Assiut University

Physics Department

LABORATORY MANUAL

Heat and Elements of Thermodynamics

First Level

Student Name	:...
Faculty	:...
Academic Number	:...
Level	:...
Year	:...
Term	:...

List of Experiments

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General Introduction

Dear Student

Welcome to the **Fundamental Physics Lab.** wish you a valuable and interesting study and a success in the course. Enjoy learning Physics with us just as you enjoy your life. The following are the Lab regulations that you have to follow:

Before attending your laboratory session, you should always read the experiment you are going to do. Be aware that the pre-Lab. reading enables you to understand well basics of the experiment and while attending the class you can do the experiment correctly. Information given in the first few Labs. will be much more detailed than that of the next subsequent Labs; many of the laboratory techniques you learn will be used repeatedly. The only acceptable way to demonstrate your experimental results in graphical form is that by "Excel" computer program. In the first Lab. session a discussion about the Excel as well as how to use the most common tools of your experiments, the Vernier Caliber, Micrometer and Spherometeretc, will be given. As you perform the Labs, your laboratory skills will be improved and you should be less dependent on exact instruction from the Lab. Manual.

Student attending the Lab. late by more than 20 minutes will **Loose** the corresponding two marks. Student late by more than 30 minutes can not attend the Lab. and he/she will be considered **Absent**. Absence of 25 % of the Lab. sessions may prevent attending the final exam. In such a case your final grade of the Lab. work is zero.

Be aware that **Cheating** during Exams and submitting experimental results which is not yours will be strongly punished according to the university regulations.

Be sure to organize your work. This will save you a great deal of time and frustration. The 3 hours Lab. time can be subdivided as:

25-30 min	General discussion
80-90 min	Conducting the experiment
15-20 min	Drawing graph by Excel
15-20 min	Answer questions
15-20 min	Correction and evaluation

Before leaving the Lab. you have to correct and evaluate your work by the assistant. Be sure that your grade, in addition to the assistant name, signature and date of attending the Lab., have been recorded in your manual and in the files of the Lab. Six marks out of 10 marks for each experiment (A sum of 100 marks for the 10 experiments of the Lab.) are given for the experimental work including **Performance**, **Lab. attitude** and **Accuracy**. Two marks are given for the **attendance**. Other two marks are given if you **correctly answer questions** that can be found at the end of each experiment. The total grad will be considered during the final course evaluation. You have to ask about the experiment you have to do in the next Lab. session in order to follow the exact way to do the experiment correctly.

A Mid-Term Exam., will be organized after the first five weeks of the semester. Time and date of Exam will be announced in the proper time. In addition, student should be ready for Quick Quizzes during any sections.

Using Lab. equipment in the correct way is your responsibility. You have to think twice before connecting power to the set up. Damage of any of the experiment components should be substituted by the student without delay.

Food or drinks is not allowed. Please keep the experiment board and the Lab. table clean and in order.

By performing this Lab., you will learn:

Fine measurements using different tools,

How to confirm some important laws and concepts of fundamental physics,

Determine the relationship between the pressure, temperature and volume of a confined gas,

Observe the transformation of work into heat; to examine the relationship between work and energy,

Learn the experimental method of calorimetry and determine the specific heat of some elements such as aluminum, and brass,

Determine experimentally the thermal expansion coefficients for different metals.

Finally: We are constantly trying to improve the quality and instructional utility of your Labs. If you can think of any modification to the equipment or clarification to the Lab. manual please let us know. Your opinion is extremely important to us so, please do not hesitate to present your suggestions to your instructor or assistant.

Study of Basic Physics Concepts in this Lab. will be much enjoyed, Good Luck

Excel 2003
A Self-Dependent Study Guide

The objectives of this guide are to help user to understand

1- How to work with Excel spreadsheets.
2- How to enter, modify and edit data.
3- How to perform a scientific graph using the Excel Chart wizard.
4- How to fit the data and obtain the best function that can express
   experimental data.

INTRODUCTION

Excel is an electronic spreadsheet program that is part of the Microsoft
Office Suit. A spreadsheet is an arrangement of data in tabular format that
makes it easier to view and modify data.

Excel is an excellent tool to organize, calculate, and analyze data. Some of
the advantages of using Excel are:

1- Complex calculations can be done easily, accurately, and faster.
2- The formulas are recalculated fast if the values of any of the variables
   change.
3- Searching for data is easy as data is arranged in the form of database
   table.
4- Charts are generated instantly with minimum effort and updated
   automatically as per the changes in the data.

Getting Started

To start the Microsoft Excel click Start button, when the menu appears
click All Programs, Microsoft Office and then click Microsoft Office Excel
2003. The screen layout of the Excel should be like that is shown in **Fig. 1**.

Spreadsheet Basics

Each Excel file is a workbook that can hold many worksheets. The worksheet is a grid of columns, designated by letters, and rows, designated by numbers. The letters and numbers of the columns and rows called labels that are displayed in gray buttons across the top and left side of the worksheet. The intersection of a column and a row is called a cell. Each cell on the spreadsheet has a cell address that is the column letter and the row number. Cells can contain text, numbers, or mathematical formulas.
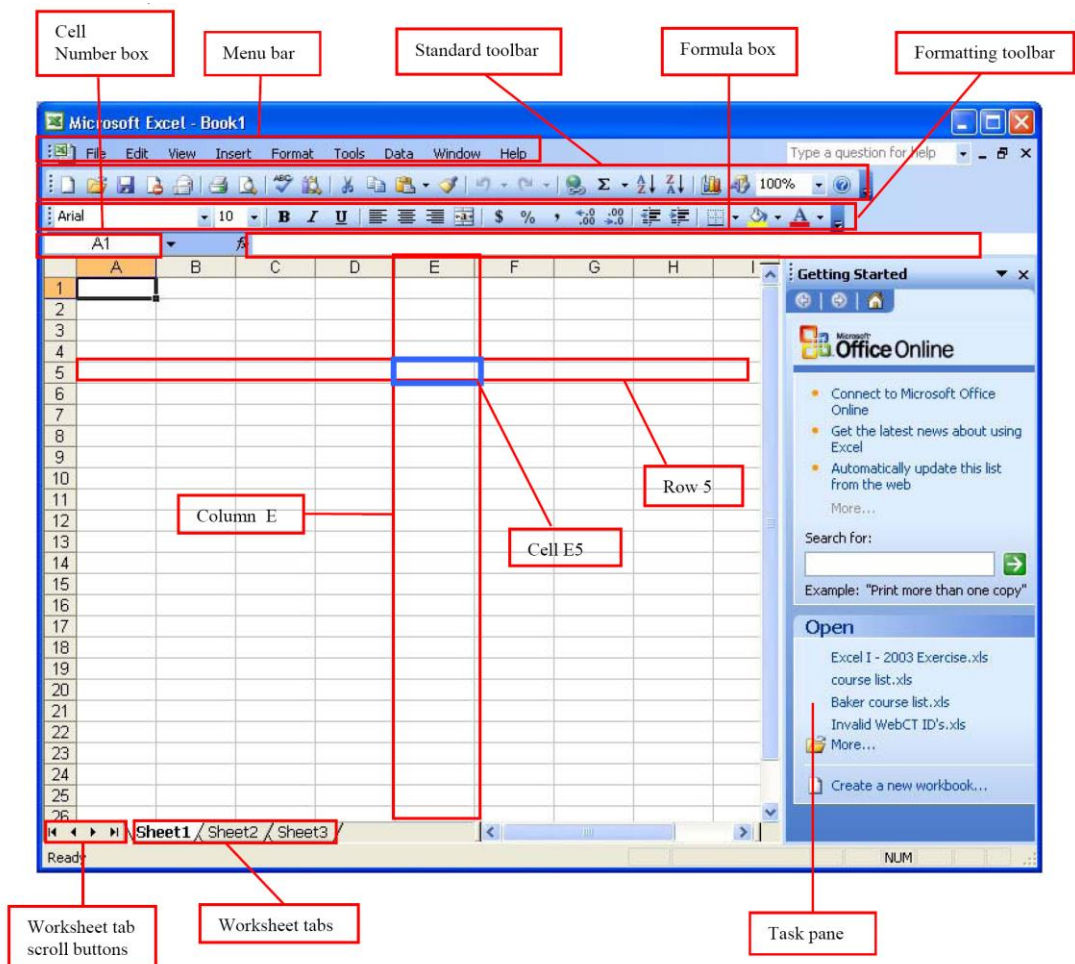

Figure 1

Title Bar

The Title bar contains the name of the program Microsoft Excel, and the default name of the file Book 1 that would change as soon as you save your file, **Fig. 2**.

Menu bar

The Menu bar contains menus that include all the commands you need to use to work your way through Excel such as File, Edit, View, Insert, Format, Tools, Data, Window, and Help, **Fig. 3**.

Standard Toolbar

This toolbar is located just below the Menu bar at the top of the screen and allows you to quickly access basic Excel commands, **Fig. 3**.
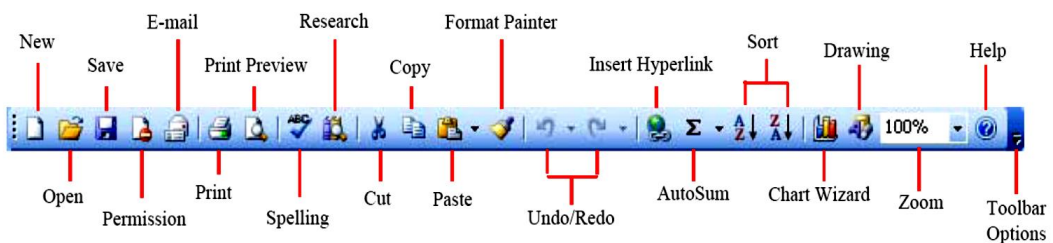

Figure 2

Cell Editing or Data Entering

Simply click in the cell you want to edit it and type the numbers or stings you want to add in the cell and click enter.

Functions & Formulas Fundamentals

The following definitions are necessary to understand the basics of creating Excel formulas and functions.

Formula Definition

A formula allows you to calculate and analyze data in your worksheet. Formulas perform calculations such as addition or multiplication; formulas can also combine values.

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Formula Syntax

Formula syntax is the structure or order of the formula elements. All formulas begin with an equal sign (=) in Excel followed by operands (the data to be calculated) and the operators. Operands can be values that don't change (constants), a range reference, a label, a name, or a worksheet function.

Formula Bar

The Formula bar is an area located at the top of the worksheet window that is used to enter or edit values or formulas in cells or charts. The Formula bar displays the constant value or formula in the active cell.
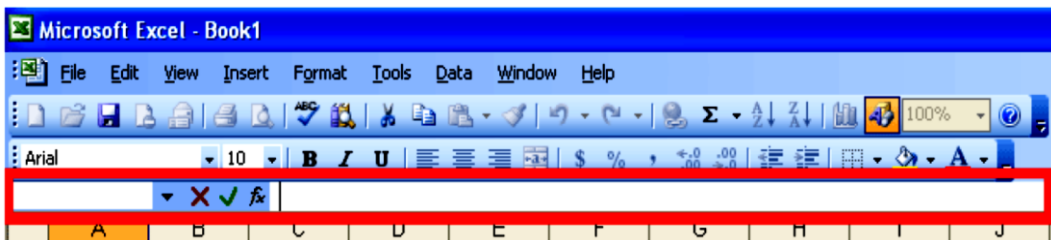

Figure 3

Functions

Function Definition
A function in Excel is a built-in formula that performs a mathematical operation or returns information specified by the formula. As with every formula created in Excel, each function starts with an equal (=) sign.

Function Syntax
The syntax of a function begins with the function name, followed by an opening parenthesis, the arguments for the function separated by commas, and a closing parenthesis. If the function starts a formula, an equal sign (=) displays before the function name. Example: =SUM (D2:F8) the function name is **Sum** and the argument for the function is the range "D2:F8".

Function Wizard
The function wizard is designed to provide the necessary arguments and descriptions for the various Excel functions.
1. Select the cell in which you want the results of the function to display.

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2. Click the Insert Function button on the formula toolbar or select Function from the insert menu.

3. From the Insert Function dialog box (**Fig. 4**), browse through the functions by selecting a function category from the drop-down menu, and select the function from the list below. As each function name is highlighted a description and example is provided below the two boxes.
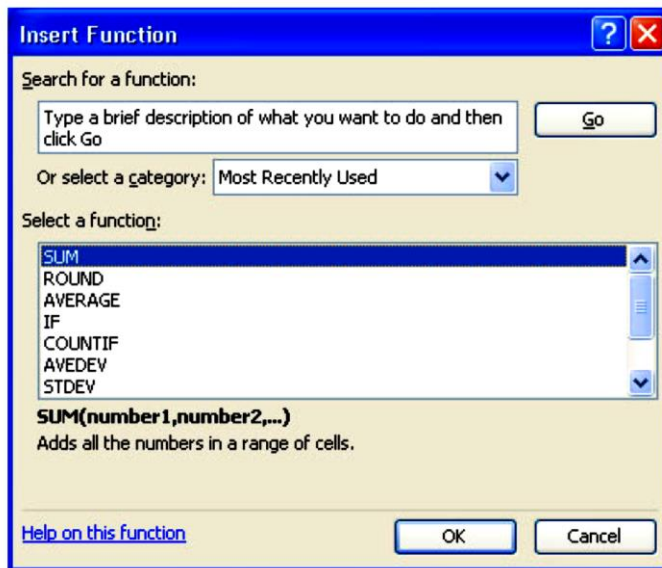
4. Click OK to select a function

Figure 4

5- The next window (**Fig. 5**) allows you to choose the cells that contain the arguments of the function. In this example, cell B2 and C2 are selected to compute their sum. The values of the cells B2, and C2 are, respectively 2 and 3. Excel identifies the range of the cells in the function to (B2:C2). In the lower part of the **F**unction **A**rgument dialogue box you can see the formula result.

6. Click the OK button.

Errors in Formulas

When a formula is prevented to run normally, Excel will notify you with an error message. Each error message helps users identify the problem they are facing. **Table 1** lists common Excel errors that you might face.
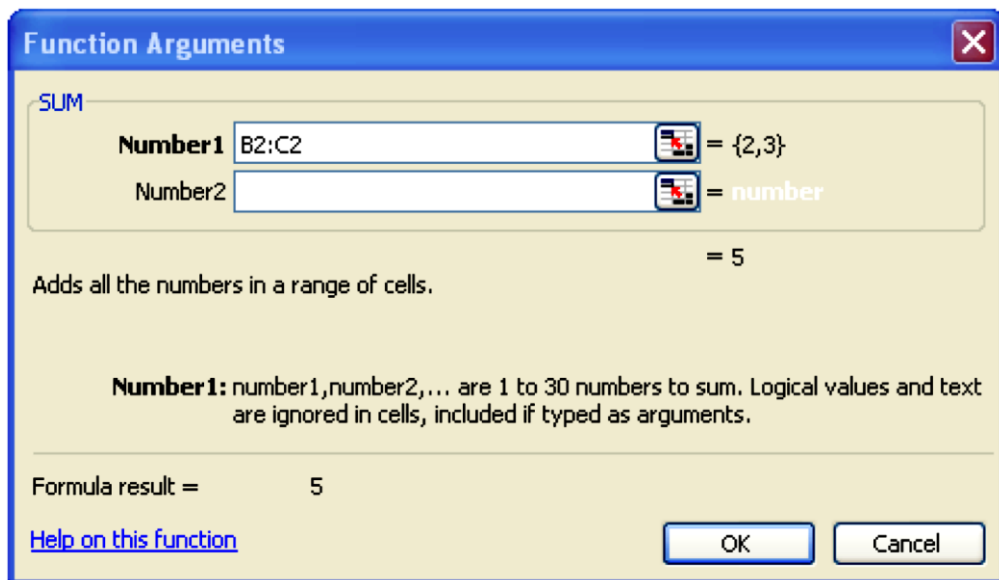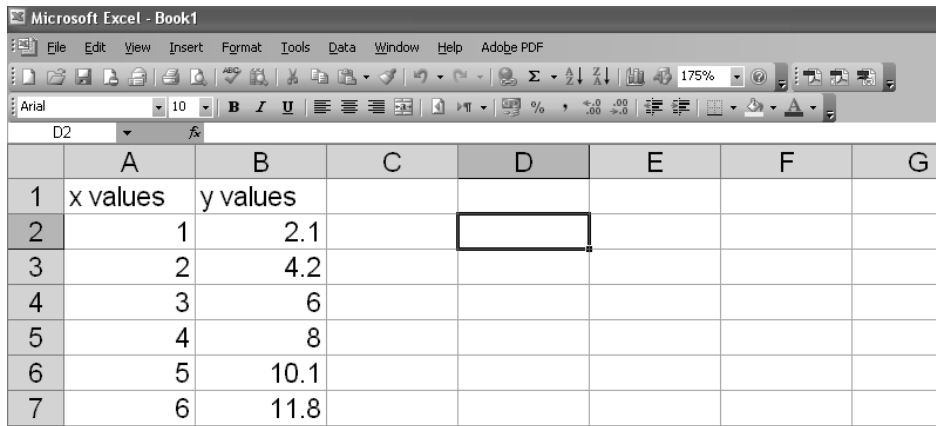
Figure 5

Table 1

Error	Meaning	How to fix
####	The column is too narrow to display the result of calculation	Expand the results cell
#VALUE	Wrong type of argument or reference	Check operands and arguments
#DIV/0!	Data is attempting to divide by zero	Change the value or the cell reference so that the formula doesn't divide by zero
#NAME?	Formula is referencing an invalid name	Be sure the name still exists or correct the misspelling
#REF!	Excel can't locate the referenced cells (for example, the cells were deleted)	Click Undo to restore references and then change formula references
#NULL	Reference to intersection of two areas that do not intersect	Check for typing and reference errors

Charts

A *chart* allows you to visually display your data. Charts help users compare data and identify trends. Excel offers different chart types. This section explains how you can create simple charts from the data selection you have on a worksheet.

Before you can create your chart you must enter data into a worksheet, (**Fig. 6**) then do the following:

Figure 6

1. Insert > chart, the chart wizard appears or click the chart wizard button on the standard toolbar, the chart wizard appears (**Fig. 7**).

    The chart wizard brings you through the process of creating a chart by displaying the chart wizard consisting of series of dialog boxes.

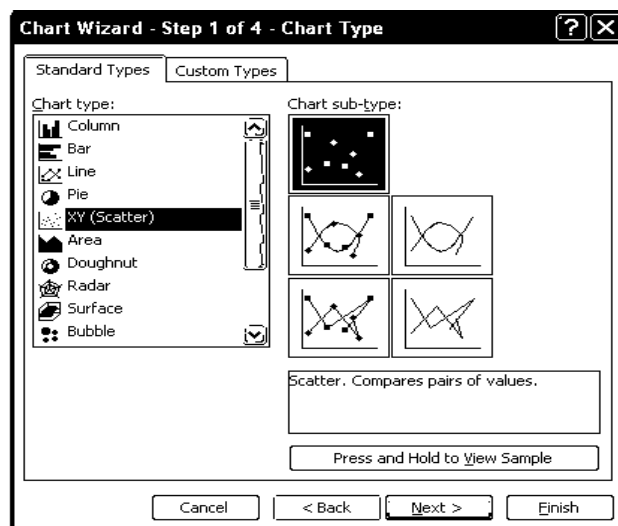2- Select the chart type [always XY (Scatter)].

Figure 7

3- After clicking **Next**, the chart wizard wants to know which data are desired to be plotted. Chart Source Data dialog box allows you to select the data set that will be plotted via the Series (**Fig. 8**) and Data Sources dialog box (**Fig. 9**)
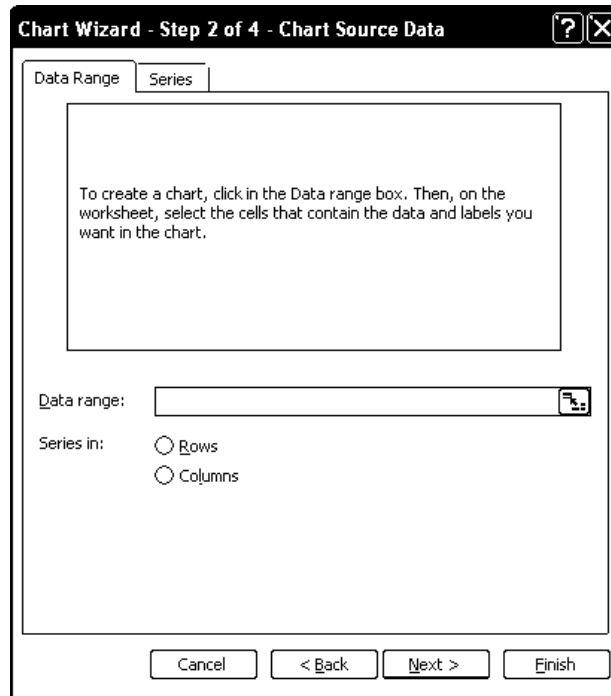
Figure 8

4- Select the x-axis and y-axis data ranges (**Fig. 9**).
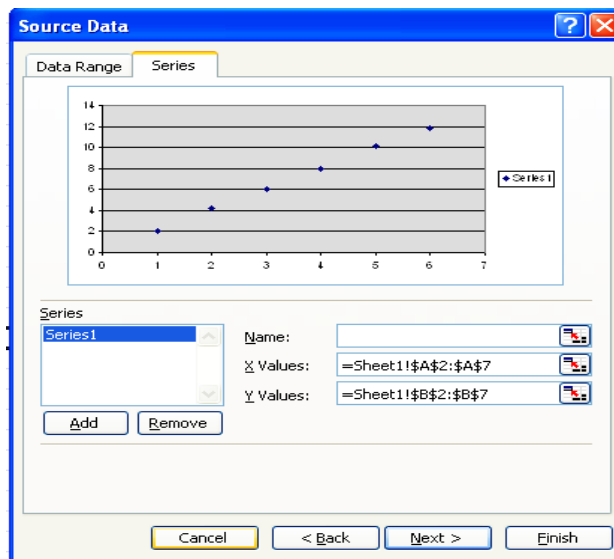
Figure 9

5- In the "Chart Options" dialog box: Enter the title of the chart and titles for the X and Y-axes. Other options for the axes, grid lines, legend, data labels, and data table can be changed by clicking on the tabs. Click Next to move to the next set of options. (**Fig. 10**).
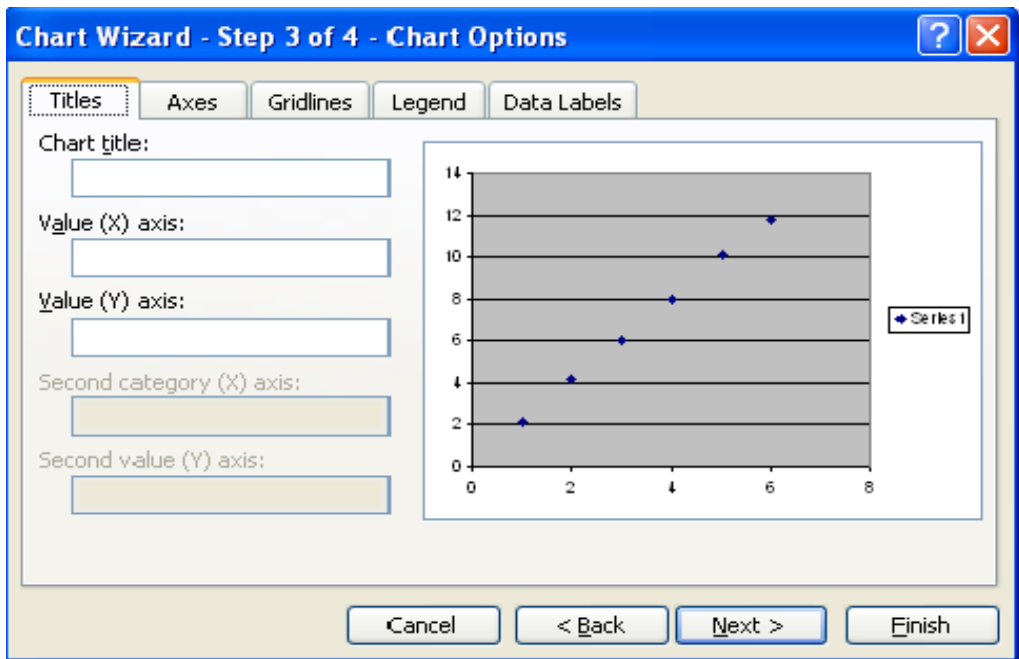
Figure 10

6. The "Chart Location" dialog box: Click "As new sheet" if the chart should be placed on a new worksheet or select "As object in" if the chart should be embedded in an existing sheet and select the worksheet from the dropdown menu. (**Fig. 11**)

7. Click Finish to create the chart.
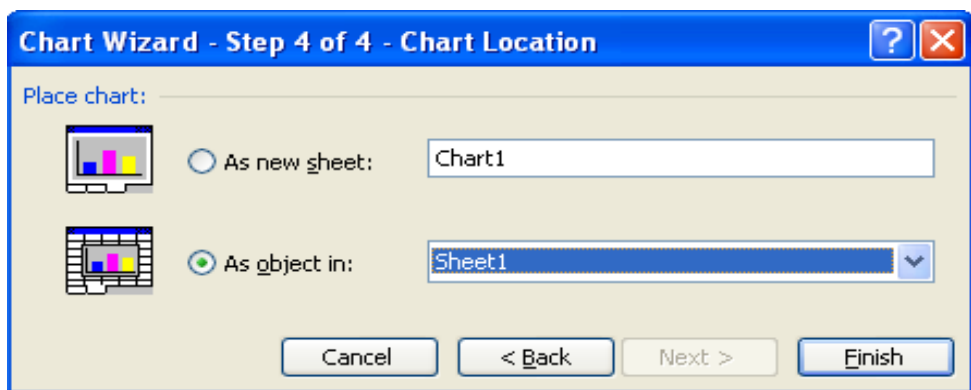
Figure 11

Now, the graph is obtained as shown in (**Fig. 12**).
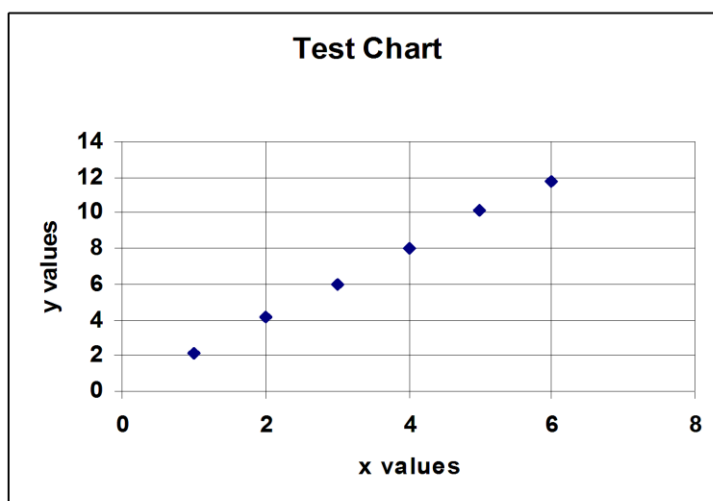
Figure 12

Double click on x or y axis opens the "Format Axis" dialog box (**Fig. 13**). This box allows you to control the scales, fonts and patterns of the axis.

Figure 13

Curve Fitting

In mathematical equations you will encounter in this course, there will be a dependent and independent variables. Identifying the dependent and independent variables in a mathematical equation facilitates solving the equation. The *independent variable* is that one whose value determines the value of the *dependent variables*. As principle, the independent variable is plotted on the x-axis, and the dependent variable is plotted on the y-axis. Other variables may also be presented in an equation, however these variables can be fixed momentarily in a given case. These constants can be identified by curve fitting. The example below illustrates this point.

**Fig. 12** shows points representing data having a trend of straight line. The equation that describes these points is:

$$y = ax + b$$

When the dependent and independent variables are plotted as shown in **Fig.12**; a and b values are obtained by adding a best fit line through the data points. a is the slope of the straight line, and b is the y-intercept. Adding a best-fit line in Excel can be done by using the "Add Trend Line" dialog box.

To perform "Add Trend Line", follow the following steps:

1- Activate the chart.
2- Choose Add Trend line from Chart menu or by right click on the points.
3- Select Linear Trend\Regression type. (**Fig. 14**)
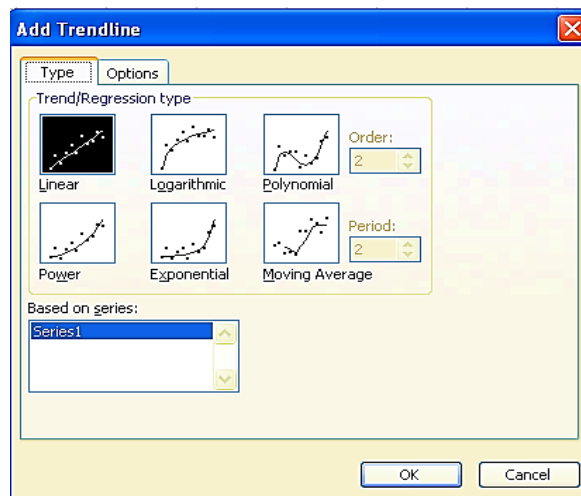
Figure 14

4- Click on the "Options tab" (**Fig. 15**). Put a check on "Display equation on chart" and "Display R-squared value on chart" boxes. Click OK when done.
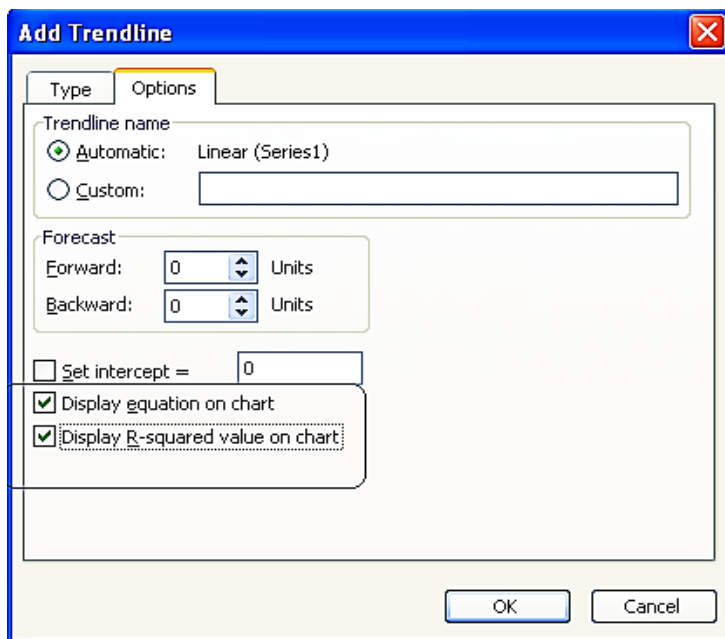
Figure 15
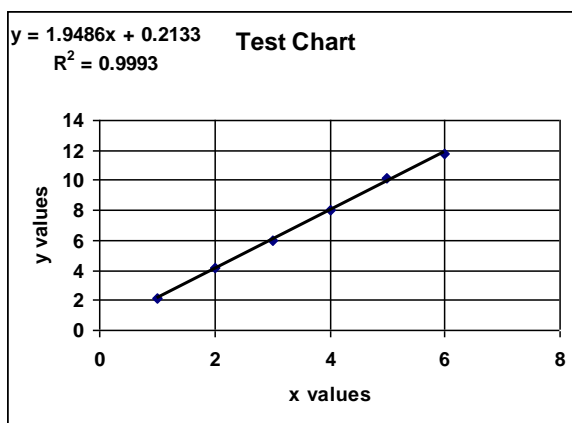
Figure 16

From the graph shown in **Fig. 16** one can obtain that:

The slope of the line is: $a = 1.9486$

The intercept of the line with y-axis is: $b = 0.2133$

The intercept of the line with x-axis is: $-\dfrac{b}{a} = -0.10946$

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The R-squared (R≡ correlation coefficient) value is: 0.9993. This value determines how the straight line represents this set of data. The acceptable value of R^2 should be more than 0.8.

How to perform Physics experiment

It is not easy to formulate precise rules as to how an experiment should be performed, because the preliminary procedure varies with the nature of the experiment and with the laboratory arrangement. The following points should be considered.

* In general, time spent in the laboratory is limited, so it is important that the best possible use is made of it. For this reason you should, whenever possible, study the subject of your experiment before your laboratory session. Then set out beforehand in your notebook, the heading diagram and tables for observation.

* When you reach the laboratory you should first collect together all the equipment needed to perform the experiment. Call your Lab. technician or teaching assistant. Then decide on the most efficient order of work- for example, if you have to use steam generator you start heating the water and carry on with your other preparations while water is heated. This is simply a matter of "commonsense" but it is astonishing how much time is lost in laboratory work through lack of this kind of planning. In all electrical experiments a circuit diagram should be put on paper before wiring up is attempted.

* In setting up your equipment arrange it so that it can easily be handled and make sure that all scales are placed so that you can read them conveniently. Leave yourself a room to write.

* When you have collected all your observations proceed with your calculations and do not dismantle your equipment until you are reasonably sure that you will need to check any measurement.

Graphs

Graphs are used in Science to present information derived from experiment in a way easily appreciated by the eye. Sometimes they are intended to convert merely the qualitative relation between two quantities and sometimes they are used to provide quantitative information of various kinds. We will mainly deal in this course with quantitative graphs.

Quantitative Graphs

Graphs which have been accurately drawn from data derived from experimental observations and which are clearly marked with numerical scales can supply information in four principle ways:

1- They often disclose information which it is more difficult to discover from the study of the table of observations itself. For example, a plot of volume V against temperature T for a fixed mass of gas at constant pressure indicates at once that, the volume would vanish at about -273°C. It would be more difficult to deduce this value from table of results.

2- Important date can be deduced from the discontinuities, maxima and minima, or gradients: for example, the melting-point of a substance could be deduced from the discontinuity of an accurate graph between temperature and time while the material was cooling down from a temperature higher than the melting point.

3- Additional numerical values can be obtained by reading between the observed points (interpolation) or "producing" the graph beyond the region of observation (extrapolation). These processes, particularly extrapolation need to be used with discretion. For example in the case cited above in (1), additional observations show that the statement "the volume of the gas vanishes" is incorrect since, as a matter of fact the gas becomes liquid before the predicted temperature (-273°C) is reached and the relation between volume and temperature is then no longer represented by a straight line. The extrapolation of a curved graph is rarely attempted since it is extremely difficult to judge how the curve will continue.

4- The relation between two physical quantities may often be deduced from a suitable graph and values of unknown physical constants may be determined. We shall consider later how this is done.

How to draw graphs

In many experiments it is desirable to plot the graph of the observations while the experiment is in progress. Such experiments are usually those in which the approximate range of values of the quantities concerned can be foreseen. In many other experiments it pays to plot thus, though; a fair copy may be needed later. The advantage of this procedure is that erroneous measurements may often be discovered and re-measured at once.

We shall assume for the moment that the quantities to be plotted have been tabulated and that they are now to be transformed into a graph.

A decision has first to be made as to which quantity should be plotted horizontally (independent) and which vertically (dependent). Sometimes this is consciously controlled steps (e.g. Length of a pendulum) while the other is measured subsequently (e.g. period of the pendulum). A working rule is to plot later vertically and former horizontally, though there are occasional exceptions.

Range and scale

Next decide whether all your observations are much more valuable for a particular purpose than others, and it may be profitable to omit some of them. If the omission enables the scale of the graph to be enlarged so that the more important features are emphasized then you have to do so.

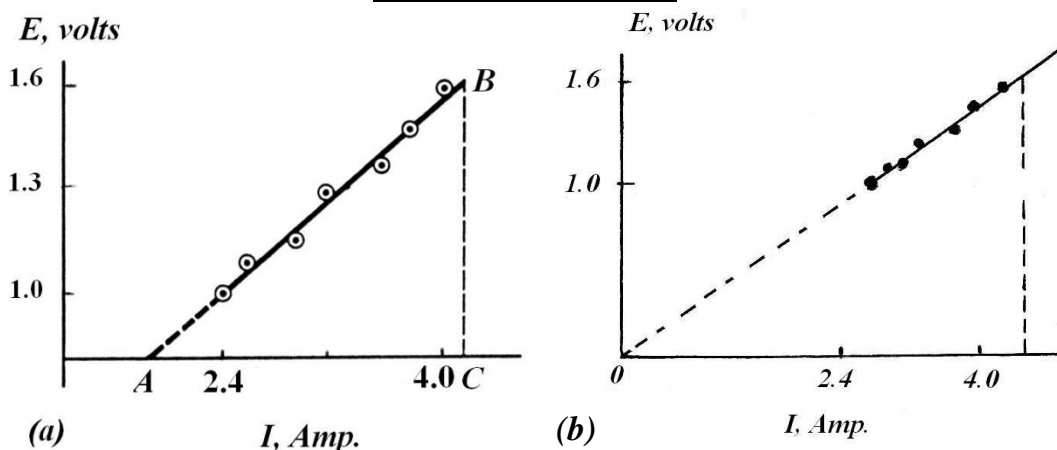| E, volts	I, Amp.
1.0	2.40
1.1	2.68
1.2	2.82
1.3	3.10
1.4	3.44
1.5	3.78
1.6	4.00

Figure 1 *(a & b)* represent two different scales for the same values of I and E.

Your Choice will depend on whether your established relationship (or your line) passes through the origin or not. If it does, your right choice should be **Fig.1 (b)**.

After selecting the range of values to be plotted choose your scale so that your finished graph will occupy the entire sheet of paper, as far as this can be arranged without employing scale difficult to read or plot. Here again we must think carefully of our aim. Thus **Fig. 1** *(a & b)* represent the same observations of potential difference applied to a resistor and resulting current plotted on two different scales. If we wish to deduce a value for the resistance we should prefer **Fig. 1(a)**, as it will enable us to obtain higher accuracy. However, if we wished for some reason to check whether the straight line passed through the origin we should choose **Fig. 1(b)**. Decision is thus needed in deciding what scale to employ. When the scale has been chosen the axis should be marked out and graduated-in pencil at first.

Plotting

Six-eight points are desirable for plotting a straight line; more if possible should be plotted for a curve. When all the points have been plotted examine them and decide whether they appear to lie on a straight line, i.e. whether their displacement from a straight line is small enough to be reasonably attributable to experimental error. It is not essential that the curve should pass through every point and it must not be artificially lined to make it do so. The line should give the impression that the points lie (about) equally distributed on each side of it (if positive and negative errors are equally likely). Do not be over impressed by the fact that perhaps three of your eight points are exactly collinear the line on which they may not lie be the true one. The Excel program much simplifies this process.

Errors

The term error when used in physics has a meaning different from its everyday life meaning. Ordinarily it means a mistake or something wrong. Mistakes of course occur in physics but they are not called errors. An error in an observational reading is a way of indicating the range of uncertainty of the reading. If the length of a rod is somewhere between 9.9 cm and 10.1 cm its length is given as 10.0 ± 0.1 cm. The 10.0 cm is the reading and 0.1 cm is the error. The error is often expressed as a fraction or as a percentage, i.e. as 0.1 cm in 10 cm or as 1%. The smaller the fractional error, the more accurate is the value.

TYPES OF ERROR

(i) Observational or personal error

When you pick up a thermometer the first two things you have to know about it are its range and its scale. The scales of most ordinary thermometers are divided into degrees, so you should estimate the temperature shown by the thermometer at least within ½ degree and would write down the temperature of some water, say, as 15.0 ± 0.5 °C. We shall call this type of error the reading error, and you should develop early the habit of writing down the appropriate error with every reading.

In this case there is no point in working out the fractional error. In most cases it is a difference of temperature that is required, and it is the fractional error in the difference of temperature that is important. For example if the temperature of the water rose to 25°C we should have

Final temperature $= 25.0 \pm (0.5)$ °C
Initial temperature $= 15.0 \pm (0.5)$ °C
Rise in temperature $= 10.0 \pm (1.0)$ °C

From our figures the greatest rise could have been from 14.5°C to 25.5°C that is 11°C so that the error is 1°C. In other words we have added the reading errors and have ignored the + and − signs. The fractional error 1 part in 10 or 10% is, therefore, a very large error. To reduce it we should have to use a more accurate thermometer (more accurate in sense that the reading error is smaller), one for instance, that could be read one fifth of a degree. The temperature could then be estimated to one tenth of a degree, and we should have the following:

Final temperature $= 25.0 \pm 0.1$ °C
Initial temperature $= 15.0 \pm 0.1$ °C
Rise in temperature $= 10.0 \pm 0.2$ °C

The fractional error is now 1 part in 50 or 2%.

(ii) Adjustment or Setting errors

The second type of error is, in many ways, similar to the first but it depends not upon the observation of one particular instrument but on the whole set up of the experiment apparatus.

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To find the EMF of a cell using a simple potentiometer, one taps a knife-edge at different points on a meter (or longer) wire until, on doing so the galvanometer pointer does not deflect. If the wire is stretched along a meter ruler the reading error is 0.1 cm. But it is usually possible to move the knife-edge several millimeters either sides before deflection of the galvanometer pointer is being noticeable. Suppose one can move it 0.5 cm. Then 0.5 is the setting error in length of the wire. Adding the reading and setting errors would give a combined errors of 0.6 cm.

Usually the student should decide which error is the larger and state that error alone, and not the combination of the two errors unless they happen to be equal.

(iii) Instrumental errors

In the laboratory we usually assume that the instruments we use give a true reading. Now the question is: does the meter ruler really have one meter long? Does the ammeter indicate 1.0 when 1.0 amp flows through? And does a clock indicate exactly 1 hour time interval after its longer pointer completed one rotation cycle. In some experiments, it is necessary to check the instruments used and for this purpose most laboratories have standard instruments that have been compared with the standard instruments at the National Institute of Standards. The student should always be aware that the instruments he/she uses might have errors but it is often not necessary to find them. Thermometers and ammeters are the two instruments whose readings most frequently need checking. It is, however, often necessary to check the zero reading of an instrument. The most quoted example is the zero reading of a micrometer gauge (i.e. the reading when the jaws are closed) but the zero reading of ammeters, voltmeters, thermometers should also be taken. When quoting the zero error of such instruments it is best to state it as a reading so that the significance of the '+' or '-' sign is immediately obvious.

How to express errors: Percentage Errors

It is frequently useful to express an estimated error as a percentage of the mean value of an observed quantity, thereby to obtain some idea of the relative magnitude of the error in the final evaluation. Thus, as an object for which three consecutive readings of its length were recorded as 2.02, 2.03 and 2.01 cm, may be stated as having a length of 2.02 cm subject to an error swing of 0.01 cm or $0.01/2.02 = 1/202 = 0.5\%$ approximately.

Again, in measuring a temperature rise using the usual simple laboratory mercury-in glass thermometer (which the student should be capable of reading 1/10 °C accuracy), it should be realized that there will be as error of 0.1 °C at either end of the temperature interval recorded. Thus a 5.0 °C rise will have as error of ± 0.2 °C, or a percentage error of 4%. A temperature rise of 20.0 °C will gave the same (± 0.2 °C) actual error, but a percentage error of only 1% - hence the need for experimental arrangements (subject, of course, to the considerations of other aspects of the procedure) to yield as high a temperature range as possible .

It should be noted that if a measured quantity is to be used with certain exponent to calculate some physical quantity the error will be greater than the error in the original measurement. As example, upon determining the cross-sectional area of a wire for which the diameter d has been measured as 1.02 mm with an error of 0.01 mm (i.e. 1 % approx.), the value of the cross-sectional area (A) will be:

$$\pi\ (d^2/4) = \pi/4\ (1.02 \pm 0.01)^2$$

$$= \pi/4\ [(1.02)^2 \pm 2 \times 1.02 \times 0.01] \quad \text{approximately}$$

Hence the percentage error in A is:

$$[2 \times 1.02 \times 0.01/(1.02)^2] = (0.02/1.02) = 2\% \quad \text{approximately}$$

Hence, it is seen that a percentage error in measuring a given quantity is doubled when that quantity appears to the power 2 in the final expression. Generally, if the quantity appears to the nth power the error contribution will be n times that of the directly measured quantity-as can be seen below:

$$Percentage\ Error\ = \frac{\left|\text{Re}\ ference - Measured\right|}{\text{Re}\ ference} \times 100\ \%$$

Heat and Elements of Thermodynamics

Experiment (H1)

Boyle's Law

Objectives

The objectives of this experiment are to:

  i. Study the relationship between the volume (V) and the pressure (P) of a given gas (Air) at constant temperature.
  ii. Determine the number of moles (n) of the given gas.
  iii. Determine the temperature (T) of the given gas.

Theory

The pressure (P), volume (V) and temperature (T) of a gas are related to each other by the general gas equation which states that:

$\frac{PV}{T} = constant$

$i.e \; \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_1} = \frac{P_3V_3}{T_1} = \cdots = \frac{P_nV_n}{T_n}$

Where **P**, **V** and **T** represent different sets of pressure, volume and temperature of certain mass of the gas.

Boyle's law is a specific case of this equation where the temperature is constant (isothermal) *i.e* $T_1 = T_2$ thus we have:

$P_1V_1 = P_2V_2$ (1)

This means that **$PV = constant$**, this constant is equal to **nRT**

where n is the number of moles of the gas; **R** is the Universal Gas Constant = **8.315 J/K.mole** and **T** is the temperature of the gas in **Kelvin** (**T [K]= t [°C]+ 273**)

Then:

$PV=nRT$ (2)

Or in other form:
$P= (nRT) /V$ (3)

First part

Hence: "The pressure of a gas varies inversely with the volume provided that the mass and the temperature of the gas are maintained constant"
From *equation (3)*, representing *P* on the *y-axis* and *1/V* on the *x-axis* we get a straight line passing through the origin as shown in **Fig. 1**.The *slope* of this line is equal to the constant *nRT*. Knowing *R* and *T* one can calculate *n* (the number of moles of the given mass of gas).

Since *n=m/M* where *m* is the mass of the gas and *M* is the molar weight in *g/mol* the value of *M* can be calculated knowing that the density of air is **1.294 kg/m³** the value of *M* can be calculated..
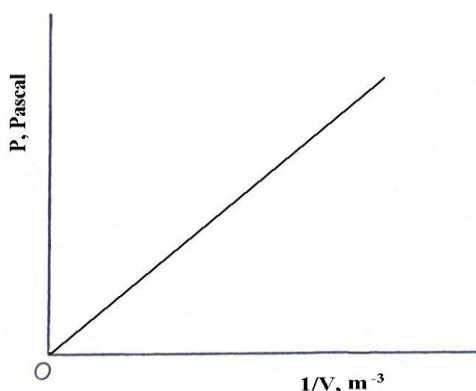
Figure 1: relationship between pressure and inverse of the volume of a gas at constant temperature

Apparatus

A glass cylinder closed from the upper and lower ends with two flinches filled with air. Inside the cylinder a piston connected to a screw can move up and down tightly with the inner walls of the cylinder. The glass cylinder is connected to a pressure gage (barometer) through a rubber tube. Rubber O-rings are used so that the piston can move easily inside the cylinder without leaking out any air. A photograph of the apparatus is seen in **Fig. 2**.
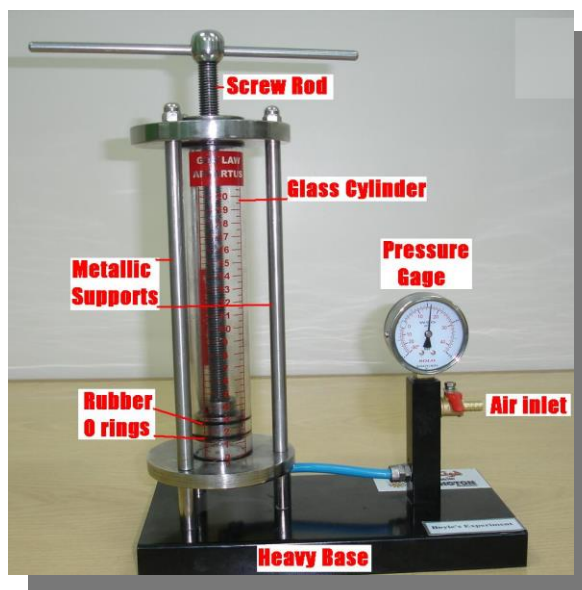
Figure 2: The apparatus used in the experiment

Procedures

1- Open the valve of the air inlet beside the pressure gage to equalize the pressure inside the tube with the air pressure.
2- Close the valve then determine the volume V_1 of the trapped air ($V=\pi r^2 L$ where r is the internal radius of the tube and L is the length of the trapped air coulomb).
3- Now, slowly use the piston to minimize the volume of the trapped air and determine the pressure (P) using the barometer.
4- Repeat the previous step with different volumes for at least 6 or 7 times.
5- Tabulate your data in **Table (1)**.
6- Measure the room temperature using a thermometer and convert its value to the **Kelvin's** scale (T).
7- Plot a relation of P on the *y-axis* versus *1/V* on the *x-axis*.
8- From the *slope* of the plotted line, find the number of molecules of the trapped air using *equation (3)* and the molar weight by knowing the air density = 1.294 *kg/m³* at normal conditions.

Results

Table (1)

L (m)	$V \ (m^3) =$ $\pi \ (2.4{\times}10^{-2})^2 \times \ L$	P (Pa)	1/V (m⁻³)

$T (K) =$

Slope of the *P* versus *1/V* relationship $=$

Number of molecule $n = slope/RT =$

Mass of the trapped air $m = \rho V =$ *kg*

The molar weight $M = m/n =$ *kg/mol*

Since the standard value of *M* is **0.029 kg/mol**;

$$\text{Percentage Error} = \frac{-0.029}{0.029} \times 100\% =$$

Second part

From *equation (3)*, representing *P* on the *y-axis* and *1/V* on the *x-axis* we get a straight line passing through the origin as shown in **Fig. 1**. The slope of this line is equal to the constant *nRT*. Knowing *R* and *n* one can calculate *T* (the temperature of gas).

We can calculate *n* from the following equation;

$n=m/M$ Where   *M =0.029 kg/mol*

m is the mass of the gas, *M* is the molar weight in *kg/mol*

Knowing that the density of air is 1.294 *kg/m³* and V_i is the initial volume the value of *m* can be calculated; where $m=\rho V_i$.

Procedures

1- Open the valve of the air inlet beside the pressure gage to equalize the pressure inside the tube with the air pressure.
2- Close the valve then determine the volume V_2 of the trapped air ($V=\pi r^2 L$ where *r* is the internal radius of the tube and *L* is the length of the trapped air coulomb).

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3- Now, slowly use the piston to minimize the volume of the trapped air and determine the pressure (P) using the barometer.
4- Repeat the previous step with different volumes for at least 6 or 7 times.
5- Tabulate your data in **Table (2)**.
6- Plot a relation of P on the *y-axis* versus *1/V* on the *x-axis*.
7- From the *slope* of the plotted line, find the temperature of gas.

Results

Table (2)

L (m)	$V (m^3) =$ $\pi (2.4\times10^{-2})^2 \times$ L	P (Pas.)	$1/V (m^{-3})$

$V_i =$ m^3

Mass of the trapped air $m = \rho V_i =$ *kg*

Since the standard value of M is **0.029 kg/mol**;

The molar weight $n = m/M =$ *kg/mol*

Slope of the P versus *1/V* relationship $=$

The temperature of gas $T = slope/n \, R =$ $^{\circ}K$

Suggested Questions

1. An ideal gas is held in a container at constant volume. Initially its temperature is **10°C**and its pressure is **70 cm.Hg**. What is its pressure when its temperature becomes **80°C**?

2. Two cylinders contain equal masses of the same gas at the same temperature. If the volume of cylinder *A* is three times greater than the volume of cylinder *B*, what you can say about the relative pressure in the cylinders?

3. The density of air at room temperature is about 1.29 kg/m^3. Use this together with the definition of 1 atm above to find the constant C in the Law of Atmospheres written above. Use your result to estimate the atmospheric pressure on top of the Blue Ridge (say 4000 feet), Snowmass (11,000 feet) and Mount Everest (29,000 feet).

4. Convert the local barometric pressure to psi units and enter the value to the nearest psi in the Data and Results Table. Some appropriate conversion factors are shown below.(Hint: 1 atm = 760 mm Hg = 29.92 in Hg = 14.7 psi)

Answer

Evaluation of the Experiment

Item	Attendance (2 marks)	Answer to Questions (2 marks)	Experimental (6 marks)	Total (10 marks)
Mark				

Assistant Name: **Signature:**

Date of Experiment:

Experiment (H2)

Charles' law

Objectives

The objectives of this experiment are to:

i. To describe and explain Charles' law.
ii. Determine the coefficient of volume temperature expansion of air at normal pressure.

Theory

The pressure (**P**), volume (**V**) and temperature (**T**) of a gas are related to each other by the general gas equation which states that:

$$\frac{PV}{T} = constant$$

$$i.\,e\;\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_1} = \frac{P_3V_3}{T_1} = \cdots = \frac{P_nV_n}{T_n}$$

Where **P**, **V** and **T** represent different sets of pressure, volume and temperature of certain mass of the gas.

Charles' law is a specific case of this equation where the pressure is constant i.e $P_1=P_2$ thus we have:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad\qquad (1)$$

This means that **V/T = constant**, this constant is equal to **nR/P**

Where **n** is the number of moles of the gas; **R** is the Universal Gas Constant = **8.315 J/K.mole;** and **P** is the pressure of the gas in **Pascal**.
Then:
$$PV = nRT \qquad\qquad (2)$$

Or in other form:
$$V = (nR/P)T \qquad\qquad (3)$$
Hence: "The volume of a gas varies directly with the temperature provided that the pressure of the gas are maintained constant"

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From *equation (3)*, representing **V** on the **y-axis** and **T** on the **x-axis** we get a straight line passing through the origin as shown in **Fig. 1**. The *slope* of this line is equal to the constant **nR/P**. Knowing **R** and **T** one can calculate **n** (the number of moles).

Figure 1: relationship between volume and the temperature of a gas at constant pressure.
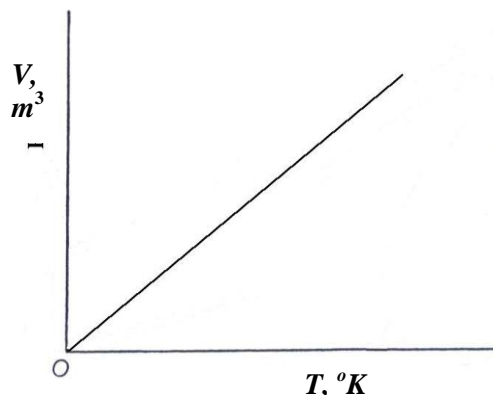
The apparatus

The apparatus consists of a U-shaped glass tube connected to gas container. The glass tube contained a fluid which level in the two branches of the U-shaped tube initially is equal. The gas container is immersed in a hot water bath, so the volume of the gas is increased gradually by rising temperature of the water bath. Accordingly the height of the fluid in the two branches of the U-shaped tube is no longer the same keeping the gas pressure in the container constant.

Figure 2: The experiment setup.

Procedures

1- The setup is connected as shown in **Fig. 2**.
2- Be sure that there is suitable amount of fluid in the *U-tube*. The height of the fluid in the two branches of the tube is initially the same indicating normal pressure of the gas inside the container.
3- Turn the heater on, the gas starts to expand gradually leading to a change in the level of the fluid in the two branches of the *U-tube*.
4- Record the reading of the difference **ΔL** height of the fluid while cooling.
5- Tabulate your data and plot using the Excel computer program a relation between **ΔL** and **ΔT**.

6-From the graph calculate the temperature coefficient of volume expansion.

Note: Since $\Delta V = (\pi r^2)\,\Delta L$ where **r** is the radius of the **U-tube**, the ΔV-ΔT graph can be replaced by a one between ΔL and ΔT. In such case the **slope** of the resultant straight line should be $k/\pi r^2$ instead of simply **k**.

Results

T, °C	T, K	ΔL
95		
90		
85		
80		
75		
70		
65		
60		
55		
50		
45		
40		

From the graph:

The **slope** $= nR/(\pi r^2\,P) =$

Since **r** =   **m**

P = 1.013×10^5 Pascal,   **P** is a constant pressure

R = 8.315 J/K.mole, then we can determine **n**

n =   **mole**

Suggested Questions

1. As the pressure of a gas at *2 atm* is changed to *1atm* at constant temperature, the volume of the gas:
   - i. Doubled.
   - ii. Shrinkage to half of its initial volume.
   - iii. Remains the same.
2. Under the same conditions of temperature and pressure, a liquid differs from a gas because the atoms or molecules of the liquid:
   - i. are in continuous straight-line motion
   - ii. take the shape of the container it occupies
   - iii. have no regular arrangement
   - iv. have stronger forces of attraction between them
3. A sample of unknown gas at *STP* has a density of **0.630 g per liter**. What is the gram molecular mass of this gas?

   1-**2.81 g**   2-**14.1 g**   3-**22.4 g**   4-**63 g**

4. Why Charles' law cannot be applied to liquids?
5. A sample of gas in a 7.5 L balloon is at a temperature of $22^{\circ}C$. What volume will the balloon expand to at $50 \,^{\circ}C$?
6. At what temperature will a sample of gas in a balloon reach a volume of 120 L if at standard temperature ($0^{\circ}C$) the gas is at 200 L?
7. I have made a thermometer which measures temperature by the compressing and expanding of gas in a piston. I have measured that at $1000 \,^{\circ}C$ the volume of the piston is 20 L. What is the temperature outside if the piston has a volume of 15 L? What would be appropriate clothing for the weather?
8. Carbon dioxide is usually formed when gasoline is burned. If 30.0 L of CO_2 is produced at a temperature of $1.00 \times 10^{3}\,^{\circ}C$ and allowed to reach room temperature (25.0 °C) without any pressure changes, what is the new volume of the carbon dioxide?

Answer

Evaluation of the Experiment

Item	Attendance (2 marks)	Answer to Questions (2 marks)	Experimental (6 marks)	Total (10 marks)
Mark				

Assistant Name: **Signature:**

Date of Experiment:

Experiment (H3)

Gay-Lussac's law

Objectives

The objectives of this experiment are to:

  i. Experimentally determine the relationship between temperature and pressure of a gas at constant volume.
  ii. Calculate number of moles *n* and the molar weight *M* of the trapped air.

Introduction

Gay-Lussac's law is the third one leading up to the ideal gas law. The first is Boyle's law, which gives the relationship between volume and pressure, the second is Charles's law, which gives the relationship between volume and temperature and finally, the third is Gay-Lussac's Law, which gives the relationship between pressure and temperature.

The founder of this particular thermodynamic relation is Joseph Gay-Lussac's (1785-1850). He not only rescued Charles' Law from oblivion by duplicating the experiments and publishing the results, but re-created similar conditions to find the connection between pressure and temperature. Gay-Lussac's found that for a gas, if the pressure increases, the temperature increases, and if the temperature decreases, so does the pressure.

Theory

The pressure of a fixed mass and fixed volume of a gas is directly proportional to the gas's temperature.

Simply, if a gas's temperature increases then so does its pressure, provided the mass and volume of the gas are held constant. The law has a particularly simple mathematical form if the temperature is measured on an absolute scale, such as in *Kelvin*. The law can then be expressed mathematically as:

$P \propto T$ (1)

Where P is the pressure of the gas; and T is the temperature of the gas (measured in **Kelvin's**).

This law holds true because temperature is a measure of the average kinetic energy of a substance; as the kinetic energy of a gas increases, its particles collide with the container walls more rapidly, thereby exerting increased pressure.

For comparing the same substance under two different sets of conditions, the law can be written as:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \qquad or \qquad P_1 T_2 = P_2 T_1 \qquad (2)$$

Where P_1 and T_1 are the original values of the gas state, while P_2 and T_2 represent its final state values. In addition to the pressure being constant, the same caveats used in any ideal gas law apply here. These results apply for systems where an equilibrium state has been reached, the gas is not too dense, and P is around the atmospheric pressure. Real gases approximate these conditions enough such that the law is applicable in everyday life.

On the other hand, from the general law of ideal gases we have:

$$PV = nRT$$
$$\frac{P}{T} = \frac{nR}{V} \qquad (3)$$

Where R is the universal gas constant. Hence the **slope** of the straight line dependence between P and T is equal to **nR/V**. If the volume of the gas sample in a container is known, the number of moles n of the trapped air can be estimated.

Since $n=m/M$ where m is the mass of the gas and M is the molar weight in **g/mole**, knowing that the density of air is **1.294 kg/m³** the value of M can be calculated.
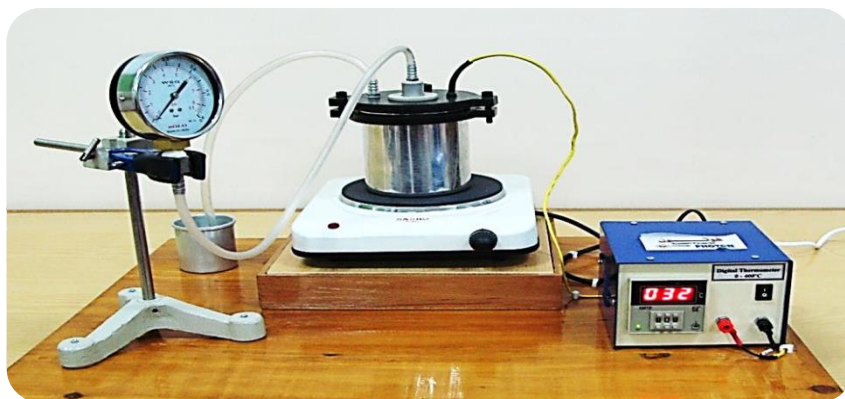
Figure 1: The experiment setup.

Procedures

1-Fill the steam generator with water,

2-Start to rise the temperature of the water,

3-Measure the temperature of the water gradually while the pressure of the trapped gas changes,

4-Step 3 is to be repeated until reaching the boiling point of water.

5-Graph the relation between **P** on the **y-axis** and **T** on the **x-axis** and calculate the **slope**.

Note

The experiment can be done different way. First let the water in the boiler reach its boiling temperature and then record the gas pressure at selected temperatures while it is cooling.

Results

Tabulate your result in the following Table

T, °C	T, K	P

Slope$=nR/V=$

Since: $V = $ $14 \times 10^{-6} m^3$ and $R = 8.315 \ J/K. mole.$

$\therefore n = (V \ slope)/R = $

Mass of the trapped air $m = \rho V = $ kg

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The molar weight $M = m/n = $ kg/mol

Since the standard value of **M** is 0.029 **kg/mol**;

$$Percentage\ Error = \frac{-0.029}{0.029} \times 100\% = $$
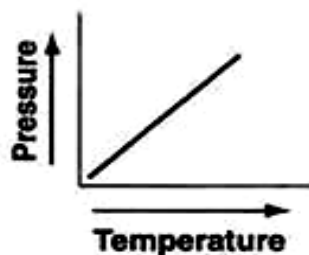
Suggested Questions

1. According to this experiment, what should happen to the pressure of a gas if the Kelvin temperature is doubled? Check this assumption by finding the pressure at **-73°C (200 K)** and at **127°C (400 K)** on your graph of pressure versus temperature. How do these two pressure values compare?   **a)** $\frac{P_1}{P_2} = \frac{1}{2}$ **b)** $\frac{P_1}{P_2} = 2$

2. If the temperature of a sample of ideal gas is increased from **101°C** to **202°C** while the volume is kept constant, the pressure:
   - i. Will increase by a factor of about **1.27005**.
   - ii. Will remain constant.
   - iii. Will double.
   - iv. Will be cut in half.

3. A sample of gas in a closed, rigid container at 750 mm Hg is at a temperature of 22 °C. What pressure would the gas exert at a temperature of 100 °C?

4. At what temperature will a sample of gas in a closed container reach a pressure of 5 atm if at standard temperature (0°C) the gas is at 1 atm?

5. Gay-Lussac's Law is the relationship between what two variables?

6. Which variable must be constant in Gay-Lussac's Law?

7. A sample of gas at 1.5 atm and 300 K is heated to 500 K. What is the new pressure?

Answer

Evaluation of the Experiment

Item	Attendance (2 marks)	Answer to Questions (2 marks)	Experimental (6 marks)	Total (10 marks)
Mark				

Assistant Name: **Signature:**

Date of Experiment:

Experiment (H4)

Specific Heat of a Solid Material

Objectives

The objectives of this experiment are to:
  i. Learn the experimental method of calorimetry.
  ii. Determine the specific heat of a metal in the temperature ranges between boiling water and room temperature.

Introduction

When energy is added to a system and there is no change in the kinetic or potential energy of the system, the temperature of the system usually rises. (An exception to this statement is the case in which a system undergoes a change of state-also called a *phase transition*- e.g., a solid is changed into a liquid phase or a liquid state is changed into its vapor phase). If the system consists of a sample of a substance, we find that the quantity of energy required to raise the temperature of a given mass of the substance by some amount varies from one substance to another. For example, the quantity of energy required to raise the temperature of **1 kg** of water by **1°C** is **4.186*kJ***, but the quantity of energy required to raise the temperature of **1 kg** of copper by **1°C** is only **0.387 *kJ***. In the discussion that follows, we shall use heat as our example of energy transfer, but keep in mind that we could change the temperature of our system by means of any method of energy transfer.

The heat capacity **C** of a particular sample of a substance is defined as the amount of energy needed to raise the temperature of that sample by **1°C**. From this definition, we see that if energy **Q** produces a change **ΔT** in the temperature of a sample, then:

$$Q = C\,\Delta T \qquad\qquad (1)$$

In the **MKS** system, the unit of heat is the kilocalorie and is defined so that the specific heat of water is one i.e., when one kilocalorie of heat is applied to one kilogram of water, its temperature will rise by one degree centigrade (*Celsius*).

The specific heat *c* of a substance is the heat capacity per unit mass. Thus, if energy **Q** transfers to a sample of a substance with mass **m** and the temperature of the sample changes by **ΔT**, then the specific heat of the substance is:

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$$c = Q/m\ \Delta\text{T} \qquad\qquad (2)$$

Specific heat is essentially a measure of how thermally insensitive a substance is to the addition of energy (it tells you how much energy is needed to raise each gram of the substance by one degree). The greater a material's specific heat, the more energy must be added to a given mass of the material to cause a particular temperature change.

Theory

When two bodies in an isolated system, initially at different temperatures, are placed in intimate contact with each other, in time they will come to equilibrium at some common intermediate temperature. Because of energy conservation, the quantity of heat lost by the hot object is equal to that gained by the cold object provided that no heat is lost to the surroundings. This is the basis for the method of calorimetry through mixture: A metal sample whose specific heat is to be determined is heated in boiling water to **100ºC**. It is then quickly transferred to a Vessel (calorimeter cup) which contains some cold water of known temperature. When the metal specimen and the calorimeter (including the water) come to equilibrium, the final temperature is measured with a thermometer, see experiment setup in **Fig. 1**. It is assumed that the heat loss to the thermometer is negligible and if the heat exchange with the environment is kept small, then the heat lost by the metal sample is equal to the total heat gained by the calorimeter cup and the water.

Conservation of energy allows us to write the mathematical representation of this energy statement as:

$$Q_{cold} = -\,Q_{hot} \qquad\qquad (3)$$

The negative sign in the equation is necessary to maintain consistency with our sign convention for heat (the energy transfer Q_{hot} has a negative value because energy is leaving the hot substance).

Suppose m_m, m_w and m_b is the mass of sample (metal), water and beaker, respectively the specific heat c_m, c_w and c_b and the initial temperatures T_m, T_w and the final equilibrium temperature after everything is mixed T_f.

The energy transfer for the water and the beaker is Q_{cold}:

$$Q_{cold} = (m_w c_w + m_b c_b)(T_f - T_w) \qquad\qquad (4)$$

The energy transfer from the metal of unknown specific heat is Q_{hot}:

$$Q_{hot} = m_m \, c_m (\mathrm{T}_f - \mathrm{T}_m) \tag{5}$$

Where, $\mathrm{T}_m > \mathrm{T}_f > \mathrm{T}_w$

Substituting from equation (4) and (5) into *equation (3)* gives:

$$(m_w c_w + m_b c_b)(\mathrm{T}_f - \mathrm{T}_w) = -m_m c_m (\mathrm{T}_f - \mathrm{T}_m) \tag{6}$$

Solving for c_m gives:

$$c_m = \frac{(m_w c_w + m_b c_b)(\mathrm{T}_f - \mathrm{T}_w)}{m_m (\mathrm{T}_m - \mathrm{T}_f)} \tag{7}$$

Apparatus

1-Calorimeter with Lid, double walled, high insulating,

2-Thermometer, range -**10** up to **110°C**,

3-Digital thermometer with temperature sensor,

4-Copper shots,

5-Electrical Balance,

6-Hard Glass beaker, **400 mL**,

7-Steam generator consisting with rubber connectors,

8-Stainless steel stand rod,

9-Multiclamp,

10-Universal clamp for thermometer fixing,

Figure 1: Experiment setup.

Procedures

1-Put the copper shots in the steam generator chamber until it is approximately heated to **100ºC**.

2-While the copper shots is heating, weigh the calorimeter empty and filled to about its two third capacity with water, and get the mass of water

3-Measure the temperature of water and calorimeter

4-When the shots reach to ~ **100ºC**, insert the copper shots in the calorimeter that contain the water.

5-Measure the equilibrium temperature of the mixture.

6-Weight the calorimeter containing water and copper shots so that you can calculate the weight of the shots.

Results:

First metal:Al			Second metal: Cu or Pb		
Quantity	Value	unit	Quantity	Value	unit
$m_b =$		g	$m_b =$		g
$m_w + m_b =$		g	$m_w + m_b =$		g
$m_w =$		g	$m_w =$		g
$T_w =$		°C	$T_w =$		°C
$T_m =$		°C	$T_m =$		°C
$T_f =$		°C	$T_f =$		°C
$m_{w+b+m} =$		g	$m_{w+b+m} =$		g
$m_m =$		g	$m_m =$		g
c_m		$cal/g.°C$	c_m		$cal/g.°C$
$(c_m)_{standard}$	Al=0.21	$cal/g.°C$	$(c_m)_{standard}$	Cu=0.093 Pb=	$cal/g.°C$

$$c_m = \frac{(m_w c_w + m_b c_b)(T_f - T_w)}{m_m (T_m - T_f)} =$$

50

$$Percentage\ Error = \frac{C_{standard} - C_{Experiment}}{C_{standard}} \times 100\% =$$

Comment in your result

Suggested Questions

1. The specific heat capacity of water is **4200 JkgK^{-1}** means that if we have **1 kg** of water:
   a. A heater of power **1W** would take **4200 s** to heat the water before boils,
   b. A heater of power **4200W** would take **1s** to heat the water from **300 K** to **301 K**.

2. By $E = m\ c\ \Delta T$ and **c = 4200 JkgK^{-1}**, calculate the energy used to heat **2 kg** of water from **80°C** to **100°C**:
   a. 672000 J   **b. 840000 J**   **c. 168000 J**   **d. 120000 J**

3. Given the specific heat of ice is **2100 JkgK^{-1}** and the specific heat of water **4200 JkgK^{-1}**. For the same mass of ice and water:
   a. To raise **1°C**, ice needed more energy
   b. To raise **1°C**, water needed more energy
   c. To raise **1°C**, ice and water needed the same energy
   d. all of the above are incorrect

4. What are the sources of error and how can one minimize the error?
5. By what method of heat transfer was the metal heated?

6. What method(s) of heat transfer was used during the entire experiment? Indicate when.
7. How would your results be affected if some water originally in the calorimeter cup is splashed out during the sample transfer? How would water condensation on the outside of the inner cup affect your results?

Answer

Evaluation of the Experiment

Item	Attendance (2 marks)	Answer to Questions (2 marks)	Experimental (6 marks)	Total (10 marks)
Mark				

Assistant Name: **Signature:**

Date of Experiment:

Experiment (H5)

Linear Thermal Expansion of Solids

Objectives

The objectives of this experiment are to:

  i. Study the phenomenon of the thermal expansion of solids.
  ii. Determine the coefficient of linear thermal expansion of a metal.

Theory

With few exceptions, materials expand somewhat when heated through a temperature range that does not produce a change in phase (i.e. melting, freezing, boiling etc.). This phenomenon is known as thermal expansion. Thermal expansion is a consequence of the change in the average separation between the atoms in an object. At ordinary temperatures, the atoms in a solid oscillate about their equilibrium positions with amplitude of approximately 10^{-11} **m** and a frequency of approximately 10^{13} **Hz**. The average spacing between the atoms is about 10^{-10} **m**. As the temperature of the solid increases, the atoms oscillate with greater amplitudes; as a result, the average separation between them increases. Consequently, the object expands.

Although this effect is small, it is very important in any application that involves using different materials in an environment where they are heated and cooled. For example, thermal-expansion joint must be included in buildings, concrete highways, railroad tracks, brick walls, and bridges to compensate for dimensional changes that occur as the temperature changes. Furthermore, the mechanism of thermostat (a device used to control temperature) is based on the liner expansion of solids. As shown in **Fig.1**, when two different materials are combined in a strip (bimetallic strip), the strip bends as the temperature changes because the two metals have different expansion coefficients.

For solids that are isotropic (i.e. uniform in all directions), the material undergoes thermal expansion as a whole: that is its volume expands. For materials that are not isotropic, such as an asymmetric crystal for example, the thermal expansion can have different values in different directions. Thermal expansion can also vary somewhat with temperature so that the

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degree of expansion depends not only on the magnitude of the temperature change, but also on the absolute temperature.
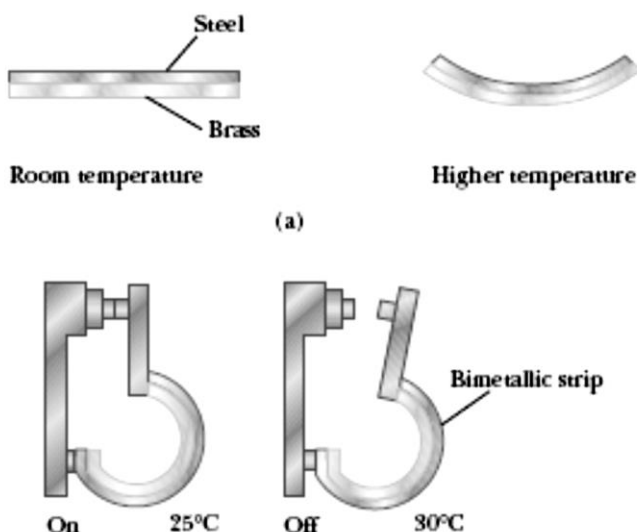

Figure 1: showing the effect of different expansion coefficients of metals.

Suppose an object of length **L** undergoes a temperature change of magnitude **ΔT**. If **ΔT** is sufficiently small, the change in length, **ΔL**, is proportional to **L** and to **ΔT**. Stated mathematically:

$$\Delta L = \alpha \, L \, \Delta T$$

Where **α** is called the coefficient of linear thermal expansion for the material. For an isotropic material, **α** will be the same in all directions, so we can measure **α** simply by measuring the change in length of a rod of the material.

Apparatus

The apparatus of this experiment is shown, schematically, in **Fig. 2** and as photograph in **Fig.3**. It consists of a metallic rod representing the material that its linear thermal expansion coefficient is to be determined. The metallic rod is connected to a steam generator via a rubber hose in order to increase the temperature of the metallic rod. The rod is fixed in such a way that it is allowed to expand in one direction where a micrometer is connected to the rod in order to measure the change of its length under the temperature change. A thermometer is used to measure the rod temperature.
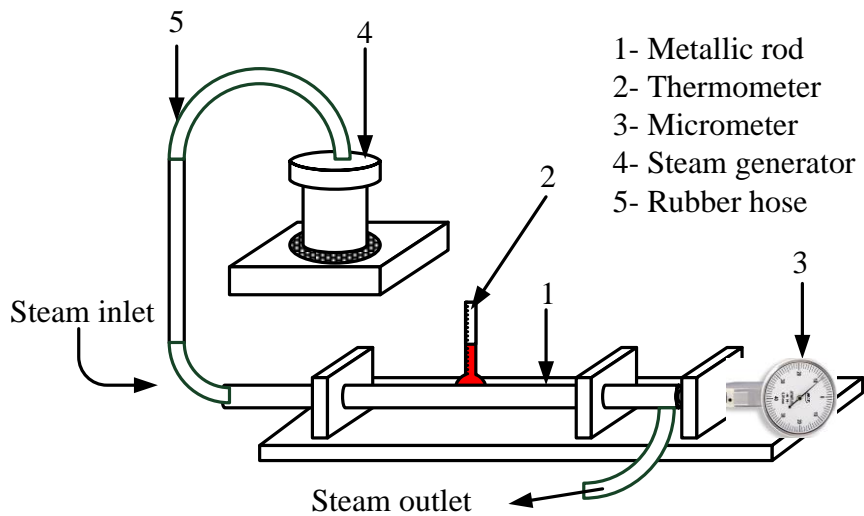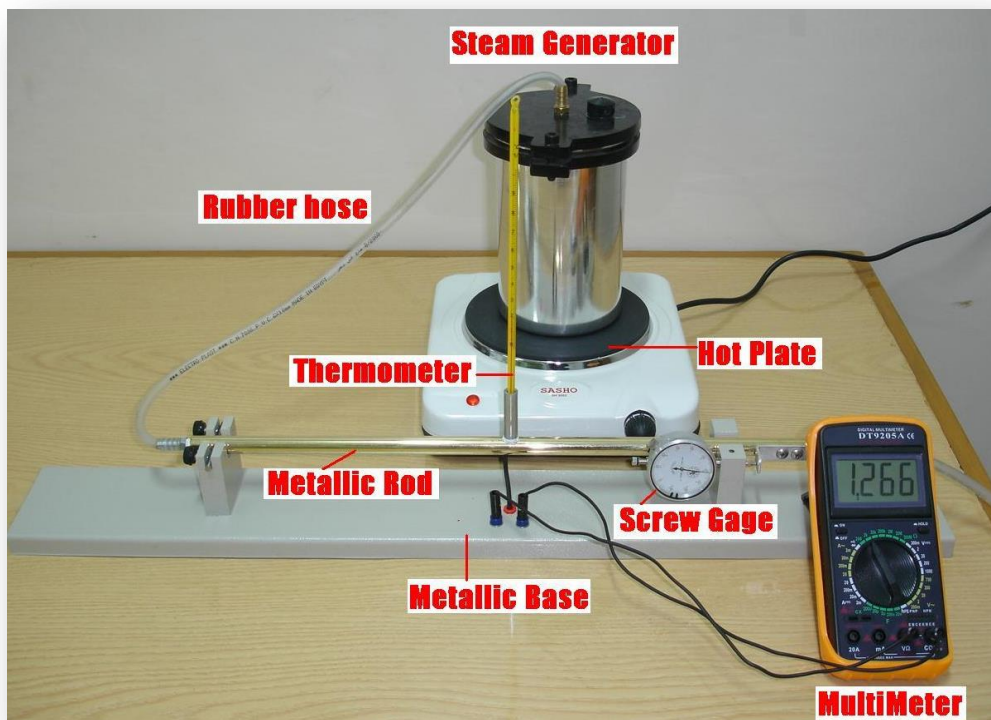
Figure 2: Schematic diagram of the experiment setup.

Figure 3: The experiment setup.

First Part
Procedures

1. Measure the initial length of the rod L_o.
2. Fill the steam generator with water.
3. Record the initial temperature T_o of the rod.
4. Start flowing the steam through the rod to rise its temperature up to a maximum of about **90-95°C**.
5. Adjust the screw gage to *zero* so that the changes in length can be easily readable.
6. Disconnect the steam generator (disconnect the hot plate supply). Record the reading of the change in length by the micrometer every **5-10°C** while cooling the rod down to ~ **30°C**.
7. Plot a relation between **ΔL** on the *y-axis* and **ΔT** on the *x-axis* and calculate the *slope* of the straight line.
8- Calculate the coefficient of linear expansion.

Results

$L_0 = 0.55m$, $T_0 =$ °C

Table (1): Data of the linear thermal expansion of brass rod

t, °C	T, K	ΔT, K	R, ohm	ΔL, mm

$slope =$

$\alpha = slope/L_0 =$ K^{-1}

Second Part

The apparatus shown in **Fig. 3** is attached with alcohol-in glass thermometer and a temperature sensor connected to ohmmeter. While you are performing your experiment record the reading of the ohmmeter simultaneously with that of temperature measured by the alcohol-in glass thermometer. A graph between the resistance of the sensor and temperature can serve as a calibration graph for the temperature sensor. Since the material of the sensor is semiconducting one it is expected that this graph (**Fig.4**) takes the form of an exponential change according to the relation:

$$R = R_0 \exp(\frac{\varepsilon}{kT})$$

Where R_o is a constant, k is Boltzmann's constant, T is the temperature in **Kelvin** and ε (in **Joules**) is the activation energy of conduction of the semiconducting material. Other alternative way to draw the calibration curve is to draw a graph between R on a logarithmic scale and the inverse of T (**Fig. 4**) according to the equation:

$$\ln R = (\frac{\varepsilon}{k})\frac{1}{T} + \ln R_0$$

From this straight line relationship, values of R_o and ε can be calculated from the intersection with the **y-axis** and the **slope** of the straight line, respectively. The value of ε is very small, hence it is more convenient to represent its value in **eV** where **eV** is a unit of energy equals to **1.6×10^{-19}** of a **joule**.
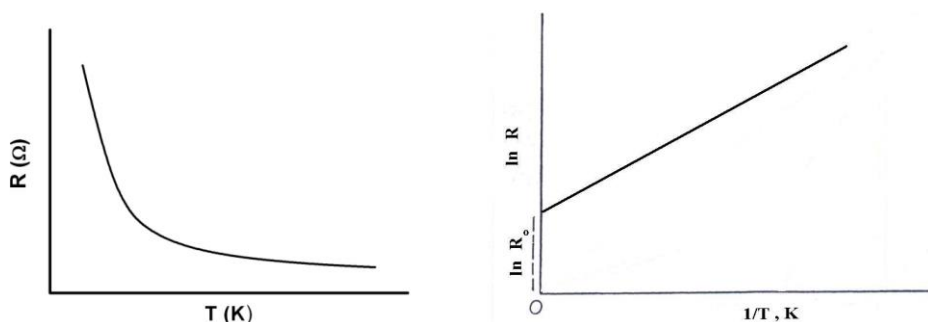

Figure 4: Shows the relation between R and logarithm R versus T and inverse T, respectively.

Results

Slope=ε/k =   ,

∴ ε= k ×slope =

Intersection with the *y-axis*=   ,

∴ **R$_0$** =

Suggested Questions

1. Rubber has a negative average coefficient of linear expansion. What happens to the size of a piece of rubber as it is warmed?
2. Explain why a column of mercury in a thermometer first descends slightly and then rises when the thermometer is placed into hot water.
3. Two spheres are made of the same metal and have the same radius, but one is hollow and the other is solid. The spheres are taken through the same temperature increase. Which sphere expands more?
   a. *Solid sphere.*
   b. *Hollow sphere.*
   c. *They expand by the same amount.*
   d. *Not enough information to say.*

4. Thin strips of iron and zinc are riveted together to form a bimetallic strip that bends when heated. The iron is on the inside of the bend because:
   a. *it has a higher coefficient of linear expansion*
   b. *it has a lower coefficient of linear expansion*
   c. *it has a higher specific heat*
   d. *it has a lower specific heat*
   e. *it conducts heat better*
5. The active element of a certain laser is made of a glass rod **30.0 cm** long. If the temperature of the rod increases by **65.0°C**, what is the increase in its length? Assume that the average coefficient of linear expansion of the glass is **9.00×10^{-6} °C^{-1}**.

6. What is happened with solids at increasing temperature? Explain the reason of the expansion.
7. Write down the formula for dependence of the body's length on temperature and explain it.
8. What is linear coefficient α of thermal expansion? What is unit of α in SI?
9. What substances have larger values of linear coefficient of thermal expansion?
10. Using the obtained value of linear coefficient α of thermal expansion, calculate the volume coefficient β of thermal expansion.
11. Which equation will you be using: $L = L_0(1 + \alpha\theta)$ or $L = L_0(1 + \alpha\Delta\theta)$ to describe how the length, L, varies with temperature, θ? Why?

Answer

Evaluation of the Experiment

Item	Attendance (2 marks)	Answer to Questions (2 marks)	Experimental (6 marks)	Total (10 marks)
Mark				

Assistant Name: **Signature:**

Date of Experiment:

Experiment (H6)

Mechanical Equivalent of Heat

Objectives

The objectives of this experiment are to:

i. Study the relationship between the electrical energy and thermal energy.
ii. Determine the relationship between conventional units of work and heat.
iii. Find the specific heat of an unknown liquid using the mechanical equivalent of heat.

Theory

Energy can be changed from one form to another form. One of the important effects of an electric current is its heating effect, whenever an electric current flow in a conductor, some electrical energy is converted into heat energy. In this experiment, you will send an electric current through a resistor submerged in water, as shown in **Fig. 1**. This will convert electric energy into heat energy which will raise the temperature of the water. From the principle of conservation of energy, it follows that the work done in pushing electric charge through the resistor is proportional to the heat energy produced. This statement is the result of the **First Law of Thermodynamics**, which states:

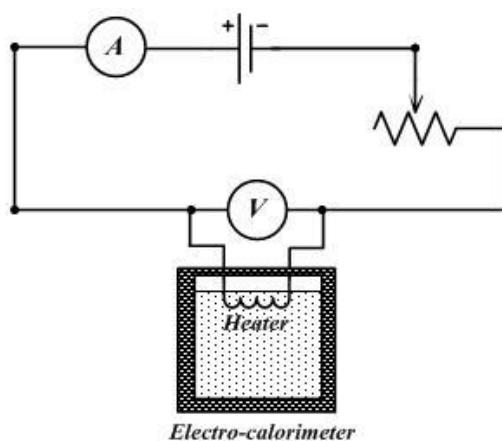$$W \, \alpha \, Q \qquad \rightarrow \qquad W = JQ \qquad\qquad (1)$$

Figure 1: Circuit diagram of the experiment.

Where the work W is in *joules* and the heat energy Q is in *calories*. The conversion factor between electric energy measured in *joules* and heat energy in *calories* is called the *mechanical equivalent of heat*. The use of the symbol J for this conversion factor is in honor of James Joule who first demonstrated the validity of *equation 1*.

Electrons flowing in a circuit get their energy from the voltage source, whether it is a battery or an electronic power supply. As the electrons pass through a copper wire, they collide with the copper atoms in the wire and lose some energy in each collision.

The energy transferred to the atoms (electrical energy converted into thermal energy) results in a temperature increase of the wire. A charge q being pushed through a circuit by a potential difference V accumulates energy equal to qV. When the voltage is constant, the work done by the voltage source on the charge is therefore $W = qV$.

$$q = It \qquad \rightarrow \qquad W = VIt \qquad (2)$$

Where I is the average current in the resistor and V is the average voltage across the resistor. This dissipated energy is called heat, Q, and it raises the temperature of the water according to the relationship:

$$Q = (m_W c_W + m_c c_c)(T_f - T_i) \qquad (3)$$

Where m_w is the mass of the water, c_w is the specific heat of water (**1 cal/g °C),** m_c is the mass of the calorimeter, c_c is the specific heat of the calorimeter, T_f is the maximum temperature of the well-stirred water after the electrical power is turned off, and T_i is the water temperature at the instant the power is first switched on and the current is started.

The total energy of the resistor/water system is conserved. In the ideal condition in which no heat energy is exchanged between the system and the surrounding air, all heat energy produced in the resistor is absorbed by the water. If you equate the energy produced in the resistor (in *joules*) to the energy gained by the water in (*calories*), you

$$J = \frac{W}{Q} = 4.186 \ \frac{Joues}{Cal} \qquad (4)$$

The mechanical equivalent of heat has the same value as the mechanical equivalent of heat, i.e., *1 cal = 4.186 joules*.

Notes:

There are different sources of error in this experiment which are due to:

1. The specific heat, the mass of the heater (power resistor), the surrounding insulators, the stirrer, etc, are not considered in our equations so they must be added to *equation (3)* in the form of:

$$Q = (m_W c_W + m_c c_c + S)(T_f - T_i) \qquad (5)$$

Where *S* **is an equivalent involves the unconsidered heat capacities** of the system, its value is equal to *20 Cal/degree*.

2. Increasing the final temperature, increases the radiation of heat which is not considered at all in our equations, so it's preferable **not to increase T_f more than 8-12 °C above the room temperature**.

3. The inhomogeneous heat distribution inside the system doesn't give a good read of the temperature so a **CONTINUOUS STIRRING is a rigorous condition in this experiment** to insure the temperature homogeneity.

Apparatus

Double walled calorimeter of aluminum (specific heat of **0.22 cal/g·°C**) with stirrer, electric heater, power supply, Rheostat, two digital multi-meters, timer, and thermometer, **Fig.2**.
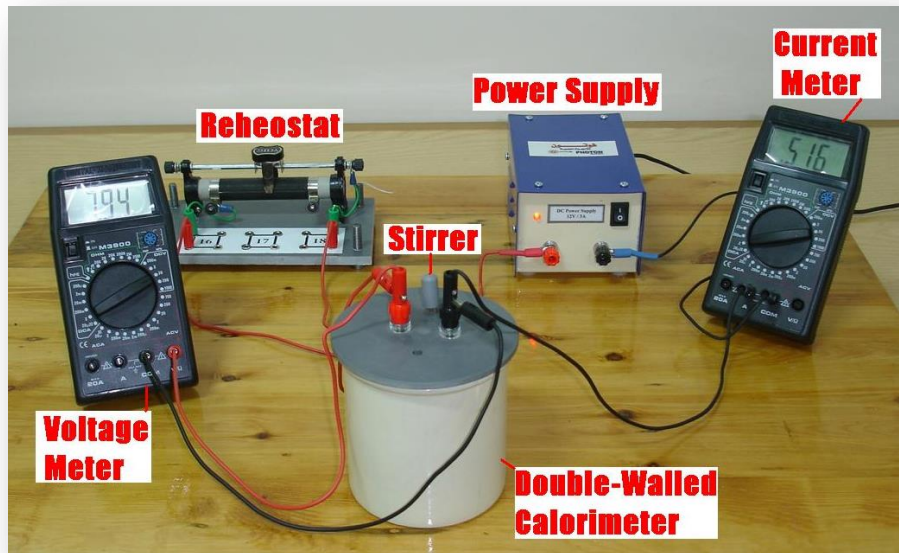

Figure 2: The experiment setup.

First Part

Finding the value of the mechanical equivalence of heat

Procedure

1-Weigh the empty calorimeter cup and record its mass m_c.

2-Pour about **170-190 g** of water into the calorimeter cup. Record the mass of the cup and water m_{cw}, calculate and record the mass of the water alone m_w.

3-Submerge the power resistor (heater) and the thermometer into the water. Cover the top of the electro-calorimeter to prevent heat transfer between the water and the room air.

Caution: Be sure the heating resistor is completely submerged in the water while the current is flowing.

4-Measure and record the initial temperature of the water T_i.

5-After your circuit is checked by the instructor, switch on the power supply.

6-Turn on the power supply and, at the same instant start the timer.

7- Measure the current I and the voltage V. Tabulate the data in **Table (1)**.

8-While the water is heated, measure and record the elapsed time t, and the temperature T in the attached table, every two degrees centigrade.

9-When the water temperature is **8–10** °C above the initial temperature, simultaneously stop the timer, and switch off the power supply.

10-Calculate W and Q using **equations (2)** and (**5**), respectively.

11-Plot **W** on **y-axis** versus **Q** on **x-axis** and calculate the mechanical equivalent of heat using the slope of the graph.

Results

$m_c =$		$c_c =$	
$m_{cw}=$		$c_w =$	
$m_w = m_{cw} = m_c$		$T_i =$	

The value of the current passing through the circuit $I=$ *Amp*.

The value of the voltage across the power resistor V =   *volts*

The value of the equivalent unconsidered heat capacities $S = 20cal/^oC$

(Refer to the instructor for the constants values)

Table (1): data collected for the mechanical equivalent of heat

T	t	$W = IVt$	$Q = (m_w c_w + m_c c_c + S)(T_f - T_i)$

Recommended values for the parameters of the experiment:

1-The water mass in the range *170 g - 190 g*,

2-The current flowing through the heating element in the range *0.8 – 1.0 Amp*,

3-The time increment between two successive readings about *2-5 min* and the total elapsed time about *35 min*.

Second Part

Determining the specific heat of an unknown liquid

By replacing the water in the previous work with the unknown liquid with the unknown specific heat, we could rewrite **equation 5** in the form:

$$Q = (m_1 c_1 + m_c c_c + S)(T_f - T_i) \qquad (6)$$

Where m_l, c_l are the mass and the specific heat of the liquid, T_i, T_f are the initial and final temperatures, respectively.
So let's start….

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Procedures

1-Weight the empty calorimeter cup and record its mass m_c.

2-Pour about two thirds of the cup of the unknown liquid into the calorimeter cup. Record the mass of the cup and liquid m_{cl}, calculate and record the mass of the liquid alone m_l.

3-Submerge the power resistor (heater) and the thermometer into the liquid. Cover the top of the electro-calorimeter.

Caution: Be sure the resistor is totally submerged.

4-Measure and record the initial temperature of the liquid T_i.

5-Turn on the power supply and, at the same instant, start measuring time.

6- Measure the current I and the voltage V.

7-While the liquid is heated, measure and record the elapsed time t, and the temperature T in the attached table, every two degrees centigrade.

8-When the liquid temperature is **8–10 °C** above the initial temperature, simultaneously stop the timer, and switch off the power supply.

9-Calculate W and $J (T\text{-}T_i)$ using **equations (2)** and**(6)**.

10-Plot W on **y-axis** versus $J(T\text{-}T_i)$ on **x-axis** and calculate the specific heat of the liquid using **slope** of your graph.

Results

$m_c=$		$c_c=$	
$m_{cl}=$		$J =$	
$m_l= m_{cl} - m_c=$		$T_i=$	

The value of the current passing through the circuit $I =$ *Amp.*

The value of the voltage across the power resistor $V =$ *Volts*

The value of the equivalent unconsidered heat capacities $S=$
(Refer to the instructor for the constants values)

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Record your data in the following table:

Table (2): Time rate of temperature increase in Joules Experiment

T	t	$W = IVt$	$J(T - T_i)$

From the graph the value of the unknown liquid specific heat =

Comment on your result

Suggested Questions

1. Was the energy **Q** gained by the water greater than the electrical energy **W** dissipated by the resistor? Explain why it was greater or lesser.

2. The mechanical equivalent of heat is **1 cal = 4.18 J**. The specific heat of water is **1 cal/g °C**. An electric heater immersed totally in water, rated at **400W**, should heat a kilogram of water from 10° **C** to 30° **C** in about:

   A. **3.5 min**   B. **1 min**   C. **15 min**   D. **45 min**   E. **15 s**

3. Given two different resistances, how does the rate of Joule heating in them differ if they are connected to a fixed voltage source:

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(a) In series   (b) In parallel
4. Compare your value of J with the accepted value (check your textbook).
5. Discuss any sources of error that you feel might have affected your results. Are some of these avoidable?
6. What affect would they have on your calculated value for J? Can you estimate the magnitude of the effects?
7. Is it experimentally possible that the heat absorbed by the cylinder could be greater than the work performed on it? Explain.
8. Can your value of J be used for determining how much mechanical energy can be produced from a specified amount of thermal energy? Why or why not?

Answer

Evaluation of the Experiment

Item	Attendance (2 marks)	Answer to Questions (2 marks)	Experimental (6 marks)	Total (10 marks)
Mark				

Assistant Name: **Signature:**

Date of Experiment: