Physics Lesson 1 Measurements, Units, Application of Vectors

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Fundamental Units of Physics

Quantity	Measured in……
Mass	
Time	
Length	
Amount	
Temperature	
Charge	Coulombs

(Note: The SI unit for charge is _____ even though Coulombs are more often used for problem solving)

Prefix	Value
Tera-	$\times 10^{12}$
Giga-	
Mega-	$\times 10^{6}$
Kilo-	
Deci-	
Centi-	
Milli-	$\times 10^{-3}$
Micro-	
Nano-	
Pico-	
Femto-	

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Derived Units, Unit Analysis of Unfamiliar Quantities

1. Express the Newton in SI units.

Answer: since F = ma,

2. The equation for gravitational force is $F = GM_1M_2/r^2$ where G = Newton's gravitational constant, M_1 and M_2 being masses and r being the separation between two bodies. Use it to deduce the SI Unit expression for G.

Answer: equating units on both sides of the equation:

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Table of Some Physical Quantities

Quantity	Symbol	Equation	SI Units
Speed	v		
Acceleration	a		
Force	F		1 N = 1 _____
Energy	KE, PE, etc	Work done = force x distance	
Power	P		
Pressure	P		1 Pa = 1 _____
Spring constant	k		
Voltage			1 V = 1 _____
Current			1 A = 1 _____
Electric resistance			
Specific Heat capacity	c		
Electric field	E	Force = Electric field x charge	
Magnetic Field	B	Force = current x length x Magnetic field	

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Unit Conversion Exercises

1 The photon is the carrier of energy of a beam of light. The equation that governs energy per photon is E = hf where E = photon energy and f is frequency of the beam of light. Use this to deduce the SI unit expression for h (which is called the Planck's constant).

2 The equation that governs drag force on a sphere falling in a fluid is $F_{drag} = 6\pi\eta rv$ where η = viscosity, r = radius of a sphere and v = velocity of sphere. Use this to deduce the SI unit expression for viscosity.

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Measurements

- **Decimal places vs. sig figs**
  e.g. The number 0.03070 has ___ decimal places and ___ significant figures.
- **Order of magnitude**: Two numbers have the same order of magnitude if they have the same power of 10 in their standard form notation
  e.g. wavelength of red light ( ) vs. wavelength of violet light ( )
- **Absolute error, relative error and percentage error:**
  The absolute error for an analogue instrument is half the smallest division on the instrument. The absolute error for a digital instrument is the smallest difference displayable on the instrument.
  Relative (or percentage) error =
  e.g. A ruler measures the length of a pencil to be 4.0 cm correct to the nearest tenth of a cm. The absolute error is _____ cm and the % error is _____.

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Decimals and Sig-figs in Science

- Adding or subtracting: Record the final answer with the same number of _____ as the least precise figure:

  e.g. 103.55 ^{o}C – 97.75 ^{o}C =

  e.g. 4.3 x 10^{-3} grams + 1.7 x 10^{-2} grams =
- Multiplying or dividing: record the final answer with the same number of _____ as the least precise figure:

  e.g. 6.6 V / 0.140 A =

  e.g. 1.36 x 10^{3} N x 0.75 m =
- A 1.20 kg sample of water is heated from 49.5 ^{o}C to 54.8 ^{o}C. The specific heat capacity of water is 4.18 J g^{-1} $^{o}C^{-1}$. Calculate the heat energy required using the equation Q = :

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Error Propagation in Science

- Adding and subtracting figures with errors:

  Final value = sum or difference of the two figures
  Final error = sum of _____

  e.g. (103.55 ± 0.01) ^{o}C – (97.75 ± 0.01) ^{o}C =
- Multiplying and dividing figures with errors:

  Final value = product or quotient of the two figures
  Final % error = sum of _____

  e.g. (6.6 ± 0.1) V / (0.140 ± 0.001) A

  (convert to relative or % errors) = (6.6 ± %) V / (0.140 ± %) A

  = 47.14..... ± Ω

  (convert back to abs. error) = 47 ± Ω

Beware of premature rounding problems

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Precision and Accuracy

- An accurate measurement is one that is in agreement with reality.
- A precise measurement has a very small percentage error. Generally, a 1% relative error is considered to be acceptably precise.

Example:

A student used a light gate to measure the time for a ball to fall 5.0 ± 0.1 meters to be 0.808, 0.931, 0.970, 0.977 and 0.994 seconds, respectively. The average time is used to estimate the value of gravitational acceleration using the equation $s = 0.5gt^2$.

The calculated value of g using the average time is _____ $m\ s^{-2}$.

The uncertainty of g according to this data set is (max – min) / 2 = _____ $m\ s^{-2}$.

Each individual measurement is _____ because _____
_____

The entire set of data is _____ because _____
_____

Overall, the experiment is _____ because _____
_____

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Using straight-line graphs in physics

Straight-line graphs are often used in physics to investigate the relation between two quantities. Obtaining a straight-line relation between two physical quantities often requires mathematical manipulation of a physics equation into the form "y" = m" x" + c

Example: oscillation period of a horizontal spring, varied mass attached, frictionless surface.

Theoretical relation:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

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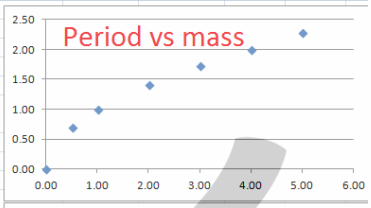
Obtaining Straight-line Graphs

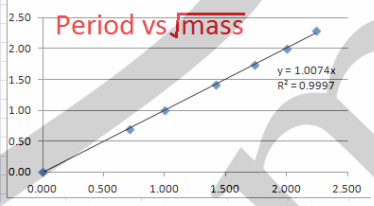
A plot of T vs square-root of m yields a straight line with gradient _____ and y-intercept = 0

The numerical value of the gradient is _____ according to Excel's best fit line equation.

The spring constant of the spring used in the experiment is calculated to be

mass (kg)	oscillation period (s)	square root of m
0.00	0.00	0.000
0.50	0.70	0.707
1.00	1.00	1.000
2.00	1.42	1.414
3.00	1.74	1.732
4.00	2.00	2.000
5.00	2.28	2.236





In addition to plotting T vs $\sqrt{m}$, you can also end up with straight lines if you choose to plot T^2 vs m, or even log T vs log m.

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Analysing Straight-line Graphs

Relation	Equation	Plot what against what?		Gradient	Y-intercept
		y	x		
Oscillation period of a metal spring, different masses attached, to measure the spring constant (k)	$T = 2\pi\sqrt{\frac{m}{k}}$	T	$\sqrt{m}$		
		T^2	m		
		log T	log m		
Oscillation period of pendula, varying pendulum lengths, in order to measure g	$T = 2\pi\sqrt{\frac{l}{g}}$	T^2			
acceleration of fixed-mass object using varying driving force under unknown constant friction	$a = \frac{F - F_r}{m}$	a	F		
Available voltage (V) of a battery when operated at different currents, with unknown constant emf (E) and unknown, constant internal battery resistance	V = E - Ir				
Relation between pressure and volume of a constant amount of ideal gas at known constant T, in order to estimate the ideal gas constant R	PV = nRT				
Radioactive decay -- radioactivity at different times, in order to estimate the half-life of a sample	$A = A_0(0.5)^{\frac{t}{\text{half life}}}$				

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Vector

- A vector is a quantity that has both a magnitude and direction associated with it.

Examples of scalars	**Examples of vectors**
Distance	Displacement (difference in position)
Speed	Velocity
Gaseous pressure	Acceleration
Energy	Force
Charge	Momentum
Time	Field
Temperature	
Amount (in moles)	

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Vector Calculations in 1 Dimension

- Designate one direction as "forward" or positive direction.
- Be aware of signs
- Draw diagrams if necessary

1. A 10-kg rock is falling in air.
   a) Calculate its weight if gravity is 9.8 m s^{-2}.
   b) Calculate the resultant force, or net force, given that drag = 75 N and upthrust = 3 N.

2. A cargo boat is sailing east at 15 m/s. A conveyor belt on the boat is transporting parcels at a belt speed of 2 m/s to the back (west) of the boat. A cat is trying to run east with a speed of 6 m/s east on the belt, relative to the belt. Let east = positive.
   a) Find the velocity of the cat relative to a parcel
   b) Find the velocity of the cat relative to the sea.
   c) Find the velocity of the cat relative to the floor of the boat.
   d) Find the velocity of a parcel relative to the cat.

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Vector Calculation in 2D

- Draw an accurate diagram.
- Use either……
  - Head-to-tail diagrams or parallelograms to give u a rough idea of the resultant
  - Components, Pythagoras and trigonometry for the most accurate answer
- Example: a bird trying to fly with a speed of 10 m/s north in the presence of a 6 m/s wind from the east:

What will happen if the bird aims straight north

How the bird should allow the wind to guide it north

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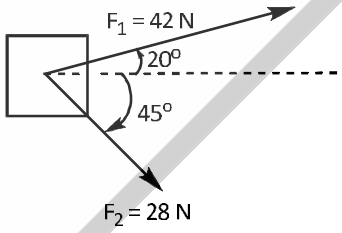
Forces in 2D

A 10-kg block is pulled by two forces in directions as shown in the diagram. Calculate the resultant force F_{net}, the magnitude of acceleration and the direction of acceleration.



Answer: resolve forces into components:

$F_{1,x}$ =
$F_{1,y}$ =
$F_{2,x}$ =
$F_{2,y}$ =

F_x =
F_y =

F_{net} (using Pythagoras) =

Direction of F_{net} (using bearings):

Acceleration =

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Review questions

1. Express the units for following quantities in fundamental SI units:
   a) Gravitational potential (gravitational potential energy per mass)
   b) Ideal gas constant, R, from PV = nRT where n = number of moles

2. A student carried out a convex-lens experiment to investigate the relation between object-lens distance (u), image-lens distance (v) and focal length (f). According to scientific theory the relation between the three quantities is 1/u + 1/v = 1/f. The student varied u and measured the v for each corresponding u. Describe what the student should plot to obtain a straight-line graph, and how the student can deduce the focal length from the graph.

3. The side length of a copper cube is 1.4 cm measured using an ordinary ruler. The mass of this cube is 24.4 grams measured using a digital balance. Calculate the density of copper, indicating the uncertainties associated with these measurements.

4. A plane needs to fly straight north 1000 km amidst wind blowing from the north-east at 80 km per hour. The plane engine is capable of getting the plane up to 650 km per hour. Draw a diagram to show how the plane should angle its direction of flight, and calculate the time required to fly 1000 km under such conditions.

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