Methods and Tools of Physics

HON

Order of Magnitude Estimation:

Give an order of magnitude estimate for each of the following quantities.

1. The number of students enrolled at NHS _______________
2. The number of teachers at NHS _______________
3. The number of seconds in this period _______________
4. The height of the door in meters _______________
5. The thickness of the door in meters _______________
6. The thickness of a piece of paper in meters _______________

Ranges of magnitudes that occur in the universe:

Sizes: 10^{-15} m (subnuclear particles)
to
10^{+25} m (extent of the visible universe)

Masses: 10^{-30} kg (electron mass)
to
10^{+50} kg (mass of the universe)

Times: 10^{-23} s (passage of light across a nucleus)
to
10^{+18} s (the age of the universe)

Size of an atom:

Size of a proton:

Significant Figures, Decimal Places, and Scientific Notation

Decimal places – the number of digits after the decimal point

Significant figures (digits) –the digits that are known with certainty plus one digit whose value has been estimated in a measured value.

Measurement	Decimal Places	Significant Figures	Scientific Notation
4003 m			
160 N			
160. N			
30.00 kg			
0.00610 m			

Rules for determining significant figures:

1) Nonzero digits in a measurement are always significant.
2) Zeros that appear *before* a nonzero digit are *NOT* significant.

   Ex – 0.002 m (1 significant figure) and 0.13 g (2 s.f.).

3) Zeros that appear *between* nonzero digits are significant.

   Ex – 0.705 kg (3 s.f.) and 2006 km (4 s.f.).

4) Zeros that appear *after* a nonzero digit are significant *only* if:

   (a) followed by a decimal point

   Ex - 40 s (1 s.f.) and 20. m (2 s.f.).

   (b) they appear to the right of the decimal point.

   Ex – 37.0 cm (3 s.f.) and 40.00 m (4 s.f.).

Calculations with Significant Figures HON

Addition and Subtraction Rule

When adding or subtracting measured values, the operation is performed and the answer is rounded to the same **decimal place** as the value with the **fewest decimal places**.

Multiplication and Division Rule

When multiplying or dividing measured values, the operation is performed and the answer is rounded to the same number of **significant figures** as the value having the **fewest number of significant figures**.

Perform the following calculations and answer to the correct number of sig figs:

a)
11.44 m
5.00 m
0.11 m
+ 13.2 m

b) Add 2.34 m, 35.7 m and 24 m

c) (0.304 cm) (73.84168 cm)

d) 0.1700 g ÷ 8.50 L

Fundamental and Derived Units

The SI (International System) system of units defines seven fundamental units from which all other units are derived.

For example:

The **meter** is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.

The **second** is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.

Fundamental Units

Quantity	Units	Symbol
Length		
Mass		
Time		
Electric current		
Temperature		
Amount		
Luminous intensity		

Derived Units

New (derived) units can be named by combining the fundamental units.

a) What is the derived unit for *mass per length*? ____________

b) What is the derived unit for *electric current times time*? ____________

c) What is the derived unit for *mass times length per time*? ____________

Note: Sometimes a derived unit will have a new name.

For example,

Metric Prefixes and Conversions

Prefixes for Powers of Ten

PREFIX	SYMBOL	NOTATION
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

1. Convert 45.20 centimeters into meters.

Factor-Label Method for Converting Units

a) Write factors so units cancel leaving desired units.

b) Write "1" next to each prefixed unit.

c) Write the power of 10 (i.e.- the exponent) with each base unit.

2. Convert 1.9 A into microamps.

3. Convert 0.0340 pm into kilometers.

4. Convert 12.8 cm^2 into m^2.

5. Convert 4700 kg/m^3 into g/cm^3

6. Convert 55 mph into m/s. (1.0 mile ≈ 1.6 km)

7. Convert 700 seconds into nanoseconds.

8. Convert 2.40 gigabytes into bytes.

9. Convert 10.25 Mℓ into mℓ.

10. Convert 45.0 m^3 into mm^3.

11. Convert 92.3 kg/cm^3 into g/m^3.

12. Convert 30. m/s in to mph.

Accuracy and Precision

HON

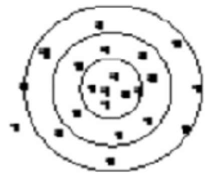
Accuracy: An indication of how close a measurement is to the accepted value (a measure of correctness)

Precision: An indication of the agreement among a number of measurements made in the same way (a measure of exactness)

Rate the following groupings of shots on their accuracy and precision:

A

B



C

D

Systematic Error: An error associated with a particular instrument or experimental technique that causes the measured value to be off by a consistent, predictable amount each time.

Random Uncertainty: An uncertainty produced by unknown and unpredictable variations in the experimental situation whereby the recorded measurement has an equal probability of being above or below the true value.

1) Which target(s) above represents measurements made with significant systematic error?

2) Which target(s) above represent measurements made with significant random uncertainty?

3) Which type of uncertainty affects the accuracy of results?

4) Which type of uncertainty affects the precision of results?

5) Which type of uncertainty can be eliminated from an experiment?

6) Which type of uncertainty can be reduced in an experiment but never eliminated?

7) State a general method for reducing random uncertainty.

8) Repeated measurements can make your answer more ________________ but not more ________________

9) An accurate experiment has low ______________________________

10) A precise experiment has low ______________________________

Measurements and Uncertainties

HON

No measurement is ever perfectly **exact** or perfectly **correct**. Every measurement has a degree of uncertainty associated with it.

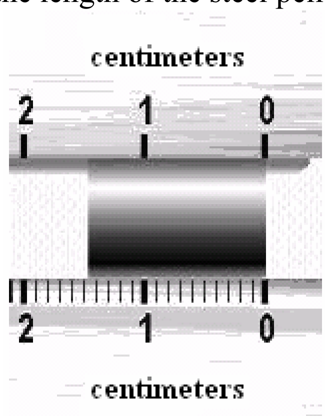
1. If possible, record as many significant figures as the calibration of the measuring instrument allows **plus** one estimated digit.

2. Record a reasonable uncertainty estimate with one sig fig that matches the measurement in place value (decimal place).

Record a measurement for the length of the steel pellet as measured by each ruler.

Top ruler:

Range of values:

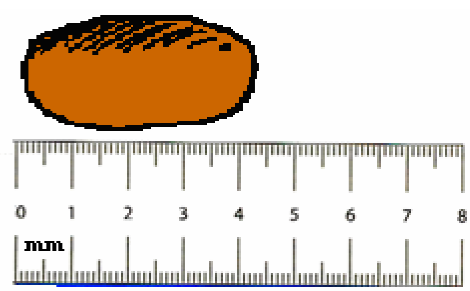


Bottom ruler:

Range of values:

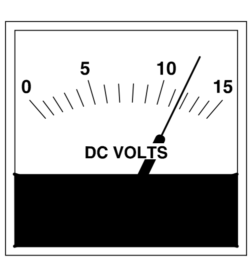
What if the object doesn't have a sharp edge to measure from?

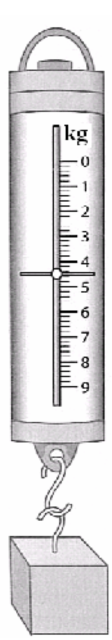
Measurement:



Record each measurement with an appropriate uncertainty:

1. Analog readings:





2. Digital readings:

3. Stopwatch:

Single Trials and Multiple Trials

Task:

Your measurement: Class measurements:

1. What are some reasons for the variations in answers?

parallax -

2. Reporting a measurement using a **single trial**: Your value: ________________ ± ________________

   Value:

   Uncertainty:

   Rules for uncertainties:

   a)

   b)

3. Reporting a measurement using **multiple trials**: Class value: ________________ ± _______________

   Value:

   Range:

   Uncertainty:

Data Processing

HON

1. Averaging multiple trials:

The following measurements were made for the height of the classroom door. (What's wrong with the data table?)

Trial	Height
1	2.152
2	2.2
3	2.18
4	2.213

What final value should be reported?

2. Measuring several cycles:

A mass bounced up and down 5 times in 7.63 seconds as measured on a stopwatch.

How should the total time be recorded?

How much time did one full bounce take?

3. Mathematical operations:

a) To find the volume of an irregular object by water displacement, the following data were taken. How should the volume of the object be reported?

Volume of water in graduated cylinder: 22.5 ml ± 0.1 ml

Volume of water plus object: 83.7 ml ± 0.1 ml

Volume of object:

Determining uncertainty:

Maximum volume:

Minimum volume:

b) To find the area of his desktop, a student took the following data. How should the area be reported?

Length of desktop: 38.4 cm ± 0.3 cm

Width of desktop: 72.9 cm ± 0.3 cm

Area of desktop:

Determining uncertainty:

Maximum area:

Minimum area:

c) To find the speed of a toy car, the following data were taken. How should the speed be reported?

Distance traveled: 4.23 m ± 0.05 m

Time taken: 8.7 s ± 0.2 s

Speed:

Determining uncertainty:

Maximum speed:

Minimum speed:

d) What is the area of a circle whose radius is measured to be 6.2 cm ± 0.1 cm?

Area:

Determining uncertainty:

Maximum area:

Minimum area:

Evaluating Results

There are many ways to evaluate the accuracy of your results. One common method is to compare your results to a previously established value, called the "accepted value" or "literature value."

1. How does a value get to become an "accepted value?"

2. Where would you look to find an "accepted value?" (Hint: Why do you think it's also called the "literature value?")

A simple method of comparing your results to the accepted value is known as "percent error."

3. A student takes measurements and determines the density of a liquid to be 0.78 g/ml. The accepted value for this liquid's density is 0.82 g/ml. Calculate her percent error and make a conclusion.

A more sophisticated method of evaluating your results is to determine if the literature value falls within your results' uncertainty range.

4. A student takes measurements and determines the density of a liquid to be 0.78 g/ml ± 0.05 g/ml. The accepted value for this liquid's density is 0.82 g/ml. Make a conclusion about her results.

Data Processing Practice

HON

1. Five people measure the mass of an object. The results are 0.56 g, 0.58 g, 0.58 g, 0.55 g, 0.59 g.
How would you report the measured value for the object's mass?

1. Adella Kutessen measured 8 floor tiles to be 2.67 m ±0.03 m long. What is the length of one floor tile?

2. The first part of a trip took 25 ± 3 s, and the second part of the trip took 17 ± 2s. How long did the whole trip take?

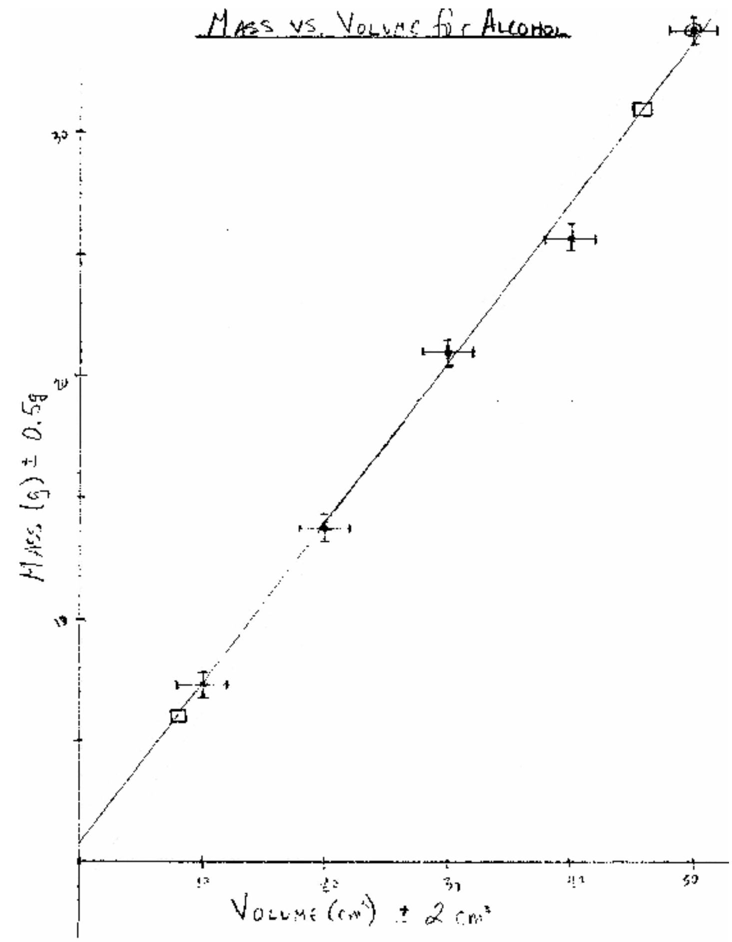
3. The sides of a rectangle are measured to be 4.4 ± 0.2 cm and 8.5 ± 0.3 cm. Find the area of the rectangle.

4. A car traveled 600 m ± 10 m in 32 ± 3 s. What was the speed of the car?

5. The radius of a circle is measured to be 2.4 cm ± 0.1 cm. What is the area of the circle?

Conventions for Graphing Data

Volume (cm^3) $\pm$ 2 cm^3	10.	20.	30.	40.	50.
Mass (g) $\pm$ 0.5 g	7.2	12.8	21.0	25.7	35.2



1. Use a clean sheet of graph paper, a ruler, and a sharp pencil and plan your graph to take up most of the page.

2. Label each axis with a variable name, symbol, and units, for example **Volume (V) (cm^3)**. Usually, the independent variable is graphed on the x-axis, though there are often times and reasons for graphing it on the y-axis, such as, if it better matches your math model this way.

3. Choose an appropriate scale for each axis. Usually you should begin the graph at (0, 0). (On a **very rare** occasion, you may need a "break" in the graph where you skip to higher values. Avoid doing this if at all possible.) Space out the units appropriately and evenly. The value of the spacing does not have to be the same on each axis.

4. Title your graph: *Dependent vs. Independent* For example: *Mass vs. Volume for a Sample of Alcohol*

5. Plot your points carefully – make the dot large enough to see.

6. Should you put a data point at (0,0)? If it was not one of the measured data points, you will have to make a judgment as to whether or not it should be included as part of your graphed data.

7. Include ***error bars*** drawn to scale for each data point in at least one direction (x or y). Choose the most significant error bars (proportionally largest) to draw.

8. Do not play "connect-the-dots" with your data points. Look at the general shape made by your data points and decide what relationship it looks like. If it looks linear, draw in with a ruler a ***best-fit line*** (regression line) that fits within all or most of your error bars. Try to have as many points above the best-fit line as below it.

9. Consider any *outlier*. This is a point where the best-fit line doesn't go through the error bars. Maybe you made some mistake when taking this data point. You will have to explain why it's an outlier in your lab evaluation. If you have too many outliers, maybe the shape isn't really linear.

10. If it looks like some other relationship (quadratic, inverse, etc.), draw in that ***best-fit curve*** smoothly by hand. (Sometimes even a curve is called a best-fit "line.")

11. If it's a straight line, calculate the ***slope*** *(gradient)* of the line. Use two points **on** the line - these may or may not be data points. Put a box around each point used, state their actual coordinates (don't count boxes) and show your calculations, including formula and substitutions. Express the result as a decimal to the appropriate number of significant digits and include units. For example:

$$slope = m = \frac{\Delta y}{\Delta x} = \frac{31.0g - 6.0g}{46.0cm^3 - 8.0cm^3} = 0.66\frac{g}{cm^3}$$

12. Write the ***experimental relationship*** for the line you've drawn by filling in the specific symbols for your data and the slope and y-intercept into the general equation for a line.

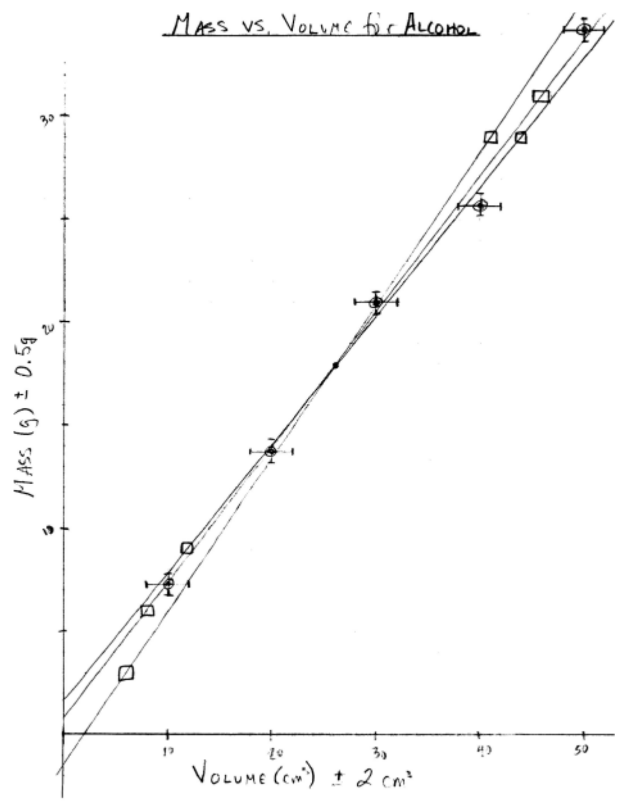
General Equation:		$slope = 0.66\frac{g}{cm^3}$		*Experimental Relationship:*
y = mx + b	⟶	y-intercept = 0.8 g	⟶	M = (0.66 g/cm^3)V + 0.8 g

13. Consider the physical significance of the slope and/or the y-intercept. Does it have a meaning or a special name? Compare your equation to a known ***mathematical model*** in order to draw conclusions.

Mathematical Model: $D = \frac{M}{V}$ *or* $M = D \cdot V$

Conclusion:
By comparing the experimental equation to the mathematical model, the slope represents the density of the liquid so the alcohol's density is 0.66 g/cm^3.

14. Draw the line of maximum slope that fits your error bars and the line of minimum slope that fits your error bars. These are called your *max/min lines***.** All three lines (best-fit, max, min) should cross at or near the midpoint of your data. The quickest and easiest way to do this is to connect the top(left) of the first error bar to the bottom(right) of the last error bar (for a minimum line) and the bottom(right) of the first error bar to the top(left) of the last error bar (for a maximum line) unless the first or last points are clear outliers – use your judgment.



15. Determine the slopes of your max and min lines. You do not need to show these calculations. Calculate therange of your slopes (max slope – min slope) and use ½ the range as the uncertainty for the slope of your best-fit line. Round the uncertainty to one sig fig and be sure to match the decimal place between the best-fit slope and its uncertainty. (You may need to round the best-fit slope to do this.)

Maximum slope: 0.74 g/cm^3

Best-fit slope: 0.66 g/cm^3

Minimum slope: 0.63 g/cm^3

Range: 0.74 g/cm^3 – 0.63 g/cm^3 = 0.11 g/cm^3

Uncertainty: ½(0.11 g/cm^3) = 0.055 g/cm^3 = 0.06 g/cm^3

***Slope with uncertainty:* 0.66 g/cm^3 ± 0.06 g/cm^3**

16. If there is a physical significance for your slope and if there is a known literature value for this quantity, then decide if your results "agree with" the literature value by considering the uncertainty range.

Conclusion:
The literature value for the density of ethyl alcohol is 0.71 g/cm^3. Our results agree with the literature value since 0.73 g/cm^3 lies within the uncertainty range of 0.66 g/cm^3 ± 0.06 g/cm^3.

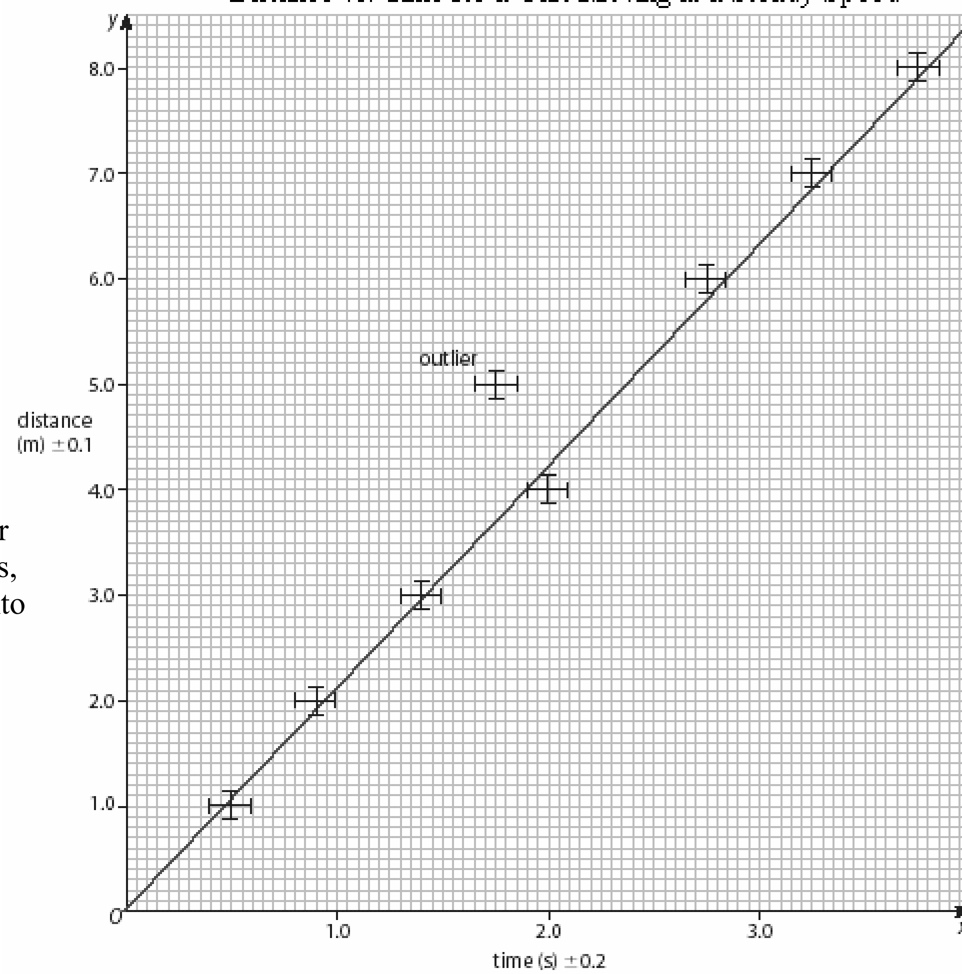
17. Does the mathematical model predict that the y-intercept should be zero? If so, see if your results agree with this by inspecting the graph to see if (0, 0) falls within the max and min lines you drew. If (0, 0) does **not** fall within the uncertainty range, you probably have a systematic error in your experiment that you will now have to account for.

Practice – Analyzing Data Graphically

HON

An experiment was done to determine the relationship between the distance a cart moved and the time it took to do this. The data is already graphed below with error bars and a best-fit line.

Distance vs. Time for a Cart Moving at a Steady Speed



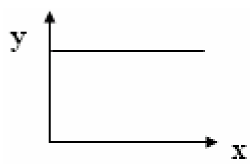
1. Calculate the slope of the best-fit line. Show your work, including equation and substitution with units.

2. Write the experimental relationship for this data. (Substitute specific symbols, the slope and y-intercept with units into the general equation for a line.)

3. Compare your experimental relationship to a math model for this experiment and make a conclusion about the meaning of the slope of the best-fit line.

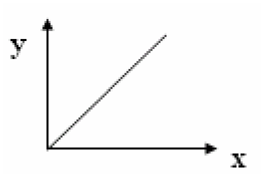
4. Use a ruler and sharp pencil to draw in the max/min lines. Calculate the slopes of these lines and find the range of slopes. Finally, write the value for the slope with its uncertainty. (Remember, slope uncertainty = ½ range.)

Graphical Representations of Relationships Between Data Sets

1. 

Name:

General equation:

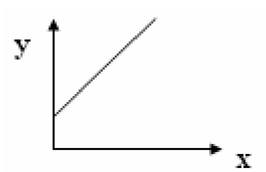
2. 

Name:

Proportion:

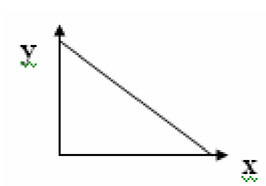
Constant of proportionality

General equation:

3. 

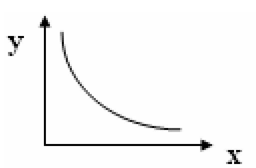
Name:

General equation:

4. 

Name:

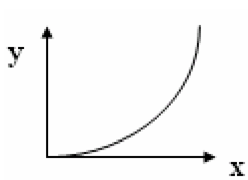
General equation:

5. 

Name:

Proportion:

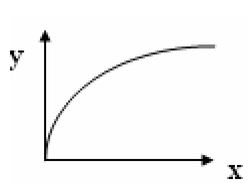
General equation:

6. 

Name:

Proportion:

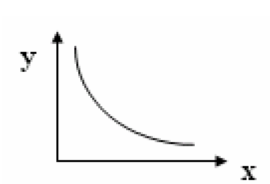
General equation:

7. 

Name:

Proportion:

General equation:

8. 

Name:

Proportion:

General equation:

Graph Straightening

Linearizing (straightening) a graph:

Transforming a non-linear graph into a linear one by an appropriate transformation of the variables and a re-plotting of the data points.

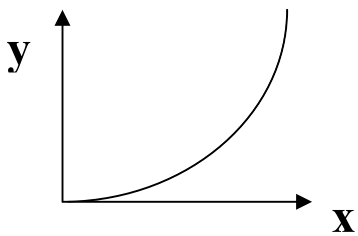
Purpose:

To find the constant of proportionality and write the experimental equation so the relationship can be compared to a mathematical model.

For each relationship shown below, give the name and the general equation for it.
Then, show the transformed variables that should be graphed in order to straighten the graph.

1.

Original Graph

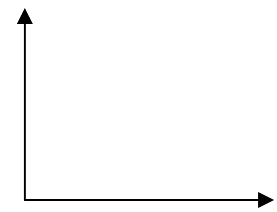


Name and General Equation

Transformation of variables

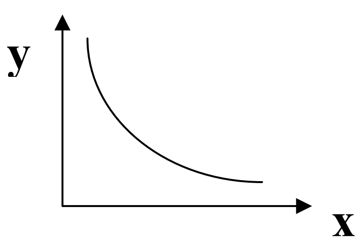
x	y	

Straightened Graph



2.

Original Graph

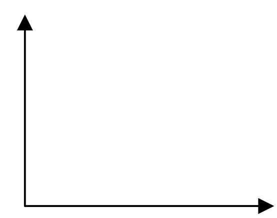


Name and General Equation

Transformation of variables

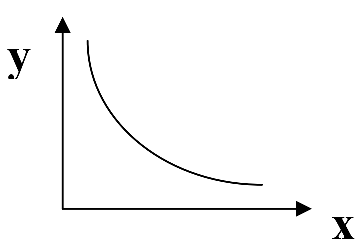
x	y	

Straightened Graph



3.

Original Graph

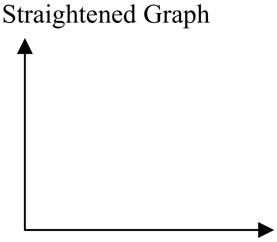


Name and General Equation

Transformation of variables

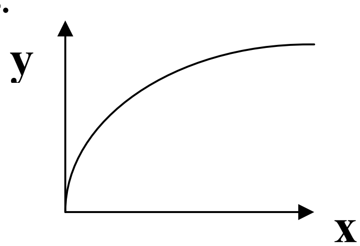
x	y	

Straightened Graph



4.

Original Graph



Name and General Equation

Transformation of variables

x	y	

Straightened Graph

How does straightening the graph help in writing the experimental equation for a non-linear relationship?

Raw score:	/ 44
Final Grade:	/ 15

Name: ___________________________________ Row: _______
Date: _______________________ Physics

WORKSHEET: Graph Straightening

Below is a sample data set for an experiment involving distance and time for a car.

Time (s) ± 0.2 s	**0**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**
Displacement (m) ± 5 m	**0**	**5**	**20.**	**44**	**78**	**123**

1. Graph the data on graph paper. Be sure to include all labels and error bars as well a best-fit curve drawn smoothly by hand. Attach the graph paper to this worksheet. (10)

2. Name the type of relationship you have plotted. (2)

2. State the general equation of the best-fit shape. (2)

3. Fill in the third data row with an appropriate heading (with units) and transformed data that will be used to straighten the graph. No uncertainties are needed on the transformed data. (6)

4. Graph the straightened data on graph paper on a new set of axes using proper graphing techniques. No error bars are needed on the straightened graph. Attach that graph to this worksheet as well. (10)

6. Calculate the slope of the straightened graph. Show your work below, including the equation and substitution with units. (4)

7. Use the general equation of your original graph and the slope of your straightened graph to write the experimental relationship for your data. (4)

8. Use the mathematical model **distance = ½ acceleration x time²** ($d = \frac{1}{2} a \cdot t^2$) to make a conclusion about the meaning of the slope by comparing the math model to your experimental equation. State your conclusion here. (2)

9. State the acceleration of the car. (2)

(2)
neatness

Raw Score:	/ 34
Final Grade:	/ 15

Name: ________________________________ Row _______
Date: _______________ Physics

WORKSHEET: Analyzing Data Graphically

EXPERIMENT: Phil Harmonic wanted to determine the relationship between time and distance as he rode his bike. He hypothesized that the relationship was linear. As he biked, his friend measured the total distance Phil had traveled after each second.

Time (s) ± 0. 2 s	Distance (m) ± 2 m
1.0	12
2.2	25
3.1	32
4.2	45
5.0	58

1. Graph the data on graph paper. Be sure to include all labels and error bars as well as a best-fit line. Attach the graph paper to this worksheet. (10)

2. Calculate the slope of the best-fit line. Show your work below, including the equation and substitution with units. (4)

3. Write the experimental relationship for your data. (4)

4. Use the mathematical model **distance = velocity x time** ($d = v \cdot t$) to make a conclusion about the meaning of the slope by comparing the math model to your experimental relationship. State your conclusion here. (2)

5. Draw a line of maximum slope and a line of minimum slope through your errors bars on the graph. Then, state the slopes of the max and min lines. (You do not need to show these calculations.) (4) (4)

6. State the value for the best-fit slope with its uncertainty. Show how you obtained the uncertainty. (4)

(2) neatness