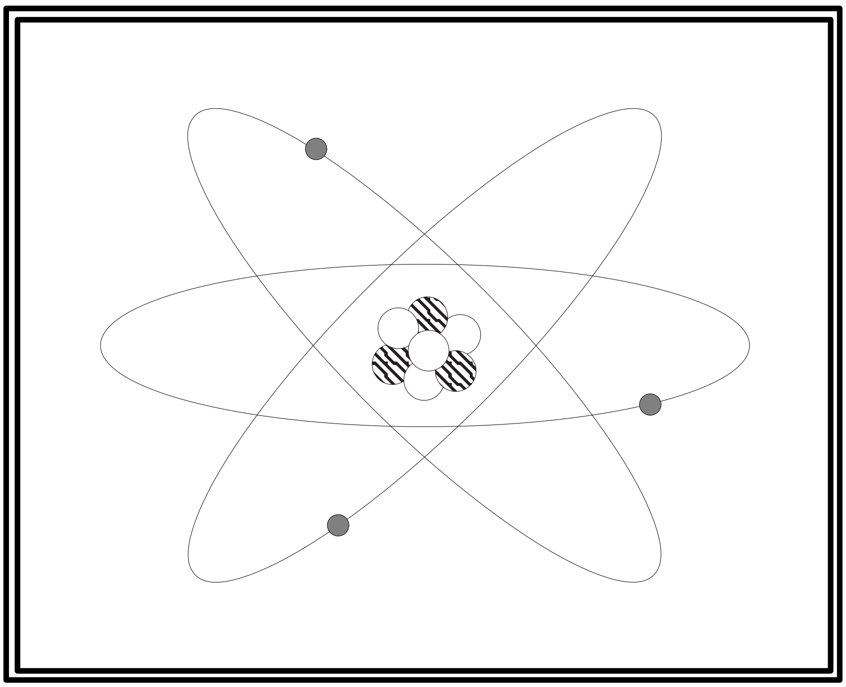
University of Northern British Columbia

Physics Program



Physics 115

Laboratory Manual

2009

Contents

Physics 115 Lab Report Outline

Each week that you perform an experiment you will be expected to submit a lab report in a paper duotang at the end of the lab period. **Label the cover of the duotang** with your name, Physics 115, the appropriate section number, and your instructor's name.

In the upper right hand corner of the first page write:	Your Name
under that write:	Your Lab Partner's Name
and:	The Date

Generally, the best laboratory report is the shortest intelligible report containing ALL the necessary information. It should be divided into sections as described below.

Object - One or two sentences describing the aim of the experiment. (Provided)

Theory - The theory on which the experiment is based. This usually includes an equation which is to be verified. Be sure to clearly define the variables used and explain the significance of the equation. (Provided)

Purpose - Explain the object and theory in you own words. It is wise to do this **before** coming to the lab. (In pen)

Apparatus - A brief description of the important parts and how they are related. In all but a few cases, **a diagram is essential**, artistic talent is not necessary but it should be neat (use a ruler) and clearly labelled. (Provided)

Procedure - Describes the steps of the experiment. In particular, remember to state what quantities are measured, how many times and what is done with the measurements (are they tabulated, graphed, substituted into an equation, etc.). Then explain what sort of analysis will be performed. (Provided)

Data - Show all your measured values and calculated results in tables. Show a **detailed** sample calculation for **each** different calculation required in the lab. Graphs should be included on the page following the related data table. Include a comparison of experimental and theoretical results. (The graphs may be filled out in pencil but everything else must be in pen.)

Conclusions - In a formal lab report you would need to summarize your discoveries. In these labs you will be given questions to guide you. Answer them in complete sentences. (In pen)

Sources of Error - Results rarely agree perfectly with the theoretical expectations, you should provide some insight on what might be the cause of the discrepancy. For example, sometimes you might need a more sophisticated apparatus to obtain more accurate values. It could also be that the theoretical calculation was based on more idealized experimental conditions or on oversimplified models. Be specific about the sources of error. (In pen)

Lab Rules:

Please read the following rules carefully as each student is expected to be aware of and to abide by them. They have been implemented to ensure fair treatment of all the students.

Missed Labs:

If a student does not attend a lab, the mark for that lab will be zero (0). If the student is ill, a doctor's note is required to miss the lab without penalty. If an absence is expected, arrangements to make up the lab can be made with the Senior Laboratory Instructor **in advance**. (Students will not be allowed to attend sections, other than the one they are registered in, without the express permission of the Senior Laboratory Instructor.)

Late Labs:

Labs will be due at the end of the lab period. Labs not received at the end of the lab period will result in a mark of zero for that lab.

Completing Labs:

To complete the lab report in time students are strongly advised to read and understand the lab (the text can be used as a reference) and write-up as much of it as possible before coming to the lab.

Conduct:

Students are expected to treat each other and the instructor with proper respect at all times and horseplay will not be tolerated. This is for your comfort and safety, as well as your fellow students'. Part of your lab mark will be dependent on your lab conduct.

Plagiarism:

Plagiarism is strictly forbidden! Copying sections from the lab manual or another person's report will result in severe penalties. Some students find it helpful to read a section, close the lab manual and then think about what they have read before beginning to write out what they understand in their own words.

Use Pen:

The lab report, except for diagrams and graphs, must be written in pen, this includes filling out tables. If your make a mistake simply cross it out with a single, straight line and write the correction below. Professional scientists use this method to ensure that they have an accurate record of their work and so that they do not discard data which could prove to be useful after all. For this reason also, you should not have "rough" and "good" copies of your work. Neatly record everything as you go and hand it all in. If extensive mistakes are made when filling out a table, mark a line through it and rewrite the entire table.

Lab Presentation:

Marks will be given for presentation, therefore neatness and following the outline is important. It makes your lab easier to understand and your report will be evaluated accordingly. It is very likely that, if the person marking your report has to search for information or results, or is unable to read what you have written, your mark will be less than it could be!

Other Penalties:

Each student is allowed to do the following once, after which penalties of one (1) mark each will be assigned for: not including your lab partner's name(s) using pencil inappropriately having no paper duotang missing information on the cover of the duotang

Supplies needed:

Clear plastic 30 cm ruler
Metric graph paper (1 mm divisions)
Paper duotang
Lined paper
Calculator
Pen, pencil and eraser

Experiment 1

Graphical Analysis

Introduction

This laboratory session is designed to introduce you to an important part of doing experiments or taking measurements, namely graphical analysis. It is important that you understand the techniques of graphing and are able to interpret the information contained in a graph.

Theory

You will be given a set of data from an experiment that measured the velocity v of an object as a function of its distance d with respect to a reference point. The object was experiencing a uniformly accelerated motion, i.e., it was moving with constant acceleration. From the kinematical analysis of such a motion, we know that this relation should be in the form:

$$v^2 = v_o^2 + 2ad \tag{1.1}$$

where v_o is the initial velocity of the object and a its acceleration. You will see that, by using the power of graphical analysis and function linearization, you can test the validity of this relation. In general, you can find the equation that relates any two variables by applying techniques similar to the ones that you will learn today, even when you do not have a theoretical relation to guide you.

Apparatus

You will usually perform the experiment yourself rather than being given the data. In that case you would include a diagram and a list of the apparatus you used. In this case you can simply list the tools you used to process the data.

Purpose

In *your own words* explain the purpose of this experiment and what you are testing.

Procedure

Usually, in an experiment, you would carry out some measurements and include your data in this part of your report. For the purpose of this lab session though, data will be given to you to analyze. The following table is a summary of a set of measurements of velocity v versus distance d for a uniformly accelerated object.

Data Table

d (m)	v (m/s)	
1	10	
2	14	
3	17	
4	19	
5	21	
6	23	
7	27	
8	25	
9	27	
10	29	

1. The first step in graphical analysis is to directly plot the two variables. Plot v versus d, with d along the horizontal (X) axis and v along the vertical (Y) axis. Draw a line or smooth curve through the plotted data points.

   Note: If you find one or two data points that do not agree with the rest, label them with a question mark on the graph. (In some cases, it may be necessary to redo the measurements to check these 'anomalous' data points.)

2. Look closely at your line. If it tends to curve toward the X-axis, then a plot of v^2 versus d is required for a linear graph. **HOWEVER** if it is tending to curve toward the Y-axis, then a plot of v versus d^2 will give you a straight line.

3. After you have determined which way the line in your first graph curves, fill the third column in the data table with the appropriate values, either v^2 **OR** d^2.

   Sample Calculation of the Squared Value:

4. Now plot the graph that you have determined will give you a straight line.

5. Once you have achieved a linear graph, you can then make use of the straight line equation,

$$Y = mX + b \tag{1.2}$$

   to write down the exact relation between the variables. To do this, extract **from the linear graph** the values of the slope, m and the Y-intercept, b.

   Sample Calculation: To find the slope, take two points on the line, (x_1,y_1) and (x_2,y_2), and use the following formula:

$$\mathbf{m} = \frac{\mathbf{y_2 - y_1}}{\mathbf{x_2 - x_1}} = \frac{\mathbf{rise}}{\mathbf{run}} = \qquad\qquad\qquad =$$

   The value for b can be found by examining the intersection of the line and the Y-axis:

   $\mathbf{b} =$

Note: Y and X refer to the variables on these axis. In this case $Y = v^2$ and $X = d$.

So the equation of the line is:

$$= \qquad\qquad\qquad + $$

6. It is important that you summarize your results clearly and compare them to expected theoretical values or relationships. In this lab, compare your results to the expected theoretical relationship given by (1.1).

   Sample Comparison (show how the variables in (1.1) and the straight line equation (1.2) are related):

7. Since (1.1) and (1.2) are both equations relating v^2 and d, a comparison of their related parts, allows you to see that $m = 2a$ and $b = v_o^2$. Calculate the acceleration a and initial velocity v_o of the motion.

   Sample Calculation:

   Since $m = 2a$, the acceleration can be calculated by rearranging this equation to:

   $$\mathbf{a} = \frac{\mathbf{m}}{\mathbf{2}} = \qquad\qquad\qquad =$$

   Similarly, since $b = v_o^2$:

   $$\mathbf{v_o} = \sqrt{\mathbf{b}} = \qquad\qquad\qquad =$$

8. Summarize your results by writing out equation (1.1) with the appropriate values filled in for the constants.

$$= \qquad\qquad\qquad + $$

Conclusions

9. Equation (1.1) predicts a relationship between the distance the cart has travelled and its velocity. Do your results support this relationship? ((For example, if two variables were directly related, you would expect a straight line if you graphed one against the other.)

10. What did you find the acceleration and initial velocity of the cart to be?

Sources of Error

Experiment 2

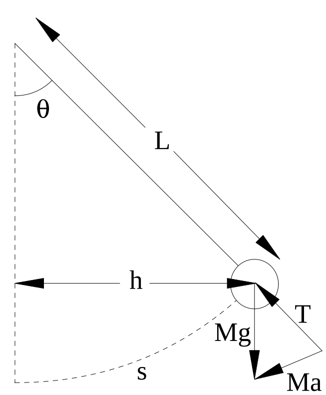
The Simple Pendulum

Introduction

In this experiment we will study periodic oscillations of a simple pendulum. We will use the method of dimensional analysis to construct a relationship between the period T of the pendulum and the length l of the string. We will experimentally test the constructed relationship by using the method of graphical analysis.

Theory

A simple pendulum consists of a mass M attached by a string to a fixed point. The mass will execute periodic motion along a circular arc when released from rest to one side of the vertical.



The position of the mass may be given in terms of the length L of the string and the angle θ of the string as measured from the vertical (see diagram). The acceleration of the mass M is in the direction perpendicular to the line of the string.

Using Newton's second law gives:

$$F = Mg\sin\theta = Ma \tag{2.1}$$

for the magnitude of the acceleration a.

Notice that we have taken the component of the weight along the direction perpendicular to the line of the string. For large angles, further analysis of the motion of the mass using equation (2.1) is complicated. However, if we restrict our investigation to small angles, we may make approximations which simplify matters. For small angles we have:

$$\sin\theta = h/L \approx s/L \tag{2.2}$$

where θ is in radians.

Putting equation (2.2) into equation (2.1) gives us an expression for the magnitude of a:

$$a \approx (g/L)s \tag{2.3}$$

Notice that the acceleration is in the direction back towards the vertical. Whenever the acceleration is proportional and opposite to the displacement, the motion is called simple harmonic motion. This type of motion occurs for the simple pendulum when the displacement, s, is small.

We can construct a relationship between the period T and the length L of the pendulum by using the method of dimensional analysis. In this method we ensure that the dimensions (units) are the same on both sides of the equation. We expect the period to depend on the acceleration due to gravity, g, because we know that no oscillations would occur if g was zero. We therefore expect a relationship of the form:

$$T = cL^{\alpha}g^{\beta}, \tag{2.4}$$

where c is a numerical constant having no dimensions, and the exponents α and β are to be found using dimensional analysis.

It can be shown that, in order that equation (2.4) provide a good estimate for the period T of the simple pendulum, the magnitude of s/L should typically be no bigger than about 0.1.

Apparatus

- Pendulum System (Stand, string and bob)
- Meter stick and Stopwatch

Purpose

In *your own words* explain the purpose of this experiment and what you are testing.

Advance Preparation: ***Before coming to the lab*** It is essential that you read the Appendix on Dimensional Analysis and attempt steps 1. and 2. in the data section of your lab report .

1. Using the method of dimensional analysis (see the Appendix), determine the values of the exponents α and β in equation (2.4). Record your equation (2.4) with these values of α and β.

   Dimensional Analysis:

2. Explain how you can test your equation using graphical analysis. What should be plotted on the "y–axis"? What should be plotted on the "x–axis"? Write your expression in the standard form $y = mx + b$. What is your expression for the slope m?

   Answer:

Procedure

3. Spend a few moments familiarizing yourself with the apparatus and the method of adjusting the length of the string.

4. Start by adjusting the string to have a length of 20 cm from the fixed point to the *bottom of the mass* and record this length, L, in the Data Table.

Data Table

L (m)	t_1 (s)	t_2 (s)	t_3 (s)	t_4 (s)	t_5 (s)	$\bar{t}$ (s)	T (s)

5. Pull the mass to one side of the vertical. Make sure that the ratio s/L (see Diagram) is no bigger than 0.1. Release the mass from rest and start the stopwatch at the same instant. Allow the bob to oscillate through 10 cycles and stop the stopwatch at the instant that the mass reaches its greatest deflection from the vertical. Record your value for the total time, t, of the 10 cycles in the Data Table.

6. Repeat step 5. until you have five values of t for the same length of the string.

7. Find and record the average time, $\bar{t}$.

   Sample Calculation:

   $$\bar{\mathbf{t}} = \frac{\mathbf{t_1 + t_2 + t_3 + t_4 + t_5}}{\mathbf{5}} =$$

   $$=$$

8. Find the average period, T, by dividing $\bar{t}$ by the number of oscillations in each trial.

   Sample Calculation:

   $$\mathbf{T} = \frac{\bar{\mathbf{t}}}{\mathbf{10}} = \qquad\qquad =$$

9. Repeat steps 4. through 8. for lengths of 25, 30, 35, 40, 45, and 50 cm. Record all your values in the Data Table.

10. Tabulate your values for what you determined to be x and y in step 2.

XY Table

11. Plot your graph of y versus x. Determine the values of the slope and the $\mathbf{x-intercept}$.

    Sample Calculation: To find the slope, take two points on the line, (x_1,y_1) and (x_2,y_2), and use the following formula:

    $$\mathbf{m} = \frac{\mathbf{y_2 - y_1}}{\mathbf{x_2 - x_1}} = \frac{\mathbf{rise}}{\mathbf{run}} = \qquad\qquad =$$

    The value for $\mathbf{x - intercept}$ can be found by examining the intersection of the line and the X-axis:

    $$\mathbf{x - intercept} =$$

12. In step 2 you found an expression for the slope. Using this expression and the numerical value you found for the slope solve for c:

    Sample Calculation:

13. We expect that $c = 2\pi$. Calculate the percent difference between this expected value and the value you found for c.

    Sample Calculation:

    $$\% \textbf{ difference} = \frac{|\mathbf{2\pi - c}|}{\mathbf{2\pi}} \textbf{ x } \mathbf{100\%} = \qquad\qquad =$$

14. Examine your graph, if you have been careful enough in collecting your data, you may well find that $\mathbf{x-intercept \neq 0}$. After thinking about it, you will agree that the distance to the center of the mass is the correct length to use in equation (2.4). Therefore you should indeed *expect* that (since you used the length *of the string*) the $\mathbf{x-intercept}$ will be nonzero. So equation (2.4) should be modified to read:

    $$T = c(L - r)^{\alpha} g^{\beta}, \tag{2.5}$$

    where l is the length of the string and r is the radius of the weight. Measure and record the diameter of the weight at the end of the string and then calculate its radius in metres.

    $\mathbf{d} =$

    $\mathbf{r} = \frac{\mathbf{d}}{\mathbf{2}} =$

15. Find the percent difference between your $\mathbf{x - intercept}$ value and the measured radius of the weight.

Sample Calculation:

$$\% \textbf{ difference} = \frac{|\mathbf{r - intercept}|}{\mathbf{r}} \textbf{ x 100\%} = \qquad\qquad\qquad\qquad =$$

Conclusions

16. The equation you found in step 2. predicts a relationship between the length of the string and the period of the pendulum. Do your results support this relationship? (For example, if two variables were directly related, you would expect a straight line if you graphed one against the other.)

17. Did the value of the $\mathbf{x - intercept}$ agree with the value of r as predicted by equation (2.5)?

Sources of Error

Experiment 3

Newton's Second Law of Motion

Introduction

The purpose of this experiment is to study the law of motion which shows how the net force acting on an object and its mass affect its acceleration. This is Newton's second law.

The experiment will be performed with the aid of a computer interface system which will allow you to use your computer to collect, display and analyze the data.

Theory

Newton's second law of motion states that the acceleration of an object or system is directly proportional to the net force acting on it and inversely proportional to its total mass. For a motion in one dimension, Newton's second law takes the form:

$$F = ma \tag{3.1}$$

This motion is an example of a uniformly accelerated motion for which the following kinematic relations should hold true: The instantaneous velocity v of the system is given by

$$v = at + v_0 \tag{3.2}$$

where t denotes time and v_0 the initial velocity, and its displacement x is given by

$$x = \frac{1}{2}at^2 + v_0 t + x_0 \tag{3.3}$$

where x_0 is the initial position.

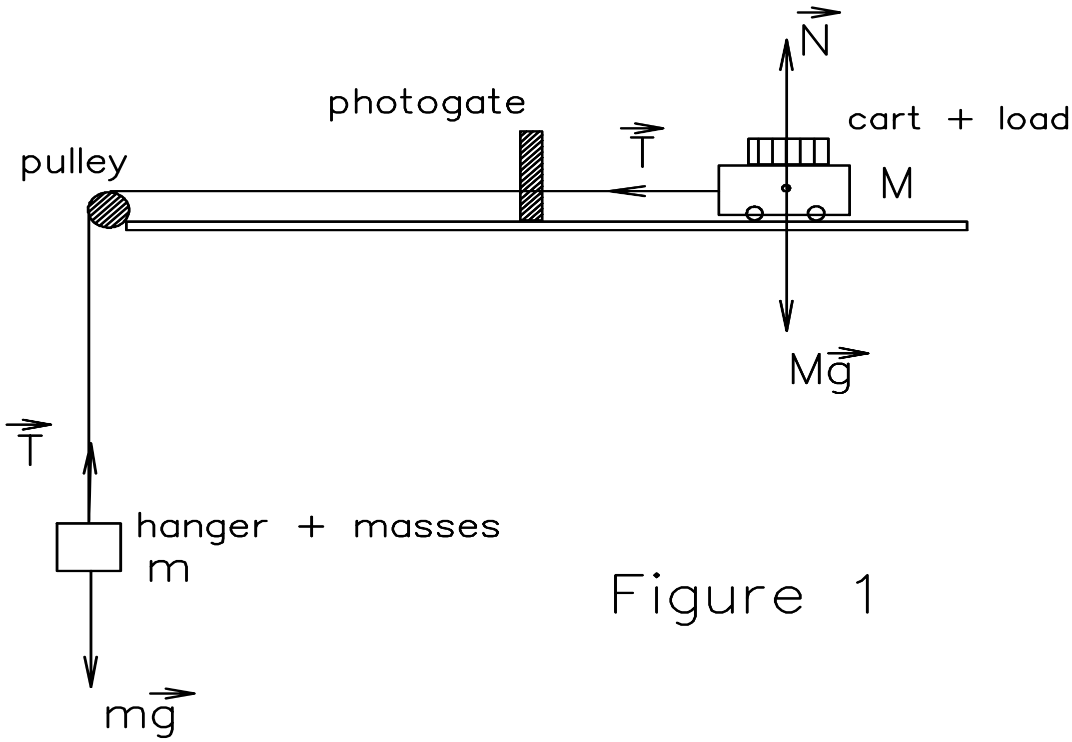


Figure 1

Consider the system shown in Figure 1. We shall neglect for now the rotational motion of the pulley, the frictional force acting on the system, and the mass of the string connecting the two masses m and M. Let us apply Newton's second law to the motion of m:

$$mg - T = ma \tag{3.4}$$

Now apply Newton's second law to the motion of M (note that Mg and N cancel each other):

$$T = Ma \tag{3.5}$$

Substituting (3.5) into (3.4) leads to:

$$mg - Ma = ma \tag{3.6}$$

which can be rearranged to:

$$a = \frac{m}{m+M}g \tag{3.7}$$

which gives the value of the acceleration of either m or M. One way to interpret this equation is to say that the acceleration of the (m + M) system is equal to the ratio between the net external force acting on it (mg) and its total mass (m + M).

Apparatus

- Computer
- Science Workshop Interface
- Dynamics Cart and Track System
- Mass Hanger and Mass Set (4x100g, 1x50g)

Purpose

In *your own words* explain the purpose of this experiment and what you are testing.

Procedure

1. At the start of your lab session, the Linear Dynamics System, Science Workshop interface box, and Dell computer will all be connected and ready to go. Familiarize yourself with the system and the various components of the apparatus.

2. A linear motion timing experiment uses a photogate to measure the motion of an object with uniformly spaced flags. These are normally provided by the black stripes of a picket fence mounted on the object whose motion is being studied. Set up the apparatus as shown in Figure 1. Make sure the picket fence and track are free of dust and dirt. If needed, ask for assistance from your laboratory instructor.

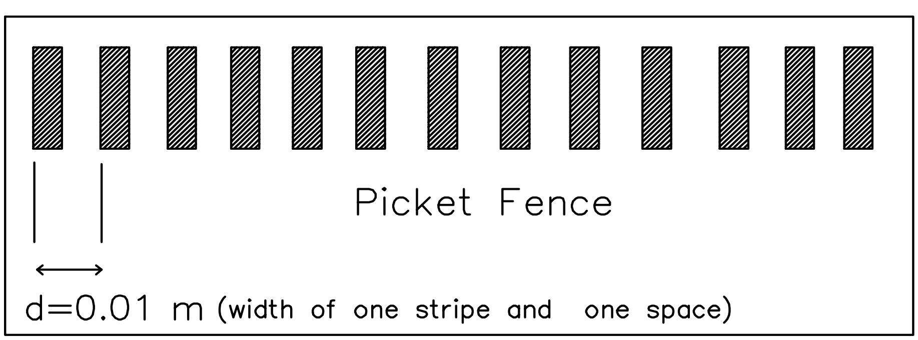


Figure 2

3. Follow the directions below to set up the DataStudio software:

   - Double click on the **Data Studio** icon on the desktop.
   - Choose **No** when the program asks whether DataStudio should choose an options set to load.
   - Choose **Create Experiment**

   The **Experiment Setup** window displaying the *Science Workshop 750 Interface* will appear.

   - Click on the first digital channel on the left.
   - Choose **Photogate & Picket Fence** on the menu that appears.
   - Deselect **Acceleration**, but make sure **Position** and **Velocity** are checked in the **Measurements** tab.
   - In the **Constants** tab, set the *Band Spacing* to $0.010m$.
   - Select **Sampling Options** at the top of the **Experiment Setup** window.
   - In the **Delayed Start** tab, select **Data Measurement** and make sure that it says:
     Position, Ch 1 (m)
     Is Above 0 m.
   - Click **OK**.
   - You can now close the **Experiment Setup** window.

4. To set up how the data will be displayed, follow these steps:

   - In the **Displays** column (at the left of the window) double click **Graph**.
   - In the **Choose a Data Source** window, select **Velocity, Ch1 (m/s)**.
   - Maximize the graphical display.

5. Run 1: Place 150 g (one 100 and one 50) on the cart and make sure there are no slotted masses on the hanger. (The mass of the hanger, m, is 50 g.) The mass of the cart (including the picket fence) is 510 g. Therefore $M = 0.510$ kg + added masses.

6. Start data collection by clicking **Start** and immediately release the cart starting at one end of the track. Make sure to halt the cart after it passes through the photogate. Stop data collection by clicking **Stop**.

7. Look at the graph of velocity vs time on the screen. Use **Scale to Fit** to adjust the ranges so the points take up most of the screen. If the line is uneven, delete the data from the run and repeat data collection until the plot is a relativity smooth line.

8. Once a smooth line is recorded, choose **Linear Fit** from the drop-down **Fit** menu to analyze the velocity-vs-time plot. Compare the equation of the line with (3.2). Extract from this analysis the value of the acceleration a_{ex} and the initial velocity $v_{0_{ex}}$ and record them in the Data Table.

   Sample Comparison (show how the variables in (3.2) and the straight line equation are related):

9. Calculate and record the total mass, $M + m$, and force, F, on the system using equation (3.1).

   Sample Calculations:

   $\mathbf{M + m =}$ $\qquad\qquad\qquad +$ $\qquad\qquad\qquad =$

   and from equation (3.1):

   $\mathbf{F = ma = mg =}$ $\qquad\qquad\qquad\qquad\qquad =$

10. Then calculate the theoretical value of acceleration, a_{th} and find the % difference between this value and your experimental value for acceleration.

Sample Calculations:

The value of the theoretical acceleration can be found using equation (3.7):

$$\mathbf{a} = \frac{\mathbf{m}}{\mathbf{m} + \mathbf{M}}\mathbf{g} =$$

$$=$$

$$\% \textbf{ difference} = \frac{|\mathbf{a_{th}} - \mathbf{a_{ex}}|}{\mathbf{a_{th}}} \textbf{ x } \mathbf{100\%} =$$

$$=$$

Data Table

Run #	1	2	3	4	5
M (kg)					
m (kg)					
a_{ex} (m/s^2)					
$v_{0_{ex}}$ (m/s)					
(m + M) (kg)					
F_{net} (N)					
a_{th} (m/s^2)					
% difference (%)					

11. RUN 2: Move 50 g from the cart load to the mass hanger. ($M = 0.610$ kg and $m = 0.100$ kg.) Repeat steps 6. to 10.

12. RUN 3: Move an additional 50 g from the cart load to the mass hanger. ($M = 0.560$ kg and $m = 0.150$ kg.) Repeat steps 6. to 10.

13. RUN 4: Add 150 g to the cart load. ($M = 0.710$ kg and $m = 0.150$ kg.) Repeat steps 6. to 10.

14. RUN 5: Add another 150 g to the cart load. ($M = 0.860$ kg and $m = 0.150$ kg.) Repeat steps 6. to 10.

15. On one piece of graph paper, sketch each of the five lines generated in the above trials and label each of them with the run # and corresponding equation. Alternatively, use **DataStudio** to plot and label all five runs on one graph and print it from the computer.

Conclusions

16. Compare the experimental results of RUNS 1, 2, and 3. Does the acceleration behave according to what you expect based on Newton's second law when the total mass of the system is kept constant? Explain.

17. Compare the experimental results of RUNS 3, 4, and 5. Does the acceleration behave according to what you expect based on Newton's second law when the net force acting on the system remains constant? Explain.

18. Give reasons as to why the % difference between a_{theory} and $a_{experiment}$ usually decreases as you go from RUN 1 to RUN 3.

Sources of Error

Experiment 4

Capacitance and Capacitors

Introduction

In this laboratory session you will learn about an important device used extensively in electric circuits: the capacitor. A capacitor is a very simple electrical device which consists of two conductors of any shape placed near each other but not touching. While a primary function of a capacitor is to store electric charge that can be used later, its usefulness goes far beyond this to include a wide variety of applications in electricity and electronics. A typical capacitor, called the parallel-plate capacitor, consists of two conducting plates parallel to each other and separated by a nonconducting medium that we call dielectric (see Fig. 1a). However, capacitors can come in different shapes, configurations and sizes. For example, commercial capacitors are often made using metal foil interlaced with thin sheets of a certain insulating material and rolled to form a small cylindrical package (see Fig. 1b). Some of the properties of capacitors will be explored in this experiment, including the concept of capacitance and the mounting of capacitors in series and in parallel in electric circuits.

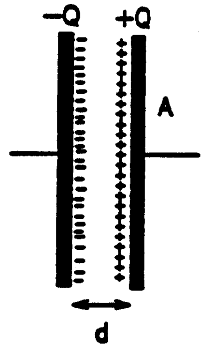


Figure 1a:

Parallel Plate Capacitor

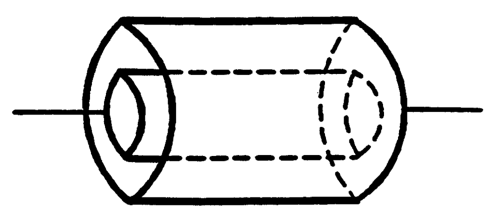


Figure 1b:

Cylindrical Capacitor

Theory

If a potential difference V is established between the two conductors of a given capacitor, they acquire equal and opposite charges $-Q$ and $+Q$. It turns out that the electric charge Q is directly proportional to the applied voltage V. The constant of proportionality is a measure of the capacity of this capacitor to hold charge when subjected to a given voltage. We call this constant the capacitance C of the capacitor and we have:

$$Q = CV \tag{4.1}$$

The value of C depends on the geometry of the capacitor and on the nature of the dielectric material separating the two conductors. It is expressed in units of Coulomb/Volt or what we call the Farad (F). For the parallel-plate capacitor (Fig. 1a) one can show that the capacitance is given by the formula:

$$C = \frac{\epsilon A}{d} \tag{4.2}$$

where A is the area of the plate, d the distance separating the two plates, and ϵ the permittivity of the dielectric material. In case of empty space, the value of ϵ is $\epsilon_0 = 8.85 \times 10^{-12}\ C^2/N.m^2$.

We can also show that if two capacitors of capacitance C_1 and C_2 are connected in series (Fig. 2a) or in parallel (Fig. 2b), then they are equivalent to one capacitor whose capacitance C is given by:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \qquad (series) \tag{4.3}$$

$$C = C_1 + C_2 \qquad (parallel) \tag{4.4}$$

Note that in a series combination each capacitor stores the same amount of charge Q, while in a parallel combination the voltage V across each capacitor is the same.

Figure 2a
Capacitors in Series

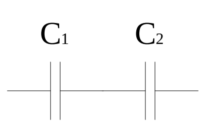
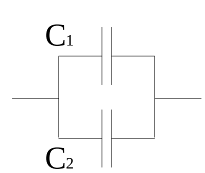


Figure 2b
Capacitors in Parallel



Apparatus

- Large Parallel Plate Capacitor and Insulating Materials
- Digital LCR Meter
- Common Capacitors

Purpose

In *your own words* explain the purpose of this experiment and what you are testing.

Procedure

Measuring the Capacitance of a Parallel-Plate Capacitor:

You are provided with a parallel-plate capacitor which you can use to test equation (4.2). A systematic approach to this would be to measure how the capacitance changes as you vary one of the parameters upon which the capacitance depends while keeping the others constant. There are two parameters that you can change here, the separation between the two plates and the insulating medium separating them.

The capacitance can be measured directly using a digital capacitance meter (LCR meter). Note, however, that your reading of a capacitance will have to be corrected for the intrinsic capacitance of the connecting cables. To see how important this correction may be, connect the cables to the LCR meter and measure the capacitance of the cables using the 200 pF scale on the meter. Move the cables around and observe how the readings change, confirming that capacitance depends on the distance separating the cables. Also investigate the effect of placing your hands around the cables. Set the plate separation to d=0.002 m. Measure and record the diameter of the plates.

1. Connect the cables to the metal posts of the capacitor and measure the total capacitance. Record your reading in the appropriate column.

2. Take a capacitance measurement of the cables at a separation equal to their separation when connected to the capacitor. Record your reading under Cable Capacitance.

Data Table 1

d (m)	$\frac{1}{d}$ (m^{-1})	Total Capacitance (F)	Cable Capacitance (F)	Actual Capacitance (F)

3. Correct for the capacitance of the cables. To calculate the actual capacitance assume that the cables behave as a capacitor connected in parallel with the parallel-plate capacitor and use equation (4.4). Record the actual capacitance.

Sample Calculation:

$$\mathbf{C_{actual} = C_{total} - C_{cable}} = \qquad\qquad - \qquad\qquad =$$

4. Repeat steps 1. through 3. for separations up to d=0.02 m in 0.002 m increments and record your results in Data Table 1.

5. Plot C versus $1/d$ and calculate the slope of the resulting best-fit line.

   Sample Calculation: To find the slope, take two points on the line, (x_1,y_1) and (x_2,y_2), and use the following formula:

   $$\mathbf{m} = \frac{\mathbf{y_2 - y_1}}{\mathbf{x_2 - x_1}} = \frac{\mathbf{rise}}{\mathbf{run}} = \qquad\qquad =$$

6. Show how the variables in (4.2) and the straight line equation are related.

   Sample Comparison:

7. Given that its diameter is 0.2 m calculate the area of the capacitor.

   Sample Calculation:

   $$\mathbf{A} = \pi \mathbf{r^2} = \pi(\frac{\mathbf{d}}{\mathbf{2}})^{\mathbf{2}} \qquad\qquad =$$

8. From the slope value and using equation (4.2) calculate an experimental value for ϵ.

   Sample Calculation:

   $$\epsilon = \frac{\mathbf{m}}{\mathbf{A}} = \qquad\qquad =$$

Capacitors in Series:

9. Choose two of the same capacitors C_1 and C_2 from the set you are provided with. Measure their values with the LCR metre and record them in Data Table 2. Connect the capacitors in series and measure the actual capacitance of the combination. Calculate the theoretical capacitance using equation (4.3) which can be rearranged to:

   Sample Calculation:

   $$\mathbf{C_{theoretical}} = \frac{\mathbf{C_1 C_2}}{(\mathbf{C_1} + \mathbf{C_2})} = \qquad\qquad =$$

10. Compare the actual value to the theoretical value by finding the % difference.

    Sample Calculation:

    $$\% \ \mathbf{difference} = \frac{|\mathbf{C_{theoretical}} - \mathbf{C_{actual}}|}{\mathbf{C_{theoretical}}} \ \mathbf{x\ 100\%} = \qquad\qquad =$$

11. Repeat steps 9. through 10. for the other pair of capacitors.

Data Table 2

C_1 (F)	C_2 (F)	$C_{theoretical}$ (F)	C_{actual} (F)	% Difference (%)

Capacitors in Parallel:

12. Now connect the first pair of capacitors in parallel. Again measure the actual capacitance and record these values in Data Table 3. Calculate the theoretical capacitance using equation (4.4) and find the % difference between it and the actual value.

Sample Calculation:

$\mathbf{C_{theoretical} = C_1 + C_2 =}$ $\qquad\qquad + \qquad\qquad =$

13. Repeat step 12. for the other pair of capacitors.

Data Table 3

C_1 (F)	C_2 (F)	$C_{theoretical}$ (F)	C_{actual} (F)	% Difference (%)

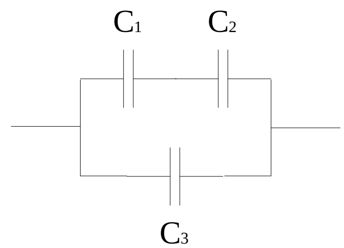
Capacitors in Combination:

14. Connect 3 capacitors as shown in Fig. 3. Create an expression in terms of C_1, C_2, and C_3 to calculate the equivalent capacitance of this combination. Use this equation to find $C_{theoretical}$.

Sample Calculation:

Figure 3

Mixed Parallel/Series Combination



15. Measure the actual capacitance and compare it to the theoretical value by finding the % difference.

Data Table 4

C_1 (F)	C_2 (F)	C_3 (F)	$C_{theoretical}$ (F)	C_{actual} (F)	% Difference (%)

Conclusions

16. Does the capacitance of the parallel plate capacitor behave as you expect when you vary the distance or the permittivity? Explain.

17. Do your results for connected capacitors support equations (4.3) and (4.4)? Explain.

Sources of Error

Experiment 5

Resistors in Circuits

Introduction

The purpose of this lab is twofold:

- To investigate the validity of Ohm's Law
- To study the effect of connecting resistors in series and parallel configurations.

Theory

Ohm's law states that the electric resistance of any device is defined as:

$$R = V/I \tag{5.1}$$

where V is the voltage drop across the device and I is the current passing through it.

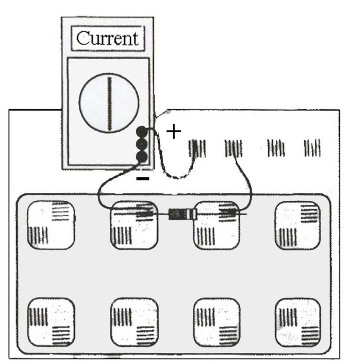


Figure 1

If both the voltage across and the current through a device change, while the ratio V/I remains the same, this device is said to obey Ohm's law.

Resistors in Series:

If we have two resistors connected in series (Figure 2), we can replace them by a single equivalent resistance R whose value is given by:

$$R = R_1 + R_2 \tag{5.2}$$

where R_1, R_2 are the values of the individual resistances.

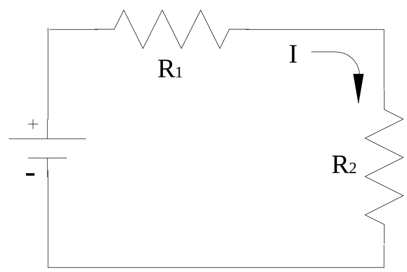


Figure 2: Resistors in Series

Resistors in Parallel:

Similarly, if we have two resistors connected in parallel (Figure 3), we can replace them by a single equivalent resistance R whose value is given by:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \tag{5.3}$$

where R_1, R_2 are the values of the individual resistances.

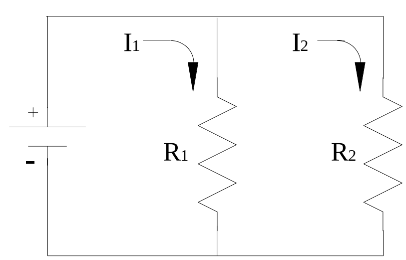
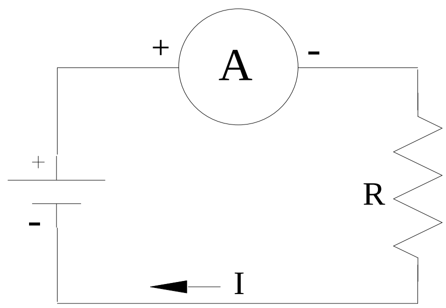


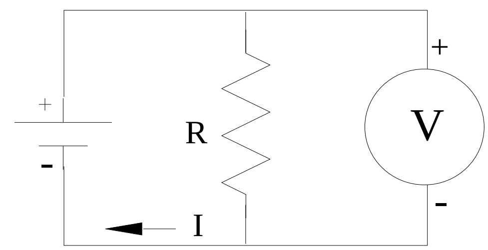
Figure 3: Resistors in Parallel

Apparatus

- Ammeter (micro-Amp. range)
  An ammeter is a device used to measure electric current flowing in a closed loop of a circuit. It has to be connected in series with the rest of the loop. It should have a negligible resistance as compared to the rest of the electric components that form the circuit. This is so in order to keep the current value unchanged when the ammeter is inserted to make a measurement. For this reason, **you should never connect an ammeter directly across the terminals of a battery.**



Measuring current
with an ammeter



Measuring voltage
with a voltmeter

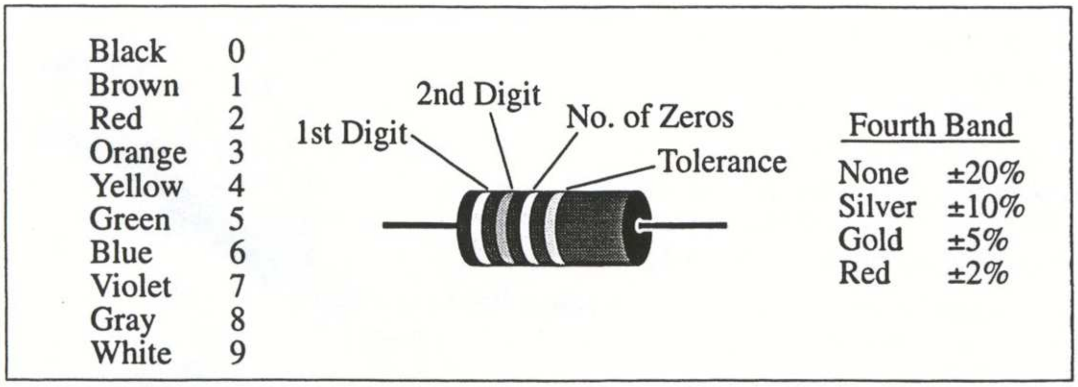
- Digital Multimeter
  A voltmeter is an instrument used to measure a potential difference across any given device. In order to do so, we have to connect it in parallel with the device as shown. It has a much higher internal resistance than any of the circuit elements. This is so in order not to alter the current value in the circuit as the voltmeter is connected.

  There are two types of meters, DC and AC meters. DC meters are distinguished by a short bar (–) under V (for voltmeter) or A (for ammeter). Similarly, the AC meters are marked by ($\sim$). It is very important to use DC meters in DC circuits and AC meters in AC circuits.

- Circuits Experiment Board, Wire Leads and D-cell Battery

- Assorted Resistors

Standard Colour Codes For Resistors



Purpose

In *your own words* explain the purpose of this experiment and what you are testing.

Procedure

1. Choose one of the resistors that you have been given. Using the legend above, find the coded resistance value and record that value in the first column of Table 1.

2. Construct the circuit shown in Figure 1 by pressing the leads of the resistor into two of the springs on the Circuit Board.

3. Connect the micro-ammeter in series with the resistor. Read the current that is flowing through the resistor. Record this value in the second column of Data Table 1.

4. Using the multimeter measure the voltage across the resistor. Record this value in the third column of Data Table 1.

5. Replace the resistor with another. Record its resistance value in Data Table 1 then measure and record the current and the voltage values as in steps 3. and 4. (As you have more than one resistor with the same value, keep all resistors in order because you will use them again in the next part of this experiment.)

Data Table 1

R_{code} (Ω)	I (A)	V (V)	R_{actual} (Ω)	$\frac{1}{R_{actual}}$ (Ω^{-1})	% Difference (%)

6. Repeat step 5. until you have completed the same measurements for all of the resistors you have been given.

7. Complete the fourth column of Data Table 1 by calculating the ratio of Voltage/Current.

Sample Calculation:

$$\mathbf{R_{actual}} = \frac{\mathbf{V}}{\mathbf{I}} = \qquad\qquad =$$

8. Compare each of the calculated resistance values with the corresponding colour coded value of each resistance by finding and recording the percent difference.

   Sample Calculation:

   $$\% \textbf{ difference} = \frac{|\mathbf{R_{code}} - \mathbf{R_{actual}}|}{\mathbf{R_{code}}} \textbf{ x } \mathbf{100\%} = \qquad\qquad\qquad\qquad =$$

9. Complete column five in Data Table 1 by calculating $1/R_{actual}$.

   Sample Calculation:

   $$\frac{\mathbf{1}}{\mathbf{R_{actual}}} = \qquad\qquad\qquad\qquad =$$

10. Construct a graph of current (Y-axis) versus [1/Resistance] (X-axis) and calculate the slope from the resulting line.

    Sample Calculation: To find the slope, take two points on the line, (x_1,y_1) and (x_2,y_2), and use the following formula:

    $$\mathbf{m} = \frac{\mathbf{y_2} - \mathbf{y_1}}{\mathbf{x_2} - \mathbf{x_1}} = \frac{\textbf{rise}}{\textbf{run}} = \qquad\qquad\qquad\qquad =$$

11. Show how the variables in (5.1) and the straight line equation are related.

    Sample Comparison:

12. Find the percent difference between the slope of your line and the average voltage reading across the resistors.

    Sample Calculations: To find the average voltage, $\overline{V}$, sum all the voltage values and divide by the number of values, N.

    $$\mathbf{\overline{V} = \frac{1}{N}\sum_{i=1}^{N} V_i = \frac{(V_1 + V_2 + V_3 + ... + V_N)}{N}}$$

    $=$

    $$\mathbf{\%\ difference = \frac{|m - \overline{V}|}{\overline{V}}\ x\ 100\%} = \qquad =$$

Resistors in Series:

13. Choose two resistors from the set whose resistances are approximately equal to 5k and 10k Ohms.

14. Measure the resistors' values with the LCR meter and record them in Data Table 2.

15. Calculate the theoretical resistance of these resistors in series using equation (5.2)

    Sample Calculation:

    $$\mathbf{R_{theoretical} = R_1 + R_2} = \qquad + \qquad =$$

16. Connect the two resistors in series as shown in Figure 2. Measure and record the total voltage drop across them as if they were one resistor. Also measure and record the current flowing through the circuit.

17. To find the resistance of this combination, divide the voltage drop by the current flowing in the circuit. Enter this value in Data Table 2. Compare this value to the theoretical value by finding the percent difference.

Data Table 2

R_1 (Ω)	R_2 (Ω)	$R_{theoretical}$ (Ω)	I (A)	V (V)	R_{actual} (Ω)	% Difference (%)

18. Repeat steps 14. through 17. for two resistors which have an approximate value of 10k Ohms.

Resistors in Parallel:

19. Choose two resistors which both have values of approximately 10k Ohms from the set of resistors.

20. Record their actual values as measured by the LCR metre in Data Table 3.

21. Calculate the theoretical resistance of these resistors in parallel using equation (5.2) which can be rearranged to:

    Sample Calculation:

    $$\mathbf{R_{total}} = \frac{\mathbf{R_1 R_2}}{(\mathbf{R_1} + \mathbf{R_2})} = \qquad\qquad =$$

22. Connect these two resistors in parallel as shown in Figure 3. Fiind the actual resistance of the combination as one resistor following the same steps as you did in the previous parts of this experiment.

23. Compare your actual value of resistance with the theoretical value by finding the percent difference.

Data Table 3

R_1 (Ω)	R_2 (Ω)	$R_{theoretical}$ (Ω)	I (A)	V (V)	R_{actual} (Ω)	% Difference (%)

24. Repeat steps 20. through 23. for resistors with the approximate values of 10k Ohms and 20k Ohms.

Resistors in Combination:

25. Create an expression to calculate the theoretical resistance of the combination given in Figure 4. Using this equation find $R_{theoretical}$ where R_1=20k Ohms and R_2=R_3=10k Ohms.

Sample Calculation:

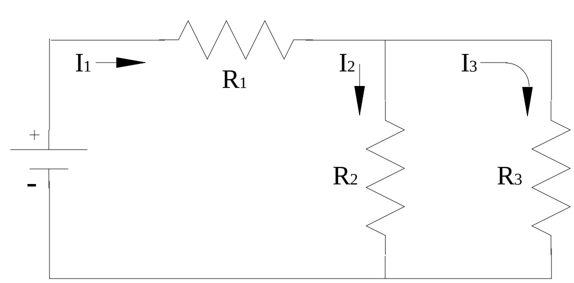


Figure 4: Resistors in Combination

26. Now set up the combination circuit as shown in Figure 4. Measure and record the current and voltage of the system. Calculate V/I and compare it to the theoretical value by finding the percent difference.

Data Table 4

R_1 Value (Ω)	R_2 Value (Ω)	R_3 Value (Ω)	$R_{theoretical}$ (Ω)	I (A)	V (V)	R_{actual} (Ω)	% Difference (%)

Conclusions

27. Does your graph shows that Ohm's Law holds true? Explain.

28. Do equations (5.2) and (5.3) hold true according to your measurements? Explain.

Sources of Error

Appendix A

Dimensional Analysis

The method of dimensional analysis simply consists of making sure that the dimensions (units) on one side of an equation are the same as on the other side. For example, the force F required to keep an object moving in a circle is known to depend on the mass, m, of the object, its speed, v, and its radius, r, so we expect a relation of the form

$$F = cm^{\alpha}v^{\beta}r^{\gamma} \tag{A.1}$$

where c is a numerical constant having no dimensions, and the exponents α, β, and γ will be found using dimensional analysis.

Writing the units for the quantities in equation (A.1), we have:

$$(\mathrm{kg}) \text{ x } (\mathrm{m}) \text{ x } (\mathrm{s})^{-2} = (\mathrm{kg})^{\alpha} \text{ x } (\mathrm{m/s})^{\beta} \text{ x } (\mathrm{m})^{\gamma}$$

Note: Force is measured in Newtons and a Newton is equal to $((\mathrm{kg})(\mathrm{m}))/\mathrm{s}^2$

Making sure that (mass) is consistent on both sides of the equation tells us that $\alpha = 1$. In order that (time) has the power -2 on both sides we must have $\beta = +2$ since the unit for time on the right is already in the denominator. Finally, to get (length) to come out to the power of one we require that:

$$1 = \beta + \gamma$$

since β and γ must combine to give 1:

$$1 = 2 + \gamma,$$

from which we see that $\gamma = -1$, and equation (A.1) becomes

$$F = cmv^2r^{-1} = c\frac{mv^2}{r} \tag{A.2}$$

Dimensional analysis does not tell us the value of c, but the description of circular motion shows that $c = 1$.