators rely on a subjective colour judgement, introducing observer bias and reducing the reliability and repeatability of the measurement.




Universal indicator colour range

A calibrated pH meter minimises subjective bias and provides more accurate and consistent readings. Because a pH meter directly measures hydrogen ion activity, it generally has greater validity in determining the true pH of a solution. Indicators are less valid in strongly coloured, cloudy or very dilute solutions, or when the pH falls near the edge of the indicator's transition range. A pH meter therefore improves both validity and precision by removing colour matching errors and operator interpretation.

1. Consider the digital balance shown on the right.
   a. What is the resolution of the balance?

   b. What is the error in each reading?

   c. Explain how this resolution affects the precision and accuracy of mass measurements.


2. The true mass of a sample is 12.00 g, but the balance consistently reads 12.11 g. Which statement is most correct. Explain

a. The accuracy can be improved by using a digital balance with a resolution of 0.0001g

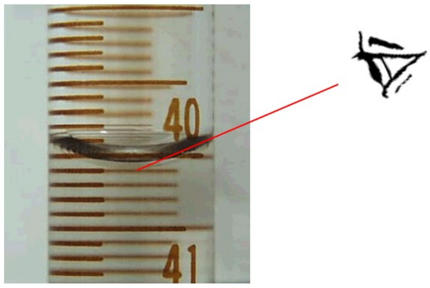
b. The accuracy can be improved if the balance was properly zeroed and calibrated.

c. The accuracy is low due to a random error which can be eliminated by using a digital balance with a lower resolution, such as 0.1g.

d. The resolution of the digital balance can be increased by proper calibration.

3. The burette in the picture has graduations marked every 0.1 mL. A student records a titre of 40.100 mL.
a. What is the resolution of the burette?

b. Is the recorded value appropriate for this resolution? Explain.




c. Is the titre accurate? Explain

4. A student weighs a sample of NaOH three times and gets 25.21 g, 25.20 g, 25.21 g. The sample shown on the right is slightly moist as it absorbs moisture from the air.

a. Comment on the precision of these readings.

b. Is this a valid result from which to calculate the mol of NaOH? Explain.

5. A digital balance in the picture only reads to the nearest 0.1 g.
A student uses this equipment to weigh a 0.150 g sample.

Explain why low resolution reduces precision and may reduce confidence
in the measurement.


______________________________________________________________

______________________________________________________________

______________________________________________________________

6. Two students performed titrations to determine the amount of acetic acid in a brand of commercial vinegar. Each student recorded three concordant results. The vinegar was titrated against a standard 0.0100M NaOH. Each student used a different burette. Below are their results.

- Experiment 1: 34.0 mL, 34.0 mL, 34.0 mL
- Experiment 2: 33.95 mL, 34.00 mL, 34.05 mL

a. Which experiment shows a higher resolution?

b. Which experiment is more precise? Explain

______________________________________________________________

______________________________________________________________

______________________________________________________________

c. Which experiment is more valid ?

______________________________________________________________

______________________________________________________________

______________________________________________________________

d. Which results are more accurate if the literature average titre of a 0.0100 M NaOH is 34.02mL?

______________________________________________________________

______________________________________________________________

______________________________________________________________