University of Cape Town
Department of Physics

Examples of context-rich physics laboratory tasks

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Introduction

We believe that first year physics laboratories should be aimed at introducing the basic elements of experimentation such as engaging with unfamiliar apparatus, taking and recording measurements in a systematic way, processing data and interpreting findings. The well-known “recipe-style” laboratory, often an exercise in reproducing well-known results, does not lend itself to foregrounding the skills and procedures listed above. Furthermore, the terse and technical way in which these tasks are formulated play an obscurant role which diminishes the value of the learning experience. Often the authoritative tone of a list of detailed instructions can intimidate students, leading to a paralyzed response for even simple tasks. For example, a seemingly simple instruction such as “locate the switch” has been observed to lead students to total inaction and finally to call for assistance! Another skill which was felt to be desirable, particularly in view of the language factor, was that of scientific report writing which serves the role of exposition as well as providing a tool for students to reflect on the proceedings of a laboratory experience as a whole. For this purpose, too, the “recipe-style” laboratory was found to be unsuited since it tends to generate a piece of writing which closely resembles the original set of instructions.

The standard laboratory tasks were, therefore, reformulated into “quasi-real” problems that could be “solved” by recourse to an experimental investigation. Students, working in groups of three, with assistance from “roving” laboratory demonstrators, generate the procedures that are required as the experiment progresses. A writing-intensive report follows as a natural consequence of the investigation, which also serves as a focus for synthesizing the various experiences in the laboratory into a whole. The way in which the task is presented, together with the positing of an audience which is not present during the investigation, obviates the problem of the report comprising a series of instructions rather than an account of the experiment.

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PHY123H

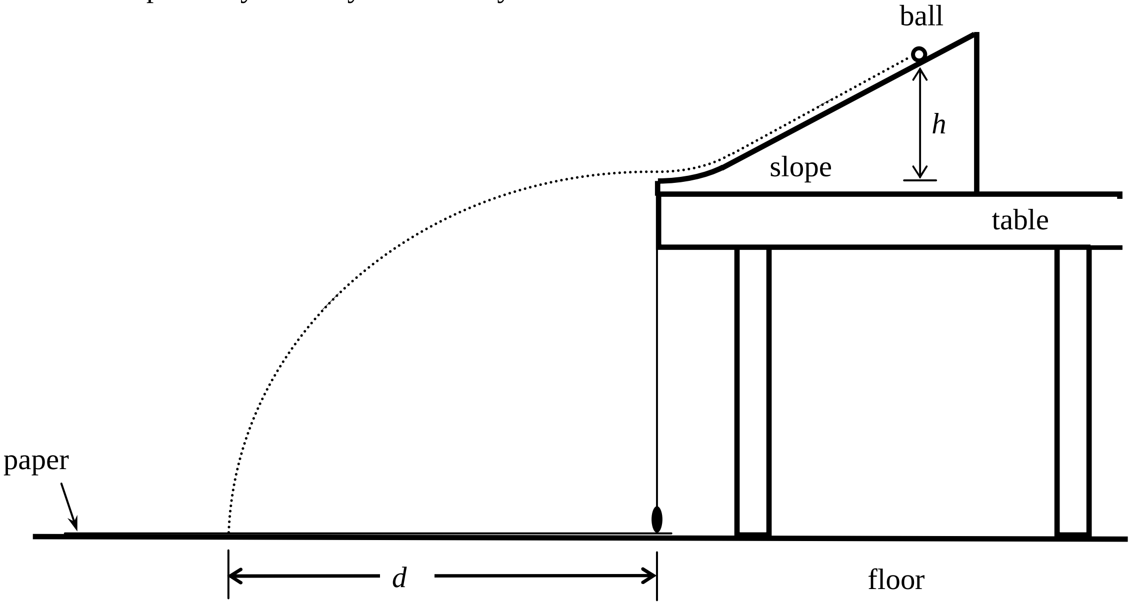
Laboratory practical

Bugsball

Work in groups of 3.
Call a demonstrator if you need help.

A new game "Bugsball" has been invented by Fizzix, a company specializing in science games. The inventors at Fizzix hope to teach science to people playing these games. The inventors of the game at Fissix are concerned because they disagree about their explanations of the physics of the game.

At the heart of the dispute is the relationship between the height above the table from where the ball is released (h) and the horizontal distance that the balls travels (d). Some of the people at Fissix have concluded that d is proportional to h^2. However, another group at Fissix repeated the study and concluded that h is proportional to d^2! Both sets of experts investigated the situation using apparatus consisting of a wooden slope and a steel ball. In both cases the steel ball was rolled down the slope from different heights h, and d measured using a metre stick. The Head of the Physics Department at UCT has been approached by Fissix to resolve the controversy and now asks you to investigate the situation urgently with the same apparatus used by the two groups. He wants a full report detailing all aspects of the experiments, measurements, calculations and graphs as well as your findings on who is right or wrong. In particular, he would like you to pay careful attention to your graphs of $\sqrt{d}$ versus h, and d^2 versus h. Your report needs to be completed by Tuesday 25 February 2003.



Here are some things to think about <u>before you start your experiment</u>. Discuss these questions with the other students in your group. Listen to each other's opinions and talk to a tutor, if necessary.

- What are the main steps that you need to carry out?
- What variables are involved and what measurements do you need to take?
- How many different heights should you roll from?
- How many times should you roll from each height?
- How are you going to measure d and h?
- What tables do you need to record all your readings?
- What graphs do you need to plot?
- What would be a valid conclusion to the experiment?

<u>After you have finished your experiment</u>, think about the following with the students in your group, and include answers to these questions in your report:

- Make a list of everything that you think influenced the measurements which you made in your experiment. (For example you might come up with things such as: starting the ball from the same position, air resistance, ...).
  Write down next to each factor whether you think it affected your results in a small way or a large way.

- If you wanted to improve your experiment next time, what do you think you should do? What changes would you make to the apparatus and the way you used it?

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PHY123H

Laboratory practical

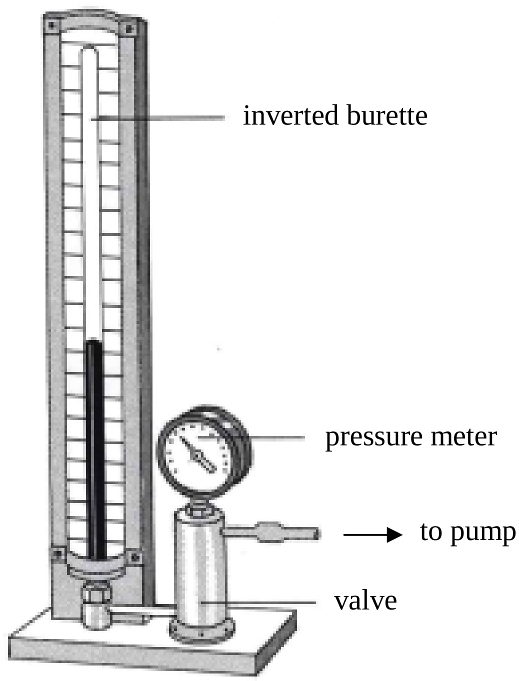
Turmoil in Chemistry Department Boyles over to Physics

Work in groups of 3.
Call a demonstrator if you need help.

In 1660 Robert Boyle established that the pressure P of a gas was inversely proportional to its volume V if the temperature T remains constant, i.e. PV = *a constant value, for a constant T.* Recently, however, a group of chemists claim to have shown that Boyle was wrong and that the pressure is in fact proportional to the volume. This has caused consternation in the Chemistry Department. In order to check the claim of the chemists, the Dean of the Science Faculty has asked you, as an expert physicist, to investigate the issue and to present him with a report detailing experiments and conclusions. Set up an experiment in which readings of pressure and volume are recorded. Draw graphs of P vs. V and P vs. $(1/V)$, and determine who was right from the shape of these graphs.

Prepare a detailed report for the Dean of Science in which you discuss the problem, the measurements you performed, your analysis and your findings. In order to support your conclusions, the Dean asks you to list all the factors that you think influenced your measurements. Write down next to each factor whether you think it affected your results in a small way or a large way.

Your full report must be handed in before 14:00 on Friday 11 April, in time for the press conference called by the Dean. Be sure to write your report as carefully as you are able to.



Before you begin to take readings, draw a flow diagram (as you have learnt in chemistry) which sets out the sequence of the main steps that you need to follow to complete the experiment. Each student must produce a flow diagram. Use one side of an A4 page for this and call a demonstrator to initial your flow diagram. Include your flow diagram as part of your report and use look at it when you write up your "Method" section.

Here are some things to think about when drawing your flow diagram.
Discuss these questions with the other students in your group. Listen to each other's opinions and talk to a tutor, if necessary.

- What are the main steps that you need to carry out?
- What variables are involved and what measurements do you need to take?
- What tables do you need to record all your readings?
- What graphs do you need to plot?
- What would be a valid conclusion to the experiment?

In order to practice what you learnt last week, determine a standard uncertainty associated with reading the scales of the burette (for V) and the pressure gauge (for P). Tabulate these standard uncertainties with your readings. (Of course this is not the only source of uncertainty for your measurements of P and V.)

You have also been given a copy of the assessment schedule which will be used by the marker of your report. Staple this to the front of your report before handing it in.

Your report must be handed in by posting it into the specially marked box in the Physics Course I laboratory before the time specified. All laboratory reports for your physics course PHY123H must be submitted in this way.

University of Cape Town
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PHY123H

Laboratory practical

"g"- uproar in Physics Department: a matter of gravity

Work in groups of 3.
Call a demonstrator if you need help.

Researchers in the Physics Department at UCT recently created a worldwide controversy when they reported that they had measured the value of the acceleration due to gravity "g " to be 12.54 m s^{-2} rather then the generally accepted value for Cape Town of 9.79 m s^{-2}. In order to quell a rising storm of protests that the measurements are fatally flawed, the Head of the Physics has set up a task team to investigate the claim. The task team, of which you are a member, has been asked to repeat the measurements.

The measurements consisted of recording the times that it took for a small ball bearing to fall through various distances. The analysis of the data was based on the kinematic equation: $\vec{y}(t) = \vec{y}_o + \vec{v}_o t + \frac{1}{2}\vec{a}t^2$

where: $\vec{y}(t)$ = final position of the ball; $\vec{y}_o$ = initial position of the ball

$\vec{v}_o$ = the initial velocity of the ball; $\vec{a}$ = the acceleration of the ball,

and t = the time of flight of the ball.

The displacement of the ball $\Delta\vec{y}$ is, of course, $\vec{y}(t) - \vec{y}_o$ and Δy is the magnitude of the displacement, in this case the distance travelled by the ball. Graphs of Δy vs. t and Δy vs. t^2 were plotted and the value of g was calculated from the slope of the graph that produced a straight line. Prepare a detailed report for the Head of the Department in which you discuss the problem, the measurements you performed, your analysis and your findings. In order to support your conclusions, the Head of Department asks you to list all the factors that you think influenced your measurements. Write down next to each factor whether you think it affected your results in a small way or a large way.

Your full report must be handed in before 14:00 on Friday 11 April, in time for the press conference called by the Head ! Take care with your graphs and calculations and be sure to write your report as carefully as you are able to.

Before you begin to take readings, draw a flow diagram (as you have learnt in chemistry) which sets out the sequence of the main steps that you need to follow to complete the experiment. Each student must produce a flow diagram. Use one side of an A4 page for this and call a demonstrator to initial your flow diagram. Include your flow diagram as part of your report and use look at it when you write up your "Method" section.

Here are some things to think about when drawing your flow diagram. Discuss these questions with the other students in your group. Listen to each other's opinions and talk to a tutor, if necessary.

- What are the main steps that you need to carry out?
- What variables are involved and what measurements do you need to take?
- How many different heights should you release the ball from?
- How many times should you release the ball from each height?
- How are you going to measure the heights ?
- What tables do you need to record all your readings?
- What graphs do you need to plot?
- What would be a valid conclusion to the experiment?

In order to practice what you learnt last week, estimate a standard uncertainty associated with reading the scale of the meter rule for each of your distance (Δy) measurements. Tabulate these standard uncertainties with your readings for Δy. (Of course this is not the only source of uncertainty for your measurements of Δy.)

As you have not yet learnt how to calculate a standard uncertainty for a set of repeated readings which are scattered, you are not expected to estimate standard uncertainties for your time (t) measurements.

You have also been given an assessment schedule which will be used by the marker of your report. Staple this to the front of your report before handing it in.

Your report must be handed in by posting it into the specially marked box in the Physics Course I laboratory before the time specified. All laboratory reports for your physics course PHY123H must be submitted in this way.

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PHY123H

Laboratory practical

Pendulum problem swings you into action

Work in groups of 2.
Call a demonstrator if you need help.

Imagine that you now work for a Scibucks Enterprises, a scientific company that consults for industry. Your boss calls you into her office and explains that she wants you to undertake an investigation for a client who is a clock maker. The clock maker says that he needs to know what the relationship is between the length of a pendulum and its period and must have proof that this relationship works in practice. You remember from your undergraduate physics days that the period, T, of a pendulum is related to the length, l, of the string by

$$T = 2\pi\sqrt{\frac{l}{g}}$$ where g is the acceleration due to gravity.

You therefore devise two experiments to test the theory:

Experiment A. Measure T for different lengths l and then plot a suitable graph to show that the above equation is valid.

Experiment B. Choose <u>one</u> length l and measure T many times, and then calculate g (using the equation above.)

For experiment B, you should determine the standard uncertainty $u(g)$ in your result for g.

In order to determine $u(g)$, you first need to calculate the standard uncertainty in T (using a type A evaluation of uncertainty) and the standard uncertainty in l (using a Type B evaluation of uncertainty).

You can then calculate $u(g)$ using

$$u(g) = g\sqrt{\left\{\frac{u(l)}{l}\right\}^2 + \left\{2\frac{u(\bar{T})}{\bar{T}}\right\}^2}$$

where g, l and $\bar{T}$ are your measured values.

If your value of g agrees with the accepted value of g for Cape Town (9.79 m s^{-2}) then this would further suggest that the equation for T is correct. (How do you think that you should compare your value with the "expected" book value of 9.79 m s^{-2} ?)

Your boss tells you that she must have your report completed before 10:00 on this Friday which should include a full description of your method, all the measurements you make, the calculations and graph and a suitable discussion and set of recommendations to the clock maker.

UCT Physics Education Group

Before you begin to take readings, draw a flow diagram which sets out the sequence of the main steps that you need to follow to complete the experiment. Each student must produce a flow diagram. Use one side of an A4 page for this and call a demonstrator to initial your flow diagram. Include your flow diagram as part of your report and use look at it when you write up your "Method" section.

Here are some things to think about when drawing your flow diagram. Discuss these questions with the other students in your group. Listen to each other's opinions and talk to a tutor, if necessary.

- What are the main steps that you need to carry out?
- What variables are involved and what measurements do you need to take?
- How many different lengths should you use in Experiment A?
- How many times should you measure the time for each length?
- How are you going to measure the lengths ?
- What tables do you need to record all your readings?
- What graph do you need to plot?
- What would be a valid conclusion to the experiment?

Is it better to measure the time for only one swing, or measure the time for many swings (e.g. 20) and then divide that time by 20 to get the period?

Is it better to start and stop the timing in the middle of the pendulum's swing or at one of the ends?

You have also been given an assessment schedule which will be used by the marker of your report. Staple this to the front of your report before handing it in.

Your report must be handed in by posting it into the specially marked box in the Physics Course I laboratory before the time specified.

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PHY123H

Laboratory practical

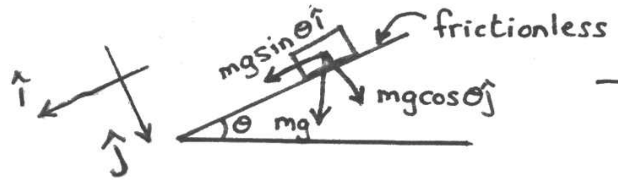
Investigating a frictionless airtrack

Work in groups of 3.
Call a demonstrator if you need help.

Your first job as a university graduate is at Scibucks Industrial, a company which designs and manufactures specialised equipment for industry. You are new on the job and are quite nervous to make a good impression. Your boss calls you into her office and explains to you that one of their top scientists has been taken ill and that she needs you to complete his work. He was investigating the effectiveness of a recently designed frictionless airtrack by measuring the acceleration of a light glider down it when sloped at an angle of θ. If the acceleration of the glider is measured to be $g \sin \theta$ (within a reasonable experimental uncertainty) then the design of the airtrack will be regarded as good and be put into production. She gives you a copy of the working notes of the scientist (overleaf) for you to repeat the experiment and complete the calculations.

Your boss reminds you that your results could cost the company a lot of money and therefore you should work carefully and write a clear report on your investigation. As you turn to leave she says that she must have your report on her desk by next Monday at 10:00 at the latest.

EXPERIMENT NOTES ON AIRTRACK



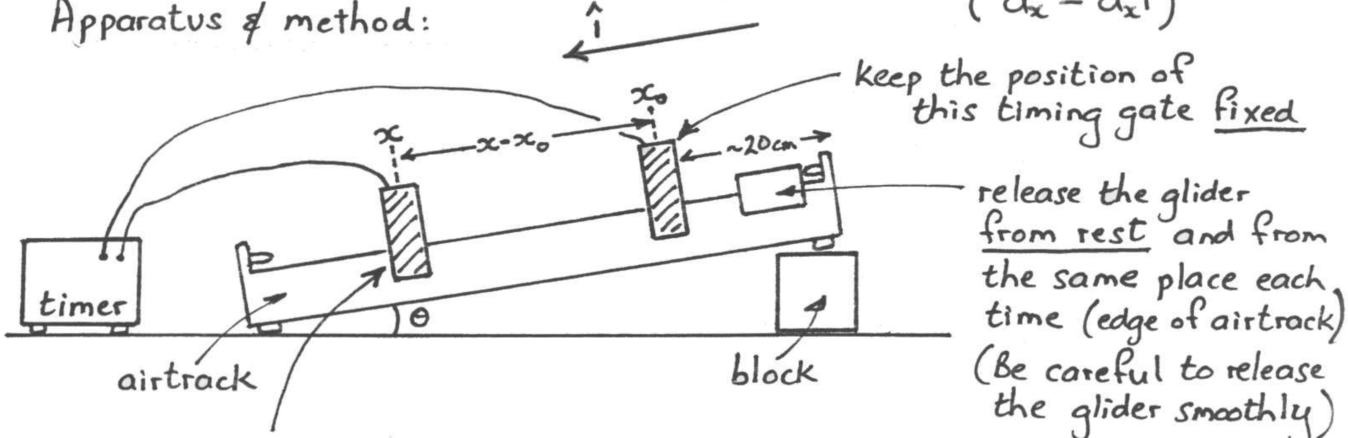
→ constant acceleration

$\therefore$ use $\vec{x}(t) = \vec{x}_0 + \vec{u}_x t + \frac{1}{2}\vec{a}_x t^2$

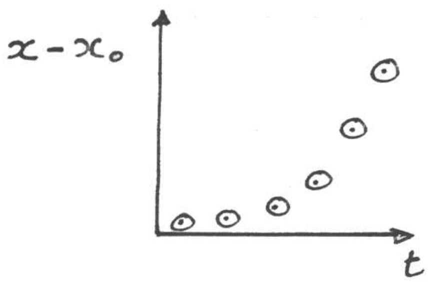
where $a_x = g\sin\theta$

$(\vec{a}_x = a_x\hat{i})$

Apparatus & method:

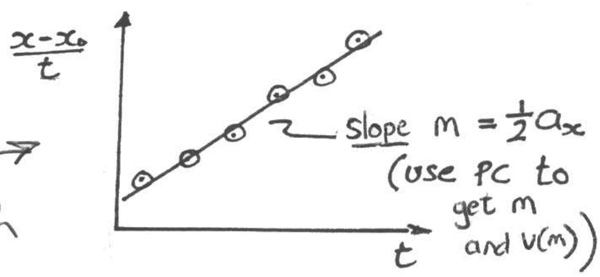


move this timing gate such that $x - x_0 = 30, 40, 50, 60$ & 70 cm and make at least 3 time measurements at each $x - x_0$



so rather write $\frac{x - x_0}{t} = u_x + \frac{1}{2}a_x t$

and plot $\frac{x - x_0}{t}$ vs t



- Measure $\theta \pm u(\theta)$
- Determine $m \pm u(m)$ from graph
- $m = \frac{1}{2}a_x = \frac{1}{2}g\sin\theta \Rightarrow$ determine g
- Calculate $u(g)$ from $u(m)$ and $u(\theta)$
- Does $[g \pm u(g)]_{\text{measured}}$ agree with $[g]_{\text{accepted value for Cape Town}}$?
- Make recommendations

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Laboratory practical

Rolling or sliding?

Work in groups of 3.
Call a demonstrator if you need help.

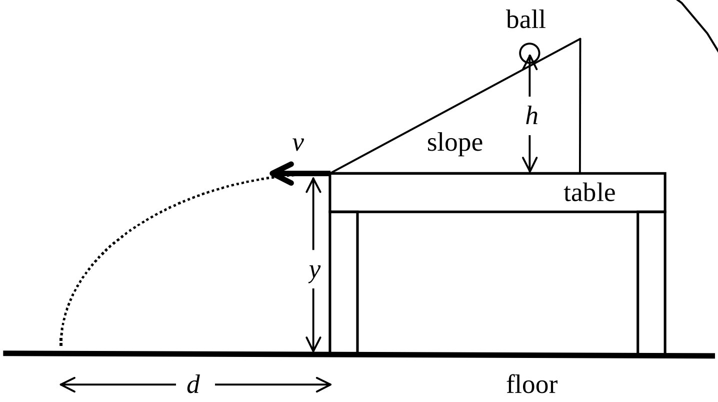
You have been hired by Sci-Fun, a company that markets toys and games, to test the physics of a new game. The idea of the game is for one player to release a mass on a ramp from a height chosen to get the landing point of the mass as close as possible to a spot on the floor specified by the opposing player. The inventors of the game based their idea on the theoretical analysis presented overleaf. Depending on the shape of the mass, and on the materials of the mass and the ramp, the mass will either slide or roll down the ramp, or the motion may be a combination of rolling and sliding. Sci-Fun has produced a prototype consisting of a steel ball and a wooden ramp. Their intuitive feeling is that the steel ball will roll without slipping, but they need experimental evidence to confirm or reject this hypothesis.

You are provided with the following apparatus: a wooden ramp that is clamped to the table, a steel ball, vernier calipers, a metre stick, a plumbline, some white paper and some carbon paper. The curved surface of the ramp is designed to launch the ball horizontally. By releasing the ball from different heights h and determining the corresponding distances d you can acquire data to plot an appropriate straight line graph. From this you can obtain an experimental value for the parameter β referred to in the analysis below.

Write a report to the directors of Sci-Fun. Describe your experimental method clearly and fully; include all the measurements and analysis you make, and the graph that you plot. Use a PC to determine the slope of your line and its uncertainty. Include a full numerical analysis of all uncertainties in your report. Inform the directors of Sci-Fun whether your experiment confirms their hypothesis or not. Your report should be handed in next Monday before 10h00.

Theoretical analysis

A wooden ramp is clamped near the edge of a table, with its end a distance *y* above the floor. A ball released from a height *h* above the launch point will move down the slope. It will be launched horizontally with speed *v*, and land on the floor a distance *d* from the end of the ramp.



The gravitational potential energy of the ball at height *h* is transformed into translational kinetic energy and rotational kinetic energy. If *v* and ω are the speed and angular speed, respectively, of the ball as it leaves the slope,

$$m\,g\,h \quad = \quad \tfrac{1}{2}\,m\,v^2 \quad + \quad \tfrac{1}{2}\,I\,\omega^2$$

where *r* is the radius, *m* is the mass, and *I* is the moment of inertia of the ball.

For a uniform solid sphere $I = \frac{2}{5}mr^2$.

If the ball rolls without slipping the angular speed and linear speed are related by $\omega = v/r$.

However if the mass slides without rolling $\omega = 0$, and the kinetic energy is purely translational.

By applying the equations of projectile motion for the trajectory of the ball to the floor,

i.e. $x(t) = x_o + u_x t + \frac{1}{2}a_x t^2$ and $y(t) = y_o + u_y t + \frac{1}{2}a_y t^2$

it can be shown that the conservation of energy equation above can be written as

$$4\,y\,h \quad = \quad d^2\,(1 + \beta)$$

where $\beta = 2/5$ for rolling without slipping, and $\beta = 0$ for sliding without rolling.

Intermediate values of β indicate a combination of rolling and sliding.

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Laboratory practical

Artificial blood

You are working for Medichem, a medical research company which develops new medical products for use in hospitals. One of your top researchers is working on manufacturing artificial blood and has produced a liquid which he hopes will form the basis of the plasma component of the blood. All the early indications are very promising - the new liquid has all the chemical properties necessary. However, it is necessary to determine whether the new liquid has a comparable viscosity to real blood plasma (which you are told has a coefficient of viscosity of 0.95 N s m^{-2}). If the viscosity of the new liquid is close to that of real blood plasma then Medichem will initiate pre-production testing of the new product. Your supervisor has asked you to complete the necessary experiments and then to write a report by 10:00 on Monday, making the necessary recommendations. You are told that the new liquid has a density of 969 kg m^{-3}. Be careful to include a full analysis of uncertainties in your report.

To characterize a liquid's viscosity, a *coefficient of viscosity* η is defined (look in any first year physics textbook). In order to measure the viscosity of the liquid, you will use a "falling ball" technique. For a spherical ball falling at its terminal speed v_T (i.e. with no acceleration) in a viscous liquid, by considering the forces acting on the falling ball (its weight, the buoyancy force and the viscous force, given by Stokes' equation) the coefficient of viscosity of the liquid is given by

$$\eta = \left(\frac{2g\left(\rho_b - \rho_f\right)}{9} \right) \frac{r^2}{v_T}$$

where

ρ_f : density of fluid (in this case 969 kg m^{-3})

ρ_b : density of the steel ball = 7780 kg m^{-3}

g : acceleration due to gravity (use 9.80 at UCT)

r : radius of the steel ball

v_T : terminal speed of the ball falling in the fluid.

What to do.

Measure the radius r of the steel balls using a micrometer screwgauge. Remember to take both an "open" and a "closed" reading with the screwgauge. The best estimate of the diameter d of the ball is then given by the difference between the open and closed readings l: i.e. $d = l_{open} - l_{closed}$.

Determine a Type B standard uncertainty for both the open and closed readings of the micrometer screwguage. Then the standard uncertainty for d is given by

$$u(d) = \sqrt{u(l_{open})^2 + u(l_{closed})^2}$$

(Do you understand where this equation comes from?)

Since the radius r of the ball is half of the diameter (of course), then the standard uncertainty for r is given by $\frac{u(r)}{r} = \frac{u(d)}{d}$.

To obtain a reliable value of v_T, a falling ball is timed over a number of different distances. Each ball can be timed (t) between two chosen marks on the measuring cylinder. To allow each ball to reach its terminal velocity, the top mark (the "start timing" mark) must be about 40 mm below the liquid's surface. Drop the balls through the hole situated centrally in the cylinder cover, timing each one as it falls a particular distance (y). Think about how many measurements of t to take at each y. How many different distances are necessary? Measure the distances y between the graduation marks you used, using the metre stick.

Plot an appropriate graph (y versus t). This should result in a straight line through the origin having slope v_T. Now use "curfit" (a least squares programme) on one of the PCs in the lab to provide you with a best estimate of the slope (v_T) and the standard uncertainty in the slope, $u(v_T)$.

You now are able to calculate a best estimate for η using the equation $\eta = \left(\frac{2g\left(\rho_b - \rho_f\right)}{9}\right)\frac{r^2}{v_T}$.

Be careful! Are you using SI units everywhere?

What about $u(\eta)$? Since the uncertainties in ρ_b, ρ_f and g are negligible, we use the equation

$$\frac{u(\eta)}{\eta} = \sqrt{\left(2\frac{u(r)}{r}\right)^2 + \left(-1\frac{u(v_T)}{v_T}\right)^2}.$$

You now have a measured value of $\eta \pm u(\eta)$. Does this agree with the book value of 0.95 N s m^{-2} for blood plasma? Think about your result carefully. Does it make sense?

A flywheel is a solid, heavy wheel, mounted on a shaft and attached to a piece of machinery which incorporates rotational motion. Basically, the flywheel stores rotational kinetic energy which can be given back to the machine when needed. For example, a flywheel which is attached to a generator will continue to turn if the generator cuts out and then can restart the engine by imparting its stored rotational kinetic energy to the engine (and turn it over). A flywheel may also be used to regulate the speed of a machine (e.g. on an engine crankshaft) by counteracting any torques acting on the machine through its rotational inertia.

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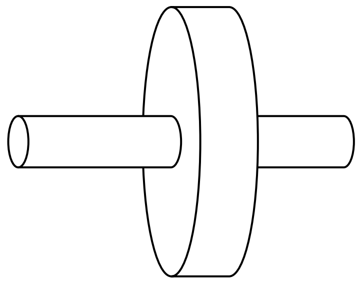
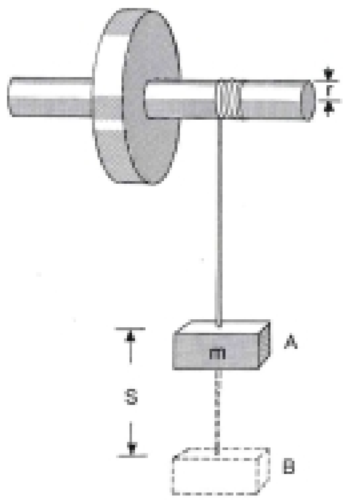
Laboratory practical

The Flywheel



An industrial firm, Weknownophysics Inc. , has approached your scientific consulting company and have asked you to investigate the flywheels in their factory. They would like to know whether or not the principle of conservation of energy applies to their flywheels. The method that you will employ makes use of a mass m attached to a length of string. The free end of the string is attached to the pin in the axle of the flywheel and wound around the axle 10 times. When the mass is released, it will accelerate as it falls to the table top. The length of the string should be just right that it detaches from the flywheel when the mass reaches the table top (check that this is the case). In addition, it has been arranged that the reference line (point 0) on the flywheel coincides with the pointer when the mass detaches (check this too). The flywheel will then rotate a further N revolutions before coming to rest.



Say that the mass is released at position **A** . It will fall through a distance s and cause the flywheel to rotate n times (here $n = 10$).
In falling to the table, the mass loses **potential energy** mgs.
At the same time, it gains **translational kinetic energy** $\frac{1}{2}mv^2$ while the flywheel (which rotates) gains **rotational kinetic energy** $\frac{1}{2}I\omega^2$.
(Here v is the final speed of the mass m and ω is the final angular speed of the flywheel when the mass has reached position **B**.)
In addition, work $2\pi n\tau$ is done against the **friction** in the flywheel.

By the **Principle of Conservation of Energy**:

decrease in potential energy (E_P) = increase in translational kinetic energy (E_K) + increase in rotational kinetic energy (E_R) + energy lost to friction (E_F)

or $$mgs = \tfrac{1}{2}mv^2 + \tfrac{1}{2}I\omega^2 + 2\pi n\tau$$

where:

$$I = mr^2\left(\frac{gt^2}{2s} - 1\right)\frac{N}{N+n}$$ is the moment of inertia of the flywheel and axle,

$\tau = \dfrac{I\omega^2}{4\pi N}$ is the frictional torque which slows the flywheel down.

N is the number of further rotations of the flywheel after the string is released,

t is the time that mass m takes to fall a distance s, and

r is the radius of the axle of the flywheel.

The average speed of the mass is s / t, and since the mass starts from rest, the final speed of the mass $v = 2s / t$ (at position B). Then the final angular speed of the flywheel $\omega = v\,r = 2s / rt$.

What to do

Attach the mass to the end of the string and the free end of the string to the pin in the axle of the flywheel. Wind the string around the axle 10 times. Release the mass and measure the time t for the mass to fall to the table. Then **count** the number of further revolutions N made by the flywheel before coming to rest. How many times should you repeat this experiment? Think about your tables carefully.
Use the vernier calipers to measure the radius of the flywheel axis and the metre rule to measure s.
Calculate best estimates for E_P, E_K, E_R and E_F. Be very careful with your units.

For the analysis of this experiment, you need to investigate whether or not $E_P = mgs$ is equal to $E_{sum} = E_K + E_R + E_F = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + 2\pi n\tau$, within their experimental uncertainties.
Do you realise that you <u>cannot</u> say whether or not $E_P = E_{sum}$ without considering their uncertainties? In other words, you need to see whether or not $E_P \pm u(E_P)$ overlaps with $E_{sum} \pm u(E_{sum})$.

The first step is to estimate values for $u(m)$, $u(s)$, $u(t)$, $u(N)$ and $u(r)$, either by a Type A or a Type B evaluation. The uncertainties in g (= 9.80 m s^{-2}) and n (=10) may be assumed to be negligible. Why is this the case?

Then you need to calculate values for $u(E_P)$, $u(E_K)$, $u(E_R)$ and $u(E_F)$.

For example, Since $E_P = mgs$, you will use the following equation for $u(E_P)$: $\dfrac{u(E_P)}{E_P} = \sqrt{\left(\dfrac{u(s)}{s}\right)^2 + \left(\dfrac{u(m)}{m}\right)^2}$

and since $E_K = \frac{1}{2}mv^2 = 2\,ms^2t^{-2}$, $\dfrac{u(E_K)}{E_K} = \sqrt{\left(\dfrac{u(m)}{m}\right)^2 + \left(2\dfrac{u(s)}{s}\right)^2 + \left(-2\dfrac{u(t)}{t}\right)^2}$.

Repeat a similar exercise to estimate $u(E_R)$ and $u(E_F)$.

The best estimate for $E_{sum} = E_K + E_R + E_F$. What about $u(E_{sum})$?

Since E_{sum} is obtained from the sum of a number of terms, $u(E_{sum}) = \sqrt{u(E_K)^2 + u(E_R)^2 + u(E_F)^2}$

Now you have $E_P \pm u(E_P)$ and $E_{sum} \pm u(E_{sum})$ and can finally say something about the conservation of energy in the flywheel and mass system. Write a report to the industrial firm which includes your measurements and analysis, and any recommendations that could improve the experimental method. The report must be completed by 10:00 on Monday.

UCT Physics Education Group

University of Cape Town
Department of Physics

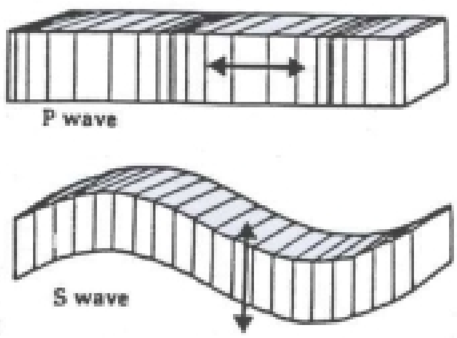
PHY124F

Laboratory practical

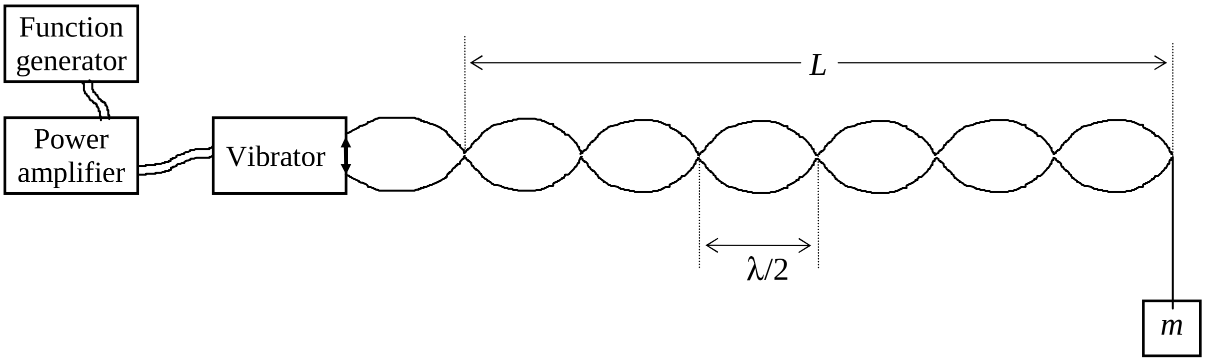
Earthquake !

Earthquakes are a great tragedy when people are killed and much damage is done. Although over 100 earthquakes registering more than 6.0 on the Richter scale occur yearly worldwide, very few of these are centred near dense residential areas and don't cause much damage. Earthquakes are very important to scientists who want to learn more about the internal composition of the earth. Much of our knowledge of the earth's interior comes from the study of waves that travel through the earth. These are seismic waves - the waves generated by earthquakes and underground nuclear explosions. The energy generated in the earth's interior, for example during an earthquake, radiates in all directions. The energy travels in the form of seismic waves to the earth's surface. Evidence of the waves is gathered on a seismograph - a sensitive instrument which records the movement of the ground beneath it. The seismograph output, when carefully analysed, provides a map of the earth's interior. More than 800 000 earthquakes occur every year but most of these are never felt by humans, they are only recorded on the many seismographs located all over in laboratories around the world.

Imagine that you are working in such a laboratory which is studying the nature of seismic waves. It is well known that seismic waves that travel through the interior of the earth occur in two forms: P-waves and S-waves. Primary waves or P-waves are longitudinal (like sound waves). They are the fastest of all seismic waves and so are the first to register on a seismograph. Secondary or S-waves are transverse waves and travel more slowly than S-waves. Since these waves are similar to those than occur in a violin or guitar string, you have devised a simple experiment to study the nature of S-waves.



S and P waves in rock



You have connected a long string to a vibrator which is connected to a function generator and amplifier. The string is kept taught by a mass m which hangs over the laboratory bench providing a tension T ($= m g$) in the string. The function generator is used to oscillate the vibrator and produce waves in the string. Since the string is effectively fixed at one end, the travelling waves propagating along the string are reflected at this end and the reflected waves interfere with the forward travelling waves. At certain frequencies, **standing waves** are produced when an integer number of half wavelengths fit exactly into the length of the string, and nodes will clearly be visible.

It is well known that the frequency f of the waves , their wavelength λ and their velocity v are related by $v = f\lambda$. Therefore since the distance between adjacent nodes of a standing wave is equal to half a wavelength ($\lambda/2$) it is therefore possible to determine the wavelength of the waves under these conditions. (You note that as the vibrating unit generates the waves in the string by oscillating the string up and down, the left point at which the string is attached to the unit is not a node. The length of the string L should therefore be measured from the extreme left and right hand nodes as shown in the figure.)

You find that standing waves having nodes from $n = 5$ to $n = 15$ are quite easy to produce in the string and the wavelength of each standing wave can be calculated from L and n in each case,

since $\lambda = \dfrac{2L}{(n-1)}$.

If you measure the wavelength λ for a series of standing waves at different frequencies f and plot f versus $\dfrac{1}{\lambda}$, you will obtain a straight line graph with slope v. The velocity v of these transverse waves in the string is related to the tension T by $v = \sqrt{\dfrac{T}{\mu}}$, where μ is the mass per unit length of the string.

Your supervisor at the laboratory is very impressed with your experiment and asks you to determine the mass per unit length μ of the string together with its uncertainty using this technique. Check your answer by weighing the string and measuring its length with a ruler. She is leaving tomorrow to go to a conference on earthquakes and must have your report by 10:00 on Friday, as she would like to be able to comment on how well your experiment is able to model the S-waves produced in seismic events.

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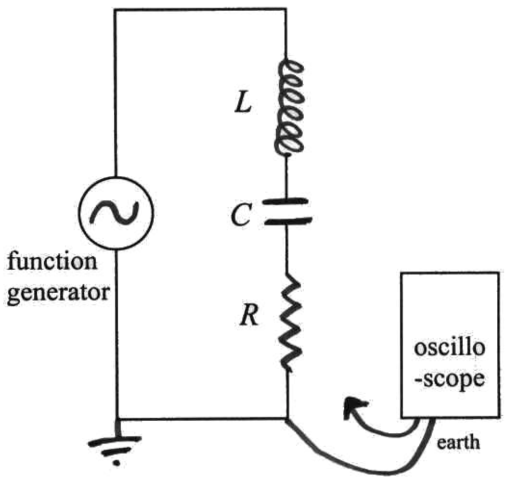
Laboratory practical

LRC resonance

Resonance circuits are used, for example, in radio receivers, where the resonance frequency of the circuit is varied by varying the capacitance. Resonance occurs when the natural frequency of the circuit equals one of the frequencies of the radio waves picked up at the antenna. At resonance, there is a relatively large current in the antenna circuit. If the Q factor of the circuit is sufficiently high, currents due to other radio station frequencies off resonance will be negligible compared with those due to the station frequency to which the circuit is tuned.

You are given an LRC circuit, a function generator (an ac supply of variable frequency) and an oscilloscope. An electronics company has asked you to measure the Q of this circuit to see whether or not it is suitable for use in a radio transmitter (a value of Q greater than 20 would be fine). Fortunately you have studied LRC resonance in physics and still have your lecture notes to refer to. Determine the Q of the circuit by studying the resonance characteristics of the circuit. The value of the resistor is 220 Ω, the capacitor's value is 0.022 μF and the value of the inductor is unknown. The frequency of the ac signal may be read on the LCD display on the front panel of the function generator and use the oscilloscope to measure voltages. Write a full report on your investigation which must be completed for the electronics company by 10:00 this Friday. Discuss your method carefully and compare and discuss your two values for Q. Also describe what factors might have introduced uncertainties to your measurement. The procedure for your measurements is described on the next page. Include a full uncertainty budget in your report.

Procedure:

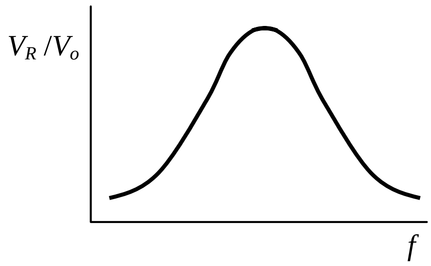


Connect up the circuit as shown in the diagram. Ensure that th earth lead of the oscilloscope is attached to the earth input of tl function generator. Set the output (waveform) of the function generator to sinusoidal and turn up the amplitude to its maximu position. Set the frequency of the function generator to about 4 kHz and establish the approximate position of the resonance frequency by sweeping the frequency and observe the change i voltage on the oscilloscope. This will also enable you to decide on a suitable range and interval for your measurements.

Now turn the frequency down to the bottom of the range and make careful measurements of f (the frequency of the generator), V_R (the voltage across the resistor) and V_o (the input voltage to the circuit). Don't record the reading on the display of the function generator, rather use the oscilloscope to measure each frequency setting. Increase the frequency slightly and measure V_R and V_o again. Repeat this procedure until you have covered the entire range of f (through the resonance). Make sure that you take sufficient readings in the vicinity of the resonance frequency.

Plot a resonance curve of (V_R / V_o) against f.

Your curve should look something like this:



From your resonance curve, determine the resonance frequency f_r, and Δf, which is the full width of the curve at (peak maximum) / $\sqrt{2}$. The Q of the circuit is then simply $f_r / \Delta f$.

The inductance L of the coil can now be calculated from $f_r = \left(2\pi\sqrt{LC}\right)^{-1}$,

and an alternative value for Q can then be calculated using $Q = \dfrac{2\pi f_r L}{R}$.

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Laboratory practical

Radioactivity and shielding

After obtaining your B.Sc. degree, you obtain your first job at the iThemba LABS. One of your first tasks is to investigate the shielding necessary for a particular experiment that is being planned. As you are new at the job, you are obviously keen to make a good impression and therefore attempt to do a careful job. You have been asked to complete two tasks. You are required to compare the shielding of gamma rays by different materials in absorbers of equal thickness. For this you are provided with 10 mm thick slabs of aluminium, wood, iron, copper, perspex and lead. Determine the ratio of the count rates with the different absorbers to the count rate with no absorber. Hence calculate the fraction of gamma rays removed by each slab. Can you recommend which of the materials are good for shielding gamma rays? What do you think this "shielding power" depends on? Remember to correct all your readings for the natural background.

Your supervisor explains to you that if a Geiger counter records N_o gamma rays per second from a source when no absorber is present then the number $N(x)$ recorded when an absorber of thickness x is placed between the source and the counter is given by:

$$N(x) = N_o \, e^{-\alpha x}$$

where α is the linear absorption coefficient of the absorber material for the gamma rays emitted by the source. She asks you to determine the linear absorption coefficient for ^{60}Co gamma rays of a special compound which is very similar to lead, but is much cheaper. This compound has the same density of lead (11.30 g cm^{-3}) and very similar chemical and physical properties. To measure α you should leave the Geiger counter and source as you had when using the different shielding materials above. Remeasure the count rate obtained with no absorber in position and then successively with one absorber, then 2, 3, 4, 5, and 6, each of thickness *about* 3 mm, in position. Measure the thickness of each absorber before using it and note the total absorber thickness x used in each measurement. Make at least 4 measurements of $N(x)$ for each value of x. Use a time interval long enough to record at least 100 counts in each measurement. Remember to correct all your measurements for the natural background. Calculate the average count rate for each value of x, and determine the linear absorption coefficient α by fitting a straight line to your data and estimate the uncertainty in your value. Using the curves given, compare the linear absorption coefficient you measure for this material with that for lead and comment on your results. She needs your report by 10:00 on Monday.

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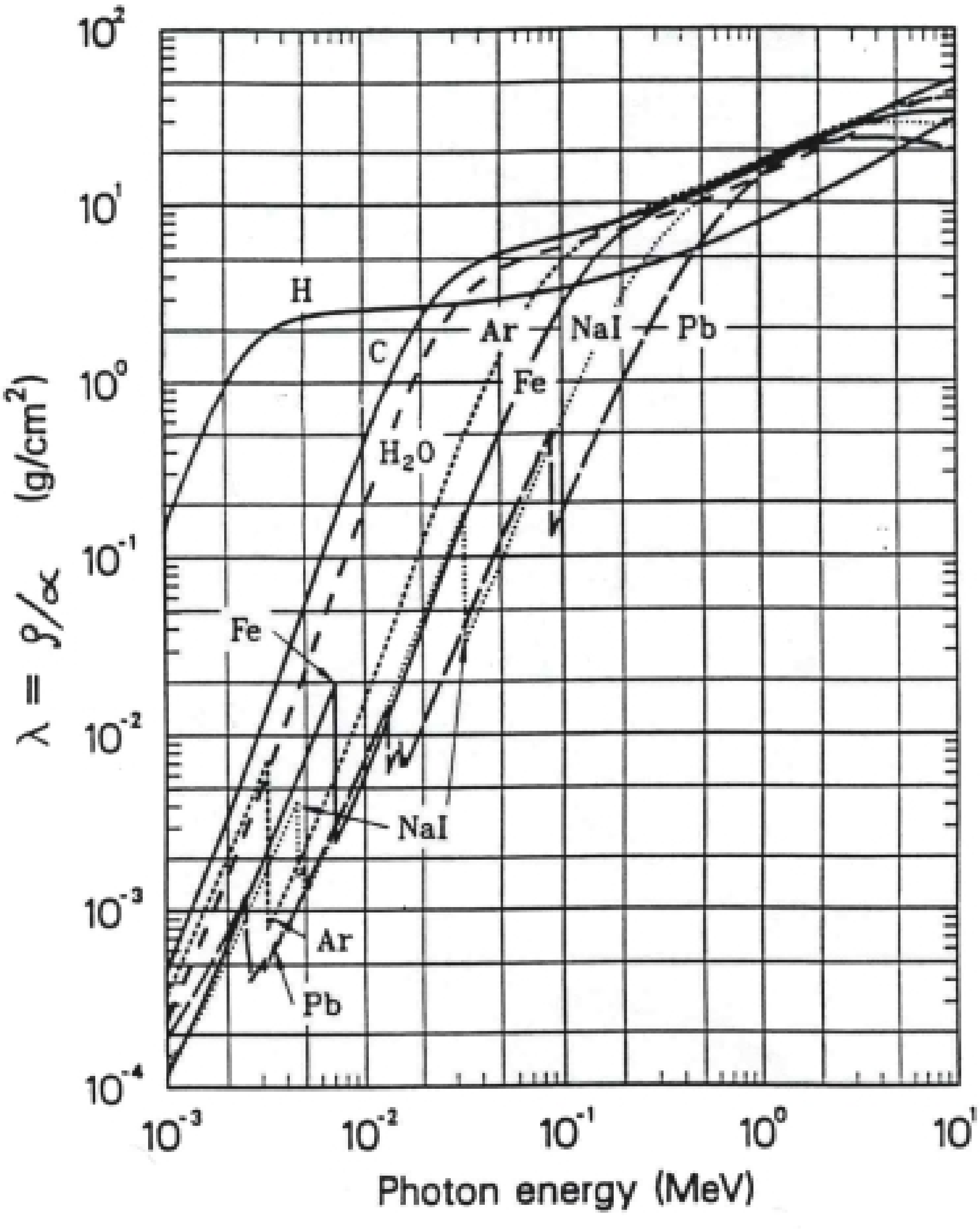
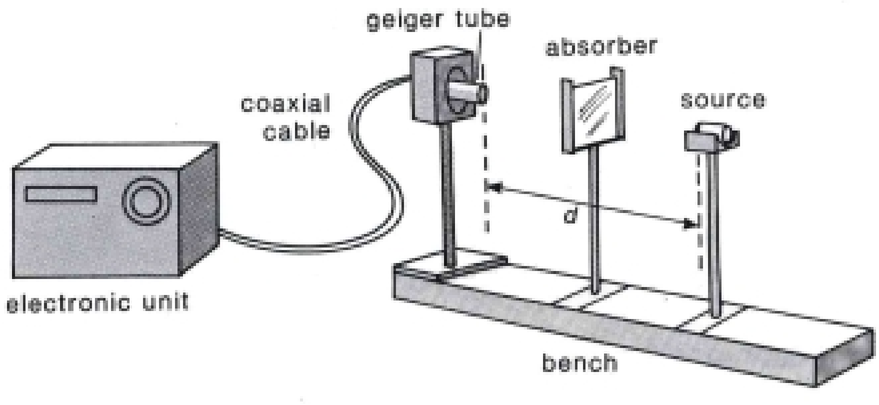
Warning: Nuclear radiation can be harmful if proper care is not taken while working with it, so possible hazards should be taken into consideration in every situation in which it is used. The source which you will use in this experiment (^{60}Co) is relatively weak and are sealed in a container which prevents the escape of radioactive material while still allowing the gamma rays emitted by the ^{60}Co source to escape. These gamma rays have a mean energy of 1.25 MeV.
The sources must be handled with care, and should not be handled unnecessarily.



The mass absorption length $\lambda = \rho / \alpha$ *(also known as the mean free path) for various absorbers as a function of photon energy. Here* ρ *is the density of the absorber and* α *is the linear absorption coefficient.*

The Geiger Counter:



A measuring bench is provided mounted on which are three stands, one to hold the Geiger counter, one to hold a radioactive source and the third to hold an absorber, or pack o absorbers, between the source and the counter.

The Geiger Counter is a fragile instrument and should be handled very gently. It should remain on its stand throughout the experiment.

The Geiger tube is connected by coaxial cable to an electronic unit which houses a power supply, an amplifier, a discriminator and a scaler. The scaler is a device which counts and displays the number of ionizing particles detected by the Geiger. The coaxial cable fulfils the dual purpose of carrying electric power from the electronic unit to the Geiger tube and carrying signals (pulses) back from the Geiger to the amplifier, discriminator and scaler. The scaler records the number of pulses occurring during a fixed counting period which may be preset to either 10, 20, 50, 100, 200 or 500 s. To set up the Geiger for operation the applied voltage must be set high enough that all detectable counts are detected, but not so high that electrical breakdown occurs, since this will produce spurious counts. For the Geiger counters used in this laboratory an operating voltage of 420 V will satisfy these twin requirements.

You will notice that the Geiger counts even when not exposed to the radioactive sources provided for this experiment. These counts can be attributed to traces of radioactivity in the natural environment and to cosmic radiation. This so-called **natural background** can be neglected when measuring a relatively high radiation level, but not when measuring a low radiation level comparable with the background itself. Place all radioactive sources well away from the Geiger counter. Measure the background using an interval of 100 seconds or longer. Always take at least four readings and determine the mean background count rate and the associated standard uncertainty. Now place the source on the stand and recorded all your measurements (different distances, different shields, etc.) Remember to also repeat these measurements a number of times. The natural background reading is then subtracted from <u>every</u> reading you obtain when measuring with a radioactive source.

For example, if you read 10 counts per minute for the background and 5.4 counts per second with a source, then your corrected reading will be $5.4 - (10/60) = 5.2$ counts.