

COMMACK HIGH SCHOOL
INTERNATIONAL BACCALAUREATE
STANDARD LEVEL PHYSICS

2018-2019

Lab Information, Errors, and Uncertainty

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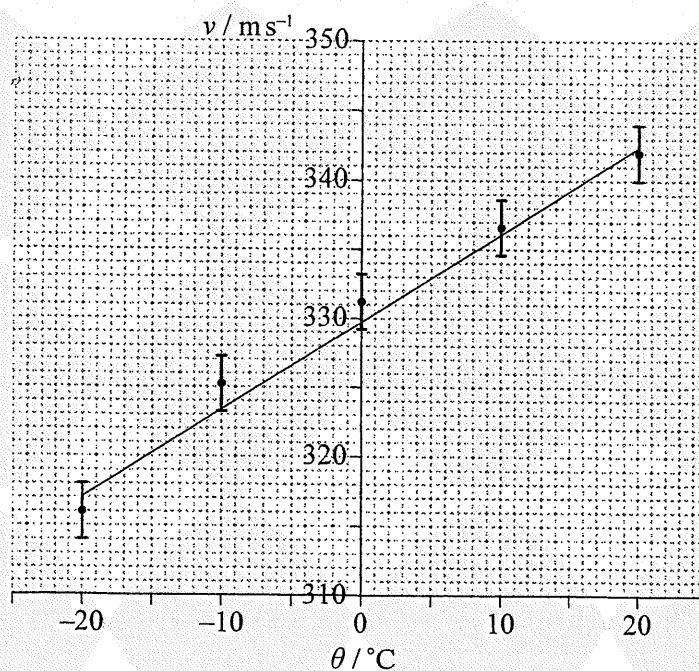
NAME _____

TEACHER _____

SECTION A

Answer **all** questions. Write your answers in the boxes provided.

1. The speed of sound in air, v , was measured at temperatures near 0°C . The graph shows the data and the line of best-fit. The error bars for temperature are too small to be shown.



A student suggests that the speed of sound v is related to the temperature θ in degrees Celsius by the equation

$$v = a + b\theta$$

where a and b are constants.

- (a) (i) Determine the value of the constant a , correct to two significant figures.

[1]

(This question continues on the following page)



(Question 1 continued)

- (ii) Estimate the absolute uncertainty in b . [3]

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- (iii) A student calculates that $b = 0.593 \text{ m s}^{-1} \text{ }^{\circ}\text{C}^{-1}$. State, using your answer to (a)(ii), the value of b to the correct number of significant figures. [1]

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- (b) (i) Estimate the temperature at which the speed of sound is zero. [1]

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- (ii) Explain, with reference to your answer in (b)(i), why the student's suggestion is not valid. [2]

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2. A student uses an electronic timer in an attempt to estimate the acceleration of free-fall g . She measures the time t taken for a small metal ball to fall through a height h of 0.50 m. The percentage uncertainty in the measurement of time is 0.3 % and the percentage uncertainty height is 0.6 %.

- (a) Using $h = \frac{1}{2}gt^2$, calculate the expected percentage uncertainty in the value of g . [1]

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- (b) State and explain how the student could obtain a more reliable value for g . [3]

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3. In an experiment to measure the specific heat capacity of a metal, a piece of metal is placed inside a container of boiling water at 100°C . The metal is then transferred into a calorimeter containing water at a temperature of 10°C . The final equilibrium temperature of the water was measured. One source of error in this experiment is that a small mass of boiling water will be transferred to the calorimeter along with the metal.

- (a) Suggest the effect of the error on the measured value of the specific heat capacity of the metal. [2]

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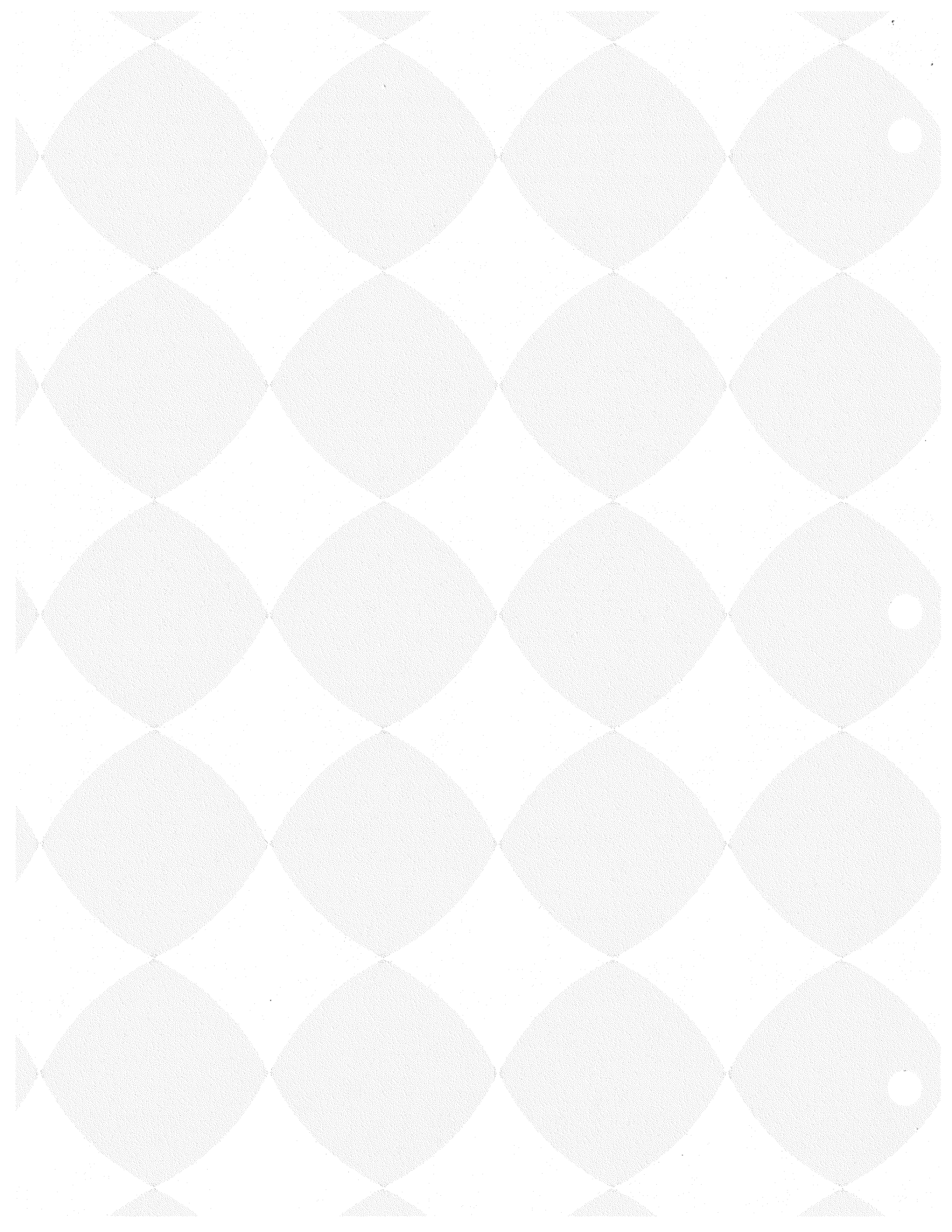
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- (b) State **one** other source of error for this experiment. [1]

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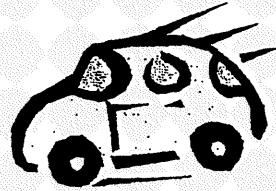




EXERCISE: Uncertainty in Gradient & Intercept

This is a workshop exercise in which you determine the gradient of a linear graph line and its uncertainty. You will consider the gradient range by appreciating the uncertainty bars, not the scatter of data about the regression line.

An electric toy car is traveling along a straight line and measurements of its position and time are taken. The uncertainty in the time Δt is $\pm 0.005\text{s}$ and the uncertainty in the distance Δs is $\pm 0.1\text{m}$. The following data has been recorded:



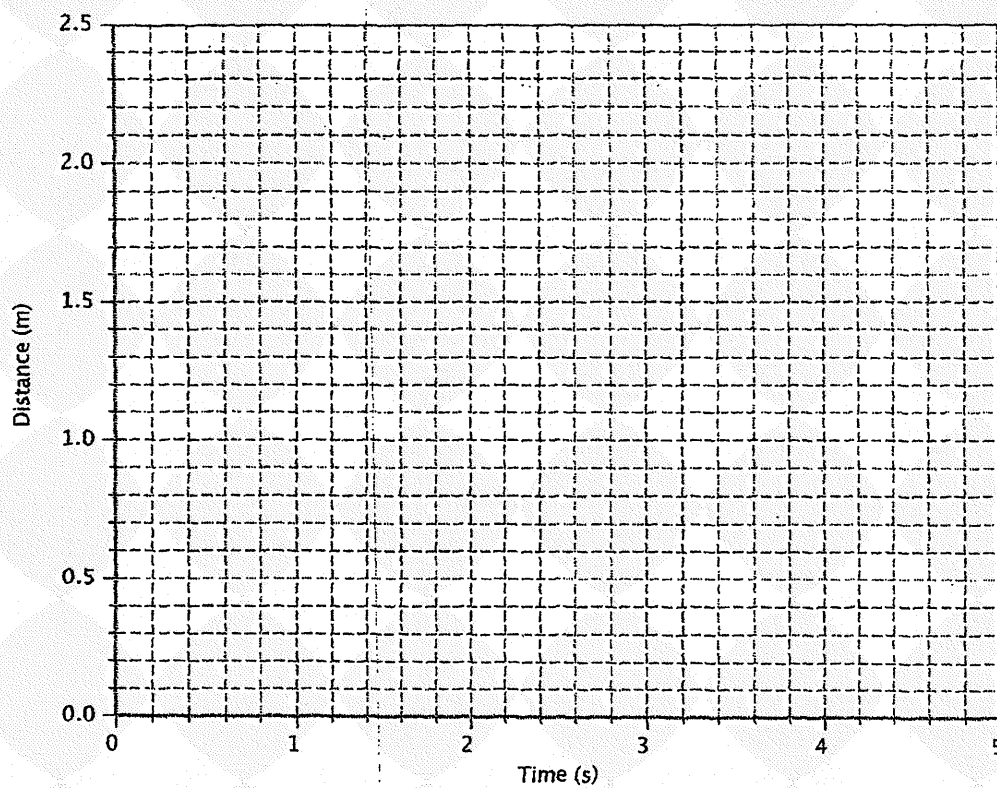
Data	Distance s / m	Time t / s
	$\Delta s = \pm 0.1\text{m}$	$\Delta t = \pm 0.005\text{s}$
1	0.3	0.802
2	0.7	1.103
3	1.0	2.110
4	1.6	3.615
5	2.0	4.610

Do not circle
data points

- (1) Graph distance against time. Plot the data points ~~as small circles~~ with a dot ~~in the center of each circle~~. Use the graph paper provided on the next page or you can do this on your computer.
- (2) Ignoring the origin, construct the best-straight line graph for this data. Extend the line to cover the entire graph sheet.
- (3) Determine which uncertainty (either in time or in distance) is the most significant. Construct uncertainty bars on your graph for all the data points for just one quantity.
- (4) Determine the gradient (slope) of your best straight-line. What physical quantity does the graph's gradient represent? Comment on the motion of the toy car.
- (5) Construct the minimum and maximum gradients for your graph and calculate their values. You are to construct minimum and maximum lines by appreciating all (or most) of the ranges represented by all the data point uncertainty bars.

Express the best gradient value with its absolute uncertainty $m \pm \Delta m$ using the range of the minimum and maximum gradients. Pay attention to significant digits.

Do the same for the y-intercept, find $y \pm \Delta y$. Comment on the origin. Does that toy car start at zero displacement? Does the car accelerate?



$$m_{\text{best}} \pm \Delta m = \underline{\hspace{2cm}}$$

$$y_{\text{best}} \pm \Delta y = \underline{\hspace{2cm}}$$

Name

Guide to Significant Figures.

Significant Figures

Determining the Number of Significant Figures:

- Significant figures are determined by the number of non-zero digits and non-leading zeroes
 - Zeroes in between non-zero numbers count
 - Trailing zeroes count when there is a decimal
- The magnitude of the number does not affect the number of significant digits

Example 1:

147.93

- There are 5 significant digits

Example 2:

0.00640

- There are 3 significant digits
 - The 6, 4 and last 0 count as significant figures
 - The preceding zeroes do not affect the significant figures

Example 3*:

30080000

- There are 4 significant digits
 - The 3, 0, 0, and 8 count as significant digits
 - The last zeroes do not count because there is no decimal
 - The leading zeroes also do not count

Example 4*:

30080000.

- There are 8 significant figures
 - The decimal means that all the digits before it count as significant digits
 - The only exception are the zeroes before the 3, those do not count.

Addition and Subtraction with Significant Figures:

- The number with the fewest decimal places determines the number of decimal places in the solution
- Round the solution to the proper number of decimal places after adding or subtracting

Example 5:

$$\begin{array}{r} 21.532 \\ + 12.01 \\ \hline 33.542 \end{array}$$

After rounding: 33.54

- The first number has 3 decimal places, the second number has 2 decimal places
- The final value must have 2 decimal places
 - Add the numbers normally, including all figures in both numbers
 - Round the final solution down to 2 decimal places
 - Integer places (to the left of the decimal) should not be altered in the solution

Example 6:

$$\begin{array}{r} 9.894 \\ + 1.11 \\ \hline 11.004 \end{array}$$

After rounding: 11.00

- The first number has 3 decimal places, the second number has 2 decimal places
- The final value must have 2 decimal places
 - Add the numbers normally, including all figures in both numbers
 - Round the final solution down to 2 decimal places

- In this case, even if the 2 decimal places are 0, include them
- Integer figures (to the left of the decimal) should not be altered
- For addition and subtraction, the number of significant figures is not always conserved, only the number of decimal places.
- This can be seen by the final number of significant figures being 4, which is larger than the smallest number of significant figures (1.11, which has 3 significant figures) but the solution still has only two decimal places, which is the proper amount

Example 7:

$$\begin{array}{r} 12.56 \\ - 3.4 \\ \hline 9.16 \end{array}$$

After rounding: 9.2

- The first number has 2 decimal places, the second number has 1 decimal place
- The final value must have 1 decimal place
 - Subtract the numbers normally, including all figures in both numbers
 - Round the final solution down to 1 decimal place
 - Since the raw subtracted value is 9.16, it rounds up to 9.2
 - Integer figures should not be altered

Multiplication and Division with Significant Figures:

- The number with the fewest significant figures determines the number of significant figures in the solution
- Round to the proper number of significant figures after multiplying or dividing

Example 8:

$$\begin{array}{r} 1.73 \\ * 24.5 \\ \hline 42.385 \end{array}$$

After rounding: 42.4

- Both numbers have 3 significant digits, so the solution must have only 3 significant digits.

Lab-2c

- Multiply the two numbers normally, round the solution to 3 most significant digits.
 - The raw solution is 42.385, which has 5 significant digits; the 3 must be rounded up to 4 to make the solution 42.3 have 3 significant digits

Example 9:

$$\begin{array}{r} 1200 \\ * 20.00 \\ \hline 24000.00 \end{array}$$

After rounding: 24000

- The first number has only 2 significant digits, since there is no decimal point; the second number has 4 significant digits
- After multiplying the numbers normally, the number must be rounded to 2 significant digits. Since trailing zeroes do not count if there is no decimal point, 24000 has only 2 significant digits

Example 10:

$$\frac{48.34}{2.76} = 17.51449275$$

After rounding: 17.5

- The top number has 4 significant digits; the bottom number has 3 significant digits.
- Divide the numbers normally, the solution must be rounded to 3 significant figures

9 Physics Skills

Use with Chapter 2.

Determining Significant Digits

Any measurement is inaccurate to some degree. The inaccuracy stems from several factors. The precision of any measuring device is limited. The person doing the measurement may introduce error. The experimental technique may be faulty. Because a measurement contains some degree of inaccuracy, the number of digits that are valid for the measurement are also limited.

There are four basic rules that can be used to determine the number of significant digits in a measurement.

1. Nonzero digits are always significant.
2. All final zeros after the decimal point are significant.
3. Zeros between two other significant digits are always significant.
4. Zeros used only for spacing the decimal point are not significant.

Suppose an observer measures the speed of an object and determines that it is moving at 6.13 m/s. The speed of a second object is determined to be 5.02 m/s. Which digits are significant in these two measurements? According to rules 1 and 3, all the digits are significant. Using the rules given above, determine the number of significant digits in each of the following measurements.

- | | | | |
|----------------------|------------------------|-------------------------|--------------------------------|
| 1. 23.30 cm
_____ | 4. 1843.02 L
_____ | 7. 2.000 12 km
_____ | 10. 0.000 101 045 0 s
_____ |
| 2. 3.65 kg
_____ | 5. 8.701°C
_____ | 8. 0.5 mL
_____ | |
| 3. 365 kg
_____ | 6. 2000.12 mm
_____ | 9. 704 000 h
_____ | |

When you perform mathematical calculations, the result of your calculations can never be more precise than the least precise measurement. Add the following quantities: $44.1 \text{ kg} + 8.002 \text{ kg} + 0.93 \text{ kg} = 53.032$. The least precise measurement, 44.1 kg, is precise only to the nearest one-tenth. The sum of the masses, therefore, must be rounded off to the nearest one-tenth. So, the answer is 53.0 kg.

11. Complete these addition problems. Write the sum as a least precise measurement.

a. $3.414 \text{ s} + 10.02 \text{ s} + 58.325 \text{ s} + 0.000 98 \text{ s}$

b. $1884 \text{ kg} + 0.94 \text{ kg} + 1.0 \text{ kg} + 9.778 \text{ kg}$

12. Complete these subtraction problems. Write the difference as a least precise measurement.

a. $2104.1 \text{ m} - 463.09 \text{ m}$

b. $2.326 \text{ h} - 0.104 08 \text{ h}$

9 Physics Skills

Multiplying and dividing are a little different. In these kinds of calculations, the product or quotient has the same number of significant digits as the least precise number. If you multiply 21.3 cm by 9.80 cm, the answer is 209, not 208.74. Because the less precise measurement, 21.3 cm, has only three significant digits, the product has three significant digits.

13. Complete these multiplication problems. Write the product as a least precise measurement.

a. $10.19 \text{ m} \times 0.013 \text{ m}$

b. $140.01 \text{ cm} \times 26.042 \text{ cm} \times 0.0159 \text{ cm}$

14. Complete these division problems. Write the quotient as a least precise measurement.

a. $80.23 \text{ m} \div 2.4 \text{ s}$

b. $4.301 \text{ kg} \div 1.9 \text{ cm}^3$

Averages follow the same rule. Suppose a car travels around a track three times. Your measurements for the three trials are 45.0 km/h, 48.21 km/h, and 47.024 km/h. Determine the average speed of the car.

$$45.0 + 48.21 + 47.024 = 140.234$$

$$140.234 \div 3 = 46.74466$$

Because the least precise measurement is 45.0 km/h, the answer can be precise only to the nearest one-tenth. Thus the correct answer, rounded off, is 46.7 km/h. Answer the following questions.

15. An experiment calls for 16.156 g of substance A, 28.2 g of substance B, 0.0058 g of substance C, and 9.44 g of substance D.

a. How many significant digits are there in each measurement?

A. _____ B. _____ C. _____ D. _____

b. What is the total mass of substances in this experiment?

c. How many significant digits are there in the answer to part b?

16. Your lab partner has measured 16.50 mL of water. You accidentally tip over the graduated cylinder and spill some of the water. You stand the cylinder up and determine that there are 8.0 mL of water left.

a. Which measurement is more precise, your lab partner's or yours? Explain.

b. How much water did you lose when you tipped over the graduated cylinder?

Name: _____

SL Physics

Measurements and Errors

From IB Ref Tables:

$$\begin{array}{ll} \text{If} & y = a \pm b \\ \text{Then} & \Delta y = \Delta a + \Delta b \end{array}$$

$$\begin{array}{ll} \text{If} & y = \frac{a * b}{c} \\ \text{Then} & \frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c} \end{array}$$

Since measurements are never perfect, experimental data must consider the possibility of an error occurring while measuring the data. Errors are dependent on the type of device being used; either digital or analog.

Digital Devices:

- Electronically determines and electronically displays data measurements
- Examples:
 - Electronic Gram Scale
 - Multi-meter (Voltmeter + Ammeter + Ohmmeter)
 - We also have analogue meters of each.
 - Stopwatch
- Error for a digital device: \pm the smallest increment the device can measure.

Example 1:

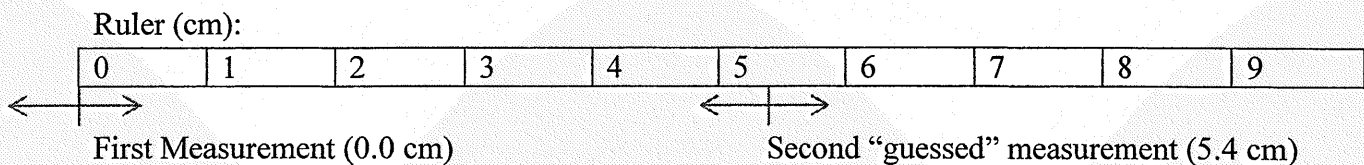
A stopwatch measures time to the nearest hundredth of a second. During an experiment, a student measures a time of 32.14 seconds. The student records this data with the error as:

$32.14 \pm 0.01 \text{ s}$ (equivalent to $a \pm \Delta a$ where a is 32.14 s and Δa is 0.01s)

- The plus-or-minus sign (\pm) denotes the error which is referred to as Δa
- Since the stopwatch measures to the nearest hundredth of a second, the smallest increment is one one-hundredth (1/100) of a second. The error is therefore one one-hundredth as well (0.01)

Analog Devices:

- Whoever is conducting the experiment must determine the measurement. Generally does not require electricity to determine or display the measurement
- Examples:
 - Ruler
 - Measuring Cup/Beaker/etc.
 - Clock (With a second hand)
- Error for an analog device: half the smallest increment
- When measurements are made with an analog device, usually two measurements must be made. The first measurement is the starting position; the second is the ending position. Both measurements must be recorded with the proper analog error.
- Generally measurements are made to one tenth the smallest increment, so the last digit is “guessed”(see star below).

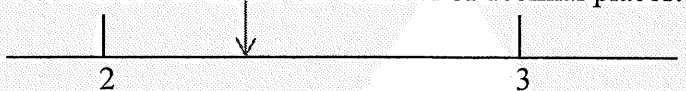


Analogue- A single measurement is always

- Read between the line
- Uncertainty $\pm \frac{\text{smallest division}}{2}$ but rounded to match the number of decimal places.

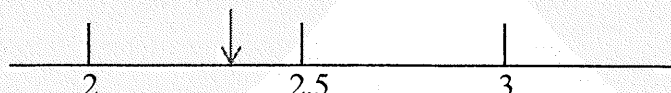
Smallest division is 1, $\pm \frac{1}{2} = \pm .5$

2.3 \pm 0.5 m



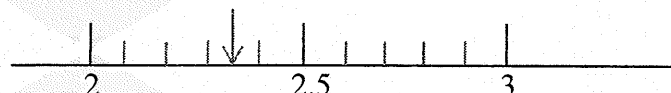
*Smallest division is .5, $\pm \frac{.5}{2} = \pm .25$

2.3 \pm 0.3 m



Smallest division is .1, $\pm \frac{.1}{2} = \pm .05$

2.36 \pm 0.05 m



Example 2:

A student uses a ruler to measure the length of an object during an experiment. The ruler's smallest increment is 1 cm. The student measures the starting position to be at 0.0 cm. The end position is at 5.4 cm. The student records the two pieces of data as (See ruler above):

0.0 \pm 0.5 cm

5.4 \pm 0.5 cm

- Even though the ruler only measures as small as centimeters, the student “guesses” (one more decimal point) to the nearest 0.1 cm, using his or her best judgment
- Also, the student determines the error to be half the smallest increment, which would be $\pm 0.5 \text{ cm}$

The measurements taken from an experiment and recorded directly are called *raw data* or *unprocessed data*. This data has not been used in calculations yet. While raw data is necessary in receiving results from an experiment, the data often times requires processing for the analysis. *Processed data* is the result of calculations being made with raw data, in order to better understand the significance of the experiment. Since the raw data has an error associated with it, the processed data must also have an error, but also since calculations are being made to the data, the errors must also be operated on and processed with the data.

*Constants and accepted values are considered “perfect” and thus have no error or an error of ± 0.0

Addition and Subtraction with Error:

When adding or subtracting two numbers, add them as one would normally, considering significant digits and **always add** the errors together. Addition and subtraction with error follows the following relationship:

Measurements:

$$\begin{aligned} a &\pm \Delta a \\ b &\pm \Delta b \end{aligned}$$

Sum:

$$\begin{aligned} c &= a + b \\ \Delta c &= \Delta a + \Delta b \end{aligned}$$

Difference:

$$\begin{aligned} c &= a - b \\ \Delta c &= \Delta a + \Delta b \end{aligned}$$

*Whether the operation is addition or subtraction, the errors always add together

$$\begin{aligned} \text{If} \quad & y = a \pm b \\ \text{Then} \quad & \Delta y = \Delta a + \Delta b \end{aligned}$$

Example 3:

A student measures two different lengths and needs to find the sum of the two. The measurements are:

$$a = 16.4 \pm 0.1 \text{ cm}$$

$$b = 25.1 \pm 0.1 \text{ cm}$$

Let's say we want to find c , the sum of these two numbers. The processed sum of the two pieces of comes out to:

$$c = a + b = 16.4 \text{ cm} + 25.1 \text{ cm} = 45.1 \text{ cm}$$

The error of this processed data is:

$$\Delta c = \Delta a + \Delta b = 0.1 \text{ cm} + 0.1 \text{ cm} = 0.2 \text{ cm}$$

The data should be finally recorded as:

$$45.1 \pm 0.2 \text{ cm}$$

Example 4:

In example 2 a student began measuring the length of an object by recording a starting and ending position on a ruler. In order to determine the actual length of the object, the two positions need to be subtracted. The two data values were:

$$0.0 \pm 0.5 \text{ cm}$$

$$48.2 \pm 0.5 \text{ cm}$$

The processed difference comes out to:

$$48.2 \text{ cm} - 0.0 \text{ cm} = 48.2 \text{ cm}$$

The error of this processed data is:

$$0.5 \text{ cm} + 0.5 \text{ cm} = 1.0 \text{ cm}$$

The final data should be recorded as:

$$48.2 \pm 1.0 \text{ cm}$$

*Make sure that the error has the **SAME number of decimal places** as the data. The error for this previous example must be $\pm 1.0 \text{ cm}$ not $\pm 1 \text{ cm}$

Multiplication and Division with Error:

Multiplying and Dividing data with errors is slightly more involved than adding and subtracting. Instead of the errors adding, the percent errors add. Multiplication and Division with error follows the following relationship:

Measurements:

$$a \pm \Delta a$$

$$b \pm \Delta b$$

Multiplication:

$$c = a * b$$
$$\frac{\Delta c}{c} = \frac{\Delta a}{a} + \frac{\Delta b}{b}$$

Division:

$$c = \frac{a}{b}$$
$$\frac{\Delta c}{c} = \frac{\Delta a}{a} + \frac{\Delta b}{b}$$

*For multiplication and division, make sure the error is calculated using the above ratios, not by simply adding the errors

$$\text{If } y = \frac{a * b}{c}$$
$$\text{Then } \frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$$

Example 5:

A student determines the acceleration of a cart rolling down a ramp to be $2.65 \pm 0.12 \frac{m}{s^2}$. The student also determines the mass of the cart to be $.1513 \pm 0.0001 \text{ kg}$. The student must use this information to calculate the force acting on the cart. The data values are:

$$2.65 \pm 0.12 \frac{m}{s^2}$$
$$.1513 \pm 0.0001 \text{ kg}$$

The product of the two data values:

$$F = ma$$
$$2.65 \frac{m}{s^2} \times .1513 \text{ kg} = 0.401 \text{ N}$$

Error of the processed data:

$$\frac{\Delta F}{F} = \frac{\Delta a}{a} + \frac{\Delta m}{m}$$
$$\frac{\Delta a}{a} = \frac{0.12 \frac{m}{s^2}}{2.65 \frac{m}{s^2}} = 0.04528$$

Lab-4e

$$\frac{\Delta m}{m} = \frac{0.0001 \text{ kg}}{.1513 \text{ kg}} = 0.0006609$$

$$\frac{\Delta F}{0.401 \text{ N}} = 0.04528 + 0.0006609$$

$$\frac{\Delta F}{0.401 \text{ N}} = 0.0459409$$

$$\Delta F = 0.018 \text{ N}$$

Final data should be recorded as:

$$0.401 \pm 0.018 \text{ N}$$

Or

$$0.401 \text{ N} \pm 4.6\%$$

Where .018 is the absolute error for F (same units).

*Remember that the error needs to be rounded so that the error has the same number of decimal places as the data value

Example 6:

A student wants to determine the electric field between two parallel plates. Through an experiment the student determines the force on an electrically charged oil drop between the two plates is $4.50 \times 10^{-3} \pm 0.10 \times 10^{-3} \text{ N}$. The student also determines that the charge of oil drop is $3.02 \times 10^{-5} \pm 0.05 \times 10^{-5} \text{ C}$. The data values are:

$$4.50 \times 10^{-3} \pm 0.10 \times 10^{-3} \text{ N}$$

$$3.02 \times 10^{-5} \pm 0.05 \times 10^{-5} \text{ C}$$

The quotient of the two data values:

$$E = \frac{F}{q}$$

$$\frac{4.50 \times 10^{-3} \text{ N}}{3.02 \times 10^{-5} \text{ C}} = 149. \frac{\text{N}}{\text{C}}$$

Error of the processed data values:

$$\frac{\Delta E}{E} = \frac{\Delta F}{F} + \frac{\Delta q}{q}$$

$$\frac{\Delta F}{F} = \frac{0.10 \times 10^{-3} \text{ N}}{4.50 \times 10^{-3} \text{ N}} = 0.02222$$

$$\frac{\Delta q}{q} = \frac{0.05 \times 10^{-5} C}{3.02 \times 10^{-5} C} = 0.01656$$

$$\frac{\Delta E}{149 \frac{N}{C}} = 0.02222 + 0.01656$$

$$\Delta E = 6 \frac{N}{C}$$

Or

$$\Delta E = 3.9\%$$

Final data should be recorded as:

$$149 \pm 6 \frac{N}{C}$$

Or

$$149 \frac{N}{C} \pm 3.9\%$$

*Significant figures still apply to scientific notation, but don't affect the number of significant figures in a number.

Applying these rules to Conversions of a given quantity –

Ex:

A cork is determined to be 12.1 grams on a digital scale.

State this quantity and state the correct uncertainty in

- A) Grams
- B) Kg
- C) weight in Newtons

Ans:

- a) 12.1 grams +/- 0.1 grams
- b) $12.1 \times 10^{-3} \text{ kg} \pm 0.1 \times 10^{-3} \text{ kg}$ or $0.0121 \text{ kg} \pm 0.0001 \text{ kg}$
- c) $0.119 \text{ N} \pm 0.001 \text{ N}$

Practice Problems

Complete the following problems relating to the packet. Show work on a separate sheet of paper.

1. Determine the Error for the given device:

- a. Digital Gram Scale Accurate to 0.01 g

Lab-4g

b. Meter stick with 1mm increments

c. Stop watch accurate to 0.01 s

d. Stop Watch with a second-hand

2. Perform the given operation on the data values; include absolute the error:

a. Add: $2.64 \pm 0.01 \text{ g}$ and $13.08 \pm 0.01 \text{ g}$

b. Add: $6.0 \pm 0.1 \text{ g}$ and $4.70 \pm 0.05 \text{ g}$

c. Subtract: $20.16 \pm 0.10 \text{ cm}$ and $0.12 \pm 0.10 \text{ cm}$

d. Subtract: $160. \pm 1. \text{ J}$ and $45.4 \pm 0.5 \text{ J}$

e. Multiply: $1.3 \times 10^3 \pm 0.1 \times 10^3 \text{ kg}$ and $12.5 \pm 0.6 \frac{\text{m}}{\text{s}}$

f. Multiply: $154.3 \pm 0.1 \text{ V}$ and $4.76 \pm 0.10 \text{ A}$

g. Divide: $309. \pm 8. \text{ N}$ by $15.8 \pm .4 \frac{\text{m}}{\text{s}^2}$

h. Divide: $521.6 \pm 1.5 \text{ J}$ by $24.96 \pm 0.01 \text{ s}$

3. Applying these concepts to physics:

a. A cube has a side length of $0.139 \pm 0.010 \text{ m}$. Determine the volume of this cube with the error.

$$V = s^3$$

b. An object with mass $120.0 \pm 1.0 \text{ kg}$ is experiencing a net acceleration of $2.80 \pm 0.05 \frac{\text{m}}{\text{s}^2}$. Calculate the force acting on the object with the error.

$$F = ma$$

c. Convert $1.73 \pm 0.10 \text{ m}$ into cm . Include the error.

$$100 \text{ cm} = 1 \text{ m}$$

d. *A car of mass $1200. \pm 50. \text{ kg}$ is moving with a speed of $22.8 \pm 1.0 \frac{\text{m}}{\text{s}}$. Calculate the kinetic energy of the car with the error.

$$K.E. = \frac{1}{2}mv^2$$

e. **A ball of mass $0.155 \pm 0.001 \text{ kg}$ is being rotated in a circle, horizontally. The length of the string holding the ball is $.520 \pm 0.010 \text{ m}$, and the ball is moving at a speed of $2.68 \pm 0.05 \frac{\text{m}}{\text{s}}$. Calculate the force acting on the ball with the error.

$$F = \frac{mv^2}{r}$$

4. Measuring and processing data:

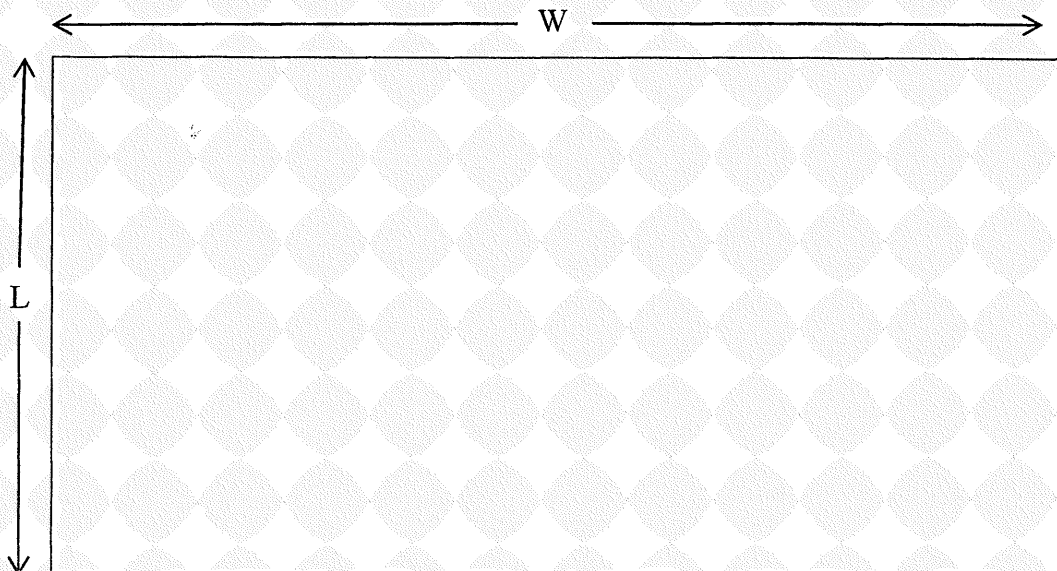
- a. Measure and record the lengths of each side of the figure below. Record data in the corresponding chart. Calculate the length of each side from the measurements. All calculations should have the proper equation used and one example of data being calculated.

Side	Start Value	Error	End Value	Error
W				
L				

Processed Values

	Value	Error
W		
L		

Figure:



- b. Calculate the area and perimeter of this figure and their proper errors

Perimeter _____

Area _____

Answer Key – measurements and errors

1. Determined Error
 - a. $\pm 0.01 \text{ g}$ (digital)
 - b. $\pm 0.5 \text{ mm}$ (analog)
 - c. $\pm 0.01 \text{ s}$ (digital)
 - d. $\pm 0.5 \text{ s}$ (analog)
2. Solutions to the given operations and data
 - a. $15.72 \pm 0.02 \text{ g}$
 - b. $10.7 \pm 0.2 \text{ g}$
 - c. $20.04 \pm 0.20 \text{ cm}$
 - d. $115, \pm 2. \text{ J}$
 - e. $1.6 \times 10^4 \pm 0.2 \times 10^4 \frac{\text{kg m}}{\text{s}}$
 - f. $734. \pm 16. \text{ W}$ (or VA)
 - g. $19.6 \pm 1.0 \text{ kg}$
 - h. $20.90 \pm 0.07 \text{ W}$ (or J/sec)
3. Applied Concepts
 - a. $2.69 \times 10^{-3} \pm 0.58 \times 10^{-3} \text{ m}^3$
 - b. $336. \pm 9. \text{ N}$
 - c. $173. \pm 10. \text{ cm}$
 - d. $3.12 \times 10^5 \pm 0.40 \times 10^5 \text{ J}$
 - e. $2.14 \pm 0.13 \text{ N}$

4. Measuring and Processing Data

a. Measured Values

Side	Start	Error	End	Error
W	0.00 cm	+/-0.05 cm	13.39 cm	+/- 0.05 cm
L	0.00 cm	+/-0.05 cm	6.80 cm	+/- 0.05 cm

Processed Values

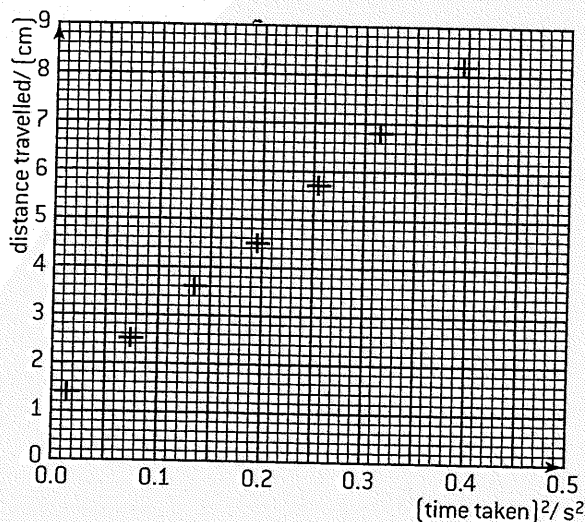
	Value	Error
W	13.39cm	0.10 cm
L	6.80cm	0.10 cm

Perimeter (=L+L+W+W): 40.38 ± 0.40 cm

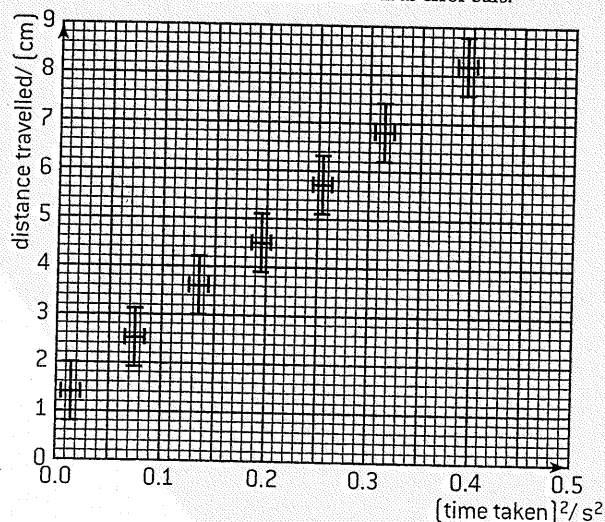
Area(=L*W): 91.1 ± 2.0 cm²

IB Questions – measurement and uncertainties

1. An object is rolled from rest down an inclined plane. The distance travelled by the object was measured at seven different times. A graph was then constructed of the distance travelled against the (time taken)² as shown below.

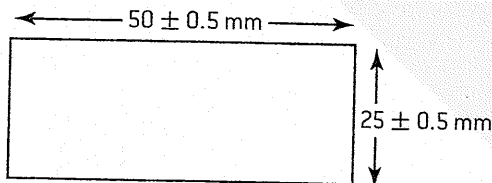


- a) (i) What quantity is given by the gradient of such a graph? [2]
 (ii) Explain why the graph suggests that the collected data is valid but includes a systematic error. [2]
 (iii) Do these results suggest that distance is proportional to (time taken)²? Explain your answer. [2]
 (iv) Making allowance for the systematic error, calculate the acceleration of the object. [2]
- b) The following graph shows that same data after the uncertainty ranges have been calculated and drawn as error bars.



Add two lines to show the range of the possible acceptable values for the gradient of the graph. [2]

2. The lengths of the sides of a rectangular plate are measured, and the diagram shows the measured values with their uncertainties.



Which one of the following would be the best estimate of the percentage uncertainty in the calculated area of the plate?

3. A stone is dropped down a well and hits the water 2.0 s after it is released. Using the equation $d = \frac{1}{2}gt^2$ and taking $g = 9.81 \text{ m s}^{-2}$, a calculator yields a value for the depth d of the well as 19.62 m. If the time is measured to $\pm 0.1 \text{ s}$ then the best estimate of the absolute error in d is

- A. $\pm 0.1 \text{ m}$ C. $\pm 1.0 \text{ m}$
 B. $\pm 0.2 \text{ m}$ D. $\pm 2.0 \text{ m}$

4. In order to determine the density of a certain type of wood, the following measurements were made on a **cube** of the wood.

Mass = 493 g

Length of **each** side = 9.3 cm

The percentage uncertainty in the measurement of mass is $\pm 0.5\%$ and the percentage uncertainty in the measurement of length is $\pm 1.0\%$.

The best estimate for the uncertainty in the density is

- A. $\pm 0.5\%$ C. $\pm 3.0\%$
 B. $\pm 1.5\%$ D. $\pm 3.5\%$

5. Astronauts wish to determine the gravitational acceleration on Planet X by dropping stones from an overhanging cliff. Using a steel tape measure they measure the height of the cliff as $s = 7.64 \text{ m} \pm 0.01 \text{ m}$. They then drop three similar stones from the cliff, timing each fall using a hand-held electronic stopwatch which displays readings to one-hundredth of a second. The recorded times for three drops are 2.46 s, 2.31 s and 2.40 s.

- a) Explain why the time readings vary by more than a tenth of a second, although the stopwatch gives readings to one hundredth of a second. [1]
 b) Obtain the average time t to fall, and write it in the form (value \pm uncertainty), to the appropriate number of significant digits. [1]
 c) The astronauts then determine the gravitational acceleration a_g on the planet using the formula $a_g = \frac{2s}{t^2}$. Calculate a_g from the values of s and t , and determine the uncertainty in the calculated value. Express the result in the form $a_g = (\text{value} \pm \text{uncertainty})$, to the appropriate number of significant digits. [3]



6. This question is about finding the relationship between the forces between magnets and their separations.

In an experiment, two magnets were placed with their North-seeking poles facing one another. The force of repulsion, f , and the separation of the magnets, d , were measured and the results are shown in the table below.

Separation d/m	Force of repulsion f/N
0.04	4.00
0.05	1.98
0.07	0.74
0.09	0.32

- a) Plot a graph of $\log(\text{force})$ against $\log(\text{distance})$. [3]
 b) The law relating the force to the separation is of the form

$$f = k/d^n$$

Lab-6

SL & HL IB PHYSICS

Multiple Choice Questions on Uncertainties

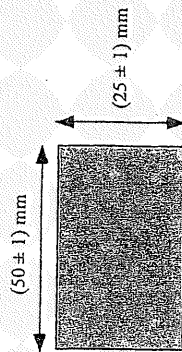
M04/431/H(1)

1. The power dissipated in a resistor of resistance R carrying a current I is equal to I^2R . The value of I has an uncertainty of $\pm 2\%$ and the value of R has an uncertainty of $\pm 10\%$. The value of the uncertainty in the calculated power dissipation is

- A. $\pm 8\%$ B. $\pm 12\%$ C. $\pm 14\%$ D. $\pm 20\%$

M02/430/H(1)

2. The lengths of the sides of a rectangular plate are measured, and the diagram shows the measured values with their uncertainties.



Which of the following is the best estimate of the percentage uncertainty in the calculated area of the plate?

- A. $\pm 2\%$ B. $\pm 4\%$ C. $\pm 6\%$ D. $\pm 8\%$

N02/430/H(1)

3. The resultant force acting on an object is measured to an accuracy of $\pm 4\%$. The mass of the object is measured to an accuracy of $\pm 2\%$. The acceleration of the object can be calculated to an accuracy of approximately

- A. $\pm 2\%$ B. $\pm 4\%$ C. $\pm 6\%$ D. $\pm 8\%$

Lab-7a

M03/430/H(1)

4. Natalie measured the mass and speed of a glider. The percentage uncertainty in her measurement of the mass is 3% and in the measurement of the speed is 10% . Her calculated value of the kinetic energy of the glider will have an uncertainty of

- A. $\pm 30\%$ B. $\pm 23\%$ C. $\pm 13\%$ D. $\pm 10\%$

N03/430/H(1)

5. A student measures a distance several times. The readings lie between 49.8 cm and 50.2 cm. This measurement is best recorded as

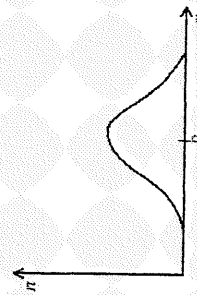
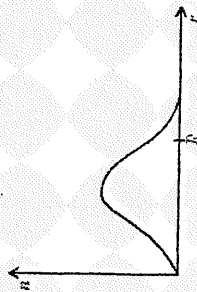
- A. 49.8 ± 0.2 cm B. 49.8 ± 0.4 cm C. 50.0 ± 0.2 cm D. 50.0 ± 0.4 cm

N03/430/H(1)

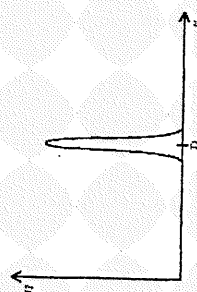
6. A measurement is made many times with four different instruments. For each instrument a graph is plotted of the variation with reading r of the number n of times that reading was obtained. The true reading is R . Which one of the following instruments provides readings that are the most precise but the least accurate?

A. Instrument 1

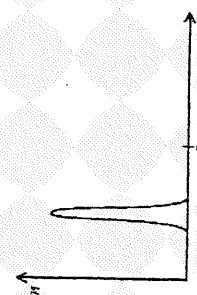
B. Instrument 2



C. Instrument 3



D. Instrument 4



Estimates / Errors

1. The diameter of the nucleus of a hydrogen atom is of the order of

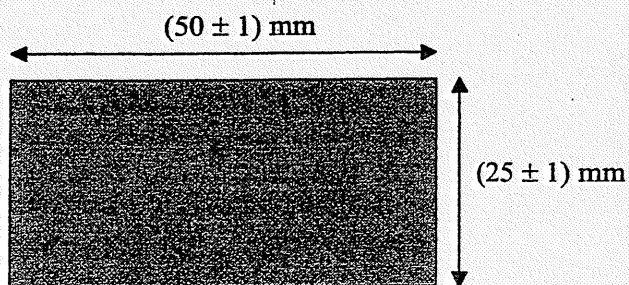
- A. 10^{-8} m.
- B. 10^{-15} m.
- C. 10^{-23} m.
- D. 10^{-30} m.

2. Which **one** of the following lists a fundamental unit and a derived unit?

A.	ampere	second
B.	coulomb	kilogram
C.	coulomb	newton
D.	metre	kilogram

3

The lengths of the sides of a rectangular plate are measured, and the diagram shows the measured values with their uncertainties.



Which of the following is the best estimate of the percentage uncertainty in the calculated **area** of the plate?

- A. $\pm 2\%$
- B. $\pm 4\%$
- C. $\pm 6\%$
- D. $\pm 8\%$

4.

The mass of an object is measured to be 4.652 kg and its volume 2.1 m^3 . If the density (mass per unit volume) is calculated from these values, to how many significant figures should it be expressed?

- A. 1
- B. 2
- C. 3
- D. 4

5.

Repeated measurements of a quantity can reduce the effects of

- A. both random and systematic errors.
- B. only random errors.
- C. only systematic errors.
- D. neither random nor systematic errors.

6.

The number of heartbeats of a person at rest in one hour, to the nearest order of magnitude is

- A. 10^1 .
- B. 10^2 .
- C. 10^3 .
- D. 10^5 .

7.

A student measures the current in a resistor as 677 mA for a potential difference of 3.6 V. A calculator shows the resistance of the resistor to be 5.3175775Ω . Which **one** of the following gives the resistance to an appropriate number of significant figures?

- A. 5.3Ω
- B. 5.32Ω
- C. 5.318Ω
- D. 5.31765775Ω

8.

The diameter of a proton is of the order of magnitude of

- A. 10^{-12} m .
- B. 10^{-15} m .
- C. 10^{-18} m .
- D. 10^{-21} m .

Lab-7c

9.

Which **one** of the following is a scalar quantity?

- A. Pressure
- B. Impulse
- C. Magnetic field strength
- D. Weight

10.

The ratio $\frac{\text{diameter of a nucleus}}{\text{diameter of an atom}}$ is approximately equal to

- A. 10^{-15} .
- B. 10^{-8} .
- C. 10^{-5} .
- D. 10^{-2} .