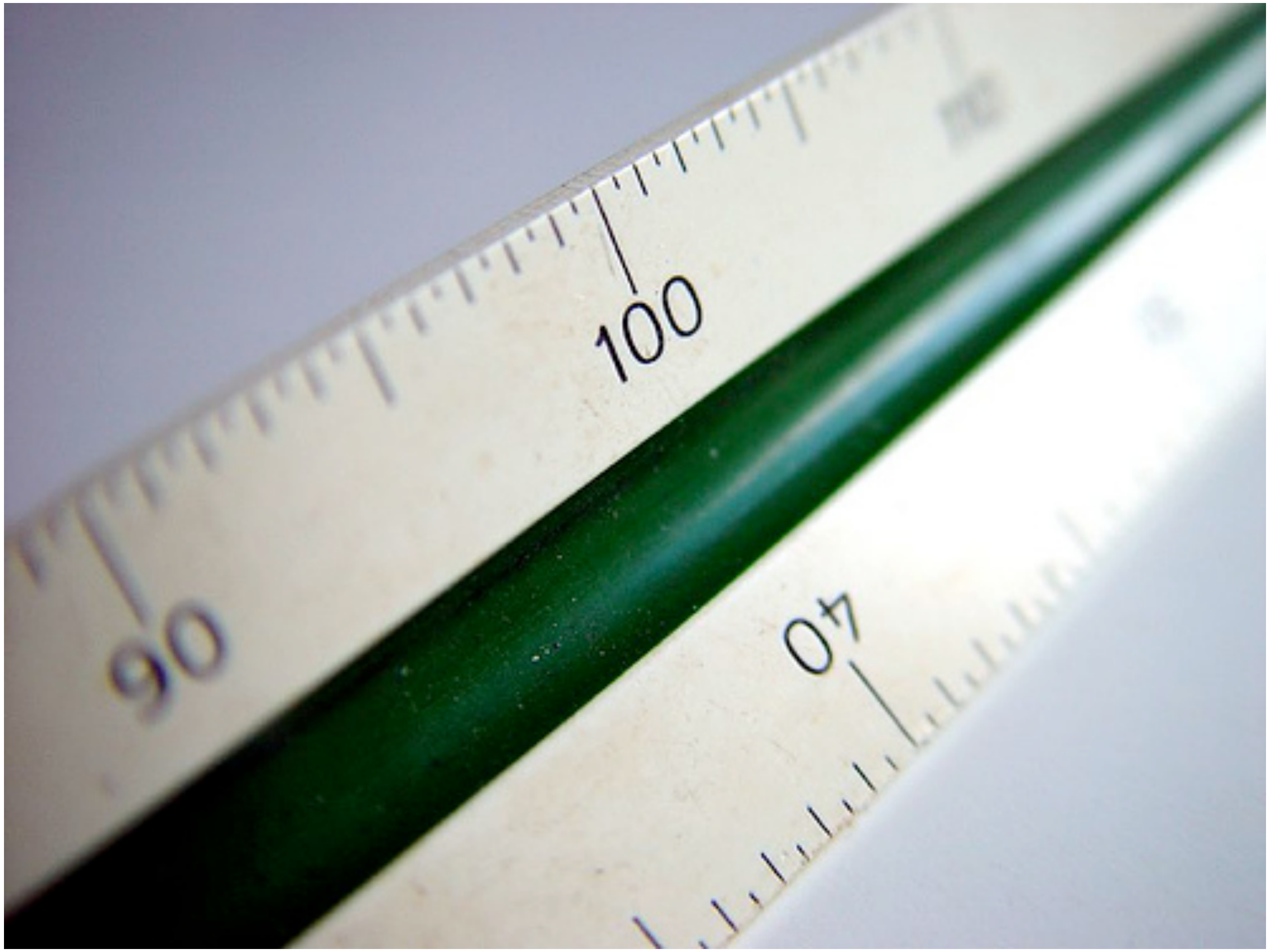
1. Physics and Physical Measurement



Topic Outline

Section	Recommended Time	Giancoli Sections
1.1 The realm of physics	1h	1.1, 1.2, 1.3, 1.4, 1.5, 1.7
1.2 Measurement and uncertainties	2h	1.4
1.3 Vectors and scalars	2h	3.1, 3.2, 3.3

- The skills in this section are important for your internally-assessed lab reports
- The graphing skills in this section are important for Paper 2, Section A

Orders of Magnitude

Metric prefixes are used to express large or small numbers in a form that is more manageable

Prefix	Symbol	Order of Magnitude
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Examples of Orders of Magnitude

Example	Order	Example	Order
Diameter of a sub-nuclear particle		Mass of a car	
Diameter of an electron		Mass of Earth	
Diameter of an atom		Mass of Sun	
Height of a person		Mass of Universe	
Diameter of Earth		Time for light to travel across nucleus	
Diameter of Sun		Time for light to travel from Sun to Earth	
Distance light travels in a year		Time for light to travel from Sun to Pluto	
Diameter of visible Universe		Average human life span	
Mass of an electron		Time for light to travel from Alpha Centuri to Earth	
Mass of an atom		Age of Universe	

Examples of Orders of Magnitude

Example	Order	Example	Order
Diameter of a sub-nuclear particle	10^{-15} m	Mass of a car	10^{3} kg
Diameter of an electron	10^{-13} m	Mass of Earth	10^{25} kg
Diameter of an atom	10^{-10} m	Mass of Sun	10^{30} kg
Height of a person	10^{0} m	Mass of Universe	10^{50} kg
Diameter of Earth	10^{7} m	Time for light to travel across nucleus	10^{-23} s
Diameter of Sun	10^{9} m	Time for light to travel from Sun to Earth	10^{2} s
Distance light travels in a year	10^{16} m	Time for light to travel from Sun to Pluto	10^{4} s
Diameter of visible Universe	10^{25} m	Average human life span	10^{9} s
Mass of an electron	10^{-30} kg	Time for light to travel from Alpha Centuri to Earth	10^{8} s
Mass of an atom	10^{-27} kg	Age of Universe	10^{18} s

Standard Form

- In standard form, we write one digit before the decimal place and then the appropriate order of magnitude

$$476\ 293\ 000 = 4.76293 \times 10^8$$

$$0.000000516 = 5.16 \times 10^{-7}$$

- Orders of magnitude can be used to estimate or compare measurements

Significant Figures

Significant figures are digits that are not merely placeholders

Number	Number of Significant Figures
4	
400	
0.000000004	
4.0	
127 000	
0.02365	
0.0236500	
500 000.00007	

Significant Figures

Significant figures are digits that are not merely placeholders

Number	Number of Significant Figures
4	1
400	1
0.000000004	1
4.0	2
127 000	3
0.02365	4
0.0236500	6
500 000.00007	11

Rounding

- Calculations are rounded to the same number of significant figures as the least accurate value in the calculation

$$2.430923485498 + 3.1 = 5.5 \text{ (2 s.f.)}$$

Exercises

- Worksheet 1: Significant figures and standard form

SI Base Units

- Physicists have an agreed system of units, called 'Le Système International d'Unités' (S.I. Units)
- There are seven base units, all other units are derived from these

Quantity	Quantity Symbol	Unit	Unit Symbol
Length	l	metre	m
Mass	m	kilogram	kg
Time	t	second	s
Electric current	I	ampere	A
Temperature	T	Kelvin	K
Amount of substance	n	mole	mol
Luminous intensity	I_v	candela	cd

Derived Units

- Derived units are formed from a combination of SI base units
- To derive a unit for a variable, we use the equation for that variable

$F = m \times a$

So the units for force are $kg \times ms^{-2} = kgms^{-2} = N$

Note: you must use negative index notation for units, e.g. use ms^{-2} *not* m/s^2

Derived Units

Quantity	Equation	Derived Unit	Other Unit
Force	F = ma	$kgms^{-2}$	N
Energy	W = Fd		
Torque	τ = Fr		
Power	P = W/t		
Charge	I = q/t		
Electric Field Strength	E = F/q		
Voltage	P = VI		
Resistance	V = IR		

Derived Units

Quantity	Equation	Derived Unit	Other Unit
Force	$F = ma$	$kgms^{-2}$	N
Energy	$W = Fd$	kgm^2s^{-2}	J
Torque	$\tau = Fr$	kgm^2s^{-2}	Nm
Power	$P = W/t$	kgm^2s^{-3}	W or Js^{-1}
Charge	$I = q/t$	As	C
Electric Field Strength	$E = F/q$	$kgms^{-3}A^{-1}$	Vm^{-1} or NC^{-1}
Voltage	$P = VI$	$kgm^2s^{-3}A^{-1}$	V
Resistance	$V = IR$	$kgm^2s^{-3}A^{-2}$	Ω

Standard Measures

- A standard measure is used as a reference
- It must be:
  - Unchanging with time
  - Readily accessible
  - Reproducible

The standard second is the time for

9 192 613 770 vibrations of the cesium-133 atom

Errors

- **Errors** are sources of uncertainty in a measurement
- There are two main classes of error:
  - **Systematic errors** are the result of the equipment or method (system), e.g. zero error, poorly calibrated instruments
  - **Random errors** occur randomly and are reduced by repeating measurements, e.g. normal variations, parallax error, insensitive instruments

Accuracy and Precision

- **Accuracy** is an indication of how close a value is to the true value (how close it is to the bull's eye)
- **Precision** is an indication of how similar repeated measurements are (the 'grouping' of shots at a target)

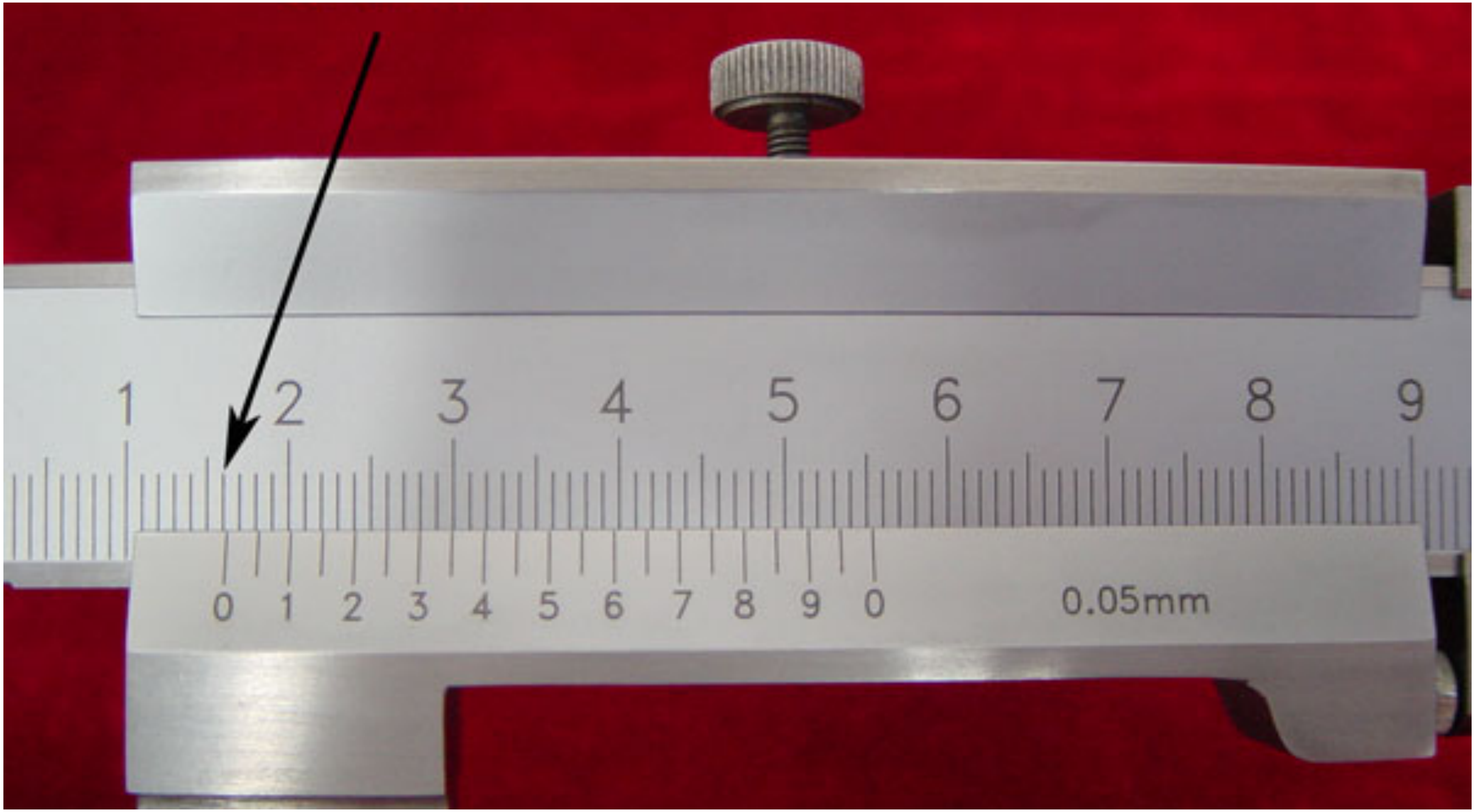
Uncertainties

- The **uncertainty** is an estimate of the possible inaccuracy in a measurement
  - We estimate the uncertainty in a measurement to be half the 'limit of reading', i.e. half the smallest scale division
  - If there is possibility for error at either end of the measurement, the uncertainty is the smallest scale division
  - If repeated measurements are made, the uncertainty is half the range of the measurements
- Uncertainties are given to 1 s.f. only

Practical

a. Observe zero error with a force meter
b. Observe parallax with an analogue meter
c. Time one oscillation of a pendulum then compare with measuring 10 oscillations and dividing by 10
d. Use Vernier calipers to measure the thickness of a piece of paper
e. Use Vernier calipers to measure the diameter of a marble, make 5 measurements to give a value and an uncertainty

Vernier Scales



Exercises

- Worksheet 2: Uncertainties
- Giancoli pp. 16-17 (section 1.4, 1.5-1.7)

Absolute and Percentage Uncertainties

- The **absolute uncertainty** is given in the same units as the measurement
- The **percentage uncertainty** is expressed as a percentage of the measurement

$$2.3 \pm 0.5 \text{ cm} = 2.3 \text{ cm} \pm 20\%$$

Combining Uncertainties

- When **adding or subtracting** measurements, **add** the **absolute uncertainties**
- When **multiplying or dividing** measurements, **add** the **percentage uncertainties**
- When raising a value to a **power**, **multiply** the percentage uncertainty by the **absolute value of the power**

Practical

- Measure the volume of a coin
- Process your uncertainties to give an uncertainty with the final measurement

Exercises

- Worksheet 3: Combining uncertainties

Graphing Skills

- When drawing a graph:
  - Use pencil, ruler and graph paper
  - Use suitable sized axes
  - Mark values with a linear scale
  - Label the axes, including units
  - Give a *descriptive* title
  - Plot data points
  - Draw a *best-fit* trend line

Graphing Skills

- To find the gradient:
  - Find two places where the best-fit line passes through easy-to-read points on the graph
  - Calculate the rise (Δy)
  - Calculate the run (Δx)
  - Calculate the gradient ($\Delta y/\Delta x$)

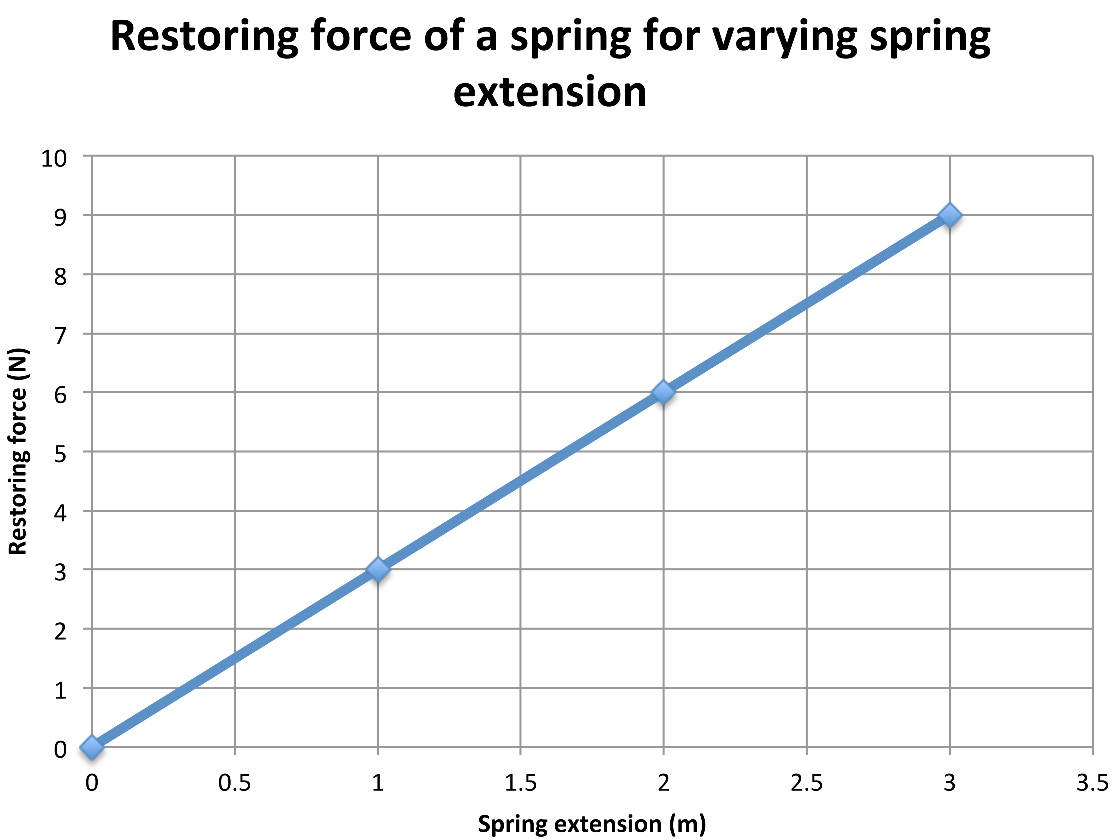
Graphing Skills

- To graph uncertainties:
  - **Error bars** are used to represent uncertainties in a measurement
  - The uncertainty in the y-value is drawn vertically
  - The uncertainty in the x-value is drawn horizontally
- The **best-fit line** is the line that best represents the data
- The **error line** is the steepest (or least steep) line that can be drawn through the error bars

Graphing Skills

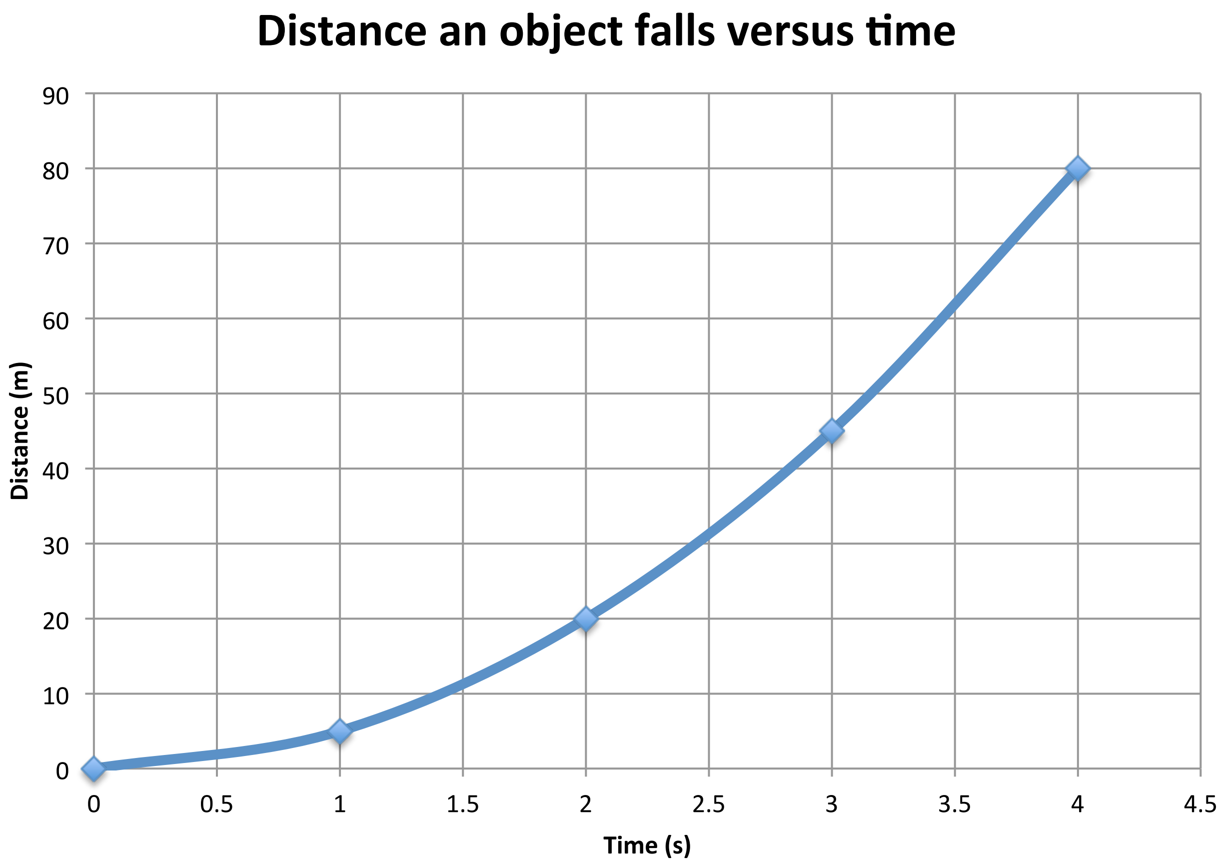
- **Interpolation** is finding a value *between* plotted points
- **Extrapolation** is finding a value *beyond* plotted points

Linear: y α x



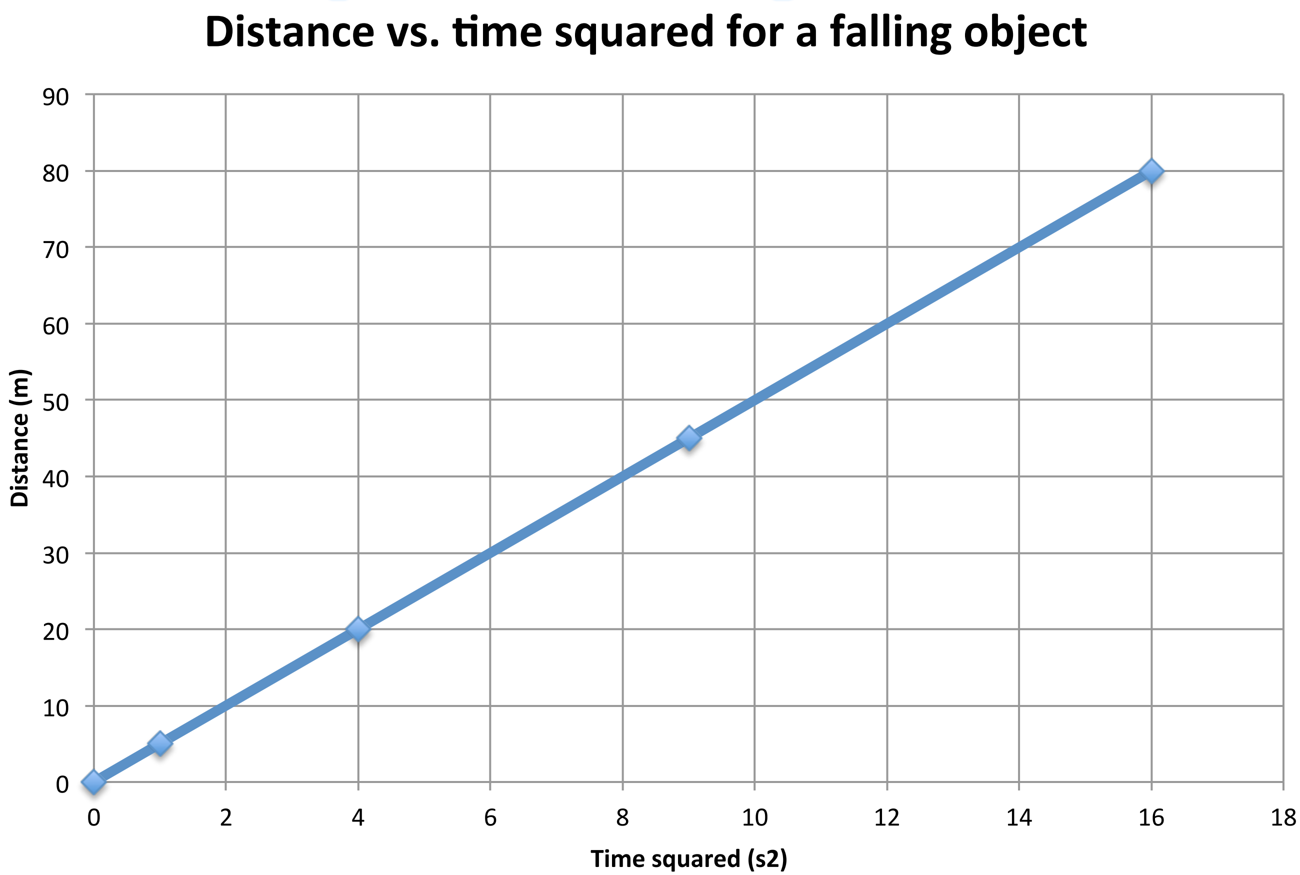
- If the y-intercept is zero, we can also say that y is *directly proportional* to x

Squared: $y \propto x^2$



- Plotting distance vs. time^2 will give a straight line graph of the form $y = mx + c$

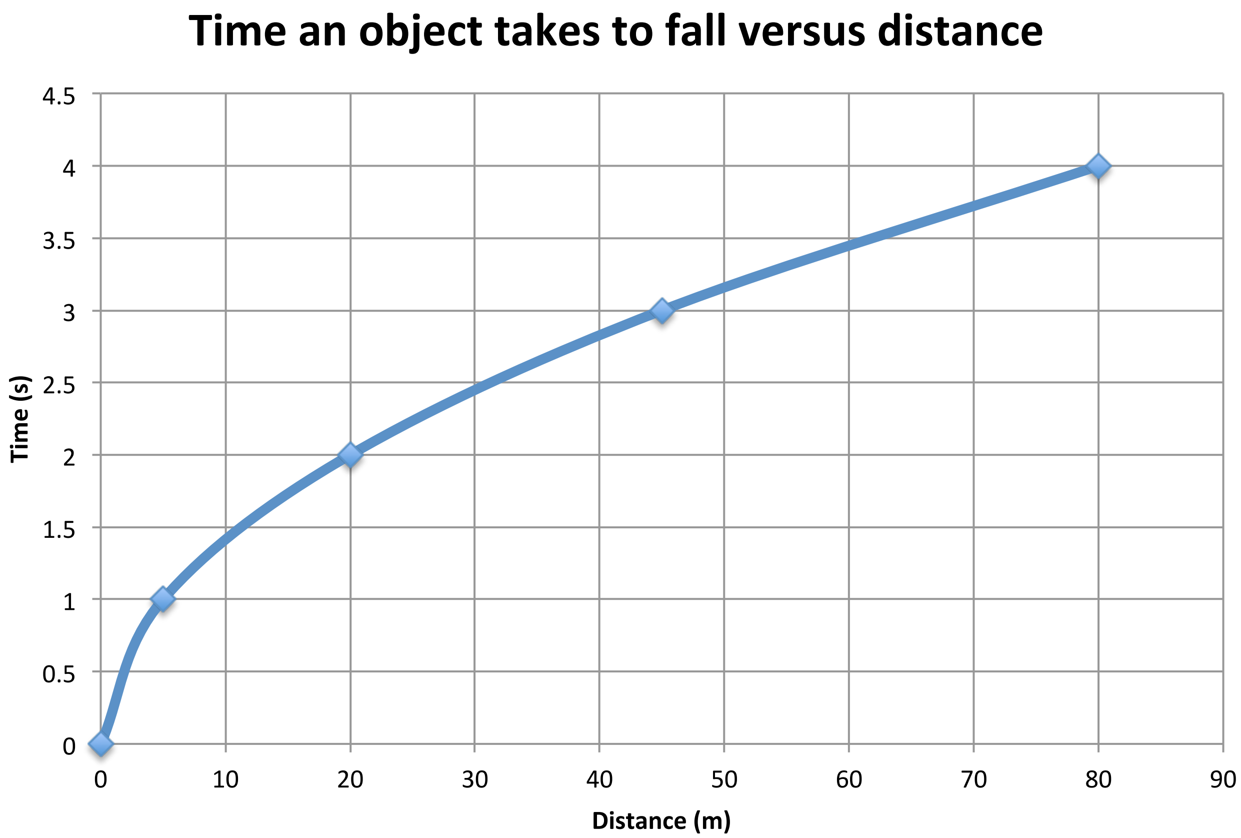
Squared: y α x^2



$$d = 5t^2 + 0$$

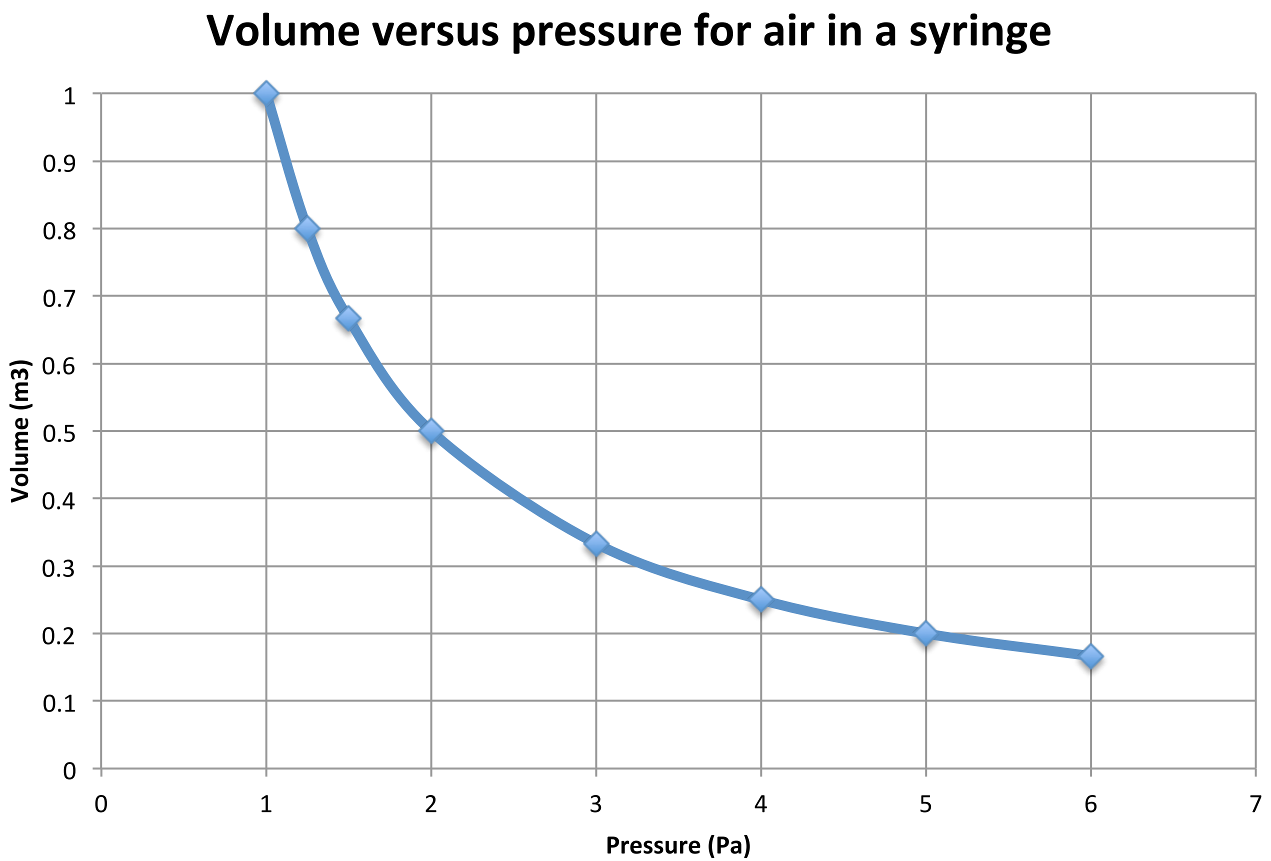
$$y = mx + c$$

Square Root: y α √x



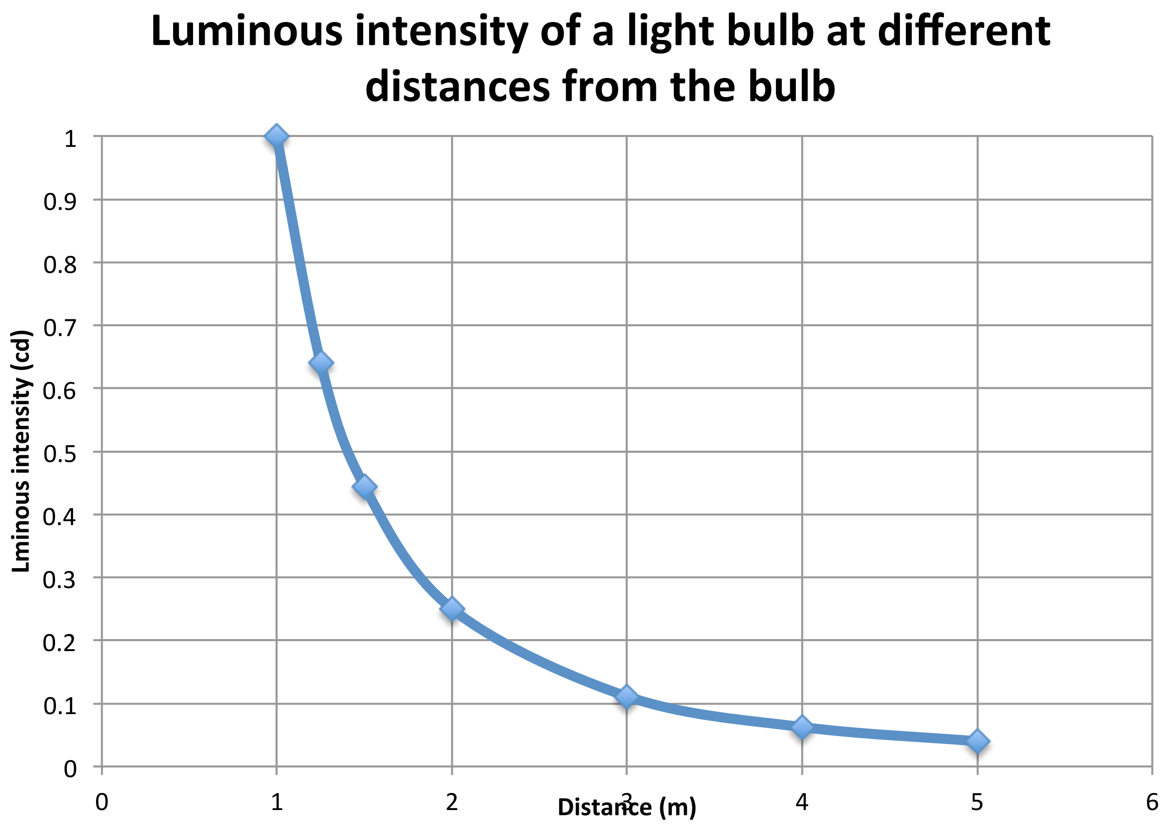
- Plotting time vs. √distance will give a straight line graph of the form y = mx + c

Inversely Proportional: y α 1/x



- Plotting volume vs. 1/pressure will give a straight line graph of the form y = mx + c

Inverse Square: $y \propto 1/x^2$

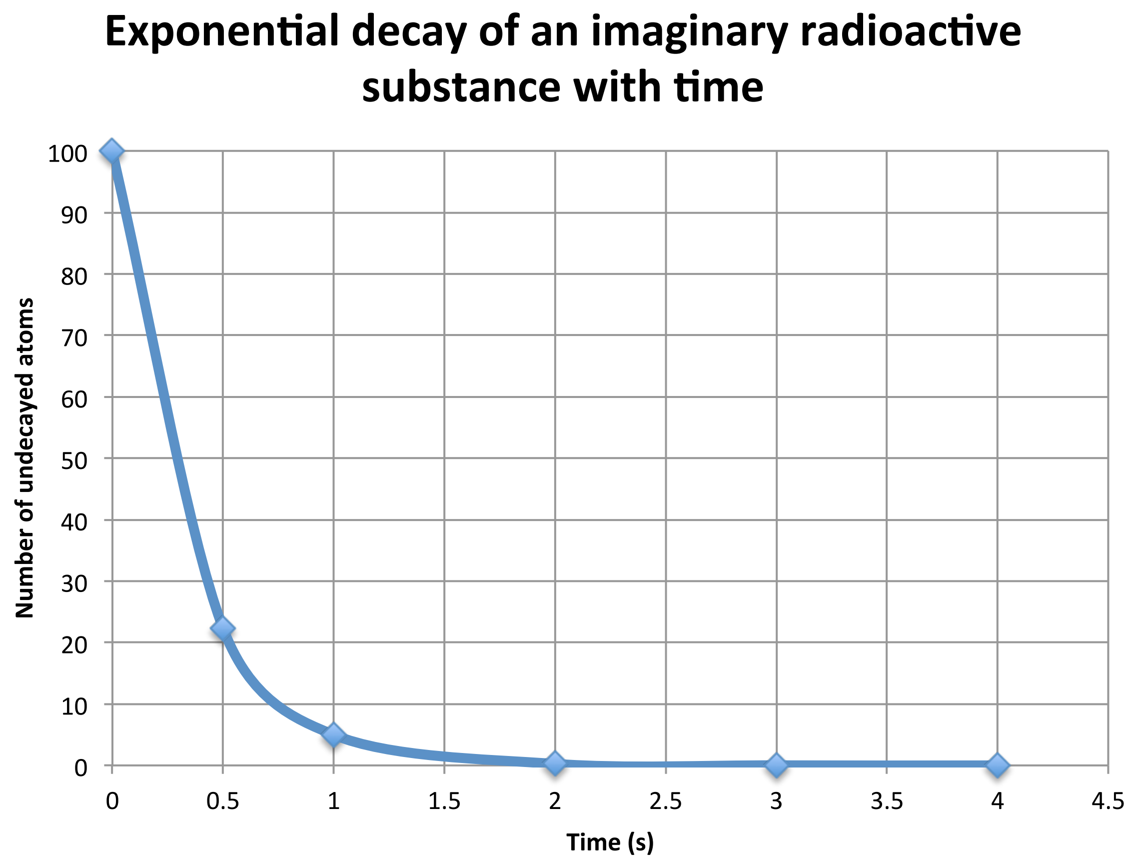


- Plotting intensity vs. 1/distance^2 will give a straight line graph of the form $y = mx + c$

Sinusoidal

- Sine and cosine graphs; these will be covered more in Topic 4

Exponential (AHL): y α e^x



Exponential decay of a radioactive sample

$$N = N_0 e^{-kt}$$

Exponential (AHL)

- Taking the natural log of both sides gives

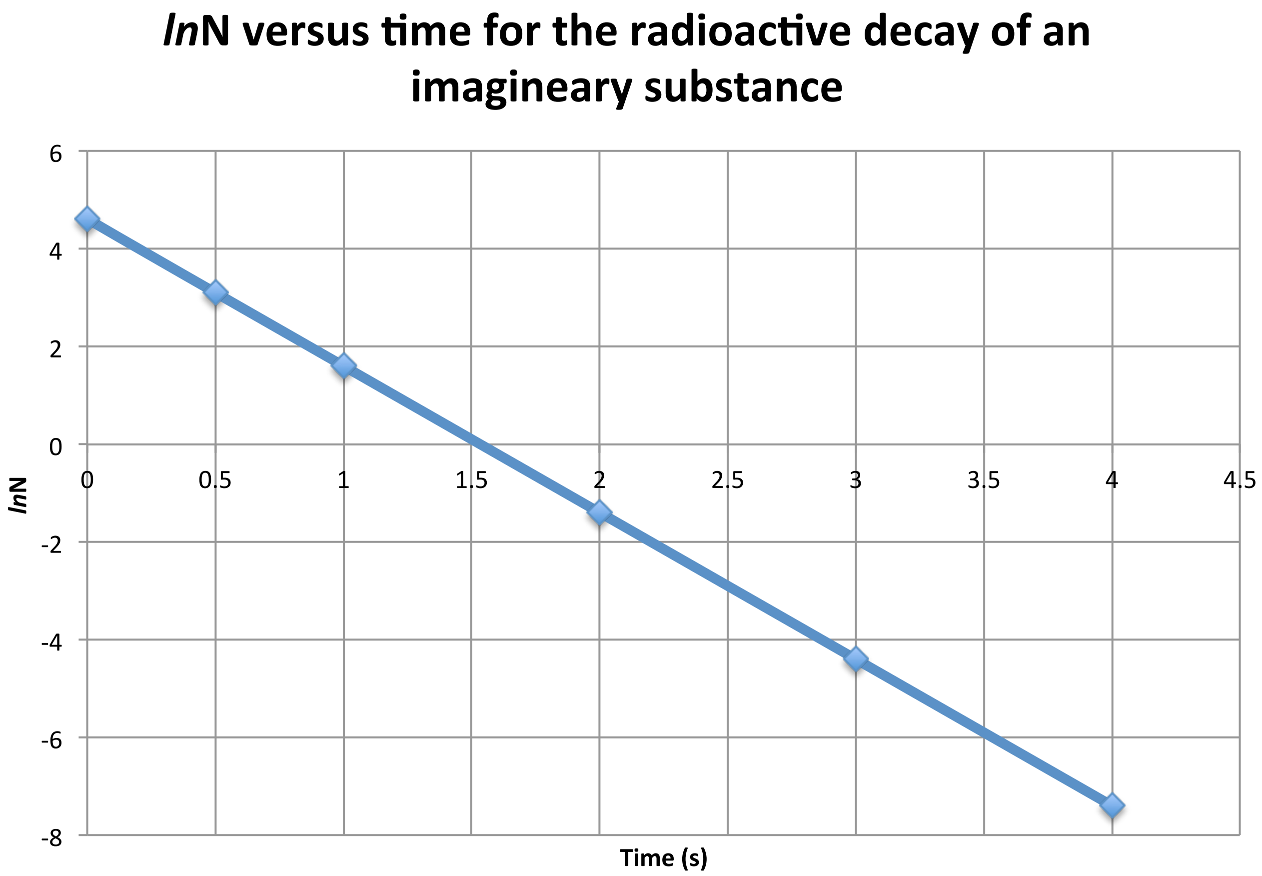
$$\ln N = \ln N_0 + \ln e^{-kt}$$

$$\ln N = \ln N_0 - kt$$

$$\ln N = -kt + \ln N_0$$

- Plotting $\ln N$ against t gives an equation of the form y = mx + c, with a gradient of –k and a y-intercept of $\ln N_0$

Exponential (AHL)



$$\ln N = -kt + \ln N_0$$

Logarithmic

- *Don’t yet have a good example, sorry*

Exercises

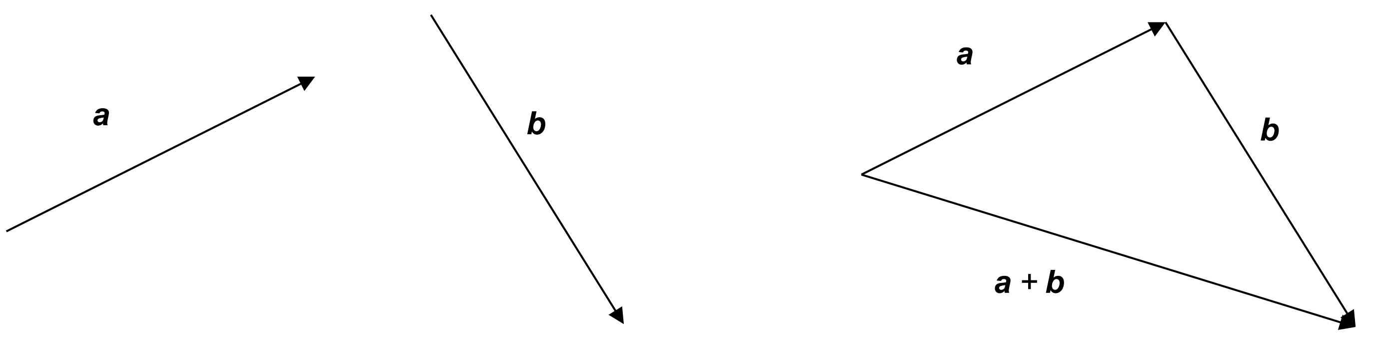
- Graphing Relationships (Rutter pp. 13-27)

Vectors and Scalars

- **Scalar** quantities only have *magnitude* (size)
  - e.g. distance, speed, mass, time,, charge, energy
  - Scalars are added algebraically
- **Vector** quantities have *magnitude* and *direction*
  - e.g. displacement, velocity, force, momentum
  - In IB, a vector is represented in bold, italicised print
  - Vectors are added in a particular way

Vector Addition

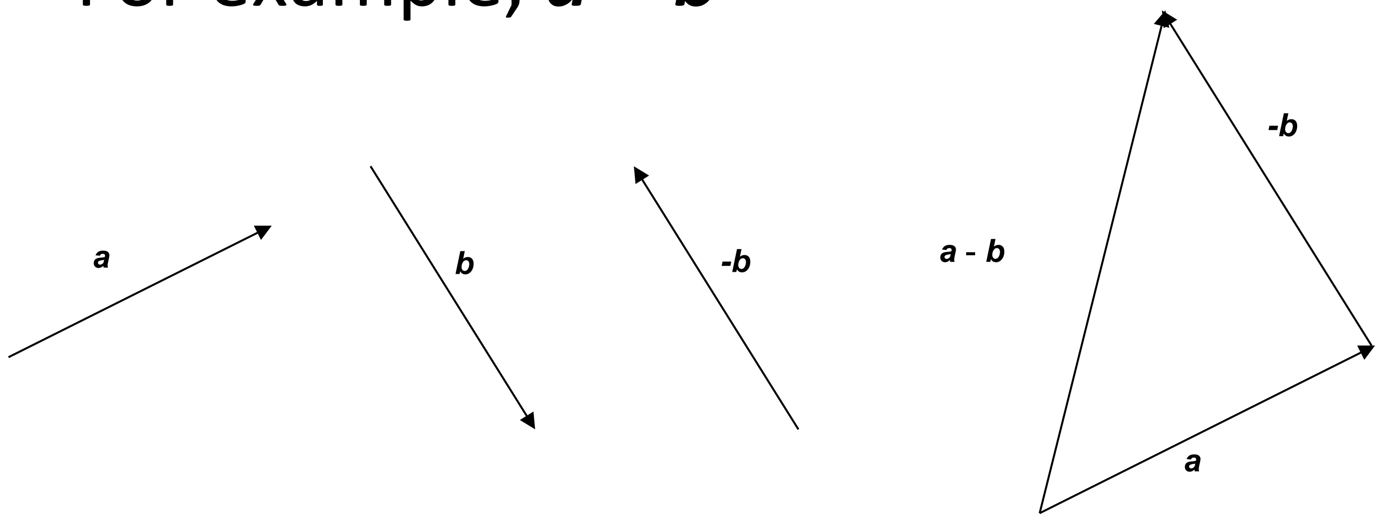
- Vectors are added 'head to tail' to find the resultant vector
- For example, adding vectors ***a*** and ***b***



- If this forms a right-angled triangle, use Pythagoras' Theorum to find the length of the resultant, and trigonometry to find the angle

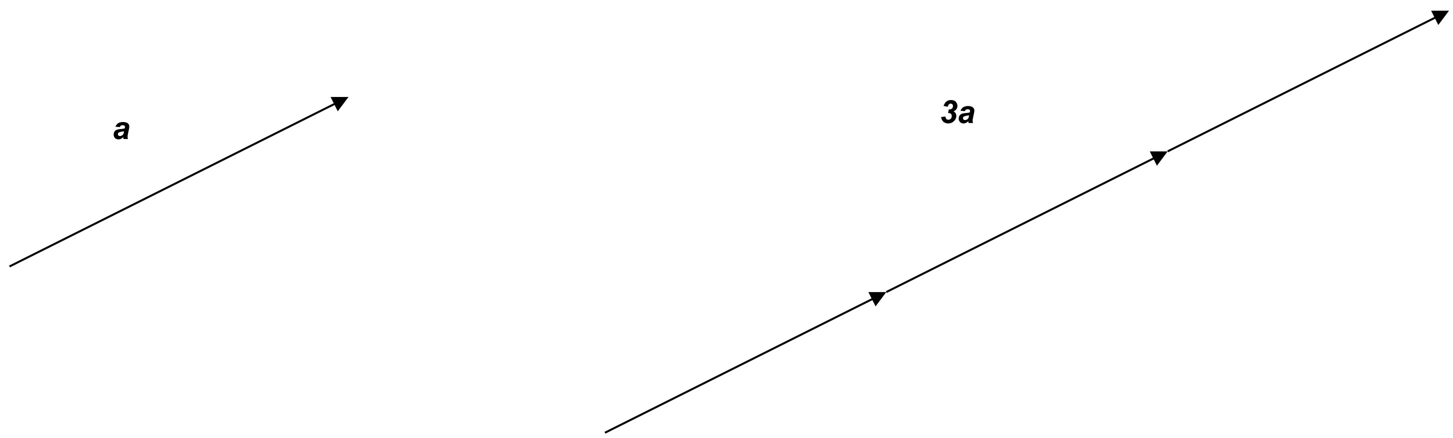
Vector Subtraction

- To subtract one vector from another, switch the direction of the arrow of the vector that is to be subtracted, then add the vectors
- For example, ***a*** - ***b***



Multiplying a Vector by a Scalar

- To multiply a vector by a scalar, keep the direction of the vector the same and multiply the magnitude by the scalar
- For example, 3 x ***a***



Multiplying Two Vectors (AHL)

- The **dot product** is when two vectors are multiplied to give a scalar
- For example W = ***F*** x ***d***
- Work is a scalar, but force and displacement are vectors
- Work is calculated by

$$W = \boldsymbol{F} \cdot \boldsymbol{d} = |F| \times |d| \times \cos\theta$$

- Where θ is the angle between ***F*** and ***d***

Multiplying Two Vectors (AHL)

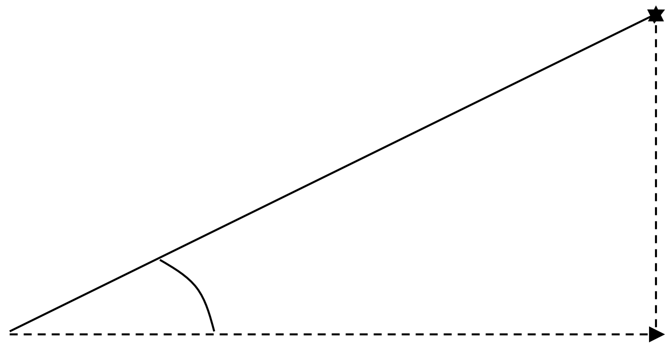
- The **cross product** is when two vectors are multiplied to give another vector
- For example, ***F*** = q***vB***
- Force, velocity and magnetic field strength are all vectors (charge is a scalar)
- The cross product ***vB*** is calculated

$$\boldsymbol{vB} = |v|\ |B|\ \sin\theta$$

- Where θ is the angle between ***F*** and ***d***
- The direction of the resultant is at right angles to both ***v*** and ***B***, given by the right-hand-thumb rule

X- and Y-Components of a Vector

- A vector can be resolved into its horizontal and vertical components



- We use trigonometry to find the lengths of the x- and y-components

Exercises

- Giancoli p. 70-71 (sections 3.2-3.4)

Revision

- Questions from Paper 2, Section A
- Practice internal – Simple Pendulum

Practical - Method

- Set up a simple pendulum
- Vary the length and measure the time period
- Use *five* values of the independent variable
- Use repeated measures (10 swings then divide by 10) for each measurement of period
- Make *five* measurements of period for each length
- Plot a graph

Practical – Results Table

Length (m) ± 0.001 m	Time for 10 Swings (s)	Time for 1 Swing (s)	Uncertainty in Period (s)
	<5 measurements>	<average>	<half range>

Practical - Graphing

- Plot a graph of period vs. length
- Include error bars in your graph
- Draw a best-fit line
- Transform your graph to give a straight line (i.e. plot T vs. √length)
- Transform your uncertainties in length
- Include error bars in your transformed graph
- Draw a best-fit line
- Draw an error line
- Find the equation of both lines
- Form a final equation, including uncertainties, for your experimental data

Practical – Write up

- See exemplar