A1 Scientific Inquiry

Planning an Investigation

In our attempts to further our understanding of the natural world, we encounter questions, mysteries, or events that are not easily explained. We can use controlled experiments or observational studies to help us look for answers or explanations. The methods used in scientific inquiry depend, to a large degree, on the purpose of the inquiry.

Controlled Experiments

Controlled experiments are performed when the purpose of the inquiry is to create or test a scientific concept. In a controlled experiment, an independent variable is purposefully and steadily changed to determine its effect on a second, dependent variable. All other variables are controlled or kept constant.

The common components of controlled experiments are outlined in the flow chart below. *Even though the sequence is presented as linear, there are normally many cycles through the steps during an actual experiment.*

Process Description	**Stating the Purpose**	**Asking the Question**	**Hypothesizing/ Predicting**	**Designing the Investigation**
	Choose a topic that interests you. Determine whether you are going to carry out a given procedure or develop a new experimental design. Indicate your decision in a statement of the purpose.	**Your Question forms the basis for your investigation. Controlled experiments are about relationships, so the Question could be about the effects on variable A when variable B is changed. The Question could be about what causes the change in variable A. In this case, you might speculate about possible variables and determine which variable causes the change.**	**A hypothesis is a tentative explanation. You must be able to test your hypothesis, which can range in certainty from an educated guess to a concept that is widely accepted in the scientific community. A prediction is based on a hypothesis or a more established scientific explanation, such as a theory. In the prediction, you state what outcome you expect from your investigation.**	**The design of a controlled experiment identifies how you plan to manipulate the independent variable, measure the response of the dependent variable, and control all the other variables.**
Example: A Test of the Collision Model	The purpose of this investigation is to provide some concrete evidence to support or refute the collision model.	How does changing the concentration of hydrochloric acid affect the time required for the acid to react completely with a fixed quantity of zinc?	According to the collision model, if the concentration of hydrochloric acid is increased, then the time required for the reaction with zinc will decrease. The following reasoning supports this prediction: A higher concentration of $HCl_{(aq)}$ produces more collisions per second between the aqueous ions in hydrochloric acid and the zinc atoms. More collisions per second produces more reactions per second and, therefore, a shorter time is required to consume the zinc.	The same amount of zinc metal is made to react with different known concentrations of excess hydrochloric acid. The time for the zinc to react completely is measured for each concentration of acid solution. The independent variable is the concentration of hydrochloric acid. The dependent variable is the time for the zinc to be consumed. The temperature of the solution, the quantity of zinc, the surface area of the zinc in contact with the acid, and the volume of the acid are all controlled variables.

There are many ways to gather and record observations during an investigation. It is helpful to plan ahead and think about what data you will need and how best to record them. This helps you clarify your thinking about the Question posed at the beginning, the variables, the number of trials, the procedure, and your skills. It will also help you organize your evidence for easier analysis later.

Gathering, recording, and organizing observations

Time to completion for the reaction will be measured using a stopwatch and recorded in a table like **Table 1**.

After thoroughly analyzing your observations, you may have sufficient and appropriate evidence to answer the Question posed at the beginning of the investigation.

Analyzing the observations

The observations will be presented in graphical format, with time on the horizontal axis and concentration of $HCl_{(aq)}$ on the vertical axis. In this format, any trends or patterns will be easier to see.

At this stage of the investigation, you will evaluate the processes that you followed to plan and perform the investigation. Evaluating the processes includes reviewing the design and the procedure. You will also evaluate the outcome of the investigation, which involves assessing the evidence—whether it supports the hypothesis or not—and the hypothesis itself.

Evaluating the evidence and the hypothesis

For a sample evaluation, see the sample lab report in Appendix A4.

In preparing your report, your aim should be to describe your design and procedure accurately, and to report your observations accurately and honestly.

Reporting on the investigation

For the format of a typical lab report, see the sample lab report in Appendix A4.

Table 1 Reaction Time for Zinc with $HCl_{(aq)}$

Concentration of $HCl_{(aq)}$ (mol/L)	Time for reaction (s)
2.5	
2.0	
1.5	
1.0	
0.5	

Observational Studies

Often the purpose of inquiry is simply to study a natural phenomenon with the intention of gaining scientifically significant information to answer a question. Observational studies involve observing a subject or phenomenon in an unobtrusive or unstructured manner, often with no specific hypothesis. A hypothesis to describe or explain the observations may, however, be generated after repeated observations, and modified as new information is collected over time.

The flow chart below summarizes the stages and processes of scientific inquiry through an observational study. *Even though the sequence is presented as linear, there are normally many cycles through the steps during an actual study.*

Process Description	Stating the Purpose	Asking the Question	Hypothesizing/ Predicting	Designing the Investigation
	Choose a topic that interests you. Determine whether you are going to replicate or revise a previous study, or create a new study. Indicate your decision in a statement of the purpose.	**In planning an observational study, it is important to pose a general question about the natural world. You may or may not follow the Question with the creation of a hypothesis.**	**A hypothesis is a tentative explanation. In an observational study, a hypothesis can be formed after observations have been made and information has been gathered on a topic. A hypothesis may be created in the analysis.**	**The design of an observational study describes how you will make observations that are relevant to the Question.**
Example: Water Quality in Public Swimming Area	Although the quality of public swimming areas is normally tested by the municipal or provincial Department of Health, no chemical analysis is done unless a problem arises. The purpose of this study is to carry out an environmental assessment to determine the chemical quality of the local public swimming area.	What common chemicals are found in the local public swimming area, and in what concentrations are they present?	At this point, we have no indication of which chemicals are present in the area, what their concentrations may be, and whether there are any threats to swimmers. We have no hypothesis and can make no predictions.	We will take a sample of water from five different locations within the local swimming area each week for a month. Note will be made of other significant conditions (such as heavy rain or wind) that are present during the course of the study. The water samples will be tested for organic and inorganic chemicals that may pose a health hazard. The testing facilities at the Department of Health will be used to determine the presence and concentrations of chemicals.

Table 2 Presence and Concentration of Chemicals in Public Swimming Area

Chemicals	Week 1					Week 2					Week 3					Week 4				
	Sample area					Sample area					Sample area					Sample area				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

There are many ways to gather and record observations during an investigation. During your observational study, you should quantify your observations where possible. All observations should be objective and unambiguous. Consider ways to organize your information for easier analysis.

Gathering, recording, and organizing observations

The data will be recorded in a table like **Table 2**. The chemicals to be tested for include the following:

- lead
- mercury
- cadmium
- nitrates/nitrites
- volatile organic compounds such as benzene, toluene, and carbon tetrachloride
- petroleum products
- chlorine

After thoroughly analyzing your observations, you may have sufficient and appropriate evidence to answer the Question posed at the beginning of the study. You may also have enough observations and information to form a hypothesis.

Analyzing the observations

The concentrations of the chemicals found in the swimming area are determined.

At this stage of the study, you will evaluate the processes used to plan and perform the study. Evaluating the processes includes evaluating the materials, the design, the procedure, and your skills. Often the results of such studies suggest further studies, perhaps correlational studies or controlled experiments to explore tentative hypotheses you may have developed.

Evaluating the evidence and the hypothesis

We must determine if our sampling and testing procedures are appropriate. Is the number of samples sufficient? Were they taken at the proper sites? Was the testing of the samples carried out with care and precision?

The presence of chemicals in concentrations higher than the acceptable levels will alert us to potential problems with the swimming area. This might suggest further studies to determine the possible source(s) of the chemical(s).

In preparing your report, your aim should be to describe your design and procedure accurately, and to report your observations accurately and honestly.

Reporting on the investigation

For the format of a typical lab report, see the sample lab report in Appendix A4.

A2 Decision Making

Modern life is filled with environmental and social issues that have scientific and technological dimensions. An issue is defined as a problem that has at least two possible solutions rather than a single solution. There can be many positions, generally determined by the values that an individual or a society holds, on a single issue. Which solution is "best" is a matter of opinion; ideally, the solution that is put into practice is the one that is most appropriate for society as a whole.

The common elements of the decision-making process are outlined in the flow chart below. *Even though the sequence is presented as linear, you may go through several cycles before deciding that you are ready to defend a decision.*

Process Description

Defining the issue

The first step in understanding an issue is to explain why it is an issue, describe the problems associated with the issue, and identify the individuals or groups (called stakeholders) involved in the issue. You could brainstorm the following questions to research the issue: Who? What? Where? When? Why? How? Develop background information on the issue by clarifying facts and concepts, and identifying relevant attributes, features, or characteristics of the problem.

Identifying alternatives/positions

Examine the issue and think of as many alternative solutions as you can. At this point, it does not matter if the solutions seem unrealistic. To analyze the alternatives, you should examine the issue from a variety of perspectives. Stakeholders may bring different viewpoints to an issue, and these viewpoints may influence their position on the issue. Brainstorm or hypothesize how various stakeholders would feel about your alternatives.

Researching the issue

Formulate a research question that helps to limit, narrow, or define the issue. Then develop a plan to find reliable and relevant sources of information. Outline the stages of your information search: gathering, sorting, evaluating, selecting, and integrating relevant information. You may consider using a flow chart, a concept map, or another graphic organizer to outline the stages of your information search. Gather information from many sources, including newspapers, magazines, scientific journals, the Internet, and the library.

Example: The Issue of Pesticide Use

In recent years, the use of pesticides (herbicides, insecticides, and fungicides) on lawns has increased despite reports of health and environmental risks. Several attempts are being made to deal with the increased use, including publicity campaigns by various groups, and attempts to ban or limit the use of pesticides at municipal and other government levels. A list of possible stakeholders in this issue is started in **Table 1** (p. 456).

Develop background information on the issue by clarifying information and concepts, and identifying relevant attributes, features, or characteristics of the problem. For example:

- While more research is needed on the health risks, many lawn chemicals currently in use are known carcinogens. As well, there are numerous other less serious symptoms (such as headaches, nausea, fever, and breathing difficulties) associated with pesticide poisoning.
- Manufacturers point out that the pesticides they manufacture have been approved for use by the federal government. Pesticides considered unsafe, such as DDT and fenitrothion, have been banned.

One possible solution for people concerned about pesticide use is to ban the production of pesticides. A solution for government might be to enforce stricter regulations governing pesticide use.

Think about how different stakeholders might feel about the alternatives. For example, citizens may be affected by the use of pesticides in their neighbourhood. What would be their perspective? What would be the perspective of a parent of small children? A farmer? A pest-control business owner? A chemist? A gardener? Employees and owners of a company that produces pesticides? An environmentalist? (See **Table 2** for a start on this process.) Remember that one person can have more than one perspective. It is also possible that two people, looking at an issue from the same perspective, might disagree about the best solution or even the available information. For example, scientists might disagree about the degree of risk associated with pesticide use.

Begin your search for reliable and relevant sources of information about the issue with a question such as, "What does the research say about the risks associated with pesticide use?" or "What are the established positions of various groups on the issue?"

There are five steps that must be completed to analyze the issue effectively:

1. **Establish criteria for determining the relevance and significance of the data you have gathered.**
2. **Evaluate the sources of information.**
3. **Identify and determine what assumptions have been made. Challenge unsupported evidence.**
4. **Determine any relationships associated with the issue.**
5. **Evaluate the alternative solutions, possibly by conducting a risk–benefit analysis.**

After analyzing your information, you can answer your research question and take an informed position on the issue. You should be able to defend your solution in an appropriate format—debate, class discussion, speech, position paper, multimedia presentation (such as a computer slide show), brochure, poster, or video.

Your position on the issue must be justified using supporting information that you have researched. You should be able to defend your position to people with different perspectives. Ask yourself the following questions:

- **Do I have supporting evidence from a variety of sources?**
- **Can I state my position clearly?**
- **Can I show why this issue is relevant and important to society?**
- **Do I have solid arguments (with solid evidence) supporting my position?**
- **Have I considered arguments against my position, and identified their faults?**
- **Have I analyzed the strong and weak points of each perspective?**

The final phase of decision making includes evaluating the decision itself and the process used to reach the decision. After you have made a decision, carefully examine the thinking that led to your decision.

Some questions to guide your evaluation:

- **What was my initial perspective on the issue? How has my perspective changed since I first began to explore the issue?**
- **How did we make our decision? What process did we use? What steps did we follow?**
- **In what ways does our decision resolve the issue?**
- **What are the likely short- and long-term effects of the decision?**
- **To what extent am I satisfied with the final decision?**
- **What reasons would I give to explain our decision?**
- **If we had to make this decision again, what would I do differently?**

Analyzing the issue → **Defending the decision** → **Evaluating the process**

After reviewing government, chemical industry, and university studies, and reading newspaper articles and papers by environmental groups, we concluded that research seems to indicate that the active ingredients in many common pesticides are carcinogenic and therefore pose a significant risk to health.

There are reports that contradict our view, and domestic pesticides have been approved for use by federal government agencies. There are many jobs, some of them based in our town, that rely on continued use of pesticides.

After performing a risk–benefit analysis of the various alternative solutions, we decided that we should attempt to reduce or eliminate the use of pesticides on lawns.

Table 3 (p. 457) shows a risk–benefit analysis of allowing pesticide use on lawns.

In our defence at the town hall meeting, we will concentrate on our evidence that there are alternative methods of pest control that are effective and safe. By concentrating on this, and on reasonable doubt about the safety of pesticide use, we hope to be able to counter arguments by opponents.

We tried to obtain information from a variety of reputable sources; however, some of the research is highly technical, and it is possible that we misunderstood its main points or misjudged its relevance.

In the town hall meeting, we created a bylaw to eliminate pesticide use on town property and to limit pesticide use on private property to exceptional circumstances. We realize that this decision will not satisfy all stakeholders, but we believe it is the best solution given the evidence at our disposal.

This decision may cause painful changes for industries that produce pesticides and for several service industries. We believe that after a transition period, these industries will survive to produce and market safe alternatives to conventional pesticides.

Table 1 Potential Stakeholders in the Pesticide Debate

Stakeholders	Viewpoint (perspectives)
parent	Children are more susceptible to pesticide poisoning than adults and should not be put at risk. (social)
scientists	1. Active ingredients in many pesticides are known carcinogens. 2. Levels of the active ingredient in pesticides pose no risk (or a risk) to humans with short-term exposure. (scientific)
doctor	Environmental factors that pose any risk to human health should be eliminated or severely restricted. (ecological/legal)
environmentalist	Pesticides from lawns are percolating into rivers, streams, and ground water and are affecting wildlife. (ecological)
pest-control business owner	Used properly, pesticides pose no risk to humans. Only trained persons should be allowed to use pesticides. The pest-control industry is a valuable contributor to the economy. (scientific/technological/legal/economic)
owners of chemical company	Pesticides have been tested and approved by the federal government. (legal) Jobs will be lost if these pesticides are banned. (economic/social)

Table 2 Perspectives on an Issue

Perspective	Focus of the perspective
cultural	customs and practices of a particular group
ecological	interactions among organisms and their natural habitat
economic	the production, distribution, and consumption of wealth
educational	the effects on learning
emotional	feelings and emotions
environmental	the effects on physical surroundings
esthetic	artistic, tasteful, beautiful
moral/ethical	what is good/bad, right/wrong
legal	the rights and responsibilities of individuals and groups
spiritual	the effects on personal beliefs
political	the effects on the aims of a political group or party
scientific	logical or research information based
social	the effects on human relationships, the community, or society
technological	machines and industrial processes

A Risk–Benefit Analysis Model

Risk–benefit analysis is a tool used to organize and analyze information gathered in research. A thorough analysis of the risks and benefits associated with each alternative solution can help you decide on the best alternative.

- Research as many aspects of the proposal as possible. Look at it from different perspectives.
- Collect as much evidence as you can, including reasonable projections of likely outcomes if the proposal is adopted.
- Classify each potential result as being either a benefit or a risk.
- Quantify the size of the potential benefit or risk (perhaps as a dollar figure, as a number of lives affected, or on a scale of 1 to 5).
- Estimate the probability (percentage) of that event occurring.
- By multiplying the size of a benefit (or risk) by the probability of its happening, you can calculate a probability value for each potential result.
- Total the probability values of all the potential risks and all the potential benefits.
- Compare the sums to help you decide whether to accept the proposed action.

Table 3 shows an incomplete risk–benefit analysis of one option in the lawn pesticide issue—making no changes in regulations. Note that although you should try to be objective in your assessment, the beliefs of the person making the risk–benefit analysis will have an effect on the final sums. The possible outcomes considered for analysis, the assessment of the relative importance of a cost or benefit, and the probability of the cost or benefit actually arising will vary according to who does the analysis. For example, would you agree completely with the values placed in the "Cost" and "Benefit" columns of the analysis in **Table 3**?

Table 3 Risk–Benefit Analysis of Continuing Use of Pesticides on Lawns

Risks				**Benefits**			
Possible result	**Cost of result (scale of 1 to 5)**	**Probability of result occurring (%)**	**Cost × probability**	**Possible result**	**Benefit of result (scale of 1 to 5)**	**Probability of result occurring (%)**	**Benefit × probability**
Pesticide use on lawns presents human health risks.	very serious 5	inconclusive research (60%)	300	Pesticides eliminate pests, which also present health risk.	high 4	somewhat likely (60%)	240
Pesticide use on lawns affects other species.	serious 4	likely (80%)	320	Lawn-care business is a valuable part of local economy.	high 4	certain (100%)	400
Health-care costs will increase.	very serious 5	likely (80%)	400	Well-kept lawn increases property value.	medium 3	likely (80%)	240
Total risk value			**1020**	**Total benefit value**			**880**

A3 Technological Problem Solving

There is a difference between science and technology. The goal of science is to understand the natural world. The goal of technological problem solving is to develop or revise a product or a process in response to a human need. The product or process must fulfill its function but, in contrast with scientific problem solving, it is not essential to understand why or how it works.

Technological solutions are evaluated based on such criteria as simplicity, reliability, efficiency, cost, and ecological and political consequences.

Even though the sequence presented in the flow chart below is linear, there are normally many cycles through the steps in any problem-solving attempt.

Process Description

Defining the problem

This process involves recognizing and identifying the need for a technological solution. You need to state clearly the question(s) that you want to investigate to solve the problem and the criteria you will use to plan and evaluate your solution. In any design, some criteria may be more important than others. For example, if a tool measures accurately and is economical, but is not safe, then it is clearly unacceptable.

Identifying possible solutions

Use your prior knowledge, experience, and creativity to propose possible solutions.

During brainstorming, the goal is to generate many ideas without judging them. They can be evaluated and accepted or rejected later.

To visualize the possible solutions, it is helpful to draw sketches. Sketches are often better than verbal descriptions for communicating an idea.

Planning

Planning is the heart of the entire process. Your plan will outline your processes, identify potential sources of information and materials, define your resource parameters, and establish evaluation criteria.

Seven types of resources are generally used when developing technological solutions to problems: people, information, materials, tools, energy, capital, and time.

Example: Inventing a pH Meter

We often need to solve technological problems before we can conduct a scientific investigation. For example, imagine that you are asked to conduct an investigation in which you cannot, for safety reasons, use the traditional, commercial pH indicators. Your task, then, is to design a safe chemical indicator for pH that will be as effective as those available commercially.

If you are not given criteria for the solution to the problem (criteria are often given in technological problem solving), you can establish your own by asking some basic questions about the situation and the function of the device.

In this case, you are asked to design and produce a chemical pH indicator to meet the following criteria:

- must be able to measure pH to at least the nearest 0.5 on the pH scale
- must be safe enough to pose no health hazard if spilled on the skin or ingested
- must have a shelf life of at least one month
- must be at least as economical as a comparable commercial product
- must be produced from readily available materials

Design 1: Poison Primrose Flower Extract

This extract is made by mixing dried and ground poison primrose flower petals, boiling the resulting powder in isopropyl alcohol, and filtering the resulting mixture to isolate the extract.

Design 2: Red Cabbage Extract

This extract is made by mixing chopped red cabbage with water in a blender and straining the juice (extract) from the resulting mush.

People: The human resources required to solve this problem include you and your partner.
Information: You already understand the concepts of acidity and basicity. You will need to understand fully the pH scale. You may also need to find out about naturally occurring substances that react with acids or bases to produce different (such as visible) effects.
Materials: Within the limitations imposed by your proposed solution, cost, availability, safety, and time, you can use whatever materials you deem necessary.
Tools: Your design should not require any specialized tools or machines that are not immediately available.
Energy: The solution to this problem should not require any external source of energy.
Capital: The dollar cost must be low. Your solution must cost less to build than a comparable commercial product would cost to buy.
Time: Because of the time limit on the scientific investigation, there is an even shorter time limit on the production of the indicator. You should be able to produce your indicator within 60 min. (This does not include designing and testing.)

The solution will be evaluated on how well it meets the design criteria established earlier.

In this phase, you will construct and test your prototype using trial and error. Try to change only one variable at a time. Use failures to inform the decisions you make before your next trial. You may also complete a cost–benefit analysis on the prototype.

To help you decide on the best solution, you can rate each potential solution based on the design criteria. Use a five-point rating scale, with 1 being poor, 2 fair, 3 good, 4 very good, and 5 excellent. You can then compare your proposed solutions by totalling the scores.

Once you have made the choice among the possible solutions, you need to produce and test a prototype. While making the prototype, you may need to experiment with the characteristics of different components. A model, on a smaller scale, might help you decide whether the product will be functional. The test of your prototype should answer three basic questions:

- **Does the prototype solve the problem?**
- **Does it satisfy the design criteria?**
- **Are there any unanticipated problems with the design?**

If these questions cannot be answered satisfactorily, you may have to modify the design or select another potential solution.

In presenting your solution, you will communicate your solution, identify potential applications, and put your solution to use.

Once the prototype has been produced and tested, the best presentation of the solution is a demonstration of its use—a test under actual conditions. This demonstration can serve as a further test of the design, as well. Any feedback should be considered for future redesign. Remember that no solution should be considered the absolute final solution.

Evaluation is not restricted to the final step. However, it is important to evaluate the final product using the criteria established earlier and to evaluate the processes used while arriving at the solution. Consider the following questions:

- **To what degree does the final product meet the design criteria?**
- **Did you have to make any compromises in the design? If so, are there ways to minimize the effects of the compromises?**
- **Did you exceed any of the resource parameters?**
- **Are there other possible solutions that deserve future consideration?**
- **How did your group work as a team?**

Constructing/testing solutions → **Presenting the preferred solution** → **Evaluating the solution and process**

Table 1 illustrates the rating for two different designs. Note that although Design 1 came out with the highest rating, there is one factor (safety) that suggests we should go with Design 2. This is what is referred to as a tradeoff. By reviewing or evaluating product and processes, we may be able to modify Design 2 to optimize its performance on the other criteria.

Table 1 Design Analysis

Criterion	Design 1	Design 2
accuracy	5	3
safety	3	5
shelf life	3	4
economy	4	4
materials	5	3
Total score	**20**	**19**

The chosen design was presented to the chemistry class. A set of 12 test tubes was set up. Each test tube contained a colourless solution of known pH, ranging from pH 1 to pH 14. Ten drops of red cabbage extract was added to each test tube. Students observed the colour changes and rated the results using a rating scale similar to the one used in the product testing stages. Students were given a list of the criteria used in the design and production stages, and were asked to provide comments regarding the indicator's performance.

Our chosen product, red cabbage extract, meets most of the established criteria. Feedback from the chemistry class demonstration was positive. Unfortunately, the indicator does not change colour in the intervals pH 3 to 4 and pH 9 to 10, which limits how it can be used.

Kept in the refrigerator, red cabbage extract is still acting as a good pH indicator one month after it was prepared. Red cabbage is readily available. Its extract is safe for all uses and cheap to prepare.

In general, our group worked well as a team. However, some individuals pitched in a little more than others, especially in areas where they felt they they were more skilled. We have agreed that in future projects, every member of the team will work on something that is new to them, which will give each of us a chance to learn, and everyone will do their fair share in the final cleanup.

A4 Lab Reports

When carrying out investigations, it is important that scientists keep records of their plans and results, and share their findings. In order to have their investigations repeated (replicated) and accepted by the scientific community, scientists generally share their work by publishing papers in which they provide details of their design, materials, procedure, evidence, analysis, and evaluation.

Lab reports are prepared after an investigation is completed. To ensure that you can accurately describe the investigation, it is important to keep thorough and accurate records of your activities as you carry out the investigation.

Investigators use a similar format in their final reports or lab books, although the headings and order may vary. Your lab book or report should reflect the type of scientific inquiry that you used in the investigation and should be based on the following headings, as appropriate. (See **Figure 1**, on pages 462–463, for a sample lab report.)

Title

At the beginning of your report, write the section number and title of your investigation. In this course, the title is usually given, but if you are designing your own investigation, create a title that suggests what the investigation is about. Include the date the investigation was conducted and the names of all lab partners (if you worked as a team).

Purpose

State the purpose of the investigation. Why are you doing the investigation?

Question

This is the Question that you attempted to answer in the investigation. If it is appropriate to do so, state the Question in terms of independent and dependent variables.

Hypothesis/Prediction

Based on your reasoning or on a concept that you have studied, formulate an explanation of what should happen (a hypothesis). From your hypothesis you may make a prediction (a statement of what you expect to observe) before carrying out the investigation. Depending on the nature of your investigation, you may or may not have a hypothesis or a prediction.

Experimental Design

This is a brief general overview (one to three sentences) of what was done. If your investigation involved independent, dependent, and controlled variables, list them. Identify any control or control group that was used in the investigation.

Materials

This is a detailed list of all materials used, including sizes and quantities where appropriate. Be sure to include safety equipment such as goggles, lab apron, prospective gloves, and tongs, where needed. Draw a diagram to show any complicated setup of apparatus.

Procedure

Describe, in detailed, numbered steps, the procedure you followed to carry out your investigation. Include steps to clean up and dispose of waste.

Observations

This includes all qualitative and quantitative observations you made. Be as precise as possible when describing quantitative observations, include any unexpected observations, and present your information in a form that is easily understood. If you have only a few observations, this can be a list. For controlled experiments and for many observations, a table will be more appropriate.

Analysis

Interpret your observations and present the evidence in the form of tables, graphs, or illustrations, each with a title. Include any calculations, and show the results of your calculations in a table. Make statements about any patterns or trends you observed. Conclude the analysis with a statement based only on the evidence you have gathered, answering the question that initiated the investigation.

Evaluation

The evaluation is your judgment about the quality of evidence obtained and about the validity of the prediction and hypothesis (if present). This section can be divided into two parts: evaluation of the investigation and evaluation of the prediction (and hypothesis). The following questions and suggestions should help you in each part of the process.

Evaluation of the Investigation

- Did the design enable you to answer the question?
- As far as you know, is the design the best available or are there flaws that could be corrected?
- Were the steps in the investigation in the correct order and adequate to gather sufficient evidence?
- What steps, if done incorrectly, could have significantly affected the results?
- What improvements could be made to the procedure?

Sum up your conclusions about the procedure in a statement that begins like this: "The procedure is judged to be adequate/inadequate because…"

- What specialized skills (such as measuring) might have an effect on the results?
- Was the evidence from repeated trials reasonably similar?
- Can the measurements be made more precise?

Sum up your conclusions about the required skills in a statement that begins like this: "The skills are judged to be adequate/inadequate because…"

- What are the sources of uncertainty and error in my investigation?
- Based on any uncertainties and errors you have identified, do you have enough confidence in your results to proceed with the evaluation of the prediction and hypothesis?

State your confidence level in a statement like this: "Based on my evaluation of the investigation, I am certain/I am moderately certain/I am very certain of my results."

Evaluation of the Prediction (and Hypothesis)

- Does the predicted answer clearly agree with the answer in your analysis?
- Can any difference be accounted for by the sources of uncertainty or error listed earlier in the evaluation?

Sum up your evaluation of the prediction in a statement that begins like this: "The prediction is judged to be verified/inconclusive/falsified because…"

- Is the hypothesis supported by the evidence?
- Is there a need to revise the hypothesis or to replace it with a new hypothesis?

If the prediction was verified, the hypothesis behind it is supported. If the results were inconclusive or the prediction is falsified, then the hypothesis is questionable. Sum up your evaluation of the hypothesis in a statement that begins like this: "The hypothesis being tested is judged to be acceptable/unacceptable because…"

Investigation 2.5: The Effect of Concentration on Reaction Time

Conducted December 15, 2009

By Barry L. and Lakshmi B.

Purpose

The purpose of this investigation is to test one of the ideas of the collision model.

Question

How does changing the concentration of hydrochloric acid affect the time required for the reaction of hydrochloric acid with a fixed quantity of zinc?

Hypothesis/Prediction

According to the collision model, if the concentration of hydrochloric acid is increased, then the time required for the reaction with zinc will decrease. The following reasoning supports this hypothesis: A higher concentration produces more collisions per second between the hydrochloric acid particles and the zinc atoms. More collisions per second produces more reactions per second and, therefore, a shorter time is required to consume the zinc.

Experimental Design

Different known concentrations of excess hydrochloric acid react with zinc metal. The time for the zinc to react completely is measured for each concentration of acid solution. The independent variable is the concentration of hydrochloric acid. The dependent variable is the time for the zinc to be consumed. The temperature of the solution, the quantity of zinc, the surface area of the zinc in contact with the acid, and the volume of the acid are all controlled variables.

Materials

- lab apron
- four 10-mL graduated cylinders
- clock or watch (precise to nearest second)
- stock solutions of $HCl_{(aq)}$: 2.0 mol/L, 1.5 mol/L, 1.0 mol/L, 0.5 mol/L
- safety glasses
- four 18-mm by 150-mm test tubes and a test-tube rack
- four pieces of zinc metal strip, 5 mm by 5 mm
- solution of a weak base (baking soda)

Procedure

1. 15 mL of 2.0 mol/L $HCl_{(aq)}$ was transferred into an 18-mm by 150-mm test tube.
2. A piece of $Zn_{(s)}$ was carefully placed into the hydrochloric acid solution. The starting time of the reaction was noted.
3. The time required for all of the zinc to react was measured and recorded.
4. Steps 2 to 4 were repeated using 1.5 mol/L, 1.0 mol/L, and 0.5 mol/L $HCl_{(aq)}$.
5. Any acid remaining in the solutions was neutralized with a solution of the weak base and then poured down the sink with large amounts of water.

Figure 1
Sample lab report

Observations

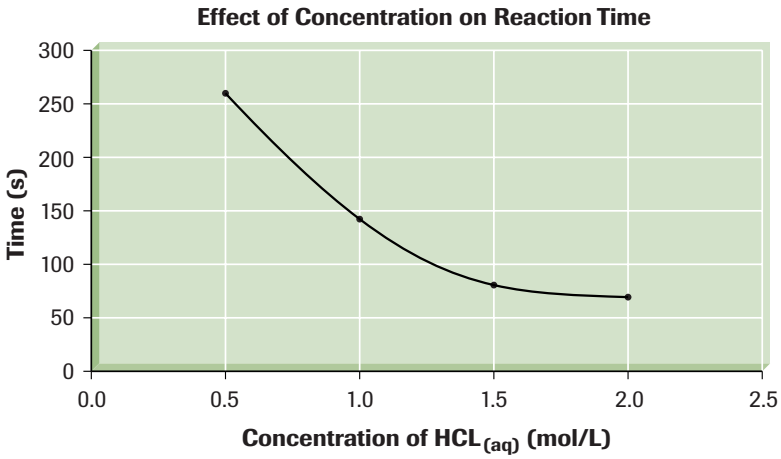
The Effect of Concentration on Reaction Time

Concentration of $HCl_{(aq)}$ (mol/L)	Time for reaction (s)
2.0	70
1.5	80
1.0	144
0.5	258

Analysis

The evidence is plotted on a graph of time versus concentration of $HCl_{(aq)}$ (below). The graph tends to level off at the two highest concentrations. From this trend, we can predict, both from the graph and from common sense, that if you keep increasing the concentration, the reaction time will never reach zero. We might also predict that as the concentration gets very low, the time required for all of the zinc to react will become very long.

Based on the evidence gathered in this investigation, increasing the concentration of hydrochloric acid decreases the time required for the reaction of hydrochloric acid with a fixed quantity of zinc.



Evaluation

The design, materials, and skills used in this investigation are adequate because this experiment produced the type of evidence needed to answer the question with a high degree of certainty. The variables were easy to measure, manipulate, and control.

The procedure is also considered to be adequate since the steps are simple and straightforward. We could have improved the procedure by extending the range of concentrations, by stirring, and by performing more than one trial for each concentration.

Sources of uncertainty in this investigation include the purity of the zinc metal strip, the concentration of the stock acid, and the determination of when the last bit of zinc had reacted.

The hypothesis is supported by the evidence, which clearly shows that the reaction time decreased as the concentration increased. Based on the evidence, the collision model is also acceptable.

Synthesis

Other investigations using one of the controlled variables (such as temperature of the acid or surface area of the zinc) as the independent variable could be carried out to determine their effect on the reaction rate. Additional investigations studying the effect of concentration on reaction rate using different reactants and reaction types could be conducted.

A5 Math Skills

Scientific Notation

It is difficult to work with very large or very small numbers when they are written in common decimal notation. Usually it is possible to accommodate such numbers by changing the SI prefix so that the number falls between 0.1 and 1000. For example, 237 000 000 mm can be expressed as 237 km, and 0.000 000 895 kg can be expressed as 0.895 mg. However, this prefix change is not always possible, either because an appropriate prefix does not exist or because a particular unit of measurement must be used. In these cases, the best method of dealing with very large and very small numbers is to write them using scientific notation. Scientific notation expresses a number by writing it in the form $a \times 10^n$, where the coefficient a is between 1 and 10, and the digits in the coefficient a are all significant. **Table 1** shows situations where scientific notation would be used.

Table 1 Examples of Scientific Notation

Expression	Common decimal notation	Scientific notation
124.5 million kilometres	124 500 000 km	1.245×10^8 km
6 billion nanometres	6 000 000 000 nm	6×10^9 nm
5 gigabytes	5 000 000 000 bytes	5×10^9 bytes

To multiply numbers in scientific notation, multiply the coefficients and add the exponents; the answer is expressed in scientific notation. Note that when writing a number in scientific notation, the coefficient should be between 1 and 10 and should be rounded to the same certainty (number of significant digits) as the measurement with the least certainty (fewest number of significant digits). Look at the following examples:

$$(4.73 \times 10^5 \text{ m})(5.82 \times 10^7 \text{ m}) = 27.5 \times 10^{12} \text{ m}^2 = 2.75 \times 10^{13} \text{ m}^2$$

$$(3.9 \times 10^4 \text{ N})(5.3 \times 10^{-3} \text{ m}) = 21 \times 10^1 \text{ N•m} = 2.1 \times 10^2 \text{ N•m}$$

On many calculators, scientific notation is entered using a special key, labelled EXP or EE. This key includes "$\times 10$" from the scientific notation, so you need to enter only the exponent. For example, to enter

7.5×10^4 press 7.5 EXP 4

3.6×10^{-3} press 3.6 EXP +/− 3

Uncertainty in Measurements

There are two types of quantities that are used in science: exact values and measurements. Exact values include defined quantities (1 m = 100 cm) and counted values (5 cars in a parking lot). Measurements, however, are not exact because there is some uncertainty or error associated with every measurement.

There are two types of measurement error. **Random error** results when an estimate is made to obtain the last significant figure for any measurement. The size of the random error is determined by the precision of the measuring instrument. For example, when measuring length, it is necessary to estimate between the marks on the measuring tape. If these marks are 1 cm apart, the random error will be greater and the precision will be less than if the marks are 1 mm apart.

Systematic error is associated with an inherent problem with the measuring system, such as the presence of an interfering substance, incorrect calibration, or room conditions. For example, if the balance is not zeroed at the beginning or if the metre stick is slightly worn, all the measurements will have a systematic error.

The precision of measurements depends on the gradations of the measuring device. **Precision** is the place value of the last measurable digit. For example, a measurement of 12.74 cm is more precise than a measurement of 12.7 cm because the first value was measured to hundredths of a centimetre, whereas the latter value was measured to tenths of a centimetre.

When adding or subtracting measurements of different precision, the answer is rounded to the same precision as the least precise measurement. For example, using a calculator, add

$$11.7 \text{ cm} + 3.29 \text{ cm} + 0.542 \text{ cm} = 15.532 \text{ cm}$$

The answer must be rounded to 15.5 cm because the first measurement limits the precision to a tenth of a centimetre.

No matter how precise a measurement is, it still may not be accurate. **Accuracy** refers to how close a value is to its true value. The comparison of the two

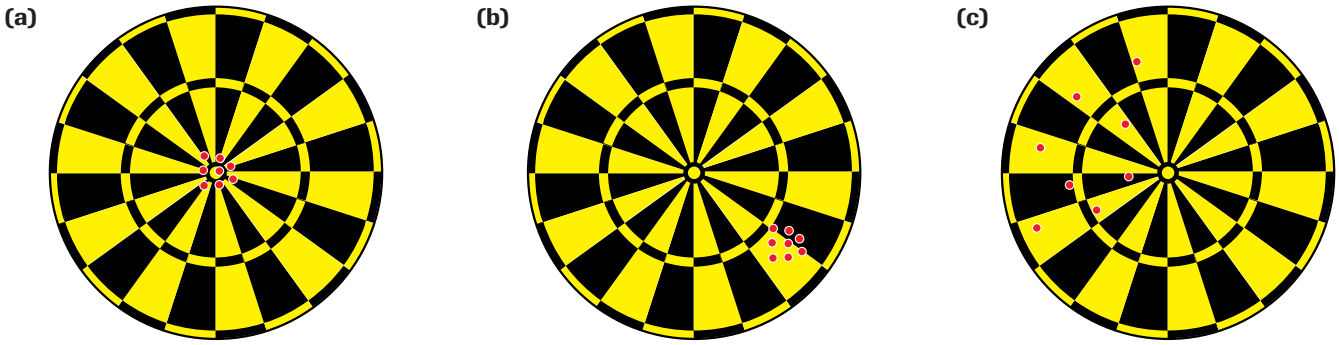


Figure 1
The positions of the darts in these diagrams are analogous to measured or calculated results in a laboratory setting. In **(a)** the results are precise and accurate, in **(b)** they are precise but not accurate, and in **(c)** they are neither precise nor accurate.

values can be expressed as a percentage difference. The percentage difference is calculated as follows:

$$\% \text{ difference} = \frac{|\text{experimental value} - \text{predicted value}|}{\text{predicted value}} \times 100\%$$

Figure 1 shows an analogy between precision and accuracy, and the positions of darts thrown at a dartboard.

How certain you are about a measurement depends on two factors: the precision of the instrument used and the size of the measured quantity. More precise instruments give more certain values. For example, a mass measurement of 13 g is less precise than a measurement of 12.76 g; you are more certain about the second measurement than the first. Certainty also depends on the measurement. For example, consider the measurements 0.4 cm and 15.9 cm. Both measurements have the same precision. If the measuring instrument is precise to ± 0.1 cm, however, the first measurement is 0.4 ± 0.1 cm (0.3 cm or 0.5 cm) for an error of 25%, whereas the second measurement is 15.9 ± 0.1 cm (15.8 cm or 16.0 cm) for an error of 0.6%. For both factors—the precision of the instrument used and the value of the measured quantity—the more digits there are in a measurement, the more certain you are about the measurement.

Significant Digits

The certainty of any measurement is communicated by the number of significant digits in the measurement. In a measured or calculated value, significant digits are the digits that are certain plus one estimated (uncertain) digit. Significant digits include all digits correctly reported from a measurement.

Follow these rules to decide if a digit is significant:

1. If a decimal point is present, zeros to the left of the first non-zero digit (leading zeros) are not significant.
2. If a decimal point is not present, zeros to the right of the last non-zero digit (trailing zeros) are not significant.
3. All other digits are significant.
4. When a measurement is written in scientific notation, all digits in the coefficient are significant.
5. Counted and defined values have infinite significant digits.

Table 2 shows some examples of significant digits.

Table 2 Significant Digits

Measurement	Number of significant digits
32.07 m	4
0.0041 g	2
5×10^5 kg	1
6400 s	2
100 people (counted)	infinite

An answer obtained by multiplying and/or dividing measurements is rounded to the same number of significant digits as the measurement with the fewest number of significant digits. For example, you could use a calculator to solve the following equation:

$$77.8 \text{ km/h} \times 0.8967 \text{ h} = 69.763\ 26 \text{ km}$$

However, the certainty of the answer is limited to three significant digits, so the answer is rounded up to 69.8 km.

Rounding Off

The following rules should be used when rounding answers to calculations.

1. When the first digit discarded is less than 5, the last digit retained should not be changed.

   3.141 326 rounded to four digits is 3.141.

2. When the first digit discarded is greater than 5, or if it is a 5 followed by at least one digit other than zero, the last digit retained is increased by 1 unit.

   2.221 672 rounded to four digits is 2.222.

   4.168 501 rounded to four digits is 4.169.

3. When the first digit discarded is 5 followed by only zeros, the last digit retained is increased by 1 if it is odd, but not changed if it is even.

   2.35 rounded to two digits is 2.4.

   2.45 rounded to two digits is 2.4.

   −6.35 rounded to two digits is −6.4.

Measuring and Estimating

Many people believe that all measurements are *reliable* (consistent over many trials), *precise* (to as many decimal places as possible), and *accurate* (representing the actual value). There are many things that can go wrong when measuring, however.

- There may be limitations that make the instrument or its use unreliable (inconsistent).
- The investigator may make a mistake or fail to follow the correct techniques when reading the measurement to the available precision (number of decimal places).
- The instrument may be faulty or inaccurate. A similar instrument may give different readings.

For example, when measuring the temperature of a liquid, it is important to keep the thermometer at the proper depth and the bulb of the thermometer away from the bottom and sides of the container. If you sit a thermometer with its bulb at the bottom of a liquid-filled container, you will be measuring the temperature of the bottom of the container and not the temperature of the liquid. There are similar concerns with other measurements.

To be sure that you have measured correctly, you should repeat your measurements at least three times. If your measurements appear to be reliable, calculate the mean and use this value. To be more certain about the accuracy, repeat the measurements with a different instrument.

Every measurement is a best estimate of the actual value. The measuring instrument and the skill of the investigator determine the certainty and the precision of the measurement. The usual rule is to make a measurement that estimates between the smallest divisions on the scale of the instrument.

Logarithms

Any positive number N can be expressed as a power of some base b where $b > 1$. Some obvious examples are

$16 = 2^4$	base 2, exponent 4
$25 = 5^2$	base 5, exponent 2
$27 = 3^3$	base 3, exponent 3
$0.001 = 10^{-3}$	base 10, exponent −3

In each of these examples, the exponent is an integer. Exponents may be any real number, however, not just an integer. If you use the x^y button on your calculator, you can experiment to obtain a better understanding of this concept.

The most common base is base 10. Some examples for base 10 are

$10^{0.5} = 3.162$
$10^{1.3} = 19.95$
$10^{-2.7} = 0.001\,995$

By definition, the exponent to which a base b must be raised to produce a given number N is called the **logarithm** of N to base b (abbreviated as $\log_b$). When the value of the base is not written, it is assumed to be base 10. Logarithms to base 10 are called **common logarithms**. We can express the previous examples as logarithms:

$\log 3.162 = 0.5$
$\log 19.95 = 1.3$
$\log 0.001\,995 = -2.7$

Most measurement scales you have encountered are linear in nature. For example, a speed of 80 km/h is twice as fast as a speed of 40 km/h and four times as fast as a speed of 20 km/h. However, there are several examples in science where the range of values of the

variable being measured is so great that it is more convenient to use a logarithmic scale to base 10. One example of this is the scale for measuring the acidity of a solution (the pH scale). For example, a solution with a pH of 3 is 10 times more acidic than a solution with a pH of 4 and 100 times (10^2) more acidic than a solution with a pH of 5. Other situations that use logarithmic scales are sound intensity (the dB scale) and the intensity of earthquakes (the Richter scale).

Tables and Graphs

Both tables and graphs are used to summarize information and to illustrate patterns or relationships. Preparing tables and graphs requires some knowledge of accepted practice and some skill in designing the table or graph to best describe the information.

Tables

1. Write a title that describes the contents or the relationship among the entries in the table.
2. The rows or columns with the controlled variables and independent variable usually precede the row or column with the dependent variable.
3. Give each row or column a heading, including unit symbols in parentheses where necessary. Units are not usually written in the main body of the table (**Table 3**).

Table 3 The Effect of Concentration on Reaction Time

Concentration of $HCl_{(aq)}$ (mol/L)	Time for Reaction (s)
2.0	70
1.5	80
1.0	144
0.5	258

Graphs

1. Write a title and label the axes (**Figure 2**).
   (a) The title should be at the top of the graph. A statement of the two variables is often used as a title: for example, "Solubility versus Temperature for Sodium Chloride."
   (b) Label the horizontal (x) axis with the name of the independent variable and the vertical (y) axis with the name of the dependent variable.
   (c) Include the unit symbols in parentheses on each axis label: for example, "Time (s)."

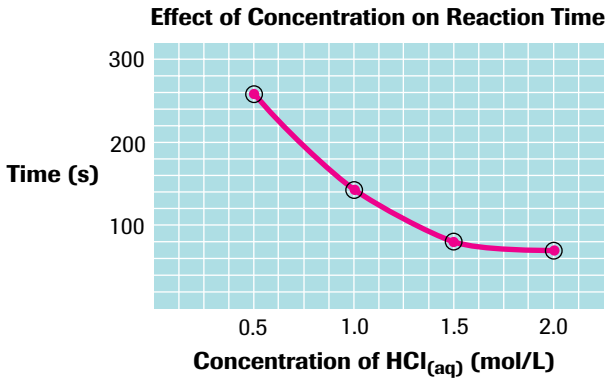


Figure 2

2. Assign numbers to the scale on each axis.
   (a) As a general rule, the points should be spread out so that at least one-half of the graph paper is used.
   (b) Choose a scale that is easy to read and has equal divisions. Each division (or square) must represent a small simple number of units of the variable: for example, 0.1, 0.2, 0.5, or 1.0.
   (c) It is not necessary to have the same scale on each axis or to start a scale at zero.
   (d) Do not label every division line on the axis. Scales on graphs are labelled in a way similar to the way scales on rulers are labelled.
3. Plot the points.
   (a) Locate each point by making a small dot in pencil. When you have drawn and checked all the points, draw an X over each point or circle each point in ink. The size of the circle can be used to indicate the precision of the measurement.
   (b) Be suspicious of a point that is obviously not part of the pattern. Double check the location of such a point, but do not eliminate the point from the graph just because it does not align with the rest.
4. Draw the best fitting curve.
   (a) Using a sharp pencil, draw a line that best represents the trend shown by the collection of points. Do not force the line to go through

each point. Imprecision of experimental measurements may cause some of the points to be misaligned.

(b) If the collection of points appears to fall in a straight line, use a ruler to draw the line. Otherwise draw a smooth curve that best represents the pattern of the points.

(c) Since the points are ink and the line is pencil, it is easy to change the position of the line if your first curve does not fit the points to your satisfaction.

Problem Solving in Chemistry: The Factor-Label Method

Solving problems is a basic aspect of working in all sciences, including chemistry. One of the characteristics of good chemists is their ability to solve problems. Although there are several different methods for solving mathematical problems in chemistry, the factor-label method (also known as dimensional analysis) is one of the most useful methods.

The Factor-Label Method

The factor-label method was developed as a logical and consistent way of converting a quantity in one unit into the equivalent quantity in another unit. For example, if you are asked to determine how many seconds there are in 2 min, you might quickly answer, "There are 120 s in 2 min." If asked to explain your answer, you might say, "Since there are 60 s in 1 min, there are 2 × 60 s in 2 min, or 120 s." Notice that the solution to the problem is based on the *equality* 1 min = 60 s. Mathematically,

$$1\text{ min} = 60\text{ s}$$
$$2(1\text{ min}) = 2(60\text{ s})$$
$$2\text{ min} = 120\text{ s}$$

To solve the same problem using the factor-label method, you determine the required value (the value you are asked to find) by multiplying the given value by a *conversion factor*.

$$\text{required value} = \text{given value} \times \text{conversion factor}$$

The conversion factor is an equality that relates the units of the required value (e.g., seconds) to the units of the given value (e.g., minutes). For the equality 1 min = 60 s, the conversion factor is obtained by stating the equality in the form of a fraction equal to 1. In this case,

$$\frac{1\text{ min}}{60\text{ s}} = 1 \quad \text{or} \quad \frac{60\text{ s}}{1\text{ min}} = 1$$

These fractions are equal to 1 because, in both cases, the numerators and denominators are of equal value: 60 s is the same length of time as 1 min, and vice versa. All conversion factors equal 1. The only difference is that one fraction is inverted when compared to the other fraction.

The conversion factor you use in the solution to a problem depends on the units of the given value. *Choose the form of the conversion factor whose denominator has the same units as the given value.* Since multiplying by a conversion factor is like multiplying by 1, only the units change.

Using the factor-label method, how many seconds are in a time (t) of 2 min?

$$t\text{ s in 2 min} = 2.0\text{ min} \times \frac{60\text{ s}}{1\text{ min}}$$

We chose the conversion factor $\frac{60\text{ s}}{1\text{ min}}$ because the unit in the denominator of the conversion factor (min) is the same as the unit of the given value (min). By performing the numerical calculation, and cancelling like units in the numerator and denominator (min), the required value is

$$t = 2.0\ \cancel{\text{min}} \times \frac{60\text{ s}}{1\ \cancel{\text{min}}}$$
$$t = 120\text{ s}$$

SAMPLE problem

One tablet of a popular antacid medication contains 0.25 g of calcium carbonate, $CaCO_{3(s)}$. What mass of calcium carbonate is in 48 tablets?

Step 1: List Given Values

number of tablets = 48

$m_{CaCO_{3(s)}} = ?$

Step 2: State Problem in Form: required value = given value × conversion factor

$m_{CaCO_{3(s)}} = 48 \text{ tablets} \times \text{conversion factor}$

Step 3: Identify Equality and Two Possible Forms of Conversion Factor

Equality: 1 tablet = 0.25 g $CaCO_{3(s)}$

Possible conversion factors:

$$\frac{1 \text{ tablet}}{0.25 \text{ g } CaCO_{3(s)}} \quad \text{or} \quad \frac{0.25 \text{ g } CaCO_{3(s)}}{1 \text{ tablet}}$$

Step 4: Substitute Appropriate Conversion Factor into Equation and Solve

In this case, we choose $\frac{0.25 \text{ g } CaCO_{3(s)}}{1 \text{ tablet}}$ as the conversion factor because the unit "tablet" in the denominator cancels the unit "tablet" in the given value.

$$m_{CaCO_{3(s)}} = 48 \text{ tablets} \times \text{conversion factor}$$

$$= 48 \cancel{\text{ tablets}} \times \frac{0.25 \text{ g } CaCO_{3(s)}}{1 \cancel{\text{ tablet}}}$$

$$m_{CaCO_{3(s)}} = 12 \text{ g}$$

Therefore, 12 g of calcium carbonate is needed to make 48 tablets of the antacid.

Example

One iron nail contains 2.6 g of iron, $Fe_{(s)}$. How many nails can be made from 143 g of iron?

Solution

$m_{Fe_{(s)}} = 143 \text{ g}$

number of nails = ?

$$\text{number of nails} = 143 \cancel{\text{ g Fe}_{(s)}} \times \frac{1 \text{ nail}}{2.6 \cancel{\text{ g Fe}_{(s)}}}$$

number of nails = 55 nails

Therefore, 55 nails can be made from 143 g of iron.

Practice

1. A 2003 Canadian $1 (loonie) coin contains 6.4 g of nickel. How many loonies can be made with 460.8 g of nickel?
2. A single compact disc (CD) has a mass of 23 g. How many discs are in a 575-g package of CDs? (Disregard the packaging material.)
3. A 250-mL cup of corn flakes contains 2.0 g of protein. What mass of protein is contained in 850 mL of corn flakes?

Answers

1. 72 loonies
2. 25 CDs
3. 6.8 g

A6 Laboratory Skills and Techniques

Using a Bunsen Burner

Practise and memorize the following. Note the safety caution. You are responsible for your safety and the safety of others near you.

1. Turn the air and gas adjustments to the off position (**Figure 1**).
2. Connect the burner hose to the gas outlet on the bench.
3. Turn the bench gas valve to the fully on position.
4. If you suspect that there may be a gas leak, replace the burner. (Give the leaky burner to your teacher.)
5. While holding a lit match above and to one side of the barrel, open the burner gas valve until a small yellow flame results (**Figure 2**). If a striker is used instead of matches, generate sparks over the top of the barrel (**Figure 3**).
6. Adjust the air flow to obtain a pale blue flame with a dual cone (**Figure 4**). For most Bunsen burners, rotating the barrel adjusts the air intake. Rotate the barrel slowly. If too much air is added, the flame may go out. If this happens, immediately turn off the gas flow and relight the burner as outlined in step 5.
7. Adjust the gas valve on the burner to increase or decrease the height of the blue flame. The hottest part of the flame is the tip of the inner blue cone. Usually a 5 to 10 cm flame, which just about touches the object heated, is used.

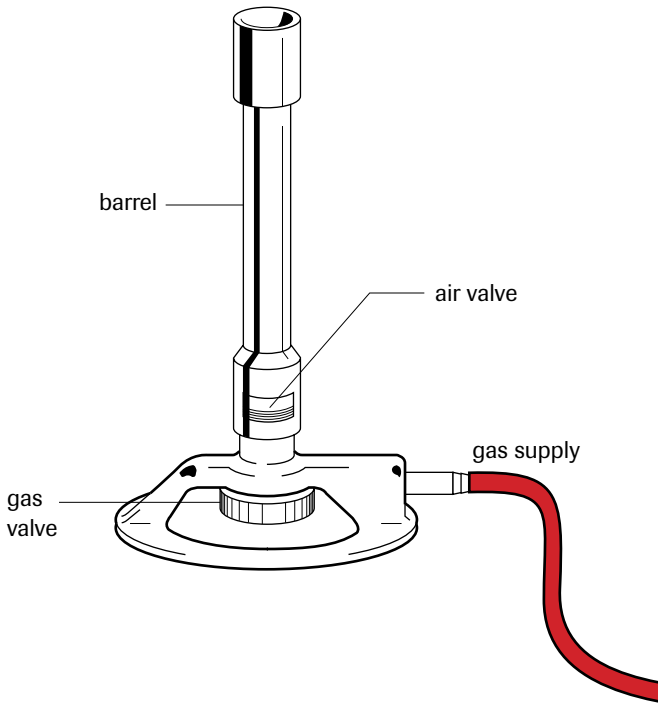


Figure 1
The parts of a common Bunsen burner

Figure 2
A yellow flame is relatively cool and easier to obtain on lighting.

Figure 3
To generate a spark with a striker, pull the side of the handle containing the flint up and across.

Figure 4
A pale blue-violet flame is much hotter than a yellow flame. The hottest point is at the tip of the inner blue cone.

8. Bunsen burners, when lit, should not be left unattended. If the burner is on but not being used, adjust the air and gas intakes to obtain a small yellow flame. This flame is more visible and therefore less likely to cause problems.

Using a Laboratory Balance

A balance is a sensitive instrument that is used to measure the mass of an object. There are two types of balances: electronic (**Figure 5**) and mechanical (**Figure 6**).

Figure 5
An electronic balance

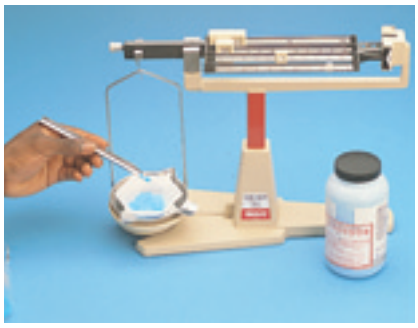


Figure 6
On this type of mechanical balance, the sample is balanced by moving masses on several beams.

Below are some general rules that you should follow when using a balance:

- All balances must be handled carefully and kept clean.
- Always place chemicals into a container, such as a beaker or plastic boat, to avoid contamination and corrosion of the balance pan.
- To avoid error due to convection currents in the air, allow hot or cold samples to return to room temperature before placing them on the balance.
- Always record masses showing the correct precision. On a centigram balance, mass is measured to the nearest hundredth of a gram (0.01 g).
- When you need to move a balance, hold the instrument by the base and steady the beam. Never lift a balance by the beams or pans.
- To avoid contaminating a whole bottle of reagent, a scoop should not be placed in the original container of a chemical. A quantity of the chemical should be poured out of the original reagent bottle into a clean, dry beaker or bottle, from which samples can be taken. Another acceptable technique for dispensing a small quantity of chemical is to rotate or tap the chemical bottle.

Using an Electronic Balance

Electronic balances are sensitive instruments, requiring care in their use. Be gentle when placing objects on the pan, and remove the pan when cleaning it. Since an electronic balance is sensitive to small movements and changes in level, do not lean on the lab bench.

To use an electronic balance, follow the steps below:

1. Place a container or weighing paper on the balance.
2. Reset (tare) the balance so the mass of the container registers as zero.
3. Add chemical until the desired mass of chemical is displayed. The last digit may not be constant, indicating uncertainty due to air currents or the high sensitivity of the balance.
4. Remove the container and sample.

Using a Mechanical Balance

There are different kinds of mechanical balance. This general procedure applies to most kinds:

1. Clean and zero the balance. (Turn the zero adjustment screw so that the beam is balanced when the instrument is set to read 0 g and no load is on the pan.)

2. Place the container on the pan.
3. Move the largest beam mass one notch at a time until the beam drops. Then move the mass back one notch.
4. Repeat this process with the next smaller mass, and continue until all the masses have been moved and the beam is balanced. (If you are using a dial-type balance, the final step will be to turn the dial until the beam balances.)
5. Record the mass of the container.
6. If you need a specific mass of a substance, set the masses on the beams to correspond to the total mass of the container plus the desired sample.
7. Add the chemical until the beam is once again balanced.
8. Remove the sample from the pan, and return all beam masses to the zero position. (For a dial-type balance, return the dial to the zero position.)

Using a Pipette

A pipette is a specially designed glass tube used to measure precise volumes of liquids. There are two types of pipettes and a variety of sizes for each type. A volumetric pipette (**Figure 7(a)**) transfers a fixed volume, such as 10.00 mL or 25.00 mL, accurate to within 0.04 mL, for example. A graduated pipette (**Figure 7(b)**) measures a range of volumes within the limit of the scale, just as a graduated cylinder does. A 10-mL graduated pipette delivers volumes accurate to within 0.1 mL.

To use a pipette, follow the steps below:

1. Rinse the pipette with small volumes of distilled water using a wash bottle, and then with the sample solution. A clean pipette has no visible residue or liquid drops clinging to the inside wall. Rinsing with aqueous ammonia and scrubbing with a pipe cleaner might be necessary to clean the pipette.
2. Hold the pipette with your thumb and fingers near the top. Leave your index finger free.
3. Place the pipette in the sample solution, resting the tip on the bottom of the container if possible. Be careful that the tip does not hit the sides of the container.

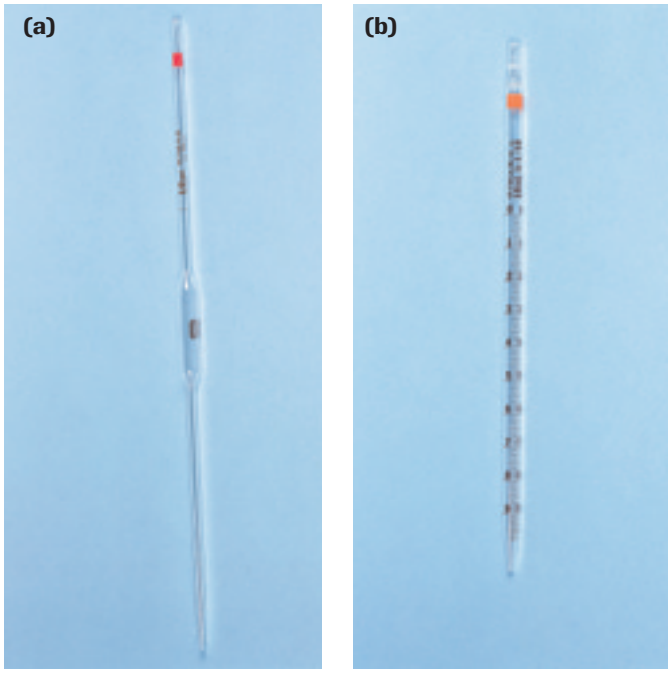


Figure 7
(a) A volumetric pipette delivers the volume printed on the label if the temperature is near room temperature.
(b) To use a graduated pipette, you must be able to start and stop the flow of the liquid.

4. Squeeze the bulb into the palm of your hand, and place the bulb firmly and squarely on the end of the pipette (**Figure 8**) with your thumb across the top of the bulb.

Figure 8
Release the bulb slowly. Pressing down with your thumb placed across the top of the bulb maintains a good seal. Setting the pipette tip on the bottom slows the rise or fall of the liquid.

5. Release your grip on the bulb until the liquid has risen above the calibration line. (This may require bringing the level up in stages: remove the bulb, put your finger on the pipette, squeeze the air out of the bulb, replace the bulb, and continue the procedure.)
6. Remove the bulb, placing your index finger over the top.
7. Wipe all solution from the outside of the pipette using a paper towel.
8. While touching the tip of the pipette to the inside of a waste beaker, gently roll your index finger (or rotate the pipette between your thumb and fingers) to allow the liquid level to drop until the bottom of the meniscus reaches the calibration line (**Figure 9**). To avoid parallax errors, set the meniscus at eye level. Stop the flow when the bottom of the meniscus is on the calibration line. Use the bulb to raise the level of the liquid again if necessary.

Figure 9
To allow the liquid to drop slowly to the calibration line, it is necessary for your finger and the pipette top to be dry. Also keep the tip on the bottom to slow down the flow.

9. While holding the pipette vertically, touch the pipette tip to the inside wall of a clean receiving container. Remove your finger or adjust the valve, and allow the liquid to drain freely until the solution stops flowing.
10. Finish by touching the pipette tip to the inside of the container at about a 45° angle (**Figure 10**). Do not shake the pipette. The delivery pipette is calibrated to leave a small volume in the tip.

Figure 10
A vertical volumetric pipette is drained by gravity, and then the tip is placed against the inside wall of the container. A small volume is expected to remain in the tip.

Crystallization

Crystallization is used to separate a solid from a solution by evaporating the solvent or lowering the temperature. Evaporating the solvent is useful for quantitative analysis of a solution; lowering the temperature is commonly used to purify and separate a solid whose solubility is temperature-sensitive. Chemicals that have a low boiling point or decompose on heating cannot be separated by crystallization using a heat source. Fractional distillation is an alternative design for the separation of a mixture of liquids.

1. Measure the mass of a clean beaker or evaporating dish.
2. Place a precisely measured volume of the solution in the container.
3. Set the container aside to evaporate the solution slowly, or warm the container gently on a hot plate or with a Bunsen burner.
4. When the contents appear dry, measure the mass of the container and solid.
5. Heat the solid with a hot plate or burner, cool it, and measure the mass again.
6. Repeat step 5 until the final mass remains constant. (Constant mass indicates that all of the solvent has evaporated.)

Filtration

In filtration, solid is separated from a mixture using a porous filter paper. The more porous papers are called qualitative filter papers. Quantitative filter papers allow only invisibly small particles through the pores of the paper.

1. Set up a filtration apparatus (**Figure 11**): stand, funnel holder, filter funnel, waste beaker, wash bottle, and a stirring rod with a flat plastic or rubber end for scraping.

Figure 11
The tip of the funnel should touch the inside wall of the collecting beaker.

2. Fold the filter paper along its diameter, and then fold it again to form a cone. A better seal of the filter paper on the funnel is obtained if a small piece of the outside corner of the filter paper is torn off (**Figure 12**).
3. Measure and record the mass of the filter paper after removing the corner.
4. While holding the open filter paper in the funnel, wet the entire paper and seal the top edge firmly against the funnel with the tip of the cone centred in the bottom of the funnel.
5. With the stirring rod touching the spout of the beaker, decant most of the solution into the funnel (**Figure 13**). Transferring the solid too soon clogs the pores of the filter paper. Keep the level of liquid about two-thirds up the height of the filter paper. The stirring rod should be rinsed each time it is removed.

Figure 13
The separation technique of pouring off clear liquid is called decanting. Pouring along the stirring rod prevents drops of liquid from going down the outside of the beaker when you stop pouring.

6. When most of the solution has been filtered, pour the remaining solid and solution into the funnel. Use the wash bottle and the flat end of the stirring rod to clean any remaining solid from the beaker.
7. Use the wash bottle to rinse the stirring rod and the beaker.
8. Wash the solid two or three times to ensure that no solution is left in the filter paper. Direct a gentle stream of water around the top of the filter paper.
9. When the filtrate has stopped dripping from the funnel, remove the filter paper. Press your thumb against the thick (three-fold) side of the filter

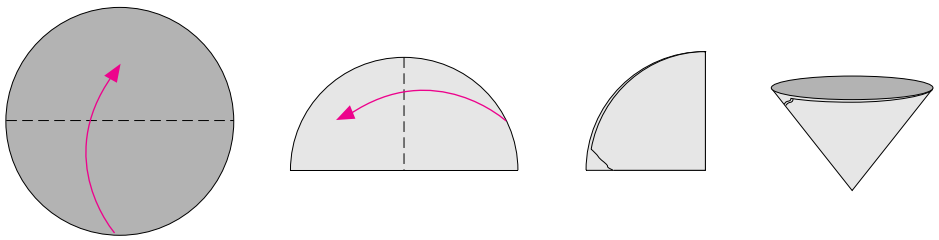


Figure 12
To prepare a filter paper, fold it in half twice and then remove the outside corner as shown.

paper, and slide the paper up the inside of the funnel.

10. Transfer the filter paper from the funnel onto a labelled watch glass, and unfold the paper to let the precipitate dry.
11. Determine the mass of the filter paper and dry precipitate.

Preparation of Standard Solutions

Laboratory procedures often call for the use of a solution of specific, precise concentration. The apparatus that is used to prepare such a solution is a volumetric flask. A meniscus finder is useful in setting the bottom of the meniscus on the calibration line (**Figure 14**).

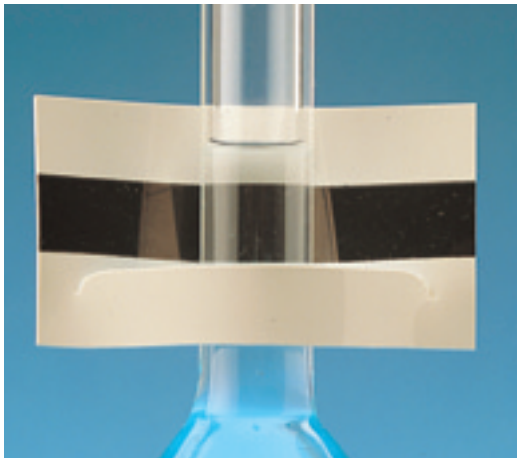


Figure 14
Raise the meniscus finder along the back of the neck of the volumetric flask until the meniscus is outlined as a sharp, black line against a white background.

Preparing a Standard Solution from a Solid Reagent

1. Calculate the required mass of solute from the volume and concentration of the solution.
2. Obtain the required mass of solute in a clean, dry beaker or weighing boat. (Refer to "Using a Laboratory Balance" earlier in this section.)
3. Dissolve the solid in pure water using less than one-half of the final solution volume.
4. Transfer the solution and all water used to rinse the equipment into a clean volumetric flask. (The beaker and any other equipment should be rinsed two or three times with pure water.)
5. Add pure water, using a medicine dropper for the final few millilitres while using a meniscus finder to set the bottom of the meniscus on the calibration line.
6. Stopper the flask, and mix the solution by slowly inverting the flask several times.

Preparing a Standard Solution by Dilution

1. Calculate the volume of concentrated reagent required.
2. Add approximately one-half of the final volume of pure water to the volumetric flask.
3. Measure the required volume of stock solution using a pipette. (Refer to "Using a Pipette" earlier in this section.)
4. Transfer the stock solution slowly into the volumetric flask while mixing.
5. Add pure water. Use a medicine dropper and a meniscus finder to set the bottom of the meniscus on the calibration line.
6. Stopper the flask, and mix the solution by slowly inverting the flask several times.

Titration

Titration is used in the volumetric analysis of a solution of an unknown concentration. Titration involves adding a solution (the titrant) from a burette to another solution (the sample) in an Erlenmeyer flask until a recognizable endpoint, such as a colour change, occurs.

1. Rinse the burette with small volumes of distilled water using a wash bottle. Using a burette funnel, rinse with small volumes of the titrant (**Figure 15**, on the next page). (If liquid droplets remain on the sides of the burette after rinsing, scrub the burette with a burette brush. If the tip of the burette is chipped or broken, replace the tip or the whole burette.)
2. Using a small burette funnel, pour the solution into the burette until the level is near the top. Open the stopcock for maximum flow to clear any air bubbles from the tip and to bring the liquid level down to the scale.

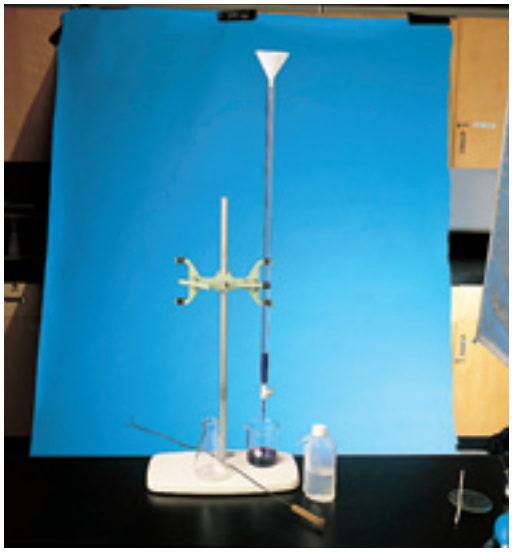


Figure 15
A burette should be rinsed with water and then the titrant before use. Use a burette brush only if necessary.

3 Record the initial burette reading to the nearest 0.01 mL. (Estimate the second decimal place.) Avoid parallax errors by reading volumes at eye level with the aid of a meniscus finder.

4. Pipette a sample of the solution of unknown concentration into a clean Erlenmeyer flask. Place a white piece of paper beneath the Erlenmeyer flask to make it easier to detect colour changes.

5. Add an indicator if one is required. Add the smallest quantity necessary (usually one to two drops) to produce a noticeable colour change in your sample.

6. Add the solution from the burette quickly at first, and then slowly, drop by drop, near the endpoint (**Figure 16**). Stop as soon as a drop of the titrant produces a permanent colour change in the sample solution. A permanent colour change is considered to be a noticeable change that lasts for 10 s after swirling.

7. Record the final burette reading to the nearest 0.01 mL.

8. The final burette reading for one trial becomes the initial burette reading for the next trial. Three trials with results within 0.02 mL are normally required for a reliable analysis of a solution of unknown concentration.

Figure 16
Near the endpoint, continuous gentle swirling of the solution is particularly important.

9. Drain and rinse the burette with pure water. Store the burette upside down with the stopcock open.

Diagnostic Tests

The tests described in **Table 1** are commonly used to detect the presence of a specific substance. Thousands more are possible. All diagnostic tests include a brief procedure, some expected evidence, and an interpretation of the evidence obtained. This is conveniently communicated using the format "If [procedure] and [evidence], then [analysis]."

Diagnostic tests can be designed using any characteristic property of a substance. For example, diagnostic tests for acids, bases, and neutral substances can be specified in terms of the pH values of the solutions. For specific chemical reactions, properties of the products that the reactants do not have (such as the insolubility of a precipitate, the production of a gas, or the colour of ions in aqueous solutions) can be used to design diagnostic tests.

If possible, you should use a control to illustrate that the test does not give the same results with other substances. For example, in the test for oxygen, inserting a glowing splint into a test tube that contains only air is used to compare the effect of air on the splint with a test tube in which you expect oxygen has been collected.

For a test to be valid, it usually has to be conducted both before and after a chemical change. Consider this control when planning your designs and procedures.

Table 1 Some Standard Diagnostic Tests

Substance Tested	Diagnostic Test
water	If cobalt(II) chloride paper is exposed to a liquid or vapour, and the paper turns from blue to pink, then water is likely present.
oxygen	If a glowing splint is inserted into the test tube, and the splint glows brighter or relights, then oxygen gas is likely present.
hydrogen	If a flame is inserted into the test tube, and a squeal or pop is heard, then hydrogen is likely present.
carbon dioxide	If the gas is bubbled into a limewater solution, and the limewater turns cloudy, then carbon dioxide is likely present.
halogens	If a few millilitres of chlorinated hydrocarbon solvent is added, with shaking, to a solution in a test tube, and the colour of the solvent appears to be • light yellow-green, then chlorine is likely present; • orange, then bromine is likely present; • purple, then iodine is likely present.
acid	If strips of blue and red litmus paper are dipped into the solution, and the blue litmus turns red, then an acid is present.
base	If strips of blue and red litmus paper are dipped into the solution, and the red litmus turns blue, then a base is present.
neutral solution	If strips of blue and red litmus paper are dipped into the solution, and neither changes colour, then only neutral substances are likely present.
neutral ionic solution	If a neutral substance is tested for conductivity with a voltmeter or multimeter, and the solution conducts a current, then a neutral ionic substance is likely present.
neutral molecular solution	If a neutral solution is tested and does not conduct a current, then a neutral molecular substance is likely present.