It’s A Chemical World

It's A Chemical World:

Matter and Energy

By

Sophia Vash, Frank Gasparro and Dan Zibello

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This manual is dedicated to all my teachers - but, especially the following!

Starting with
My parents, Frank & Anna

From the 50s
Sr. Patricia Mary, SND
Fr. William Laferty, OSA
Francesca Toscani

From the 60s
Kenneth F. O'Driscoll
Tack Kuntz

From the 70s
Betty Rock
Jacques Fresco
Eric Ressner

From the 80s & 90s
Rick Edelson

From the 00s
Don Mascola
Dan Zibello
Bob Izzo
Keith Kaliszewski

For 40 plus years

My wife, Paula

—Frank Gasparro

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PREFACE

This lab manual owes its origins to my predecessor, Dan Zibello, with whom I overlapped for one year (1993, his 34th and final year at Hamden Hall). These are all well-designed labs that work! I also want to acknowledge the skilled work performed by my dedicated administrative assistant, Sophia Vash, who put in innumerable hours assembling this edition.

There are a multitude of full experiments and shorter lab demos designed for the instructor to perform as a demo, usually as an introduction to a new topic. Each lab includes an overview of the lab goals and procedures.

These labs are designed to expose students to a comprehensive experience from the outset. The lab demos are intended to be performed by the instructor typically when starting a new topic. These are best performed in a give-and-take presentation peppered with many questions aimed at 'keeping the students on their toes' and getting students to 'think' about what's going on during the lab demo.

These labs have stood the test of time, having been performed by our teachers over a 50-year period. With its official publication, we will next be working on a help web page in which the set-up and timing for each lab will be discussed.

Finally, I would like to acknowledge the expert assistance of Alison Duffy from Cambridge Scholars Pub.

FOREWORD

The study of Chemistry will be one of the most difficult challenges that you face. This is not only because of the breadth and depth of the subject, but because of the many skills you will need to apply:

Conceptual skills – you will need to imagine an *invisible world of particles* such as atoms, ions, molecules, and especially electrons, and connect their *theoretical* behavior to the *observed factual* behavior of matter and energy.

Communication skills – you will need to develop a vocabulary of abstract words like mole, uncertainly, heat, mass, volume, etc. which sound familiar but indeed have very specific scientific meanings. You will then need to use these words to write **concise** descriptions, explanations, and analyses.

Symbolic skills – you will need to learn chemical symbols like Fe and Cl and use them to write formulas like $FeCl_3$ and equations like $2Fe + 3Cl_2 = 2FeCl_2$ and interpret them as if they were ordinary words and sentences.

Quantitative skills – you will need to apply algebraic principles like percent, ratio, substitution and "word problems" to chemical quantities and lab measurements in metric units. To make things even more challenging, you will use numbers that range in size from 10^{-8} to 10^{23}!

Physical skills – you will be called upon, especially in using this lab manual, to manipulate unfamiliar tools such as measuring devices and calibrated glassware (some of it hot or containing corrosive materials).

Looking at all this positively, you can succeed in Chemistry in many different ways!

The last-mentioned idea – **physical skills** – distinguishes Chemistry from other academic pursuits. And it is one area that anybody with common sense can excel in. Lab work is at once challenging and exciting, but it is above all the heart of chemistry. And you will be right in the middle of it this year as you use this lab manual as your guide and workbook.

Doc Gasparro has aptly built upon a Chemistry curriculum developed specifically for Hamden Hall students over many years. I am personally gratified by his efforts to expand and improve the laboratory aspects of this course and am honored to be a part of it all.

I want to acknowledge my own chemistry professors, William Masterton and Emil Slowinski, who taught me at the University of Connecticut and later published outstanding texts (one is used in our AP course) and lab manuals that influenced many of the labs that you will be doing. Another great influence, especially on the lecture demonstrations in this book, was Hubert Alyea who taught at Doc's *alma mater*, Princeton University.

But all the books and manuals are of little impact without a knowledgeable guide to highlight the grand sights along the way and to instill an appreciation of what you are seeing. Doc is that guide. I had the pleasure of teaching with him during the transition year of my retirement. I know from that experience that you are in good hands. And so is Hamden Hall Chemistry!

No one is born knowing how to walk and talk, or dance, or play sports. Like Chemistry these take effort, practice and persistence. Your growth over this year will be amazing if you work the program. In facing the many challenges of Chemistry, you might need help, tutorials, encouragement, or maybe a little jump-start. Doc's the one who wants to see you succeed, the one who will give life and meaning to the words in this manual, the one you should approach for help. Keep at it and you will be amazed at what you can accomplish! Good luck along the way.

Dan Zibello,
Hamden Hall Chemistry Teacher
1971-2005

INTRODUCTION

Chemistry is the study of matter and its various transformations. Chemical changes may lead to new substances with a multitude of properties having applications in all phases of our lives. Chemical changes may also be used to generate the many forms of energy that power our 21st Century society. Thus, chemical changes are essential for life as we know it. Yet chemistry also presents us with some challenges - the primary one being the disposal of unwanted chemical waste - the byproducts of most chemical processes. The environmental movement of the 1970s led to an awareness of this issue, which has resulted in a steady improvement of water and air quality.

Recently political and economic factors have contributed to some backsliding. As a specific example, consider China - a country of more than a billion people - which is experiencing rapid development of environment-impacting energy needs. To meet a large part of its energy demands, China is burning coal using old technology power plants and hence its polluting by products can be found not only in Peking but also in California! While rapidly developing countries like China present new problems, there are also issues at the individual level.

Each liter of fossil fuel that is burned produces approximately 3 kilograms (about 6 pounds) of carbon dioxide (trivia question: a liter of gasoline weights about 1 kilogram - where does the extra 2 kilograms come from?). A typical car getting 20 miles to a gallon of gas generates 10 tons of carbon dioxide annually! Hummers will produce more, and hybrids less - approximately 15 and 3 tons respectively. To understand the impact of the assault of this seemingly innocuous gas on the planet's well-being, it is important to know more about our atmosphere - the aerial ocean that we breathe! The earth's atmosphere consists of a mixture of chemical gases. In order of decreasing percentages there is **nitrogen** at 78%, followed by **oxygen** at 21% and then **argon** at 0.9% - so these three gases add up to 99.9%. There are 10-15 other gases present in the atmosphere, but only two are present in significant amounts. The amount of **water** varies from 1-4% depending on geography and local weather conditions. Another fixed gas is **carbon dioxide** whose 2014 level was 0.0401%. This very small amount of carbon dioxide supports all of the life-giving photosynthesis that occurs in earth's vegetation. With a single car emitting about 10 tons of carbon dioxide a year, it is not hard to envision its potential impact - and it is NOT more photosynthesis. Carbon dioxide is the major 'greenhouse' gas as it traps previously captured solar energy and hence attenuates significantly the day to night temperature variations on earth.

Just 0.0401% of earth's atmosphere is carbon dioxide, and this is what is vital to all our vegetative cohabitants on the planet as they convert solar energy to carbohydrates and oxygen during photosynthesis. As stated above, carbon dioxide plays yet another role. It is the primary greenhouse gas in our atmosphere. As such it helps maintain an average earthly temperature near 50ºF (or about 10ºC using the scientific T scale of Celsius or Centigrade) by trapping some of the escaping heat previously captured from the sun. Billions and billions of years ago, a photosynthetic organism used the then carbon dioxide rich atmosphere to generate oxygen and thus created what became our life-giving atmosphere.

It is estimated that 25% of the atmosphere's carbon dioxide comes from natural processes like volcanic eruptions. The remainder comes from human induced processes. Analysis of ice core samples dating back to 1750 shows that carbon dioxide levels have increased almost 37% in a little more than 250 years. From 1750 to 1950 the level of carbon dioxide increased just 14% but since then, in just 50 years, it has increased another 23%. Now we have hit 0.04% level (**which would amount to an 11% increase over the last 2 decades).** So, the rate of addition of carbon dioxide

to the atmosphere is growing exponentially. Were all the CO_2 to remain in the atmosphere, that would be one thing, however, recent studies have shown that about a quarter of all of the CO_2 produced since the Industrial Revolution has been absorbed by the oceans leading to a drastic change in their acidity levels. We have yet to learn of the ultimate impact - only time will tell.

We must ask, "could there be a tipping point or a critical amount of the gas that will have severe effects on global climate". Think about how plates on the earth's surface can move just centimeters a year and eventually (and without warning) lead to destructive, cataclysmic earthquakes. Or think about sighting an iceberg from a passenger ship like the Titanic. Even a relatively slow-moving ship requires a lot of time to execute a maneuver to avoid hitting the iceberg. Is the exponentially growing rate of carbon dioxide dumping like sighting an iceberg several miles ahead? What does a prudent captain do? Start steering away from the anticipated path of the iceberg as soon as possible!

There are two sides to this issue – the bad news and the good news. Starting with the bad news - the planet has to deal with the inertia of institutions (including governments) whose vested interests parallel the continued use of fossil fuels. Now for the good news - a growing number of earth's citizens are coming to an appreciation of the signs of carbon dioxide impact on planet earth's long-term sustainability. They are rejecting the assumption that our atmosphere is just a vast ocean impervious to the increased dumping of a waste product like carbon dioxide (remember there is no 'away' as in 'throw away'). These citizens are taking matters into their own hands by installing photovoltaic panels, windmills and solar water heaters on homes and businesses and purchasing greater and greater numbers of hybrid cars - in short, they are taking personal steps to enhance earth's sustainability.

While there are many reasons for weaning ourselves from fossil fuels – including vexing geopolitical issues – there is a more significant imperative – we need to 'kick our oil addiction' to save our planet. If we were talking about a process that added lots of nitrogen to the atmosphere, our 'problem' would be 2000 times smaller (that's how much more nitrogen is in air compared to carbon dioxide). Because carbon dioxide exists naturally in our atmosphere at a very small percentage, humans have the power to impact it. The effect of human activity on the magnitude of carbon dioxide in our atmosphere is the most pressing environmental issue of the 21st Century.

As the rational inhabitants of the planet, we are trusted with its stewardship. While our scientific **theories** about climate change may not be as exact at this point as we might like them to be, they are not **guesses**! These theories are based on data collected at many worldwide sites over many years (more than 50). One might wonder whether most frequent extreme weather events are a temporary cyclical variation in our weather or related to human-induced atmospheric changes. But the reality is that it is clear that **we have the potential to modify our environment**. Once we realize this, we are duty bound as good stewards to strive to preserve and sustain our eco-system for future generations.

As I amend these words in mid-August 2017, it was recently reported in the NY Times that the Alaskan permafrost is warming at an alarming rate which will release long-trapped gases (methane and carbon dioxide) that could impact the rate of global warming.

What does this have to do with you as you begin your high school chemistry course? Keep in mind Francis Bacon's dictum "Knowledge is power!". The goal of this course is threefold. The first is to introduce you to basic chemical concepts. The second is to teach you be careful observers. Finally, the third goal is to teach you be analytical thinkers so you can learn to interpret data. With these combined skills you will emerge from this course with a new perspective on your world - the Chemical World!

Francis P. Gasparro August 24, 2017
(Originally written in Summer, 2007)

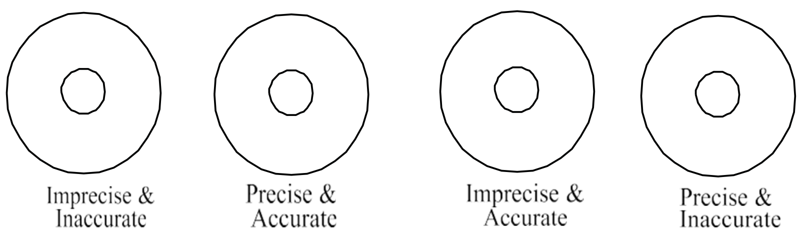
Precision & Accuracy in Lab Measurements

Because there is some potential for *error* in ALL measurements (this is also called *uncertainty*), no matter how carefully they are done, scientists are always concerned about making **accurate** and **precise** measurements. They are also concerned about communicating how much error is in their results and about identifying the sources of that error. This is called '*Error* Analysis'.

Accuracy refers to how **close (*i.e., on target)*** *the* measurement is to an **accepted value**.

Precision refers to **reproducibility** or how close several measurements are to **each other.**

Visually, we can show the meaning of accuracy and precision using the analogy of target shooting. In the four targets below, fill in four shots per target to illustrate the indicated descriptions of precision and accuracy.



Precision or Accuracy can be quantified using the following formulas

Precision *or* % **Uncertainty** = $\frac{\text{Uncertainty}}{\text{Quantity}}$ x 100%

Accuracy *or* **% Uncertainty** = $\frac{\text{Quantity} - \text{Accepted Value}}{\text{Accepted Value}}$ x 100%

A quicker way to imply the **precision** of a measurement or calculated quantity is to note the **number of significant** digits in the quantity. The more significant figures (SF) you are able to read, the more precise the measurement can be.

Accuracy is not communicated by significant digits. Accuracy can be known **only by comparing the result to some accepted value** that is determined by agreement of the scientific community or that is predicted by a theory (the degree of accuracy is measured by % Error which may also be called % Deviation).

Homework (on a separate sheet of paper – you get a zero if your turn in any portion of this sheet):

Given the following measurements, answer questions 1-9 below.

A = 2.33 $\pm$ 0.01 cm B = 1556 $\pm$ 1 cm C = 0.30 $\pm$ 0.01 cm^3

<table>
<tr><td colspan="2">1. Which has the highest uncertainty?</td><td colspan="2">2. Which is the least precise?</td></tr>
<tr><td colspan="2">3. Which has the most significant digits?</td><td colspan="2">4. Which is the most precise?</td></tr>
<tr><td colspan="2">5. Which has the least significant digits?</td><td colspan="2">6. How many SF in the answer to Q5?</td></tr>
<tr><td>7. What is the % Uncertainty in A?</td><td colspan="2">8. What is the % Uncertainty in B?</td><td>10. What is the % Uncertainty in C?</td></tr>
<tr><td colspan="4">9. Doc just got a new laser caliper and remeasured A and found its length to be exactly 2.29 cm. Use this information to calculate the % Error in the original A=2.33 cm reading.</td></tr>
</table>

WELCOME

This manual will serve as the lab manual for the year - that is not to say there will not be additional handouts - but this is the bulk of the lab-related handouts.

Now that we have got that out of the way, here are a few words about this book. The **primary emphasis** is on developing your **observational skills**. Repeatedly throughout these experiments and demonstrations you are asked to make and record observations, that is - take **what you can detect with your senses** - primarily seeing, and perhaps smelling - and print a **succinct, accurate** and **complete** description. The second aspect of these labs involves **interpretation of the observations** - to a chemist that means using **theoretical ideas** to **explain** the 'why' behind the observations you made - primarily in terms of **particle behavior**. What are these particles? Atoms, molecules, and ions - invisible to the eye - make up all of the matter in our world - **The Chemical World!**

The idea of **particle interpretation** of observations is developed very early in most Chemistry courses - and then it is constantly emphasized throughout the year. In addition to particle representations for atoms and molecules there will be representations of ionic compounds and their complementary ions, polymeric molecules, network solids etc. In many labs the students will be asked questions about their observations and then they will be asked to **'think like a particle'**.

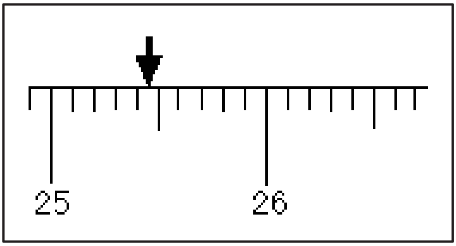
Some of the labs are quantitative in nature - you will be making measurements. You will then be guided through a set of calculations. In the **Question and Analysis** section of the lab write-up, you may then be asked to interpret these numbers. Or perhaps you will be asked to think about how a change in the lab procedure could affect the results. You will also be asked to consider **error analysis**. In Science **'error' does NOT mean mistake** - if you do something wrong in lab because you did not follow the directions that is a **BLUNDER,** not a scientific error. Scientific error arises from the **inherent limitation** of our senses or measuring devices. These terms are typically discussed and illustrated early on during lectures - pay close attention!

In these labs there is another consistent theme or linkage. **Lab skill development is cumulative and integrated**. What is done early on will come back and be useful later on. So, it is extremely important to get a good start and build a solid foundation for the rest of the year. There are lab tests and observations made in September that will be needed in May!

Comprehension of lab material is often tested for in quizzes/tests and in addition it is part of **both** the **midterm** and **final exams**. So, you should resist the temptation to think that because a teacher is not standing in front of the room writing on the white board - **this is play-time**. It is hands-on-time, and it can be fun, but it is not a time for socializing etc. To get the maximum out of lab you must be thoroughly prepared. You must listen carefully and get the principles developed in class related to a particular lab. In addition, you must prepare for labs as described in a subsequent section. These labs have been developed over many years - they all work! Have fun as you become great observers! **Welcome to the Chemical World!**

EXPERIMENTAL "ERROR" (UNCERTAINTY)

What is the reading (arrow point) on this meter stick?



Thankfully, when you reported your measurement, you didn't say "exactly 25.45 centimeters"! Let's see why. First of all, 25.45 cm is a measurement - made by a real measuring instrument, in this case a meter stick. A typical meter stick has marks at 1-millimeter intervals - your 25.45 cm measurement is pictured at left. The arrow appears to be halfway between the 25.4 cm mark and the 25.5 cm mark - therefore, you were justified in calling the length 25.45 cm. The last digit of the measurement is an estimate! Certainly, there is nothing wrong with this. **In fact, it is clearly more reasonable to call the length 25.45 cm than to call it either 25.4 cm or 25.5 cm (or something like either 25.41 or 25.49).**

However, how could you justify saying that the measurement was *exactly* 25.45 cm? You could certainly judge the measurement to the nearest 0.25 mm, and a strong case could be made, probably, for an estimate to the nearest 0.1 mm in this case. But *exactly*? That's just an unjustified guess! A **careful estimate** is not the same as a **wild guess**! So, in reporting this data 'exactly' is an unnecessary and inappropriate word. In the same way, you would **NOT** be justified in calling your measurement 25.452 cm. Doing this would mean that using your eyes you are able to divide a single millimeter into 10 equal parts - accurately - by eye!

It should be clear that the **accuracy** of a measurement is **limited** by the markings on the measuring instrument. The best that a competent chemist can be expected to do is estimate **1 or 2 or 3 digits** between the **finest**

markings on the measuring scale (Chemistry students are also expected to be able to do that!).

This limitation on the accuracy of a measurement is commonly called error. Actually, this is unfortunate, since “error” carries the connotation of “mistake” - but **measurement errors are NOT mistakes!** For this reason, the term uncertainty is commonly used. The **uncertainty** is the ultimate **limit** to the accuracy of a measurement, but it might **not** be the largest factor affecting the precision of a measurement (more on this at another time).

At this point, you should realize that the accuracy of any measurement is limited by the instrument used to measure it (as well as by the skill and care of the user). This inherent limitation is called the **error** or **uncertainty** of the instrument. To get less uncertainty, you need a more expensive and usually more difficult to use instrument.

NOTE TO STUDENTS & TEACHERS

The remainder of this manual is divided into three sections:

1. Experiments
2. Special Experiments
3. Demonstrations

The Experiments have been designed so that **well-prepared** and **attentive** students can complete the work (usually with a partner) in one normal lab period.

The Special Experiments are a bit more complicated and may only be suited for Honors Students.

The Lab Demonstrations involve more complicated or expensive equipment (or perhaps hazardous materials). These can typically be done in about 30 minutes as they are performed by the teacher.

INTRODUCTION TO EXPERIMENTS 0 & 2

These two experiments are designed to introduce you to the scientific way of making observations and measurements, and to the chemistry lab and its facilities.

“Fire” is an Ice-Breaker activity done in the 2nd day of classes.

Experiment 0 asks you to make observations on a candle - a common everyday item: before lighting, while burning and after extinguishing. You will never look at a burning candle the same way as you did before doing this lab!

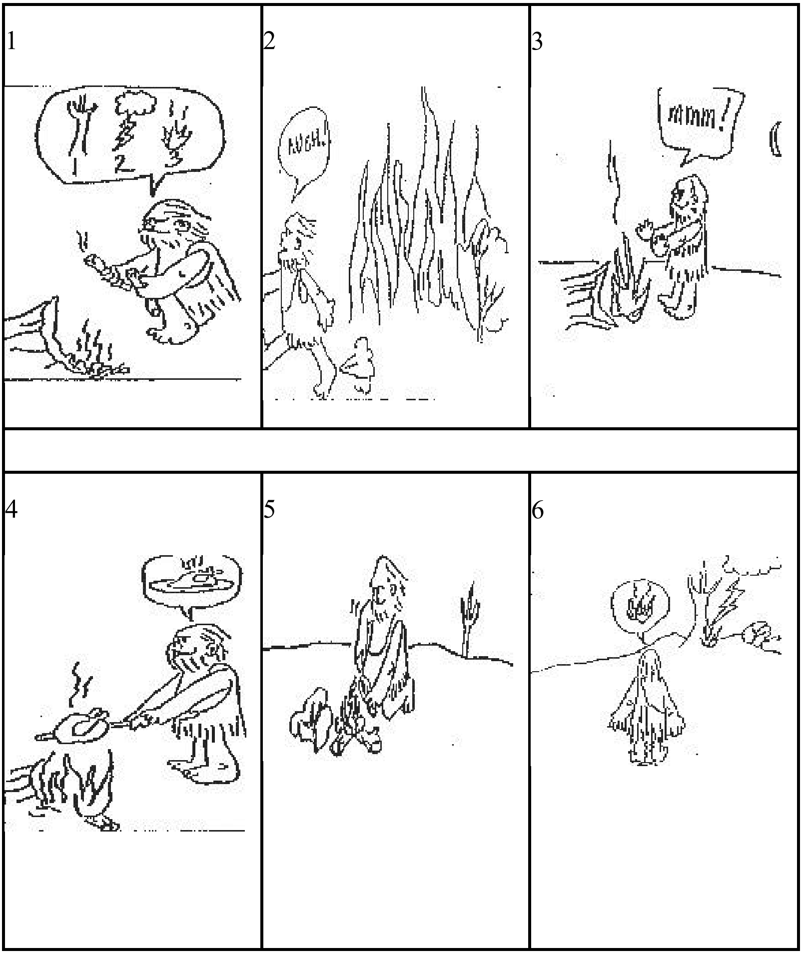
Experiment 1 introduces you to your first set of quantitative measurements. You will measure volumes of water using various pieces of glassware. The main goal is for you to gain some appreciation of experimental error (also called uncertainty).

Experiment 2 requires using your new skills to determine the density of an unidentified metal object as well as a penny using the water displacement method.

Dry Lab - Fire!

[ ] H^3P A[ ] B[ ] C[ ] D[ ] F[ ] G[ ]
Team Members (Print each Name)

Date_________



Pre-Lab: This page is for your itemized LIST of **observations** on each of the preceding panels. Line up the following numbered blocks with each of the numbered cartoon blocks on the first page.

1	2	3
4	5	6

Experiment 0 Observations of a Candle

Name________________

Lab Section________________

Date________________

Introduction. Always keep in mind the difference between observations and interpretations. **Observations** *(synonyms:* evidence, data, measurements) are **objective facts** obtained using human senses or mechanical extensions of the senses, *i.e.,* laboratory devices or instruments. **Interpretations** *(synonyms:* inferences, hypotheses, theories) are subjective generalizations based on personal experience, knowledge, concepts, or sometimes personal bias. These are ideas we have that attempt to *explain* the observations that have been made.

Also, keep in mind the difference between **qualitative observations** which tell "what kind". *vs.* **quantitative observations** which tell "how much". When observing matter, focus on the characteristic properties of the substances being observed. These are the properties that make the substance unique and different from all other substances.

Characteristics of *physical* properties: color, odor, density, state, melting temperature, solubility, etc. Characteristic *chemical* properties are flammability, reaction toward air, water, acids, etc.

You should understand why shape and size are NOT CHARACTERISTIC PROPERTIES. Finally, be aware of the fact that **your observations may be incomplete, or an observation might be poorly worded or incomplete.**

Hints on Recording Observations

1. If not already given, write a Title for the experiment. Make it brief and descriptive.
2. Use simple diagrams and label their important parts.
3. Make a numbered list of observations.
4. Use a systematic approach in searching for data.
5. Make your observations accurate and complete but brief and succinct.
6. Use words that convey specific images.
7. List even obvious events.
8. Whenever possible, quantify your observations.