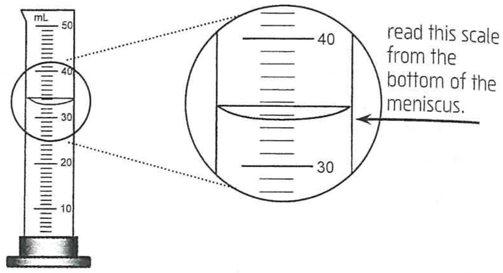


Figure 8 The smallest divisions on this scale are 1 mL. It is reasonable to read it to within 0.5 ml, ie half the smallest division. As the divisions are quite large you may choose to measure to within 0.1 ml, ie 1/10th the smallest division. Thus, at best the volume in this measuring cylinder could be recorded as 33.7 mL or 33.8 mL. The last digit is known to have some uncertainty. It is **not** appropriate to record 33.75 mL as this indicates a higher precision than is available from this scale.

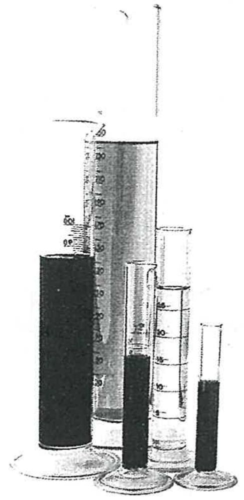
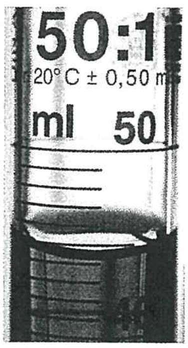


Figure 9 Scale division size and hence the random error varies with the size of a measuring cylinder. Typically, larger cylinders have larger scale divisions and hence larger random errors.

To minimise random errors in experimental work choose the most precise instrument that is practical for the task. When measuring volumes of 10 mL or less use a 10 mL measuring cylinder, not a 50 mL or 250 mL cylinder as these have a greater inherent random error. Only use larger cylinders as appropriate, eg for measuring 30 mL, a 50 mL measuring cylinder may be suitable but not a 10 mL or 250 mL measuring cylinder.

Notice the reference temperature, **20 °C** and random error, **±0.5 mL** (half the 1 mL graduations) shown on this 50 mL cylinder.



Attempt Set 7 # 2 and 3.

Every digit in a measurement, including the final uncertain one is a **significant figure**. The more significant figures there are in a measurement, the greater the precision. (See Example 3.) Table 1 shows the typical precision offered by some measuring cylinders.

Sometimes the inherent random error present in the measurements from an instrument are expressed as a **plus or minus**, ± amount. This indicates the actual measured amount could be higher or lower than the recorded value by the ± amount. (See Table 1.) For instruments with a scale the random error is usually ± half the smallest scale division, for a digital display instrument it is ± half the value of the last digit displayed. As well as quoting the random error, all measuring cylinders also quote a **temperature**, usually 20 °C, at which the measurements should be made. If the measuring temperature varies significantly from this then a systematic error will be introduced into the measurements. Random errors are minimised by using the most precise instrument that is practical for the task. (See Fig 9.)

Table 1 Random error and recording measurements for a variety of measuring cylinders

Measuring cylinder	Smallest scale division	Random error as ±	Measurement examples	
			Using significant figures only	Including ± random error
10 mL	0.1 mL	± 0.05 mL	3.45 mL 7.80 mL	3.45 mL ± 0.05 mL (ie 3.40-3.50 mL) 7.80 mL ± 0.05 mL (ie 7.75-7.85 mL)
50 mL	1 mL	± 0.5 mL	15.5 mL 42.5 mL	15.5 mL ± 0.5 mL (ie 15.0-16.0 mL) 42.5 mL ± 0.5 mL (ie 42.0-43.0 mL)
250 mL	2 mL	± 1 mL	153 mL 227 mL	153 mL ± 1 mL (ie 152-154 mL) 227 mL ± 1 mL (ie 226-228 mL)

Example 3	A student used three different digital mass balances to measure the mass of the same zinc granule. The values she recorded were 20.670 g, 20.7 g and 21 g. Comment on the **precision** and ± **random error** in each of the balances used.
Measurement	**Comment**
20.670 g	The recorded mass has five significant figures and so is the most precise measurement. The balance used is capable of measuring to one thousandth of a gram and has a random error of ± 0.0005 g, ie half the value of the last displayed digit.
20.7 g	The recorded mass has three significant figures. This balance is capable of measuring to one tenth of a gram with a random error of ± 0.05 g.
21 g	The recorded mass has two significant figures and is the least precise result. The balance can read to 1 g and has a random error of ± 0.5 g.

5.5 Processing data and significant figures

When processing data from an investigation it is important to be aware of the number of significant figures in the measurements being processed. The following rules are used to count the number of significant figures (SF) in a measurement:

① All **non-zero** digits are significant, eg 7.92 (three SF). (**See border note at left.**)

② Zeros **between** two significant digits are significant, eg 60.3 (three SF), 9.0002 (five SF).

③ Zeros **before** the first non-zero digit are not significant, eg 0.35 (two SF), 0.009217 (four SF).

④ Zeros at the **end** of a number and **after** the decimal point are significant, eg 3.500 (four SF), 0.0710 (three SF).

⑤ Zeros at the **end** of a number and **before** the decimal point are not significant unless otherwise indicated, eg 3500 (two SF). If these zeros are significant then scientific notation can be used to show this, eg 3.500×10^4 (four SF), 3.50×10^4 (three SF) or 3.5×10^4 (two SF).

Zeros!
The **non-zero** digits in a measurement are **always** significant but zeros **may** be significant.

Key: significant zero's 0
not significant zero's....... 0

1**00**819.5**0**4	②
0.181954	③
0.00181954	③
181954.**0**	④
181954.**000**	④
181954**0**	⑤
181954**000**	⑤
181954.**0**	④
181954**000.0**	② and ④

Example 4 How many significant figures are present in each of the following volume measurements?		
7.08×10^3 mL	**three** significant figures	see rule ① and ②
7.800×10^3 mL	**four** significant figures	see rule ① and ④
7.0800×10^3 mL	**five** significant figures	see rule ①, ② and ④
0.758 mL	**three** significant figures	see rule ① and ③
0.0708 mL	**three** significant figures	see rule ①, ② and ③
780 mL	**two** significant figures	see rule ① and ⑤

Exact numbers are those which contain no uncertainty. Some examples include the number of protons in an oxygen nucleus is exactly 8, the coefficients of a balanced equation or the subscripts in a formula.

Attempt Set 7 # 4, 5 and 6.

Data collected in an investigation often needs to be processed in order to calculate the value of some variable of interest. When this is done, the calculated result **must not** be more precise than the measured data used to calculate it. For a calculation that requires **multiplication** or **division**, the answer is given with as many significant figures as the measurement with the **least number** of significant figures.

Example 5 Evaluate the following and give the answer to the correct number of significant figures.	
a. $1.498 \text{ g} \div 6.2 \times 10^{-1}$ L = $2.416129 \text{ g L}^{-1}$ = 2.4 g L^{-1} (2SF)	This calculation involves division so the answer only has as many SF as the number with the least SF. As 6.2×10^{-1} L has the least SF (two) so the answer is rounded to two significant figures even though 1.498 g has four SF.
b. $\dfrac{1.04 \text{ g} \times 7.000}{12.01 \text{ g mol}^{-1}}$ = 0.6061615 = 0.606 mol (3SF)	This calculation involves multiplication and division so the answer only has as many SF as the number with the least SF. As 1.04 g has the least SF (three) so the answer is rounded to three significant figures even though 7.000 and 12.01 both have four SF.

Important note to students:
The Current SCASA year 12 Examination design brief for use in 2016 refers to the use of significant figures in the following way. 'Numerical answers should be expressed to the **appropriate number of significant figures** and include units where applicable.'

Students would be advised to check the current requirements regarding numeric answers and significant figures closer to the time of their examination.

Attempt Set 7 # 7.

Sometimes a calculation will require **addition** or **subtraction** of data values. In this case, the answer is quoted with as many **decimal places** as the measurement with the least number of decimal places. When counting decimal places, the measurements must be expressed with the **same powers of ten**. See Example 6.

Example 6 Evaluate the following and quote the answer to the correct number of decimal places (DP).	
a. 1.49×10^2 g + 6.2 g = 149 g + 6.2 g = 155.2 = 155 g (0 DP)	This calculation involves addition so the answer only has as many DP as the number with the least DP. As the measurement 1.49×10^2 g has the least decimal places (nil) when written to the same powers of ten as 6.2, ie 1.49×10^2 g becomes 149 g so the answer has nil decimal places.
b. 7.5530×10^3 L - 6.790 L = 7553.0 L - 6.790 L = 7546.21 L = 7546.2 L (1 DP)	This calculation involves subtraction so the answer only has as many DP as the number with the least DP. Using the same powers of ten, the numbers are 7553.0 and 6.790. Thus 7553.0 has the least decimal places (one, when expressed with the same powers of ten) so the answer is rounded to one decimal place.

Complete Set 7.

Worksheet 4.5

Precision, accuracy and significant figures

NAME: **CLASS:**

INTRODUCTION

For a quantity to have an exact value, it must either be defined or obtained by counting. All measured quantities have an **inherent uncertainty** because all instruments used to make measurements have limitations, and the people operating the instruments have varying skills.

The **accuracy** of a measurement is an expression of how close the measured value is to the 'correct' or 'true' value. The **precision** of a set of measurements refers to how closely the individual measurements agree with one another. Thus, precision is a measure of the reproducibility or consistency of a result.

The precision of measurements is sometimes expressed as an **uncertainty** using a plus/minus notation to indicate the possible range of the last digit. An alternative method is to indicate the certainty of the measurement by the use of **significant figures**.

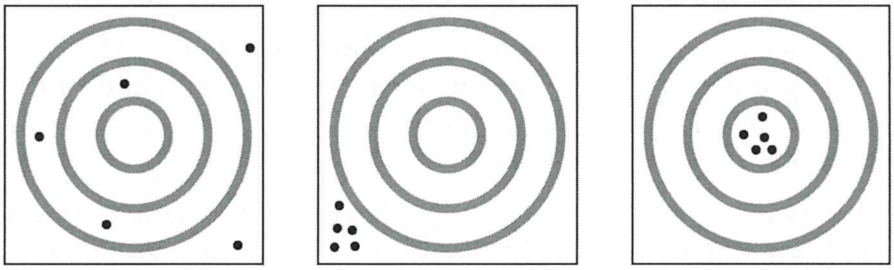
To clarify the number of significant figures in a measurement, the value may be written in **standard form**. A number written in standard form is expressed as a number greater than 1 but less than 10, multiplied by 10^x, where x is an integer.

When a calculation involves multiplication and division, the result should have the same number of significant figures as the factor with the least number of significant figures. For addition and subtraction calculations, the result should have the same number of decimal places as the number used with the fewest decimal places. In most calculations you will need to **round off** numbers to obtain the correct number of significant figures.

No.	Question	Answer
1	Which of the following quantities would have an inherent uncertainty? **A** The number of pages in your textbook **B** Your measured height (in cm) **C** The number of mL in 6.0 L **D** A volume of liquid measured using a pipette	

Precision, accuracy and significant figures

2	Shooting targets may be used as an analogy to show the ideas of precision and accuracy in measurements. Label each of the shooting targets below as representing one of the following situations: **N** for neither accuracy nor precision **B** for both precision and accuracy **P** for precision, but inaccuracy.	
3	Why are measurements in experiments often repeated several times and the results averaged?	
4	State the number of significant figures in each of the following measured quantities. **a** A temperature reported as 26.1°C **b** A burette reading of 32.34 mL **c** A mass reading of 0.0471 g **d** A time recorded as 6.000 s	
5	Express each of the following numbers in standard form, ensuring you use the correct number of significant figures. **a** 140.7 **b** 5005 **c** 980.0 **d** 0.0075	
6	Round each of the following numbers to 3 significant figures, and express in standard form. **a** 7.8001 **b** 600.4 **c** 98.345 **d** 0.000600	
7	Express the number 6000 in standard form to show that it contains: **a** 1 significant figure **b** 4 significant figures	



a b c

8	Calculate each of the following and express the answers to the correct number of significant figures. **a** 5.6×120 **b** 0.0045×67.1 **c** $0.046 \div 0.023$ **d** 63×7.06	
9	Perform the following calculations and round off the answers to the correct number of significant figures. **a** $3.256 + 45.2 - 3.815$ **b** $12.13 + 342.0 + 4.108$	
10	A dozen eggs have a mass of 722 g. What is the average mass of the eggs?	

Worksheet 4.5: Solutions

Precision, accuracy and significant figures

No.	Answer
1	**B** and **D**. Measured quantities have an inherent uncertainty.
2	**a** N **b** P **c** B
3	Averaging a set of results reduces the effects of random errors associated with taking measurements.
4	**a** 3 **b** 4 **c** 3 **d** 4
5	**a** 1.407×10^2 **b** 5.005×10^3 **c** 9.800×10^2 **d** 7.5×10^{-3}
6	**a** 7.80 **b** 6.00×10^2 **c** 9.83×10^1 **d** 6.00×10^{-4}
7	**a** 6×10^3 **b** 6.000×10^3
8	**a** 6.7×10^2 **b** 0.30, or 3.0×10^{-1} **c** 2.0 **d** 4.4×10^2
9	**a** 44.6 **b** 358.2
10	$\frac{722}{12} = 60.2$ g The answer should be given to 3 significant figures. The 12 is an exact number and is therefore not relevant to the significant figure count.