

1st Science Physics Laboratory Manual

PHYC 10140
Physics – Diagnostic Imaging
2017-2018



Name.....

Partner's Name

Demonstrator

Group

Laboratory Time

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Introduction

Physics is an experimental science. The theory that is presented in lectures has its origins in, and is validated by, experiment.

Laboratories are staged through the semester in parallel to the lectures. They serve a number of purposes:

- ***an opportunity, as a scientist, to test theories by conducting meaningful scientific experiments;***
- ***a means to enrich and deepen understanding of physical concepts presented in lectures;***
- ***an opportunity to develop experimental techniques, in particular skills of data analysis, the understanding of experimental uncertainty, and the development of graphical visualisation of data.***

Based on these skills, you are expected to present experimental results in a logical fashion (graphically and in calculations), to use units correctly and consistently, and to plot graphs with appropriate axis labels and scales. You will have to draw clear conclusions (as briefly as possible) from the experimental investigations, on what are the major findings of each experiment and whether or not they are consistent with your predictions. You should also demonstrate an appreciation of the concept of experimental uncertainty and estimate its impact on the final result.

Some of the experiments in the manual may appear similar to those at school, but the emphasis and expectations are likely to be different. Do not treat this manual as a ‘cooking recipe’ where you follow a prescription. Instead, understand what it is you are doing, why you are asked to plot certain quantities, and how experimental uncertainties affect your results. It is more important ***to understand and show your understanding*** in the write-ups than it is to rush through each experiment ticking the boxes.

This manual includes blanks for entering most of your observations. Additional space is included at the end of each experiment for other relevant information. All data, observations and conclusions should be entered in this manual. Graphs may be produced by hand or electronically (details of a simple computer package are provided) and should be secured to this manual.

There will be six 2-hour practical laboratories in this module evaluated by continual assessment. Note that each laboratory is worth 5% so each laboratory session makes a significant contribution to your final mark for the module. Consequently, attendance and application during the laboratories are of the utmost importance. At the end of each laboratory session, your demonstrator will collect your work and mark it.

Laboratory Schedule:

Please consult the notice boards, Blackboard, or contact the lab manager, Thomas O'Reilly (Room Science East 1.41) if you have questions regarding which of the experiments you will be performing each week. This information is also summarized below.

Timetable:

Thursday 11-1 for groups 1 and 2.

Tuesday 11-1 for groups 3 and 4.

UCD	Semester 2	Room		
week	week	Science East 143	Science East 144	Science East 145
20	1			Springs: 1,3
22	3			Springs: 2,4
23	4	Beta-Ray: 1,3		
24	5		Hydrogen Spect: 1,3	
25	6	Beta-Ray: 2,4		
29	8		Hydrogen Spect: 2,4	
30	9	Half-life 1,3		
33	12	Half-life 2,4		

Grading Process

Grading is an important feedback for students and as such this is staged through the semester in close synchronisation with the labs. Students benefit from this feedback for continuous improvement through the semester. This is the grading process:

1. A lab script is graded and returned to the student in the subsequent scheduled lab slot.
2. Students resolve concerns regarding their grade with the demonstrator either during or immediately after this lab slot.
3. Grades are preliminary but can be expected to count towards a module grade once visible online. A grade is visible online within two weeks of the graded script being returned.

If the above doesn't happen, it is the student responsibility to resolve this with the demonstrator as early as possible.

Lab Rules

1. No eating or drinking
2. Bags and belongings should be placed on the shelves provided in the labs
3. The school of physics lab manual for your module is available in print from the school of physics admin office and is also available online from the school of physics pages. Students are only permitted to start a lab where they have this school of physics manual in print.
4. It is the student's responsibility to attend an originally assigned lab slot. Zero grade is assigned by default for no attendance at this lab.

In the case of unavoidable absence, it is the student's responsibility to complete the lab in an alternative slot as soon as possible. The student is graded if doing so, however such a slot can't be guaranteed as lab numbers are strictly limited. The lab manager, Thomas O'Reilly (Room Science East 1.41), may be of help in discussing potential alternative lab times. Where best efforts have been made to attend an alternative but this still hasn't been possible, students should then discuss with their module coordinator.

5. Students work in pairs in the lab, however students are reminded that reports should be prepared individually and should comply with UCD plagiarism policy (see next page).

UCD Plagiarism Statement

(taken from http://www.ucd.ie/registry/academicsecretariat/docs/plagiarism_po.pdf)

The creation of knowledge and wider understanding in all academic disciplines depends on building from existing sources of knowledge. The University upholds the principle of academic integrity, whereby appropriate acknowledgement is given to the contributions of others in any work, through appropriate internal citations and references. Students should be aware that good referencing is integral to the study of any subject and part of good academic practice.

The University understands plagiarism to be the inclusion of another person's writings or ideas or works, in any formally presented work (including essays, theses, projects, laboratory reports, examinations, oral, poster or slide presentations) which form part of the assessment requirements for a module or programme of study, without due acknowledgement either wholly or in part of the original source of the material through appropriate citation. Plagiarism is a form of academic dishonesty, where ideas are presented falsely, either implicitly or explicitly, as being the original thought of the author's. The presentation of work, which contains the ideas, or work of others without appropriate attribution and citation, (other than information that can be generally accepted to be common knowledge which is generally known and does not require to be formally cited in a written piece of work) is an act of plagiarism. It can include the following:

1. Presenting work authored by a third party, including other students, friends, family, or work purchased through internet services;
2. Presenting work copied extensively with only minor textual changes from the internet, books, journals or any other source;
3. Improper paraphrasing, where a passage or idea is summarised without due acknowledgement of the original source;
4. Failing to include citation of all original sources;
5. Representing collaborative work as one's own;

Plagiarism is a serious academic offence. While plagiarism may be easy to commit unintentionally, it is defined by the act not the intention. All students are responsible for being familiar with the University's policy statement on plagiarism and are encouraged, if in doubt, to seek guidance from an academic member of staff. The University advocates a developmental approach to plagiarism and encourages students to adopt good academic practice by maintaining academic integrity in the presentation of all academic work.

Name: _____

Student No: _____

Partner: _____ Date: _____ Demonstrator: _____

Springs

What should I expect in this experiment?

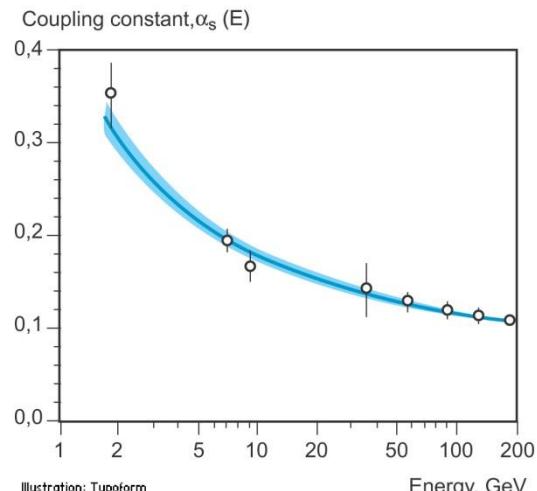
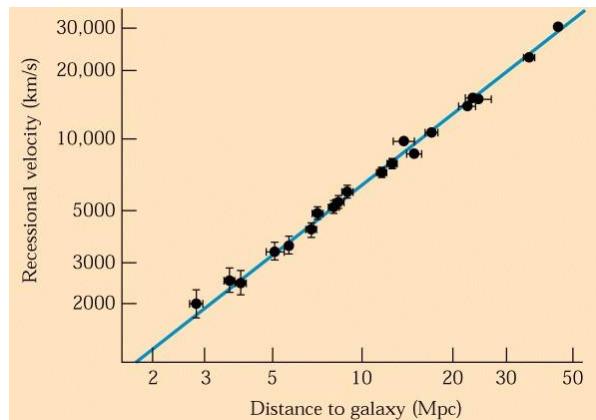
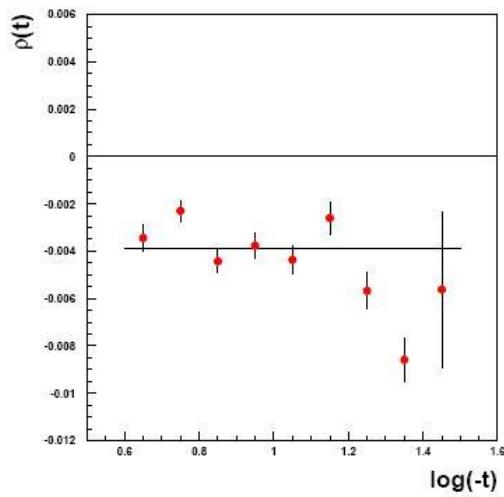
You will investigate how springs stretch when different objects are attached to them and learn about graphing scientific data.

Introduction: Plotting Scientific Data

In many scientific disciplines, and particularly in physics, you will often come across plots similar to those shown here.

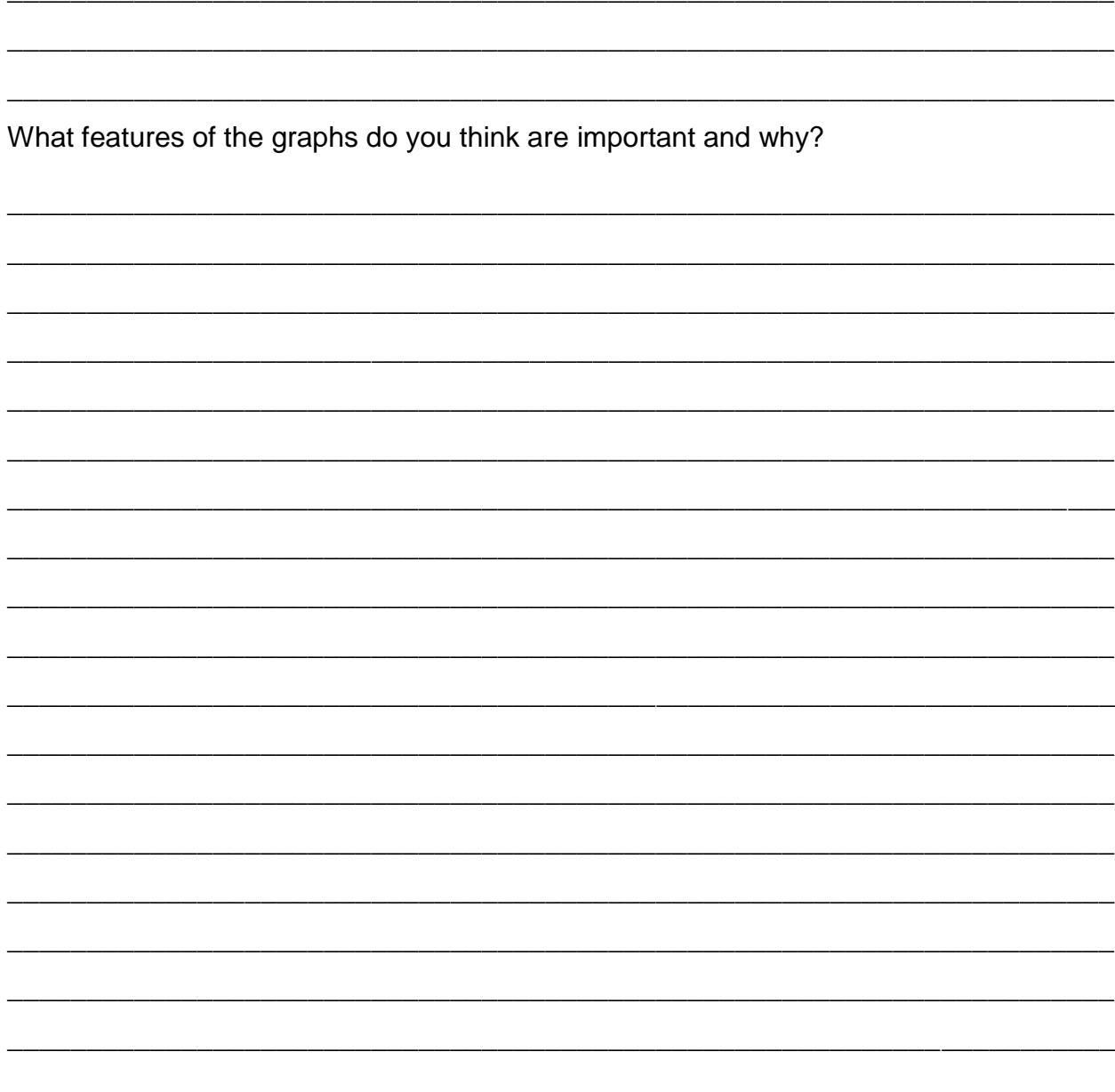
Note some common features:

- Horizontal and vertical axes;
- Axes have labels and units;
- Axes have a scale;
- Points with a short horizontal and/or vertical line through them;
- A curve or line superimposed.



Why do we make such plots?

What features of the graphs do you think are important and why?

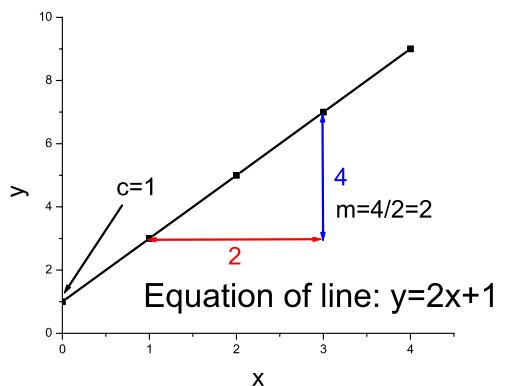


The equation of a straight line is often written as

$$y = mx + c.$$

y tells you how far up the point is, whilst x is how far along the x-axis the point is.

m is the slope (gradient) of the line, it tells you how steep the line is and is calculated by dividing the change in y by the change in x , for the same part of the line. A large value of m , indicates a steep line with a large change in y for a given change in x .



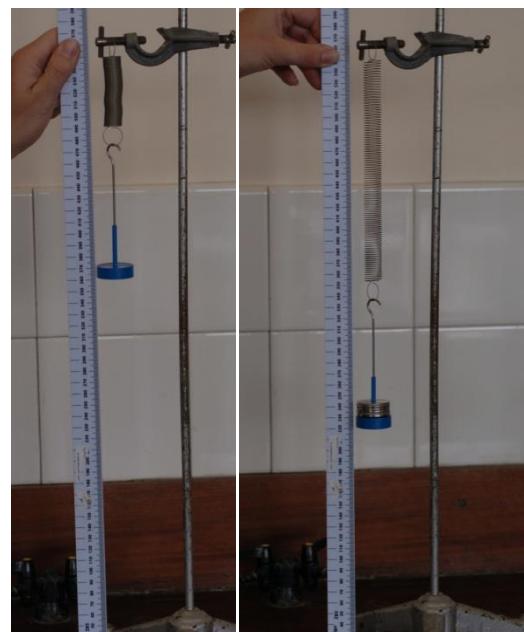
c is the intercept of the line and is the point where the line crosses the y -axis, at $x = 0$.

Apparatus

In this experiment you will use 2 different springs, a retort stand, a ruler, a mass hanger and a number of different masses.

Preparation

Set up the experiment as indicated in the photographs. Use one of the two springs (call this one spring 1). Determine the initial length of the spring, be careful to pick two reference points that define the length of the spring before you attach any mass or the mass hanger to the spring. Record the value of the length of the spring below.



Think about how precisely you can determine the length of the spring. Repeat the procedure for spring 2.

Calculate the initial length of spring 1.

Calculate the initial length of spring 2.

Procedure

Attach spring 1 again and then attach the mass hanger onto the spring. Measure the new length of the spring, using the same two reference points that you used to determine the initial spring length.

Length of springs with mass hanger attached (+ 10 g)

	Spring 1	Spring 2
Position of the top of spring		
Position of the bottom of spring		
New length of spring		

Add a 10 gram disk to the mass hanger, determine the new length of the spring. Complete the table below.

Measurements for spring 1

Object Added	Total mass added to the mass hanger (g)	New reference position (cm)	New spring length (cm)
Disk 1	10		
Disk 2	20		
Disk 3			
Disk 4			
Disk 5			

Add more mass disks, one-by-one, to the mass hanger and record the new lengths in the table above. In the column labelled ‘total mass added to the mass hanger’, calculate the total mass added due to the disks.

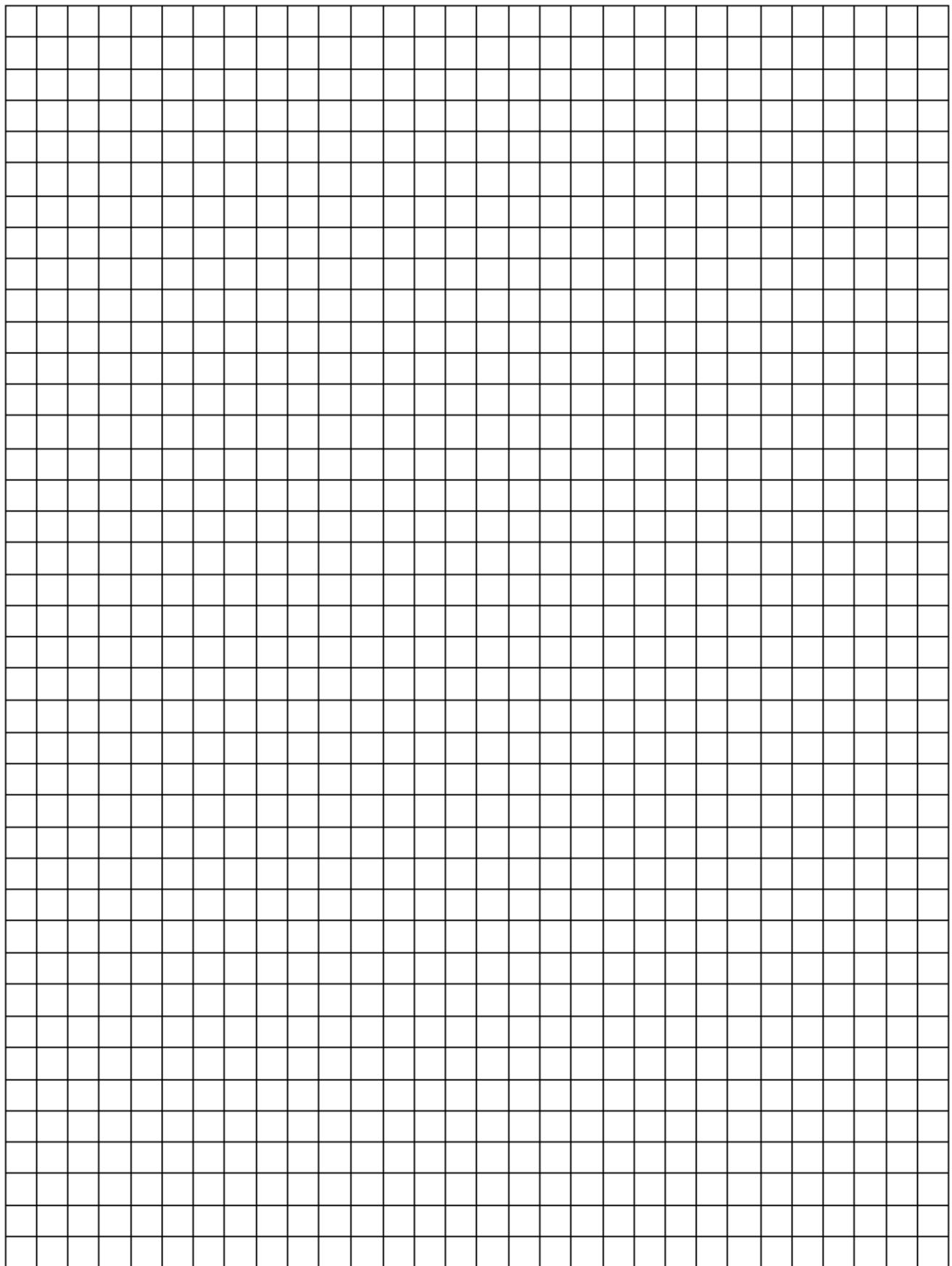
Carry out the same procedure for spring 2 and complete the table below. Use the same number of weights as for spring 1.

Measurements for spring 2

Object Added	Total mass added to the mass hanger (g)	New reference position (cm)	New spring length (cm)
Disk 1	10		
Disk 2			

Graphical Analysis

Add the data you have gathered for both springs to the graph below. You should plot the length of the spring in centimetres on the vertical y-axis and the total mass added to the hanger in grams on the horizontal axis. Start the y-axis at -10 cm and have the x-axis run from -40 to 100 g. Choose a scale that is simple to read and expands the data so it is spread across the page. Label your axes and include other features of the graph that you consider important.



Graph representing the length of the two springs for different masses added to the hanger.

In everyday language we may use the word ‘slope’ to describe a property of a hill. For example, we may say that a hill has a steep or gentle slope. Generally, the slope tells you how much the value on the vertical axis changes for a given change on the x-axis.

Algebraically a straight line can be described by $y = mx + c$ where x and y refer to any data on the x and y axes respectively, m is the slope of the line (change in y / change in x), and c is the intercept (where the line crosses the y -axis at $x=0$).

Suppose the data should be consistent with straight lines. Superimpose the two best straight lines, one for each spring, that you can draw on the data points.

Examine the graphs you have drawn and describe the ‘steepness’ of the slopes for spring 1 and spring 2.

Work out the slopes of the two lines.

What are the two intercepts?

How can you use the slopes of the two lines to compare the stiffness of the springs?

In this experiment the two intercepts, the points at which the straight lines cross the y-axis where $x = 0$ g, correspond to physical quantities (related to the springs) that you have determined. How well do the graphical and measured values compare with each other?

Look at the graphs on page 7, the horizontal and vertical lines through the data points represent the experimental uncertainty, or precision of measurement in many cases. In this experiment the uncertainty on the masses is insignificant, whilst those on the length measurements are related to how accurately the lengths of the springs can be determined.

How large a vertical line would you consider reasonable for your length measurements?

What factors might explain any disagreement between the graphically determined intercepts and the measurements of the corresponding physical quantity?

The behaviour of the springs in this experiment is said to be “linear”. Looking at your graphs does this make sense?

Name: _____

Student No: _____

Date: _____ Partner: _____ Demonstrator: _____

Electrons in Atoms: The Spectrum of atomic Hydrogen

Introduction

The aim of this experiment is to observe the spectrum of hydrogen, to explain the spectrum in terms of the motion of electrons between discrete energy levels in the hydrogen atom and to evaluate a constant that is fundamental to calculating the wavelengths of the lines in the spectrum of hydrogen. The spectral emission lines that are seen in the visible region of the spectrum (red through violet) belong to the *Balmer* series and the positions of these lines may be determined using a spectrometer. From the observed wavelengths, the Rydberg formula may be applied and the Rydberg constant obtained.

Background theory and historical perspective

At the turn of the last century measurement of the wavelengths of spectral lines in the light given off by low pressure hydrogen gas in an electrical discharge gave very consistent, highly repeatable results. The emission of light came to be understood in terms of electrons moving between discrete energy levels. The wavelengths of the lines fitted a very regular pattern. It was found that all of the wavelengths, λ_i , could be

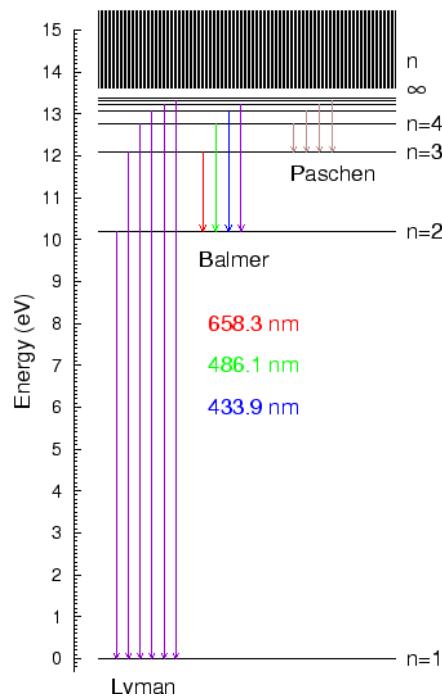
calculated by using the Rydberg formula:
$$\frac{1}{\lambda_{f,i}} = R \left[\left(\frac{1}{n_f} \right)^2 - \left(\frac{1}{n_i} \right)^2 \right] \quad (\text{Eq. 1})$$

Here, n_f and n_i are both integers (called the principal quantum numbers) with $n_i > n_f$. R is a constant known as the Rydberg constant. These numbers were originally fitted to the series without any understanding of their physical meaning. However, most physicists felt that something basic must be inherent in such a simple equation. **Niels Bohr** was one of them. Having worked with Rutherford, he was aware of the nuclear model of the atom. In 1913 he postulated:

- that the electron in the hydrogen atom is in circular motion (in orbit) about the nucleus (which he assumed to be stationary),
- that it can only exist without radiating electromagnetic energy in certain "allowed" states of definite energy,
- that these were specified by quantised values $nh/2\pi$ where h is Planck's constant and n is an integer,

- that transitions between these "allowed" states can occur only if photon emission or absorption occurs and the photon energy must be equal to the energy difference between the initial and final states. The photon energy (E) is given by:
$$E_i - E_f = hf \quad (\text{Eq. 2})$$

Based on this model, we can state that the number n_i refers to the initial (or upper) level. The values for n_f are lower than those of n_i , as they refer to the lower (or final) level involved in the electronic transition which results in the emission of light. The value of n_f is 2 for the Balmer series, as all of the electronic transitions terminate with the electron in the $n = 2$ level. The first three of these series (electrons “falling” to $n = 1$, $n = 2$ and $n = 3$) are illustrated in Fig.2 below. The Balmer series involves electrons moving between $n_i = 3, 4, 5, 6, 7, \dots$ to $n_f = 2$. Three transitions in this series are shown below.



Identify the series of transitions (Lyman, Balmer or Paschen) that occur at the longest wavelength. Explain your reasoning.

Calculate the energy of a photon in the red region of the spectrum ($\lambda = 658$ nm), using equation 2 above and the fact that the speed of light (3×10^8 ms $^{-1}$) is related to the wavelength (λ) and frequency (f) by the equation $c = \lambda f$.

Using these postulates, Coulomb's law, and Newtonian mechanics, Bohr was able to derive the above equation from first principles and express the Rydberg constant in the form:

$$R = \frac{me^4}{8c\varepsilon_o^2 h^3} \quad (\text{Eq. 3})$$

Calculate the value of R, given the following values:

m, the mass of the electron = 9.11×10^{-31} kg.

e, the charge on the electron = 1.60×10^{-19} C.

ε_0 , the permittivity of a vacuum = 8.85×10^{-12} C 2 N $^{-1}$ m $^{-2}$

h, Planck's constant = 6.63×10^{-34} Js.

c, speed of light = 3.00×10^8 ms $^{-1}$

Fill in the table below using equation 1, and the value for R above to calculate λ for the numbers $n_i = 3, 4, 5$ and $n_f = 2$.

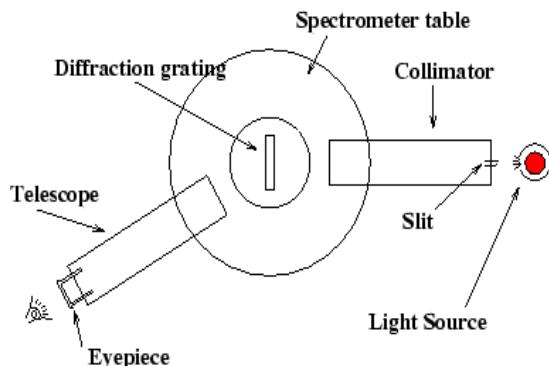
	$n_i = 3$	$n_i = 4$	$n_i = 5$
$(1/n_f)^2 - (1/n_i)^2$			
λ_i			

The results of the Bohr Theory were not perfect, but they were close enough to point the physics community in the proper direction to more fully develop the new quantum physics.

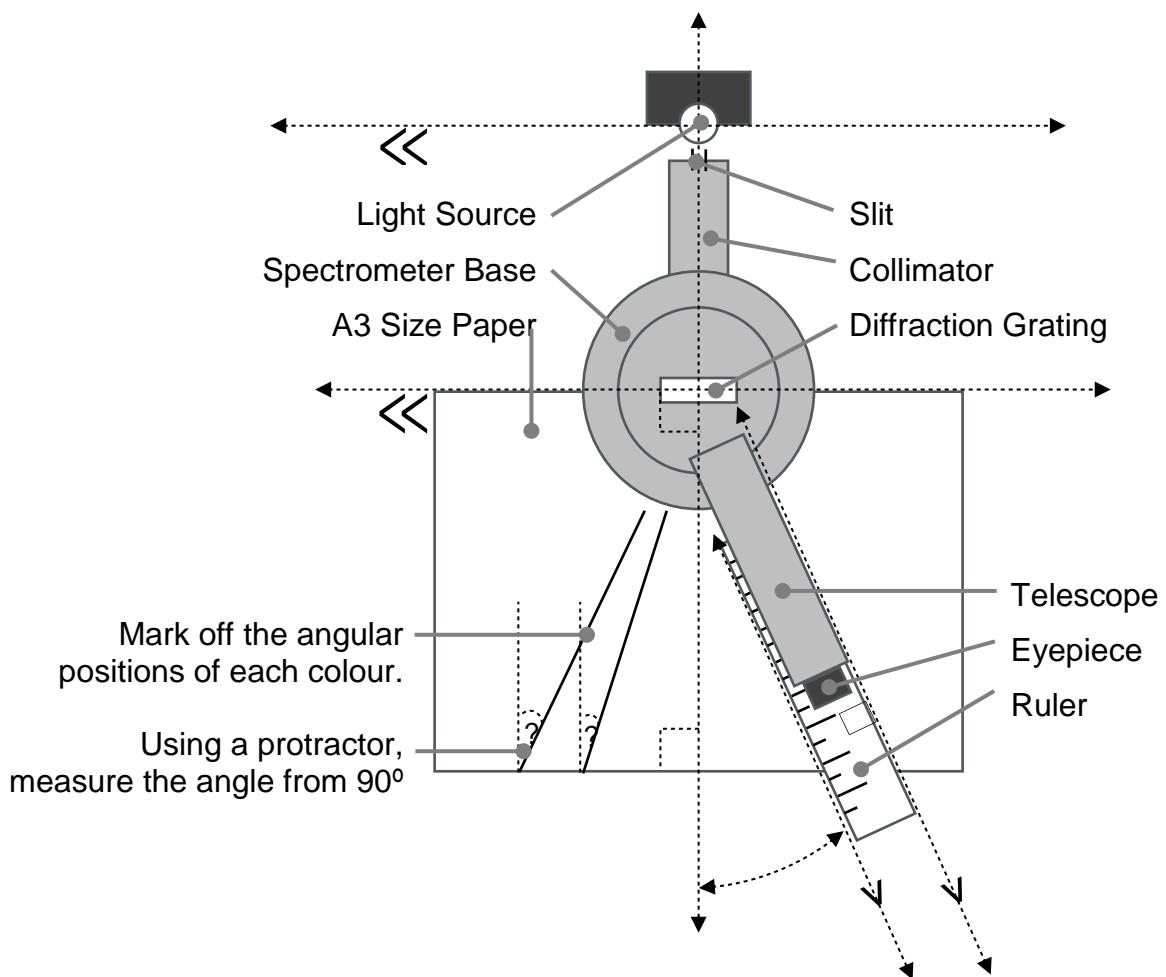
The purpose of this experiment is to use the spectrometer to observe the angles at which different wavelengths (colours) of light are diffracted and to calculate those wavelengths. This will allow you to verify the value of the Rydberg constant.

Procedure:

The experimental arrangement and a schematic of the spectrometer are shown below. The hydrogen discharge tube (light source) is positioned in front of the entrance slit of the spectrometer.



Setup the apparatus as shown in the diagram below, making sure to position the slits of the collimator directly in front of the light source. Align the diffraction grating and long edge of the sheet of A3 paper so that they are parallel with each other and perpendicular to the collimator and light source.



The spectrometer is adjusted as follows: **(1)** Set the entrance slit vertically. **(2)** Adjust the length of the collimator until the mark on the inner barrel is just visible. At this setting the light emerging will be collimated. **(3)** Set the grating perpendicular to the collimator and with the grooves vertical. **(4)** Align the telescope with the collimator when an image of the entrance slit will be seen. **(5)** Adjust the eyepiece until the crosswire is in sharp focus. **(6)** Adjust the length of the telescope until the image of the slit is in sharp focus. **(7)** Point the spectrometer directly at the discharge tube so that the light through the entrance slit is as bright as possible.

With the collimator and telescope in a straight line, the light viewed is the zero order line ($m=0$) from the diffraction grating. All of the colours from the lamp are viewed simultaneously at the zero order. The telescope arm is rotated to the left whilst looking through the eyepiece until a coloured spectral line appears centered in the crosshairs of the telescope. Use a ruler aligned to the telescope to mark the line on the A3 sheet of paper. Using a protractor measure the angle this line creates from perpendicular and label it Θ_L . Continue rotating the telescope to the left and repeat the process until no more spectral lines are found. Return the telescope back through the centre line and repeat the procedure this time rotating to the right and labeling the angles Θ_R .

Record the data in the table below. By taking the average reading between Θ_L and Θ_R , correction is made for any slight deviation from the perpendicular of the diffraction grating to the optic axis of the spectrometer.

Colour	n_i	$1/n_i^2$	m	θ_L	θ_R	$\theta_m = (\theta_L - \theta_R) / 2$	λ_i	Mean λ_i	$1/\lambda_i$
Purple	5		1						
			2						
Blue-Green	4		1						
			2						
Red	3		1						
			2						

Analysis & theory of operation of the spectrometer

The wavelengths of the visible emission lines of the hydrogen spectrum are recorded using a spectrometer equipped with a diffraction grating. In passing through the grating, light of different wavelengths (colours) is diffracted at different angles. The diffraction grating formula is given by:

$$m\lambda = d \cdot \sin \theta_m \quad (\text{Eq. 5})$$

where λ is the wavelength of the spectral line being observed, d is the groove spacing of the diffraction grating, m is the order of the spectrum, θ_m is the corresponding angle at which the m^{th} order spectrum is observed. The 1st order ($m = 1$) occurs at the smallest angle with respect to 90° to the grating surface, the 2nd order occurs at larger angles and so on. Which colour do you expect to be diffracted through the largest angle? Explain your reasoning.

From your data and using Eq. 5, calculate the wavelengths of the visible lines in the spectrum of hydrogen. Create a plot of $1/\lambda_i$ against $1/n_i^2$ ($i = 3, 4, 5$). By re-arranging Eq.

1 in the form $y = mx + c$ as $\frac{1}{\lambda_{f,i}} = -R\left(\frac{1}{n_i}\right)^2 + R\left(\frac{1}{n_f}\right)^2$

the value of R can be found from the slope of the graph.

Write the values of the slope and intercept of the graph.

Write the value of R calculated earlier.

Write the value of R estimated from the slope of the graph.

The intercept of this graph will give R/n^2 .

Write the value of R estimated from the intercept of the graph.

Compare the values you obtained based on your measurements with the calculated value of R and comment on the accuracy of your measurements.

What conclusions can you draw from the experiment?

Name: _____

Student No: _____

Date: _____ Partner: _____ Demonstrator: _____

The Absorption of β -rays by Materials

Nuclear Emissions historically have been classified as α -rays, β -rays or γ -rays. Each is due to a very different process. α -rays consist of two protons and two neutrons and are caused by the strong force. β -rays are energetic electrons liberated through the weak force. γ -rays are due to electromagnetic interactions of the nucleus.

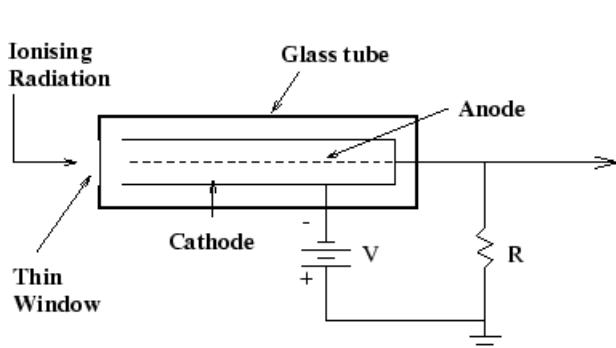
This experiment investigates how materials absorb β -rays, which is important in estimating the effects of radioactivity and in creating effective shielding.

Apparatus

β -rays are detected using a Geiger counter which consists of a Geiger-Muller tube and associated electronics. Each charged particle entering the tube is detected and the total number of counts displayed.

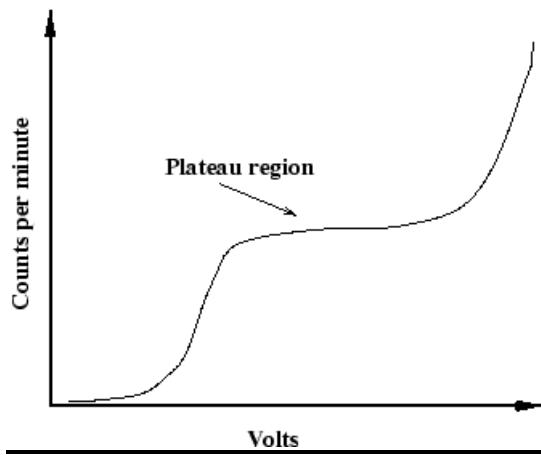
At the heart of the Geiger counter is a Geiger-Muller tube that consists of a sealed cavity that contains a thin-walled metallic cylinder with a wire positioned along the axis of the cylinder. The cavity contains a mixture of gases at very low pressure. Under normal operation, the cylinder is connected to the negative side of a high power voltage supply.

A charged particle passing through the gas ionises a gas molecule, the resulting electron is attracted by the central wire and the positive ion is attracted towards the cylindrical electrode. There is a very high electric field close to the central wire and the approaching



electrons are accelerated and gain a lot of kinetic energy. These high energy electrons undergo collisions with the gas molecules causing more and more ionisations. The multiplication of ions by this process is known as an "avalanche" and continues until there is a complete electrical discharge along the entire length of the electrode. A sudden pulse of current appears in the external circuit and the potential difference created across the resistor, R, results in a signal which is passed to the counter/rate-meter.

At low voltages, the avalanche process is inhibited and very few counts will be measured, while at high voltages too many counts will be measured as the avalanche process continuously ionises the gas within the tube. The flat portion of the curve where the counting rate is nearly constant over a reasonable voltage range, is called the **Geiger plateau**. Once the plateau is determined for a given Geiger-Muller tube, one should operate the tube with a voltage close to the middle of the plateau.



Procedure

Set the detector voltage to the mid-point of the plateau (if necessary determine the plateau position). With the radioactive source well away from the GM tube count the background radiation for 5 minutes and hence find the background count per minute.

Background Rate =	\pm	counts/minute
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Your source of β -rays is Thallium204 which decays with a half-life of 3.78 years - thus the activity of the source will remain constant during the course of the experiment. Place the source directly below the entrance window of the Geiger-Muller tube and adjust the height until a count rate of approximately 3600 counts per minute (or as high as you can achieve) is recorded with no absorber in position. This is the optimum position of the detector with respect to the source and neither counter nor source should be moved for the remainder of the experiment. You will need to leave room to insert several mylar foils between the source and the detector.

Investigation 1: To investigate how absorption depends on the mass per unit area of absorber.

Find the mass per unit area of an absorber.

How did you do this?

--

Start by recording the number of counts in one minute. Subtract the background rate. Insert one mylar foil between the source and detector. Record the number of counts in one minute. Insert a second foil and repeat. Continue inserting foils until the rate reaches a value close to the background. Tabulate your results below.

*To determine the uncertainty on the count rate see the summary on combining uncertainties.

Plot a graph of the count rate against the mass per unit area of absorber.

From your graph, calculate the mass per unit area of absorber that would give rates of 1000 and 3000 counts per minute.

Investigation 2: Find the absorption coefficient of mylar

The β -particles are absorbed exponentially according to the equation

$$N = N_0 \exp(-\lambda x) \quad (\text{Eq.1})$$

where N_0 are the number present at $x = 0$, N are the number still present after travelling a distance x in the material and λ is the absorption coefficient. Taking the natural log of Eq.1 gives

$$\ln N = \ln N_0 - \lambda x \quad (\text{Eq.2})$$

From the data you have already taken for mylar, make a plot of $\ln N$ against x . (You will need to calculate x by finding the thickness of one foil using a micrometer screw and multiplying by the number of foils.)

Number of Absorbers	x (m)	N Background subtracted rate (counts/minute)	$\ln N$

Write down the slope and intercept of the graph.

Slope =

Intercept =

Use this information to find the absorption coefficient, λ , for mylar. What can you determine from the intercept of the graph?

What conclusions can you draw from the experiment?

Name: _____

Student No: _____

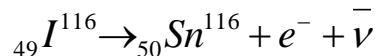
Date: _____ Partner: _____ Demonstrator: _____

Determination of the Half-Life of Indium

Theory

Radioactive nuclei undergo transmutations to daughter nuclei. The rate at which this process takes place is characteristic of the particular nucleus. A sample of many radioactive nuclei will have decreasing numbers of nuclei available for decay as time progresses. The time it takes for half of the available radioactive nuclei to decay, which also reduces the number decaying per unit time by one-half, is called the **half-life** of the nucleus. In this experiment the half-life of ^{116}In will be determined. (^{116}In contains 116 nucleons (i.e. protons and neutrons) of which 49 are protons.

$^{49}\text{In}^{116}$ is unstable and decays to an isotope of tin $^{50}\text{Sn}^{116}$, with emission of a beta particle (which is a fast electron) and an anti-neutrino according to the scheme:



There are protons and neutrons in $^{49}\text{I}^{116}$

There are protons and neutrons in $^{50}\text{Sn}^{116}$

Explain what fundamental process (at the level of the nucleon) is responsible for radioactive decay.

The radioactive Decay Law:

The decay reaction proceeds at a rate which depends only on the nature of $^{49}\text{In}^{116}$ and the number of $^{49}\text{In}^{116}$ atoms present at any time. Thus,

$$-\frac{dN}{dt} \propto N \quad (\text{Eq.1})$$

where dN/dt , the decay rate, is proportional to the number of atoms, N , present at time t . Rewriting with λ as a constant of proportionality we obtain

$$-\frac{dN}{dt} = \lambda N \quad (\text{Eq. 2})$$

λ is known as the **decay constant or disintegration constant** of the radioactive material. Each different type of radioactive atom has a characteristic λ .

Eq. 2 can be solved by integrating to give

$$N = N_0 e^{-\lambda t} \quad (\text{Eq. 3})$$

where N_0 is the number of nuclei present at $t = 0$.

A more intuitive number which characterises the decay is the **half life**: the time after which only half the original sample remains. With this definition and using Eq. 3,

$$\frac{N_0}{2} = N_0 e^{-\lambda T_{1/2}} \quad (\text{Eq. 4})$$

showing the half-life is related to the decay constant by

$$T_{1/2} = \ln 2 / \lambda \quad (\text{Eq. 5})$$

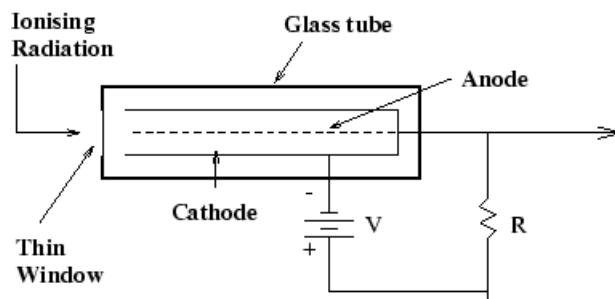
In this experiment you will not measure the total number of atoms in the sample at a given time but will count an observed rate, R , which is proportional to the rate, dN/dt , at which atoms decay. Using Eq.2 and 3,

$$R = \frac{dN}{dt} = -\lambda N = -\lambda N_0 e^{-\lambda t} = \left(\frac{dN}{dt} \right)_0 e^{-\lambda t} = R_0 e^{-\lambda t} \quad (\text{Eq. 6})$$

and so $R = R_0 e^{-\lambda t}$ (Eq.7)

Apparatus

The Geiger counter consists of a Geiger-Muller tube and associated electronics. Each charged particle (in this experiment it will be beta-rays) entering the tube is detected and the total number of counts displayed.

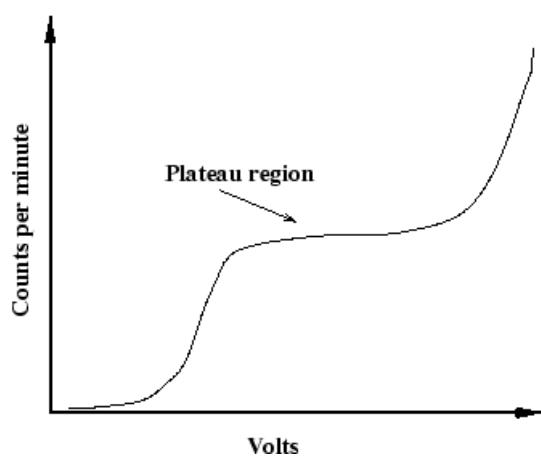


At the heart of the Geiger counter is a Geiger-Muller tube that consists of a sealed cavity that contains a thin-walled metallic cylinder with a wire positioned along the axis of the cylinder.

The cavity contains a mixture of gases at very low pressure. Under normal operation, the cylinder is connected to the negative side of a high power voltage supply.

A charged particle passing through the gas ionises a gas molecule, the resulting electron is attracted by the central wire and the positive ion is attracted towards the cylindrical electrode. There is a very high electric field close to the central wire and the approaching electrons are accelerated and gain a lot of kinetic energy. These high energy electrons undergo collisions with the gas molecules causing more and more ionisations. The multiplication of ions by this process is known as an "avalanche" and continues until there is a complete electrical discharge along the entire length of the electrode. A sudden pulse of current appears in the external circuit and the potential difference created across the resistor, R, results in a signal which is passed to the counter/rate-meter.

At low voltages, the avalanche process is inhibited and very few counts will be measured, while at high voltages too many counts will be measured as the avalanche process continuously ionises the gas within the tube. The flat portion of the curve where the counting rate is nearly constant over a reasonable voltage range, is called the **Geiger plateau**. Once the plateau is determined for a given Geiger-Muller tube, one should operate the tube with a voltage close to the middle of the plateau.



Since alpha and beta particles are charged they can be detected by the Geiger counter. Gamma rays will only be detected in the unlikely event that they interact with the gas molecules within the tube. To allow the α - and β -particles to enter the tube, there is a

very thin delicate mica window at one end of the cylindrical cavity. ***This should not be touched as it is easily broken.***

Procedure:

Set the Geiger-Muller tube voltage to the value given for your particular apparatus (**380V**). This corresponds to the midpoint of the plateau region.

With the source well away from the Geiger-Muller determine the **background rate (counts / minute)**, R_b , by counting for 4 minutes.

The radioactive indium foil, housed within a protective covering, is placed on the bench and, to get the maximum count rate, the Geiger-Muller tube is lowered until it is as close as possible to the source.

You will need to measure the number of counts in a series of four-minute intervals. The stop-clock and counter/rate-meter should be reset and started simultaneously. To measure the counts in the first four-minute interval, the counter should be stopped after 4 minutes but the stop-clock should continue to run. The count rate, R (allowing for background), should be calculated. Reset the counter, but not the continuously running stop-clock. Measure the number of counts in the four-minute interval starting at time = 5 minutes and then repeat the measurement by counting for 4 minutes at strictly regular intervals of five minutes. Tabulate the results below.

Time (seconds)	# counts	# counts (background subtracted)	$\sqrt{\#}$ counts	Rate (counts/second)	Uncertainty in Rate (counts/sec)	In (Rate)
0						

Measurements should continue until the count rate is approximately one quarter of the original count rate. Note that the statistical uncertainty on the number of counts is the square root of the number of counts.

Plot the rate, R , against time, t .

What do you observe?

Take the natural logarithm of both sides of Eq.7.

For more information about the study, please contact the study team at 1-800-258-4929 or visit www.cancer.gov.

If you plot $\ln R$ on the y-axis and t on the x-axis, what will the slope and intercept of the graph correspond to?

Slope

A large, empty rectangular box with a black border, occupying most of the page below the title.

Intercept

ANSWER

Now plot $\ln R$ against t .

Slope is

A large, empty rectangular frame with a black border, occupying most of the page. It appears to be a placeholder for an image or diagram.

Intercept is

±

Calculate the half life of Indium (with its associated uncertainty.) Comment on the goodness of fit of your graph and discuss any systematic errors that may be present.

What conclusions can you draw from the experiment?

Graphing

Many of the experiments in the 1st Year laboratory involve the plotting of a graph. Graphs are very important in Physics as they provide a simple display of the results obtained in an experiment and of the relationship between two variables. More accurate and reliable information can be obtained from a graph than from the analysis of any particular set of results.

Plotting graphs by hand:

- (1) **Scale:** It is important to choose the scales so as to make full use of the squared page. The scale divisions should be chosen for convenience; that is, one unit is either 1, 2 or 5 times a power of ten e.g. 0.5, 5, 100 etc., but never 3, 7, 9 etc.
- (2) **Marking the points:** Readings should be indicated on the graph by a ringed dot \otimes and drawn with pencil, so that it is possible to erase and correct any unsatisfactory data.
- (3) **Joining the points:** In the case of a straight line which indicates a direct proportion between the variables, the ruler is positioned so that the line drawn will pass through as many points as possible. Those points which do not lie on the line should be equally distributed on both sides of the line. A point which lies away from this line can be regarded as 'doubtful' and a recheck made on the readings. In the case of a curve, the individual experimental points are not joined with straight lines but a smooth curve is drawn through them so that as many as possible lie on the curve.
- (4) **Units:** The graph is drawn on squared page. Each graph should carry **title** at the top e.g. Time squared vs. Length. The axes should be labelled with the name and units of the quantities involved.
- (5) In the case of a straight-line graph, the equation of the line representing the relationship between the quantities x and y may be expressed in the form

$$y = mx + c$$

where **m** is the slope of the line and **c** the intercept on the y -axis. The slope may be positive or negative. Many experiments require an accurate reading of the slope of a line.

Using JagFit

In the examples above we have somewhat causally referred to the '**best fit**' through the data. What we mean by this, is *the theoretical curve which comes closest to the data points having due regard for the experimental uncertainties*.

This is more or less what you tried to do by eye, but how could you tell that you indeed did have the best fit and what method did you use to work out statistical uncertainties on the slope and intercept?

The theoretical curve which comes closest to the data points having due regard for the experimental uncertainties can be defined more rigorously¹ and the mathematical definition allows you to calculate explicitly what the best fit would be for a given data set and theoretical model. However, the mathematics is tricky and tedious, as is drawing plots by hand and for that reason....

We can use a computer to speed up the plotting of experimental data and to improve the precision of parameter estimation.

In the laboratories a plotting programme called Jagfit is installed on the computers. Jagfit is freely available for download from this address:

<http://www.southalabama.edu/physics/software/software.htm>



Double-click on the JagFit icon to start the program. The working of JagFit is fairly intuitive. Enter your data in the columns on the left.

- Under **Graph**, select the columns to graph, and the name for the axes.
- Under **Error Method**, you can include uncertainties on the points.
- Under **Tools**, you can fit the data using a function as defined under **Fitting Function**. Normally you will just perform a linear fit.

One of the experiments in this manual was developed by the Physics Education Group, CASTeL, Dublin City University.

¹ If you want to know more about this equation, why it works, or how to solve it, ask your demonstrator or read about 'least square fitting' in a text book on data analysis or statistics.

Experimental Uncertainties

Experimental Uncertainties

When you make a scientific measurement there is some ‘true’ value that you are trying to estimate and your equipment has some intrinsic **uncertainty**. Thus you can only estimate the ‘true’ value up to the uncertainty inherent within your method or your equipment. Conventionally you write down your measurement followed by the symbol \pm , followed by the uncertainty. A surveying company might report their results as 245 ± 5 km, 253 ± 1 km, 254.2 ± 0.1 km. You can interpret the second number as the ‘margin of error’ or the **uncertainty** on the measurement. If your uncertainties can be described using a Gaussian distribution, (which is true most of the time), then the true value lies within one or two units of uncertainty from the measured value. There is only a 5% chance that the true value is greater than two units of uncertainty away, and a 1% chance that it is greater than three units.

Errors may be divided into two classes, systematic and random. A **systematic error** is one which is constant throughout a set of readings. A **random error** is one which varies and which is equally likely to be positive or negative. Random errors are always present in an experiment and in the absence of systematic errors cause successive readings to spread about the true value of the quantity. If in addition a systematic error is present, the spread is not about the true value but about some displaced value.

Estimating the experimental uncertainty is at least as important as getting the central value, since it determines the range in which the truth lies. Frequently scientists will spend much more time estimating the experimental uncertainty than finding the central value.

For most of the experiments you will do in first year it is sufficient to:

1. Consider the various uncertainties that could have affected your result;
2. Roughly estimate the size of each;
3. Find the source with the largest relative uncertainty;
4. Find the effect of that source on your result.

1. How do you find the sources of uncertainty?

In all the experiments you will have made a number of measurements that are combined together to produce a final result for some physical quantity. Think about the uncertainties that could enter each measurement, due to both the intrinsic precision of your tools and changeability of the environment.

2. How do you find the size of each source of uncertainty?

Use common sense!

If you are reading a scale, how precisely can you read off the gradations?

If a display or instrument is unstable or moves, over what range does it change?

If you are timing something, what are your reaction speeds?

If you are viewing something by eye, with what precision can you line it up?

If you are counting something, the uncertainty in the number of counts is generally the square root of the number of counts.

Sometimes, a good way to estimate the size of a source of uncertainty is to repeat the measurement a few times and see by how much your reading varies on average.

3. Find the source with the largest relative uncertainty

4. Find the effect of that source on your result

Once you have identified the largest source of uncertainty, you must figure out how that affects your final result. There are two ways to do this: (i) calculate the uncertainty on your final result by changing the source value by its uncertainty; (ii) plug your numbers into a formula (but you have to know which formula to use!)

4.1 Method 1: Recalculating your result by changing the source values.

- From your measurements, calculate the final result. Call this f , your answer.
- Now move the value of the source up by its uncertainty.
Recalculate the final result. Call this f^+ .
- The uncertainty on the final result is the difference in these values: i.e. $|f - f^+|$

You could also have moved the value of the source down by its uncertainty and recalculated the final result. You should get the same answer (in most situations).

If you like to express this in mathematics, let $x \pm \delta_x$ be the measurement and $f(x)$ the result you want to calculate, then $\delta_f = |f(x + \delta_x) - f(x)|$ and your final answer is $f \pm \delta_f$.

4.2 Method 2: Using a formula.

Suppose you calculate f which is some function of variable x with an associated uncertainty Δx . What is the uncertainty Δf on f ?

For errors with a Gaussian distribution, the uncertainty on f , Δf , is given by

$$\Delta f = \frac{\partial f}{\partial x} \Delta x.$$

Example 1: $f=Ax$

You just multiply x by a constant A ; then $\Delta f = A \Delta x$.

Suppose you calculate f which is some function of variables x and y , with associated uncertainties Δx and Δy . What is the uncertainty Δf on f ?

For errors with Gaussian distributions, the uncertainty on f , Δf , is given by

$$\Delta f = \sqrt{(\frac{\partial f}{\partial x} \Delta x)^2 + (\frac{\partial f}{\partial y} \Delta y)^2}$$

Example 2: $f=x-y$

You add or subtract two independent measurements; then $\Delta f = \sqrt{\Delta x^2 + \Delta y^2}$.

(Short cut: If one error is at least twice as big as the other, you can ignore the smaller error. So in this case if $\Delta x > 2\Delta y$ then $\Delta f \approx \Delta x$.)