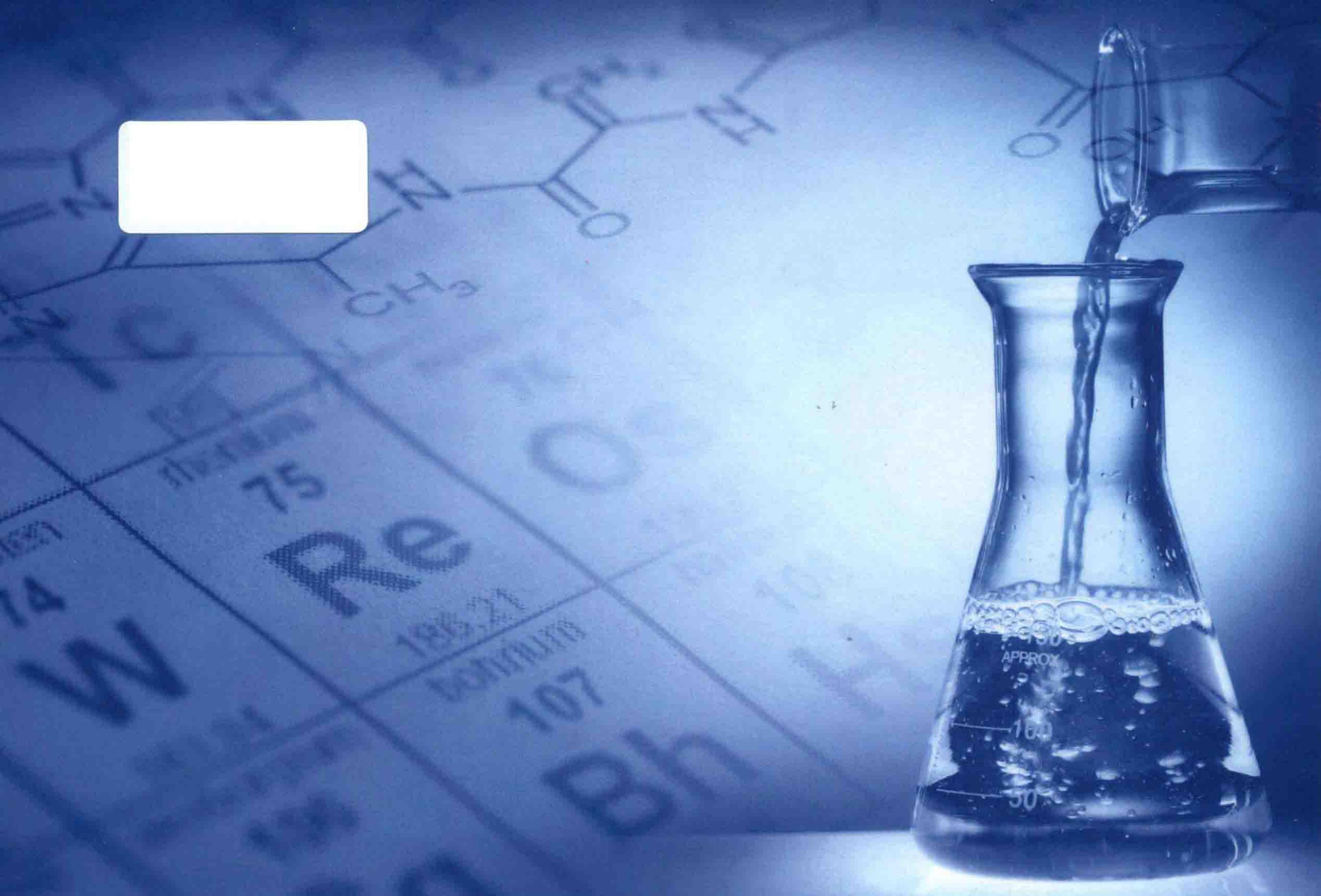

Introductory Chemistry

A GUIDED INQUIRY

Michael P. Garoutte • Ashley B. Mahoney

POGIL

WILEY

INTRODUCTORY CHEMISTRY

A GUIDED INQUIRY

First edition

A Process Oriented Guided Inquiry Learning Course

POGIL™

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Library of Congress Cataloging-in-Publication Data

Garoutte, Michael P.
Introductory chemistry : a guided inquiry / Michael P. Garoutte, Ashley B. Mahoney. — First edition.
pages cm
Includes bibliographical references.
ISBN 978-1-119-04683-7 (pbk. : alk. paper) 1. Chemistry—Textbooks. I. Mahoney, Ashley B. II. Title.
QD33.2.G38 2016
540—dc23
2015021978

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

To the instructor

Each activity in this set may be used independently, but some questions may depend upon topics examined in earlier activities. Facilitation guides for each activity are available at the Instructor Companion Site (www.wiley.com/college/garoutte). The facilitation guides give the content and process learning objectives, instructor facilitation notes, and suggested answers to the Critical Thinking Questions. Solutions to the Exercises at the end of each activity are also available. The facilitation guides are not intended for distribution to students, although the learning objectives and Exercise solutions may be shared with them.

This collection of POGIL activities is designed for use in a **preparatory or introductory chemistry** course. These activities could also be used in a **one-term GOB** (General-Organic-Biological) chemistry course, or perhaps even a **high school chemistry** course. There is another collection of activities designed for a **full-year GOB** chemistry course sequence. Information about both collections, including suggested orders of activities for the types of courses listed above, may be found at the web link given in the first paragraph. For orders of 25 or more books, Wiley Custom Select (customselect.wiley.com) currently allows custom publishing of subsets of the activities and even inclusion of other activities or your own uploaded content.

The Process Oriented Guided Inquiry Learning (POGIL) Project supports the dissemination and implementation of these types of materials for a variety of chemistry courses (high school, organic, physical, *etc*.) and in other disciplines such as materials science, biology, and mathematics. Information about The POGIL Project and its activities, including additional materials, workshops, and other professional development opportunities, can be found at www.pogil.org.

Feedback regarding the effectiveness of the materials and suggestions for improvements would be appreciated. Send this assessment information to the authors by email (addresses available from our University websites). Another method to give feedback or ask questions is the Yahoo discussion group moderated by the authors, available at: goo.gl/vfrr5Q

How to use this book (for instructors)

How instructors use these materials varies, but during most POGIL sessions:

- **Students work in teams of three or four** to answer the *Critical Thinking Questions*. These questions are carefully designed to guide student teams toward discovery of a concept.
- **The instructor serves as the facilitator of learning** rather than the primary source of information. Effective facilitators spend significant class time observing student group work, asking and answering questions, leading whole-class discussions, and delivering just-in-time mini-lectures (usually no more than five minutes long).
- **Students are assigned specific roles,** a key feature of POGIL pedagogy. Some roles to try and other implementation tips are available at: goo.gl/xmtVvL
- **These ChemActivities are designed to be a student's first introduction to a topic.** A very short review of the *previous* activity can be helpful when delivered at the beginning of the class. If you are employing a flipped classroom model or other structure that includes some formal lecture, make sure that any lecture on a topic comes *after* students have had the opportunity to discover that topic by completing the activity. If you find that students are having difficulty completing the activity in the allotted time, you might consider asking students to complete the first few exploration questions of the activity on their own before coming to class. Some instructors have employed this strategy successfully.
- **Students will often ask you: "Is our answer right?"** Remind them that their job is to *construct a valid understanding of the underlying concepts*. Telling them the "right" answer can bring their processing of the ideas to a premature end. Ask how

you can help. Usually students can rephrase their question to highlight the source of their confusion. Often, if they proceed to a following question, they will find the answer themselves.

- **These activities do not replace a traditional textbook, but rather enhance its use.** Any standard text may be used, and you are encouraged to correlate reading and/or homework assignments from the text for students to do *after* completing the ChemActivities in this book.

How to use this book (for students)

These activities are designed to be used by students working in teams during class. For each activity, read the Model or Information, and then work with your team to answer the Critical Thinking Questions (or "CTQs") that follow. For each CTQ, be sure to compare answers with your teammates before moving onto the next CTQ. Working together is everyone's collective responsibility. Studies show that this method of learning allows students to develop a deeper understanding of the material and retain it longer—even in later classes or on standardized exams.

In a class such as this, you may be frustrated at times because you cannot immediately see the "right" answer to a question. It is by design that some answers are not immediately obvious. Sometimes you will write an answer and go on to a later question, only to find that the later question causes you to reevaluate your earlier answer. This is OK! Later, when you have the "aha!" moment, you will not easily forget what you have learned.

If you are unsure of an answer, even after checking with your teammates, some good strategies are to read the following question, ask a nearby group, or (finally) pose a question to the instructor. However, try to avoid asking the instructor: "*Is our answer right?*" Instead, explain why you are confused, or ask a question that gets at the source of your confusion.

Before the next class, finish all assigned parts of the activity, including homework and reading from a textbook. Even better: find a study partner or group, and meet regularly! When you have study partners, you have a reason to be prepared (they are counting on you), and if you can't come up with the answer together, then you are less shy about asking the instructor.

Some comments from former students in this course

Being able to work with people was very beneficial. At first, it was a difficult adjustment to this learning style – but now I really enjoy it.

I thought that I wouldn't like this class but it has been really interesting to come to class every day and actually learn something that pertains to life.

If you work well with others and are able to learn as a group and be challenged by your group of peers to strive to really learn the subjects then I recommend this class. But if you'd rather work on your own and not get help from others then this class would be of no benefit to you.

Group discussions really encourage a better learning atmosphere that helps all group members understand the material better.

This is one of the hardest classes I have ever taken. But was the only one that taught me to seek out the answer instead of having it handed to you. This class will help me in future classes, because I have gained good study skills. For that I wish to thank [the instructor] :)

In high school I just memorized stuff, but now I finally understand.

Go to class if you don't want to do a whole lot else...even by showing up and doing the activities. I didn't have to spend a lot of time outside of class. I learned but didn't spend a huge amount of time doing it!

Acknowledgments

We would like to thank our numerous allied health students who have patiently worked through earlier versions of this material and have helped direct our revisions. Your questions and insights have taught us so much.

Michael P. Garoutte

I would like to thank several folks who have been influential in my path to author this book in the first edition and to work with Professor Mahoney on the second edition.

- To my graduate advisor, Richard L. Schowen, Professor Emeritus, University of Kansas: Dick, you said that I might want to consider authoring a textbook someday. I didn't forget. Thank you for the encouragement. It meant a lot, and still does.
- Andrei Straumanis and Renée Cole of The POGIL Project introduced me to POGIL at a workshop in 2003. They, and so many others in the project, have provided much advice and inspiration ever since. I can't imagine a more helpful and supportive group of folks.
- Rick Moog and Jim Spencer of Franklin & Marshall College didn't laugh when I showed them the first draft of these activities, and apparently believed in the adage "if you can't say something nice, don't say anything at all." Special thanks to Rick, who has continued to cheerfully answer any and all questions and has been all around encouraging in the entire process.
- My colleagues at Missouri Southern have supported my choice to "try something different" in class. Many teachers don't have it so good. Thanks especially to Professor Emeritus Mel Mosher, who gave me advice when I was new to teaching and continued to mentor me for the next decade and more. Mel passed away in 2010, and I still miss him.
- Thanks to my first editor, Debbie Edson, and our current editor, Nick Ferrari, and all the folks at Wiley who have been patient with all my questions.
- Finally, I would like to dedicate my portion of this book to the people I share my life with—Susan, Audrey, and Madeleine. Thank you for your ever-present love and support, especially during all the time I have spent working on this project. S. D. G.

Ashley B. Mahoney

- To Rick Moog who encouraged me to jump in with both feet, and I haven't looked back.
- To many in the POGIL Project (Renée Cole, Andrei Straumanis, Rick Moog, Vicky Minderhout, Jenny Loertscher, and many others) who provided review of early drafts of the material and weren't afraid to be brutally honest. These activities are significantly better thanks to you.
- To the POGIL community for being welcoming and providing support and encouragement both in the classroom and in research. I have grown tremendously in both areas thanks to you. I also now have a well-stocked jewelry drawer!
- To my administrators and colleagues at Bethel University who supported me on many levels in trying a different approach and persevering through the initial trials. Thanks specifically to Rich Sherry and Ken Rohly who were willing to stand behind a non-tenured professor who quit lecturing. Not many faculty have such tireless administrators on their side.
- To my close friends, extended, and immediate family for their patience and incredible support in this process. Thanks for keeping me grounded and reminding me of what is important in life. Hopefully meals will now improve (or not).
- To my parents for instilling a love of learning at an early age and providing me with a foundation built upon the rock.

Table of Contents

Working in Teams; Estimation

Information: Brief description of roles

Much of the class time in this course will be spent working in teams of three or four. Each member of the team will be assigned a particular role. Some typical roles (and their descriptions) are listed below. If a team member is absent on a particular day, then one member may have to fulfill more than one role. Your instructor will let you know how the roles will function in your course.

Manager (or Facilitator): Manages the team. Ensures that members are fulfilling their roles, that the assigned tasks are being accomplished on time, and that all members of the team participate together in activities and understand the concepts.

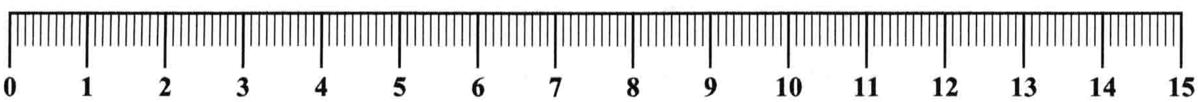
Spokesperson (or Presenter): Frequently the instructor will ask what the team responded to a particular question or whether the team agrees with another team's response. It is the spokesperson's role to reply to these questions. If an outside source is needed, the spokesperson ensures that everyone in the team agrees on what question to ask.

Quality Control: Guides the team to build consensus and ensures that the team agrees on responses to questions. Verifies that the team's answers to Critical Thinking Questions are consistent on paper. Ensures that all team members make revisions, if necessary, after class discussion.

Process Analyst (Reflector, Strategy Analyst): Observes and comments on team dynamics and behavior with respect to the learning process. Reports to the team periodically on how the team is functioning. For example, the Process Analyst might comment that a particular team member is dominating the discussion, or that the team needs to pause to allow one member to catch up.

Recorder: Records (on report form) the names of each of the team members at the beginning of each day. Keeps track of the team answers and explanations, along with any other important observations, insights, *etc.* The completed report with answers to any questions asked may be submitted to the instructor at the end of the class meeting.

Model 1: A centimeter ruler



Critical Thinking Question:

1. Estimate the number of table tennis ("ping-pong") balls that would completely fill the room you are working in. First, decide upon a "plan of attack" as a team. You may or may not choose to use the centimeter ruler. For the purposes of this exercise, you may choose to assume that the room is rectangular in shape and that it is completely empty of desks, people, *etc.* You may get up and move around the room. When your team has an answer, the spokesperson may be asked to write it on the board.

Exercise:

1. Read the assigned pages in the text, and work the assigned problems.

Types of Matter; Chemical and Physical Changes

(How can we classify matter?)

Model 1: Examples of some pure substances at room temperature

Item	Classification	State (or states)	Formula
aluminum	element	solid	Al(s)
hydrogen	element	gas	$H_2(g)$
mercury	element	liquid	Hg(l)
baking soda	compound	solid	$NaHCO_3(s)$
table salt	compound	solid	NaCl(s)
water	compound	liquid	$H_2O(l)$

Critical Thinking Questions:

Refer to Model 1 to help you answer Critical Thinking Questions (CTQs) 1–3.

1. What is the formula for hydrogen gas? ______ For liquid water? ______
2. How can you distinguish elements from compounds based on their chemical *formulas*? Consult with your team and write your consensus answer in a complete sentence or two.
3. Based on your answer to CTQ 2, complete the definition for

   A *compound* is composed of at least ______ different ________________ that are combined chemically.

Model 2: Examples of some mixtures at room temperature

Item	Classification	State (or states)	Formula (or formulas)
hydrogen peroxide solution (3%)	homogeneous mixture	aqueous solution	$H_2O(l)$ and $H_2O_2(aq)$
salt water	homogeneous mixture	aqueous solution	$H_2O(l)$ and NaCl(aq)
coffee (“black”)	homogeneous mixture	aqueous solution	$H_2O(l)$ and many others
muddy water	heterogeneous mixture	liquid + solid	$H_2O(l)$ and other stuff

Critical Thinking Questions:

4. The 3% hydrogen peroxide solution available in drugstores is 97% water. What is the formula for the hydrogen peroxide present in this solution (consult Model 2)?
5. Elements and compounds are considered pure *substances*. Compare Models 1 and 2. How does a *substance* differ from a *mixture*? Discuss with your team and write a consensus answer.

6. Devise a team hypothesis about the meaning of the labels (s), (l), (g), and (aq) on the formulas.

Information: States of matter

Matter can be classified by its physical **state** (or **phase**): **solid, liquid,** or **gas**. Most solids can be melted and even vaporized if the temperature is high enough.

The **phase labels** (s), (l), or (g) can be written after a formula to signify the physical state. So, $H_2O(g)$ would mean gaseous water, *i.e.,* water vapor.

Model 3: Equations for some chemical and physical changes

	Equation	Type of change
I	$H_2O(l) \rightarrow H_2O(s)$	physical
II	$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(g)$	chemical
III	$2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g)$	chemical
IV	$C_3H_6O(l) \rightarrow C_3H_6O(g)$	________

Critical Thinking Questions:

Questions 7–10 refer to Model 3. ***Manager:*** *For each question, ask a different team member to begin discussion by explaining his or her answer to the team.*

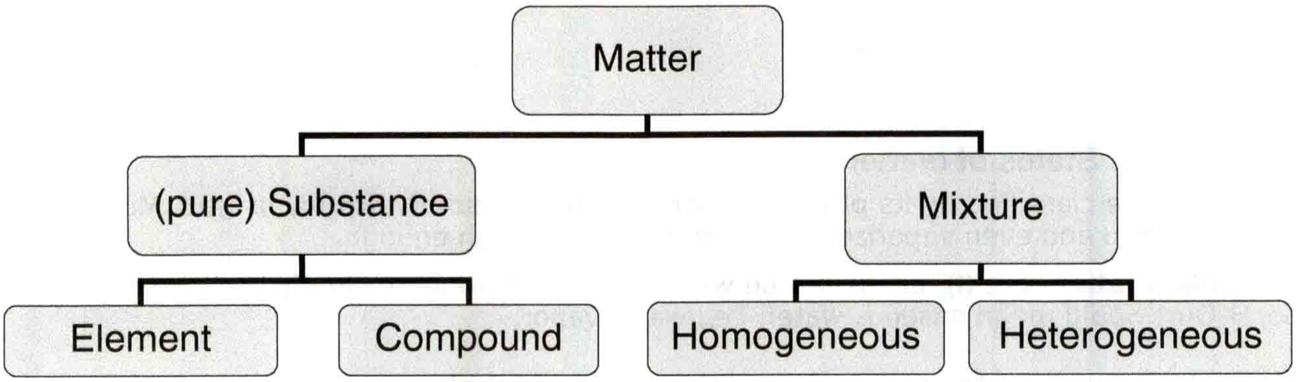
7. Write a complete sentence to describe in words (no formulas) what is happening in Equation I. Why is this process considered to be a *physical* change?

8. Describe in words what is happening in Equation II. Why is this a *chemical* change?

9. Describe in words what is happening in Equation III. Why is this a *chemical* change?

10. The formula for acetone is C_3H_6O. Without using formulas, write a sentence to describe what is happening in Equation IV. Is this a chemical or physical change? Fill in the blank in Model 3.

Model 4: Flow chart for classifying matter



Information: Classifications of matter

Matter can be divided into two main types: pure **substances** and **mixtures** of substances.

A **substance** cannot be separated into other kinds of matter by physical processes such as filtering or evaporation, and is either an **element** (*e.g.*, aluminum) or a **compound** (*e.g.*, H_2O). Compounds are made of two or more elements chemically combined. The elements themselves cannot be separated into simpler substances even by a chemical reaction.

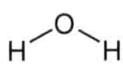
On the other hand, **mixtures** can be separated by physical means. Mixtures that have the same composition throughout are called **homogeneous** (*e.g.*, salt water); those that do not have uniform composition throughout are called **heterogeneous** (*e.g.*, Italian salad dressing).

Critical Thinking Questions:

11. Have one team member reread your team's answer to CTQ 5 out loud. Add to or revise it if necessary.
12. As a team, try to brainstorm a physical method that you could use to separate salt water into two pure substances. Write your idea here.

Model 5: Some different representations of the water molecule

H_2O HOH H–O–H



formulas | Lewis structures | ball-and-stick | Spacefilling

Critical Thinking Questions:

13. The "2" in H_2O is subscripted (written below the line). Based on Model 5, what do subscripts following an element in a formula represent?

14. Look at the periodic table of the elements. About how many elements are known? _____
15. Approximately how many elements are metals? (Estimate, don't count!) _____

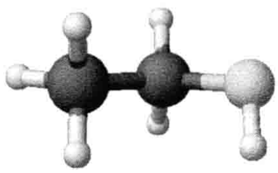
16. There are **thousands** of organic compounds known—compounds formed out of only a few different elements (carbon, hydrogen, oxygen, and nitrogen). How might this be possible?

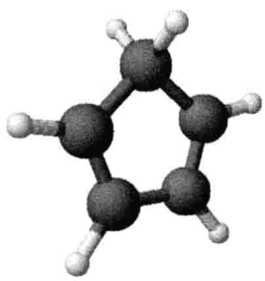
17. Did everyone in your team contribute to the activity today? If so, explain how. If not, identify what individuals need to do to ensure participation by all in the next session.

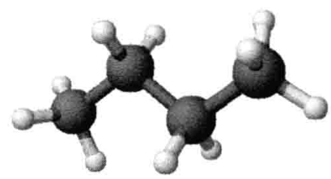
Exercises:

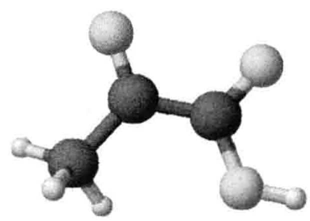
1. Write the formula of each molecule for which the ball-and-stick structures are shown.

Key:  = carbon  = oxygen  = hydrogen

a. 

b. 

c. 

d. 

2. Using the periodic table, identify the elements represented in each formula, and state the number of atoms of each element in the formula. The first one has been done for you.
   a. NH_3 (ammonia) *one nitrogen atom, three hydrogen atoms*
   b. $C_6H_{12}O_6$ (glucose)
   c. $Mg(OH)_2$ (milk of magnesia)
   d. H_2SO_4 (sulfuric acid, "battery acid")
   e. $C_{17}H_{18}F_3NO$ (fluoxetine, Prozac)

3. Using the flow chart in Model 4 to help you, first classify each of the following as either a **mixture** or a pure **substance**. Then, for each **substance**, tell whether it is an **element** or a **compound**. For each **mixture**, tell whether it is **homogeneous** or **heterogeneous**; then list two or more components of the mixture.
   a. a lead weight
   b. apple juice

c. baking soda ($NaHCO_3$)

d. air

e. a 14-karat gold ring

f. a 24-karat gold coin

g. helium in a balloon

h. beach sand

i. concrete

j. whole blood

k. carbon dioxide

4. In the space below, draw a picture of three water molecules in the ball-and-stick representation.

5. Which of the choices below (I or II) would best represent the three molecules you drew in Exercise 4? Explain your choice.

Choice I	Choice II
H_6O_3	$3\ H_2O$

6. Can you think of some commercial products you might have at home that are heterogeneous mixtures? List one or more.

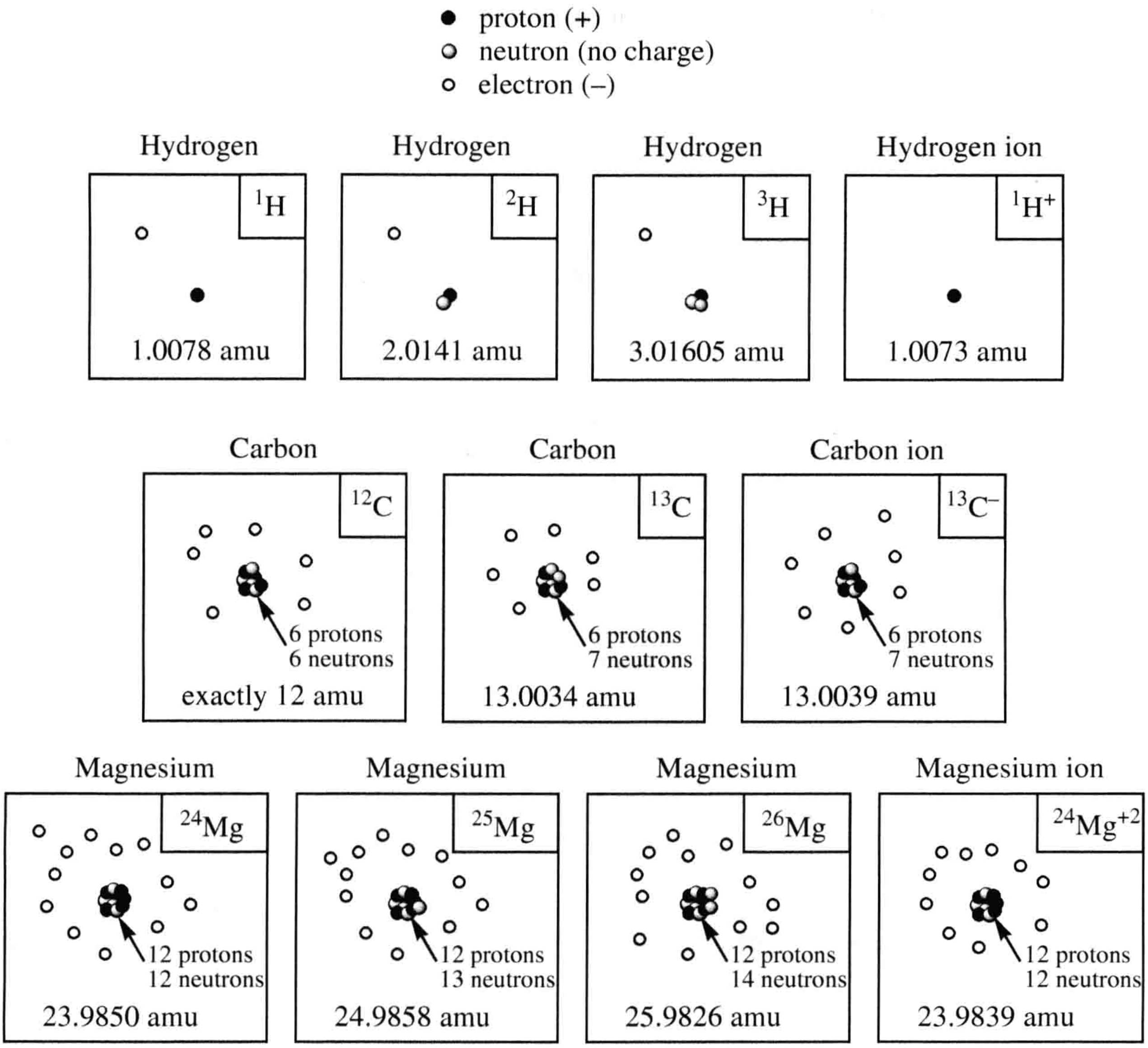
7. Learn the **names** and **symbols** of the elements your instructor suggests. A good starting point is the first 30 elements, plus Br, Sr, Ag, Sn, I, Ba, Pt, Au, Hg, and Pb. Spelling counts! You do **not** need to memorize any **numbers**, as the periodic table will always be available for your use.

8. Read the assigned pages in the text, and work the assigned problems.

*Atoms and the Periodic Table**

(What are atoms?)

Model 1: Schematic diagrams for various atoms



^{1}H, ^{2}H, and ^{3}H are **isotopes** of hydrogen. ^{12}C and ^{13}C are **isotopes** of carbon.

^{12}C and ^{13}C may also be written as "carbon-12" and "carbon-13"

The **nucleus** of an atom contains the protons and the neutrons (if any).

An "amu" is an **atomic mass unit**.

* Adapted from ChemActivity 1, Moog, R.S. and Farrell, J.J., *Chemistry: A Guided Inquiry*, 5th ed., Wiley, 2011, pp. 2–6.

Critical Thinking Questions:

Manager: *For questions 1–3, identify a different team member to give the first explanation.*

1. Look at the schematic diagrams for carbon. What do all three carbon atoms (and ions) have in common?

2. What do all four hydrogen atoms (and ions) have in common?

3. What do all magnesium atoms (and ions) have in common?

4. Look at the periodic table (*e.g.,* in your text). Considering your answers to CTQs 1–3, what is the significance of the **atomic number**, above each element in the table?

5. How many protons are in all chlorine atoms?_____ Do you think chlorine atoms exist with 18 protons? _____ Why or why not? Confer with your team and once you agree, write your answer in a complete sentence.

6. How many electrons are found in ^{12}C? ____ ^{13}C? ____ $^{13}C^{-}$? ____

7. Engage in a team discussion to identify what feature distinguishes a neutral atom from an ion. Write the consensus answer in a complete sentence.

8. Engage in a team discussion and once your team agrees, write a formula for calculating the charge of an ion. ***Spokesperson (Presenter):*** Be prepared to share the team answer with the class.

9. A positively charged ion is called a <u>cation</u> (pronounced "cat ion"), and a negatively charged ion is called an <u>anion</u> (pronounced "an ion"). Which term applies to the magnesium ion?

10. ***Process Analyst (Reflector):*** Comment to your team on strengths and needed improvements for your teamwork so far.