

Measuring devices: resolutions used to estimate errors

- You can **estimate** the error generated by measuring quantity as **plus or minus half the resolution** of the instrument
- For example, a tape measure used to make a plan of a crime scene measures to the nearest 10cm, so the estimated absolute error from using that tape measure is going to be 5cm.
- Below are some devices used for measuring lengths – we will need those for the blood spatter pattern practical – and angles
- See if you can complete the table!

Device	Resolution	Error	Systematic?	Typical length range	Relative error (illustrative)
10m tape measure	10cm	±5cm	Damage to end? Not straight?	10 metres by definition!	$\frac{5}{1000} \times 100 = 0.5\%$
30 cm ruler	1 mm		Physical damage to scale?		
Vernier calipers	0.1 mm		KPB finds he needs glasses to read the scale!		
Screw micrometer gauge	0.01mm		Zero error can be calibrated		

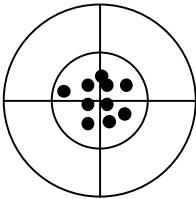
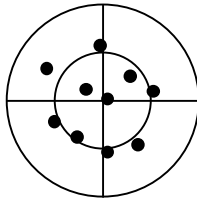
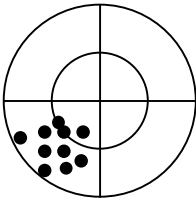
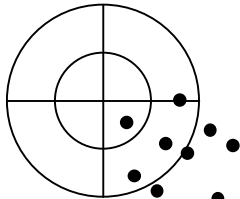
- A protractor is usually used to measure angles. The steepest angle that a blood drop can make to the ground is 90 degrees, and small protractors measure to the nearest degree – so you have a percentage or relative error of $\frac{0.5}{90} \times 100 = 0.56\%$.
- My *guess* is that we might get lower errors on the angle measurements by measuring the length and height of the sample of surface used to drop the blood drop onto for each height – but I could be wrong, *especially* for small heights...
- If you used a 30 cm ruler to measure the height of the sample board above the lab table, what height in cm would correspond to a *relative* error of 0.5%?
- If you decided to use a protractor to measure the angle, what kinds of **systematic error** might be creeping in?
- You can use relative errors or percentage errors estimated from the resolutions of the various devices to **compare measurements** even when the *quantities* you are measuring are different (length, angle).

Accuracy and precision

Precision is a word used to say how *fine* the measurement is – how fine the divisions on the ruler scale.

Accuracy is the word used to say how close to the true value the measurement is - so we can never know the true accuracy!

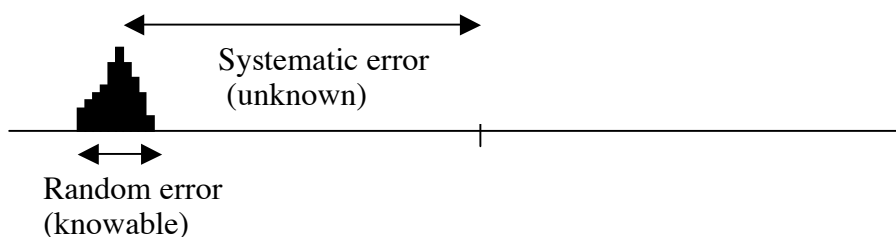
Just about every Physics lab manual I have ever seen has a drawing something like the one below showing how **accuracy and precision relate together** when you take a series of measurements.... Imagine a series of four dart boards...

	High precision	Low precision
High accuracy		
Low accuracy		

Comment 1: in a real measurement, **you don't know where the bulls eye is!** You don't know the 'true value'.

Comment 2: To see how *precise* your measurements are, you may have to repeat the measurements a number of times and see how the values vary. The analysis of repeated measurements gives rise to statistical concepts in a natural way – which is why half this Unit is about statistics.

Comment 3: Look at the High Precision, Low Accuracy dartboard. Imagine that you sliced the board along a line at 45 degrees through the centre and drew a bar chart to show how many points were a given distance from the bulls eye. You might get something like this...



Kinds of errors

When you measure something (say the length and width of a room), your measurement will have some level of error. Errors can come from a variety of sources

- The tape measure you use to measure the width of the room may not be laid flat along the floor
- The tape measure may not be at right angles to a wall
- The tape measure may have a damaged end, so the starting point of the tape may not be zero
- Someone might read the scale on the tape measure incorrectly and add a metre to the length (say)
- Someone might not line the marks on the tape measure scale with the wall properly

Some kinds of error can be minimised by taking a number of readings and averaging out the results. These kinds of error are called **random errors**.

Some kinds of error will always affect your results, no matter how many times you repeat the measurements. These kinds of error are called **systematic errors**.

A third kind of error might be called **gross error** - caused by misuse of the instrument. Gross errors are difficult to quantify and are usually avoided by practice and by checking results against manuals.

Random errors can be handled using statistical procedures. Systematic errors are harder to cope with and you might not realise that they are present. A lot of experimental design is to do with eliminating systematic error.

Resolution and random errors

A 30cm ruler usually has a mark on the scale at each 1mm division. You can say that the ruler has a resolution of 1mm – it can't read anything finer than that unless you want to try to estimate. If you lined up 20 people and got them all to measure a line drawn on a piece of paper using the same ruler, you would probably get 20 similar results – there would be no random error apparent given the poor resolution of the ruler.

If you repeated the exercise using a micrometer gauge to measure the diameter of a ball bearing, you would get 20 slightly different results. A micrometer gauge has a resolution of 0.01 mm – and the way people use the micrometer (and variations on different diameters of the ball bearing) would lead to differences larger than 0.01mm. In this second case, the resolution of the instrument is fine enough to show variation due to random errors.

Absolute and relative error

Absolute error is the error in units of the measurement – suppose you knew that a steel rod was really 10 cm long but someone measured the rod as being 9.8 cm long. The absolute error on the measurement would be 0.2 cm.

Relative error is the error expressed as a percentage of the measurement. In the example above, the relative error would be $\frac{0.2}{10} \times 100 = 2\%$ or as a formula...

$$\frac{\text{error}}{\text{true value}} \times 100$$

The catch is that we don't know what the true value is. We can **use the measured value as an approximation to the true value** to get a rough estimate of the relative error.

The relative error depends on the length (or other quantity) you measured. So if you use a ruler to measure a short length (say the bands on an electrophoresis gel) you will get a large relative error. Moral: choose instruments that suit the length (or other quantity) and that give you a balanced relative error.

Questions

- 1) Complete the following table

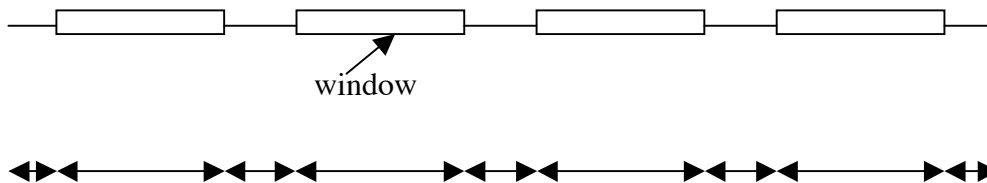
Measurement	Error	Relative error
50 cm	2 cm	
35 mm	1 mm	
85 mm		3%
95 cm		0.5%

- 2) You measure a gel electrophoresis band with a 30 cm ruler which has an error of 1 mm. If the band is measured as 14 mm from the well, what is the percentage error?
- 3) Suspect substances are tracked to 5 decimal places according to Home Office regulations. If a sample of white powder has a weight of 15.23562g what is the relative error on this measurement?

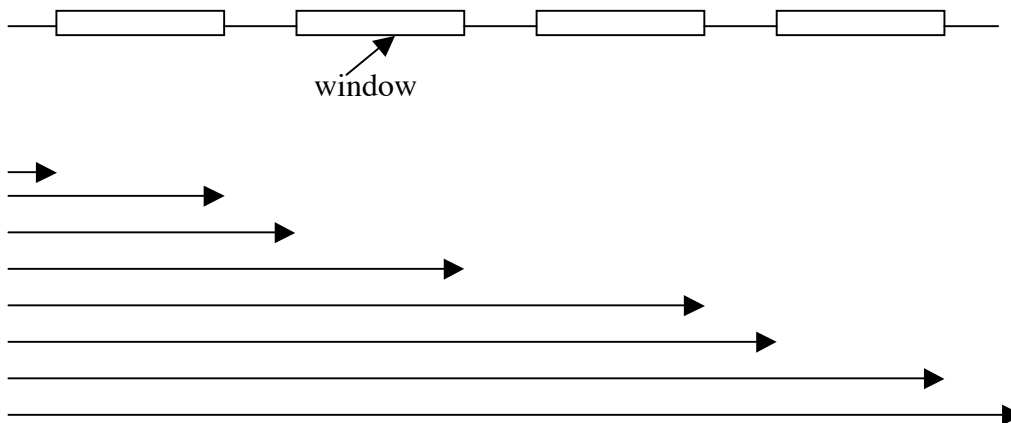
A bit of an exercise

Two scene of crime officers (who for the sake of this exercise will be referred to as Paul and Malcolm) have to measure the positions of windows in a crime scene room.

One officer favours the measurement plan below...



The other favours an alternative plan...



Which scheme for measuring is likely to give the best accuracy for the plan?

Can you say why?

Combining errors

- When you need to calculate a quantity from two or more measurements you can also calculate an **estimated error** for the answer
- There are sophisticated formulas for **combining errors** according to the calculation you have to do on the data – search on ‘combining experimental errors’ on the Web if you are curious
- For this unit, we shall adopt a **much simpler method** based on using the lowest possible value, the estimated value and the highest possible value for each of the measurements.
- The **resulting error bound is much wider than it should be** as we are assuming that independent measurements will all be at the lowest possible value (say) when the chances of that happening are actually quite small

Example: volume of a darkroom

Photographic darkrooms need ventilation to remove the (relatively small amount) of fumes that are generated by the photographic chemicals when processing prints.

To calculate the size of fan needed, you would need to know the volume of the darkroom. Suppose the room was cuboid in shape and about 5 metres long, 2 metres wide and 2.5 metres high, and suppose these measurements have an error of $\pm 10\text{cm}$.

$$vol = length \times breadth \times height$$

The table below helps set out the calculation...

	length / m	breadth / m	height / m	volume / m ³
smallest	4.9			22.34
estimated	5.0	2.0	2.5	25
highest	5.1			