UBC

# *The University of British Columbia*

## Laboratory Manual

for

## Physics 102

04W Edition

Labs start on Monday January 10, 2005
Check Web-CT to see which experiment
you are doing first.

Name: ______________________

Laboratory Section: ___________

*Prepared by F.E.L. Bates, December 2004*

# Physics 102

## Laboratory Manual

04W Edition

Table of Contents | Page

# Experiment Schedule – Physics 102 (04W)

| | | Monday<br>L2A<br>L2K<br>L2B | | | | Tuesday<br>L2C<br>L2L<br>L2D | | | | Wednesday<br>L2E<br>L2F | | | | Thursday<br>L2G<br>L2H | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Magenta | Yellow | Violet | Cyan | Magenta | Yellow | Violet | Cyan | Magenta | Yellow | Violet | Cyan | Magenta | Yellow | Violet | Cyan |
| 1 | Jan 3 | | | | | | | | | | | | | | | | |
| 2 | Jan 10 | 1 | 2 | – | – | 1 | 2 | – | – | 1 | 2 | – | – | 1 | 2 | – | – |
| 3 | Jan 17 | – | – | 1 | 2 | – | – | 1 | 2 | – | – | 1 | 2 | – | – | 1 | 2 |
| 4 | Jan 24 | 2 | 1 | – | – | 2 | 1 | – | – | 2 | 1 | – | – | 2 | 1 | – | – |
| 5 | Jan 31 | – | – | 2 | 1 | – | – | 2 | 1 | – | – | 2 | 1 | – | – | 2 | 1 |
| 6 | Feb 7 | 3 | 4 | – | – | 3 | 4 | – | – | 3 | 4 | – | – | 3 | 4 | – | – |
| | Feb 14 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| 7 | Feb 21 | – | – | 3 | 4 | – | – | 3 | 4 | – | – | 3 | 4 | – | – | 3 | 4 |
| 8 | Feb 28 | 4 | 3 | – | – | 4 | 3 | – | – | 4 | 3 | – | – | 4 | 3 | – | – |
| 9 | Mar 7 | – | – | 4 | 3 | – | – | 4 | 3 | – | – | 4 | 3 | – | – | 4 | 3 |
| 10 | Mar 14 | 5 | 6 | – | – | 5 | 6 | – | – | 5 | 6 | – | – | 5 | 6 | – | – |
| 11 | Mar 21 | – | – | 5 | 6 | – | – | 5 | 6 | – | – | 5 | 6 | – | – | 5 | 6 |
| 12 | Mar 28 | 6 | 5 | – | – | 6 | 5 | – | – | 6 | 5 | – | – | 6 | 5 | – | – |
| 12 | Apr 4 | – | – | 6 | 5 | – | – | 6 | 5 | – | – | 6 | 5 | – | – | 6 | 5 |
| | | | | | | | | | | | | | | | | | |

Check Web-CT on or after January 5, 2005 to see your TA section

Prelab exercises are completed on-line using Web-CT

**February 3rd** - Last day for Experiments 1 and 2

**March 10th** - Last day for Experiments 3 and 4

**April 7th** - Last day for Experiments 5 and 6

# Physics 102 – Elementary Physics II – Course Information

**Material Required:**
Textbook: Physics for Scientists and Engineers (with modern physics), by Douglas C. Giancoli (Third Edition);
Laboratory Manual for Physics 102, 04W edition, Physics Laboratory Notebook.

**Lecture Schedule**

*Overall responsibility for the course* — *Dr. Fran Bates (Hennings 329)*

| | | |
|---|---|---|
| Section 201 | M.W.F. 10:00 | Dr. Fran Bates (Hennings 329)<br>elf@physics.ubc.ca |
| Section 202 | M.W.F. 2:00 | Dr.Marina Milner-Bolotin (Hennings 278)<br>milnerm@physics.ubc.ca |
| Section 203 | T/Th 11:00 | Dr. David Williams (Hennings 283)<br>williams@physics.ubc.ca |
| Section 204 (CSP) | T/Th. 9:30 | Dr. Jaymie Matthews (Hennings 320B)<br>matthews@astro.ubc.ca |

**Laboratory:**
6 experiments on alternate weeks, check page i for schedule
*Laboratory: Supervisor in charge* — *Dr. Fran Bates (Hennings 329)*

**Tutorial Times**
Note tutorials alternate with the labs. Each tutorial is 2 hours

| Lab Section | Tutorial Time | Tutorial Room |
|---|---|---|
| L2A | Mon 9:00 | Hebb 10 |
| L2K | Mon 11:00 | Hebb 10 |
| L2B | Mon 2:00 | Hebb 10 |
| L2C | Tues 8:00 | Hebb 12 |
| L2L | Tues 12:00 | Hebb 10 |
| L2D | Tues 2:00 | Hebb 10 |
| L2E | Wed 8:00 | Hebb 10 |
| L2F | Wed 2:00 | Hebb 10 |
| L2G | Thurs 9:00 | Hebb 12 |
| L2H | Thurs 2:00 | Hebb 10 |

*Course information available: http://www.physics.ubc.ca/~phys102/*

# PHYSICS 102 LABORATORY

## GENERAL INTRODUCTION

This laboratory will operate very much like the Physics 101 laboratory did. Students are supervised by a faculty member and a teaching assistant. The T.A.s are graduate students and are in charge of a maximum of 24 students. The faculty member and T.A.s are anxious to give you as much personal help as possible, so **when in doubt please ask for assistance**. There is also a technician, Joseph O'Connor (Office Hebb 23) in charge of all equipment.

## Administrative Procedures and Regulations

A laboratory section (Magenta, Yellow, Violet or Cyan) will be assigned to you. You should check Web-Ct to see which section you are in, when your first laboratory is and what your first experiment will be. The laboratory schedule is on page i of this manual.

All laboratory reports are to be written straight into the laboratory notebook during the laboratory period. You will be able to use the same notebook you used in Physics 101 the previous term. The notebook does not leave the laboratory and must be handed in at the end of each laboratory period. Any student who takes a laboratory notebook home will receive a zero for the experiment. The laboratory notebook stays in the marking room to be marked by the T.A. at the end of each experiment. The T.A.s follow a prescribed marking scheme and every effort is made to be as fair as possible. Laboratory marks are normalized at the end of the term to allow for the fact that some T.A.s mark harder than others. There is nothing to be gained by switching laboratory sections to get a T.A. who has a reputation for "easy marking". Laboratory Notebooks are not returned at the end of term. All notebooks will be kept for one year and then destroyed. In special circumstances, you may apply in writing to Dr Bates for your notebook.

## Attendance

To obtain credit for the course, a passing mark must be obtained for both the laboratory and lecture component of the course, i.e. if you fail either the lecture or the laboratory component, you fail the course. The Physics 102 Laboratory generally operates at full capacity, so it is very difficult to schedule make-up laboratories. ***It is the student's responsibility to attend their regular sessions.*** A missed session will result in a zero mark for that experiment. If you are sick or you miss a laboratory due to unexpected circumstances, you should go to the Physics 102 laboratory during regular operating hours and see the laboratory supervisor to book a make-up lab at some time when space is available. Make-up labs need to be completed within one weeks of the missed experiment. Make-up labs not completed within the time limits will have 30% deducted from the assessed mark. Missing two consecutive experiments will mean an automatic fail in the course.

## Laboratory Section Changes

Only laboratory section changes approved by Dr. Bates are allowed. If it is necessary to change sections because of time-table conflicts, make sure that your T.A.s know that you have changed sections, so they can record the change in their mark books.

## Preparation for Experiments

Since you are limited to a total of two hours and fifty minutes for each experiment, you are not required to produce a "formal report" i.e. a complete account of the experiment. Just exactly what is required is described in detail in the front section of the Physics 101 manual - see "The Laboratory Report ".

The three-hour period is sufficient provided you do the prelaboratory exercises, study the introduction, references to relevant theory and the instructions for each experiment beforehand. Some of the experiments you will be doing without a partner so, it is essential that you study the manual ahead of time in order to use your laboratory time efficiently. The laboratory component represents 20% of your final Physics 102 mark. Your Teaching Assistant will assess marks for not only the written report handed in but also on your preparedness and understanding of the experiments.

| Component | Marks |
|---|---|
| Each experiment 10 marks | 60 |
| TA evaluation | 10 |
| Web-Ct prelab exercises | 10 |
| Total marks to be scaled out of 20 | 80 |

## Plagiarism

Among other things, plagiarism occurs when a student submits the work of another person as his or her own. ***Students who use data from old laboratory notebooks or any material from other students and copy this material into their notebook or even bring such material into the laboratory will receive a zero for their work.*** The university considers this type of misconduct to be a serious offense and may impose severe penalties for this. (See "Student Discipline", U.B.C. Calendar.) Any suspicious material will be confiscated.

### OBJECTIVES OF THIS LABORATORY

The laboratory component of Physics 102 consists of six biweekly two hour and fifty minute sessions. The objectives of this course are to provide the student

-with opportunities to observe and study some physical phenomena and with some *hands on* experience related to the material covered in the lecture section of the course.

- with experience in using some standard laboratory equipment such as computers, digital meters, oscilloscopes, function generators and Geiger counters.

-with the skills to present a clear and concise record of observations made during an experiment and to present conclusions concisely.

- with the ability to analyze a result and compare it with predicted theory.

# *Physics 102 Laboratory Reference Sheet*

Prepare ahead for the laboratory by reading through the experiment and doing the prelaboratory exercises.
No food or beverages are allowed in the laboratory.

## Experimental Write-ups

All laboratory write-ups are completed within the laboratory. Please use pen - if you make a mistake just cross out the mistake. Write-ups are supposed to be informal but should include the following elements:

***Experiment Number and Title*** ***Date***
***Lab Partner and Bench Number***

***Objective:***

***Data:*** a clear record of any observations and data (with estimated uncertainty) taken. Enter your data directly into your notebook. Data tables are usually the best way to present your results. Columns need labels and units.

***Sample Calculation:*** your TA needs to know how you are processing your data.

***Graphs:*** properly labelled with error bars if required.

***Error Analysis:*** if specifically asked for or if you are comparing results. Uncertainties in *final* answers should be given to only one significant figure.

***Comments/Conclusions:*** Do your results agree with the literature values or the theory? Could the experiment be improved? Answer any questions.

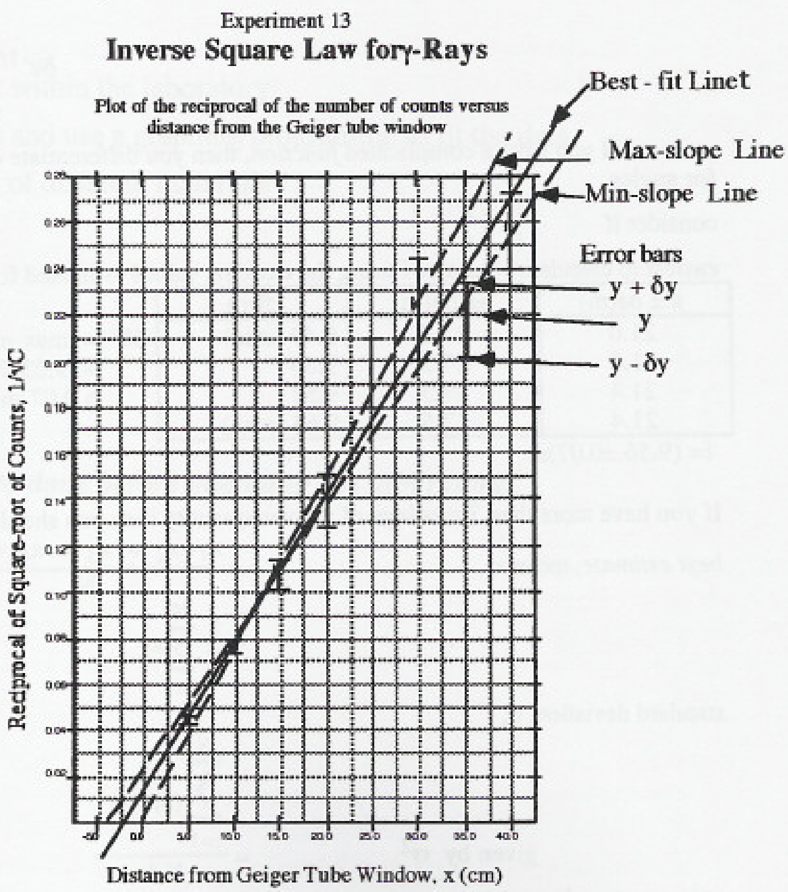
## *Graphs*

Use the whole page - plot area should be > 50%
Use pencil and indicate points used to determine slope.
Need a title and axes labelled with variable and units.
If error bars too small, indicate on graph.
For error in slope - determine maximum and minimum slope then:

$\delta m = (\text{max} - \text{min})/2$

Comment on graph
- is it a straight line?
- does it go through most of the data points?
- what does the slope represent?
- intercepts?

y-axis (ordinate)




x- axis (abscissa)

# Error Analysis

## *Individual Measurements*

Estimate a reading error for all measurements i.e. a = (21.2 ±0.2)m and b = (17.4±0.1)m - a good *initial* estimate for a scale reading is half the smallest division. The absolute error in a is 0.2 m, its relative or fractional error is 0.2/21.2 = 0.0094 and its percentage error is 0.94%

## *Combining errors* (random errors)

If you *add or subtract* two readings, then you add the absolute errors i.e.

$$a+b = (21.2 \pm 0.2)m + (17.4 \pm 0.1)m = (38.6 \pm 0.3)m$$

$$a-b = (21.2 \pm 0.2)m - (17.4 \pm 0.1)m = (3.8 \pm 0.3)m$$

If you *multiply or divide* two readings, then you add the percent or relative errors i.e

$$a/b = (21.2 \pm 0.2)m / (17.4 \pm 0.1)m = 1.22 \pm 0.02$$

$$\frac{\delta(a/b)}{a/b} = \frac{\delta a}{a} + \frac{\delta b}{b} = 0.0094 + 0.0057$$

$$\delta(a/b) = 1.218 \times 0.0151 = 0.018$$

$$a \times b = (21.2 \pm 0.2)m \times (17.4 \pm 0.1)m = 369 \pm 6$$

$$\frac{\delta(a \times b)}{a \times b} = \frac{\delta a}{a} + \frac{\delta b}{b} = 0.0094 + 0.0057$$

$$\delta(a \times b) = 368.9 \times 0.0151 = 5.6\ m^2$$

If you raise a reading to an *exponent*, then you multiply the percent or relative error by the absolute value of the exponent. i.e.

$$a^{-1/2} = (21.2 \pm 0.2)^{-1/2}\ m^{-1/2} = (0.217 \pm 0.001) m^{-1/2}$$

$$\frac{\delta a^{-1/2}}{a^{-1/2}} = |-1/2| \frac{\delta a}{a} = \frac{1}{2} \times 0.0094$$

$$\delta a^{-1/2} = 0.217 \times 0.0047 = 0.00102$$

If you have a complicated *function*, then you differentiate or substitute - for differentiation you need to use radians for angles.

consider if $\frac{1}{f} = \frac{1}{a} + \frac{1}{b}$

easiest to calculate values of f using the extreme values estimated for a and b.

| a ± δa(m) | b± δb(m) | f(m) |
|---|---|---|
| 21.0 | 17.3 | 9.49 (min) |
| 21.0 | 17.5 | 9.55 |
| 21.4 | 17.3 | 9.57 |
| 21.4 | 17.5 | 9.63 (max) |

$$\delta f = (\text{max-min})/2 = (9.63-9.49)/2\ m = 0.07\ m$$

f= (9.56 ±0.07)m

If you have more than 3 readings of a given quantity then you should use statistical methods.

*best estimate*, mean $\bar{x}$

$$= \frac{x_1 + x_2 + x_3 + x_4 + \ldots}{N} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

standard deviation, σ,

given by $\sigma^2$

$$= \frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}$$

*estimate error in mean:*

standard error, ε

$$= \frac{\sigma}{\sqrt{N}}$$

# EXPERIMENT 1

## RADIOACTIVITY

**Terms you should know and understand: (check text and lab manual)**

$\alpha$ and $\beta$ particle, $\gamma$-ray

Half-life

Activity (decay rate)

Background radiation

**Equipment you will be using:**

Radioactive sources

Computer interfaced Geiger counter

Absorbers

**What you will be doing:**

Measure the background count within the laboratory

Simulate a half-life experiment and use a graphing programme to fit the data

Study the absorbing properties of different materials

***Note the Web-CT prelab exercise is to done before attending the laboratory.***

# EXPERIMENT 1

## RADIOACTIVITY

**Objective**: An introduction to the properties of α, β, and γ-rays.

## INTRODUCTION

Radioactivity is the spontaneous disintegration or rearrangement of the internal structure of atomic nuclei. This process is characterized by the emission of radiation in the form of alpha-particles (α; ${}^{4}_{2}He$), beta-particles (β; ${}^{0}_{-1}e$) and gamma-rays (${}^{0}_{0}\gamma$). Radioactive decay occurs due to the basic principle that any system will change to a state of lower total potential energy if possible. If an isotope is stable, it will not spontaneously decay (emit energy) of its own accord. For an unstable isotope, the nuclei will eventually undergo a radioactive decay. Some heavy nuclei like plutonium-239 decay by emitting an α-particle (a fast helium nucleus). Other nuclei like strontium-90 decay by emitting a β-particle (a fast electron) and an electron antineutrino (${}^{0}_{0}\bar{v}$), a particle with very small mass and no charge. After one of these decays, the product nucleus may be left in an excited state. Such an excited nucleus will then make a transition to the ground state, releasing the energy in the form of one or more γ-rays (high-energy photons or light quanta). Originally, when the exact nature of these particles was not known, they were simply called α, β, and γ-rays; this nomenclature is still used.

Radioactivity is a subject of paramount importance in many widely separated fields of science, from potassium-argon dating in geology, carbon dating in archeology, tracer analysis in medical and life sciences, to uranium and induced fission in nuclear reactors for power generation (and the hazards associated with them).

### Radioactive Sources

The radioactive sources used for Study II are mounted in holders. These sources are not dangerous but ***should not be touched*** on the active surfaces. The sources have to be signed out since they are strictly controlled by government regulations.

The **α-source** is either americium-241 or plutonium-239. Americium is commonly used in smoke detectors to ionize the molecules in air, allowing them to conduct an electric current. It is an artificial element produced from plutonium. By emitting an α-particle the americium changes into neptunium, this decay can be written as:

$$ {}^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\mathrm{He} $$

The α-decay of plutonium-239 is written as:

$$ {}^{239}_{94}\mathrm{Pu} \rightarrow {}^{235}_{92}\mathrm{U} + {}^{4}_{2}\mathrm{He} $$

α-Particles consist of two protons and two neutrons (i.e. $He^{2+}$), they typically have energies of 0.5 to 10 MeV depending on their source. They are very ionizing. It requires about 10 eV to ionize an air molecule, so a 5 MeV α-particle can produce about $5 \times 10^5$ ion pairs.

The **β-source** will be either a small amount of strontium-90 or thallium-204. Strontium-90 was one of the isotopes that was showing up in milk in parts of Europe in increasing amounts in 1986, during the Chernobyl accident. The equations for beta decay are:

$${}^{90}_{38}\mathrm{Sr} \rightarrow {}^{90}_{39}\mathrm{Y} + {}^{0}_{-1}e + {}^{0}_{0}\tilde{\nu}$$

$${}^{204}_{81}\mathrm{Tl} \rightarrow {}^{204}_{82}\mathrm{Pb} + {}^{0}_{-1}e + {}^{0}_{0}\tilde{\nu}$$

β-Particles typically have energies of 0.01 to 10 MeV. Unlike α-particles and γ-rays, they are not emitted with a well-defined energy for a given source, but can have a range of energies. This is because during β-emission, a neutrino is also given off and it shares the available energy with the β–particle. The α and β-particles are charged, and as they pass through matter, they collide with atoms, knocking out electrons from these atoms. They continually lose energy in this ionization process, and are eventually brought to rest. When slowed down sufficiently, the α-particle captures two electrons and becomes a neutral helium atom. α-Particles are stopped by a few centimeters of air, while the β-particles can penetrate a few thicknesses of aluminum foil before being brought to rest.

The **γ-source** is a small amount of cobalt-60 mounted in a round plastic disc with a radioactivity sign on top. This source also emits β-rays. The equation for this decay is given by:

$${}^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni}^{*} + {}^{0}_{-1}e + {}^{0}_{0}\tilde{\nu}$$

$$\downarrow$$

$${}^{60}_{28}\mathrm{Ni} + 2\,{}^{0}_{0}\gamma$$

Cobalt-60 is the isotope that is used for cancer treatment, destroying the tissues with controlled doses of γ–radiation. It is also used for sterilizing medical equipment. The γ-rays actually come from the de-excitation of the daughter nucleus nickel-60, but we still refer to them loosely as the cobalt-60 γ-rays. γ-Rays are high energy photons and typically have energies of 0.01 to 10 MeV. They are not charged and so are not as ionizing as α or β-particles. γ-Rays are very penetrating – when one eventually strikes an atom, the incident photon disappears completely and its energy shows up as energetic electrons and positrons (antielectron) and in secondary γ-rays of lower energy. These processes are called photoelectric effect, pair production and Compton effect, respectively. All these types of rays cause ionization that can be detected with a Geiger counter.

The radioactive process is said to be spontaneous. By this we mean that we cannot predict when a particular nucleus will decay – we can only specify the probability that the nucleus will decay in a given time interval. Although the decay of an individual nucleus is quite unpredictable, the average rate of decay for a very large number of nuclei can be predicted quite accurately. The decay of the large group is expressed in terms of a time interval, the *half-life*. The half-life is the time required for half the number of nuclei in a sample to undergo the radioactive transformation. Thus, if an isotope has a half-life of 20 minutes and our sample has 1000 of these nuclei, then after 20 minutes about 500 of the nuclei will have decayed. We have no idea though which nuclei will decay next, we only know that on average half will decay for a specific half-life. For a radioactive species to be found in nature it (or a preceding element) must have a very long half-life. For such species the number of counts will stay effectively constant during a laboratory experiment. Such radioactive species will be used in Study II.

**Fluctuations in Radioactive Decays**

When you are using the Geiger counter you will notice an inherent fluctuation in the number of counts per time interval that you measure. This fluctuation occurs because any radioactive process has associated with it a degree of randomness. A useful analogy to make is throwing dice. If one hundred dice are thrown, then you would expect on average one sixth or about 16 or 17 of the dice to show the number 3. Each time you throw the 100 dice though, you may get 17, 14 or even 10 "threes". If you threw the dice a lot of times and plot the number of "threes" for each throw in the form of a histogram, then your results would look like Figure 1.1a.which shows the probability for getting a given number of "threes" for 100 dice.

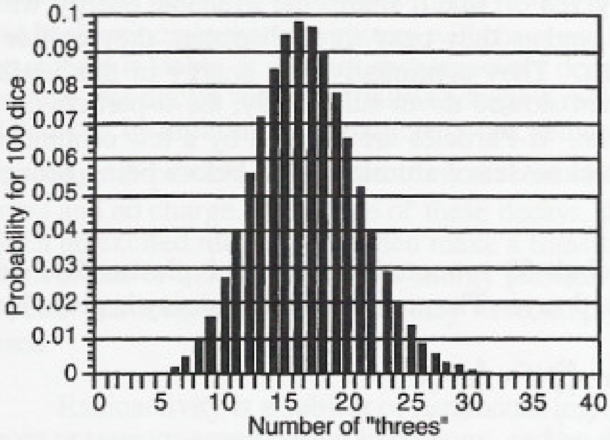



Figure 1.1a

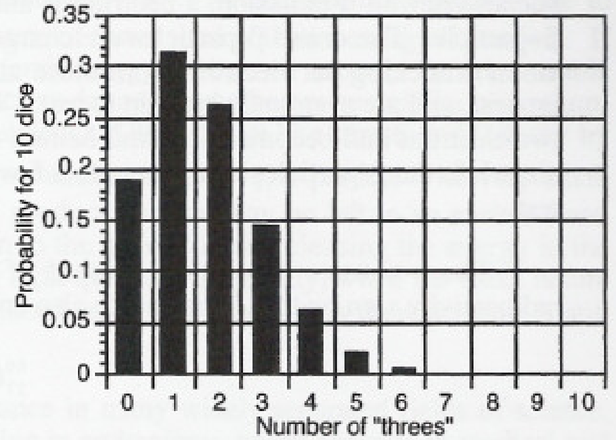



Figure 1.1b

If you have only 10 dice and if you threw them a lot of times then you would get a histogram similar to Figure 1.1b. From this figure you can see that you should not get any "threes" for just under 20 percent of the time. For throwing dice, the type of distribution you get is given by the binomial distribution. For radioactive decay, if you collect enough data then the type of distribution that you get is called a Poisson distribution. The Poisson distribution is a limiting case of the binomial distribution for a large number of objects and a small probability of outcome and its form is given by:

$$P(x) = \frac{m^x e^{-m}}{x!}$$

where x is the number of nuclei that decay in a given time, and m is the average or mean value for the number of disintegrations in a given time. This distribution has the special property that the standard deviation, $\sigma$, is equal to the square-root of the mean value. Given only one count measurement, C, one has to assume that the measurement is typical so that the average value is close to C and then $\sigma \approx \sqrt{C}$ . This is clearly very approximate and crude, but nevertheless it is very useful to remember in radioactivity counting experiments as it tells you the sort of fluctuation in count rate that you can expect. It is also useful in other situations involving counting, e.g. the number of people entering a store in a day, the number of seeds that fail to germinate from a batch, etc. Note that for a count accuracy of at least 10%, then a count of at least 100 must be taken!

## STUDY I – INTRODUCTION TO RADIOACTIVE COUNTING

In this study you will use a computer interfaced Geiger counter to investigate the randomness of the counts produced by background radiation within the lab and also look at the properties of some common materials.

**********

*RADIOACTIVITY CAN BE HARMFUL TO YOUR HEALTH. DO NOT TOUCH THE ACTIVE AREA OF THE SOURCES. FOLLOWING THIS LABORATORY YOU SHOULD WASH YOUR HANDS BEFORE EATING OR DRINKING.*

*********

***During this laboratory, you will need to use you time efficiently. There will be times during the experiment that you will set the computer to automatically record data - use this time to record your data, comments or calculations in your notebook.***

The file you will be using for this study is on the desktop and called *P102Exp1Study1*. It is a program that automatically collects data and then present the results as a plot of counts over time and also as a histogram of the number of times a given count occurs versus the count value. Check that the Geiger tube is plugged into the electrical socket.

**Procedure:**

1. During the TA introduction to the experiment, set the computer to record a background count. From the Menu select **Experiment**, then **Data Collection**. The **Experiment Length** should be **300 seconds** and the **Count Interval** should be **5 seconds** i.e. the Geiger counter will count the number of times it detects an ionization event for five seconds and then record the total number of events or counts during this 5 second period.

2. Select **Collect** from the main menu bar. Once the data has been collected - a text box should show on the top graph. If the text box is not there: click on the top graph of *Radiation versus Time* to select the window and then select **Stat** from the top menu bar.
   - Report the value for the mean count and its standard deviation, record this data in your notebook and also on the blackboard.

   Recall that *under ideal conditions*, the predicted value for the standard deviation is the square-root of the number of counts.
   - In the second study, you will be recording data for 20 second time intervals, **what should be the background count for this time interval?**

3. Print a copy the graphs to include in your notebook - if you select **Print (Ctrl+P)** from the **File Menu**, both graphs will be plotted on one page. Note that before you print the graphs, you may wish to rescale the graphs. To do this just click the blue **A** (autoscale) on the top menu bar.

4. Repeat the data collection for the KCl (salt substitute). Don't store the previous data, select **Erase and Continue**. Also collect data for one of the other samples provided (clock, watch dish). You do not have to print the graphs just record the average count and its standard deviation.

5. Collect your data for the simulated half-life. Draw a table similar to the one below. On your bench there is a box containing 100 cubes. Each cube has one face with an X on it. Shake the box, and remove any cubes that have an X face-up – it has *decayed* radioactively. Repeat 6 more times. Record your results in your book and also on the blackboard.

| Shake Number | Number of Cubes remaining | Class Total<br><br>Number of Cubes remaining |
|---|---|---|
| 0 | 100 | |
| 1 | | |
| 2<br>.... | | |

## STUDY II – RADIATION SHIELDING

Placing a Geiger tube over a radioactive source gives an indication of the activity of the source. The efficiency with which the Geiger tube detects radioactivity, however, can vary considerably and depends on the characteristics of the tube and the source of the radioactivity. One way to distinguish between the different types of particles emitted in radioactive decay is to see how the particles are absorbed by different materials. For $\alpha$-particles, it is found that absorption increases with the density of the absorbing material and with the thickness of the material. In this study you will determine the thickness of different materials required to significantly reduce the activity of the sources. The program that you will be using is on the desktop and called P102Exp1Study 2. The program will count for a given time interval and then will allow you to enter the number of layers of shielding material that you have used. You will use up to seven layers of the different materials.

Once you have collected your data, you can automatically fit your data to given functions. For most studies of absorption of radiation as a function of thickness, the count rate is of the form:

$$R = R_0 e^{-kt}$$

where $R_0$ is the count-rate with no absorber, R is the count-rate for a thickness t of the absorber and k is a constant that depends on the type of radiation and absorber material.

**Procedure:**

1. Sign out the three sources from your TA. When you are not using any of the sources, place them on the bench as far away from the Geiger tube as possible. From the Menu select **Experiment** then **Data Collection** and **Mode: Events with Entry**. The **Count Interval** will be 20 seconds. You will be using three absorber materials that are in order of increasing density: air, plastic and copper.

2. Start with the alpha source. Set the source height so that you can just fit the 5 sheets of plastic between the source and Geiger tube. Initially the plastic sheets are only going to be used for setting the spacing. Remove the sheets and click **Collect** and wait for the number to appear on the meter window. Click the **Keep** button to store the radiation count for this initial position and then enter a five for the number of layers of material you have used. Before you click **Continue**, change the spacing between the source and Geiger tube so that you can just fit 4 sheets of plastic. Continue until you are only using a single piece of paper as a spacer (i.e zero sheets of plastic). **Stop Collection**. Record the data in your notebook in the form of a data table as follows:

| Number of Layers | Counts for 20 seconds |
|---|---|
| **0**<br>**1**<br>**2**<br>**-**<br>**-** | |

3. Try and fit your data - select **Analyze** from the upper menu bar and then **Automatic Curve Fit** and choose the function **A*exp[-C*x] + B**.
   - Is the graph of Counts versus number of layers exponential?
   - Estimate the thickness of air required to reduce the alpha count rate to 50%.

4. For the alphas source, investigate the shielding properties of a single piece of paper and a single piece of plastic
   - comment on your findings.

5. Next use the beta source and investigate the shielding properties of the plastic and copper sheets. Set the initial separation of the source and detector so that you can just fit 5 sheets of plastic or copper. Keep this separation constant – and then take measurements for 0-5 sheets of plastic and copper.
   - Determine the number of sheets of each material required to reduce the initial count rate to 50%

6. Repeat the measurements for the gamma source, using 7 sheets of the copper or plastic.
   - Comment on the efficiencies of the different materials to shield the different sources.
   - Calculate the amount of material needed to reduce the count rate to 50% in terms of density times thickness i.e. $\xi=\rho d$ (g/cm$^2$).

**When you have completed this study, please ensure that all of the radioactive sources are returned to your TA.**

**STUDY III – HALF-LIFE**

1. Input the half-life data collected in Study I into the Graphical Analysis programme with x as the shake number and y as the number of cubes remaining. On the graph, click and drag to select your data, from the top menu bar select **Analyze** and then **curve fit**. Try the function y=A*exp(-C*x)+B. This is equivalent to using the equation $N=N_0e^{-\lambda t}$, where $\lambda$ is the decay constant. Report your value for the decay constant – could you have predicted this value?

2. Select Analyze again and try the function y=A*0.5^(b*x) – you will need to input this yourself using **Define Function**. How does the previous fit compare to this one? Are the two equations you have used to fit your data related?

**CONCLUSTION/QUESTIONS:**

1. In study I, how did your background readings compare to the average class value. Is the assumption that standard deviation, $\sigma$, is equal to the square-root of the mean value valid?

2. Is KCl radioactive?

3. In the prelaboratory exercise you estimated the activity of the $\gamma$-source. How does this value compare with the actual number of counts you measured with your Geiger tube in study II?

4. If you are given an unknown radioactive material, how would you distinguish if it is an alpha, beta or gamma emitter?

5. In some medical studies a radioactive material is injected into a body to be used as a tracer. What type of source would this have to be?

## Prelaboratory Exercise

1. The $\gamma$-source you will be using had an activity of approximately $3.70 \times 10^4$ becquerel (1Bq=1 disintegration/second) in July 2004. Given that the half-life of cobalt-60 is 5.2 years, estimate the activity of the $\gamma$-source today.

2. The risk associated with radioactive samples depends on the type of radiation, activity of the sample, distance from the sample and the time of exposure. The theoretical dose an individual receives is given by:

$$X = \frac{\Gamma A t}{d^2}$$

where X is the dose in sieverts(Sv), the unit of biological effectiveness of the radiation, $\Gamma$ is a specific constant for a given isotope, A is the activity of the sample, t is the time and d is the distance from the source. For cobalt-60, $\Gamma = 3.57 \times 10^{-13}$ Sv.m$^2$/hour.Bq. Use the value you determined for the activity of the $\gamma$-source calculated above and estimate the radiation dose that a person would receive if they had an average separation from the source of 1 metre and used the source for a) three hours only b) three hours a day for 100 days. (The average radiation dose received in one year due to cosmic rays and internal radioactive isotopes such as potassium-40 is 0.0008 Sv; an X-ray is typically 0.0007 Sv.)

# EXPERIMENT 2

## Meters

**Terms you should know and understand: (check text and lab manual)**

- Resistance
- Ohm's Law
- Parallel and series circuit
- Temperature dependence of resistance/resistivity
- Power delivered to a resistor
- Stefan's Law

**Equipment you will be using:**

- Resistors, light-bulb
- D.C. Power Supply
- Digital Multimeters
- Computer for graphing

**What you will be doing:**

- Measure resistance using an ohmmeter
- Use the colour code of a resistor to determine its nominal value
- Measure resistance using an ammeter and a voltmeter
- Determine the temperature of a tungsten filament by measuring its resistance
- See if Stefan's Law is obeyed for a light bulb

***Note the Web-CT prelab exercise is to be completed before doing the experiment.***

## EXPERIMENT 2

## Meters

**Overview**: A basic introduction to the use of a digital multimeter to measure resistance, current and voltage in a direct-current circuit.

### STUDY I – RESISTANCE MEASUREMENTS

The resistance of a component, R, is defined by the familiar equation:

$$\Delta V = IR \quad (2.1)$$

where $\Delta V$ is the potential difference across the component and $I$ is the current through the component. For metallic conductors under normal conditions, $\Delta V$ is directly proportional to $I$ so that $R$ is a constant and we say Ohm's Law holds. Ohm's Law is not a law in the usual sense of the word in Physics – it summarizes the experimental facts for normal conductors, but has no *universal* validity. For example, even for metallic conductors the value of R varies with temperature; so if the current I is sufficient to raise the temperature then Ohm's Law will no longer apply – but $R = \Delta V/I$ will still define the resistance at that value of the current.

When a Digital Meter is used as an ohmmeter, the battery of the meter provides a small direct voltage across the component whose resistance you are measuring. You ***never*** connect an ohmmeter if the component is connected to an active voltage source such as a battery, function generator or power supply.

**Procedure:**

*Note that the uncertainty in the digital meter for resistance measurements is ±4 digits in the last digit read i.e. if the reading is 1.003kΩ then the resistance is (1.003±. 004) kΩ.*

1. Make sure that you have read the Appendix on the use of the Digital Meter. Connect a red lead to the VΩ terminal of the Digital Meter and a black lead to the COM terminal.

2. Connect each of the carbon resistors to the Digital Meter, initially set to 20M(Ω) and determine the resistance value for each resistor. Change the scale setting until you have the scale which will give you the most precise value for the resistance. A reading that is greater than the scale setting is indicated by: **1_ _ .**

3. Check the nominal value of your resistors by reading the colour codes of the resistors and using the colour code chart. When reading the colour bands, the order should be such that **the fourth band will be either silver or gold.** Note whether your values agree within the accuracy marked on your resistors.

4. Connect the two resistors in series and measure their "combined" resistance. Repeat for the two resistors in parallel. How do these values compare with those you would predict from the **measurements** you made in Procedure 2?

### STUDY II – CURRENT AND VOLTAGE MEASUREMENTS

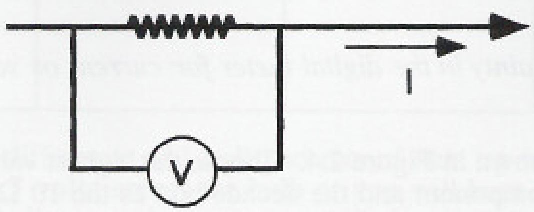
**Measuring Current**

When you use an ammeter, it has to be inserted into a circuit so that the current passes directly through it; i.e. the ammeter has to be connected in series with the component (as shown in Figure 2.1). Ideally the ammeter should have zero resistance so that it does not effect the current to be measured.


An ammeter has a low resistance
Figure 2.1

**Measuring Voltage**

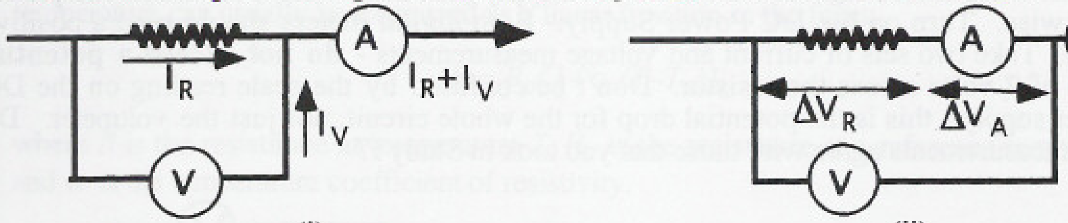
A voltmeter reads the potential difference (or voltage) between two points and must be connected in parallel between the points whose potential difference is to be measured as shown in Figure 2.2. It should not appreciably affect the voltage between these points, hence, it must draw only a very small current and it should be constructed so as to have high internal resistance.




A voltmeter has a high resistance

Figure 2.2

When measuring current and voltage *simultaneously* for a circuit element (i.e. to measure resistance or the power dissipated), there are two possible circuits that you can use:




(i) (ii)

Figure 2.3

For Circuit (i), the voltmeter measures the correct voltage across the component but the ammeter measures the combined current through the component and voltmeter. For Circuit (ii), the ammeter measures the correct current through the component, but the voltmeter measures the potential drop across the component and the ammeter. Which circuit you use depends on the resistance of your component, R, relative to that of the ammeter, $R_A$ and the voltmeter, $R_V$. The relative error in the measurement of the resistance, R, of the component (i.e. $\Delta R/R$) is given as follows:

**For Circuit (i)**

V measures $\Delta V_R$ exactly
A measures $(I_R+I_V)$

$$\frac{\Delta R}{R}=\frac{I_V}{I_R}=\frac{\Delta V_R/R_V}{\Delta V_R/R}=\frac{R}{R_V}$$

$$\therefore \text{Rel Error}\frac{\Delta R}{R}\to 0 \quad as \quad R\to 0,$$

**For Circuit (ii)**

V measures $(\Delta V_R+\Delta V_A)$
A measures $I_R$ exactly

$$\frac{\Delta R}{R}=\frac{\Delta V_A}{\Delta V_R}=\frac{I_R R_A}{I_R R}=\frac{R_A}{R}$$

$$\therefore \text{Rel Error}\frac{\Delta R}{R}\to 0 \quad as \quad R\to \infty$$

It follows therefore that if you don't apply a correction, then you should use Circuit (i) for small R, and use Circuit (ii) for large R. But how small is 'small'? Well, the two relative errors are equal if

$$R/R_V = R_A/R \text{ or } R = (R_A R_V)^{1/2} \qquad (2.2)$$

So 'small R' means R $<(R_A R_V)^{1/2}$ and 'large R' means R $> (R_A R_V)^{1/2}$. Typically the resistance of the digital meter, when used as a voltmeter, is 10 M Ω and when used as an ammeter, is a few ohms (i.e.~2 Ω for most scales). All the resistors you will use are less then 10 kΩ, **so circuit (i) should be used throughout the experiment**.

**Procedure:**

*Note that the uncertainty in the digital meter for current or voltage readings is ±4 digit in the last digit read.*

1. Set-up the circuit shown in Figure 2.4. Choose the highest value resistor that you measured in Study I as the component and the decade box as the 10 Ω resistor. Always when you construct a circuit, make sure the power supply is off. Build the circuit in a systematic way – i.e. start at the positive terminal of the power supply and proceed around the circuit so that you have a "loop" and finish up at the negative terminal of the power supply. Usually, the voltmeter is the last component you connect into the circuit.

2. Set the voltmeter to the 20 V scale, set the ammeter initially on the 200mA scale. Ensure that the current limiting knob of the Power Supply (labelled current) is turned completely clockwise. Turn on the DC Power Supply. Both digital meters should read a positive value. Take two sets of current and voltage measurements - **do not exceed a potential drop of 7 volts** across the resistor. Don't be confused by the scale reading on the DC power supply - this is the potential drop for the whole circuit, not just the voltmeter. Do your measurements agree with those that you took in Study I?

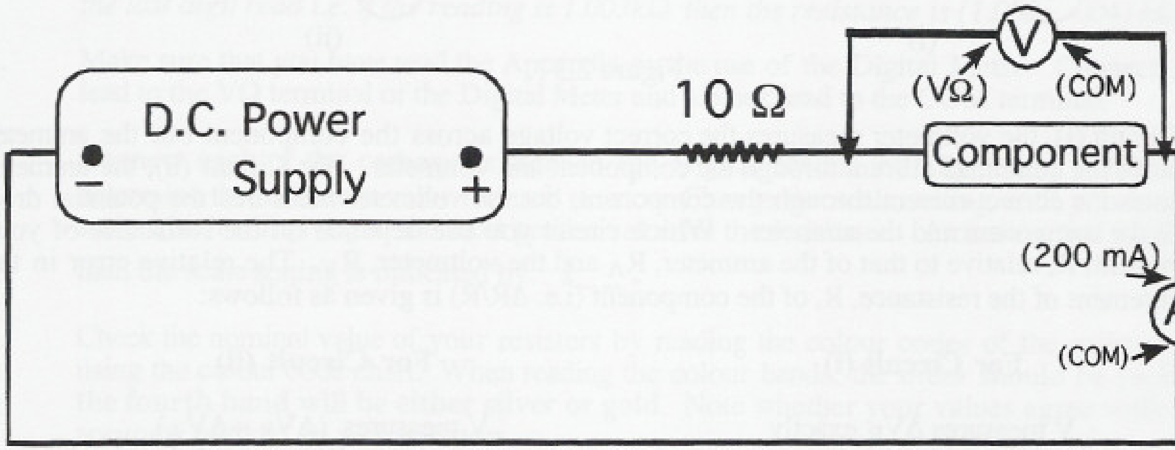



Figure 2.4

**Study III - VOLTAGE –CURRENT MEASUREMENTS FOR A LIGHT BULB**

**Procedure:**

1. Measure the room temperature resistance of the light bulb by using the sensitive digital meter that is set-up at the front of the laboratory. This resistance should be in the range of 1 – 8 Ω.

2. Use the light bulb as the component in the circuit given in Figure 2.4. You will need to use the set-up of circuit (i) of Figure 2.3, since the resistance of the light bulb is very low. Ensure that the decade box is set to 10Ω. Set-up a data table similar to the one below to record your data.

| Current (Amps) | Voltage (V) | Resistance (ohms) | Bulb appearance |
|---|---|---|---|
| | | | |

3. Start at a potential difference of 1 volt and record data up to 7 volts. **Do not exceed a potential drop of 7 volts** across the bulb or you will burn it out. *Note the intensity and colour of the light bulb as you increase the applied potential.* Note when the filament has a red glow and when it begins to glow white. As the current increases the temperature of the filament increases which results in an increase in its resistance. You will be using the computer to plot your data.

For normal metallic conductors at room temperature, the variation of resistance with temperature can usually be expressed as a linear function in the form:

$$R = R_o\{1+\alpha\,(T-T_o)\}, \qquad (2.3)$$

where $R$ is the resistance at temperature $T$, $R_o$ is the resistance at a reference temperature ($T=T_o$) and $\alpha$ is the temperature coefficient of resistivity.

Manipulation of (2.3) yields:

$$\alpha = \frac{1}{R_o}\,\frac{R-R_o}{T-T_o} \qquad (2.4)$$

which shows that $\alpha$ is simply the fractional change in resistance per degree change in temperature relative to the reference temperature $T_o$. This is analogous to the coefficient of linear expansion

($\alpha = \dfrac{\Delta L/L}{\Delta T}$; now we have $\alpha = \dfrac{\Delta R/R}{\Delta T}$)

If the dependence of resistance with temperature is linear, $\alpha R_o$ is the slope of the graph of R vs. $T$. If the dependence is not linear, then it is better to regard equation 2.3 as containing the first terms of a power series i.e.,

$$R = R_o\{1 + a\,(T-T_o) + \beta(T-To)^2 + \ldots\}, \qquad (2.5)$$

where the $\beta(T-T_o)^2$ term is usually quite small unless $(T-T_o)$ is quite large. For a given metal, $\alpha$ and $\beta$ are constants and can readily be determined experimentally. The actual resistance of a metal, at a given temperature, also depends on the length and cross-sectional area of the metal. It is useful, therefore, to consider the temperature dependence of the ratio of $R/R_o$, since this quantity will be independent of the geometric size of the metal conductor. On your bench you should find a graph of $R/R_o$ as a function of temperature for tungsten. If you know the ratio of $R/R_o$, then you could use this graph to determine the temperature of the bulb filament.

The power consumed by the light bulb is given by the product of the voltage across the bulb and the current through it and increases dramatically with the temperature of the filament. Usually the relationship is of the form

$$\Delta VI = kT^n \qquad (2.6)$$

Where $\Delta VI$ is the power supplied to the bulb and T is the temperature in Kelvin. The easiest way to confirm this type relationship is to plot a graph of log ($\Delta VI$) versus logT.

4. Enter your data points of current and voltage across the light bulb into the computer program; also enter your value for the room temperature resistance, $R_o$. How to do this will be given on the text window of the computer program. The program is set-up to calculate $R/R_0$ and from this the temperature of the filament, T. It also calculates the power consumed by the light bulb ($\Delta VI$) and then will graph Power($\Delta VI$) versus temperature or log ($\Delta VI$) versus logT. When you plot the graph press **Ctrl+P**. Check that the table entries make sense i.e. confirm the values for a row of data.

5. From your graph of log (Power) versus log (Temperature), determine a value for n given in equation (2.6).

According to the Stefan's law, the power or intensity radiated by an object is given by:

$$P = A\varepsilon\sigma T^4 \qquad (2.7)$$

where P is the power in watts radiated by an object that is at a temperature of T (K) and A is the surface area of the object. The constant $\sigma$ is the Stefan-Boltzmann constant ($5.67\times10^{-8}$ $W/m^2.K^4$) and $\varepsilon$, the emissivity, is a constant that depends on the condition of the surface of the object. For an ideal blackbody radiator $\varepsilon = 1$.

6. If you plot a graph of log P versus logT, according to equation 2.7, what should be the slope of the graph? Does the bulb filament obey the Stefan's Law? What factors could affect your results?

7. Any object heated to a temperature of 1000 K($R/R_o = 4.5$) has a red glow and if heated to a temperature of 1700 K($R/R_o = 8.4$) has a white-hot appearance. How does the appearance of the bulb filament correlate with the temperature you have estimated for the filament? Tungsten melts at a temperature of about 3500 K; what is the maximum possible resistance that you could measure for your light bulb?

**Bonus Exercise.**
Use the simple converging lens as a magnifier. Project the filament image onto a piece of paper and estimate the area of the bulb filament. Compare your value with the one you would calculate from the y-intercept of the log P versus log T graph. Assume the emissivity is such that $\varepsilon = 0.5$.

## Clean-up

Disconnect all circuits, turn the digital meters off.

## Prelaboratory Exercise

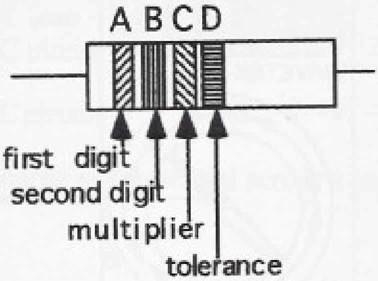
1. A student used circuit (ii) of Figure 2.3. The voltmeter measured 5V and the ammeter measured 1mA. If the student now repeats the measurement with circuit (i) what would the result be?

| | *Reading on voltmeter* | *Reading on ammeter* |
|---|---|---|
| A | more than 5V | more than 1mA |
| B | more than 5V | less than 1mA |
| C | 5V | 1mA |
| D | less than 5V | more than 1mA |
| E | less than 5V | less than 1mA |

2. Given that the resistance of the ammeter is 2 Ω and that of the voltmeter is 10 MΩ, what circuit {(i) or (ii) of Figure 2.3} should you use to measure the approximate resistances of

a) 10 Ω  b) 10 kΩ  c) 10 MΩ

3. The colour code for resistors is as follows:




| Colour | A or B | C | D |
|---|---|---|---|
| Black | 0 | 1 | - |
| Brown | 1 | 10 | - |
| Red | 2 | 100 | - |
| Orange | 3 | 1,000 | - |
| Yellow | 4 | 10,000 | - |
| Green | 5 | 100,000 | - |
| Blue | 6 | 1,000,000 | - |
| Purple | 7 | 10,000,000 | - |
| Grey | 8 | 100,000,000 | - |
| White | 9 | 1,000,000,000 | - |
| Silver | - | 0.01 | ±10% |
| Gold | - | 0.1 | ±5% |

e.g. If the four bands on a resistor are: -

| yellow | purple | orange | gold |
|---|---|---|---|
| ↑ | ↑ | ↑ | ↑ |
| A | B | C | D |

then the nominal value of the resistance is 47,000 Ω.

If two resistors with colour bands of (Brown, Black, Orange, Gold) and (Green, Black, Red, Silver) are connected i) in series and ii) in parallel, what should their combined resistance be?

**Hint: Calculating the Error for Resistors in Parallel**

Use the substitution method i.e. if $R_1=100\pm10\ \Omega$ and $R_2=300\pm10\ \Omega$

$$\textit{For Parallel}\quad \frac{1}{100}+\frac{1}{300}=0.01333 \Rightarrow R_{equiv}=75.0\ \Omega$$

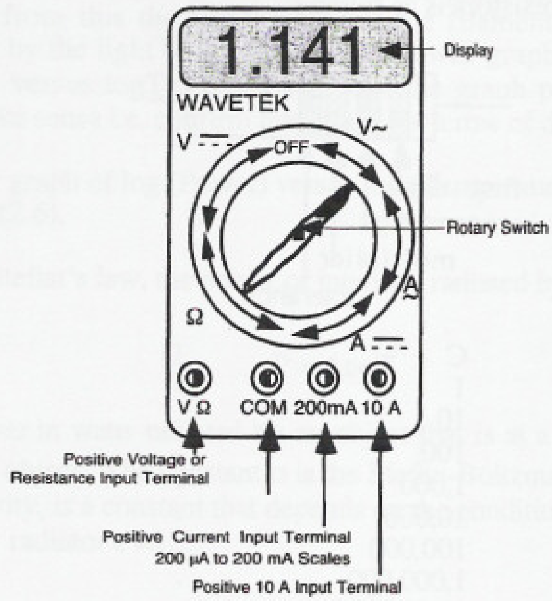
$$\textit{Min R:}\quad \frac{1}{90}+\frac{1}{290}=0.1456 \Rightarrow R_{max}=68.7\ \Omega$$

$$\textit{Max R:}\quad \frac{1}{110}+\frac{1}{310}=0.1232 \Rightarrow R_{max}=81.2\ \Omega$$

$$\textit{Answer}: R_{equiv}=(75\pm6)\ \Omega$$

## *Appendix*
### *Digital Meter*

Digital Multimeters are very versatile and can be used to measure voltage, current or resistance in AC (alternating current) or DC (direct current) circuits. The basic set-up of the digital meters that you will use is given in the figure below.




**Measurement Set-up**

1) Turn off power to device or circuit under test.

2) Select the appropriate AC (~) or DC (⎓) setting on the digital meter.

3) Connect test leads (usually red for positive and black for common or ground) to appropriate terminals of meter.

***To measure voltage or resistance use the V-Ω terminal and the COM terminal.***
***To measure current use the 200mA terminal and the COM terminal.***

4) Connect the test leads to the circuit or device - to measure current, the digital meter must be in series in the circuit while to measure voltage, it must be in parallel.

5) Set the rotary switch to the appropriate setting. If measuring current or voltage, turn on the power to the device or circuit under test. If the magnitude of the signal is not known start with the highest range and reduce the setting until a satisfactory reading is obtained.

*Note an overload is indicated by a "1" or a "-1" in the display.*

6) Make sure that when you have finished your measurements, you turn the digital meter off and disconnect the leads.

***Manufacturer's Specifications***

**Readings** - random reading error of ± 4 digit in last digit read plus a calibration error of approximately 1% for different current and voltage scales.

If all your measurements are taken using the same scale then you need not worry about the calibration scale.

# EXPERIMENT 3

## DIRECT-CURRENT CIRCUITS

**Terms you should know and understand: (check text and lab manual)**

Emf and internal resistance of a battery

How to determine the resistance of a component from a plot of potential versus current

Time constant for an RC circuit

Time constant for an RL circuit

Relationship between charge and potential across a capacitor

**Equipment you will be using:**

Batteries, resistors, light bulb, diode

Unknown RC circuit box

Inductor on RCL circuit board

Current and voltage probes interfaced to a computer

**What you will be doing:**

Measure the current-voltage relationship across a resistor, diode and light bulb

Measure the time response of the voltage across a capacitor and resistor in an RC circuit as you charge the capacitor

Determine the time constant for an RC circuit and hence the capacitance

Determine the total charge on a capacitor

Measure the time constant for an RL circuit

Determine the emf and internal resistance of different 9-volt batteries

***Note the Web-Ct prelab exercise is to be completed before attending the laboratory period.***

***You also need to bring two different types of 9-volt batteries***

# EXPERIMENT 3

## DIRECT-CURRENT CIRCUITS

Overview: An introduction to direct-current circuits containing simple components such as resistors, capacitors and inductors.

## INTRODUCTION

In this experiment you will investigate the properties of some electric circuit components. You will use either a DC power supply or batteries as the source of emf. These devices supply energy and set up the electric field which exerts force on electrons and drives the current. When the circuit is initially closed it may take time for a steady current to be established and charge may build up in some components. In time, equilibrium will be reached and a steady current will be reached throughout the circuit. In study I, you will investigate the equilibrium condition of a steady current and measure the current-voltage relationship for different circuit components. In study II, you will investigate the time response of capacitors and inductors when an applied potential difference is suddenly applied or discontinued and in study III you will investigate the current and voltage relationship for two different 9-volt batteries. All of the circuits you will investigate are direct-current i.e. the current in any part of the circuit is always in the same direction.

## STUDY I – CURRENT VOLTAGE RELATIONSHIP FOR CIRCUIT COMPONENTS

Applying a given potential difference to different components can have very different effects. If a component is a good conductor then a large current results and if it is a poor conductor a very small current results. Components can also have very different behaviors as you change the potential difference across them. Figure 3.1 shows the general current-voltage relationship for three types of circuit components.

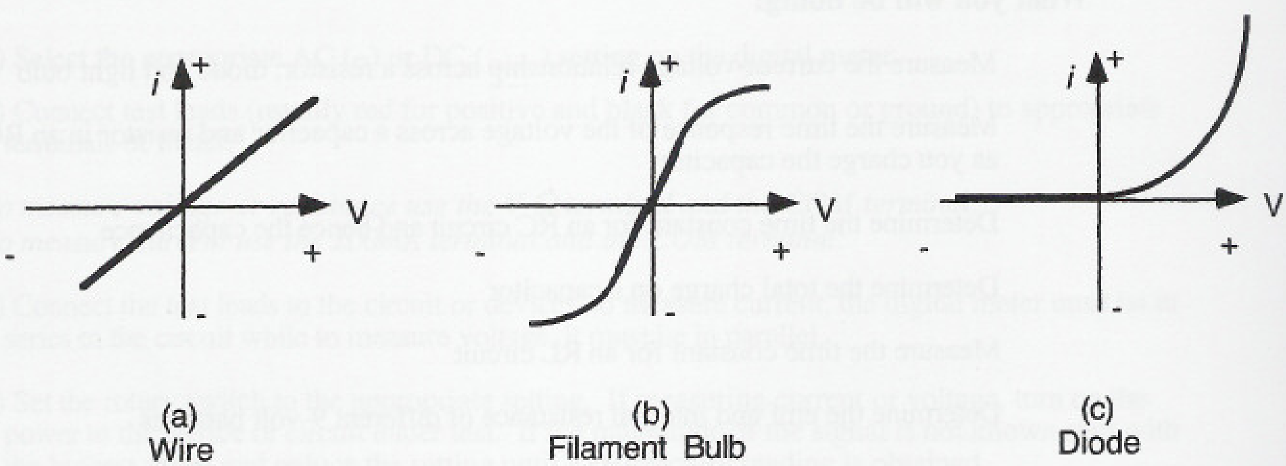


Figure 3.1

The resistance of a component is defined as the potential difference across the component divided by the current through the component i.e. $R = V/i$ where V is the potential difference and i is the resulting current through the component. If the component has the property that its resistance is independent of the magnitude and polarity of the potential difference (or direction of current), then the component obeys Ohm's law and it is called an ohmic device. Ohm's law is not a true law; rather it is an empirical law. In Figure 3.1, only the wire is an ohmic device. Its current-voltage curve is a straight line so the slope (=1/R) is constant. For simple metallic conductors Ohm's law generally holds unless the temperature is changed. For the filament bulb, the current-voltage curve is symmetric; it has the same value of V/i for a positive applied potential difference as for the corresponding negative potential difference. For the filament bulb, the resistance at a given potential difference does not depend on the polarity but it does depend on the magnitude of the potential difference and therefore it is a non-ohmic device. The current-voltage curve for the diode is not symmetric, neither is its slope constant, so it also is not an ohmic device. Diodes are important devices in that they allow a current to flow only in one direction.

In this study you will use the circuit given in Figure 3.2 to measure the current-voltage relationship for a resistor, light bulb and diode. To measure the current, you will use a computer-interfaced probe as an ammeter this has to be inserted into a circuit so that the current passes directly through it, as shown in Figure 3.2. The potential difference across the component will be measured using another computer-interfaced probe. Like a voltmeter, the voltage probe is always connected in parallel between the two points whose potential difference is to be measured.

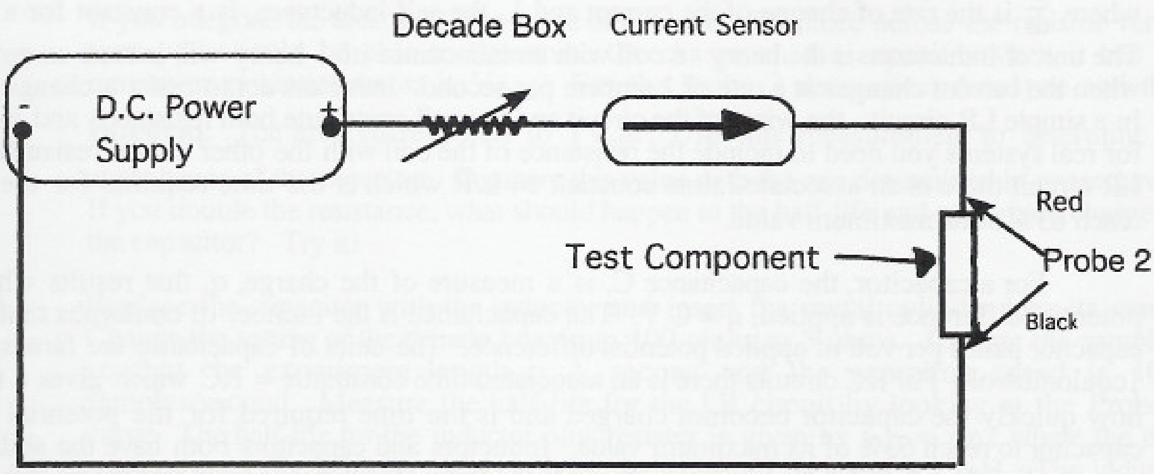



Figure 3.2

**Procedure:**

1. Check that the computer has the correct experimental set-up. Select **Experiment,** then **Data Collection** and be sure that **Selected Events** is selected. From the **Experiment** select **Zero** and then **OK. Note that you should never zero the sensors while they are in the circuit or you will arbitrarily assign some current and voltage as being zero.**

2. Set-up the circuit given in Figure 3.2. Use the resistor of the RC circuit box as the test component. Record the code number of your RC circuit box. Ensure that you connect the correct colour leads of the voltage probe and that you have the correct direction for the current probe. Set the decade box to 10 ohms and then turn on the DC power supply and set its output to 3 volts. The readout of the probes is shown on the computer screen. Check that the circuit and probes are set-up correctly by disconnecting one of the circuit connections - the probes should read close to zero and then when the circuit is reconnected they should both indicate positive readings.

3. To take data, select **Collect** and then when you have a data point you wish to store, select **Keep**. Keep decreasing the D.C.Power Supply output, taking data.

4. Reverse the two DC power supply leads and repeat taking readings for the up to 3 volts on the Power supply. Reversing the leads should result in negative current and voltage readings.

5. After you have collected the data select **Stop**. Look at the plotted data, if there is a linear relationship, then from the **Analyze** menu select **Curve Fit** and then the linear function. Does the resistance depend on the polarity of the current? Is the resistance constant?

6. Repeat your measurements for the light bulb and the diodes.

## STUDY II – TIME CONSTANT OF RC AND LR CIRCUITS

RC and LR circuits are discussed in your text. An inductor is simply a coil of wire. For an ideal inductor, if the current through the inductor is constant there is no potential difference across it. However if the current is changing, then a counter emf is induced across it that is given by:

$$V_L = -L\frac{di}{dt}$$

where $\frac{di}{dt}$ is the rate of change of the current and L, the self-inductance, is a constant for a given coil. The unit of inductance is the henry - a coil with an inductance of 1 henry will induce an emf of 1 volt when the current changes at a rate of 1 ampere per second. Inductors act to resist a change in current. In a simple LR circuit - the wires of the circuit and the coil contribute both resistance and inductance – for real systems you need to include the resistance of the coil with the other circuit resistance. For an LR circuit there is an associated time constant $\tau = L/R$ which is the time required for the current to reach 63% of its maximum value.

For a capacitor, the capacitance C, is a measure of the charge, q, that results when a given potential difference is applied, $q = CV$. The capacitance is the number of coulombs that are on the capacitor plates per volt of applied potential difference. The units of capacitance are farads, 1 farad = 1coulomb/volt. For RC circuits there is an associated time constant $\tau = RC$ which gives a measure of how quickly the capacitor becomes charged and is the time required for the potential across the capacitor to reach 63% of its maximum value. Inductors and capacitors both have the ability to store energy. For the capacitor the energy is stored in the form of an electric field and for an inductor in the form of a magnetic field.

**Procedure:**

1. Close the Study 1 file (do not save anything) and then open the Study II file. Use the same circuit as in Figure 3.2 using the capacitor of your RC circuit box as the component and set the decade box to 100 Ω. Connected to a third input is another voltage probe, connect this probe across the decade box. Set the DC power supply to 3 volts.

2. From the **Experiment** menu select **Data Collection**. For Mode: select, **Time Based**. For **Length:** select 2 seconds and for **Sampling Rate:** select 200 samples/second.

3. Select **Collect** to start data collection. Practice connecting the lead from the decade box to the positive terminal of the power supply to the negative terminal - this will discharge the capacitor and then reconnect the lead to the positive terminal - this will charge the capacitor. You need to select **Collect** to start the data collection and then make the connection. If the capacitor is initially uncharged its potential difference (Probe 2) will be zero. When you connect the lead to the power supply, the potential difference across the resistor (Probe 3) is the same as that across the power supply. As the capacitor charges, the potential difference across it increases and that across the resistor decreases. If you then take the lead and touch it to the negative terminal of the power supply, you will see the capacitor discharge. Practice selecting Data Collection and connecting the lead - it takes some coordination!

4. Once you have a good trace for charging the capacitor, select **Analyze** and **Examine.** In the Examine mode you can move the cursor by moving the mouse. Move the cursor to the point where the potential across the capacitor (Probe 2) begins to increase and record this time then move the cursor to the point where the potential difference is half of

its maximum value and record the time. Find the difference in the two times - this is the half-life, $t_{1/2}$, the time it takes to charge the capacitor to half its maximum potential and it is related to the time constant ($\tau$=RC) by:

$$t_{1/2} = \tau \ln 2$$

Determine the capacitance of the capacitor of your RC box, using $t_{1/2} = 0.693RC$.

5. The potential across the resistor is proportional to the current through the circuit. The charge on the capacitor is given by:

$$Q = \int I dt = \frac{1}{R}\int V_R dt = CV_{max}$$

If you integrate the area under the curve of potential difference across the resistor versus time you should be able to determine the charge on the capacitor when it has the maximum potential across it, $V_{max}$. For the Probe 3 data select **Analyze** and then **Integral**. The area corresponds to $\int V_R dt$. Use this measurement to determine the capacitance of the capacitor. Compare this value with the one determined in procedure 4. If you double the resistance, what should happen to the half-life and maximum charge on the capacitor? Try it!

6. Replace the capacitor with the inductor and insert the metal cylinder into its centre. Change the setting of the decade box from 100 ohms to 5 ohms. Change the sampling so that the experiment length is 1 second and the sampling speed is 1000 samples/second. Measure the half-life for the LR circuit by looking at the Probe 3 curve. The half-life for the inductor plus resistor is given by $t_{1/2} = \tau \ln 2$ where the time constant $\tau = L/R$. With no metal cylinder, the value of L is about 8.2 mH. The inductor also has a resistive component of about 10 ohms, so the total resistance will be 15 ohms for your circuit. Substituting in these values yields a half-life of approximately 0.5 ms. What is the effect of the metal cylinder on the half-life?

## STUDY III – PROPERTIES OF COMMERCIAL BATTERIES

You may have noticed a significant difference in the cost of a standard 9-volt battery. In this study you are asked to investigate the differences between two different types of 9-volt batteries. Maybe you have wondered if it is really worth investing in alkaline batteries instead of using the less expensive carbon-zinc batteries. Rechargeable batteries can be reused many times but do they perform as well as a regular or alkaline battery? Simply measuring the current-voltage characteristics of a battery can provide some insight into these questions.

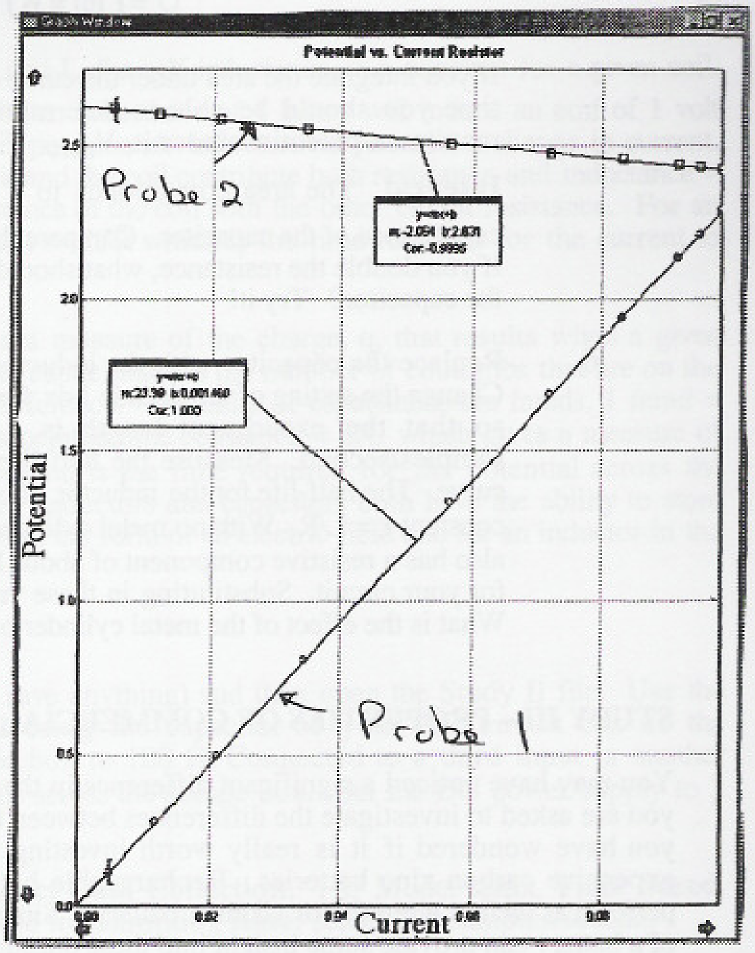
1. Close the Study 2 file and open the Study 3 file. Set-up a simple series circuit of the battery holder, current probe, 10Ω resistor and decade box set to 5000Ω. Connect Probe 3 across the battery holder terminals.

2. When you are ready to start taking data, place one of your batteries in the battery holder. Collect current and voltage data for settings of the decade box from 5000 to 10Ω.

3. From the graph of Potential versus Current, determine the emf and internal resistance of the battery. Repeat your measurements with your second battery. Compare the values of the emf and internal resistance of each battery. Does the more expensive battery perform better?

## Prelaboratory Exercise

1. The following graph of potential difference versus current was obtained for a simple series circuit. Probe 1 is placed across a resistor, the slope of the line is 23.4Ω and the y intercept is 0.001V. Probe 2 is placed across the battery in the circuit, the slope of the line is -2.09Ω and the y-intercept is 2.83 V. What is the value of the resistor, emf of the battery and internal resistance of the battery?




2. If the half-life measured for an RC circuit is 8.7 ms and the resistor is 100 Ω, what is the capacitance?

# EXPERIMENT 4

## CAPACITANCE AND ALTERNATING CURRENT

**Terms you should know and understand: (check text and lab manual)**

Reactance, resistance

rms current, rms voltage, peak to peak voltage

Equivalent capacitance for capacitors in series or parallel

Dimensional analysis

**Equipment you will be using:**

Function generator

Digital meters

Counter–timer (to measure frequency)

Capacitors

**What you will be doing:**

Measure the reactance of known capacitors as a function of frequency

Determine the relationship between reactance, angular frequency and capacitance

Determine the capacitance of an unknown capacitor

Measure the equivalent capacitance for capacitors in series and parallel

***Note the Web-CT prelab exercise is to before attending the laboratory.***

# EXPERIMENT 4

## CAPACITANCE AND ALTERNATING CURRENT

Overview: – A basic introduction to alternating current and the properties of capacitors.

### INTRODUCTION

In Experiments 2 and 3, you have investigated the properties of some direct-current circuits; circuits in which the current flows in one direction. For alternating-current (AC) circuits, the current reverses direction twice during each cycle. An AC circuit consists of an AC voltage source plus circuit components such as resistors, capacitors and inductors. Consider the signal output of an AC voltage source such as a Function Generator (FG) set to sine waves with a frequency of 100 Hz. The output voltage cycles 100 times per second. For 1/200 s the core of the coaxial connector of the FG (red terminal) is positive with respect to the sheath (black terminal), for the next 1/200 s the polarities are reversed. A graph of the voltage variation of one terminal relative to the other is shown below. If one terminal is at a fixed potential, for example, if the black terminal is grounded, then the graph shows the absolute potential of the other terminal.

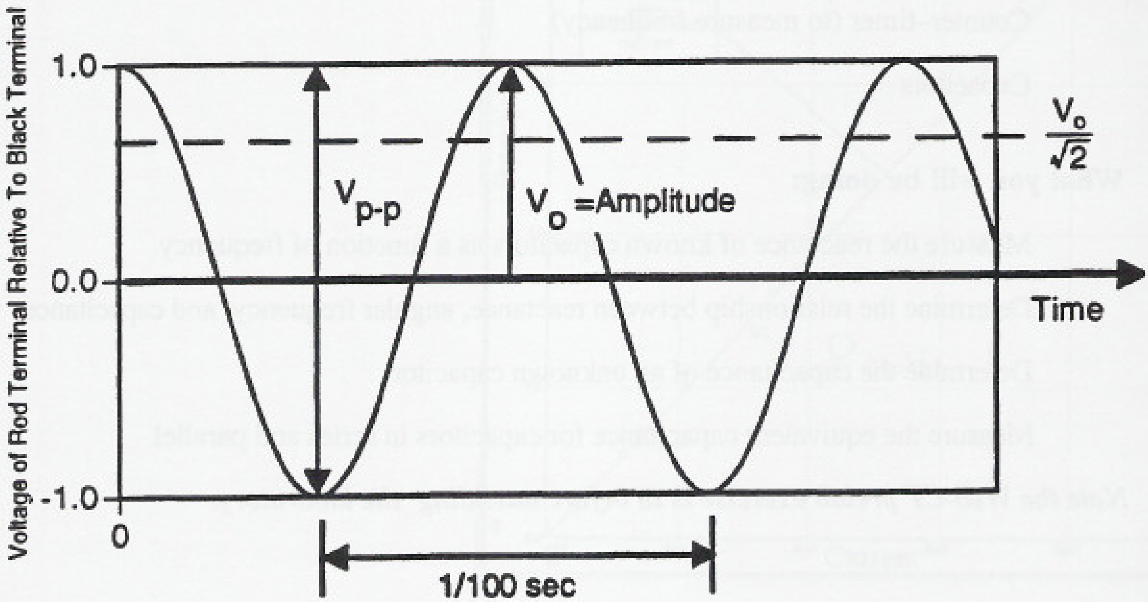
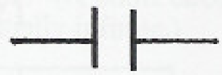



FIGURE 4.1

When the AC function of a multimeter is used it is possible to measure alternating voltage or current because a rectifier is switched into the internal circuitry of the meter. The voltage that an AC voltmeter would read is not the average voltage since this would be zero but rather the effective or *root mean square* (rms) value of the voltage which is represented in Figure 4.1 by the dotted line: $V_{rms} = V_o/\sqrt{2}$. Similarly the current that an AC ammeter gives is the rms value of the current. AC meters always read current and voltage as rms values. Thus when we say that the household line voltage is 120 V, we mean that the rms value is $V_{rms}$ = 120 volts, but that the peak voltage is, $V_o$ = 170 V.

## CAPACITORS

Capacitors are electrical devices that can store charge and electrical energy. They consist of two metal plates that are separated from each other by a material which does not conduct electric charge. The symbol for capacitance in a circuit diagram is :



Capacitors are often made from a long narrow sandwich of two pieces of aluminum foil, separated by an insulating plastic such as Mylar film. This sandwich is rolled into a cylinder and encased in plastic. This is the type of capacitor you will be working with in this experiment. There will be a capacitor taken apart at the front of the laboratory, so that you can see what one looks like inside.

The potential difference across a capacitor, ($V_c$) is proportional to the charge on the plates, i.e. $q = CV_c$ where C is a constant called the capacitance of the given capacitor. Capacitance is a measure of how much charge a capacitor can hold. The unit of capacitance is the farad (F). One farad is an extremely large unit of capacitance; the unit μF (microfarad), equal to $10^{-6}$ farad is commonly used, so is the unit PF (picofarad), equal to $10^{-12}$ farad. One farad equals one coulomb/volt. If we place two capacitors in parallel with each other, the total capacitance of the two is found by *adding* them, because the total charge stored is the sum of the charges on the two capacitors.

When charge is placed on one plate of a capacitor, this immediately affects the electrons on the other plate, and hence a 'signal' (a voltage fluctuation) can be transmitted across a capacitor even though there is no direct electrical connection. One talks about the current 'through' the capacitor, but no electrons actually pass between the plates – the current on one side is driven by the voltage fluctuations on the other side and it appears that the current is continuous from the readings of meters placed in the circuit. The potential difference across a capacitor is a maximum just before the current reverses direction, so that $V_c$ is not in phase with the current, $V_c$ lags the current by a quarter of a cycle or 90°.

Incidentally, a capacitor can be quite dangerous. If you short the leads connecting the two *charged* plates with your hand, your body will act as a conductor and the electrons will quickly flow from the negative plate through your body to the positive plates, creating a very large, perhaps dangerous current through your body. As a safety precaution, always use a piece of insulated conducting wire to short the two capacitor leads of the capacitors you use, before and after use, so the current is through the wire, not you.

## Experimental Procedure

### STUDY I – THE REACTANCE OF A CAPACITOR AS A FUNCTION OF FREQUENCY AND CAPACITANCE

A capacitor obeys a sort of " Ohm's Law"

$$\frac{V_c}{I} = X_c \qquad (4.1)$$

where $X_c$ is called the capacitance resistance or reactance. However, unlike the resistance of a resistor, the reactance of a capacitor depends on frequency. In this study you will investigate how the reactance varies with respect to the frequency of the input AC signal and with respect to capacitance. Assume that the reactance obeys the relationship

$$X_C = \beta\omega^a C^b, \qquad (4.2)$$

where $\beta$ is an unknown constant, $\omega = 2\pi f$ is the angular frequency, and $a$ and $b$ are simple integers.

**Procedure:**

1. Set the frequency of the FG to 2000 Hz on sine waves. Read the actual frequency from the counter-timer. Set the output level to zero.

2. Connect the 0.05 µF capacitor and the two Digital Meters as shown in Figure 4.2. Set Meter #1 on the 20 mA range A~ and Meter #2 on the 20 V range V~.

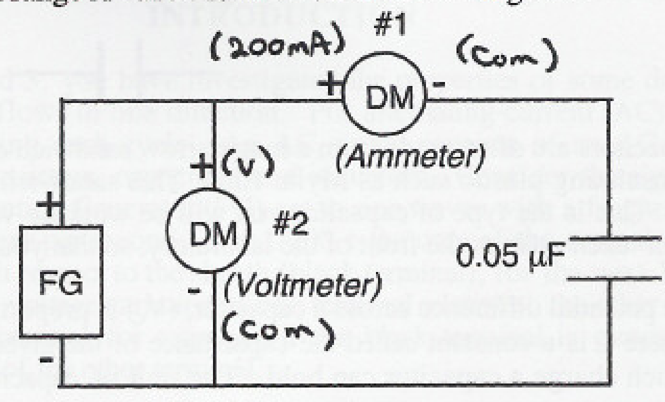



FIGURE 4.2

3 . Increase the voltage in 1 volt steps (increase the output level) until a voltage of 7 V is reached. Record your data in a suitable data table. Do not worry about recording uncertainties in your data.

4. Repeat Part 4 using the 0.02 µF capacitor.

5 . Repeat Part 4 with the 0.02 µF capacitor and $f$ = 1000 Hz. Plot a graph of potential difference versus current for your data.

6. Determine the reactance, $X_c$, for the three different sets of conditions i.e. measure the slopes of your three curves.

   From the three slopes you should be able to form a hypothesis on

   i) how the reactance, $X_C$, depends on $C$ when $\omega$ is constant (Parts 4 and 5).

   ii) how $X_C$ depends on $\omega = 2\pi f$ when $C$ is constant (Parts 5 and 6).

(Hint: *Assuming (4.2) holds, the dependence of $X_C$ on $C$ can be determined by substituting the values from Part 4 into (4.2) and the values from Part 5 into (4.2) then dividing the two equations.)*

i.e. for two set of conditions you have $X_{c1} = \beta\omega_1^a\ C_1^b$ and $X_{c2} = \beta\omega_2^a\ C_2^b$

Taking the ratios of these two relations yields

$$\frac{X_{C1}}{X_{C2}} = \frac{\beta\omega_1^a C_1^b}{\beta\omega_2^a C_2^b} = \left(\frac{\omega_1}{\omega_2}\right)^a \left(\frac{C_1}{C_2}\right)^b$$

$$\text{if} \quad \omega_1 = \omega_2 \ \text{ then } \ \frac{X_{C1}}{X_{C2}} = \left(\frac{C_1}{C_2}\right)^b$$

$$\text{or if} \quad C_1 = C_2 \ \text{ then } \ \frac{X_{C1}}{X_{C2}} = \left(\frac{\omega_1}{\omega_2}\right)^a$$

7. Determine *integer* values for $a$ and $b$ of (4.2) and rewrite (4.2) in your notebook with these values.

8. Draw up a small table showing $C$, $f$, $\omega$, $X_C$ (slope), and $\beta$ for your three curves. What do you conclude about $\beta$? Now that you have evaluated a, b and $\beta$ ,rewrite equation 4.2 in its simplified form.

Answer the following questions in your notebook. (A short circuit means the resistance is negligible and an open circuit means the resistance is essentially infinite.)

i)What is the limit of the capacitative reactance as $f \rightarrow \infty$ ? Is this a " short-circuit" or an " open-circuit"?

ii)What is the limit of the capacitative reactance as $f \rightarrow 0$ ? Is this a " short-circuit" or an " open-circuit"? N.B. The limit of $f \rightarrow 0$ is 'DC'. If you measure the "resistance" of a capacitor, what would you measure? Try it!

iii) If you only take a single measurement of current and voltage at a known frequency can you accurately determine the capacitance of a capacitor?

**STUDY II – CAPACITORS IN SERIES AND PARALLEL**

1. Connect the 0.05 μF and 0.02 μF capacitors in series. As in Study I with $f$ = 2000 Hz, take measurements of the current and voltage for the two capacitors in series. What is the reactance for the two capacitor in series. Use equation 4.2 and determine the equivalent capacitance of the two capacitors. How does your value compare with the predicted value?

2. Connect the 0.05 μF and 0.02 μF capacitors in parallel and repeat your measurements. What is the equivalent capacitance for the two capacitors in parallel? How does your value compare with the predicted value?

3. Determine the capacitance of the unknown capacitor. Report the unknown code.

**CLEAN-UP -** **Disconnect all circuits and turn FG and Digital Meters off.**

## Prelaboratory Exercise

1. For a 0.023 μF capacitor the reactance is $3.2 \times 10^3\ \Omega$ at 2000 Hz and $6.3 \times 10^3 \Omega$ at 1000Hz. Determine the value of $a$ in equation 4.2.

2. Two capacitors, 0.034μF and 0.056μF are connected in series and in parallel. What is the equivalent capacitance for each circuit?

3. For a capacitor in an ac circuit, if you plot a graph of voltage versus current, how do you determine the reactance?

4. Suppose you constructed a capacitor using two 10cmx30cm sheets of foil and a 0.1 mm thick piece of paper ($\kappa$=3.7) - what is its capacitance?

# EXPERIMENT 5

## ALTERNATING-CURRENT CIRCUITS

**Terms you should know and understand: (check text and lab manual)**

Relationship between current and voltage for a resistor, inductor and capacitor in an ac circuit

Impedance in an ac circuit

Phase angle for an ac circuit

Resonant frequency of an RCL circuit

**Equipment you will be using:**

Resistor, inductor and capacitor

Function generator and current and voltage probes interfaced to a computer

**What you will be doing:**

Study resonance in an RLC circuit

Measure the current and voltage relationship for a resistor, inductor and capacitor

Determine impedance and phase constant for different components

Identify an RC or an RL circuit by the phase relationship between current and voltage and determine the nominal values of each component

# EXPERIMENT 5

## ALTERNATING-CURRENT CIRCUITS

**Overview:** An introduction to alternating-current circuits containing simple components such as resistors, capacitors and inductors.

## INTRODUCTION

In this experiment you will investigate the behavior of a resistor, a capacitor and an inductor when an alternating voltage is applied to them. In Experiment 3, you determined that a resistor impedes a current such that the ratio of the voltage to the current is a constant i.e. $V/I = R$, and R is constant. In Experiment 4, you investigated the behavior of a capacitor and found that for a given frequency the capacitor impedes the current such that $V_{rms}/I_{rms} = X_c$ where rms stands for the root-mean-square value and $X_c$ is the reactance of the capacitor. 'Resistance' and 'reactance' are the two types of 'impedance'. The difference between them is that $V$ and $I$ are in-phase for resistance but out-of-phase for reactance. Impedance, Z, is defined by:

$$Z = V_m/I_m \qquad (5.1)$$

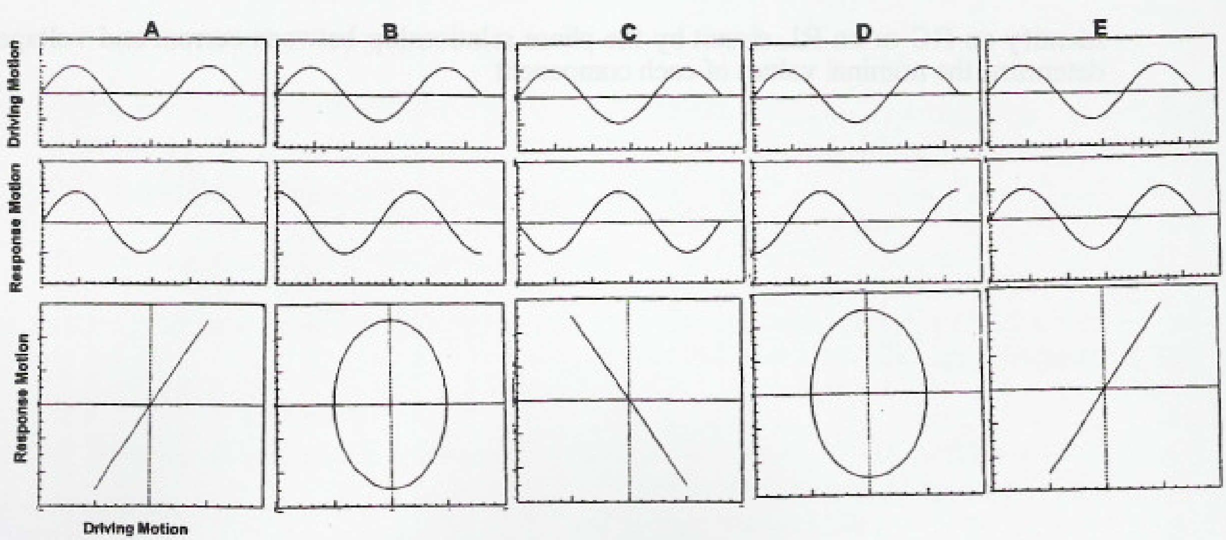
where $V_m$ and $I_m$ are the amplitudes of the voltage and current. The maximum values of the voltage and current need not occur at the same instant. It is, therefore, useful to define a phase constant, $\phi$, which defines the angle difference between the maximum in the current and the voltage. If the current is represented as:

$$I(t) = I_m \sin\omega t \qquad (5.2)$$

then the potential can be represented as

$$V(t) = V_m \sin(\omega t + \phi) \qquad (5.3)$$

where $\phi$ is the phase constant. In this experiment, you will also see that a series circuit containing an inductor and a capacitor provides an electrical example of resonance, similar to the mechanical example you studied in Experiment 3 of Physics 101. You will be using a novel way to look at the voltage and current relationship for the different circuit elements - Lissajous figures. These figures are obtained by plotting one sinusoidal signal against another and the pattern obtained depends on the amplitude, frequency and phase difference of the two signals. Shown below are the Lissajous figures obtained for two sine curves with the same frequency but different phases as might have been constructed for the Simple Harmonic Motion Experiment.




Phase Difference $\phi = 0$ | $\phi = 90°$ or $\pi/2$ | $\phi = 180°$ or $\pi$ | $\phi = 270°$ or $3\pi/2$ | $\phi = 360°$ or $2\pi$

**Figure 5.1 - Phase Difference and Lissajous Figures**

From Figure 5.1, you can see that as the phase difference changes from zero through to $2\pi$ the Lissajous figures change from a straight line through an ellipse and back to a straight line.

## STUDY I – RESONANCE IN AN AC CIRCUIT

### Procedure:

1. Open the Experiment 5 file - on the screen you will see something similar to the figure below. The program displays two plots, one of Potential versus Current and the other a plot of Current and Potential versus Time.

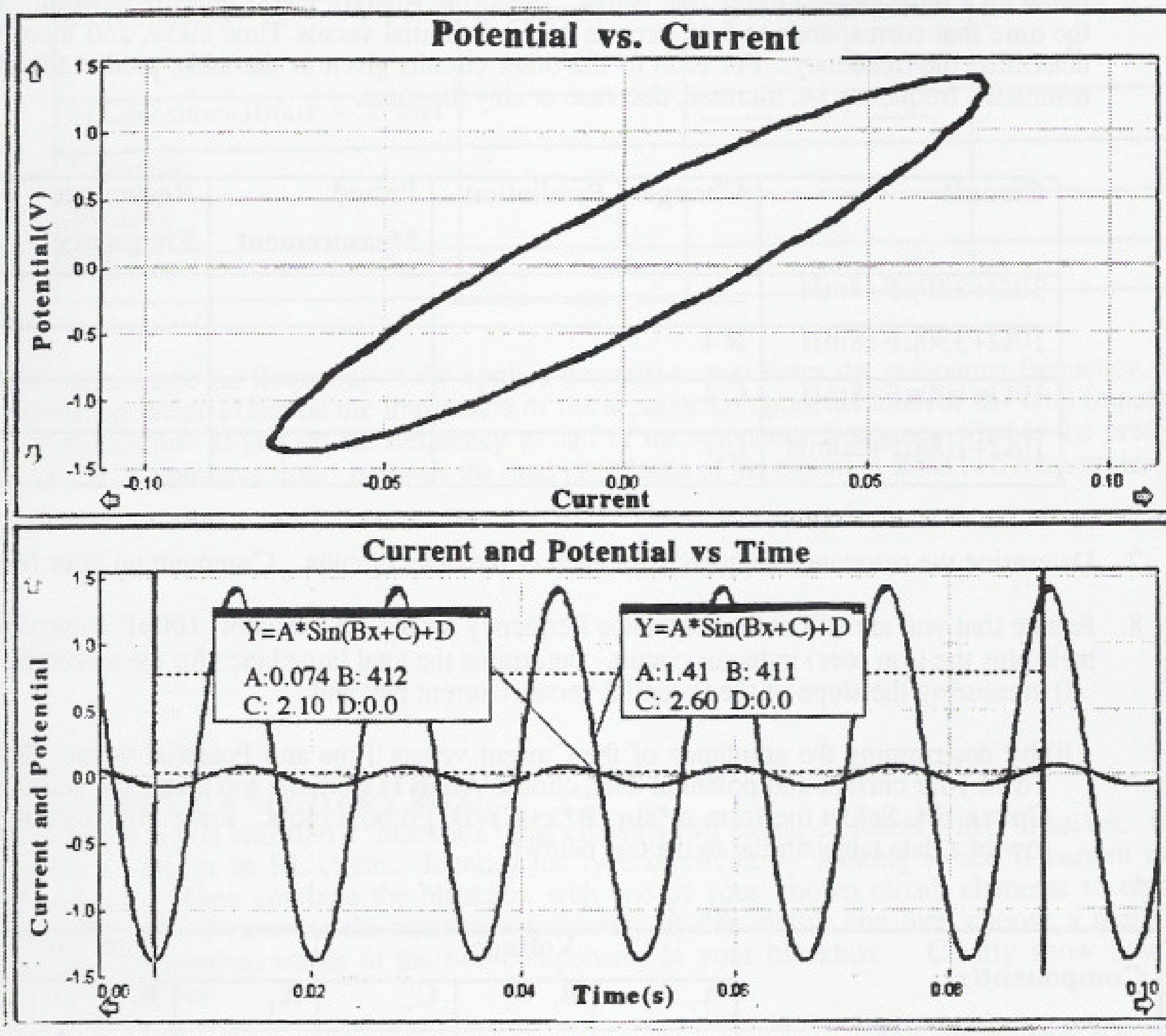



**Figure 5.2 - Computer Screen Display for Experiment 5**

2. From **Experiment** select **Zero** and **Zero all sensors.**

3. From the **Experiment** select:
   **Data Collection:**
   For **Mode**, select **Time Based**
   For **Sampling**, set the **Experiment length** to 0.1 seconds and 5000 samples/second.

4. Construct a series circuit of function generator (FG), 33 Ω resistor, inductor and the 330 μF capacitor of the RCL circuit board and current sensor. Set the FG initially to 50 Hz and connect the voltage probe across the function generator - you are going to monitor the current in and the

potential difference across an RCL circuit. Make sure that the red lead of the probe is closest to the red terminal of the function generator.

5. To take data, select **Collect.** Adjust the frequency of the function generator until you get a Lissajous figure like diagram A of Figure 5.1. The line for the upper plot means that the current and the voltage are in phase and for a series RCL circuit this means that you are at the resonance frequency. Initially you are going to investigate the effect on the resonance frequency of changing the resistance, capacitance and inductance of your RCL circuit.

6. Draw up a table similar to the one below. From the Analyze menu select, **Examine.** Measure the time that corresponds to 5-10 periods of the Potential versus Time curve, and then from this determine the frequency. For each of the other circuits given in the table, predict the change in resonance frequency i.e. increase, decrease or stay the same.

| **Circuit** | **Change** | **Prediction** | **Period Measurement** | **Resonance Frequency** |
|---|---|---|---|---|
| 30Ω+330μF+8mH | ______ | ______ | | |
| 10Ω+330μF+8mH | **R↓** | | | |
| 10Ω+100μF+8mH | **C↓** | | | |
| 10Ω+100μF+20mH | **L↑** | | | |

7. Determine the resonance frequency for each of the other circuits. Comment on your findings.

8. Ensure that you are still at the resonance frequency for the 10Ω resistor, 100μF capacitor and 20 mH (plus the iron core) inductor circuit. Determine the total impedance for the circuit by
   i) measuring the slope of the Potential versus Current plot and

   ii) by determining the amplitude of the Current versus Time and Potential versus Time plots. To fit your current and potential data, choose **Analyze** from the top menu bar and then select **Curve Fit**. Select the form **A*sin (B*x+C)+D**. Fit both plots. Enter your data in the first row of a data table similar to the one below:

| **Component(s)** | **Voltage** | | | **Current** | | |
|---|---|---|---|---|---|---|
| | $A_v$ | $B_v$ | $C_v$ | $A_I$ | $B_I$ | $C_I$ |
| 10Ω+100μF+20 mH | | | | | | |
| Capacitor | | | | | | |
| Resistor | | | | | | |
| Inductor | | | | | | |

9. Move the voltage probe so that you only measure the potential across the capacitor. Select **Collect** and then analyze the data to determine the impedance and phase difference between the current and potential across the capacitor. Check that you have connected the voltage probe correctly -the current should lead the voltage for a capacitor. The phase angle $\phi$ can be determined from the fit parameters i.e.

$$\phi = (C_V - C_I) \qquad (5.4)$$

10. Typically the nominal values given for capacitors have a 10% tolerance. From the measured impedance of the capacitor - determine a more precise value for the capacitance.

11. Repeat your measurements for the resistor and the inductor. For the inductor, you should find that the voltage leads the current. Determine a value for the inductance of the inductor. You will need to correct for the resistive component of the inductor i.e.

$$X_L = \sqrt{Z^2 - R_L^2}, \qquad X_L = \omega L \qquad (5.5)$$

12. Summarize your results in a suitable data table:

| Components | Impedance (Ω) | Value of Component | Phase $\phi$ |
|---|---|---|---|
| 10ΩResitor+100μF + 20 mH | | ____________ | |
| Capacitor | | | |
| Resistor | | | |
| Inductor | | | |

13. If you change the frequency of the applied potential to two times the resonance frequency, what is the predicted effect on the impedance of the separate components and for the total impedance of the circuit? If you set the frequency to half of the resonance frequency what is the predicted effect? If you have time - measure the total impedance of the circuit at these two frequencies.

**STUDY II – MYSTERY BOX!**

On your bench you will find a "blackbox" that contains two circuit elements wired in series. It will be either an RC or an RL circuit. Identify the type of circuit by looking to see if current or the voltage leads. Then combine the blackbox with one of your known circuit elements to obtain a resonant circuit. Determine the resonance frequency of this circuit and then choose a method to determine the nominal values of the two components in your blackbox. Clearly show how you obtain your values.

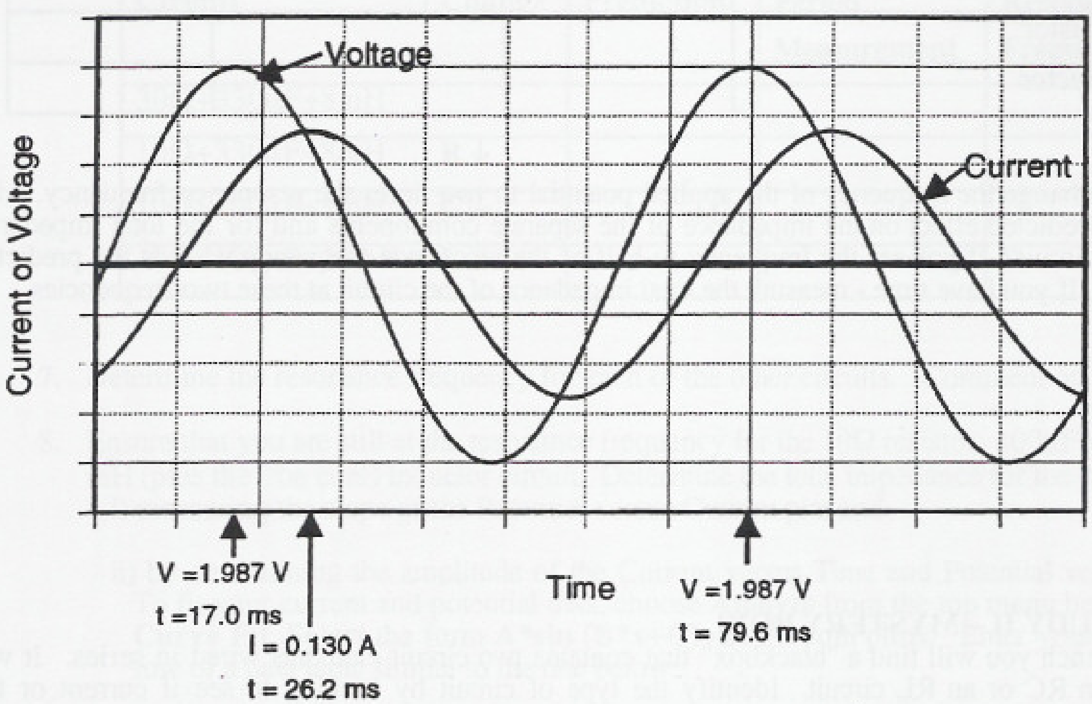
## Prelaboratory Exercise

The curves given below are of the applied potential and current through a device. From the curves deduce:

a) the period and frequency of the applied emf.

b) the impedance of the device.

c) the phase constant or phase difference between the current and applied emf.



# EXPERIMENT 6

# Induction

**Terms you should know and understand: (check text and lab manual)**

Lenz's Law

Definition of magnetic field direction i.e. north pole of a compass points to Geographic North, what does this mean?

Direction of magnetic field for a current in a wire and in a coil

Faraday's Law

Step-up and step-down transformer

**Equipment you will be using:**

Magnet

Compass

Two coils

Digital meter

Battery

Function generator

Counter-timer to measure frequency and time

Oscilloscope

Cylindrical magnet and masses plus a copper or aluminum tube

**What you will be doing:**

Determining the direction of the magnetic field for a current in a coil

Induce a current in a coil by changing the magnetic flux

Determine the direction of the induced magnetic field

Measure the ac current and voltage relationship for a coil of wire and so determine its reactance

Determine the inductance of the coil from its measured reactance

Measure the voltage across the primary and secondary coils of a transformer

Determine the relationship between average velocity and mass for a magnet dropped through a vertical tube

## EXPERIMENT 6

# Induction

Electromagnetic induction is the generation of an emf by a changing magnetic flux. This process plays an important role in power transmission, in sound reproduction and in electric motors and generators.

### STUDY I - INDUCED CURRENT AND LENZ'S LAW

Lenz's Law states that the induced current in a conducting loop will appear in such a direction that it opposes the change that produced it. In this study you will investigate qualitatively the direction of an induced current.

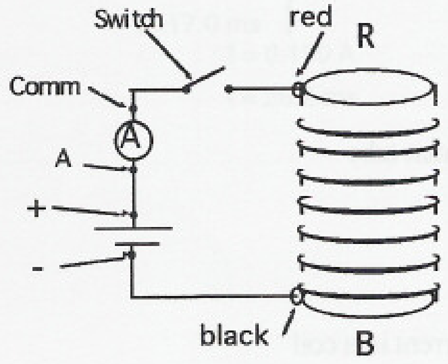
**Procedure:**

1. Set-up the circuit shown in Figure 6.1(a). Set the ammeter to the 200 mA dc, A=scale.

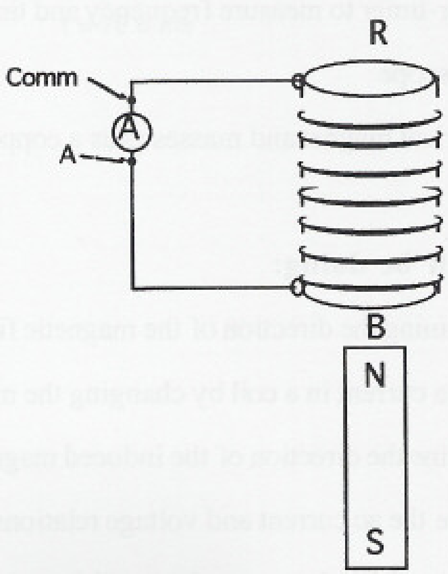
2. When the switch is depressed the coil behaves as an electromagnet. Use the compass to investigate the direction of the magnetic field at the two ends of the coil. Place the compass very close to the R (red terminal) end of the coil. Briefly depress the switch. The compass needle will deflect. Is the north pole of the compass attracted or repelled by the magnetic field of the coil? Report the direction of the current in the circuit (i.e. as given by the ammeter - is the current positive or negative?) and the polarity of the R end of the coil (i.e. does it behave as a north or south pole).

3. Repeat procedure 2. for the B (black terminal) end of the coil.

4. Use the right-hand rule and determine the sense of the current in the coil - i.e. as you look down the coil with the R end up, does the current flow clockwise or counterclockwise through the windings? Recall the convention for the direction of current flow.




(a)




(b)

Figure 6.1

5. Remove the battery and switch from your circuit and set-up the circuit shown in Figure 6.1(b).

6. Set the ammeter to the 2 mA scale. Hold the bar magnet and rapidly push the north pole of the bar magnet into the black terminal end of the coil. Note if a negative or positive induced current reading is obtained. Pull the magnet out; what is the direction of the induced current? From the direction of the current, deduce if a north or south pole is induced at the B (black terminal) end of the coil when the north pole of the magnet enters the coil and when it is removed from the coil.

7. What reading does the ammeter give if the bar magnet is stationary within the coil?

8. Repeat procedure 6. using the south pole of the magnet. Does the speed with which you move the magnet affect the magnitude of the induced current?

9. Summarize your results in terms of the direction of the induced current and the effect of the rate of change of the magnetic field on the magnitude of the induced current.

## STUDY II - DETERMINING THE SELF INDUCTANCE OF A COIL

In Study I, you saw that if a steady current flows through a coil, a magnetic field is generated. For a coil of N turns, the magnetic flux, $\Phi$, that is within the coil is related to the current, i, that flows through the coil by:

$$N\Phi = Li \qquad (6.1)$$

Where L is a constant, the self-inductance, that depends only on the geometry of the coil. In the prelaboratory exercise, you have calculated the self-inductance for a coil similar to what you will use in this experiment. In Study I, you also have seen that a varying magnetic flux can induce a current in the coil. If the current changes through the coil then this produces a change in the magnetic flux in the coil. According to Faraday's Law, there will be a voltage, $v_L$ whose magnitude will be equal to the change in magnetic flux, i.e.

$$v_L = -\frac{d(N\Phi)}{dt} = -L\frac{di}{dt} \qquad (6.2)$$

For a sinusoidal current if $$i = i_o \sin 2\pi ft \qquad (6.3)$$

then $$\frac{di}{dt} = 2\pi f i_o \cos 2\pi ft \qquad (6.4)$$

and substituting (6.4) into (6.2) $$v_L = -L2\pi f i_o \cos 2\pi ft \qquad (6.5)$$

The maximum value of $v_L$ is $v_o = 2\pi f L i_o$, so the reactance, $X_L$, of the inductor is given by:

$$X_L = \frac{v_o}{i_o} = 2\pi fL \qquad (6.7)$$

You, therefore, expect the reactance of the inductor to increase linearly with frequency.

**Procedure:**

1. The coil, you will use in this study is not a pure inductor, since it also has a resistive component. Use the digital meter and measure its resistance. Record the number of the coil that you are using.

2. Set up the circuit shown in Figure 6.2. Ensure that the counter/timer is also connected to the Function Generator. Set the FG to sine waves and to a frequency of 1000 Hz. Set the ammeter initially to the 20 mA, A~scale. Turn on the scope and set the volts/div of Channel 1 to 1V/div. Adjust the time base until you get a reasonable trace. You will use the scope just to observe the behaviour of the circuit. Channel 1 of the scope is measuring the voltage drop across the coil as a function of time, while the voltmeter is measures the root-mean-square, rms, value.

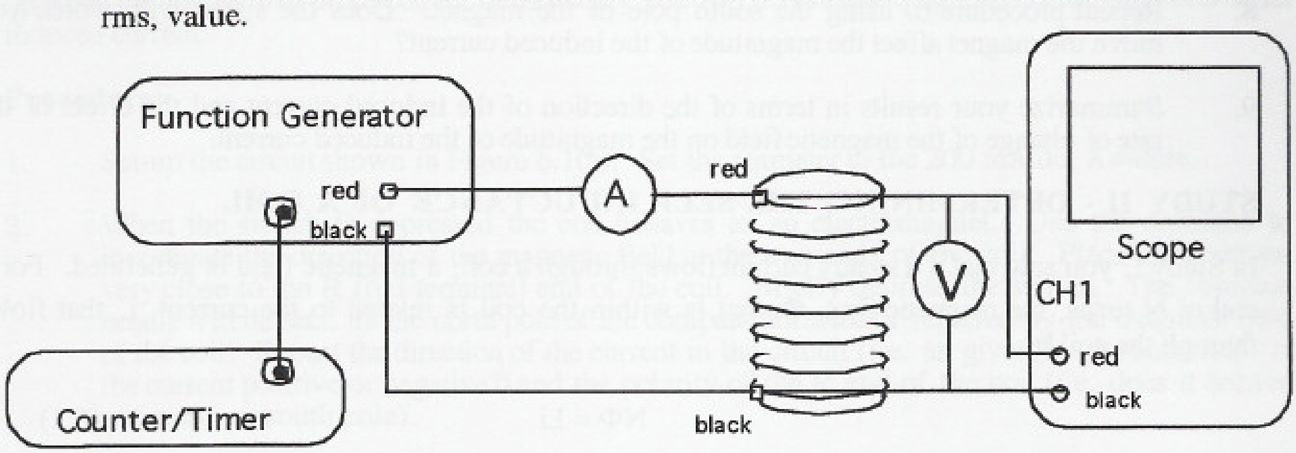



Figure 6.2

3. Adjust the output level until the peak to peak voltage, $V_{p-p}$, as measured on the scope is 5 volts. Measure the current in the circuit, $I_{rms}$, and the voltage across the coil, $V_{rms}$, at this setting. Determine the ratio $V_{p-p}/V_{rms}$. Ideally, what should this ratio be? Repeat your readings at 2000 Hz.

4. The impedance for the inductor, Z, is such that

$$Z = \frac{V_{rms}}{I_{rms}} \tag{6.8}$$

The impedance has a resistive component and a reactive component. The reactance of the inductor, $X_L$, is therefore given by:

$$X_L = \sqrt{Z^2 - R^2} = 2\pi f L \tag{6.9}$$

where R is the measured dc resistance of the coil. Calculate the values of Z, $X_L$ and L.

5. The coil you are using is very similar to the Coil A of the prelab exercise - there is however some variation in the number of turns wound on the coil. From your value of L determine the number of turns, N, for your coil.

6. Another way to check the number of turns in a coil is to use it as part of a transformer. Take your coil to the front of the lab to where the transformer set-up is. Measure the voltage across your coil, used as the secondary and the provided coil, used as the primary. Compare the value for N determined with that determined in the procedure 5.

**STUDY III - EDDY CURRENTS**

In this study you are provided with a copper or aluminum tube, a small magnet and some additional masses. You are asked to investigate the relationship between the average velocity of a magnet-mass system as it falls through the tube as a function of mass.

**Procedure:**

1. Measure the length of the tube. Drop the magnet into the tube and measure the time it takes for it to fall through the tube. Take a couple of readings, to ensure that the time is reproducible. Change the mass of the system by using the additional masses with the magnet.

2. Calculate the average velocity of each mass through the tube. What is the relationship between the average velocity and mass? You can use the Graphical Analysis programme to plot a suitable graph. Try to interpret your results. Can you make any conclusions concerning the drag force acting on the magnet.

## Prelaboratory Exercise

1) In a similar experiment to this one, you have two coils (solenoids) whose physical dimensions are:

Coil A Length = 10.0 cm, Diameter = 3.0 cm, Number of turns = 2700

Coil B Length = 11.0 cm, Diameter = 1.6 cm, Number of turns = 235

The self-inductance L, of the coils is given by:

$$L = \mu_0 n^2 l A$$

where $\mu_0 = 1.26\times10^{-6}$ H/m is the permeability constant, $n$ is the **number of turns per length,** $l$ is the length of the coil and $A$ is its cross-sectional area. Calculate the inductance of each coil.

2) When you drop a small object down a vertical copper tube you find that it takes 0.5 s for it to fall through the tube. How long is the tube? You drop an identical shaped object that is a magnet, down the same tube. Will it take a longer or a shorter time for the magnet to fall through the tube? (Magnets do not "stick" to copper!)

# Appendix Experiment 6 - Transformers

In Study II, you saw that an ac current, which produces a changing magnetic flux, generates an induced emf in a coil. This same changing magnetic field can also induce an emf in an adjacent coil and this is the basis of a transformer. The transformer is a device that transfers energy from one circuit to another and consists of two coils that are usually wound around each other. They are not connected electrically but are coupled by their magnetic flux. The primary coil is connected to a power source and the secondary coil is connected the "output". If the secondary coil has $N_s$ turns, then the component of the magnetic flux through the secondary coil, $\Phi_p$, due to current through the primary coil, $i_p$, is given by:

$$N_s\Phi_p = Mi_p \tag{6.10}$$

Where M is a constant, called the mutual inductance of the coil. An induced current, $i_s$, flows through the secondary coil and this also contributes a component, $\Phi_s$, to the total flux through the secondary coil which will be given by:

$$N_s\Phi_s = L_s i_s \tag{6.11}$$

where $L_s$ is the self-inductance of the secondary coil.

For the total flux through the coil then, equations (6.10) and (6.11) yield:

$$N_s\Phi = Mi_p + L_s i_s \tag{6.12}$$

According to Faraday's Law of Induction, the emf induced in the secondary coil, $v_s$ is given by:

$$v_s = -\frac{d(N_s\Phi)}{dt} = -M\frac{di_p}{dt} - L\frac{di_s}{dt} \tag{6.13}$$

The mutual inductance M can be evaluated much as the self-inductance was in Study II.

For a transformer the rate of change of the magnetic flux is the same for both coils so the induced emf in the primary coil, $v_p$, is related to the induced emf in the secondary coil by:

$$-\frac{d\Phi}{dt} = \frac{v_p}{N_p} = \frac{v_s}{N_s} \tag{6.14}$$

First Letter of Last Name: 

The University of British Columbia
Final Examination - April 19, 2002
Physics 102
Elements of Physics II TIME: 2.5 hours

Short answer questions. Please answer each question with one or two short sentences or a drawing.

1.1 A battery is connected to a large parallel plate capacitor. Sketch the forces on the plates of the capacitor. Why do manufacturers put dielectrics between the plates of capacitors?

1.2 If in an electric circuit charges flow slowly with the drift velocity, why doesn't it take hours for the light to come on when you close the light switch?

1.3 How can the motion of a charged particle be used to distinguish between electric and magnetic fields?

1.4 Why do nearly all natural occurring large nuclei have more neutrons than protons?

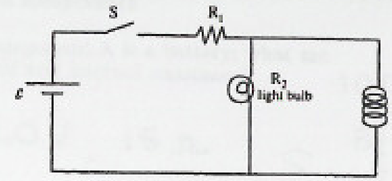
1.5 Two samples of the same nuclide are prepared. Initially, sample A has twice the activity of sample B. How does the half-life of A compare to B?

1.6 Why does a statically charged balloon stick to the ceiling? Is the ceiling charged?

01W

Name: ________________ Student Number: ________________

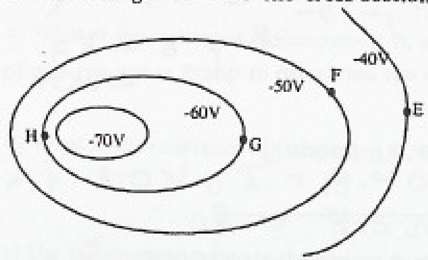
1.7 For the circuit below, the switch is initially open.




a) Sketch the brightness of the bulb from the time the switch is closed until the current is nearly at equilibrium.

b) After the switch has been closed for a long time, the switch is opened and it is found that the light bulb flashes brightly and then goes out -explain how this happens.

1.8 The diagram shows the cross-sections of equipotential surfaces for an electric field.




a) At which point (E, F, G or H) is the magnitude of the electric field the greatest? Why?

b) At which point would an electron have greatest potential energy.

c) What is the direction of the electric field at point G?

Name: ____________________ Student Number: ____________

2. A spherical conducting raindrop of radius 0.70mm carries a charge of $-1.00 \times 10^{-12}C$,
a) what is the Electric field outside the rain drop?
b) what is the potential at its surface?
c) what are the electric field and electric potential inside the rain drop?

Two identical rain drops as above, each with radius 0.70mm carries a charge of $-1.00 \times 10^{-12}C$ collide and merge into one larger drop.

d) What is the radius of the larger drop?
e) What is its potential at the surface of the drop?

a) $E = \frac{kq}{r^2}$ + depends on distance
At surface $E = 1.83 \times 10^4 \frac{N}{C}$ radially inward.

b) −12.8V

c) 0, −12.8 V

d) 0.88 m

e) −20.4 V.



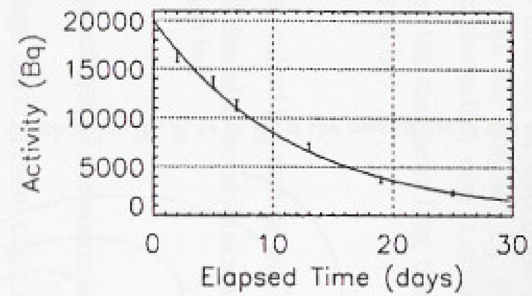
O1W

Name: ____________________ Student Number: ____________

3. Iodine-131 is a radioactive isotope that is taken internally to be used as a radioactive tracer or to treat thyroid cancer. It is produced by bombarding an isotope of tellurium with neutrons. The iodine-131 then undergoes a beta minus decay (energetic electrons are emitted).

a) Write the two reactions describing the production of iodine-131. Write the subsequent radioactive decay reaction.

The following graph shows the result of measuring the activity of an I-131 sample as a function of time. The best-fit curve for the data is drawn.




b) Use the above graph to determine the decay constant for I-131. (Give your answer in $s^{-1}$.)

$t_{\frac{1}{2}} = 8$ days

$\lambda = 1.003 \times 10^{-6} s^{-1}$

c) How many radioactive iodine atoms were there in the original sample?

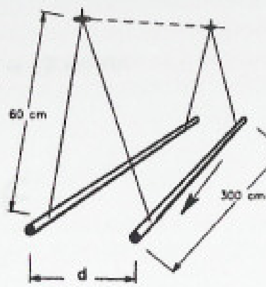
$2.00 \times 10^{10}$ atoms

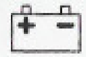
d) Taken internally which type of source is more destructive, an alpha or a gamma source? W

e) Stored in a laboratory, which type of source is more dangerous, an alpha or a gamma sourc
Why?

Name: ______________ Student Number: ______________

4. Two thin long parallel copper wires carrying a constant current are supported by insulating strings **60 cm** long as indicated in the figure. Each of the wires has a mass of **120 g** and a length of **3.0 m**. In equilibrium, the current in **wire 1** is flowing from right to left as shown and the two wires are separated by a distance d.

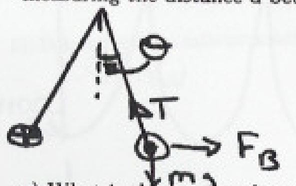


a) What is the direction of the current in **wire 2** in order that this be the equilibrium position? Complete the electric circuit in the drawing and indicate the direction of the current in **wire 2**. State whether you have to connected the wires in parallel or in series.

Series

b) Explain how you can determine the current just by measuring the distance d between the wires.




$F_B = T\sin\theta$

$mg = T\cos\theta$

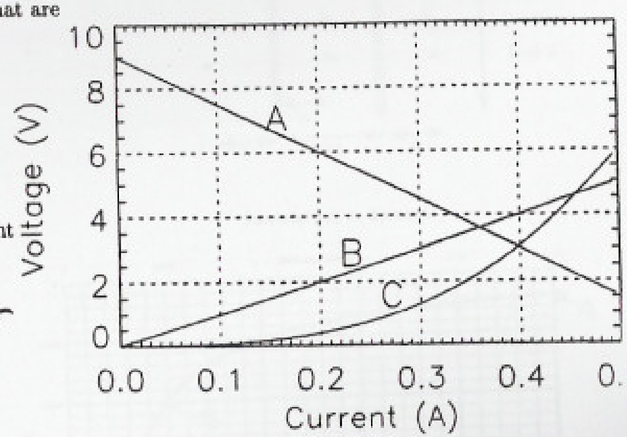
c) What is the current through each wire if the distance d is **5.0 cm**?

64 A



Name: ______________ Student Number: ______________

5. The following graph shows the current-potential difference characteristics of three DC circuit components.




a) Component A is a battery; what are its emf and internal resistance?

9.0 V, 15 Ω

b) Identify the type of component for B and C.

B (ohmic) resistor

C bulb

c) What is the resistance of Component B, when the potential difference across it is 3.0V?

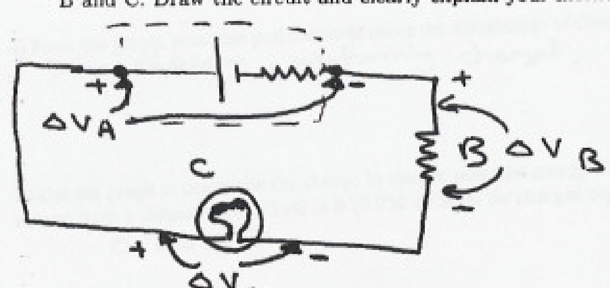
10 Ω

d) What is the resistance of Component C, when the potential difference across it is 3.0V?

At 3.0 V $I = 0.40$ A

$\therefore R = 7.5\ \Omega$

e) Use the graph to estimate the current in a series circuit containing only Components A, B and C. Draw the circuit and clearly explain your method to determine the current.




Need $\Delta V_A = \Delta V_B + \Delta V_C$

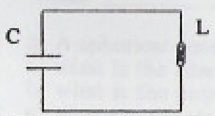
$\therefore \sim 0.3$ A



01W

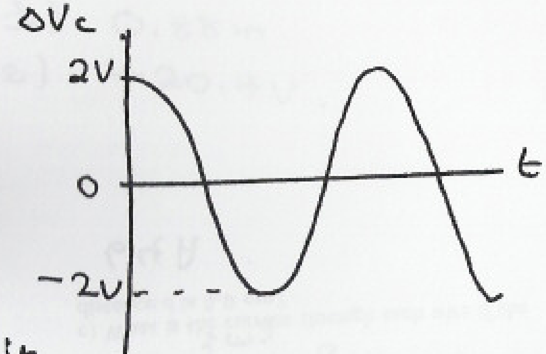
ne: ______________________ Student Number: ______________

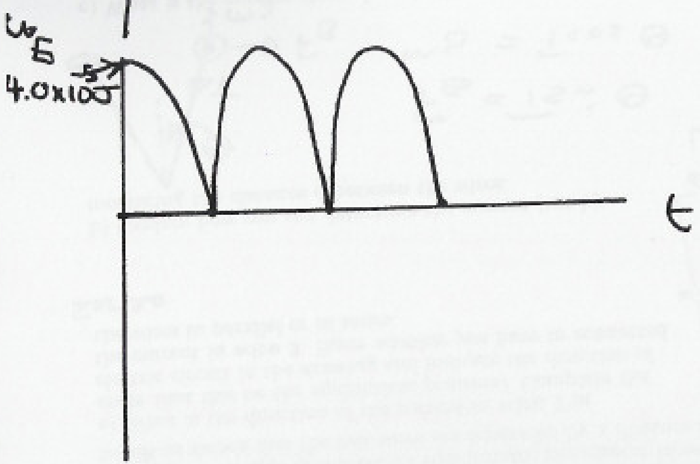
3.




Consider the above diagram of a simple LC circuit where L=50 mH C=20 $\mu$F.
At time t=0 the current in this circuit is zero and the charge on the capacitor is 40 $\mu$C.
a) What is the voltage across the Capacitor at t=0?
b) Determine $dI/dt$ at t=0, remembering that i=0 at t=0. (Use Kirchoff's law.)
c) How much energy is stored in the capacitor at t=0?
d) Graph the voltage across the capacitor as a function of time. A rough sketch is fine, but label both axes, and show zero intercepts and amplitudes.
e) Graph the energy stored in the capacitor as a function of time. Make the time axis of this plot be the same scale as the graph in part D.

a) 2.0 V
b) −40 A/s
c) $4.0 \times 10^{-5}$ J
d)



**Question 2a**
Sodium-22 is radioactive:
i) Write the complete equations for the $\beta^+$ and the $\beta^-$ decay of sodium-22.

ii) Use the atomic masses given below to determine if sodium-22 is a $\beta^+$ or a $\beta^-$ emitter.
$\beta^+$

iii) Determine the maximum kinetic energy of the emitted beta particle.
1.82MeV

$m_e = 0.000549u$: $m_p = 1.007276u$: $m\,{}^1_1H_{atom}$: $1.007825u$: $m_n$: $1.008665u$

| Element | Atomic Masses (u) A = 21 | A = 22 | A = 23 |
|---|---|---|---|
| $_{10}$Ne | 20.993847 | 21.991386 | 22.994467 |
| $_{11}$Na | 20.997655 | 21.994437 | 22.989769 |
| $_{12}$Mg | 21.011742 | 21.999574 | 22.994125 |

**Question 2b**
An animal bone fragment is found in an archaeological site and has a carbon mass of 200 grams. If the activity of the sample due to ${}^{14}_{6}C$ is16 decays/s, what is the age of the bone?

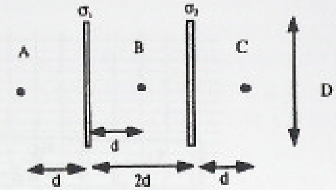
[$t_{1/2}$ (${}^{14}_{6}C$) = 5730 years, normal abundance $\frac{{}^{14}_{6}C}{{}^{12}_{6}C} = 1.3\times10^{-12}$]
9430 yrs

02W

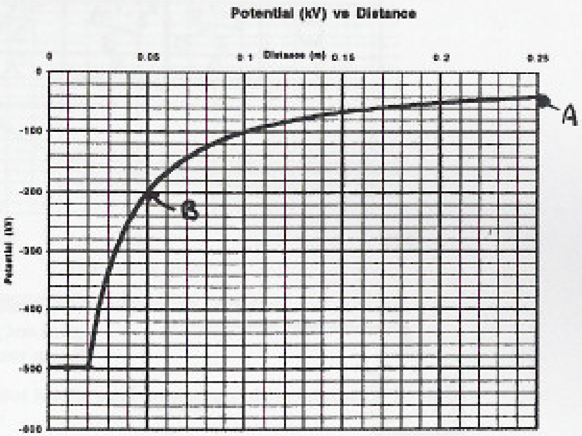


**Question 3a**
Two very large square conducting plates, have charge densities $\sigma_1 = +\sigma$ and $\sigma_2 = -2\sigma$. Determine the electric field at points A, B and C as shown.

A → $\sigma/2\epsilon_0$
B → $\frac{3\sigma}{2\epsilon_0}$
C ← $\frac{\sigma}{2\epsilon_0}$




**Question3b**
Shown is a plot of electric potential versus radial distance from an isolated charged object held fixed at some point.




a) Why is the potential negative?

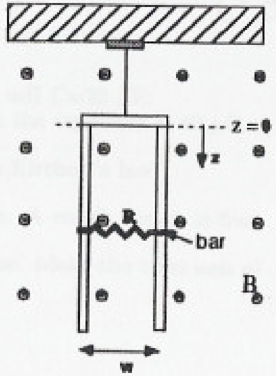
b) **Use the graph** to determine the electric field due to the isolated charged object at a distance of 0.070 m from the object. Slope = 2000 kV/m radially inward

c) From the graph, what can you conclude about the distribution of charge (shape, size and total charge).
Size 0.020m , uniformly charged, q = −1.11μC

d) Use the graph to determine the change in electric potential energy of a +0.010 μC point charge as it is moved from a distance A (0.25 m) to B (0.050 m) from the charged object.
0.0016 J

**Question 4**

A U-shaped conductor with negligible resistance and width w, is hanging vertically from an insulating string.
A conducting cross bar with resistance R is free to slide down the conductor as it remains in (frictionless) contact with it, thus forming a conducting loop with variable area.
The whole device is immersed in a region of uniform magnetic field B, perpendicular to the plane of the loop, as shown.




a) What is the direction of the current induced in the loop? Explain! Clockwise

b) With reference to the coordinates shown, what is the direction of the magnetic force, $F_B$ acting on the cross bar? Explain!

$\vec{F}_B \parallel -\hat{k}$

c) $F_B$ is proportional to the speed of the bar i.e. $F_B = \kappa v_{bar}$. Find the proportionality constant κ in terms of R, w, B and z(t) - the vertical position.

$K = \frac{(wB)^2}{R}$

d) In this system, the speed of the bar will increase until $F_B$ balances the weight of the bar. What is the terminal speed, $v_T$, of the bar?

$V_T = \frac{mgR}{(wB)^2}$

e) What is the induced current for this terminal speed?

$I_{ind} = \frac{mg}{wB}$

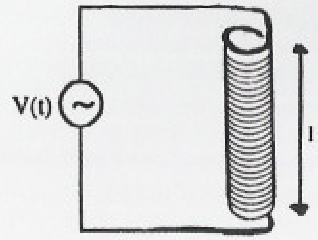


**Question 5a**

A solenoid consists of N = 100 turns in length l = 0.10 m. The cross-sectional area is A = 0.010m².

A voltage is applied giving rise to a current :

$I(t) = I_o \sin \omega t.$




a) What is the magnetic field, B(t) at the centre of the coil?

$1.26 \times 10^{-3}$ T

b) Assume that B is uniform throughout the volume of the coil. What is the total flux, ϕ(t), through the coil?

$1000 \mu_0 I_0 \sin \omega t$

c) What is the inductance, L of the coil?

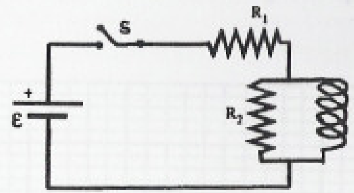
$4\pi \times 10^{-4}$ H

d) What is the potential across the coil, V(t)

$1000 \mu_0 I_0 \omega \cos \omega t$

**Question 5b**

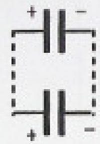
Consider the circuit opposite:
Switch S has been open for a long time.
It is closed suddenly at t = 0.
A long time later it is opened.
Determine the potential across and the current through each component at the following times. *(If you need more room, show your work on the page opposite.)*




| | $R_1$ | | $R_2$ | | L | |
|---|---|---|---|---|---|---|
| Time | $V_1$ | $I_1$ | $V_2$ | $I_2$ | $V_L$ | $I_L$ |
| Immediately after S closes | $\frac{R_1 \mathcal{E}}{R_1+R_2}$ | $\frac{\mathcal{E}}{R_1+R_2}$ | $\frac{R_2 \mathcal{E}}{R_1+R_2}$ | $\frac{\mathcal{E}}{R_1+R_2}$ | $\frac{R_2 \mathcal{E}}{R_1+R_2}$ | 0 |
| A long time after S closes | $\mathcal{E}$ | $\mathcal{E}/R_1$ | 0 | 0 | 0 | $\mathcal{E}/R_1$ |
| Immediately after S is reopened | 0 | 0 | $-\frac{\mathcal{E} R_2}{R_1}$ | $-\frac{\mathcal{E}}{R_1}$ | $-\frac{\mathcal{E} R_2}{R_1}$ | $\mathcal{E}/R_1$ |

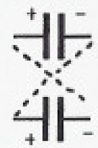
**Question 6a** Consider a capacitor, $C_1 = 2.40\ \mu F$ charged to a voltage of 880 V and a second capacitor $C_2 = 4.0\ \mu F$ charged to a voltage of 560 V.

a) If they are disconnected from their batteries and their positive plates are connected together and their negative plates connected together, what will be the final voltage and charge on each capacitor after a long time?



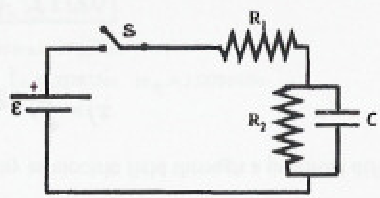
$Q_1 =$ 1.63 mC $V_1 =$ 680 V $Q_2 =$ 2.72 mC $V_2 =$ 680 V

b) If they are mistakenly connected together so that the positive plate of $C_1$ is connected to the negative plate of $C_2$, and the negative of $C_1$ is connected to the positive plate of $C_2$, what will be the resulting charge and voltage for each capacitor?



$Q_1 =$ 48.7 μC $V_1 =$ 20.3 V $Q_2 =$ 81.2 μC $V_2 =$ 20.3 V

**Question 6b** Consider the circuit opposite:
Switch S has been open for a long time.
It is closed suddenly at t = 0.
A long time later it is opened.
Determine the potential across and the current through each component at the following times: *(If you need more room, show your work on the page opposite.)*

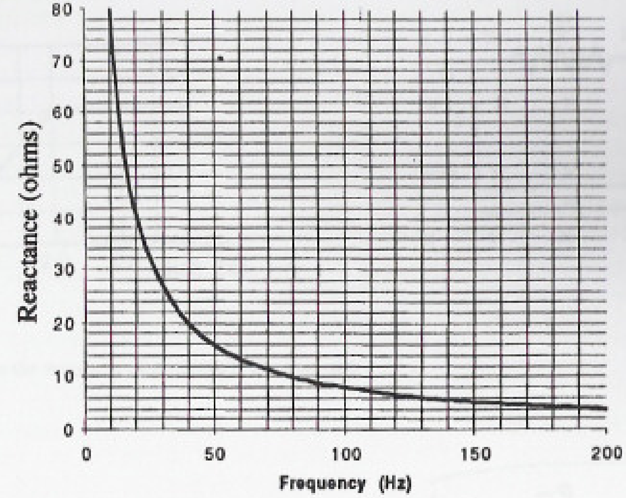



| | $R_1$ | | $R_2$ | | C | |
|---|---|---|---|---|---|---|
| Time | $V_1$ | $I_1$ | $V_2$ | $I_2$ | $V_C$ | $I_C$ |
| Immediately after S closes | $\varepsilon$ | $\varepsilon/R_1$ | 0 | 0 | 0 | $\varepsilon/R_1$ |
| A long time after S closes | $\frac{\varepsilon R_1}{R_1+R_2}$ | $\frac{\varepsilon}{R_1+R_2}$ | $\frac{\varepsilon R_2}{R_1+R_2}$ | $\frac{\varepsilon}{R_1+R_2}$ | $\frac{\varepsilon R_2}{R_1+R_2}$ | 0 |
| Immediately after S is reopened | 0 | 0 | $-\frac{\varepsilon R_2}{R_1+R_2}$ | $\frac{\varepsilon}{R_1+R_2}$ | $\frac{\varepsilon R_2}{R_1+R_2}$ | $\frac{\varepsilon}{R_1+R_2}$ |

02W



**Question 7**
The graph, shows how the reactance, $X_C$ of a capacitor varies with frequency, f.




a) Use the information on the graph to determine the value of the capacitor.
199 μF

b) What is the inductance of an inductor that has the same reactance as this capacitor at 50 Hz?
0.051 H

c) On the graph above, plot the reactance versus frequency for an inductor that has the same reactance as the capacitor at 50 Hz.
linear through (0,0 & 50,16)

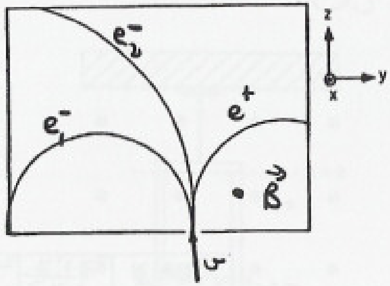
d) If the inductor is connected in series with a 10 Ω resistor, what would be the impedance of the combination at:

i) 50 Hz? 18.9 Ω

ii) 100 Hz? 33.5 Ω

**Question 8a**

The figure represents the detection of an electron-positron pair and a so-called recoiling electron. The particles are detected as they enter a region of uniform and constant magnetic field. The direction of the incoming velocity, v, is shown.




i) Identify the paths corresponding to the positron $e^+$, the electron $e_1^-$ and the recoiling electron $e_2^-$, in the figure.

ii) What is the direction of the magnetic field with respect to the coordinate system indicated – show its direction on the diagram? $\vec{B}$ ∥ +x

iii) Two of the tracks appear to have curvature of the same sign, but different radii. What can you infer about the relative kinetic energies of these two particles?

$KE_{e2} > KE_{e1}$

**Question 8b**

Electrons in a TV picture tube are accelerated from rest by an electric field through a potential difference of 2.5 kV.

i) What is the final speed of the electrons? $2.96 \times 10^7$ m/s

ii) The beam of electrons is then deflected by a perpendicular magnetic field with magnitude 0.80 T. What is the acceleration of the electrons in the magnetic field?

$a_c = 4.2 \times 10^{18}$ m/s$^2$

iii) What is the speed of the electrons after they travel 4.0 mm through the magnetic field?

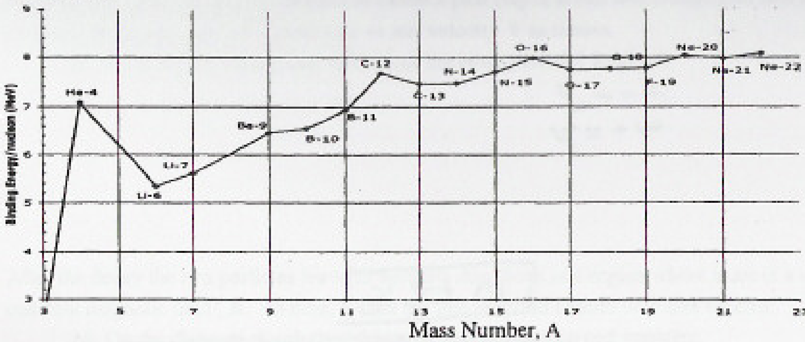
No change

iv) What strength of electric field would give the same magnitude acceleration as in part ii)?

$2.39 \times 10^7$ N/C.

02W

**Question 2**




The above graph is a plot of binding energy per nucleon for the stable nuclides with mass numbers of 4 to 22.

a) Use the above graph to estimate the total energy released if three ${}^{4}_{2}He$ nuclei are fused to form a ${}^{12}_{6}C$ nucleus.

7.2 MeV

b) Use the graph and the masses given below to calculate the atomic mass of ${}^{21}_{10}\mathrm{Ne}$.

$$m_e = 0.000549\mathrm{u};\quad m_p = 1.007276\mathrm{u};\quad m\left[{}^{1}_{1}\mathrm{H}_{atom}\right] = 1.007825\mathrm{u};\quad m_n = 1.008665\mathrm{u}$$

20.993 u

c) Carbon-11 (${}^{11}_{6}\mathrm{C}$) is radioactive with a half life of 20.4 minutes. What is the activity of a sample that contains 1.00 μgrams of carbon-11?

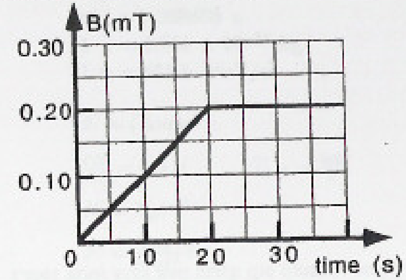
$3.1\times10^{13}$ Bq

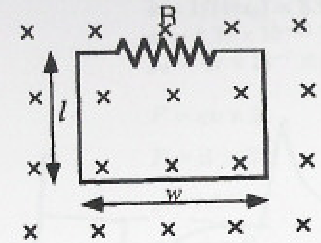
d) Carbon-11 undergoes either a beta-plus or a beta- minus decay. Write the equations describing both types of decay. Which of these two decays is more likely? State your reasoning.

$\beta^+$

**Question 3**

A loop of wire has sides $l = 0.30$ m and $w = 0.50$ m and is immersed in a region with a time varying magnetic field, B(t) as shown.




a) Determine the magnetic flux through the loop at t = 10 s

$1.5\times10^{-5}\ \mathrm{T.m^2}$

b) Calculate the induced emf, $\mathcal{E}_{ind}$ in the loop at t = 10 s

$1.5\times10^{-6}$ V

c) If the total resistance of the loop is 2.0 Ω, what is the induced current, $i_{ind}$ in the loop at t = 10 s?

$7.5\times10^{-7}$ A

d) What is the direction of the induced currentat t = 10 s?. Explain!

e) What are the values of , $\mathcal{E}_{ind}$, $i_{ind}$ at t= 30 s? Explain!

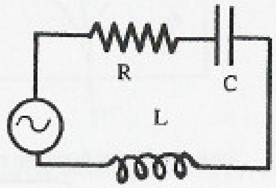
$\mathcal{E}_{ind} = 0 \quad i_{ind} = 0$

03W

**Question 4**

A series LCR circuit is connected to an AC power supply with a 12-V amplitude and frequency $f = 2.5$ kHz. Given $R = 22.0\ \Omega$, $C = 8.0\ \mu F$ and $L = 0.15$ mH,

a) Determine the current amplitude at this frequency.




0.529A

b) What is the average power dissipated at this frequency?

3.073 W

c) What is the resonant frequency for the circuit?

4.59 k Hz

d) Assume that the power supply maintains a 12-V amplitude, what is the current amplitude at resonance?

0.545A

e) What would the average power dissipated be at resonance?

3.27 W

03W



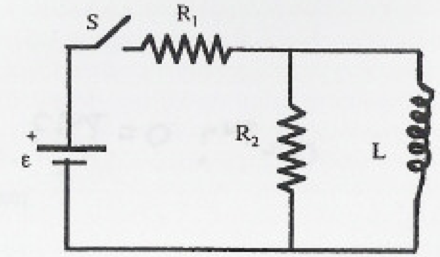
**Question 5**

For the given circuit, the switch S has been open for a long time and no current is flowing.

At time $t_0$ the switch is closed.

Then a long time later at $t_1$, the switch is suddenly opened again.

**Immediately after the switch is closed at $t_0$**




a) What is the current through $R_1$?

$i_1 = \frac{\varepsilon}{(R_1+R_2)}$

b) What is the current through the inductor L?

0

c) What is the rate of change of the current di/dt flowing through the inductor L?

$\frac{di}{dt} = \frac{\varepsilon}{L}\frac{R_2}{R_1+R_2}$

**Just before the switch is re-opened at time $t_1$**

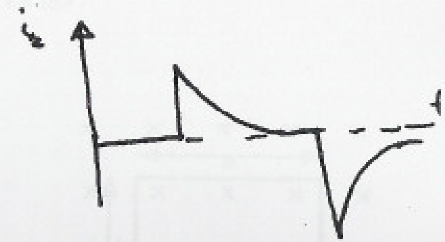
d) What is the current through the inductor?

$i_L = \varepsilon/R_1$

**For the time period from before the switch is initially closed until after the switch is re-opened,**

i.e. $t<t_0$ to $t>t_1$

e) Sketch in the space provided the voltage across the resistor $R_2$ as a function of time. Assume the resistances of $R_1$ and $R_2$ are comparable. Label your axes and mark the times $t_0$ and $t_1$.



**Question 6**

An electrically neutral subatomic particle called a pion ($\pi_0$) is at rest and decays into two charged particles, both with mass, m, and one with charge +e and velocity $\vec{v}$ as shown.

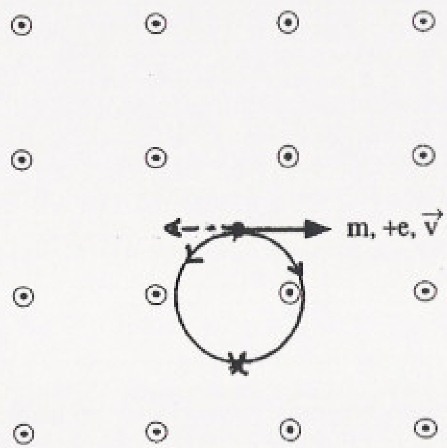
a) What are the charge and velocity of the other particle? Explain!

$q = -e$

$v_2 = -v$

After the decay the two particles leave in opposite directions in a region where there is a uniform and constant magnetic field , B. At time, t, later the two particles collide with one another.

b) On the diagram sketch the trajectories of the two charged particles.




c) Write an expression for the elapsed time from the decay until the two particles collide, in terms of the particle's mass, initial velocity and charge and the magnitude of the magnetic field.

$t = \frac{\pi m}{eB}$

03W

$c = 3.00 \times 10^8$ m/s
$N_A = 6.02 \times 10^{23}$ mole$^{-1}$
$|e| = 1.602 \times 10^{-19}$ C
$m_e = 0.00054858$ u
$m_p = 1.007276$ u
$m_n = 1.008665$ u
1 u $= 1.661 \times 10^{-27}$ kg
1 u $= 931.5$ MeV/c$^2$

$g = 9.8$ m/s$^2$
$v = v_0 + at$
$x = x_0 + v_0 t + \frac{1}{2}at^2$
$v^2 = v_0^2 + 2a(x - x_0)$

$k = 1/(4\pi\epsilon_0) = 8.99 \times 10^9$ N
$\epsilon_0 = 8.85 \times 10^{-12}$ F/m or C$^2$
$\mu_0 = 4\pi \times 10^{-7}$ H/m or T·m

$E = (\Delta m)c^2$

$\frac{dN}{dt} = -\lambda N$ $\quad T_{1/2} = \frac{\ln 2}{\lambda}$

$N = N_0 e^{-\lambda t}$

$F = \frac{q_1 q_2}{4\pi\epsilon_0 r^2}\hat{r}$

$F = qE$

$E = \frac{q}{4\pi\epsilon_0 r^2}\hat{r}$

$\Phi_E = \int E \cdot dA$

$V_B - V_A = -\int_A^B E \cdot dl = \frac{W_{AB}}{q}$

$\Delta V = Ed$

$V = \frac{q}{4\pi\epsilon_0 r}$

$Q = CV$

$C = \frac{K\epsilon_0 A}{d}$

$U_E = \frac{1}{2}CV^2$ $\quad u_E = \frac{1}{2}\epsilon_0 E^2$

$i = \frac{dQ}{dt}$

$j = nqv_d$

$R = \rho\frac{l}{A}$ $\quad \rho = \rho_0[1 + \alpha(T - T_0)]$

$P = Ri^2$

$Q(t) = Q_{max}(1 - e^{-t/RC})$

$Q(t) = Q_{max}e^{-t/RC}$

$i(t) = i_{max}e^{-t/RC}$

$F = qv \times B$

$F = il \times B$

$\mu = iAN$

$\tau = \mu \times B$

$|B(r)| = \frac{\mu_0 i}{2\pi r}$

$F = \mu_0 \frac{i_1 i_2}{2\pi d} l$

$B = \mu_0 n i$

$\Phi_B = \int B \cdot dA$

$\mathcal{E} = -N\frac{d\Phi_B}{dt}$

$N\Phi_B = Li$

$L = \mu_0 n^2 l A$

$\mathcal{E} = -L\frac{di}{dt}$

$i = \frac{\mathcal{E}}{R}\left(1 - e^{-Rt/L}\right)$

$U_B = \frac{1}{2}Li^2$ $\quad u_B = \frac{1}{2}\frac{B^2}{\mu_0}$

$\frac{V_1}{V_2} = \frac{N_1}{N_2}$

$X_L = \omega L$ $\quad X_C = \frac{1}{\omega C}$

$Z^2 = R^2 + (X_L - X_C)^2$

$\tan\phi = \frac{(X_L - X_C)}{R}$

$\bar{P} = \frac{I_0 \mathcal{E}_0}{2}\cos\phi$

$\oint E \cdot dA = \frac{Q_{encl}}{\epsilon_0}$

$\oint B \cdot dA = 0$

$\oint E \cdot dl = -\frac{d}{dt}(\int B \cdot dA)$

$\oint B \cdot dl = \mu_0 i_{encl} + \mu_0\epsilon_0\frac{d\Phi}{dt}$

$a \cdot b = a_x b_x + a_y b_y + a_z b_z = ab\cos\theta$

$a \times b = (a_y b_z - a_z b_y)\,i + (a_z b_x - a_x b_z)\,j + (a_x b_y - a_y b_x)\,k$

$|a \times b| = ab\sin\theta$