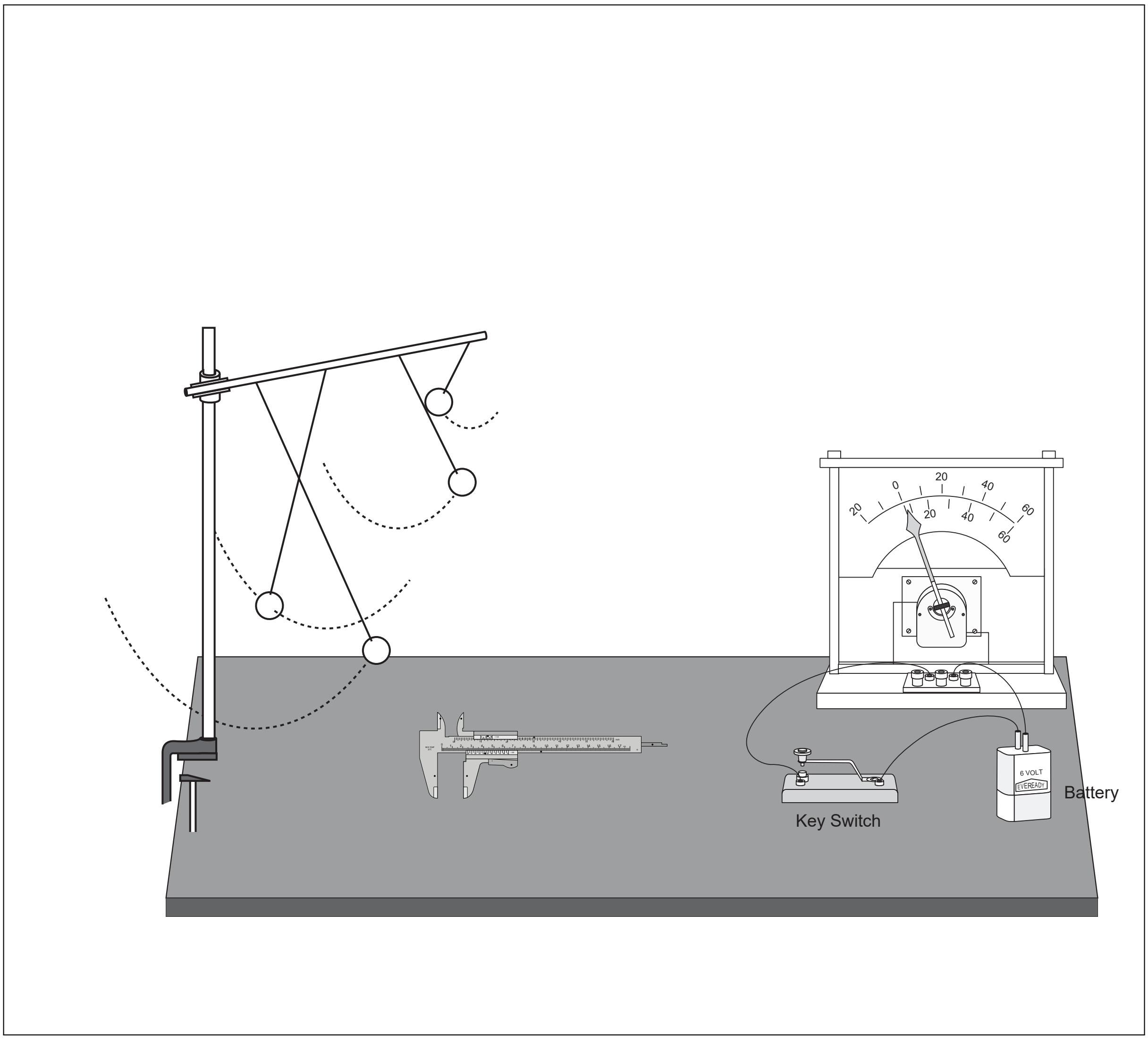
EXPERIMENTS IN GENERAL PHYSICS

PHYS 1011



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PREFACE

The goal of this course is to introduce learners to the art and science of experimental physics, and to the tools physicists use to analyze, document and present results.

The experiments in this lab will fascinate you, give you a first look at modern instrumentation and techniques, and give you a taste of what *real experimental physics* is all about. Some experiments are easier than others.

Each experiment is designed to require three hours in lab and about 6 hours of homework to obtain presentable results. The manual for each experiment has the following sections:

Pre-Lab Assignment: Pre-laboratory assignment that is based upon the laboratory description is provided under the heading Pre-Lab preparation. The intention is prepare students to perform the laboratory by having them answer a series of questions about the theory and working numerical problems related to the calculations in the experiment.

Objectives: itemized list of actions describing the purpose of the investigation following a heading "In this experiment you will determine:-"

Theory: Scientific theory, principle and laws are presented under this sectio

Equipment: Equipment requirement for the experiment is listed down

Procedure and Data Collection: Detailed procedure is given on how to perform the measurements. The data tables provided include the units in which the measurements are to be recorded. SI units are used.

Data Analysis:

Questions: This section is a list of questions. The questions are usually related to the actual data taken by the student and attempt to require the student to think critically about the significance of the data with respect to how well the data can be said to verify the theoretical concepts that underlie the laboratory.

Learning Resources: Additional online/stand alone resources related to the experiment are listed.

References:

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To the Student ...

Come Prepared

There are no regular lectures in Experimental Physics Courses. Only cursory explanations of the relevant theory are generally presented in the lab guides. Therefore, you will find it essential for a proper understanding of the experiments to dig the theoretical background out of the textbooks of relevant courses.

Plan your work ahead of time

The time available for your work in the laboratory is limited. It is advisable to plan your work ahead of time:

- List the Objective(s);
- List the Tasks i.e. make a list of the things you have to do and the data you must obtain;
- Identify required instrument reading techniques, calibrations, precautions etc.;
- Attempt to foresee how particular problems can be circumvented.

Record Your work Clearly

You must record, in your lab notebook, sufficient information about what you have done so that you could write a complete and publishable account of your experiments days or years later without having to do anything over again. That means your lab notebook must have dates, diagrams, narratives, tables of raw data, formulas, computations, reduced data, error analysis and conclusions in a neat, compact, and orderly arrangement.

You are expected to read the lab manual before coming to the lab. You are expected to come properly equipped with calculators, graph papers and copies of the lab reports and manual.

You are expected to follow the usual rules of the laboratory; *arrive on-time, arrive prepared, no food or drink and no goofing off.* The instructors will expect that the lab report will be completed and handed in by the end of the lab period.

The Pre-Lab Questions are preparatory and must be turned in at the beginning of each lab. They are designed to prepare you for the lab and exams as well. Instructors may refuse admittance to students who do not come to lab prepared

You are required to produce a Laboratory Report at the end of your work. The report should include the data and calculations tables. You should answer the questions given at the end of the each laboratory experiment/demonstration.

EXPERIMENT 1

MEASUREMENT AND UNCERTAINTY

1.1 Prelab Assignment

1. What scientific concept(s) are used in this experiment? State them clearly.
2. Describe the specific actions you are expected to do in this experiment. Do not copy the objectives from this lab manual. Instead, try to figure them out from the lab procedures.
3. State briefly how the objectives will help you learn about the scientific concepts of measurements, errors, precision and accuracy by doing this experiment.
4. Predict the outcome of this experiment based on your understanding of the scientific concepts of measurement uncertainties. Write your hypothesis in a couple of sentences.

1.2 Objective(s) of the Experiment

In this experiment you will:-:-

- practice estimating distance, mass and time interval,
- practice how to use vernier calipers and micrometer screw gauges,
- make basic length, mass, and time measurements with increasing precisions,
- make calculations of volume and density.

1.3 Theory

In physics, measurements, observations, and data analysis are equally important as theory and conceptualization in order to understand and describe how things work. Basic measurements and observations require the use of measuring devices like the meter stick, vernier calipers, the micrometer, beam or digital balances, analog or digital timers. Data analysis is done using formulas for obtaining derived quantities and using statistics for calculating averages and errors.

All measurements have errors and uncertainties, no matter how sophisticated the measuring instrument is and no matter how hard the experimenter attempts to minimize them. Understanding and managing the sources of errors and controlling uncertainties are crucial in drawing valid and strong conclusions from the outcomes of experimental data analyses.

In addition to measurement uncertainties, calculations introduce uncertainties in the results. Below, the major concepts in measurements and handling uncertainties will be discussed in two parts: the first part focuses on measurements and units; the second part deals with the nature of error and uncertainty.

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A) Measurements and Units

Scientific measurements normally use metric units. The International System of Units (SI) is a modern form of the metric system based on units of ten.

LENGTH: The meter

The meter (m) is the basic SI unit of length. Since 1983, the meter has been defined as the distance travelled by light in a vacuum in 1/299,792,458 of a second.

There are three commonly used instruments for measuring length in the physics lab: the meter stick (or simple ruler), the vernier calipers and the micrometer screw gauge.

The Meter Stick

The simplest way to measure length is to use an ordinary meter stick. Laboratory meter sticks are carefully calibrated in centimeters with a millimeter least count which can be seen in Figure 1. This means the millimeter is the unit of the smallest reading that can be made without estimating.

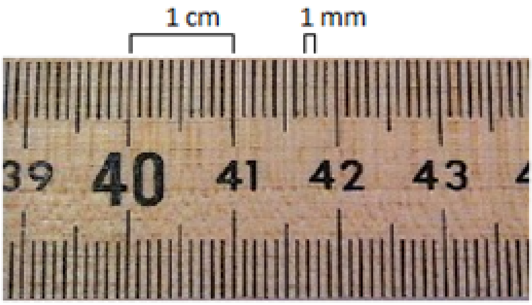


Fig. 1.1: This meter stick is calibrated in centimeters (major divisions) with a least count of millimeters.

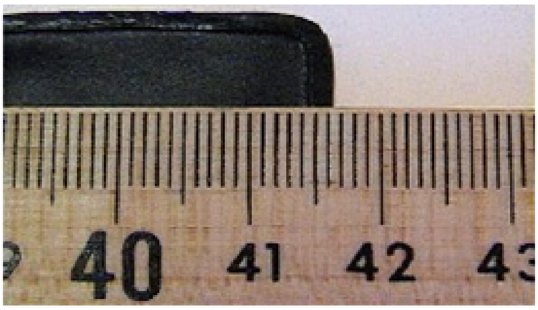


Fig. 1.2: The object's length is measured to be 41.64 cm.

The least count of the laboratory meter sticks is 0.1 cm = 1 mm and therefore a reading can be made to 0.01 cm. Figure 1.2 above shows a meter stick being used to measure the length of a plastic strip. Certainly, the length of the strip is between 41.6 cm and 41.7 cm. We then estimate the strip's length to the fractional part (doubtful figure) of the least count subdivision and report it as 41.64 cm or 0.4164 m.

The Vernier Caliper

The vernier caliper, shown in Figure 3, is used in length measurements that require better precision compared to the meter stick. The vernier is convenient when measuring small thicknesses, outer and inner diameters of round objects, and the depth of a hole.

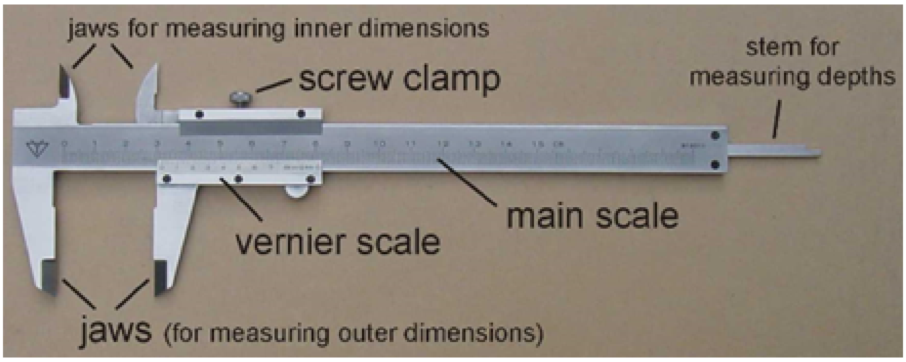


Fig. 1.3: The parts of the vernier calipers

As shown in Figure 1.3, the vernier caliper has a main scale (in millimeters) and a sliding vernier scale. The vernier scale is divided into 50 equal divisions and thus the least count of the instrument is 0.02 mm (see Figure 4). The main scale reading is the mark on the main scale immediately to the left of the zero of the vernier scale (37 mm), while the vernier scale reading is the mark on the vernier scale which exactly coincides with a mark on the main scale (the 23rd mark from zero). Therefore, the reading in Figure 4 is 37 mm + 23 x 0.02 mm = 37.46 mm. (Note that each division on the vernier = 0.02 mm.)

The Micrometer Screw Gauge

The micrometer screw gauge (Figure 1.5) is used to measure even smaller dimensions than the vernier caliper. The micrometer screw gauge has a main scale and a rotating scale. The 50 divisions on the rotating scale

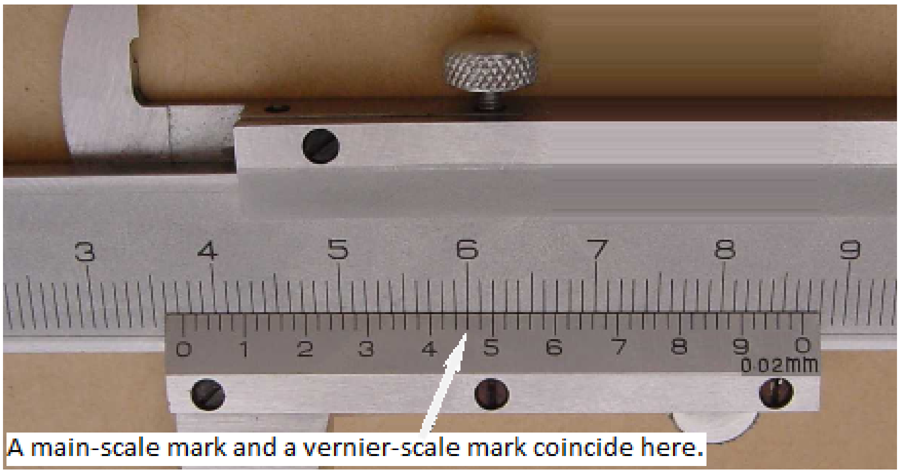


Fig. 1.4: The reading here is 37.46 mm

(thimble) are equivalent to 0.5 mm on the main scale, so the micrometer has a least count of 0.01 mm. The jaws can be adjusted by rotating the thimble using the small ratchet knob.

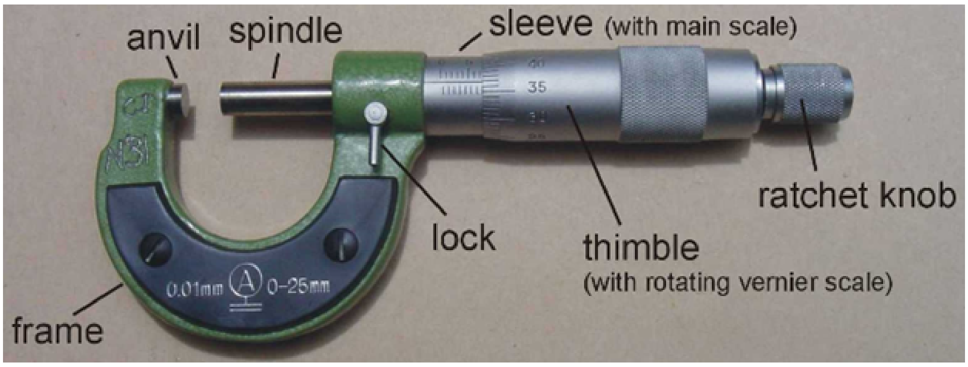


Fig. 1.5: The micrometer screw gauge

In Figure 1.6 the last main-scale mark clearly visible to the left of the thimble is 7 mm and the thimble lines up with the main scale at 38th mark (0.38 mm); therefore, the reading is 7.38 mm. In Figure 6b, the last mark on the main scale clearly visible to the left of the thimble is 7.5 mm; therefore, the reading is 7.5 mm plus the thimble reading of 0.22 mm, giving 7.72 mm.

MASS: The Kilogram

The kilogram (kg) is the SI unit of mass. In the lab, we usually work with the gram (g) which represents one-thousandth of a kilogram, and with the milligram (mg) which equals one-thousandth of a gram.

To read the mass value on the triple beam balance in Figure 1.9, start with the middle scale, then read from the upper scale and finally read from the lower scale.

TIME: The Second

The second (s) is the basic SI unit of time. In the physics lab we use analog or digital stopwatches to measure time intervals.

Volume

The basic unit of volume used in the science lab is the liter (L). A fraction of the liter is the milliliter (mL) which is one-thousandth of a liter (0.001 L).

Density

Density can be calculated from measured values of mass and volume using the formula:

$$\rho = \frac{m}{V} \qquad \text{(The SI unit is kg/m}^3\text{)}$$

(a): The reading is 7.38 mm

(b): The reading is 7.72 mm

Fig. 1.6: Readings of vernier caliper

Volume can also be calculated from other measurements. For example, for a right cylinder:

$$V = \pi r^2 \ell = \frac{1}{4}\pi d^2 \ell$$

where: r = radius, d = diameter, ℓ= length and π = ratio of circumference to diameter ($\approx 22/7$). Combining the two euaton we obtain a density forula interms of measurale quantities

$$\rho = \frac{4m}{\pi d^2 \ell}$$

The densities of liquids are usually reported in grams per milliliter (g/mL). The densities of solids are usually reported in grams per cubic centimeter (g/cm^3). The density of water is 1 g/mL. Substances with densities less than 1 g/mL will float on water. Other densities: Aluminum = 2.70 g/cm^3, Iron = 7.85 g/cm^3, Lead = 11.35 g/cm^3, Gold = 19.30 g/cm^3.

B) The Nature of Error and Uncertainty

C) Error

Error is defined as the difference between an observed value and a true value.

$$\text{Error} = \text{observed value} - \text{true value}$$

The observed value is either a result of direct measurement or a calculated value using other measured values in a formula. The “true” value exists but is unknown. Then how can one determine the error in measurements? The goal of measurement is to estimate the true value of a physical constant using experimental methods.

D) Sources Error

Measurement errors can arise from three possible origins: the measuring device, the measurement procedure, and the measured quantity itself. Usually the largest of these errors will determine the uncertainty in the data. Errors can be divided into two different types:

Systematic errors: Arise from procedures, instruments, bias or ignorance. Systematic errors bias every measurement in the same direction, that is, they will cause your measurement to consistently be higher or lower than the accepted value. Example: A mis-adjusted digital timer either lags or advances in time

One instrument for measuring mass is the triple-beam balance (Figure 1.8). The triple-beam balance measures the mass of an object by balancing it with sliding masses of known values. The triple-beam balance is usually calibrated in grams with a least count of 0.01 g. Before the triple-beam balance is used to make a measurement, verify that the balance is properly zeroed. Fine adjustments may be made by turning the knob under the balance pan.

Fig. 1.7: A standard one-kilogram weight kept inside glass jars. (Notice that this physical standard is replaced by quantum methods in 2019.)

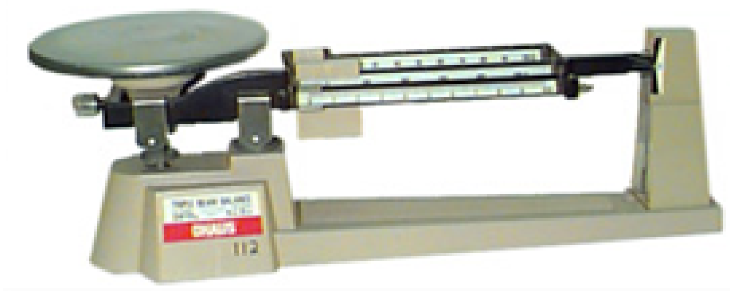


Fig. 1.8: The triple-beam balance)

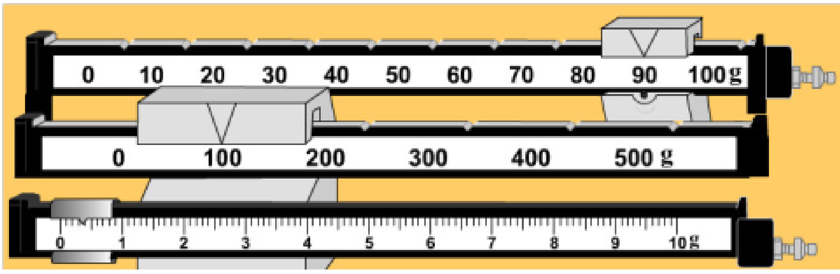


Fig. 1.9: Reading of a triple beam balance Middle scale reading: 100 g Upper scale reading: 90 g, Lower scale reading: 0.4 g, The mass is 190.4 g

(a): Analogue *(b): Digital*

Fig. 1.10: Stopwatches

compared to the standard measure of time. Systematic errors can be estimated from understanding the techniques and instrumentation used in an observation.

Random errors: Uncontrollable differences between measurements because of environment, equipment, or other sources, no matter how well designed and calibrated the tools are. Random errors are unbiased small variations that have both positive and negative values. Random errors can be estimated from statistical repetition. In general, making multiple measurements and averaging can reduce the effect of random errors.

Note: Any measurement is reported by including an estimate of the random uncertainty. If we measure a time of 7.6 s and expect a random error of about 0.2 s, we write the result as t = (7.6 ± 0.2) s where $\pm$ indicates the random uncertainty is unbiased.

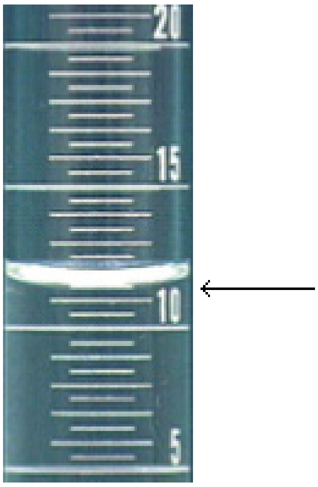


Fig. 1.11: Graduated cylinder with meniscus at 11.5 mL

$$1\,\mathrm{L} = 1000\,\mathrm{mL} = 1000\,\mathrm{cm}^3, 1\,\mathrm{mL} = 1\,\mathrm{cm}^3$$

The volume of an irregularly shaped object may be determined with the use of a graduated cylinder. To do so, fill the cylinder with water and completely immerse the object in the liquid. The volume of the object is the difference in the water levels before and after the object was immersed. Graduated cylinders are usually calibrated in milliliters or cubic centimeters but their least counts vary from 1 mL to 10 mL depending on the size of the vessel. Figure 1.11 shows a 25 mL graduated cylinder with a least count of 0.5 mL.

When reading a glass graduated cylinder, read the volume at the bottom of the meniscus. The meniscus is the curved surface of the water. In Figure 1.11, the meniscus is marked with an arrow. The volume equals 11.5 mL.

Fluctuations

Fluctuations are other contributors to uncertainty that are not classified as âĂŸexperimental error', but still represent differences between measured and âĂŸtrue' values. Fluctuations indicate the variability in a measurement from its average due to some physical process. They are not random errors in the same sense as above. Example: the number of air molecules in an open glass fluctuates not because of a random error but because of the physical process of molecular motion into and out of the glass.

E) Accuracy vs. Precision

In physics, there are two distinct and independent aspects of measurement related to uncertainties:

Accuracy: refers to the closeness of a measured value to the âĂŸtrue' (standard or known) value. It describes how well we eliminate systematic error. Example: if you measure the weight of a given substance as 3.2 kg, but the actual or known weight is 10 kg, then your measurement is not accurate. In this case, your measurement is not close to the known value.

Precision: refers to the closeness of two or more measurements to each other without referring to the 'true' value. It describes how well we suppress random errors. Example: if you weigh a given substance five times, and get 3.2 kg each time, then your measurement is very precise

Precision and accuracy are independent. A measurement can be precise but inaccurate, or accurate but imprecise as illustrated by the several independent trials of shooting at a bullseye target in Figure 1.12.

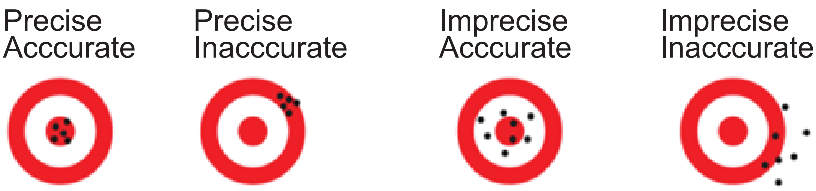


Fig. 1.12: Illustration of the difference between accuracy and precision

F) Notation of Uncertainties

Let δx represent the magnitude of the absolute uncertainty of a measurement in x in the same units. The result is then expressed as $x \pm \delta x$.

Example: suppose a length measurement of L=2 m has uncertainty $\delta L = 6\,\mathrm{cm}$. We would then write $L = (2.00 \pm 0.06)$ m. Note that L and δL have the same number of digits after the decimal point.

G) Estimating Uncertainties

We will now discuss three approximation techniques to estimate uncertainties.

Upper Bound

In Figure 1.13, a meter stick is used to measure the length of an object. Definitely, the length is between 46.4 cm and 46.6 cm. To estimate the instrumentâĂŹs accuracy, assume, as an upper bound of the uncertainty, an amount equal to half of the smallest division (least count) that can be unambiguously read from the device. The least count of the meter stick is 1 mm (0.1 cm). The uncertainty in using the meter stick is therefore 0.5 mm (0.05 cm). The final result can be written as:

$$L = (46.5 \pm 0.1)\,\text{cm}$$

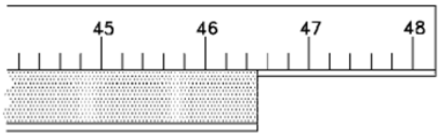


Fig. 1.13: Measuring Length

Estimation from the Spread

Find the interval around the mean ($\bar{x}$) that contains about 68% of the measured points: half the size of this interval (34%) is a good estimate of the uncertainty in each measurement. If a value is given as $\bar{x} \pm \delta x$, the range $\pm\delta x$ is called the **level of confidence** of the result. Assuming no systematic biases, the true value lies between $\bar{x} - \delta x$ and $\bar{x} + \delta x$ 68% of the time. Calculating the mean and standard error in repeated measurements is discussed below under "Quantifying Uncertainties".

Square-Root Estimation in Counting

For inherently random phenomena that involve counting individual events or occurrences, we measure only a single number N. The (absolute) uncertainty of such a single measurement is estimated as the square root of N, that is, a counting measurement is expressed as $N \pm \sqrt{N}$.

Example: if we observe 50 radioactive decays in 1 second, we should present the result as $50 \pm \sqrt{50}$ i.e. 50 ± 7 decays per second indicating that a subsequent measurement performed identically could easily result in numbers differing by 7 from 50.

H) Quantifying Uncertainties

Experimental precision requires using statistics to quantify random errors. Although statistical analysis is beyond the scope of this general physics lab, few important derivations are discussed below.

The mean

Suppose a quantity x is measured N times. A sample of the measured values is $(x_1, x_2, x_3, \ldots x_N)$. We want the mean, μ, of the *population* from which such a data set was randomly drawn. We can approximate μ with the sample mean (average) of this particular set of N data points:

$$\mu \cong \bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

Of course, this is not the true mean of the population, because we only measured a small subset of the total population. But it is our best guess and, statistically, it is an unbiased predictor of the true mean μ.

The standard deviation

The precision of the value of x is determined by the sample standard deviation, s_x,defined as

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

The square of the sample standard deviation is called the sample variance, s_x^2. The sample standard deviation is our best 'unbiased estimate' of the true statistical standard deviation σ_x of the population from which the measurements were randomly drawn; It is what we use for a 68% confidence interval for one measurement (i.e. each of the x_i).

The standard error

If we do not care about the standard deviation of one measurement but, rather, how well we can rely on a calculated average value, $\bar{x}$, then we should use the standard error or standard deviation of the mean $s_{\bar{x}}$. This is found by dividing the sample standard deviation by $\sqrt{N}$

$$s_{\bar{x}} = \frac{s_x}{\sqrt{N}}$$

Reporting Data

Under normal circumstances, the best estimate of a measured value x predicted from a set of measurements x_i is reported as $x = \bar{x} \pm s_{\bar{x}}$, where the standard error is now the statistical uncertainty $\delta x = s_{\bar{x}}$. The uncertainties should be given to the same number of decimal places as the measured values.

Example: $x = \bar{x} \pm s_{\bar{x}} = (434.2 \pm 1.6)$ nm.

I) Error Propagation

Measurement uncertainties propagate through calculations that depend on several uncertain quantities. Suppose that you have two quantities x and y, each with an uncertainty δx and δy, respectively. What is the uncertainty of the quantity $x \pm y$ or xy (or x/y)? The rules for uncertainty propagation assume that the errors δx and δy are uncorrelated, i.e., they are completely random.

1. Multiplication by an exact number: If $z = cx$, then $\delta z = c\delta x$
2. Addition or subtraction by an exact number: If $z = c + x$, then $\delta z = \delta x$
3. Addition or subtraction: If $z = x \pm y$, then $\delta z = \sqrt{(\delta x)^2 + \delta y)^2}$
4. Multiplication or division: If $z = xy$ or $z = x/y$, then
$$\frac{\delta z}{z} = \sqrt{\left(\frac{\delta x}{x}\right)^2 + \left(\frac{\delta x}{x}\right)^2}$$
5. Power: If $z = x^c$, then $\frac{\delta z}{z} = c\frac{\delta x}{x}$

Example:

The Atwood machine consists of two masses M and m (with $M > m$) attached to the ends of a light string that passes over a light, frictionless pulley. When the masses are released, they accelerate with $a = g(M-m)/(M+m)$. Suppose that M and m are measured as $M = 100 \pm 1$ and $m = 50 \pm 1$, both in grams. Find the uncertainty in the acceleration measurement, δa.

Solution:

$$\delta a = g\,\delta\left(\frac{M-m}{M+m}\right) \quad \text{by rule 1}$$

$$\delta a = g\left(\frac{M-m}{M+m}\right)\left[\left(\frac{\delta(M-m)}{M-m}\right)^2 + \left(\frac{\delta(M+m)}{M+m}\right)^2\right]^{\frac{1}{2}} \quad \text{by rule 4}$$

$$\delta a = g\left(\frac{M-m}{M+m}\right)\left[\frac{(\delta M)^2+(\delta m)^2}{(M-m)^2} + \frac{(\delta M)^2+(\delta m)^2}{(M+m)^2}\right]^{\frac{1}{2}} \quad \text{by rule 3}$$

$$\delta a = \frac{2g}{(M+m)^2}\sqrt{m^2(\delta M)^2 + M^2(\delta m)^2} = \frac{2\times 9.8}{150^2} \times \sqrt{50^2 + 100^2} = 0.097$$

$$a = g\frac{M-m}{M+m} \pm \delta a = 9.8 \times \frac{50}{150} \pm 0.097 = (3.3 \pm 0.1)m/s^2$$

1.4 Significant (Essential) Figures

The *significant figures* of a number are the digits that contribute to the precision of the number. For example, if the uncertainty in a measurement of length is ± 0.1 cm, the length value should not be expressed as 70.056 cm. The result should be rounded to three significant figures as 70.1 cm, discarding the completely uncertain digits called noise.

Leading zeroes are not significant. Example: 0.12 and 0.040 have just two significant figures. Other zeroes are significant. Example: 1002, 1200 and 10.02 have four significant figures. In scientific notation, the number 1.20×10^1 has three significant figures while 1.20×10^2 has only two significant figures.

1.5 Equipment

Equipment Needed	**Quantity.**
Meter Stick or Metric Ruler	1
Vernier Caliper	1
Micrometer Screw Gauge	1
Triple-beam balance	1
Graduated Cylinder, 25 mL	1
Stopwatch-digital	1
Rectangular block	1
Cylindrical Blocks (copper and aluminum)	2
Coin (1 Birr)	1

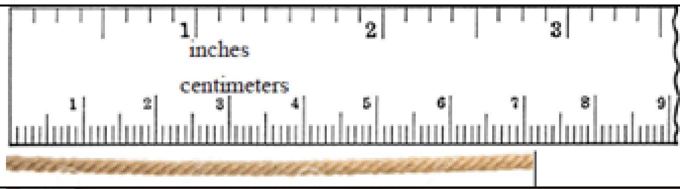
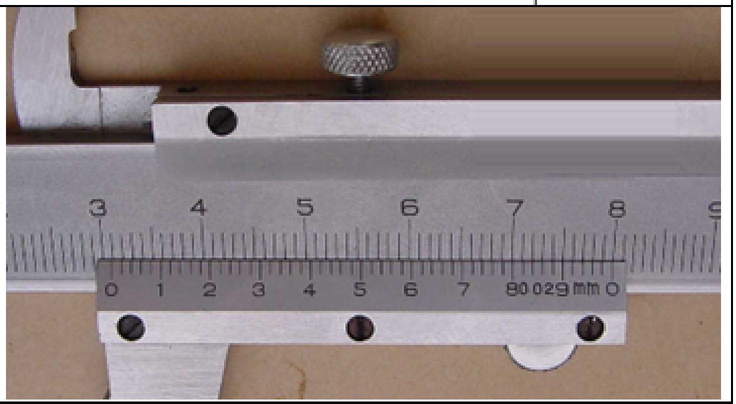
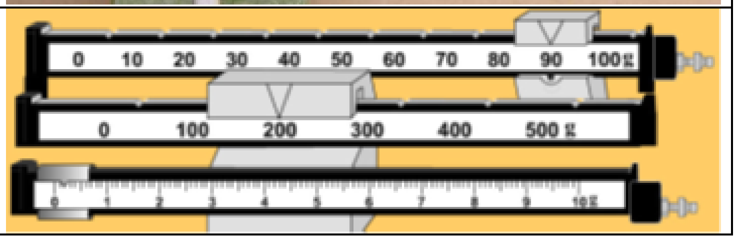
1.6 Procedure/ Data Collection

1.7 Data Analysis and Results

1. Complete each data table with calculated values. Show clearly standard formulas for calculating areas and volumes for each object.
2. Discuss the accuracy and precision of your length, mass and time measurements in terms of the percent errors in calculations and measurement uncertainties.
3. Make valid conclusions from your results.

1.8 Questions

1. Why is it important to correctly estimate length, time, and mass?
2. Compare your estimates of length, mass and time to actual measurements by calculating the percent errors.
3. Sometimes many trials are run and recorded. Then the highest and lowest data points are disregarded when taking the average. Explain why.
4. Which is more accurate, individual measurements or their average? Explain.
5. Suppose you are provided with a ruler the ends of which are worn a bit. How should you start your measurements in order to minimize the possibility unacceptable errors?
6. For the figures below identify the value of the major mark and the value of the minor mark (least count) and write the reading from the instrument

Meterstick	
Vernier caliper	
Micrometer screw gauge	
Triple beam balance	

1.9 Additional Learning Resources

- PhET Interaction Simulations
- OpenStaxCollege
- ScienceOnline
- Hyperphysics
- Physics LibreTexts

1.10 References

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EXPERIMENT 2

LOCAL ACCELERATION DUE TO GRAVITY USING SIMPLE PENDULUM

2.1 Pre-Lab Assignment

1. How is a pendulum set?
2. What are the required apparatuses?
3. What is the known and standard acceleration due to gravity?
4. What are the factors affecting the acceleration due to gravity?

2.2 Objective(s) of the Experiment

In this experiment you will:-

- investigate the relation between the period of a simple pendulum and its length.
- determine local acceleration due to gravity

2.3 THEORY

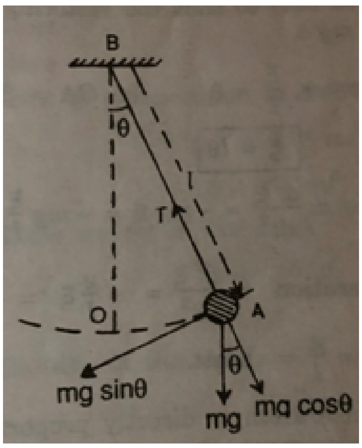

Fig. 2.1: Forces on oscillating pendulum

The simple pendulum consists of a small bob (in a theory a 'particle') of mass m suspended by a light inextensible thread of length l from the fixed point B. If the bob is drawn aside slightly and released, it oscillates to-and -fro in a vertical plane along the arc of a circle. We shall show that it describes S.H.M. about its equilibrium position O.

Suppose at some instant the bob is at A where arc OA = R and angle $\angle OBA = \theta$. The forces acting on the bob in this position are

(i) The tension T along the string, and

(ii) The weight mg acting vertically downward. Resolving mg into its rectangular components, radially and tangentially at A

The component $mg\cos\theta$ acting perpendicular to the tangent is balanced by the tension T, whereas $mg\sin\theta$ acting along the tangent is the only unbalanced force which tends to restore the bob back to its normal position.

Hence the equation of motion of the bob is

$$ma = -mg\sin\theta$$

where a is the acceleration of the bob along the arc at A due to the force $mg\sin\theta$.

The negative sign indicates that the force is towards O while the displacement R is measured along the arc from O in the opposite direction.

When θ is small, *sin* $\theta \approx \theta$ in radians *(eg.* If θ *= 50; sin* θ *= 0.0872* then θ *0.0873 rad)* so that the restoring force becomes $mg\theta$.

Moreover,

$$\frac{R}{l} = \theta \qquad \text{(OA=R), Therefore, } R = I\theta\text{, Hence}$$

$$ma = -mg\theta = -mg\frac{R}{l}$$

$$\text{acceleration} = a = -\frac{g}{l} - \omega^2 R$$

where $\omega^2 = \frac{g}{l} =$ constant and $\omega = \frac{2\pi}{T} = \frac{\nu}{R}$

As the acceleration is directly proportional to the displacement, the motion of the bob (or simple pendulum) is simple harmonic if the oscillations are of small amplitude i.e., θ *does not exceed* 10^0.Hence the period T of the simple pendulum;

$$T = 2\pi\sqrt{\frac{l}{g}}$$

from which the acceleration due to gravity, g, can be obtained as

$$g = 4\pi^2\frac{l}{T^2}$$

2.4 Apparatus

Equipment Needed	Quantity.
Mass (bob of different size)	3
String with manageable length	
Support (stand and ceiling)	1
Digital/analog stop watch	1
Meter stick	1

2.5 PROCEDURE/ DATA COLLECTION

1. Connect the bob to the string which is suspended from some height (ceiling).
2. Make the initial length of the pendulum 80 cm., and consecutively increase the length by 10 cm interval five times.
3. For each of the increment give the pendulum a small displacement.
4. Allow each pendulum to make four complete cycles. Record the time taken.
5. Divide the total time into four to get average period T (time for each oscillation).
6. Repeat the experiment by changing the bob of small/large mass.

2.6 DATA ANALYSIS

1. Calculate acceleration due to gravity using the average period.
2. Find average($\bar{g}$).
3. Find the standard deviation.

Table 2.1: Add caption

Number of activity	Time t of oscillation	Length (l)	Time T for each oscillation	T^2	g	$g-\bar{g}$	$(g-\bar{g})^2$
1							
2							
3							
4							
5							
Average							

4. Using the standard $9.81\mathrm{m/s}^2$, find the percentage error.
5. Plot the period g vs. T.
6. Plot l vs. g.

2.7 QUESTIONS

1. What is the relation between period and the amplitude of the oscillations?
2. Does the change of mass affect the acceleration due to gravity?

2.8 REFERENCES

1. K.K. Mohindroo, 1999. Basic Principles of Physics, 3rd ed. Vol.1., Pitambar Publishing Company, New Delhi.
2. Sears and Zimansky, University Physics with modern Physics, Yaoung and Freedman, 13th edition, 2012.

PROJECTILE MOTION

3.1 Pre-Lab Assignment

1. During projectile motion, what are the velocity and acceleration of the horizontal motion?
2. Suppose you are running at constant velocity and you wish to throw a ball such that you will catch it as it comes back down. In what direction should you throw the ball relative to you?
3. A ball is thrown in such a way that its initial vertical and horizontal components of velocity are 30 m/s and 40 m/s, respectively. Estimate the total time of flight and the distance the ball is from its starting point when it lands.
4. Referring to the preceding question, find the maximum height that can be reached.

3.2 Objective(s) of the Experiment

In this experiment you will:-:-

- To determine the range as a function of the angle of inclination.
- To determine the maximum height of projection as a function of the angle of inclination.
- To determine the (maximum) range as a function of the initial velocity.

3.3 THEORY

In this experiment, you will observe an object that would move in both the x-and y-directions simultaneously under constant acceleration. An important special case of this two dimensional motion is called projectile motion.

Whenever you toss any kind of object in to air you observe a projectile motion. If the effects of air resistance and the rotation of Earth are neglected, the path of the projectile in Earth's gravitational field is curved in the shape of a parabola, as shown in Active Figure 3.1

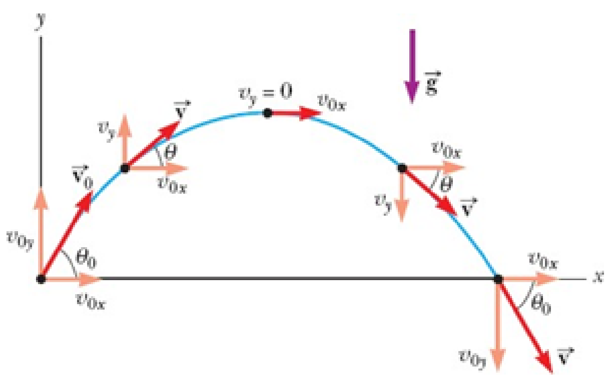

Fig. 3.1: Motion of an object under the effect of gravitational force

The positive x-direction is horizontal and to the right, and the y-direction is vertical and positive upward. The most important experimental fact about projectile motion in two dimensions is that the horizontal and vertical motions are completely independent of each other. This means that motion in one direction has no effect on motion in the other direction.

Following the aim of this experiment, the formulas of the maximum height and maximum range should be defined.

There are two alternatives in order to find the maximum height.

1. The formula

$$v_{fy}^2 = v_{oy}^2 - 2gH \tag{3.1}$$

Can be used, where v_{oy}, v_{fy}, g and H are the initial speed, the final speed, the gravitational acceleration and the maximum height, respectively. Since the gravitational acceleration is in the opposite direction of the ground, it causes the decreamentation of speed. Therefore its sign will be negative, as shown in eq 3.1. Since the final vertical speed is equal to 0 ($v_{fy} = 0$) at the maximum height, hence eq. 3.1 can be rearranged as:

$$v_{oy}^2 = v_o \sin\theta \tag{3.2}$$

where the initial speed can be defined as

$$v_{oy} = v_o \sin\theta \tag{3.3}$$

where θ is the angle with the horizontal axis x which can also be seen in Fig.3.1. Substituting eq 3.3 in eq 3.2 and rearranging, the maximum height becomes

$$H = \frac{v_o^2 \sin^2\theta}{2g} \tag{3.4}$$

2. The other method is, after the ball arrive the highest point, its speed is instantly zero. Then it takes the maximum height H by free motion (without any initial vertical speed). As a consequence, the formula of

$$y(t) = \frac{1}{2}gt^2 \tag{3.5}$$

where t is time for the half flight of the ball. These time, t, can be obtained by the general formula of

$$v_y = gt \qquad \text{or} \tag{3.6}$$

$$t = \frac{v_y}{g} \tag{3.7}$$

Here, v_y is a velocity for down ward flight at any time t. If the first speed is zero, then the flying time can be found directly by eq 3.7. It is also known that the initial vertical speed is equal to the final vertical speed when the motion is completed. Therefore, the half of flying time $t = t_{down} = t_{up}$ and hence, the total time of flight t can be obtained,

$$t_{down} = \frac{v_o \sin\theta}{g} \tag{3.8}$$

substitutin this in equation 3.5, it follows

$$H = \frac{v_o^2 \sin^2\theta}{2g} \tag{3.9}$$

which is the same result as eq 3.4.

In this step, after the calculation of the maximum height, the maximum range which will be named as R can be found.

The horizontal motion has the constant speed which is equal to $v_\circ \cos\theta$. The general range R formula of the constant speed motion can be expressed as

$$R = v_{av} t \tag{3.10}$$

$$v_{av} = \frac{v_{ox} + v_{fx}}{2} = v_\circ \cos\theta \tag{3.11}$$

The motion takes double of half of the whole flight time, t_{fly}, which can be defined as

$$t_{fly} = t_{up} + t_{up} = \frac{2v_\circ \sin\theta}{g} \tag{3.12}$$

substituting this in equation 3.10 we obtain

$$H = \frac{v_\circ^2 \sin^2\theta}{2g} \qquad \text{where } \sin 2\theta \cos\theta \tag{3.13}$$

3.4 Equipment

Equipment Needed	Quantity.
Ballistic unit	1
Recording paper, 25 m	1 roll
steel balls, hardened and polished, d = 19mm.	2
Two tier plat form support	1
Meter Scale, ℓ= 1000 × 27mm	1
Barrel base	1
Speed measuring attachment	1
Power supply 5 VDC/2.4 A with DC-socket 2.1mm	1

3.5 PROCEDURE/ DATA COLLECTION

1. The ballistic unit and barrel base which are used for launching the steel ball have three speed levels from the lowest to the highest speed, respectively. The angle of motion can be adjusted by changing the barrel base, as can be refereed from Fig 3.2.

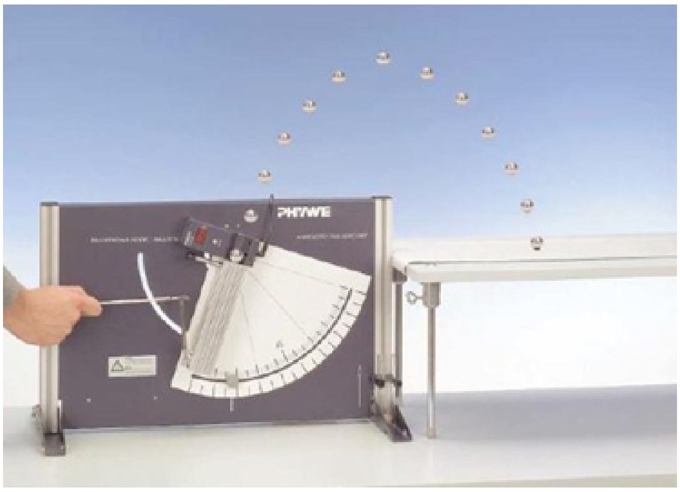

Fig. 3.2: Experimental set-up for measuring the maximum range of a projectile with additional equipment to measure the initial velocity

2. There cording paper is used for the determination of the point where the steel ball hits. It also represents the maximum range point for the related motion.

3. The speed measuring device which is shown by red digital segment depicts (shows) the launching speed of ball.

4. The meter scale which has the scale of 1000mm = 1m is used in order to measure both maximum height in vertical direction and maximum range in horizontal direction.
5. The maximum height H and maximum range R will be investigated for the different motion angles.
6. Please only use the first speed level of the projection system due to the laboratory conditions that cannot especially satisfy the maximum range, but you can make changes if you have enough room space.
7. For the angle of 15°

3.6 DATA ANALYSIS

1. Repeat the procedure for the angle 30° and 45° with the same initial velocities. What will happen if the angle increases further?
2. Plot the angles θ vs. R.
3. Plot the angles θ vs. H.
4. Determine the percentage errors between the calculated and measured average values.
5. Discuss the graphs.

3.7 QUESTIONS

1. Discuss the possible sources of errors.
2. At what angle is the maximum height reached do you think? What about maximum horizontal range?

3.8 REFERENCES

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2. PHYWE System Gmb H & Co. K G, Robert-Bosch-Breite 10D-37079 Göttingen, Germany `www.phywe.com`
3. INDOSAW: Science Teaching,www.indosawedu.com

EXPERIMENT 4
CENTRIPETAL FORCE

4.1 Pre-Lab Assignment

1. What are the main purposes of this experiment? Discuss briefly.
2. Write down the quantities that you are required to measure during the experiment.
3. Suppose a particle of mass m moves in a circle of radius r at constant speed v. Then,
   (a) write down the equations for the centripetal acceleration and force,
   (b) determine the direction of the centripetal acceleration and force, and
   (c) determine its period and the angular frequency.

4.2 Objective(s) of the Experiment

In this experiment you will:-:-

- study the nature of centripetal force, and
- to study the relationship between centripetal force, mass, and velocity.

4.3 THEORY

An object moving with a changing speed in the same direction is undergoing acceleration. If an object moves with a constant speed but is changing direction, it is also undergoing acceleration. Both types of accelerations require a force. A change in direction is called *centripetal acceleration*, and the force producing it is called *centripetal force*.

Consider the schematic shown in Fig 4.1: an object of mass is traveling in uniform circular motion with radius r, at a constant tangential speed of v_t. Because the mass is constantly changing direction it is subject to centripetal acceleration, a_c, given by the equation:

$$a_c = \frac{v_t^2}{r} \tag{4.1}$$

where r is the radial distance from the top of the tubing to the center of the rotating rubber stopper of mass m_1.

The force causing the centripetal acceleration, the centripetal force, must obey Newton's second law:

$$F_c = m_1 a_c = \frac{m_1 v_t^2}{r} \tag{4.2}$$

In this experiment, mass m_1 will be the mass of a rubber stopper moving at a constant tangential speed of v_t at the end of a nylon cord of length r. The centripetal force will be supplied by a mass m_2 that is attached to the bottom of the nylon cord (See Fig. 4.1). Mass m_2 will include both the slotted mass and a hanger. The weight of this hanging mass is determined by the equation:

$$F_w = m_2 g$$

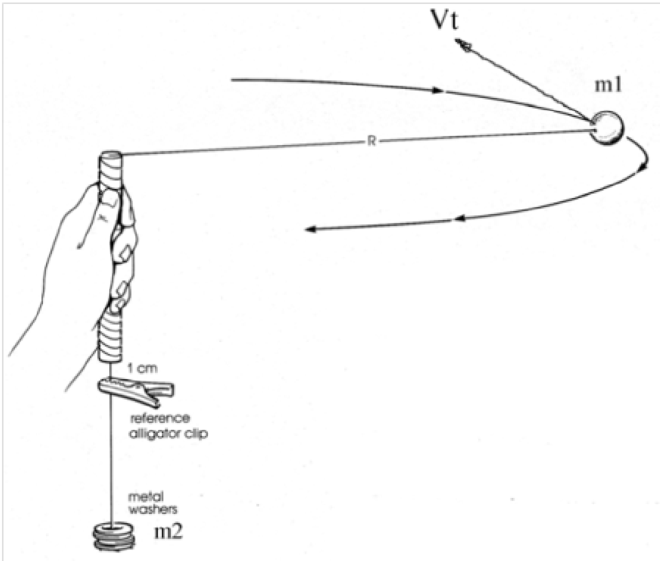


Fig. 4.1: Centripetal force.

The weight of the hanging mass is the centripetal force applied to mass m_1 , keeping it in a horizontal circular orbit

$$F_c = F_w \qquad \text{or}$$
$$\frac{m_1 v_t^2}{r} = m_2 g$$

Therefore, the tangential velocity ($v = v_t$) required to keep this system in equilibrium, will be:

$$v_t = \sqrt{\frac{m_2 g r}{m_1}}$$

The measured tangential velocity is determined using the following formula:

$$v_t = \omega r$$

where ω is the angular velocity given by

$$\omega = \frac{2\pi}{T} \qquad \text{(in rad/sec)}$$

where T is the period which is equal to the time for one complete revolution

4.4 Apparatus

Equipment Needed	**Quantity.**
Centripetal Force Kit consisting of	
PVC tubing	1
Nylon cord, and	1
Rubber stopper	1
Slotted masses: 50 g, 100 g, 150 g, 200 g	4
Slotted mass hanger	1
Stop watch	1
Triple beam balance	1
Paper clip	1

4.5 PROCEDURE/ DATA COLLECTION

1. Measure the mass of the rubber stopper using a triple beam balance, and record this value as mass m_1 below.
   m_1 = ______ kg (rubber stopper mass)

2. Measure the mass of the hanger and slotted mass (initially 50 g) and record this value as mass m_1 in the data Table 2 shown below.

3. Pass the nylon cord attached to the rubber stopper through the PVC tubing. Attach a 50 g mass and hanger to the free end of the cord. Adjust the length of the cord between the top of the tubing and the center of the rubber stopper to approximately 80 cm.

   Mark the location of the cord by placing a paper clip one centimeter below the tubing, as shown in Fig 4.1. Record this length as r.
   r = ______ m

4. Support the 50 g mass assembly with one hand and hold the tubing in the other hand. Whirl the rubber stopper in a horizontal orbit above your head, by revolving the tubing. Slowly release the 50 g mass assembly and adjust the speed of the revolution so that the paper clip stays just one centimeter below the bottom of the tube.

5. When you have learned how to keep the rotation speed and position of the paper clip constant, have your lab partner measure the time interval required for ten complete revolutions (Remember to start counting at zero, not at one!). When the timing is over, grab the cord at the bottom of the tube before the speed of the stopper changes. Perform three measurements (trials) and calculate the average time for ten revolutions - Record the measurements as in Table 4.1.

Table 4.1: Data for Procedure No. 5.

Trials	Time, t, for 10 revolutions (rev)
1	
2	
3	
Average time for 10 rev:	

6. Repeat Steps 4 and 5 for different hanging masses (100 g, 150 g, 200 g). For each mass perform three measurements and calculate the average time for ten revolutions. Summarize your data and results in the table below. Be sure that all units are SI.

Table 4.2: Data and calculation table

Mass, m_2 (kg)	Av. time for 10 rev	Time, T, for 1 rev	$\omega = 2\pi/T$ (rad)	$v_t = \omega r$ (Measured)	$v_t = \sqrt{m_2 g r / m_1}$ (Calculated)	$F_c = F_w = m_2 g$
0.050						
0.100						
0.150						
0.200						

4.6 DATA ANALYSIS

Note: In your experimental (lab) report, be sure to include a sample of all calculations, error analysis, and a conclusion.

1. Determine the time (period, T) it takes for one revolution and record that time in the data Table 4.2.

2. Calculate and record the centripetal speed and the centripetal force.

3. Compare the calculated centripetal speed with the measured centripetal speed and calculate the percent error.

$$\text{Percentage Error} = \frac{\text{Calculated value} - \text{Measured Value}}{Calculated value} \times 100\%$$

4.7 QUESTIONS

1. A particle of mass 0.350 kg moves in a circle of radius r = 1.35 m at a constant speed of v = 6.70 m/s. What is the magnitude and direction of the centripetal force acting on the particle? ______

2. A 0.5 kg particle moves in a circle of radius r = 0.15 m at constant speed. The time for 20 complete revolutions is 31.7 s.
   (a) What is the period T of the motion? ______
   (b) What is the frequency f of the circular motion? ______
   (c) What is the speed v of the particle?______
   (d) What is the magnitude of the centripetal acceleration?______

EXPERIMENT 5

COEFFICIENTS OF STATIC AND KINETIC FRICTION

5.1 Pre-Lab Assignment

1. What do you expect to know/learn from this experiment?
2. What are the quantities that are to be measured during the experiment? Also, write down the quantities that are to be determined (calculated) from the measured values.
3. Suppose a block of mass m lies on a plane inclined at an angle θ. Let θ_s be the maximum angle at which the mass can remain static on the plane. Let θ_k be the angle at which the block slides down the incline at constant speed. Show that the coefficient of static friction is $\mu_s = \tan\theta$ and that the coefficient of kinetic friction is $\mu_k = \tan\theta_k$. (Draw the force diagram.)
4. For either type of coefficient of friction, what is generally assumed about the dependence of the value of the coefficient on the area of contact between the two surfaces? ________________.

5.2 Objective(s) of the Experiment

In this experiment you will:-:-

- measure the coefficient of static and kinetic friction between two surfaces.

5.3 THEORY

When a body rests or slides on a surface, contact forces are present as part of the interaction of the object and the surface it is residing on. The contact force can be resolved into its perpendicular and parallel components. The perpendicular component of the contact force is called the normal force (N) and the component parallel to the surface is the frictional force (f). The direction of the frictional force is always such as to oppose the motion of the body relative to the surface.

For an object in motion, the frictional force is called kinetic friction. Kinetic friction is present whenever two surfaces are in motion with respect to each other. The magnitude of this force is proportional to the normal force and is given by

$$f_k = \mu_k N \tag{5.1}$$

where N is the magnitude of the normal force and μ_k is called the coefficient of kinetic friction.

Friction is always present even when there is no relative motion. This is called the static friction force and we could define a corresponding coefficient of static friction μ_s. The static friction is also proportional to the magnitude of the normal force while at rest and reaches maximum at the point where the body just starts to move relative to the surface. In general, we have

$$0 \leqslant f_s \leqq (f_s)_{max} \tag{5.2}$$

where f_s is the static friction and its maximum value is given by

$$(f_s)_{max} = \mu_s N \tag{5.3}$$

These coefficients are generally dependent on the nature of the surfaces. In particular the coefficient of kinetic friction depends on the relative speed of the surfaces. For certain range of speed, the coefficient of kinetic friction is fairly constant.

In the experiment, the frictional force (f) will be measured as a function of the normal reaction force (N). The graph of f versus N is plotted. The graph is expected to be a straight line, as shown below.

The coefficient of friction (static or kinetic) is determined from the slope of the graph. That is,

$$\mu_s = \text{Slope} = \frac{f}{N} \tag{5.4}$$

5.4 Equipment

Equipment Needed	Quantity.
Wooden block (A) with a hook attached to it	1
A plane piece of wood (B) with a grooved wheel at one end	1
Scale pan (D)	1
Light string	1
Set of standard weights	1 set
Spring balance	1

5.5 PROCEDURE/ DATA COLLECTION

1. Arrange the apparatus as shown in Fig 5.1

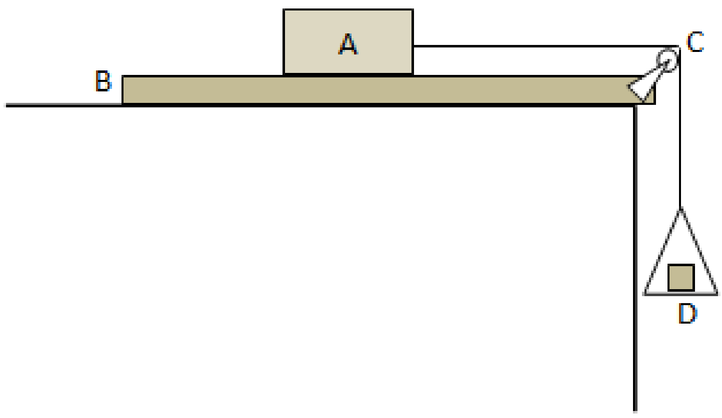


Fig. 5.1: Experimental setup

2. Weigh the block A (m_A) and the scale pan D (m_D) on the spring balance. Record the readings.
3. Attach the scale pan D to the hook of A by a light string passing round the wheel C.
4. Mark the initial position of the block A with a pencil.

A) Coefficient of Static Friction

1. Mark the initial position of the block A with a pencil. Then gently add weights to the scale pan D until block A just begins to slide. Record the weight in the scale pan D.
2. Next return A to its initial position and increase the reaction force of the wooden block B by placing a known weight on A. Then add weights to D until A begins to slide again. Record the weight in D.
3. Repeat Step 2 for two more increasing weights on A. Record the weights both on the block A and the scale pan D, and tabulate as in Table 5.1.

Table 5.1: Data for calculating the coefficient of static friction

Mass added on A (m_i)	Mass on D when A just begins to slide (m'_i)
$m_1 = 0$	$m'_1 =$ ______
$m_2 =$ ______	$m'_2 =$ ______
$m_3 =$ ______	$m'_3 =$ ______
$m_4 =$ ______	$m'_4 =$ ______

B) Coefficient of kinetic friction

1. Place a weight on D and give a slight push toward C. Add increasing weights to D, giving a slight push each time. At some stage, the block A will be found to continue moving with a steady, small velocity. Record the corresponding weight in the scale pan.
2. Now increase the reaction force of B by adding weights to A. Then, repeat Step 1 for two more weights on A, returning the block to its original position on B each time. Tabulate the readings in a table similar to Table 5.2.

Table 5.2: Data for calculating the coefficient of kinetic friction

Mass added on A (m_i)	Mass on D when A moves with small constant velocity (m'_i)
$m_1 = 0$	$m'_1 =$ ______
$m_2 =$ ______	$m'_2 =$ ______
$m_3 =$ ______	$m'_3 =$ ______
$m_4 =$ ______	$m'_4 =$ ______

5.6 DATA ANALYSIS

A) Coefficient of Static Friction

1. Using the data in Table 5.1, calculate the normal reaction force, $N = (m_A + m_i)g$, where m_A is the mass of block A, m_i is the mass added on block A and g is the acceleration due to gravity.
2. Using the data in Table 5.1, Calculate the frictional force, $f_s = (m_D + m_i)g$, where m_D is the mass of the scale pan D, m_i' is the mass added on the scale pan D.
3. Tabulate the results of Steps 1 and 2 in a table similar to Table 5.3. Using the calculated values of f_s and N, plot a graph of f_s versus N. Draw the “best” straight line that is nearest to all the points and determine its slope.
4. Determine the coefficient of static friction ($\mu \equiv \mu_s$) using Eqn 5.4.
5. Draw the lines with the list and greatest slopes, which just agree with the plotted points. Find the error in μ_s from the variation in slope. Discuss possible sources of error.

Table 5.3: Calculation Table.

Normal force, $N = (m_A + m_i)g$	Frictional force, $f = (m_D + m'_i)g$

B) Coefficient of Kinetic Friction

1. Using the data in Table 5.2, calculate the normal reaction force, .
2. Using the data in Table 5.2, calculate the frictional force, .
3. Tabulate the results of Steps 1 and 2 in a table similar to Table 5.3. Using the calculated values of f_k and N, plot a graph of f_k versus N . Draw the "best" straight line that is nearest to all the points and determine its slope.
4. Determine the coefficient of kinetic friction ($\mu = \mu_k$) using Eqn 5.4.
5. Discuss possible sources of error.

5.7 QUESTIONS

1. What are the factors that greatly affect the coefficients of static and kinetic friction?
2. How will μ_s and μ_k vary if we place standard mass on top of the wooden block?
3. Is friction beneficial? Cite real life situations to assert your point.

EXPERIMENT 6

ARCHIMEDES PRINCIPLE

6.1 Pre-Lab Assignment

1. What scientific concepts (principles, laws, relationships etc.) is this experiment based on? State them clearly.
2. Describe the specific actions you are expected to do in this experiment in order to achieve the objectives. Do not copy the objectives from this lab manual. Instead, try to figure them out from the lab procedures.
3. State briefly how the objectives will help you learn about the scientific concepts of Archimedes' principle by doing this experiment.
4. Predict the outcome of this experiment based on your understanding of the scientific concepts of buoyant force and Archimedes' principle. Write your hypothesis in a couple of sentences.
5. Briefly explain the methods used in Part 1 through Part 3 of this experiment to determine buoyant force.
6. Draw a free-body diagram for an object of mass M, for the following two situations:
   (i) a submerged object suspended by a string and
   (ii) a floating object. Draw to scale.

6.2 Objective(s) of the Experiment

In this experiment you will:-:-

- investigate the buoyant force acting on a variety of objects,
- measure the density of solid objects and the density of tap water.

6.3 THEORY

It is common experience to see that some objects float on water (like ships) and some totally submerged. This is because of an upward force called *buoyancy*. This physical phenomenon is succinctly described by Archimedes' principle which states:

Archimedes' Principle

A body wholly or partially immersed in a fluid is buoyed up by a force equal in magnitude to the weight of the fluid displaced by the body.

In this experiment, you will investigate the buoyant force using the following methods: (i)Direct Measurement of Mass; (ii) Displacement Method.

An object submerged in water loses weight by an amount equal to the buoyant force. The method of the *direct measurement of mass* will measure the mass of an object first in air and then in water. The buoyant force, $\vec{F}_B$, is equal to the weight in air ($\vec{W} = mg$) minus the weight in water $m'\vec{g}$,

$$\vec{F}_B = \vec{W} - \vec{W}' = (m - m')\vec{g} \tag{6.1}$$

The *displacement* method requires measurement of the volume of fluid displaced by the object. The weight of the fluid displaced is equal to the buoyant force exerted on the object. Thus, the buoyant force is given by:

$$\vec{F}_B = \rho V_{dip}\vec{g} \tag{6.2}$$

where ρ is the density and V is the volume of fluid displaced by the object, and g is the acceleration due to gravity.

The accepted values for the density of pure water at different temperature are shown in Table 6.1 below. You have to first measure your lab temperature to select the nearest value that will be used for Part 2 through Part 5 of the procedure.

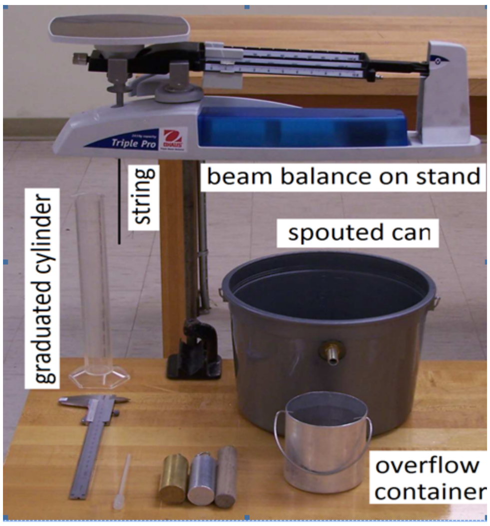
Table 6.1: Density of Water at varied temperatures with uncertainty $\pm 0.01\,(\mathrm{kg/m^3})$

Temperature°C	Density$(\mathrm{kg/m^3})$
0	999.83
4	999.97
10	999.7
15	999.1
20	998.21
25	997.05
30	995.65
40	992.2
50	988.1
60	983.2
70	977.8
80	971.8
90	965.3
100	958.4

For part 6 you will experimentally determine the density of the tap water you use and compare it to the density of water at 20°C. When comparing the experimental densities of your objects or tap water, please refer to Experiment on Measurement and Uncertainty.

6.4 EQUIPMENT

Equipment Needed	Quantity.
Triple-Beam Balance with string	1
Graduated Cylinder (100 ml)	1
Pipette	1
Brass Cylinder	1
Aluminum Cylinder	1
Wood Cylinder	1
Overflow Container	1
Spouted Can	1
Digital Balance	1
123-Blocks	2
Wood Board	1
Rod & Clamp	1
Paper Towels	1
Tap Water	1



6.5 PROCEDURE/ DATA COLLECTION

PART I) Overflow Method

1) Measure the mass of the brass cylinder in air. Determine its weight, W_{brass} .
2) Place the overflow container on the digital balance and read off its mass, m.
3) Fill the spouted can with water. Position it so that water pours into the overflow container.
4) Immerse the brass cylinder fully in the water. Collect displaced water in the overflow container.
5) Measure the mass of the overflow container again, m. Calculate the mass of the displaced water; calculate its weight. This is the buoyant force, $\vec{F}_B = \rho_w V_{disp} \vec{g}$.
6) Calculate the density of brass:

$$\rho_{brass} = \frac{m_{brass}}{V_{brass}} = \rho_w \frac{W_{brass}}{F_B}$$

Table 6.2: Measurement of Buoyant force/Calculation of density of brass (Overflow method)

Lab Temperature (°C): ____________ Density of tap water (kg/m^3): ____________

Trial	Mass/weight of brass cylinder		Mass/volume of displaced water				Buoyant Force	Density of brass	Error
	m (kg)	W_{brass} (N)	m_i (kg)	m_f (kg)	$m_f - m_i$ (kg)	V_{disp} (m^3)	F_B (N)	ρ_{brass} (kg/m^3)	In %
1									
2									
3									
Mean									

PART II) Direct Measurement of Mass

7) Calibrate the triple beam balance. Note the least count.
8) Suspend the brass cylinder from a string attached to the balance.
9) Fill partially the overflow container with water. Immerse the brass cylinder into the water being careful not to touch the container. Measure its apparent mass, m'. Calculate $W_{brass} = m'g$
10) Determine F_B on the object by $W_{brass} - W'_{brass}$. See Equation 1 and Part 1 above.
11) Calculate ρ_{brass} using Equation 3.

Table 6.3: Measurement of Buoyant force/Calculation of density of brass (Direct Method)

Least count of triple-beam balance: ________ Density of tap water (kg/m^3): __________

Trial	Mass/weight of brass cylinder in air from *PART 1*		Mass/weight of brass cylinder in water		Buoyant Force	Density of brass	Error
	m (kg)	W_{brass} (N)	m' (kg)	W'_{brass} (N)	$F_B = W_{brass} - W'_{brass}$ (N)	ρ_{brass} (kg/m^3)	In %
1							
2							
3							
Mean							

PART III) Direct Measurement of Mass

12) Partially fill the graduated cylinder with water; take note of the water level, V_i. Use the pipette to fine-tune the meniscus. Also note the least count of the graduated cylinder.
13) Carefully immerse the brass cylinder in the water and read off the new water level, V_f.

14) Determine the volume of the brass cylinder by taking the difference $V_f - V_i$.

15) Determine F_B on the brass cylinder with Equation 2.

16) Calculate ρ_{brass} using Equation 6.3

17) Remove and dry the brass cylinder, empty the graduated cylinder and dry it with a paper towel. Repeat your measurement two more times.

$$\rho_{brass} = \frac{m}{V} \tag{6.3}$$

Note: Use the mass determined in PART 1, i.e., m not m'.

Table 6.4: Measurement of Buoyant force/Calculation of density of brass (Displacement Method)

Least count of triple-beam balance: ________ Density of tap water (kg/m^3): __________

Trial	Mass/weight of brass cylinder in air from *PART 1*		Volume of water in graduate cylinder			Buoyant Force	Density of brass	Error
	m (kg)	W_{brass} (N)	V_i (m^3)	V_f (m^3)	V_{dip} (m^3)	$F_B = \rho V_{disp} g$ (N)	ρ_{brass} (kg/m^3)	In %
1								
2								
3								
Mean								

PART IV) **PART 4: Aluminum Cylinder**

18) Repeat Part I through Part III for the next object (aluminum cylinder). Tabulate all your data as shown in Table 6.4.

PART V) **PART 5: Buoyant Force - Floating Object**

19) Repeat Part I through Part III for the wood cylinder by omitting Step 6, Step 11, and Step 16. Also modify Step 4, Step 9 and Step 13: Allow the wood object to float. You also need to modify the Data Tables.

PART VI) **PART 6: Density of Tap Water**

20) For each metal object, use Equation 6.4 and the graduated cylinder volume from PART 3 to determine the density of the tap water.

$$\rho_w = \frac{m - m'}{V} \tag{6.4}$$

6.6 DATA ANALYSIS and RESULTS

1. Complete all the Data Tables with calculated values.
2. For the three methods, compare the calculated values of the densities of brass and aluminum with the standard values: $\rho_{brass} = 8400\,kg/m^3$ and $\rho_{aluminium} = 2700\,kg/m^3$, $\rho_{aluminum} = 2700 kg/m^3$. Which method is most accurate?
3. Compare the density of water you calculated in Step 20 with the accepted value at room temperature (20°C) given in Table 6.1.
4. Using the measured values of buoyant force and volume of displaced water for the three objects (brass, aluminum and wood), plot a graph of buoyant force (F_B) versus displaced volume (V_{disp})?. What is the relationship between F_B and (V_{disp}) ?
5. Write a conclusion about your results.

6.7 QUESTIONS

1. Sketch a free-body diagram for an object that is floating in water. How much water does it displace? Does it displace its volume in water? Does it displace its weight in water?

2. Sketch a free-body diagram for an object that is submerged in water. How much water does it displace? Does it displace its volume in water? Does it displace its weight in water?

3. A nugget gold and a block of aluminum of the same volume are immersed in water. Which object experiences the greater buoyant force?

4. A ship made of steel ($\rho_{steel} = 7.8 \times 10^3 kg/m^3$ will float in water. Explain, in terms of densities, how this is possible.

5. A ship at a sea port is taken out of the water. Does the water at the shore rise, fall, or stay at the same level? Explain, in terms of Archimedes' principle (density, volume, or weight), why this happens.

6.8 ADDITIONAL LEARNING RESOURCES

1. PhET Interaction Simulations

2. OpenStaxCollege

3. ScienceOnline

4. Hyperphysics

5. Physics LibreTexts

6.9 REFERENCES

1. Daniel O., Joseph U., Harrison O. and Ambrose E. (2017). Archimedes Principle and the Law of Floatation.

2. Raymond A. S. and Chris V. (2018). College Physics. 11ed. Boston, USA: Cengage Learning. Articles

3. Mohazzabi, P. (2017). Archimedes' Principle Revisited. Journal of Applied Mathematics and Physics, 5, 836-843. https://doi.org/10.4236/jamp.2017.54073

4. Jeffrey B. and Eric K. (2003). Reconsidering Archimedes' Principle. The Physics Teacher, 41(6), 340-344. doi: 10.1110/1.1607804.

EXPERIMENT 7

CURRENT, RESISTANCE AND OHM'S LAW

7.1 Pre-Lab Assignment

1. What is the electrical current flowing through a circuit?
2. What is the potential difference or voltage across two points?
3. what is the meaning of resistance of a conductor ?
4. What is an ammeter? a voltmeter? What is the major difference in the way one uses each to measure electrical quantities in a simple electronic circuit? Be specific.

7.2 Objective(s) of the Experiment

In this experiment you will:-:-

- To determine the unknown resistance of the given material of the wire and hence to verify the ohm's law
- measure the electrical resistance of a conductor and verify the Ohm's Law.

7.3 THEORY

Today it is impossible to imagine a world without electricity. All our activities would almost hamper in the absence of electricity. How were the basics of electricity understood? Where did it all begin? Questions like these might be intriguing for you. The building blocks for manipulating and utilizing electricity are voltage, current, and resistance. The energy transfer in electrical circuits cannot be detected without the help of the instruments like ammeter, voltmeter, etc. George Simon Ohm was a German physicist who proposed a relationship between electrical current and potential difference.

Ohm's law states that if physical conditions (temperature) of a conductor remains same, the potential difference across a conductor is directly proportional to the current I flowing through the conductor. In other words the ratio of voltage and current for a conductor (resistor) is constant and that is represented by a constant R; known as the resistance of the conductor. If V is potential difference in volts and A is current in amp then we can represent $V = RI$ or $R = V/I$. The unit of R is Ohm.

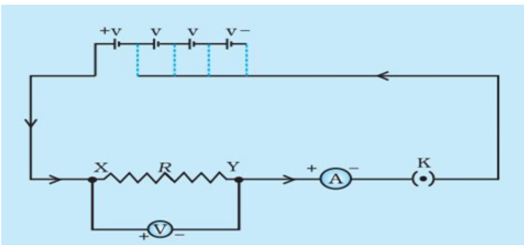


Fig. 7.1: Ohm's law experiment circuit diagram

In figure 7.1 a resistor R is connected to a variable d.c. battery through an ammeter A in series and a off/on switch K. A voltmeter V is connected across two terminal XY of the resistor. The battery can be a combination of several cells in series or a electronic d.c, power supply.

By changing the potential applied through the battery the current I can be changed through resistor and corresponding voltage difference at the ends of resistor can be measured by the volt meter. The readings can be tabulated as shown below. Using individual values of each set R is calculated. You will see that nearly constant value of R from each calculation confirms the validity of Ohm's law. Average value of R can be calculated which gives the resistance of the resistor R.

Table 7.1: Data Table for Ohm's Law Experiment

S.No.	Current I in (A)	Potential difference V in (Volt)	R = V/I in Ohm
1			
2			
3			
4			
5			
6			

Figure 7.2 shows a graph between current I in (A) and potential difference V in (volt)can be plotted. This is plotted for fictitious value of I and V. The graph as shown is a straight line. This also confirms the verification of Ohm's law.

7.4 Apparatus

Equipment Needed	Quantity.
variable D.C. power supply of suitable range may be upto 10 V (This can be also combination of cells as shown in the diagram)	
different resistance wires or coils to be used as resistors	
D.C. ammeter	
D.C. Voltmeter	
Off/On key	
some connecting copper wires	
A digital multimeter for the alternate measurements of resistance	

7.5 PROCEDURE/ DATA COLLECTION

1. Make the circuit as shown in figure 7.1 using the equipments from No. 1 to 6. The positive end of the ammeter should be connected to the positive terminal of the power supply. Similarly the positive end of the voltmeter should be connected to the positive terminal X of resistor and negative to the Y terminal. Ammeter is to be connected in series with the resistor and voltmeter in parallel at points X and Y.

2. For the data connection plug in the key K and start from minimum current. Measure the current in ammeter (A) and voltage in voltmeter (V) note down the readings in column 2 and 3 in the above table. Repeat the measurements by increasing the current in resistor by varying the potentiometer of d.c, power supply. Measure the corresponding values of voltage from voltmeter and enter in the table.

3. Such measurements can be repeated for different resistors and readings can be noted in different tables.

7.6 DATA ANALYSIS

1. take the ratio of 3rd column reading and 2nd column reading and write the result in 4th column. This is the value of R; resistance of resistor.

$$R = \frac{V}{I} \text{ ohm}$$

2. Find out the value of R from each set of measurements and writ down the values of R in last column. You may notice these values of R in last column from different sets of measurements are nearly same. This constant value of R also confirms the statement of Ohm's law.

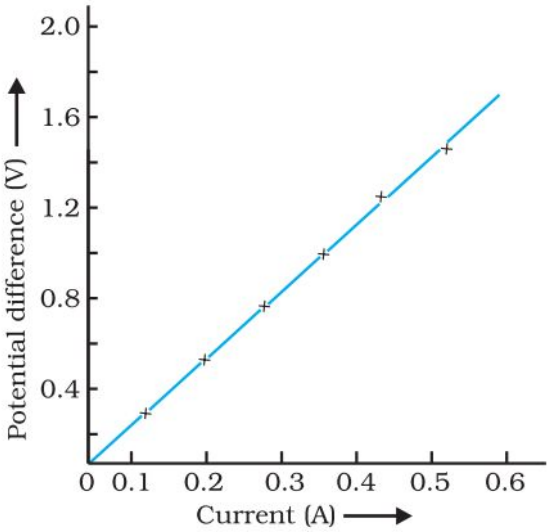


Fig. 7.2: A plot of I vs V for the verification of ohm's law

3. From all the calculations of resistance values of R an average value can be calculated which gives more accurate value of resistance of resistor (R_{av})
4. For the checking of your measurements the R value can be also measured using digital multimeter (Rm) and difference from your calculations can be calculated. This gives error in your measurements .
5. Percentage of error may be calculated as

$$\Delta R\% = \frac{R_{av} - _{m}}{av}$$

6. From the readings of table column 2 and 3 plot a graph between I and V. Straight line nature of this plot also confirms the validity of OhmâĂŹs law . Calculate slope of this curve which gives the value of R_{av}.

7.7 Result

The average values of resistances of different resistors are ____________
And the percentage errors are ____________
The straight line nature of I-V curve verifies the ohms law

7.8 QUESTIONS

1. How are the voltmeter and ammeter placed in circuit for the measurement and why?
2. Which of the meter (voltmeter, ammeter) forces all the current into meter for the measurement?
3. Which meter has the largest resistance and why?
4. Which meter measures the flow rate of electrons?

7.9 ADDITIONAL LEARNING RESOURCES

1. Now you should understand the concepts of voltage, current, resistance, and how the three are related. The majority of equations and laws for analyzing circuits can be derived directly from Ohm's Law. By knowing this simple law, you understand the concept that is the basis for the analysis of any electrical circuit!

2. These concepts are just the tip of the iceberg. If you're looking to study further into more complex applications of Ohm's Law and the design of electrical circuits, be sure to check out the following hands on activities. Go to the references given below

7.10 REFERENCES

1. Hugh D. Young & Roger A. Freedmann University Physics 2008
2. Raymond A. Serway Physics for Scientists & Engineers Thomson Brook 2004
3. Paul M. Fishbane, Stephene Gasiorowiez, Stephen T. Thoronton , Physics for Scientists & Engineers , 2005.

EXPERIMENT 8

RESISTANCES COMBINATION LAW

8.1 Pre-Lab Assignment

Before doing this experiment, You are supposed to read the current, potentials, resistors and resistance, voltmeter, ammeter and the use of digital multi-meter.

8.2 Objective(s) of the Experiment

In this experiment you will:-:-

- set up two circuits: one with resistors in series and one with resistors in parallel;
- measure the resistances of different known resistances in series combination and in parallel combination;
- calculate combined resistances theoretically and;
- verify the laws of combination of resistances.

8.3 THEORY

In the first part of this experiment you will study the properties of resistors, which are connected "in series". Figure 8.1 shows two resistors connected in (a) series and (b) the equivalent circuit with the two resistors replaced by an equivalent single resistor .

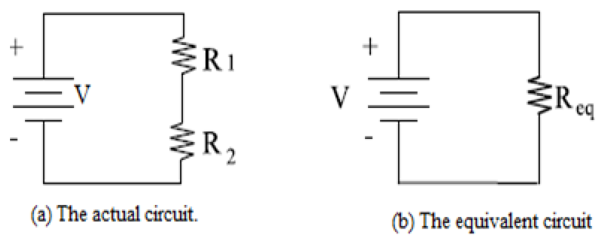


Fig. 8.1: Resistors in series

When resistors are connected in series, each one "sees" the same current. Recall the water analogy: If you have two pipes that have different diameters but are connected in series and you send water through them, each receives the same amount of water, there are no branches into which the water can split. In theory we have seen that the equivalent resistance for resistors in series is:

$$R_{eq} = R_1 + R_2 \tag{8.1}$$

this equation can be extend to any number of resistors in series, so that for N resistors the equivalent resistance is given by

$$R_{eq} = R_1 + R_2 + R_3 + \ldots + R_N = \sum_i^N R_i \tag{8.2}$$

In the second part of this lab we will arrange them together as in Figure 2. We say these resistors are connected in parallel. In series they were connected one after the other, but in parallel, as the name suggests, they are 'side by side' in the circuit. When resistors are in parallel, the current flowing from the battery will come to a junction where it has a "choice" as to which branch to take.

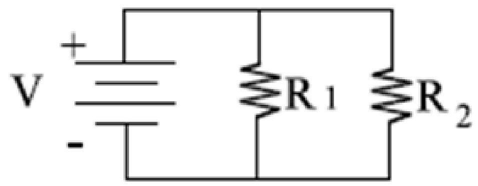


Fig. 8.2: Two Resistors in parallel

Therefore, they "see" different amounts of current, just the way water branching into two different pipes will flow more through the larger pipe (lower resistance) than through the narrower pipe (greater resistance). Resistors in parallel "see" different currents, but they each experience the same potential difference (voltage).

In theory we got a mathematical relation to get the equivalent resistance of parallel combination. In this case, the equation is a bit more complicated than for resistors in series. Instead of the resistances adding directly, we calculate

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_N} = \sum_{i}^{N} \frac{1}{R_i}$$

It is important to remember that after you do this calculation, you would get $\frac{1}{R_{eq}}$.

8.4 Apparatus

Equipment Needed	Quantity.
D.C. power supply	1
known value resistors	2
D.C. voltmeter	1
D.C. ammeter	1
some connecting wires	10
Digital multimeter.	1

8.5 PROCEDURE/ DATA COLLECTION

1. Take two resistors of different values. Measure their values using digital multimeter, if their values are not known. Make the following circuit ,connecting ammeter in series and voltmeter in parallel with the resistor combination. Put ON the power supply. By adjusting the power supply

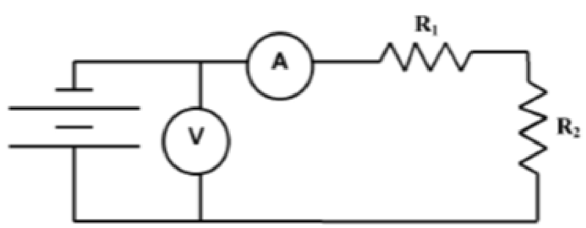


Fig. 8.3: Circuit for series combination of resistance

$(R_{eq})_{av}$ =__________

2. Change the potential of supply source and measure the readings of ammeter(I) and voltmeter (V) Tabulate these readings. Take the ratio of V and I and calculate the value of $R_{eq} = V/I$.

Table 8.1: Data Table

S.no.	Ammeter reading In AMP (I)	Volt meter reading In volts (V)	R_{eq} =V / I ohm
1			
2			
3			
4			
5			
6			

3. Find out the average value of $R_{eq})_{av}$. Calculate the value of $R_{eq})_{cal} = R_1 + R_2$. See that the value of $R_{eq})_{av} = R_{eq})_{cal}$. This verifies the law of series combination of resistances.
4. Make the circuit as shown below for the second part of the experiment.

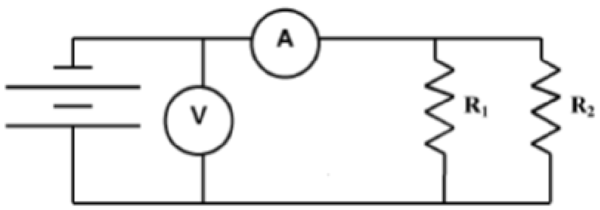


Fig. 8.4: Circuit for the parallel combination of resistors

This is for the parallel combination of resistances. Put ON the d.c. power supply. Start experiment with minimum value of the current and measure the value of current and voltage from ammeter A and voltmeter V. Take various readings by changing the potentiometer of the power supply. Tabulate them in a table. For each reading find out the ratio of V/I which gives the equivalent resistance (R_{eq}) of the circuit. Find out average value $(R_{eq})_{av}$ from all the value of R_{eq}.

Table 8.2: Data Table

S. No.	Ammeter (A) I in amp	Voltmeter V volt	R_{eq} = V / I ohm
1			
2			
3			
4			
5			
6			

Now calculate the value of equivalent resistors using formula of parallel combination $1/(R_{eq})_{cal} = \frac{1}{R_1} + \frac{1}{R_1}$. It is observed that $(R_{eq})_{av} = (R_{eq})_{cal}$. This verifies the law of parallel combination of resistances.

8.6 DATA ANALYSIS

As explained in theory part above compare the measured results with calculated from formula in both series and parallel combination. These comparisons will verify the law of resistance combinations.

8.7 QUESTIONS

1. In series circuit if the voltage of each resistor R_1 and R_2 is measured and current flowing from each is calculated from the known values of resistances, what would be the values of currents. Different or same. Give the arguments.

2. In parallel circuit current from each resistance is calculated from measured value of potential difference. What will be the value of total current. Show this by calculation and compare with the measured value of current as given in table. What do you observe. Argue the answer.

8.8 ADDITIONAL LEARNING RESOURCES

1. Now you should understand the concepts of voltage, current, resistance, and how the three are related. The majority of equations and laws for analyzing circuits can be derived directly from Ohm's Law. By knowing this simple law, you understand the concept that is the basis for the analysis of any electrical circuit!

2. These concepts are just the tip of the iceberg. If you're looking to study further into more complex applications of Ohm's Law and the design of electrical circuits, be sure to check out the following hands on activities. Go to the references given below

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EXPERIMENT 9

FOCAL LENGTH OF LENSES

9.1 Pre-Lab Assignment

1. Mark the following statements about lenses as true or false.
   (a) ______ Incident parallel light rays converge if the lens's focal length is negative.
   (b) ______ If the path of converging light rays is traced backward, the rays appear to come from a point called the focal point.
   (c) ______ A double convex lens has a negative focal length.
   (d) ______ The focal length of a lens is always positive.
2. A double convex lens is made from glass with an index of refraction of $n = 1.50$. The *magnitudes* of its radii of curvature R_1 and R_2 are 10.0 cm and 15.0 cm, respectively. What is the focal length of the lens?
3. What is a virtual image? How is it different from a real image?
4. For a diverging lens, state what kinds of images can be formed and the conditions under which those images can be formed.
5. For a converging lens, state what kinds of images can be formed and the conditions under which those images can be formed.
6. A lens has a focal length of $f = +10.0$ cm. If an object is placed 30.0 cm from the lens, where is the image formed? Is the image real or virtual?
7. An object is 16.0 cm from a lens. A real image is formed 24.0 cm from the lens. What is the focal length of the lens?
8. One lens has a focal length of $f = +15.0$ cm. A second lens of focal length $f = +20.0$ cm is placed in contact with the first lens. What is the equivalent focal length of the combination of lenses?
9. Two lenses are in contact. One of the lenses has a focal length of $f = +15.0$ cm when used alone. When the two are in combination, an object 20.0cm away from the lenses forms a real image 40.0 cm away from the lenses. What is the focal length of the second lens?

9.2 Objective(s) of the Experiment

After completing this experiment you would be able to:-

- investigate the properties of converging and diverging lenses.
- determine the focal length of converging lenses both by a real image of a distant object and by finite object and image distances.
- determine the focal length of a diverging lens by using it in combination with a converging lens to form a real image.

9.3 THEORY

A beam of parallel rays to the principal axis of a convex lens converge to a point, called *focal point*, after passing through a convex lens. The distance from the focal point to the center of the lens is known as the *focal length*.

The relation between the image distance S', object distance S and focal length f is given by

$$\frac{1}{S}+\frac{1}{S'}=\frac{1}{f}$$

Suppose the lens produces a sharp image of the candle at the two positions as shown in fig 9.1. Let the distance between the objct and the image be D and the distance between the two positons of the lens leading to a sharp image be d. We have

$$S_1 = S_2' \qquad \text{and} \qquad S_2 = S_1'$$

From figure 9.1 and the above relations we have

$$S_1 + S_1' = D \qquad \text{and} \qquad S_1' - S_1 = d$$

$$\text{Hence, } S_1 = \frac{D-d}{2} \qquad \text{and} \qquad S_1' = \frac{D+d}{2}$$

Using the thin lens equation,

$$\frac{1}{f} = \frac{2}{D-d} + \frac{2}{D+d} \qquad \text{and} \qquad f = \frac{D^2-d^2}{4D} \tag{9.1}$$

9.4 EQUIPMENT

1. Optical bench ()
2. holders for lenses ()
3. a screen to form images ()
4. meter stick ()
5. concave lens (1)
6. convex lenses different focal lengths (2)
7. Lamp with object on face (illuminated object) (1)

9.5 PROCEDURE/ DATA COLLECTION

1. Place the screen at a distance D from the illuminated object as shown in fig 9.1.
2. Place the lens between the object and the screen at a point where a clear image appears on the screen. Note the position of the lens stand.
3. Keeping the object and the screen fixed, a second position is found in which the lens gives a well focused image on the screen.

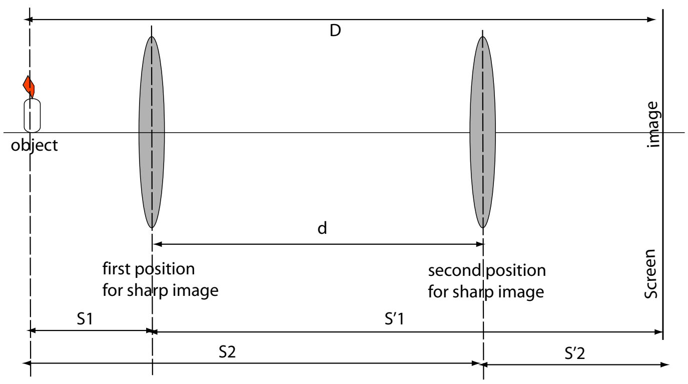

Fig. 9.1

4. Repeat the above steps for five different values of D
5. tabulate the corresponding sets of D and d

S. No.	D	d	$D^2 - d^2$	$4D$	$f = \frac{D^2-d^2}{4D}$
1					
2					
3					
4					
5					

Discovery Problems:-

(a) determine the average value of the focal length $\bar{f}$
(b) plot $D^2 - d^2$ vs $4D$ and determine the focal length f^* from the slope
(c) compare $\bar{f}$ and f^*

6. repeat the above procedure for the second convex lens
7. repeat the above procedure for the concave lens.

9.6 QUESTIONS

1. Two real images can be found for a given object screen distance. What are the similarities and differences of the images? What general principle explain the existence of two images?
2. The lens in the human eye is convex. It forms real image on the retina therefore the image on the retina is inverted. Despite this fact we see upright images. Is there any contradiction?
3. What is the focal lengths of the lenses 1, 2 and 3

9.7 ADDITIONAL LEARNING RESOURCES

1. An interactive simulation on image formation by thin lenses is available at `https://www.cengage.com/physics/phet/sims/geometric-optics/geometric-optics_en.html` the simulation can also be downloaded to your desktop/laptop.
2. You can find a good discussion and online activities on lens-makers formula and focal lengths, online `http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/foclen.html#c1`.

9.8 REFERENCES

1. Physics Laboratory Manual, 3^{rd} Edition, David H. Loyd, Thomson Brooks/Cole, USA, 2008.
2. College Physics, 9^{th} Edition, Raymond A. Serway and Chris Vuille, 2012, Brooks/Cole 20 Channel Center Street Boston, MA 02210 USA.

EXPERIMENT 10

MEASURING THE SPECIFIC HEAT OF METAL ELEMENTS

10.1 Pre-Lab Assignment

1. The specific heat of different substances are different. For example specific Heats (near room temperature) of Lead is 128 J/kg °C and that of Brass is 385 J/kg °C. Find out the specific heat of common substances like water, steel, oil, ice,
2. which substance has the highest heat capacity?
3. coolants are used in motors to take away heat. What property can be used to compare different coolants?
4. In this experimet you will measure the masses of the metal (m_m), the water (m_w), and the calorimeter (m_c), the initial temperatures of the metal (T_{wi}), and the final temperature (T_f).
   (a) Derive a formula for the specific heat of the metal mass in terms of measureable quantities defined above.
   (b) Derive a formula for the uncertainty in the specific heat of the metal elements

   You may assume that the uncertainties in the masses of the objects and in the specific heats of water and the cup are negligible. In other words, you only have to consider uncertainties in the temperatures.

10.2 Objective(s) of the Experiment

After completing this experiment, you will be able to:

- Use a simple calorimeter to conduct an experiment to measure heat transfer.
- Calculate the specific heat of a solid sample using the calorimeter experiment data.
- Analyze possible sources of error in a calorimetry experiment.

10.3 THEORY

The Specific Heat of a substance (c), is the amount of heat required to raise the temperature of one gram of the substance by 1 °C (or 1 K).

Different substances have different specific heats. for example the specific heat of water is 4.18 J/g K.

If an object is made of a substance with specific heat equal to c_{sub}, then the heat, ΔH, required to raise the temperature of that object by an amount ΔT is:

$$\Delta H = (\text{mass of the object}) \times c_{sub} \times \Delta T \tag{10.1}$$

In this experiment you will measure the specific heats of aluminum, copper, and iron blocks

10.4 EQUIPMENT

1. Calorimeter (1)
2. Thermometer (1)
3. Balance (1)
4. Iron block (1)
5. Copper block (1)
6. Aluminium block (1)
7. Thread
8. Water

PRECAUTIONS AND SPECIAL INSTRUCTIONS

Always keep in mind the Laboratory Safety Rules, in general the safety rules to be observed in handling heat sources. It is your responsibility to make sure that you follow all safety rules at all times, and to graciously help everybody else in the laboratory (including the instructor) to do the same.

10.5 PROCEDURE/ DATA COLLECTION

1. Measure M_{cal}, the mass of the calorimeter you will use (it should be empty and dry). Record your result in Table 10.1.

Table 10.1: Data and Calculations

	Trial 1	Trial 2	Trial 3
M_{cal}			
M_{sample}			
T_{cool}			
T_{final}			
M_{total}			
M_{water}			
ΔT_{water}			
ΔT_{sample}			
c			

2. Measure the masses of the aluminum, copper, and iron samples. Record these masses in Table 10.1 in the row labeled M_{sample}.
3. Attach a thread to each of the metal samples and suspend each of the samples in boiling water. Allow a few minutes for the samples to heat thoroughly.
4. Fill the calorimeter approximately 1/2 full of cool water-use enough water to fully cover any one of the metal samples.
5. Measure T_{cool}, the temperature of the cool water. Record your measurement in the table.
6. Immediately following your temperature measurement, remove one of the metal samples from the boiling water, quickly wipe it dry, then suspend it in the cool water in the calorimeter (the sample should be completely covered but should not touch the bottom of the calorimeter).
7. Swirl the water and record T_{final}, the highest temperature attained by the water as it comes into thermal equilibrium with the metal sample.
8. Immediately after taking the temperature, measure and record M_{total}, the total mass of the calorimeter, water, and metal sample.
9. For each metal tested, use the equations you derived in the pre-lab assignment and determine the specific heat of the metal.
10. Record your results in the bottom part of Table 10.1.

10.6 QUESTIONS

1. If we had accounted for the heat absorbed by the calorimeter, how would that have affected the calculated value for the specific heat? Would it have been larger or smaller? Be specific, referring to how heat is transferred and the equation(s) used to calculate the specific heat capacity.
2. Considering your answer to number 1, does the loss of heat to the calorimeter account for the error you observed in the experiment?

10.7 ADDITIONAL LEARNING RESOURCES

1. A very good simulation of heat exchange and heat capacity is available at `https://phet.colorado.edu/en/simulation/legacy/energy-forms-and-changes` the simulation can be downloaded to your desktop/laptop.

2. You can practice calculations related to specific heat capacity, online `http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/spht.html`.

10.8 REFERENCES

1. Physics Laboratory Manual, 3rd Edition, David H. Loyd, Thomson Brooks/Cole, USA, 2008.

2. College Physics, 9th Edition, Raymond A. Serway and Chris Vuille, 2012, Brooks/Cole 20 Channel Center Street Boston, MA 02210 USA (pp 365–367)

Appendix A

Reporting your laboratory work:

The report for each experiment should be started on a page and should normally consist of the following parts:

1. Title, name and date (cover page)
2. Introduction - it contains the objectives of the experiment and some background information on the experiment.
3. Theory - it contains detailed explanations of the physical principles (laws, formulae, etc.) of the experiment.
4. Apparatus - it contains a complete description of the devices used in the experiment.
5. Procedure - it contains a complete description of the experimental setup and the steps employed in performing the experiment.
6. Data - the values of the measurements are displayed, usually in tabular form.
7. Data analysis and error analysis - it contains calculations of the observed data and the corresponding errors.
8. Results and discussion - it contains the results of the experiment expressed in terms of numbers, tables, figures, graphs, etc. obtained from the experiment are presented.
9. Conclusions - in this section the writer highlights the important results of the experiment.
10. Solutions or answers - it contains the solutions (showing all the necessary steps) or (and) answers to the questions given at the end of each experiment.

If you do not complete an experiment during a session, a statement of the reasons for discontinuing the experiment should be given.