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1. Number and algebra / 1.6 Approximation

The big picture

Quantities such as length and time can be measured using varying degrees of accuracy.

Think about what is wrong or unusual in each of the situations described below.

- A hairdresser asks a customer before a haircut, 'What length would you like me to cut off?' The customer replies, '4.26 cm.'
- A car's satellite navigation (satnav) system tells the driver, 'Continue along this road for 2.74615 km and then turn right.'
- A 100 m race takes place at a top international athletics competition. After the race, the athletes' times are displayed to the nearest second. They are all 10 s.
- Air traffic control is guiding an aeroplane into an emergency landing. The controller asks the pilot, 'What is your current altitude?' The pilot replies, 'We are 105 m above the ground, plus or minus 1050 m or so.'

Credit: ideabug Getty Images

Credit: LiptonCNX Getty Images

Credit: stefanschurr Getty Images

Credit: shaunl Getty Images

Four situations which require different degrees of accuracy in the measurements

These are all examples where the accuracy in the given values is not appropriate. In the first two cases, it is greater than is necessary or useful and in the last two cases it is not enough.

In real life, no measurement is exact. Every measurement is made to the nearest integer, or tenth, or hundredth and so on.

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Concept

Rounded numbers are approximations of exact values. In this subtopic you will learn how to round values to a specific degree of accuracy and how to measure and report errors associated with rounding. Consider why rounded numbers are used in mathematics and how you can determine when approximation is appropriate.

Rounding

Decimal places

Activity

Use the ruler provided in the below applet to measure the length of the pencil using different scales on the ruler. Record your measurement for each scale.

Discuss how your measurements change as you change the scale. Think of situations where it would be appropriate to measure a pencil to the nearest centimetre and others where you might want to know the measurement correct to the two or more decimal places. Discuss your thoughts with a classmate.

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Interactive 1. Measurement Using Different Scales on the Ruler.

Credit: GeoGebra (https://www.geogebra.org/m/sZN7kF7J) Anthony OR

More information for interactive 1

This interactive tool allows users to explore the concepts of measurement precision and error calculation. Users can adjust the length of a virtual pencil\textemdash ranging from 3 cm to 10.1 cm\textemdash by clicking, pressing, and dragging the tip, thereby simulating different measured values. They can then select a precision level, such as 1, $\frac{1}{2}$, $\frac{1}{5}$, or $\frac{1}{10}$, to observe how measurement accuracy is affected. The tool dynamically calculates and displays key metrics, including the upper and lower limits of the true value, the maximum error, the relative error, and the percentage error. This helps users clearly understand the impact of precision on these calculations.

To enhance learning, results are presented step-by-step using a series of checkboxes. Users can reveal each calculation in order: starting with the measured value, followed by the upper and lower limits of the true value, the

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maximum error, the relative error, and finally, the percentage error. This structured approach enables users to focus on one concept at a time, reinforcing their understanding of how measurement errors propagate.

For example, if a user sets the measured length to 3.9 cm with a precision of $\frac{1}{10}$, The tool calculates the true value's range as 3.85 cm to 3.95 cm, reflecting the precision's impact. The maximum error is derived as half the precision interval (0.05 cm), while the relative and percentage errors (0.0128 and 1.2821%, respectively) demonstrate the proportional deviation from the measured value. By experimenting with different lengths and precision levels, users gain practical insights into the relationship between precision, accuracy, and error analysis.

Often when dealing with measurements or statistics from real-world data, you will work with values that have many (sometimes infinitely many) decimal places.

When the calculation or measurement is complete, you do not need to write down all the decimal places. Instead, you round to a certain level of accuracy, such as 2 decimal places or 3 decimal places.

Rounding is a way to indicate which value a number is closer to when it falls somewhere in between.

Example 1

★☆☆

The arrow on the number line points to 4.23.

Determine whether this number is closer to 4.2 or 4.3 and hence round 4.23 to 1 decimal place.

4.23 is closer to 4.2

$4.23 = 4.2$ (correct to 1 decimal\:place)

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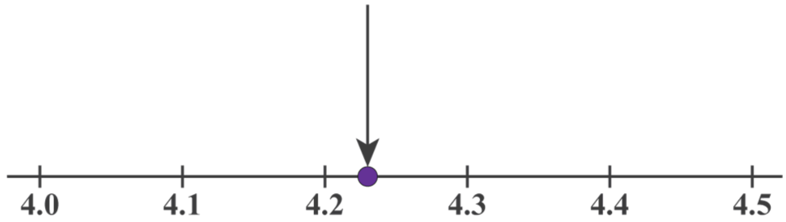

The arrow shows the position of 4.23

Activity

Use a number line to round each of the following correct to 2 decimal places.

$$-2.37641 \quad 12.91083 \quad 4.554$$

Write down a set of rules that you can use for rounding.

Important

If the digit following the required decimal place is

- less than 5 , you round down by keeping the number in the decimal place unchanged
- is 5 or more, you round up by increasing the number in the decimal place by 1 .

In each case, you remove all digits that follow the required decimal place.

Example 2

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Round each of these to 3 decimal places:

a) 2.48357

b) -5.849821

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	Steps	Explanation
a)	$2.48357 = 2.484$ **(3 decimal places)**	The number in the third decimal place is 3, the number to its right is 5. You need to round up: $3 + 1 = 4$ so, you get 2.48
b)	-5.849821 **=** -5.850 **(3 decimal places)**	The number in the third decimal place is 9, the number to its right is 8. You need to round up; $9 + 1 = 10$ so, you get -5.850.

International Mindedness

When banks transfer funds from one currency to another using an exchange rate, they start with an exact number such as $£800$ which (at the time of writing) converts to approximately 935.368383 EUR. Do some research to find out how these values get rounded by banks.

Consider how the errors due to rounding change as the amount being converted increases.

Example 3

★★☆

Evaluate $\frac{3 + \sqrt{5}}{\sqrt{2}}$. Write your answer correct to 3 decimal places.

Steps	Explanation
$\frac{3 + \sqrt{5}}{\sqrt{2}} = 3.702459\ldots$	Use your calculator to evaluate.
$3.702459\ldots \approx 3.702$	Round to 3 decimal places.

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Upper and lower bounds for rounded quantities

Activity

A question asks you to find the mass of a watermelon. In the solution, the mass (rounded to 1 decimal place) is given as 3.7 kg . Determine which of the following values could have been the answer before rounding:

$$3.7621\text{ kg} \quad 3.7415\text{ kg} \quad 3.7056\text{ kg} \quad 3.7173\text{ kg}$$
$$3.6914\text{ kg} \quad 3.6499\text{ kg} \quad 3.6512\text{ kg}$$

Use your findings to write a range of values in the form of $a \leq$ mass $< b$ for the mass of the watermelon before it is rounded to 3.7 kg .

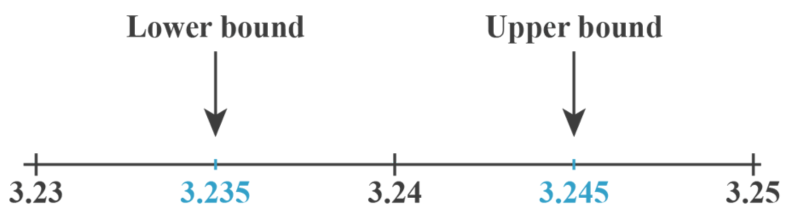
Using what you know about rounding rules explain why the mass can be greater than or equal to a while being less than but not equal to b .

Rounded numbers are easier to work with but rounding reduces the amount of information that you know about the original measurement.

Important

All rounded numbers have an upper and lower bound that tells you the range of values for the initial (unrounded) measurement.

If $x = 3.24\text{ cm}$, then the unrounded value of x is somewhere in the interval $3.235 \leq x < 3.245$. The lower bound is 3.235 and the upper bound is 3.245 .



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The image is a number line diagram illustrating how to find the upper and lower bounds by adding and subtracting half of the smallest unit from the rounded measurement. The number line ranges from 3.23 to 3.25 with marks at 3.23, 3.24, and 3.25. Below the line, there are two labeled points: 3.235 marked as 'Lower bound' and 3.245 marked as 'Upper bound.' Arrows point from the labels 'Lower bound' and 'Upper bound' to their respective points on the number line.

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Upper and lower bounds are found in an exam question by adding and subtracting half of the smallest unit from the rounded measurement.

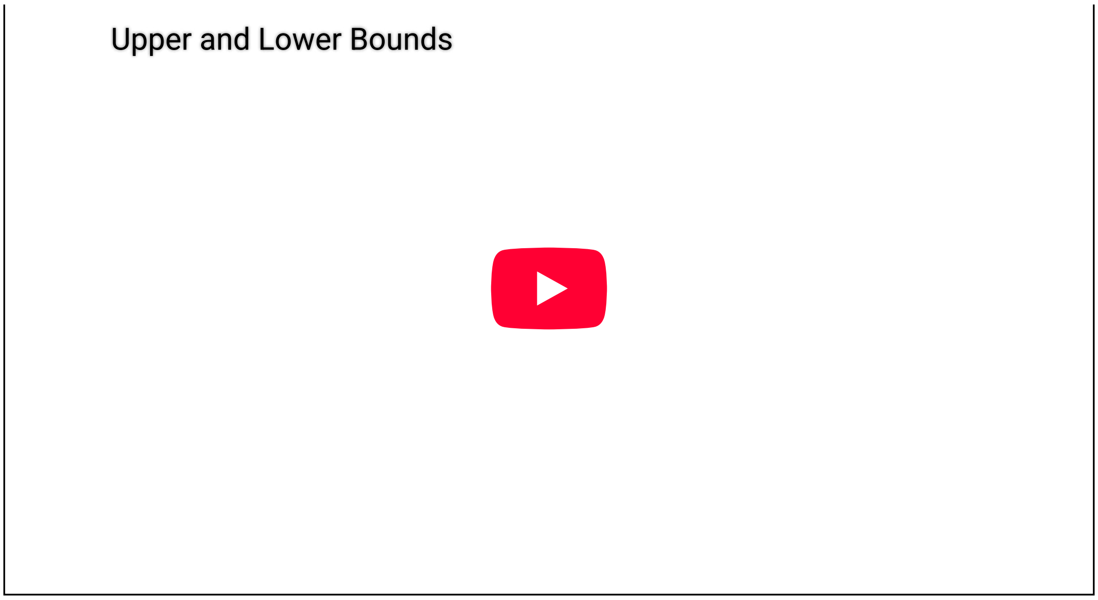
Example 4

★★☆

The height of a tree is recorded as 4.75 m correct to 2 decimal places. Write the interval within which the exact height of the tree is found.

Steps	Explanation
Upper bound: $$4.75+0.005=4.755\text{ m}$$ Lower bound: $$4.75-0.005=4.745\text{ m}$$	Half of the smallest unit in this case is $\frac{0.01}{2}=0.005$
The actual height of the tree is in the interval $4.745\leq x<4.755$.	You can check your interval by making sure that both the upper and lower bounds round to the given value of $x=4.75$. Why is the upper limit of the error interval $< 4.7\!$ and not ≤ 4.755?

Watch the video to see a different way to think about finding the upper and lower bounds.



Example 5

★★☆

The volume of a soda can is measured to be 334 ml to the nearest ml.

Determine the upper and lower bounds of the volume for this soda can.

Steps	Explanation
Upper bound: $$334 + 0.5 = 334.5 \text{ ml}$$ Lower bound: $334 - 0.5 = 333.5 \text{ ml}$	Half of the smallest unit in this case is $\frac{1}{2} = 0.5.$

✓ Important

Upper and lower bounds are used to indicate that there is some uncertainty about which unrounded value the rounded answers came from.

This uncertainty can also be incorporated into calculations where two or more rounded values are used.

Activity

The length of a rectangular piece of paper is measured to be 31 cm and the width 18 cm. Both measurements are given to the nearest centimetre. Use upper and lower bounds for each measurement to determine the maximum and minimum length of the perimeter of this paper.

Describe how your approach can be generalised for finding the upper and lower bounds for calculations of area and volume.

Example 6

★★☆

The length of a rectangular flag is 27.5 cm and the width is 16.8 cm. Both measurements are given to the nearest millimetre.

Determine the upper and lower bounds for the area of this flag. Give your answer correct to one decimal place.

Steps	Explanation
Let $l = \text{length.}$ The range of values for the length is: $$27.45 \leq l < 27.55$$ Let $w = \text{width.}$ The range of values for the width is: $16.75 \leq w < 16.85$	You need to find the upper and lower bounds for each measurement used.

Steps	Explanation
Minimum area: $$A = l \times w = 27.45 \times 16.75 = 459.7875\ \text{cm}^2$$ Maximum area: $$A = l \times w = 27.55 \times 16.85 = 464.2175\ \text{cm}^2$$	The upper and lower bounds for the area are found by calculating the maximum and minimum area Maximum area is found by using the upper bounds for the length and width measurements. Minimum area is found by using the lower bounds for the length and width measurements.
The upper bound is: $$464.2\ \text{cm}^2\ \ (1\ \text{decimal place})$$ The lower bound is: $$459.8\ \text{cm}^2\ \ (1\ \text{decimal place})$$	

Example 7

★★☆

The length of a rectangular field is measured to be 112 m and the area is found to be $8630\ \text{m}^2$. Both of these measurements are given correct to the nearest metre.

Find the upper and lower bounds of the width of the field giving your answers correct to 1 decimal place.

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Steps	Explanation
Let A be the area. The range of values for the area is: $$8629.5 \leq A < 8630.5$$ Let l be the length. The range of values for the length is: $$111.5 \leq l < 112.5$$	
Maximum width: $$w = \frac{8630.5}{111.5} = 77.4$$ (1 decimal place) Minimum width: $$w = \frac{8629.5}{112.5} = 76.7$$ (1 decimal place)	The upper and lower bounds for the width are calculated by finding the maximum and minimum width. Since $w = \frac{A}{l}$, the maximum width is found by taking maximum area and dividing by minimum length. The minimum width is found by taking the minimum area and dividing by maximum length.
The upper bound is: 77.4 m (1 decimal place) The lower bound is: 76.7 m (1 decimal place)	

4 section questions

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Significant figures

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Approximation and percentage error

Significant figures

Significant figuresare the digits in a number that express its value. The first significant figure in a number is the first non-zero digit from the left. Measuring instruments such as thermometers, scales, and rulers are limited in the number of digits that they can measure to (the resolution) and this determines the number of significant figures that can be given for a measured value. The words significant figures are often abbreviated to s.f.

Interactive 1. Determine the Maximum Number of Significant Figures That Can Be Measured with the Ruler.

More information for interactive 1

This interactive tool allows users to explore key concepts of measurement precision and error calculation using a virtual pencil and ruler setup. Users can simulate different measured values by clicking and dragging the nib (tip) of the pencil, adjusting its length within a range of 0 to 10 cm. The precision of the measurement can be selected from a dropdown menu with options such as 1, $1/2$, $1/5$, or $1/10$, influencing how the measured value is interpreted and

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how errors are calculated. A series of checkboxes allows users to selectively display important quantities—including the measured value, true value range (upper and lower limits), maximum error, relative error, and percentage error—encouraging step-by-step exploration and analysis.

For example, when the measurement has a precision of 12, resulting in a measured value of 9 cm. This precision establishes the true value's range, with an upper limit of 9.25 cm and a lower limit of 8.75 cm. Consequently, the maximum error is calculated to be 0.25 cm. The relative error, determined by dividing the maximum error by the measured value 0.259 , is approximately 0.0278. Finally, the percentage error is obtained by multiplying the relative error by 100%, yielding approximately 2.7778%. However, for the same measurement, when precision is 110, The measured value is 9 cm. This precision defines the true value's boundaries, with an upper limit of 9.05 cm and a lower limit of 8.95 cm. The maximum error is calculated to be 0.05 cm. The relative error, found by dividing the maximum error by the measured value 0.059, is approximately 0.0056. Finally, the percentage error, calculated by multiplying the relative error by 100, is approximately 0.556.

By experimenting with different pencil lengths and precision levels, users gain a deeper understanding of how measurement tools and rounding affect accuracy, as well as the role of error in real-world scientific and mathematical contexts.

Activity

Use the ruler in the applet above to measure the length of the pencil. Change the scale on the ruler and determine the maximum number of significant figures that can be measured with this ruler.

There is a list of rules that tell you which digits are significant:

- **All non-zero digits are significant.**
- **Zeros at the beginning of a number, such as the first three zeros in 0.00908, are not significant.**
- **Zeros to the right of a decimal point are significant, such as in 3.70 (3 significant figures) or $3.0\ \ (2\text{ significant figures})$.**
- **Zeros between two significant digits are significant.**
- **Zeros at the end of a whole number may or may not be significant. The number of significant figures that a value is given to depends on the context and the resolution of the measuring device.**

Here are some examples of the significant digits in different numbers.

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Number	First significant digit	Second significant digit	Third significant digit	Fourth significant digit
31.4	3	1	4	
0.7	7			
10.06	1	0	0	6
0.0098	9	8		

Example 1

★☆☆

The mass of one grain of sand was recorded as 0.000604 g.

Write down the number of significant figures in this measurement.

Steps	Explanation
There are 3 significant figures.	The significant figures in this number are highlighted bold 0.000 **604** . The zeros to the left of the 6 are not significant because they are placeholders that tell you that the units of the measurement are small. The easiest way to see which figures are significant it to convert the number to scientific notation and then count all the digits. $0.000604 = 6.04 \times 10^{-4}$ There are 3 digits in 6.04 so there are 3 significant figures.

Making connections

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Writing a number in $a \times 10^k$ form (scientific notation) allows you to count the number of significant figures correctly without getting confused between significant and not significant zeros.

Example 2

★☆☆

The distance from the Earth to the Moon is measured at $384\ 400\ \mathrm{km}$.

Determine the number of significant figures in this measurement.

The first four non-zero digits are significant. The two zeros at the end may or may not be significant, depending on how accurate the measurement is. This distance can be seen as rounded to either 4, 5 or 6 significant figures.

Reporting the same number using scientific notation can have different forms, indicating different accuracy.

- $384\ 400 = 3.844 \times 10^5$ **indicates 4 significant figures**
- $384\ 400 = 3.8440 \times 10^5$ **indicates 5 significant figures**
- $384\ 400 = 3.84400 \times 10^5$ **indicates 6 significant figures**

Exam tip

Unless otherwise indicated, answers to exam questions should be given correct to 3 significant figures. Therefore, it is important that you know how to count the number of significant figures.

Making connections

In subjects such as Physics, Chemistry and Biology, it is good practice to round your final answers to the fewest number of significant figures found in the measurements that you used in the calculations.

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Why do you think that this is the case?

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Example 3

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The density of a substance is found by dividing its mass by its volume. A block of ice with a volume of 3.72 litres was found to have a mass of 3.45 kg. Find the density of the ice correct to 3 significant figures.

Steps	Explanation
$D = \dfrac{3.45}{3.72} = 0.927419 \approx 0.927\text{ kg}^1$	To round a value correct to 3 significant figures count the digits starting from the left and stop at the third one. Round correct to this digit by considering whether the digit to the right of it is < 5 or 5. So, $0.927419 =\ 0.927$ is rounded correct to 3 significant figures.

Example 4

★☆☆

Round 3075.21 to 2 significant figures.

Steps	Explanation
30 75.21	All digits in this number are significant. Find the first two significant digits by counting from the left and stopping at the second digit (the first two significant digits are highlighted in bold).

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Steps	Explanation
$3075.21 = 3100$ **(2 significant figures)**	**Round to the last significant digit highlighted. The third significant figure is ≥ 5 so you round 0 up to 1. Are the two zeros at the right-hand end of the number significant? Why is it necessary to add two zeros at the end of the number?**

You can practise rounding numbers to the correct number of significant figures using the applet below.

Interactive 2. Rounding Numbers to the Correct Number of Significant Figures.

More information for interactive 2

This interactive tool allows users to practice rounding numbers to various levels of significant figures. A default number is displayed, which users can modify by clicking the “Change number” button. Beneath the number, there are checkboxes for rounding to 1, 2, or 3 significant figures. Selecting any of these options instantly reveals the rounded result.

An additional “Special Examples” checkbox provides more challenging cases, such as numbers with trailing zeros or values that require extra care when identifying significant digits. These examples help users explore edge cases and deepen their understanding of rounding rules.

For instance, if the number 50304 is displayed, users can round it to:

- 1 significant figure: 50000
- 2 significant figures: 50000

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- 3 significant figures: 50300

Through this interactive, learners develop a solid understanding of significant figures in both scientific and mathematical contexts, while also gaining insight into how rounding impacts precision and accuracy.

4 section questions

Estimation and percentage error

Estimation

It is very useful to estimate the answer to a calculation before doing the calculation exactly.

Exam tip

Even if you have a calculator, it is useful to estimate the answer to a calculation first. If your estimate is very different from the calculator's answer, this warns you that you may have typed the calculation into your calculator incorrectly.

To estimate the answer to a calculation, you can round each number in the calculation to 1 significant figure.

For example, to estimate 416×1723:

$$416 \times 1723 \approx 400 \times 2000 = 800\ 000$$

A calculator gives the exact answer: $416 \times 1723 = 716\ 768$.

The estimated answer is not the same as the exact answer, but it is close enough to reassure you that you probably typed the calculation correctly.

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The symbol $\approx$ means 'approximately equals'. It would be wrong to write $416 \times 1723 = 400 \times 2000$ in the working above, because the two sides are not exactly equal.

Example 1

★☆☆

Calculate an estimate of $0.785 - 0.349$. Then use a calculator to calculate the exact answer.

Steps	Explanation
$0.785 - 0.349 \approx 0.8 - 0.3 = 0.5$	Round both numbers to 1 significant figu before doing the calculation.
$0.785 - 0.349 = 0.436$	Find using the calculator.
The estimated value is close to the exact answer.	

Example 2

★☆☆

Calculate an estimate for $\dfrac{5.82 + 6.34}{3.56}$.

Then use a calculator to calculate the answer, and round it to 1 decimal place.

Comment on your results.

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Steps	Explanation
$\frac{5.82+6.34}{3.56} \approx \frac{6+6}{4} = \frac{12}{4} = 3$	Round each number to 1 significant figure before doing the calculation.
$\frac{5.82+6.34}{3.56} = 3.4157\ldots = 3.4$ (1 decimal place)	Find using the calculator.
The estimated value is close to the actual result rounded to 1 decimal place.	

Making connections

In Physics you can use estimation to compare orders of magnitude for various measurements. In this case, the values are rounded to the nearest power of 10 .

Percentage error

When you considered the estimated values in **Example 1** and **Example 2** they were described as being 'close' to the actual value. To quantify this description, you can find the percentage error.

Activity

The time it takes to complete a 5 km run was estimated to be 27 min . The actual time was recorded as 34 min . Describe a method that you can use to quantify the error in the estimate.

Now you are told that the race distance was not exactly 5 km but actually 5.27 km . Can you compare the error in the time estimate with the error in the distance estimate?

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Important

Percentage error is calculated using:

$$\varepsilon = \left|\frac{v_A - v_E}{v_E}\right| \times 100\%,$$

where v_E is the exact value, v_A is the approximated value, ε is the percentage error and $|v_A - v_E|$ is the absolute value of the difference between v_a and v_e.

This formula is given in the IB Formula booklet on the exam.

Why is it necessary to find the absolute value of $v_A - v_E$ in the percentage error formula?

Example 3

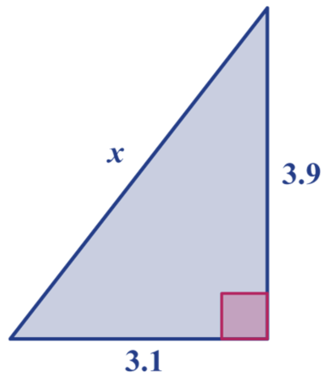
★★☆

The two shorter sides of a right-angled triangle, shown below, are measured to be 3.1 cm and 3.9 cm.

a) Calculate the estimated length of the hypotenuse, x.

b) Find the value of the length of the hypotenuse correct to 3 significant figures.

c) Calculate the percentage error.



More information

The image shows a right triangle with one angle marked as a right angle. The side opposite the right angle, known as the hypotenuse, is labeled with the number 3.9. One of the legs adjacent to the right angle is labeled with the number 3.1, while the other leg is labeled with the variable 'x'. The triangle illustrates the relationship between the sides in the context of solving for 'x', typically using the Pythagorean theorem in geometry.

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	Steps	Explanation
a)	$x^2 = 3.1^2 + 3.9^2 \quad \Leftrightarrow \quad x = \sqrt{3.1^2 + 3.9^2}$ $x \approx \sqrt{3^2 + 4^2} = \sqrt{25} = 5$ $x \approx 5 \text{ cm}$	Use Pythagoras' theorem.
b)	$x = \sqrt{3.1^2 + 3.9^2}$ $= \sqrt{24.82}$ $= 4.98 \text{ cm (3 significant figures)}$	The exact value is $\sqrt{24.82}$. Once you t the square root you need to round your answer.
c)	$\varepsilon = \frac{\lvert 5 - \sqrt{24.82} \rvert}{\sqrt{24.82}} \times 100\% = 0.361955\ldots \approx 0.362\%$ (3 significant figures)	Using: $\varepsilon = \frac{\lvert v_A - v_E \rvert}{v_E} \times 1($ where $v_E = \sqrt{24.8$ $v_A = 5$. Use an unrounded v for v_e in your calculations. Unless told otherwis give your final answ correct to 3 significa figures.

Example 4

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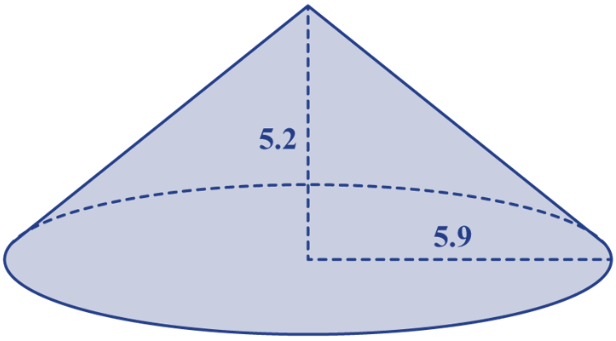
The volume of a cone is found by using $V = \frac{\pi}{3}r^2h$, where r is the radius of the base, and h is the height.

Use integer approximation of π and the measurements to find an estimate of the volume of the cone shown below (all measurements are in cm) and calculate the percentage error for your estimate as compared with the stated values.



Steps	Explanation
$V = \frac{\pi}{3} \times 5.9^2 \times 5.2 \approx \frac{3}{3} \times 6^2 \times 5 = 180$ Estimated volume is 180 cm^3.	
$\varepsilon = \frac{\left\lvert 180 - \frac{\pi}{3} \times 5.9^2 \times 5.2 \right\rvert}{\frac{\pi}{3} \times 5.9^2 \times 5.2} \times 100\%$ $= 5.040915\ldots$ $= 5.04\% \text{ (3 significant figures)}$	Use the exact value of the volume for percentage error calculations. $V = \frac{\pi}{3} \times 5.9^2 \times 5.2$

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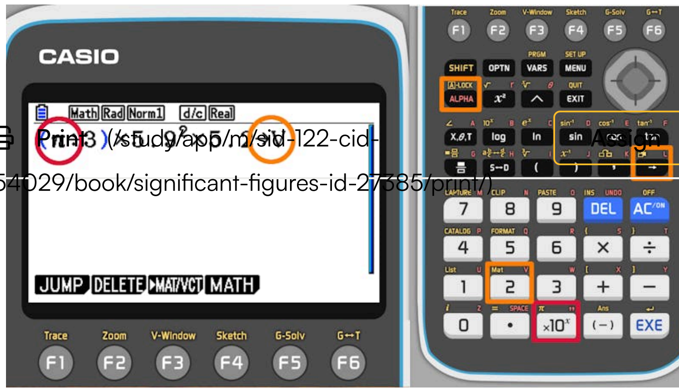
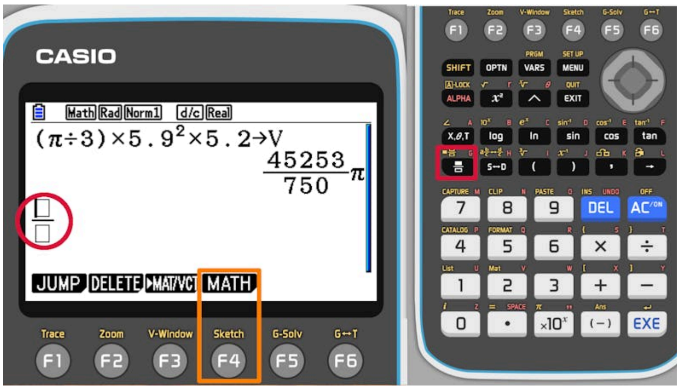
Steps	Explanation
To work out the percentage error in Example 4, it is useful to store the volume of the cone in the memory of the calculator. Make sure you use π (and not an approximate value you might know). Use the arrow to store the value. Use the ALPHA key to choose a variable name.	
In the numerator of the percentage error formula you will need to take the absolute value. You can access the absolute value function among the math options, so press F4 ...	

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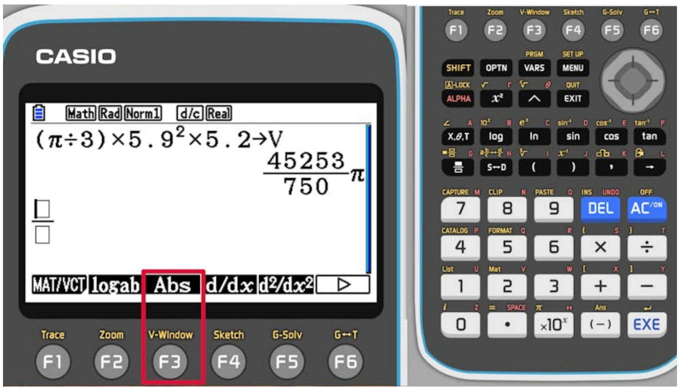
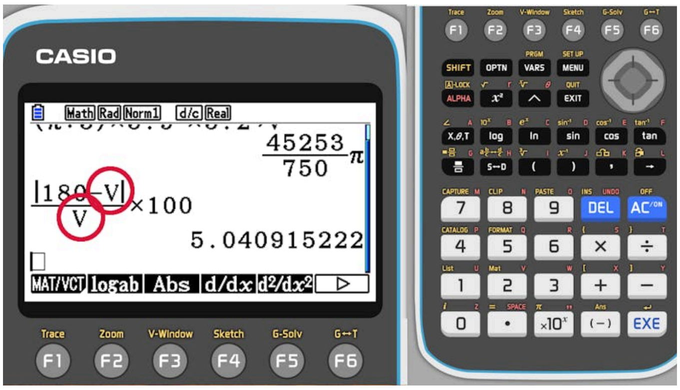
Steps	Explanation
... and then F3.	
In the percentage error formula, you can use the variable name you used to store the exact volume.	

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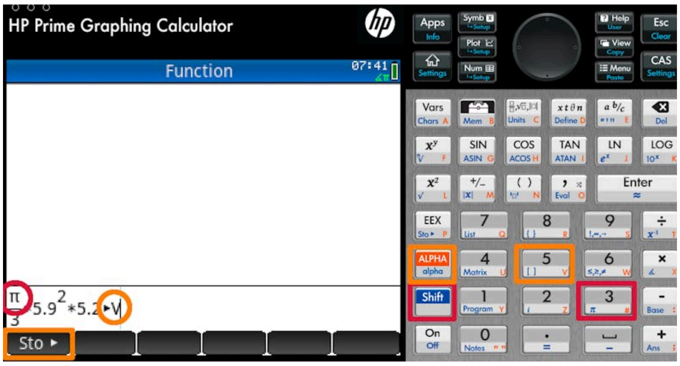
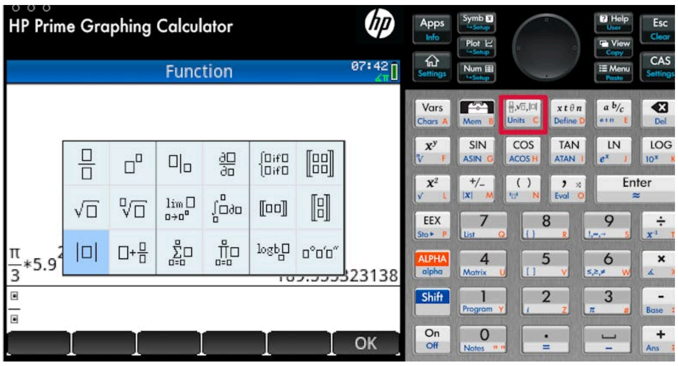
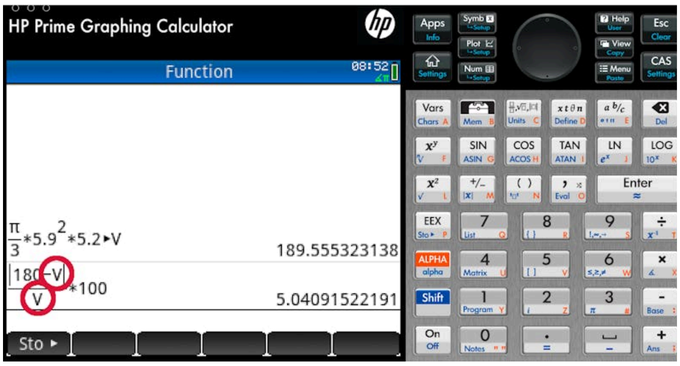
Steps	Explanation
To work out the percentage error in Example 4, it is useful to store the volume of the cone in the memory of the calculator. Make sure you use π (and not an approximate value you might know). Use the store option (Sto ▶) to store the value. Use the ALPHA key to choose a variable name.	
In the numerator of the percentage error formula you will need to take the absolute value. You can access the absolute value function using the template menu.	

Steps	Explanation
In the percentage error formula, you can use the variable name you used to store the exact volume.	

Steps	Explanation
To work out the percentage error in Example 4, it is useful to store the volume of the cone in the memory of the calculator. Make sure you use π (and not an approximate value you might know). Use the store option (sto $\rightarrow$) to store the value. Use the alpha key to choose a variable name.	

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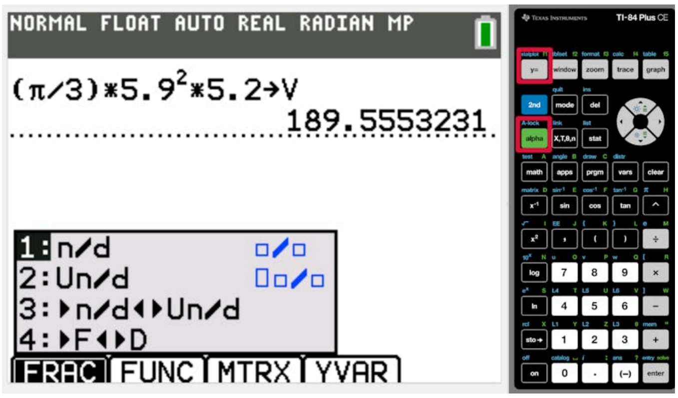
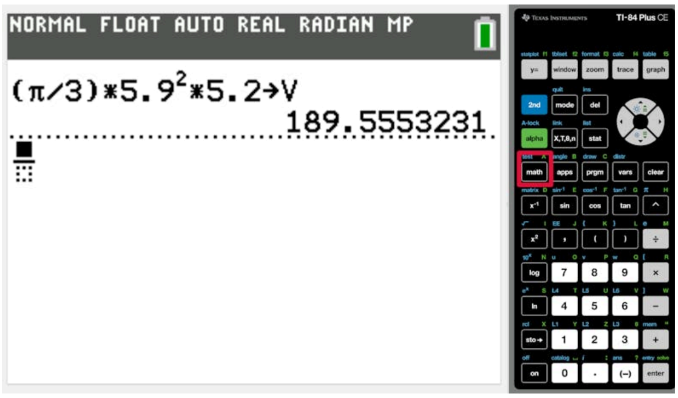
Steps	Explanation
You can enter the formula for the percentage error in a fraction form. You can access this option by pressing alpha/f1.	
In the numerator of the percentage error formula you will need to take the absolute value. You can access the absolute value function among the math options.	

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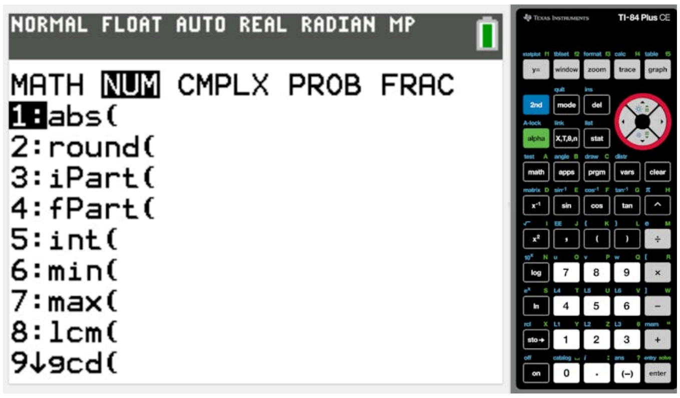
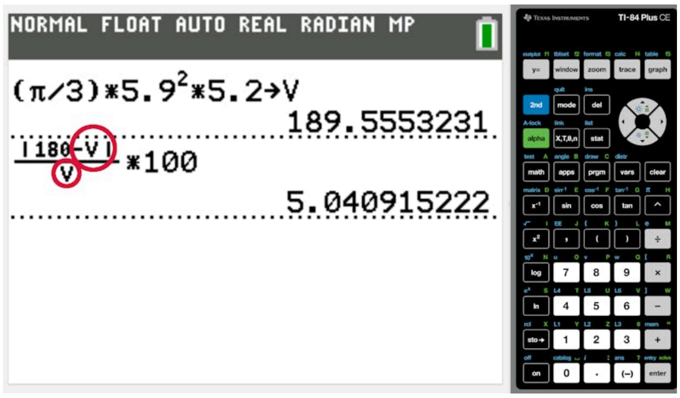
<table>
<tr><th>Steps</th><th>Explanation</th></tr>
<tr><td>The absolute vale function is the first of the numerical options.</td><td>
</td></tr>
<tr><td>In the percentage error formula, you can use the variable name you used to store the exact volume.</td><td>
</td></tr>
</table>

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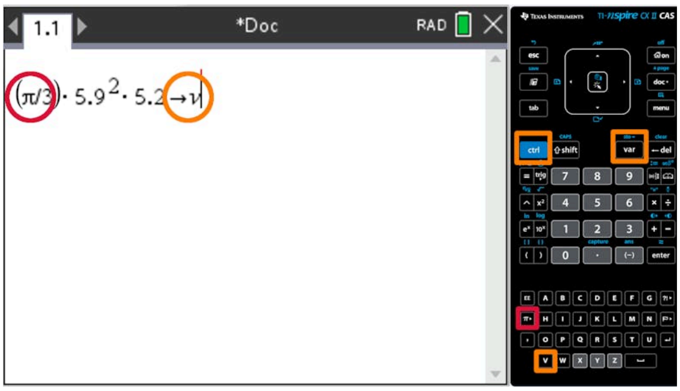
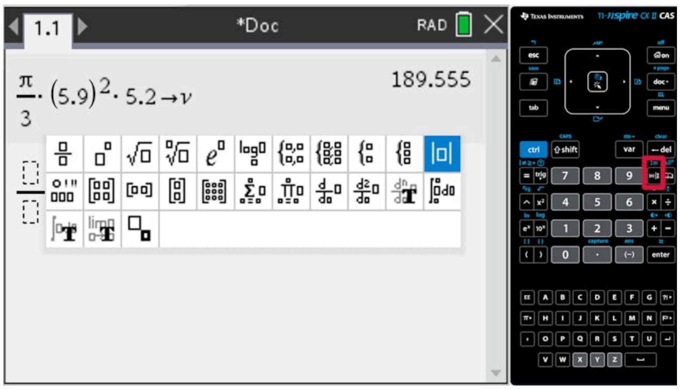
Steps	Explanation
To work out the percentage error in Example 4, it is useful to store the volume of the cone in the memory of the calculator. Make sure you use π (and not an approximate value you might know). You can use the store option (sto $\rightarrow$) to store the value. You can use any variable name.	
In the numerator of the percentage error formula you will need to take the absolute value. You can access the absolute value function using the template menu.	

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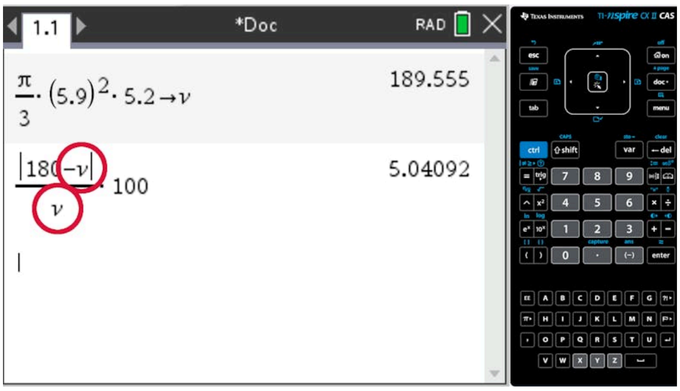
Steps	Explanation
In the percentage error formula, you can use the variable name you used to store the exact volume.	

5 section questions

1. Number and algebra / 1.6 Approximation

Checklist

What you should know

By the end of this subtopic you should be able to:

- round to a specified number of decimal places
- round to a specified number of significant figures
- determine upper and lower bounds for a rounded value
- determine upper and lower bounds for calculations performed with rounded values
- determine whether the answer to a calculation is sensible by estimating
- calculate the percentage error in estimated values using

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$$\varepsilon = \frac{|\nu_A - \nu_E|}{\nu_E} \times 100\% \,.$$

Investigation

Part 1

Explain how you can estimate the height of the house shown below. What additional information would you want to know to make your estimate more accurate?

Can the same strategy be used to estimate the height of a tree? Explain your reasoning.

Think of at least two more methods for estimating the height of a tree. Compare the accuracy of each method.

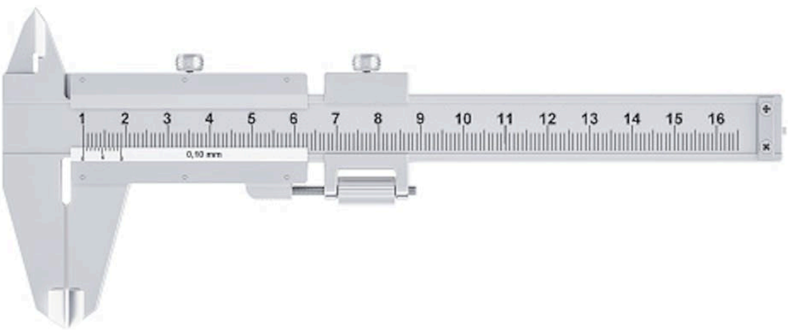
Watch the video to see how loggers and forestry students are taught to estimate heights of trees. How do your methods compare with the one shown in the video?

Section Student... (0/0) Feedback Print (/study/app/m/sid-122-cid-754029/book/investigation-id-27388/print/) Assign

Part 2

The picture below shows a measuring device called callipers. How can you tell what kind of quantities are measured by this device?

Do some research to find out how callipers are used. Describe an investigation or an experiment that you might carry out where you would want to use callipers to collect measurements.



Credit: AlexLMX GettyImages

Rate subtopic 1.6 Approximation

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