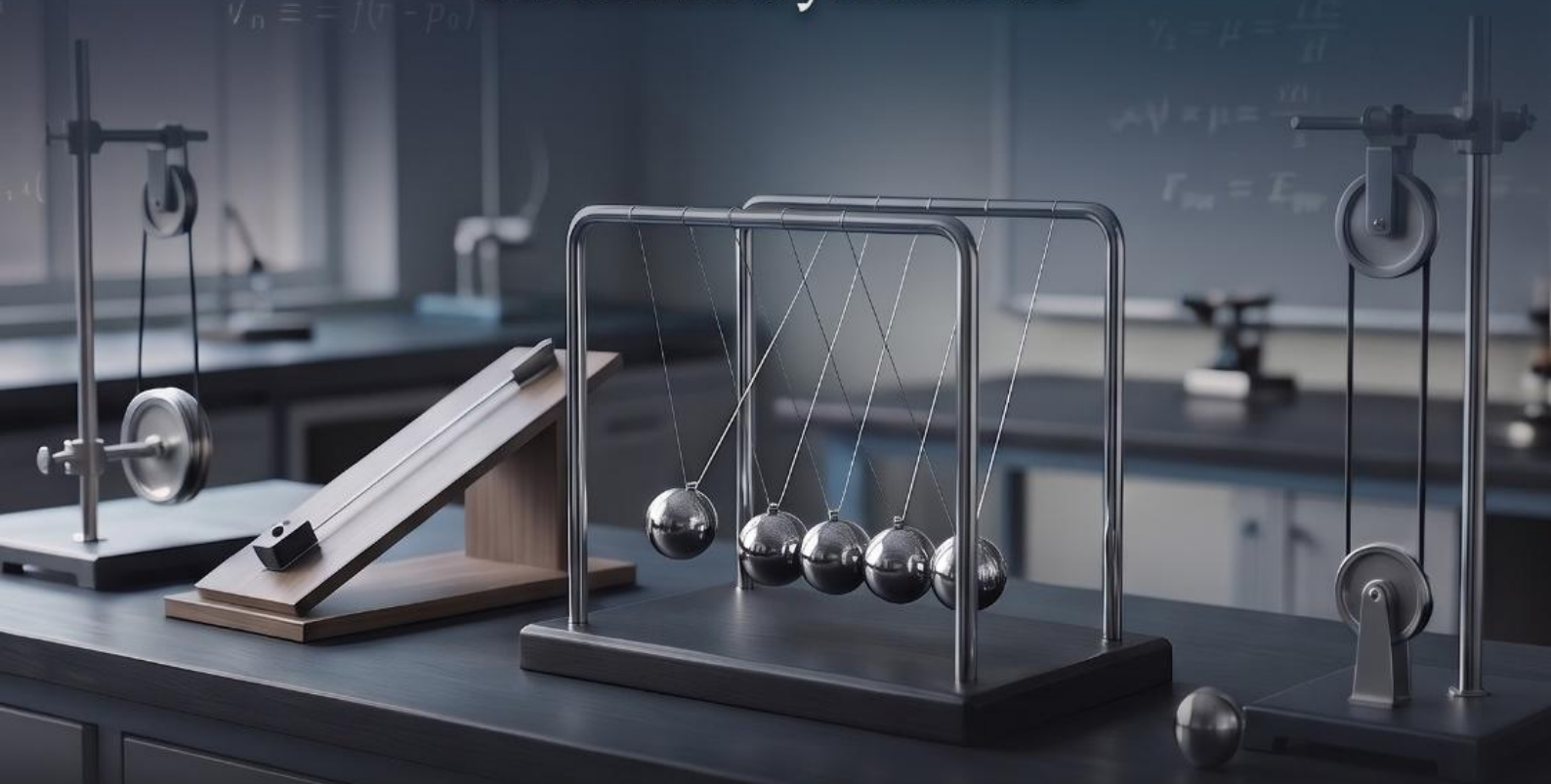
BASIC PHYSICS I
EXPERIMENTAL GUIDE

English Version

Basic Mechanics and Thermodynamics



BASIC PHYSICS LABORATORY TEAM
DEPARTMENT OF PHYSICS
FACULTY OF MATHEMATICS AND NATURAL SCIENCES
UNIVERSITAS NEGERI SURABAYA
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Preface

This practical guide was written as a manual for the Basic Physics 1 practical course in the Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya in 2020. This manual covers Mechanics and Thermodynamics divided into two main experiment codes: M for Mechanics and T for Thermodynamics. Guidelines regarding data analysis, scientific discussions, and plotting experimental graphs are also included.

This Basic Physics 2 manual has been developed using a guided inquiry framework so that students enrolled in the course can actively construct their own knowledge regarding the experiment concepts. Students are provided with the opportunity to design their own experimental procedures to achieve the learning objectives outlined in Section A of each module and are expected to formulate and test their own hypotheses.

Practical activities in physics education represent a fundamental scientific process. In this guided inquiry guide, physics concepts are studied based on real-world conditions aligned with stated goals. Students are then tasked with designing or refining their problem-solving procedures. The writing team from the Basic Physics Laboratory extends sincere gratitude to all parties who supported the compilation of this guide.

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INTRODUCTION

A. Description of the Basic Physics Laboratory Course

At the Faculty of Mathematics and Natural Sciences of Universitas Negeri Surabaya (FMNS UNESA), Basic Physics is a common first-year course that students in the Department of Physics, in both the Physics Education and Physics degree programs, must take. It aims to develop students' understanding of the foundations of physics, building on the physics they studied at senior high school. Topics include mechanics; oscillations, waves, and sound; thermal physics; electricity and magnetism; geometrical optics; and the fundamentals of modern physics.

The theoretical instruction in Basic Physics is complemented by practical activities in the Basic Physics Laboratory. These activities introduce various measuring instruments and provide practice in their use, introduce the fundamentals of experimentation and their application in laboratory work, and develop cognitive strategies that support understanding of the Basic Physics course.

B. Objectives of the Basic Physics Laboratory Course

Physics laboratory activities can essentially be divided into three types: (1) measuring physical quantities; (2) conducting experiments to test established theories or laws; and (3) conducting experiments to obtain new findings. After completing the Basic Physics Laboratory course, students are expected to be able to:

1. assemble apparatus correctly;
2. use measuring instruments and read their scales correctly;
3. write a concise theoretical background relevant to an experiment;
4. describes experimental procedures;
5. analyze data and calculate uncertainties correctly;
6. discuss the results of data analysis;
7. draw conclusions; and
8. writes an appropriate laboratory abstract.

Students must also be able to cooperate with their group members and carry out laboratory work in an orderly and disciplined manner.

C. Conduct of the Laboratory Course

The Basic Physics Laboratory course is conducted in three stages: pre-laboratory preparation, experimental work, and reporting.

1. Pre laboratory preparation

Pre-laboratory activities are carried out in groups to prepare students for a particular experiment. Before beginning an experiment, students need the following basic competencies:

1. understand the objectives of the experiment;
2. understand the relevant concepts;
3. identify the variables to be measured and calculated;
4. understand the specifications and use of the apparatus;
5. determine the data required, how to obtain them, and how to analyze them;
6. write Chapter 1 (background, research questions, and objectives), Chapter 2 (theoretical background), and Chapter 3 (apparatus and materials, experimental diagram, variables, and experimental procedure) of the report; and
7. answer the questions in the manual for the experiment to be performed.

2. Experimental work

During experimental work, students are trained to act as researchers. They are therefore required to be objective, systematic, logical, and meticulous. Students work in groups on the

assigned experiment using the material in this manual. The instructor observes their affective performance (attitudes) and psychomotor performance (skills), then awards scores using the established rating scale.

Assessment at this stage covers:

1. the ability to assemble the apparatus correctly;
2. the ability to use measuring instruments and read their scales correctly; and
3. cooperation among group members.

3. Reporting

After conducting an experiment, students process and analyze their measurement data and prepare a report in the format illustrated in this manual. The instructor evaluates the report using the established scoring guidelines. Report assessment covers:

1. the ability to write an abstract;
2. the ability to write a concise theoretical background supporting the experiment;
3. the ability to formulate experimental procedures;
4. the ability to analyze data, calculate uncertainties, and answer questions correctly;
5. the ability to discuss the results of data analysis; and
6. the ability to formulate conclusions.

D. Assessment

Assessment is conducted at each stage: pre-laboratory preparation, experimental work, and reporting.

1. Assessment of pre laboratory preparation

Pre-laboratory preparation is assessed as a group and determines whether the group is permitted to conduct the experiment. A group that has not yet been approved must repeat the pre-laboratory preparation until it is judged ready. A minimum score of 10 is required.

No.	Criterion	Good	Fair	Poor
1	Understanding the experimental objectives			
2	Understanding the relevant concepts			
3	Identifying variables to be measured and calculated			
4	Understanding apparatus specifications and use			
5	Determining the required data, how to obtain them, and how to analyze them			
Total				

Score = (number of Good × 3) + (number of Fair × 2) + (number of Poor × 1)

Grade = $\frac{score}{15} \times 85$

2. Assessment of experimental work

Experimental work is assessed individually.

No.	Criterion	Good	Fair	Poor
1	Assembling apparatus correctly			
2	Using measuring instruments and reading their scales correctly			
3	Cooperating with group members			
Total				

Score = (number of Good × 3) + (number of Fair × 2) + (number of Poor × 1)

Grade = $\frac{score}{9} \times 85 \times 85$

3. Assessment of reporting

Reports are assessed individually.

No.	Criterion	Score
1	Writing an abstract	
2	Writing a concise theoretical background supporting the experiment	
3	Formulating the experimental method	
4	Analyzing data, calculating uncertainties, and answering questions correctly	
5	Formulating. conclusions	
Total		

Scoring scale:

Excellent : 85

Good : 80

Fair : 70

Poor : 65

Very poor : 60.

Grade = $\frac{total\ score}{5}$

The final Basic Physics Laboratory grade is determined from the pre-laboratory, experimental-work, and reporting grades as follows:

Final grade = (2 × Pre-laboratory) + (3 × Experimental work) + (5 × Reporting)

E. Laboratory Rules

1. Requirements

Students are required to:

1. enter the laboratory at the scheduled time;
2. wear appropriate clothing: shoes, long trousers or a long skirt, and a collared shirt;
3. wear an identification card;
4. submit evidence of permission to conduct the experiment from the laboratory instructor (the pre-laboratory sheet);
5. place all belongings other than the necessary stationery, laboratory manual, and preliminary report sheets in the designated lockers;
6. sign the attendance register;
7. submit the report one week after the experiment;
8. complete the apparatus loan register;
9. work quietly and seriously;
10. return all apparatus clean and neatly arranged;
11. submit the preliminary report to the laboratory assistant or instructor for approval no later than 2 × 24 hours after the start of the laboratory activity;
12. obtain permission from the laboratory assistant or instructor before leaving for any reason;
13. request permission to enter from the laboratory assistant or instructor if arriving late;
14. leave promptly when the laboratory session has ended; and

15. submit the formal laboratory report according to the established schedule.

2. Prohibitions

Students must not:

1. violate agreed written or unwritten requirements;
2. eat or drink in the laboratory;
3. use apparatus other than that specified without permission from the laboratory assistant or instructor;
4. move to a laboratory bench other than the one assigned;
5. disturb or interfere with another group's work;
6. alter or replace experimental apparatus without permission from the laboratory assistant or technician;
7. conduct experiments outside scheduled laboratory hours without a laboratory assistant or instructor present;
8. manipulate data so that they no longer reflect the experimental results;
9. damage laboratory equipment, whether intentionally or unintentionally; or
10. miss a scheduled experiment without a valid reason or permission.

3. Penalties

Violations may result in:

1. an immediate verbal warning;
2. being refused entry to, or being removed from, the Basic Physics Laboratory during the session;
3. a reduction in grades; or
4. the group being required to replace the damaged equipment with an equivalent item or have it repaired.

F. Laboratory Reports

The formal Basic Physics laboratory report is prepared after the preliminary report has been approved by the laboratory assistant or instructor. The following requirements apply:

1. Write in black ink.
2. Use the abstract and preliminary-report sheets specified by the laboratory technician.
3. Use plain, unruled F4 paper.
4. Use margins of 3 cm on the left and 2 cm at the top, right, and bottom.
5. Figures and graphs may be printed and pasted into the report.
6. Bind the report neatly.

The structure of the formal report and an explanation of each part are given below.

Abstract

A single paragraph of approximately 120 words briefly describing the laboratory activity. Include the title, objectives, main activities, experimental variables, numerical final results, and conclusions. Place keywords below the abstract.

Chapter I Introduction

A. Background: Explain the reasons for conducting the experiment.
B. Research questions: State concise questions that the experiment is intended to answer.
C. Objectives: Describe what is to be achieved by conducting the experiment.

Chapter II Theoretical Background

Present the material needed to support the experiment and provide the basis for analyzing the data.

Chapter III Experimental Methodology

A. Apparatus and materials: List of the apparatus and materials required for the experiment.
B. Experimental diagram: Provide a drawing of the experimental arrangement.
C. Experimental variables: (1) Controlled variables are deliberately kept unchanged. (2) Independent or manipulated variables are deliberately varied. (3) Dependent or response variables change in response to changes in the manipulated variables.
D. Experimental procedure: Describe the steps carried out in the experiment as a numbered or bullet sequence.

Chapter IV Data and Analysis

A. Data: Present the processed experimental data as tables, graphs, figures, or descriptions.
B. Analysis: Explain how the data are analyzed to obtain the final results.
C. Answers to questions: Answer the questions provided for the experiment.

Chapter V Conclusions and Recommendations

A. Conclusions: Explain the final experimental results in relation to the objectives and research questions.
B. Recommendations: Provide suggestions concerning the conduct of the experiment.

References

List the sources used to prepare the formal report. Sources may include books and reliable internet materials.

Preliminary Report

Present the data recorded during the laboratory activity, endorsed by the laboratory assistant or instructor.

Appendices

Include material not presented in the main report, such as calculations used to obtain the results and the stated level of precision, as well as supporting figures.

MEASUREMENT UNCERTAINTY AND SIGNIFICANT FIGURES

A. Measurement Uncertainty and Error

Every measurement of a physical quantity inevitably involves uncertainty. The precision, accuracy, and reliability of an experimental measurement depend strongly on how accurately its uncertainty can be estimated. For example, a resistance measured using an accurate digital multimeter may be reported as 20.03 ± 0.01 Ω. This means that the true resistance is expected to lie between 20.02 Ω and 20.04 Ω. The interval in which the expected value lies represents the measurement uncertainty. It also expresses the accuracy or precision of the measured data: a narrower interval indicates greater precision and accuracy, and vice versa.

The difference between the true value of a quantity and its measured value is often called the measurement "error." The source suggests that this difference is more appropriately described as a "deviation," while reserving "error" for a mistake in the general sense.

In many measurements, the true value of a quantity is unknown and may even be unknowable. For example, two groups of students may measure the same physical quantity using the same apparatus and experimental method, with comparable care, yet obtain slightly different results: (5.00 ± 0.02) and (5.02 ± 0.02). Each group may claim that its error is smaller than the other's. In this situation, however, both groups may have worked correctly: they followed the appropriate procedure and used appropriate measurement precision. Their slightly different results do not necessarily indicate that either group made a mistake.

B. Why Measurement Uncertainty Matters

Consider the resistance measurement above. When the resistor is heated to 100 °C, its measured resistance becomes 20.04 Ω. What does this imply? If the values before and after heating, 20.03 Ω and 20.04 Ω, are used without considering uncertainty, we would conclude that the resistance increased by 20.04 − 20.03 = 0.01 Ω. However, if the uncertainty at 100 °C is also ±0.01 Ω, the true resistance may have remained unchanged or even decreased. The change in resistance could therefore lie between −0.01 Ω and +0.03 Ω. This example, like many others, shows why measurement uncertainty must be considered in experimental work: it indicates how accurately and precisely the measured data represent the true value. More generally, there are three principal reasons for considering uncertainty and measurement precision whenever experimental data are collected:

1. Other users of the data need to know their accuracy and precision for their own purposes.
2. Hypotheses based on the data must be formulated and tested appropriately.
3. The history of the natural sciences shows that theoretical and measured values of physical quantities differ, however slightly, even as experimental apparatus, methods, and procedures become more advanced.

C. Sources of Uncertainly

1. Systematic uncertainty

Systematic uncertainty arises from faults in the use of an instrument or faults already present in the instrument itself. If the cause lies in the instrument, the same uncertainty will recur whenever it is used. Examples include the following.

a. Instrument errors.

An incorrectly calibrated scale produces readings that differ from the correct value. For example, a current that should be 2 A may consistently be measured as 2.3 A by an ammeter. This can be addressed by
(1) calibrating the instrument so that it reads correctly or
(2) replacing it with a more precise instrument.

b. Zero errors.

These occur when the instrument does not indicate zero when it should, or has a nonzero reading before use. Ensure that the instrument reads zero before taking measurements.

c. Inappropriate response timing.

Uncertainty arises when a reading is taken at a different time from the event that should have been measured. A common laboratory problem is taking a reading after the desired condition has passed. For example, when intending to record the temperature of heated water at 70 °C, the reading may instead be taken at a higher temperature.

d. Improper conditions.

The instrument may not be suitable for the measurement conditions. For example, a metal ruler is unsuitable for measuring the length of an object at a high temperature because the ruler itself expands.

2. Random uncertainty

Random uncertainty commonly appears in repeated measurements, causing results to vary around their mean. Results may differ because:
(a) each measurement is made at a different moment;
(b) the measuring instrument introduces uncertainty; or
(c) other sources of uncertainty are associated with taking the measurements.

3. Human errors

Insufficient skill in operating or reading a measuring instrument can introduce errors, such as parallax errors or calculation mistakes.

D. Determining Measurement Uncertainly

The following basic methods are suitable for laboratory work in the common first-year program.

1. Uncertainty in a single measurement

A direct, single measurement of x is reported as $\mathbf{x \pm \Delta x}$, where **x** is the instrument reading and Δx is the absolute uncertainty. The absolute uncertainty is taken as half the smallest scale division readable on the instrument.

$$\textbf{Percentage uncertainty} = \frac{\mathbf{\Delta x}}{\boldsymbol{x}} \times \mathbf{100\%}$$

Precision level = 100% − Percentage uncertainty

Example:

A ruler gives a distance of 10 cm. Its smallest scale division is 1 mm, or 0.1 cm. Then:

$$s = 10 \text{ cm}$$
$$\Delta s = 0.1 \times 0.5 = 0.05 \text{ cm}$$

The result is written as:

$$(10.00 \pm 0.05) \text{ cm}$$
$$\text{Percentage uncertainty} == \frac{\mathbf{0{,}05}}{\mathbf{10}} \times 100\% = 0.50\%$$
$$\text{Precision level} = 100\% - 0.50\% = 99.50\%$$

2. Uncertainty in repeated measurements

For n repeated measurements of x, the final result is written as $\bar{x} \pm \Delta x$, where $\bar{x}$ is the mean and Δx is the absolute uncertainty.

$$\textbf{Percentage uncertainty} = \frac{\mathbf{\Delta x}}{\boldsymbol{x}} \times \mathbf{100\%}$$
$$\textbf{Precision level} = \mathbf{100\% - \text{Percentage uncertainty}}$$

Example:

No.	(s ± Δs) cm	δ	δ²
1	10	0.0	0.00
2	10.2	0.2	0.04
3	10.1	0.1	0.01
4	10	0.0	0.00
5	10	0.0	0.00
6	9.9	-0.1	0.01
7	10.1	0.1	0.01
8	9.8	-0.2	0.04
9	9.9	-0.1	0.01
10	10	0.0	0.00
n = 10	Σs = 100	Σδ = 0	Σδ² = 0.12

Several methods can be used to determine the final result

a. Method 1

$$\bar{s} = \frac{(s_{max} + s_{min})}{2} = \frac{(10{,}2 + 9{,}8)}{2} = 10 \text{ cm}$$
$$\Delta s = \frac{(s_{max} - s_{min})}{2} = \frac{(10{,}2 - 9{,}8)}{2} = 0.2 \text{ cm}$$

Result : (10.00 ± 0.2) cm

Percentage uncertainty : $\frac{0{,}2}{10} \times 100\% = 2.0\%$

Precision level : $100\% - 2\% = 98.0\%$

b. Method 2

$$\bar{s} = \frac{\Sigma s}{n} = \frac{100}{10} = 10 \text{ cm}$$

$$\Delta s = \delta_{max} = 0.2 \text{ cm}$$

Result : (10.00 ± 0.2) cm
Percentage uncertainty : $\frac{0,2}{10} \times 100\% = 2.0\%$
Precision level :100% − 2% = 98.0%

c. Method 3

$$\bar{s} = \frac{\Sigma s}{n} = \frac{100}{10} = 10 \text{ cm}$$

$$\Delta s = \sqrt{\frac{\Sigma \delta^2}{n}} = \sqrt{\frac{0,12}{10}} = \sqrt{0,012} = 0.11 \text{ cm}$$

Result : (10.00 ± 0.11) cm
Percentage uncertainty : $\frac{0,11}{10} \times 100\% = 1.10\%$
Precision level : 100% − 1.1% = 98.90%

d. Method 4

$$\bar{s} = \frac{\Sigma s}{n} = \frac{100}{10} = 10 \text{ cm}$$

$$\Delta s = \sqrt{\frac{\Sigma \delta^2}{(n-1)}} = \sqrt{\frac{0,12}{10}} = \sqrt{0,01} = 0.1 \text{ cm}$$

Result : (10.00 ± 0.1) cm
Percentage uncertainty : $\frac{0,1}{10} \times 100\% = 1.0\%$
Precision level : 100% − 1.1% = 98.90%

e. Method 5

$$\bar{s} = \frac{\Sigma s}{n} = \frac{100}{10} = 10 \text{ cm}$$

$$\Delta s = \sqrt{\frac{\Sigma \delta^2}{n(n-1)}} = \sqrt{\frac{0,12}{90}} = \sqrt{0,0013} = 0.04 \text{ cm}$$

Result : (10.00 ± 0.04) cm
Percentage uncertainty : $\frac{0,04}{10} \times 100\% = 0,40\%$
Precision level : 100% − 0.40% = 96.60%

f. Method 6

$$\bar{s} = \frac{\Sigma s}{n} = \frac{100}{10} = 10 \text{ cm}$$

$$\Delta s = \frac{1}{n}\sqrt{\frac{n\Sigma \delta^2 - (\Sigma \delta)^2}{n(n-1)}} = \frac{1}{10}\sqrt{\frac{10(0,12) - 0}{9}} = 0,036 \text{ cm}$$

Result : (10.00 ± 0.036) cm

Percentage uncertainty : $\frac{0{,}036}{10{,}000} \times 100\% = 0{,}36\%$

Precision level : $100\% - 0{,}36\% = 99.6\%$

E. Calculations with Uncertain Quantities

1. Addition and subtraction

If $X = (x \pm \Delta x)$ and $Y = (y \pm \Delta y)$, and $R = X \pm Y$, then $R = r \pm \Delta r$, where:

$$\mathbf{r = x \pm y \quad and \quad \Delta r = \Delta x + \Delta y}$$

Example:

If A = B + C and D = B – C

with B = (10.0 ± 0.2) m and C = (5.0 ± 0.1) m,

then A = (15.0 ± 0.3) m and D = (5.0 ± 0.3) m.

2. Multiplication and division

If $X = (x \pm \Delta x)$ is a derived quantity and a, b, c, … are its constituent quantities, with uncertainties Δa, Δb, Δc, … respectively, Δx is obtained using the differential rule:

$$\Delta x = \left|\frac{\partial x}{\partial a}\right|\Delta a + \left|\frac{\partial x}{\partial b}\right|\Delta b + \left|\frac{\partial x}{\partial c}\right|\Delta c + \cdots$$

Example 1

The measured length, width, and thickness of a rectangular block are (20 ± 0.05) cm, (10 ± 0.05) cm, and (5 ± 0.05) cm, respectively. What are its volume and uncertainty?

Solution: The volume of the block is:

$$V = l \times w \times t$$
$$V = 20 \times 10 \times 5 = 1000 \text{ cm}^3$$

Its volume uncertainty is:

$$\Delta V = \left|\frac{\partial V}{\partial p}\right|\Delta l + \left|\frac{\partial V}{\partial l}\right|\Delta w + \left|\frac{\partial V}{\partial t}\right|\Delta t$$
$$\Delta V = (wt\Delta l) + (lt\Delta w) + (lw\Delta t)$$
$$\Delta V = (10 \times 5 \times 0.5) + (20 \times 5 \times 0.5) + (20 \times 10 \times 0.5)$$
$$\Delta V = 25 + 50 + 100 = 175 \text{ cm}^3$$

The result is written as:

$$(1000 \pm 175) \text{ cm}^3$$
$$\text{Percentage uncertainty} = (175 / 10) \times 100\% = 17.50\%$$
$$\text{Precision level} = 100\% - 17.5\% = 82.50\%$$

Example 2

The measured mass and volume of a liquid are (1000 ± 0.05) g and (1000 ± 175) cm³, respectively. What are its density and uncertainty?

Solution:

The density of the liquid is:

$$\rho = \frac{m}{v} = \frac{1000}{1000} = 1 \text{ g/cm}^3$$

The uncertainty calculation is presented in the source as:

$$\Delta\rho = \left|\frac{\partial\rho}{\partial m}\right|\Delta m + \left|\frac{\partial\rho}{\partial V}\right|\Delta V$$

$$\Delta V = \left(\left|\frac{1}{V}\right|\Delta m\right) + \left(\left|\frac{m}{V^2}\right|\Delta V\right)$$

$$\Delta V = \left(\left|\frac{1}{1000}\right|0{,}05\right) + \left(\left|\frac{1000}{1000^2}\right|175\right)$$

$$\Delta V = 0.00005 + 0.175 = 0.17505 \text{ g/cm}^3$$

The result is written in the source as:

$$1 \pm 0.17505 \text{ cm}^3$$

$$\text{Percentage uncertainty} = \frac{0.17505}{1} \times 100\% = 17.505\%$$

$$\text{Precision level} = 100\% - 17.505\% = 82.495\%$$

F. Graphs

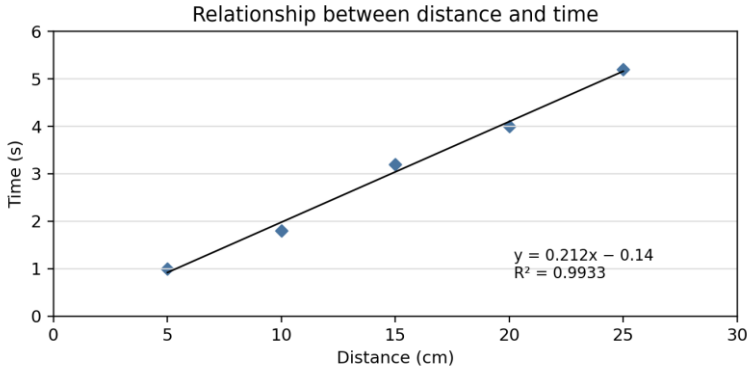
A graph can show the relationship between two variables. A linear graph follows y = mx + c, where c is the y-intercept and m is the gradient or slope. To determine a quantity experimentally using a graph, place the dependent-variable term on the y-axis and the independent-variable term on the x-axis so that m contains the quantity being sought. The source expresses the graph's precision level as $R^2 \times 100\%$.

Example 1: For t = s/v, plot t on the y-axis and s on the x-axis. Then m = 1/v, so v = 1/m.

Example 2: For $t^2 = 2s/a$, plot t^2 on the y-axis and s on the x-axis. Then m = 2/a, so a = 2/m.

Note: Choose the variables plotted to match the research objective. The gradient should allow the required quantity to be determined while still showing the effect of the manipulated variable on the response variable.

Example:



The graph places time t on the y-axis and distance s on the x-axis. From t = s/v, the slope m is 1/v, so v = 1/m. The graph gives m = 0.212, hence v = 1/0.212 = 4.717 cm/s. The stated precision level is 0.9933 × 100% = 99.33%.

G. Significant Figures

When reporting laboratory measurements, the rules for significant figures must be observed. The number of significant figures reported reflects the precision of a measurement. Significant figures are the digits in a numerical result obtained from experimental measurements. Their number indicates the accuracy and precision with which a particular quantity has been measured.

1. Rules for significant figures

a. If a decimal point is present, the rightmost digit, whether zero or nonzero, is the rightmost significant figure.
b. If there is no decimal point, the rightmost nonzero digit is the rightmost significant figure.
c. Whether or not there is a decimal point, the leftmost nonzero digit is the leftmost significant figure.
d. All digits between the leftmost and rightmost significant figures are significant.

2. Significant figures in measurement results

Significant figures in a measurement consist of certain digits and an estimated digit. The estimated digit is also called the uncertain digit. The more precise the measurement, the more significant figures are reported. For example, a ruler with a smallest division of 0.1 cm gives a length

$X = 12.5$ cm and has an uncertainty of ± 0.05 cm.

The result is written as:

$X = (12.50 \pm 0.05)$ cm

3. Rounding significant figures

To reduce the number of significant figures, some digits must be discarded. If the first discarded digit is:

a. less than five, do not round up;

b. greater than five, round up;

c. equal to five, round up if the preceding retained digit is odd.

4. Calculations with significant figures

a. Addition and subtraction.

Carry out the calculation to the first decimal position containing an estimated digit. In the source, underlining indicates estimated digits. Example:

$$1482.372 + 13.8 + 1.49 = 1497.5$$

b. Multiplication and division.

According to the source, the result of multiplying or dividing two or more numbers should contain one more significant figure than the smallest number of significant figures in the input values. Example:

$$1.55 \times 72.431 \times 125.025 = 14036.31295$$

The value 1.55 has the fewest significant figures, namely 3. The result is therefore reported with $3 + 1 = 4$ significant figures. Rounding 14036.31295 to four significant figures gives 14040, or 1.404×10^4.

H. Operational Definitions of Variables

An operational definition describes what a variable means in the context of an experiment. It is necessary to ensure that measurements or data collection are consistent across data sources. In addition to defining a variable operationally, specify the measurement method, the measurement result or category, and the measurement scale used. The source introduces an example involving a viscosity experiment with mass as the independent variable.

M1 PULLEY MOMENT OF INERTIA

A. EXPERIMENTAL OBJECTIVES

1. Determine the acceleration of the system using a kinematic analysis.
2. Determine the moment of inertia of the pulley using a dynamic analysis.

B. RESEARCH QUESTIONS

_____

_____

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

_____

_____

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Atwood machine kit	1 set
2	Masses	As required
3	Balance	1
4	Ruler	1
5	Stopwatch	1

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

_____

ODV of the independent or manipulated variable:

_____

Dependent or response variable:

_____

ODV of the dependent or response variable:

_____

Controlled variables:

_____

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design, including a diagram, to test your hypothesis using the variables you have identified.

Preparing a data table

Create a table to record the data you obtain.

4. Plotting a graph

Using your data, plot a graph showing the relationship between the independent and dependent variables.

F. DISCUSSION AND ANALYSIS

1. How can the acceleration of the system be determined using a kinematic analysis?

2. What factors affect the acceleration of a moving object?

3. How can the moment of inertia of the pulley be determined using a dynamic analysis?

4. What factors affect the moment of inertia of the pulley in a dynamic analysis?

5. What are the differences between kinematic and dynamic analyses?

6. Calculation. Using your experimental data, calculate the moment of inertia of the pulley using a dynamic analysis.

7. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data and graphs above?

H. APLICATION

Two objects of masses 15 kg and 10 kg are suspended from the two ends of a string passing over a solid pulley of radius 10 cm and mass 300 g. Neglect the mass of the string, assume that the string does not slip, and that the pulley rotates without friction. Determine the speed of the two objects when they are at the same height if their initial difference in height is 5 m. Take $g = 10\ m/s^2$.



A. EXPERIMENTAL OBJECTIVES

1. Determine the acceleration of a moving object using a kinematic analysis.

2. Determine the coefficients of static and kinetic friction between two surfaces using a dynamic analysis.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Sliding-board kit	1 set
2	Masses	As required
3	Balance	1
4	Ruler	1
5	Stopwatch	1

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design, including a diagram, to test your hypothesis using the variables you have identified.

3. Preparing a data table

Create a table to record the data you obtain.

4. Plotting a graph

Using your data, plot a graph showing the relationship between the independent and dependent variables.

F. DISCUSSION AND ANALYSIS

1. How can the acceleration of a moving object be determined using a kinematic analysis?

2. What factors affect the acceleration of a moving object?

3. How can the coefficients of static and kinetic friction between two surfaces be determined using a dynamic analysis?

4. What factors affect the coefficients of static and kinetic friction between two surfaces in a dynamic analysis?

5. What are the differences between kinematic and dynamic analyses?

6. Calculation. Using your experimental data, calculate the coefficients of static and kinetic friction between the two surfaces using a dynamic analysis.

7. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data and graphs above?

H. APLICATION

A parachutist is descending with an acceleration of 1.5 m/s^2. The combined mass of the parachutist and parachute is 90 kg. What is the air-resistance force acting on the parachute?

M3 PULLEY SYSTEM

A. EXPERIMENTAL OBJECTIVES

1. Determine the mechanical advantage of different pulley systems.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Pulleys	3
2	Retort stand	1
3	String	As required
4	Masses	As required
5	Balance	1

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Develop an experimental design, including a diagram and procedure, to test your hypothesis using the variables you have identified.

3. Preparing a data table

Create a table to record the data you obtain.

4. Plotting a graph

Plot a graph to determine the mechanical advantage of the pulley system. Show the relationship between the independent and dependent variables using the data obtained. Place W on the x-axis and F on the y-axis.

F. DISCUSSION AND ANALYSIS

1. How can the mechanical advantage of a pulley system be determined?

2. Does the number of pulleys affect the mechanical advantage? Explain.

3. Calculation. After plotting the graph, calculate the mechanical advantage from its gradient.

4. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data and graphs above?



A. EXPERIMENTAL OBJECTIVES

1. Determine the center of mass of an irregularly shaped object.
2. Determine the coordinates of the center of mass of an irregularly shaped object.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Irregularly shaped objects	As required
2	String	As required
3	Needle	1
4	Mass	1
5	Laboratory balance	1

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Provide a diagram and a description of an experimental design to test your hypothesis using the variables you have identified.

3 Constructing a coordinate system

Draw a two-dimensional coordinate system to determine the coordinates of the center of mass.

F. DISCUSSION AND ANALYSIS

1. How can the center of mass of a regularly shaped object be determined by calculation and by experiment?

2. Can an object have two or more centers of mass? Explain.

3. How can the center of mass of an irregularly shaped object be determined? Can it be calculated mathematically? Explain.

4. What role does gravity play in determining the center of mass?

5. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the experiment and analysis?

H. APLICATION

In a circus performance, a person walks along a tightrope without safety equipment. How can the performer maintain balance without falling, and where is the performer's center of mass?

M5 SIMPLE PENDULUM

A. EXPERIMENTAL OBJECTIVES

1. Determine the effect of string length on the period of a simple pendulum.
2. Determine the effect of bob mass on the period of a simple pendulum.
3. Determine gravitational acceleration from simple-pendulum experimental data.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Masses	As required
2	Retort stand	1
3	Thread	As required
4	Ruler	1
5	Protractor	1
6	Stopwatch	1

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design to test your hypothesis using the variables you have identified.

3. Preparing a data table and graph

Create a table to record the data you obtain.

Using your data, plot a graph showing the relationship between the independent and dependent variables.

F. DISCUSSION AND ANALYSIS

1. How can gravitational acceleration be determined from a simple-pendulum experiment?

2. Equation analysis. Analyze the equation of motion of a simple pendulum using a Newtonian approach to determine gravitational acceleration.

3. Calculation. Using your experimental data and the operating principle of a simple pendulum, calculate gravitational acceleration.

4. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data and graphs above?

H. APLICATION

A simple pendulum with a bob of mass 10 g is displaced through an angle of 10°. Its displacement is given by $x = A \sin(10t)$. What is the maximum displacement of the pendulum? Take $g = 10\ m/s^2$.



A. EXPERIMENTAL OBJECTIVES

1. Determine a spring constant using a static method.
2. Determine the equivalent spring constant for series, parallel, and combined spring arrangements.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Springs	1 set
2	Masses	As required
3	Retort stand and clamp	1
4	Ruler	1

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design to test your hypothesis using the variables you have identified.

3. Preparing a data table

Create a table to record the data you obtain.

4. Plotting a graph

Using your data, plot a graph showing the relationship between the independent and dependent variables.

F. DISCUSSION AND ANALYSIS

1. How can a spring constant be determined using a static method?

2. Why is a static method used to determine the spring constant?

3. How can the equivalent spring constant be determined for series, parallel, and combined spring arrangements?

4. Must the springs have identical characteristics when determining an equivalent spring constant? Explain.

5. Calculation. Using your experimental data, calculate the spring constant by the static method and the equivalent spring constants for series, parallel, and combined arrangements.

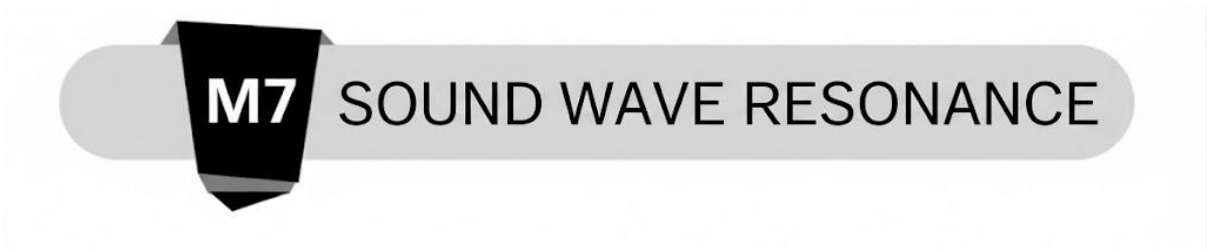
6. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data and graphs above?

H. APLICATION

A mass of 100 g is suspended from a spring, producing an extension of 5 cm. What is the spring constant? Take $g = 10\ m/s^2$.



A. EXPERIMENTAL OBJECTIVES

1. Determine the speed of sound in air from resonance-tube experimental data.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Resonance-tube kit	1 set
2	Audio-frequency generator (AFG)	1
3	Ruler	1

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design to test your hypothesis using the variables you have identified.

3. Preparing a data table

Create a table to record the data you obtain.

4. Plotting a graph

Using your data, plot a graph showing the relationship between the independent and dependent variables.

F. DISCUSSION AND ANALYSIS

1. How can the speed of sound in air be determined?

2. Are there any factors that affect the speed of sound in air? Explain.

3. Calculation. Determine the speed of sound in air using your experimental data.

4. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data and graphs above?



A. EXPERIMENTAL OBJECTIVES

1. Determine the viscosity coefficients of different liquids from experimental data.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Vernier caliper	1
2	Micrometer screw gauge	1
3	Ruler	1
4	Laboratory balance	1
5	Stopwatch	1
6	Hydrometer	1
7	Thermometer	1
8	Barometer	1
9	Large solid iron sphere	1
10	Small solid iron sphere	1
11	Glass tubes	2
12	Liquids (glycerin and oil)	As required
13	Holding magnet	1
14	String	As required

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design to test your hypothesis using the variables you have identified.

3. Preparing a data table

Create a table to record the data you obtain.

4. Plotting a graph

Using your data, plot a graph showing the relationship between the independent and dependent variables.

F. DISCUSSION AND ANALYSIS

1. How can the viscosity of a liquid be determined?

2. Are there factors that affect the viscosity of a liquid? Explain.

3. What is the resultant of the forces acting on an object in the liquid?

4. Calculation. Using your experimental data, calculate the viscosity coefficient of the liquid used in the experiment.

5. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data and graphs above?

H. APLICATION

Does the equation used to determine the viscosity coefficient in this experiment apply to a sphere falling through air? Explain and provide mathematical evidence when air resistance is neglected. Take $g = 10\ m/s^2$.

T1 THERMOMETER CALIBRATION

A. EXPERIMENTAL OBJECTIVES

1. Compare measurements made with an ungraduated thermometer and a Celsius thermometer.
2. Determine the scale of an ungraduated thermometer.

B. RESEARCH QUESTIONS

_____

_____

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

_____

_____

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Graduated thermometer	1
2	Ungraduated thermometer	1
3	Vessel	1
4	Plastic cup and lid	1
5	Funnel	1
6	Thread	As required
7	Retort stand	1
8	Bunsen burner	1
9	Tripod and wire gauze	1
10	Millimeter graph paper	1 sheet
11	Ice cubes	As required
12	Water	As required

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

_____

ODV of the independent or manipulated variable:

_____

Dependent or response variable:

_____

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design, including a diagram, to test your hypothesis using the variables you have identified.

3. Preparing a data table

Create a table to record the data you obtain.

F. DISCUSSION AND ANALYSIS

1. How can the scale of an ungraduated thermometer be determined?

2. What is meant by calibration? If you are asked to calibrate a clinical thermometer, what would you use as the calibration reference, and how would you proceed?

3. If an ungraduated thermometer is heated while touching the wall of the heater, how accurate will its readings be in comparison with those of the graduated thermometer?

4. Calculation. From your data, determine how much the ungraduated thermometer scale changes for each one-degree change on the Celsius thermometer.

5. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data and calculations?

T2 HEAT CAPACITY OF CALORIMETER

A. EXPERIMENTAL OBJECTIVES

1. Determine and describe the heat capacity of a calorimeter.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Calorimeter	1
2	Bunsen burner	1
3	Tripod and wire gauze	1
4	Laboratory balance	1
5	Measuring cylinder	1
6	Vessel	1
7	Thermometer	1
8	Water	As required

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design to test your hypothesis using the variables you have identified.

3. Preparing a data table

Create a table to record the data you obtain.

F. DISCUSSION AND ANALYSIS

1. How can the heat capacity of a calorimeter be determined?

2. Can the heat capacity of a calorimeter change?

3. How does heat transfer in a calorimeter relate to the zeroth law of thermodynamics?

4. Calculation. After obtaining the data, calculate the heat capacity of the calorimeter used.

5. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data above?

T3 SPECIFIC HEAT OF SOLID

A. EXPERIMENTAL OBJECTIVES

1. Determine the specific heat capacity of a solid experimentally.
2. Compare the experimental specific heat capacity with its theoretical value.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Calorimeter	1
2	Bunsen burner	1
3	Tripod and wire gauze	1
4	Balance	1
5	Measuring cylinder	1
6	Vessel	1
7	Thermometer	1
8	Water	As required
9	Metal sample	1

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design to test your hypothesis using the variables you have identified.

3. Preparing a data table

Create a table to record the data you obtain.

F. DISCUSSION AND ANALYSIS

1. Explain the difference between specific heat capacity and specific latent heat of fusion.

2. How can the specific heat capacity of a solid be determined?

3. Explain whether Black's principle of calorimetry and the zeroth law of thermodynamics are the same or different.

4. Calculation. After obtaining the data, calculate the specific heat capacities of the different solids used. Compare your results with the theoretical values.

5. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data above?

T4 LATENT HEAT OF FUSION OF ICE

A. EXPERIMENTAL OBJECTIVES

1. Determine the quantity of heat required to melt 1 g of ice at its melting point.

B. RESEARCH QUESTIONS

C. HYPOTHESIS

Formulate a hypothesis that answers the research questions above and can be tested using the apparatus and materials listed below.

D. APPARATUS AND MATERIALS

No.	Apparatus or material	Quantity
1	Calorimeter	1
2	Bunsen burner	1
3	Tripod and wire gauze	1
4	Balance	1
5	Measuring cylinder	1
6	Vessel	1
7	Thermometer	1
8	Water	As required
9	Ice cubes	As required

E. PROCEDURE

1. Identifying variables and their operational definitions

Identify the independent variable (the variable deliberately varied), the dependent variable (the variable that changes in response to the independent variable), and the controlled variables (the variables kept constant). State the operational definition of each variable (ODV).

Independent or manipulated variable:

ODV of the independent or manipulated variable:

Dependent or response variable:

ODV of the dependent or response variable:

Controlled variables:

ODV of the controlled variables:

2. Designing the experiment

Describe an experimental design to test your hypothesis using the variables you have identified.

3. Preparing a data table

Create a table to record the data you obtain.

F. DISCUSSION AND ANALYSIS

1. How can the quantity of heat required to melt 1 g of ice at its melting point be determined?

2. Explain whether Black's principle of calorimetry and the zeroth law of thermodynamics are the same or different.

3. Calculation. After obtaining the data, calculate the quantity of heat required to melt 1 g of ice at its melting point.

4. Correction factors. Were any variables neglected in your experiment? Which variables did you neglect?

G. CONCLUSIONS

What conclusions can you draw from the data above?

H. APLICATION

Research at the United States National Aeronautics and Space Administration (NASA) and the National Snow and Ice Data Center in Colorado has revealed that Arctic ice is diminishing. The source states that Arctic ice, formerly "680,000 km² thick," has decreased by 43%. How does the melting of Arctic ice occur?

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