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Investigating the Impact of the Science Writing Heuristic on Student Learning in High School Chemistry

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Abstract

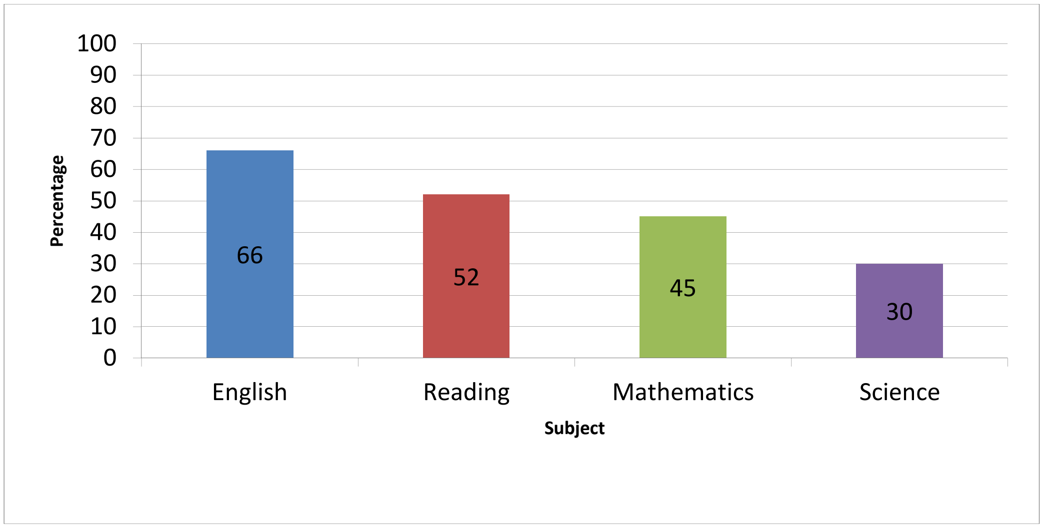
George D. Nelson, former director of the American Association for the Advancement of Science's Project 2061 said, "Without a science-literate population, the outlook for a better world is not promising." Ten years into the 21st century, the nation's approach to science education continues to struggle in the development of scientific literacy. This study builds on past research that links the use of inquiry in the science classroom toward improvement of science literacy and overall conceptual understanding of scientific principles. Specifically, this study examined the effects of the use of the Science Writing Heuristic (SWH) on student learning in a high school chemistry classroom. Participants in this study were divided into two groups: a control group that used a traditional, directed inquiry approach generated from their textbook, and a treatment group that involved a guided inquiry approach based on the SWH. Two assessments were administered in a pre/post fashion to determine if the use of the SWH in a high school chemistry laboratory improved conceptual understanding of the gas laws and overall student scientific reasoning. Results showed that there were no significant learning gains in the treatment group (SWH) as compared to the control group with regards to either conceptual understanding of the gas laws or in student scientific reasoning ability. This lack of significance may be attributed to the short duration of the study, which in turn resulted in only one learning unit used for comparison in this study. This limitation supports the belief that improvement of scientific literacy and scientific reasoning through the use of the SWH does not occur over the short term. In order to demonstrate measurable improvement in conceptual understanding and scientific reasoning, the SWH needs to be implemented in a holistic fashion that covers several instructional units.

Chapter One

Introduction

After ten years into the 21st century, our nation's approach to science education continues to fail our students. In the American College Testing (ACT) Program's 2011 annual report, the statistics indicate that only 1 in 3 of our nations' high school graduates meet the College Readiness Benchmark for science (Act, Inc., 2011). Of the four core subjects tested, science had the lowest percentage of students meeting the College Readiness Benchmarks, making science our most crucial subject area in need of educational critique and improvement.

Figure 1. Percent of ACT-tested high school graduates meeting College Readiness Benchmarks, 2011.



Based on decades of student performance data, ACT defines "college readiness" in science as students having a 50% chance of earning a grade of B or higher, or about a 75% chance of earning a grade of C or higher in first-year college Biology (ACT, Inc., 2011). Based on most collegiate grading scales, this is not an unusually high academic expectation. Using this nationally representative sample of high school graduates, the science benchmark is a median course placement value for our national colleges, and as such represents a *typical* set of expectations. ACT's established College Readiness Benchmark for science is a sub-score of 24 on the Science Reasoning Test (SRT) of the ACT. The SRT is a 40-question, 35-minute test that measures the skills required in the natural sciences: interpretation, analysis, evaluation, reasoning, and problem solving (ACT, Inc., 2011). The questions require the reader to: (1) recognize and understand the basic features of, and concepts related to, the provided information; (2) to examine critically the relationship between the information provided and the conclusions drawn or hypotheses developed; and (3) to generalize from given information and draw conclusions, gain new information, or make predictions. Based on these learning targets, the SRT can be utilized as a national indicator of our high school graduates' state of science literacy.

As demonstrated by these 2011 statistics, there is an urgent need to analyze and remodel current science education pedagogies to improve students' scientific literacy. As today's societal dependence on technology increases exponentially, these future citizens and workers are being left behind without the scientific literacy to adeptly function in today's world (Lederman, 1999). From ensuring the safety of our drinking water to the conservation of fragile land areas, our students need the foundational framework to minimize our increasing impact on the planet and to secure sustenance of our life support. More critically, our students lack the scientific mindset to adapt to the ever-changing environment around them (Lederman, 1999). In order to successfully navigate within this construct, our students need the skills and attitudes to critically analyze the global issues that arise and to be able to work collaboratively through negotiation and argumentation toward ethical and moral solutions that benefit all human populations. With the increasing complexity of ensuring human survival, these recognized shortcomings have been the impetus toward science education reform since even before the beginning of the 21st century.

One of the most noted events that discussed this criticality toward science educational reform was the April 1999 meeting of the American Educational Research Foundation in Montreal, Canada. At this meeting, the underlying theme was to discuss the "underdevelopment of learning" within our nation's public educational system. Within this theme, Leon M. Lederman, Nobel Laureate (Physics 1988) and science education leader, proclaimed our disservice to our students and urged for drastic changes in how we educate our primary and secondary students, specifically in the area of science. In his paper, "On the threshold of the 21st century: Comments on science education" (1999), Lederman defined the purpose of schools as public institutions that should "produce graduates who can cope in the world into which they emerge" (p. 2). To clarify his definition, Lederman stated that "projections of the human condition, the strength of family, the level of moral and ethical behavior, the economic health, social and political stability are all subject to the advance of science and technology" (p. 3). In order words, our students' lack of scientific literacy affects every aspect of their lives based on the current state of our techno-savvy culture. In addition, Lederman asserts that these issues dominate "the world into which they emerge" (p. 2) and should be used as guidelines for what we must do within our schools so that "no matter what road they choose (work, technical, liberal arts, science or engineering), that our students will be able to 'cope'" (p. 3). Therefore, it is in the best interest of our nation's future that we critically analyze how we educate our students within the realm of science so that our graduates possess the skills, attitudes and habits of mind to successfully lead us toward the continued propagation of the human species beyond the 21st century.

Project 2061

Another movement based on the need for national reform in science education comes from the American Association for the Advancement of Science (AAAS). In 1985, the AAAS initiated a program known as Project 2061, a long-term effort to improve education so that all citizens attain scientific literacy. This collaborative effort was meant as a national strategic plan for all of our citizens to reach a better understanding of how the natural sciences, social sciences, mathematics, and technology all interact within our world and how they affect all human endeavors (AAAS, 2001). As the 21st century approached, AAAS released two seminal reports: *Science for All Americans* (1989) and *Benchmarks for Science Literacy* (1993) that were meant as preludes to their *Atlas of Scientific Literacy* (2001).

The first report, *Science for All Americans* described the specific knowledge and abilities that define and characterize science literacy. This report documented the need for all citizens to become scientifically literate based on several provocative arguments, including the following: (1) science provides humanity with the knowledge of their environment and of social behavior needed to develop effective solutions to its global and local problems; without that knowledge, progress toward a safe world will be severely hampered; (2) science explains the dependency of living things on each other and on their physical environment, and fosters intelligent respect for nature that should inform decisions on the uses of technology; without that respect, our physical environment becomes recklessly endangered and will cease to support life; and (3) scientific habits of mind can help every citizen to sensibly handle challenges that often involve evidence, quantitative considerations, logical arguments, and uncertainty; without the ability to think critically and independently, citizens fall prey to the trappings of pseudo-science

(AAAS, 1990). With this report, the AAAS established a strong case against maintaining a "status quo" with regards to our nation's science educational plan.

After presenting their arguments for the need for reforming our nation's science education programs, the AAAS released their second report, *Benchmarks for Science Literacy*. *Benchmarks* specified how students should progress toward science literacy, recommending what they should know and what they should be able to do by the time they reach certain grade levels: 2, 5, 8, and 12 (AAAS, 1993). This report provided recommendations for making reasonable progress toward the goal of adult science literacy that was argued and defined in their first report, *Science for All Americans* (AAAS, 1993). In summary, the first report provided the reasons why there should be a concentrated effort on behalf of our national educational system to engage in improving science literacy for all our students, and the second report provided the specifics of what scientifically literate knowledge and skills look like, so our teachers and administrators can help students to attain scientific literacy by the time they finish 13 years of schooling within our national system (AAAS, 1993).

To culminate their position on the criticality of science educational reform, the AAAS released their third report, *Atlas for Science Literacy* (2001). In this two volume set, the *Atlas* attended to the challenge of making science education reform a reality (p. 3). According to its authors, *Atlas* suggested that "science literacy should be approached not as a *collection* of isolated abilities and bits of information, but as a rich *fabric* of mutually supported ideas and skills that must develop over time" (p. 3). In this framework, the authors believed that what students learn from grade to grade "should build on what they learned before, make sense in the terms of what else they are learning, and prepare them for what they will learn next" (p. 3). In order to achieve adult science literacy, the authors contended that teachers need to understand the interplay between what their students learn in other grades, topics, and disciplines, and what they want to teach their students in the present. In other words, educators must understand that what their students learn in a particular classroom depends on and supports what they were taught before the students got there, and has an effect on what they are going to learn in the future.

To demonstrate this interdependency among student science learning, the *Atlas* authors presented the "how-to" information as *conceptual strand maps* (p. 3). These maps graphically show educators the growth of science understanding on behalf of their students as they make their way through various science, math, and technology topics as they move from grade to grade. According to the authors,

> unless educators understand how scientific ideas and skills develop over time and how they relate to one another, students will be left with nothing more than a heap of unrelated, poorly understood, and quickly forgotten facts, algorithms, and technical terms (p. 3).

Fortunately, the *Atlas* authors do not prescribe a specific curricular plan to follow in order for students to reach adult science literacy. Instead, they offer a framework that is meant to allow a variety of different ways to design and organize learning experiences to meet the needs of individual student populations.

How Students Learn Science

While the AAAS developed their Project 2061, the National Research Council (NRC) also played a significant role in the science education reform movement. In their 1999 publication, the authors emphasized three fundamental principles of learning that educators should incorporate into their instructional pedagogy: (1) students come to the classroom with preconceptions about how the world works; (2) in order to succeed within an inquiry construct, students must have a firm foundation of factual knowledge, the comprehension of how that factual knowledge fits together; and the ability to retrieve and apply that knowledge in new settings; and (3) students need to take control of their learning through the teacher's use of a meta-cognitive approach that allows them to define learning targets and self-monitor their progress in pursuit of those targets. In addition, the NRC continued to explain four instructional design characteristics that can be used as "lenses" to evaluate the effectiveness of teaching and learning environments in our classrooms. These four design characteristics are:

- *Learner-centered* = starting instruction from where the learners are
- *Knowledge-centered* = what is taught, why it is taught, what mastery looks like
- *Assessment- centered* = formative assessment opportunities to be used as checkpoints of learning along the way
- *Community-centered* = respectful engagement that allows for questioning, risk-taking

Although these recommendations are enlightening, putting them into practice remained challenging for most educators, experienced or not. Recognizing this inherent roadblock to science education reform, the NRC continued their research of how people learn through an exploration into the content specific standard, "Science as Inquiry".

In their 2000 publication, the NRC clarified their position on the importance of teaching science as inquiry with the following:

> inquiry is at the heart of the *National Science Education Standards*. The *Standards* seek to promote curriculum, instruction, and assessment models that enable teachers to build on children's natural, human inquisitiveness. In this way, teachers can help all their students understand science as a human

> endeavor, [through the acquisition of] the scientific knowledge and thinking skills important in everyday life (p. 6).

In this manner, the NRC validated the work of the AAAS' Project 2061 and provided a venue of national support by which educational researchers could embark on their academic pursuits to investigate the advantages of an inquiry approach to science education.

Based on the instructional changes suggested by the NRC, moving science education towards an inquiry approach provides a plausible answer to the nation's problem of science illiteracy. Based on its inherent nature, teaching from a "science as inquiry" perspective forces the students to make and evaluate decisions using careful questioning, valid evidence, and critical reasoning (NRC, 2000). Switching the focus from what scientists already know to pondering why we know or how we know helps students to develop the critical processing skills to successfully navigate through the global challenges that they will face in their adult lives. Studies have found that not only do students learn more science content through inquiry, but they also develop the ability to "study the natural world and propose explanations based on the evidence derived from their work" through inquiry (NRC, 1999, p. 17). Further, the NRC specifies that "inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (NRC, 2000, p. 23), all of which are imperative to the science education reform movement towards improved scientific literacy on behalf of all citizens.

Chapter Two

Review of Literature

Based on the suggestions presented from the AAAS and the NRC, many questions arise regarding the implementation of the "science as inquiry" reform movement. As these questions emerge, some common themes can be seen such as to why there should there be a shift toward "science as inquiry", how to define "science as inquiry", what does inquiry look like in the science classroom, and what are the "best practices" of inquiry that improve the scientific literacy of our nation's high school graduates. These questions deserve substantial individual attention where reasonable solutions can be discussed and validated if our science education plan is to be transformed.

The Case for "Science as Inquiry"

According to the NRC, "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (2000, p. 29). The use of an inquiry approach in the science classroom allows teachers and students "to learn how to do science, learn the nature of science, and learn science content" (NRC, 2000, p. 30). Through the process of inquiry, students enhance their understanding of the natural world around them, and develop their science processing skills. When using inquiry in the science classroom, students get an opportunity to act like scientists where they engage in offering questions, posing hypotheses, performing research and experiments, analyzing data, and developing evidence-based conclusions. As students encounter science in an inquiry-based setting, they become more actively involved in their discovery, which in turn, allows them to become more responsible for their own learning (The Access Center, 2009).

These declarations about the benefits of inquiry are supported by the body of educational research that first answered the question of how people learn. From this research, it was found that conceptual understanding is key to competent performance, learning transfer, and problem solving (Bransford, Brown & Cocking, 1999). As previously stated, these skills are critical to students' success in the 21st century, where it is simply not enough to know how to read and write. Being successful today means that students need to "think and read critically, to express themselves clearly and persuasively, and to solve complex problems in science and mathematics" (p. 4). Specifically, the authors suggested that teachers maintain three guiding principles throughout their instructional pedagogies: engagement of resilient preconceptions, organization of content knowledge around core concepts, and continuous support of meta-cognition. When these three principles are successfully implemented in the classroom, students are allowed to be "active" participants in control of their own learning. Based on these suggestions, the authors maintained that the classroom-learning environment becomes more conducive to how the human brain learns (NRC, 2005).

Throughout the research dedicated to science education reform, there is a recurring theme of success with the use of an inquiry-based instructional approach where the student is an "active" learner. For instance, Handelsman et al. (2004), it was found that students taught by active learning "demonstrate better problem-solving abilities, conceptual understandings, and success in subsequent science courses that those who learned in more traditional, passive ways" (p. 521). These conclusions drawn by Handelsman et al. (2004) are supported by several research studies which investigated the benefits of teaching science through the use of an inquiry-based model (Akkus, R., Gunel, M., & Hand, B., 2007; Hand, B. & Keys, C., 1999;

Hand, B., Prain, V., Lawrence, C., & Yore, L. D., 1999; Omar, S. & Gunel, M., 2004; Rudd II, J. A., Greenbowe, T. J., Hand, B. M. & Legg, M. J., 2001).

Defining Inquiry

Before a conversation about *how* to teach "science as inquiry" can begin, there needs to be a clarification of the different types of inquiry and how each type does or does not fit the learning model proposed by the NRC. According to The Access Center (a cooperative agreement funded by the U.S. Department of Education and the Office of Special Education Programs, awarded to the American Institutes for Research), teaching "science as inquiry" can be classified into one of three categories: *structured, guided or open* (The Access Center, 2009). The most teacher-centered of the three types of inquiry is *structured inquiry*. This type of inquiry is commonly seen in science classrooms as a textbook reproduced laboratory exercise. Using the worksheets provided by the teacher, the students carry out the investigation based upon following the directions given. Usually, the students reach a common result or conclusion based on the specific data required and their answers to structured post-activity questions. Often, when this method of inquiry is utilized students spend most of their learning time making sure their answers are "right", rather than negotiating how the activity clarified their understanding of the scientific concept being investigated. Structured inquiry is the most traditional approach to inquiry where the focus of learning is on the laboratory skills performed, not the "unpacking" of a scientific concept or the negotiation of student understanding (The Access Center, 2009). This type of inquiry does not fit the model suggested by the NRC, nor does it develop the skills, attitudes, and meta-cognition necessary to improve students' scientific literacy because the instructional focus is placed on the teaching rather than the learning.

On the opposite side of the inquiry spectrum is *open inquiry*. This type of inquiry requires the least amount of teacher intervention and is completely student led. Students often work in groups (small at 3-4, or large at 8-10) and plan all phases of the investigations. This is the "purest" form of inquiry conducted in science classrooms where the students posit a question, research its implications, formulate a hypothesis, develop an investigative plan, carry out the experimentation and collect relevant data, and generate conclusions based on their experiential evidence (The Access Center, 2009). Within all phases of this type of inquiry, the students lead the process and thereby, are provided unique opportunities to increase their scientific vocabulary, hone their scientific reasoning skills, and explore their own meta-cognition regarding the scientific concepts being investigated. During this type of inquiry, the responsibility for learning shifts completely from teacher to student. Based on the NRC's 1999 report, this shift in learning responsibility is key for students to activate their prior knowledge, to gain true conceptual understanding, and to develop the meta-cognitive awareness that will guide them toward adult scientific literacy.

Somewhere in the middle of this instructional spectrum, lies *guided inquiry.* This approach is commonly used when students are asked to make models or develop a procedure that results in a desired outcome. For example, a science teacher gives her seventh grade students materials to create a rocket, but no instructions for designing it. The students must activate their prior knowledge to design the rocket so that it will launch properly, fly a certain distance, and land without becoming disassembled. In guided inquiry, the teacher provides the problem and materials while the students develop their model using their own scientific processing skills (The Access Center, 2009). As long as the teacher maintains the three learning principles suggested by the NRC, this type of inquiry can help students to develop the higher ordered thinking and critical processing skills necessary to move toward adult science literacy (1999). In relation to the advanced sciences, guided inquiry allows for the classroom to remain student-centered, assessment-centered, and community based while still maintaining student, facility and environmental safety. For instance, when working in chemistry, the use of a guided inquiry approach utilizes the experience of the teacher to ensure that certain chemicals will not be mixed, and that certain chemicals will be disposed of properly. Due to the inherent safety precautions necessary to successfully experience chemistry, the teacher needs to be in control of certain aspects of the learning environment. However, the teacher's "control" of the classroom should end with safety so as to encourage the development of critical reasoning skills necessary for the promotion scientific literacy on behalf of their students. This becomes this biggest challenge for the chemistry teacher, knowing when and where the students can safely attend to their own learning and understanding.

Inquiry in the Science Classroom

With the expectation that transitioning science education from the more traditional, direct teaching model to a more student-centered, collaborative model would be difficult, the NRC released *How Student Learn: Science in the Classroom* in 2005. In this text, the NRC provides several examples of how to implement "science as inquiry" within various science classroom settings. In Chapter 11, "Guided Inquiry in the Science Classroom", Minstrell and Kraus provide a four-part description of how they implemented guided inquiry within their physical science classroom. Ensuring that they maintained the three principles suggested by the NRC, the authors detailed how they activated prior knowledge in "Part A: What Gravity is Not" (p. 477-492), and how they developed conceptual understanding and meta-cognitive awareness through "Part B: What is Gravitational Attraction?" (p. 492-510). In addition, the authors also provided an opportunity for transference of their students' new understandings to novel situations presented in "Parts C and D: What Are the Effects of Gravity? " (p. 510-511).

In Chapter 12, "Developing Understanding Through Model-Based Inquiry", Stewart, Lartier, and Passmore (1999) illustrate how "science as inquiry" can be implemented in the biology classroom, specifically using the MUSE (Modeling for Understanding in Science Education) curricular units of genetics and evolution. Through their detailed explanations, it is clear that they adhered to the NRC's three learning principles and maintained a focus on a student-centered, knowledge centered, assessment-centered, and community-centered classroom environment (1999). At the close of this text in Chapter 13, "Pulling Threads", Donovan and Bransford articulate the challenges of maintaining the three learning principles of effective instruction and provide some suggestions on how to overcome them so that students can reach deep conceptual understanding and clarify their meta-cognition regarding their new understandings. By the end of this text, it is clear that "science as inquiry" is do-able, and that this instructional pedagogy is our best defense against producing scientifically illiterate high school graduates.

Best Practices of "Science as Inquiry"

Since the 2000 release of the NRC's *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning,* many models of this newly prescribed "best science teaching practice" have been offered, tested, and revised. With a brief look at the library of the National Science Teachers Association (NSTA) press, science teachers can find many resources to help them to define, research, and implement "science as inquiry" in their classrooms. Within NSTA's collection, there are two books that warrant significant attention from chemistry teachers looking for a solid "how to" text for implementing inquiry within their classroom: *Teaching Inquiry-Based Chemistry: Creating Student Led Scientific Communities* (2004) and *Whole Class Inquiry: Creating Student Centered Science Communities* (2009), both written by Smithenry and Gallagher-Bolos.

Both books provide a detailed portrayal of how the authors turned their classroom into a completely student-led scientific community that worked collaboratively on various chemistry projects. Their *Whole Class Inquiry* book (2009) provides a two DVD set of classroom videos of their inquiry lessons in action, and offers a final chapter that speaks of the impact and utility of their Whole Class Inquiry curriculum based on their own action research. Within *Teaching Inquiry-Based Chemistry* (2004), an introductory text that presents an overview of their whole class inquiry approach, Smithenry and Galagher-Bolos briefly discuss their general observations of the benefits of their whole class inquiry approach on their students and themselves. With their students, the authors found that they became pupils that took ownership of their learning, who became responsible for the final outcomes, who used their time constructively, who practiced their talents and improved their weaknesses, who became well-rounded consumers of science, and who had fun *doing* science (p. xi-xii). As far as themselves as educators, Smithenry and Gallagher-Bolos found that they became teachers who behaved as guides rather than disseminators, who felt comfortable as collaborators rather than experts, and who also had fun (p. xii). Based on the results of their class action research in *Whole Class Inquiry* (2009), the authors contend that their students also gained in the areas of foundational chemistry knowledge, chemistry conceptual and relational understandings, and improvement of scientific processing skills, all aspects of positive movement toward their students' scientific literacy as adults (p. 189-190). These contentions were based on a two-year study conducted in a mid-western United States high school chemistry classroom where the authors studied the impact of their whole class inquiry approach on students' acquisition of knowledge and skills. Both books are excellent resources for seeing a practical, real-world application of the "science as inquiry" pedagogy.

Besides the NSTA press, there are other resources that offer "best practices" of inquiry-based science instruction. Within the educational research on inquiry-based chemistry, two practices are most prevalent, the Science Writing Heuristic (SWH) and the Process-Oriented Guided Inquiry Learning (POGIL) [Hand et al., 2009; Hanson, 2006). Their prevalence can be attributed to their research initiatives being funded by the National Science Foundation (NSF), an independent U.S. government agency responsible for promoting science and engineering through research programs and education projects. Both pedagogies are quite similar in their approach in that they both are student-centered where the teacher is a facilitator of knowledge, they both utilize negotiation and argumentation to clarify student understanding, they both foster collaboration as a means to answer a posited question, and they both have culminate with a writing task (Hand et al., 2009; Hanson, 2006). With regards to their differences, POGIL emphasizes the learning cycle, uses the traditional formal lab report format, and the inquiry is based on pre-determined concepts chosen by the instructor (Hanson, 2006), while the SWH emphasizes reflective writing, utilizes a format-specific template, and the inquiry is based upon essential questions asked by the students (Hand et al., 2009). Based on the adaptability of the SWH toward an open inquiry format, a hypothesis can be made that it may be a more promising pedagogy for improving the scientific literacy of high school chemistry students.

The Science Writing Heuristic

To reach the science educational goals set forth by the *National Science Educational Standards* (NRC, 1996), Hand and Keys offered a teaching tool known as the Science Writing Heuristic (SWH) (1999). Specifically, the SWH is a teaching approach that provides learners with a heuristic template, or plan, to guide their science laboratory activities using argumentation, negotiation and writing. This heuristic template, or plan, is designed around the following questions:

1. ***Beginning Ideas****….what questions do I have?*
2. ***Tests****….what did I do to answer my questions?*
3. ***Observations****….what did I find when I tested?*
4. ***Claims****….what inferences can I make? (Explain what you think happened)*
5. ***Evidence****….How do I know? (Justify your claims by providing evidence for claims)*
6. ***Reading****….how do my ideas compare with others? What do the experts say?*
7. ***Reflection****…how have my ideas changed?*

Each question prompts the learner to utilize scientific thinking and reasoning through critically analyzing their prior knowledge, negotiating their own meaning of scientific concepts, developing links between claims and evidence, and constructing explanations that are based on relationships or generalizations observed (Hand et al., 2009). In addition, the SWH provides the teacher with a template of suggested strategies to best facilitate student learning during laboratory exercises. In the same manner as the student template, the teacher template of the SWH allows the focus to remain on the student's development of scientific reasoning, and clarification of their own meta-cognition regarding scientific principles. Figure 2 displays the interrelationship between the two templates of the SWH.

Figure 2. The two templates of the Science Writing Heuristic (Hand and Keys, 1999).

The Science Writing Heuristic, Part I *A plan for teacher-designed activities to promote laboratory understanding.*	**The Science Writing Heuristic, Part II** *A plan for students.*
1. Exploration of pre-instruction understanding through individual or group concept mapping or working through a computer simulation.	1. Beginning ideas - What are my questions?
2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions.	2. Tests - What did I do?
3. Participation in laboratory activity.	3. Observations - What did I see?
4. Negotiation phase I - writing personal meanings for laboratory activity. (For example, writing journals.)	4. Claims - What can I claim?
5. Negotiation phase II - sharing and comparing data interpretations in small groups. (For example, making a graph based on data contributed by all students in the class.)	5. Evidence - How do I know? Why am I making these claims?
6. Negotiation phase III - comparing science ideas to textbooks for other printed resources. (For example, writing group notes in response to focus questions.)	6. Reading - How do my ideas compare with other ideas?
7. Negotiation phase IV - individual reflection and writing. (For example, creating a presentation such as a poster or report for a larger audience.)	7. Reflection - How have my ideas changed?
8. Exploration of post-instruction understanding through concept mapping, group discussion, or writing a clear explanation.	8. Writing = What is the best presentation that explains what I have learned?

The SWH is more than just another teaching pedagogy to be utilized in order to engage students to “do” science. This strategy acts as a framework to guide student activities, as well as to provide learning opportunities to improve their science literacy and support the development of their meta-cognition regarding their comprehension of scientific concepts (Hand et al., 2009). Within this construct, students are driven to not only perform the laboratory activity, but also to think, discuss, and negotiate their own meaning to truly reach conceptual understanding as they work through the stages of the SWH template. What becomes the challenge for the novice SWH teacher is that in order to engage students in this type of learning modality, the pedagogical focus needs to remain on the student *learning* that occurs, rather than the details of the lesson delivery. In other words, Hand et al. (2009) contend that what is taught becomes a *consequence* of learning, rather than the learning being a consequence of the teaching. According to Hand et al.'s (2009) experience with the SWH, this paradoxical switch in focus is what facilitates a dramatic improvement in students' science conceptual understanding, science reasoning, and scientific literacy.

The challenge of the SWH lies in its implementation. In order to reap the full benefits, there needs to be a paradigm shift in the pedagogical approach of the teacher's science instruction. As stated earlier, the strategy of the SWH is to focus on the learning that is occurring rather than on the teaching that will be done. For the teacher to be successful, this approach requires five essential skills: 1) determining the big idea for the topic; 2) planning the learning activities; 3) finding out what students know; 4) questioning; and 5) group work (Hand et al., 2009). To begin, the teacher needs to determine the end result: what "big idea" should the students understand based on this educational experience? Once the core concept is identified, then the teacher needs to create learning experiences that are connected and authentic to it. As the students are experiencing this new educational opportunity, the teacher needs to be acutely aware of where the students' prior knowledge fits into the new learning encounter. This background is necessary for the teacher to facilitate the new learning with guiding questions that allow the students to construct their own meaning from the lessons and activities. After the students have experienced the new learning opportunity, then meta-cognition can be supported through small and large group dialogue, negotiation and argumentation, and reflection. Upon a closer look at these essential five skills recommended by Hand et al. (2009), it is evident that the SWH incorporates the three learning principles presented by the NRC's *How People Learn: Brain, Mind, Experience and School* (1999): activation of student's prior knowledge, core concept organization, and meta-cognitive support. This evidence can clearly be seen in Figure 2 which provides specific actions of both teacher and student during the implementation of the SWH.

One of the most beneficial aspects of the SWH approach is its integration of literacy. Several literacy strategies can be found embedded throughout both its student template and its teacher template. These literacy components allow students to negotiate their own meaning from the lessons and activities presented during the utilization of the SWH. This integration of literacy is seen as a vital aspect of learning, which in turn has been found to be a key component to true conceptual understanding (Hand, Prain, Lawrence & Yore, 1999). Without conceptual understanding, student learning is reduced to the acquisition of school-based factoids for success on the next standardized test, rather than for the promotion of life-long learning and competency within our technologically advanced society (Hand et al., 1999). In addition, conceptual understanding is necessary for knowledge transfer in order for students to solve problems within different contexts, as well as to apply their new knowledge within various socially constructed situations experienced outside of the classroom. In order to develop this cross-categorical literacy, students need to be exposed to educational opportunities that practice its use through reading, writing, debate, and reflection. Through repeated successful applications, students will then recognize the importance of this literacy within their everyday lives. As an added benefit, students have the potential to become informed, involved citizens of society as they experience the advantages to such literacy, as deemed crucially important by the AAAS (Hand et al., 1999).

Impact of the SWH on Student Learning

Within the current educational research, there is strong evidence that the SWH approach increases student conceptual awareness and understanding, improves their critical thinking skills, and develops their scientific literacy. One of the first major studies to investigate the effects of the SWH on student learning was conducted by Keys, Hand, Prain and Collins (1999). This study was the first of its kind to describe how the SWH templates were utilized in the classroom, including its integration within the lesson unit through the use of concepts maps, informal journal entries with teacher provided prompts, team discussions based on guided focus questions, and the writing of formal reports. The purpose of this interpretative study was to explore how students were engaged in scientific thinking during the use of the SWH templates, particularly looking at the evidence of student engagement in meaning generation, conceptual change, and reasoning.

According to Keys et al. (1999), their results were indicative of improvement of student learning based on evidence expressed within their target teams' formal report writing. Based on their coding analysis, the authors maintained that three themes emerged from these students' reports: (1) their use of meta-cognition and reflection to understand knowledge growth, (2) their generation of meaning for data in relation to specific knowledge claims, and (3) their use of extension, elaboration, and enhancement of science ideas. Also, the authors found evidence that the use of the SWH improved their target teams' understanding of the nature of science within three main constructs: (a) collaboration and argumentation, (b) nature of evidence, and (c) nature of scientists' work. Interpretation of this evidence came from a pre-study questionnaire and a post-study interview.

In 2004, Hand, Wallace and Yang conducted a study to determine the quantitative impact of the SWH on student learning and to collect qualitative data regarding students‘ conceptual understanding. Within this mixed-method study, Hand et al. (2004) utilized a quasi-experimental design to evaluate the performance of 93 seventh grade students on tests of conceptual understanding of the cell. In addition, the authors utilized an interpretive qualitative approach to characterize students‘ understanding of questions, claims, and evidence in science and to investigate their views on learning with the SWH (p. 135). For this study, quantitative data on each participant's performance was collected using an instructor created pre- and post-test composed of 34 multiple-choice questions (pre = PRMQ; post = POMQ), and three conceptual essay questions (pre = PRCQ; post = POCQ). To establish basic language skills, the authors used results from the Stanford Diagnostic Reading Test (SDRT) that their participants took at the beginning of the school year. Qualitative data was collected using audio-taped student interviews conducted with three members from each of the SG and the STG groups. These interviews were semi-structured with questions that surveyed students' views as to which SWH activities they found most useful in constructing biology knowledge in the post-test, how they developed questions, claims, and evidence, and how they viewed writing in the context of the SWH classroom (p. 140).

Hand et al. (2004) performed pair-wise statistical analysis on the participants' results on the SDRT, the PRCQ, and the PRMQ to assess possible pre-existing differences among the experimental groups, which led to the use of these three scores as co-variates to reduce error variance (p. 141). In addition, the POMQ and the POCQ were analyzed using three separate ANCOVA treatments. The pair-wise test results indicated that the STG outperformed the SG and the CG on the conceptual essay questions, and the STG and the SG outperformed the CG on the multiple choice questions (p. 142). Within the qualitative data, Hand et al. (2004) made three assertions regarding the students' views on the use of the SWH in the classroom: (1) students attributed their increased understanding of cells to the specific features of the SWH template (p. 142); (2) students demonstrated a sophisticated understanding of the nature of a knowledge claim in science (p. 144); and (3) students valued the textbook writing task as a means to further their scientific understandings (p. 146).

At the conclusion of their study, Hand et al. (2004) found two implications that arose from their study: the concept of "science as inquiry" and the communicative aspects of "science as inquiry". As for the first implication, the authors found that using the SWH within an inquiry based instructional model promoted "greater ownership and responsibility for the decisions made on the outcome of the laboratory activity", and "a greater sense of participation in the laboratory activity" which "led to a greater sense of understanding of the conceptual outcome of the activity" (p. 147). Additionally, the authors found that the second implication came from the strong emphasis placed by the SWH on "students having to communicate their understandings to each other, both in constructing claims and assessing their claims against current scientific understandings" (p. 147). The authors attributed this implication from the incorporation of a peer driven textbook writing task. Due to this shift in audience from their teacher to their peers, the students had "to examine their understandings, identify gaps in their knowledge and to translate the technical language into more everyday language" (p. 148). Hand et al. (2004) posited that this shift in writing audience was critical to their target group's deeper conceptual understanding, as demonstrated by the higher scores of the target group on conceptual essay questions.

With such positive results for the SWH on student learning, educational research also examined its effect on student learning within specific science disciplines, such as undergraduate general chemistry. In this genre, a quasi-experimental study performed by Rudd, Greenbowe, Hand and Legg (2001) produced similar results as Keys et al. (1999) and Hand et al. (2004). Within this study, the authors focused on comparing the SWH approach to the traditional lab report format to see if there was an improvement in student conceptual understanding of physical equilibrium. This quasi-experimental study was performed in a large mid-western state university, with 80 participants across four sections of a general chemistry II laboratory. Assessment of the research questions was done through the use of two tests: a written portion that presented a physical equilibrium problem within the lecture setting, and a practical portion that presented a physical equilibrium task within the laboratory setting. Results showed that the SWH students outperformed the traditional students in both the written exam and the practical exam. Also, the researchers administered a survey to the treatment group to compare their SWH experience in general chemistry II to their traditional experience in general chemistry I. The results were impressive with “positive attitudinal changes and increased understandings about chemistry” (p. 1681). Specifically, Rudd et al. (2001) found that the students using the SWH were more engaged in the laboratory through active discussion and knowledge negotiation, demonstrated higher order thinking both in class and in written reports, and displayed improved performance on practical and lecture exams.

Within the most recent collection of SWH research, there are a few studies directed towards investigating the efficacy of implementation of the SWH and its impact on student learning. Poock, Burke, Greenbowe and Hand (2007) and Akkus, Gunel and Hand (2007) both investigated the differences in instructor implementation of the SWH and its effects on student learning. Poock et al. (2007) examined teacher implementation of the SWH within a college chemistry classroom, while Akkus et al. (2007) focused on teacher implementation of the SWH within secondary educational settings (grades 7-11) over three science disciplines: chemistry, physics, and biology.

Akkus et al's study qualitatively measured the level of teacher implementation of the SWH through the use of an interpretative case study design. The authors used observational data from two earlier studies conducted by Omar (2004) and Omar & Gunel (2004). To determine the level of SWH implementation by the teacher participants, there were three criteria constructed by Omar and Gunel: dialogical interaction, focus of learning, and unit preparation and making connections. These three criteria were used to evaluate the teacher's implementation of the SWH during the course of the study. Prior to participation in the 2007 study, Akkus et al established a baseline of instructional discourse for those teacher involved using this observational data from Omar (2004) and Omar and Gunel (2004). Based on these three criteria, the teachers were ranked according to their level of implementation as either High, Medium, or Low. An instructor participant that received a rating of "high" would have had a classroom where: (1) teacher-student dialogue was more open-ended and inquiry minded, (2) the focus of learning was placed on the student and their negotiation of meaning through small/large group discussion, and (3) unit preparation was based on "big ideas" and activation of students' prior knowledge. This high/medium/low ranking was also used for the comparison group (traditional instruction). Student academic performance was determined based on analysis of student scores on their respective teacher created pre- and post-tests of the science concepts covered during the course of the 2007 study.

Poock et al's 2007 study also used observational data of the instructor participants, but specifically collected this data during the course of their study. However, their observation criteria focused primarily on the amount of scientific dialogue that occurred in the classroom while the study was being conducted. For the duration of this study, the observers took note of the scientific dialogue exchanged among the students and between student(s) and the instructor. The authors also used High and Low as levels of SWH implementation, with an instructor getting a "high" categorization if the discussions were directed towards chemical principles rather than procedural clarifications, and if the scientific dialogue involved a group of four or more students. Student academic performance was determined through analysis of student total points earned at the end of the college semester.

For both of these studies published in 2007, their results were remarkably positive for those instructor participants with a high SWH implementation rating. Within the Akkus et al. study, the results indicated that the students in the high implementation SWH groups scored significantly higher than students in the high traditional groups on their post-test unit evaluation. In addition, Poock et al. found that the students in the high implementation SWH groups earned more total points at the end of the semester than did the students in the low implementation SWH groups.

When considering the evidence presented by these studies, it is clear that the use of the SWH approach can improve student conceptual understanding, critical thinking strategies, and scientific literacy. Although there were positive gains in the undergraduate chemistry classroom, it would be interesting to see if a secondary chemistry educational setting would demonstrate the same positive gains. Due to the lack of evidence within this scientific discipline and context, a study was performed to investigate the impact of the Science Writing Heuristic on student learning within a high school chemistry classroom. Based on the above research, two research questions were posited for further exploration:

1. How do high school chemistry students who use the Science Writing Heuristic during laboratory activities compare on conceptual and recall questions about the gas laws with students who use a more traditional laboratory worksheet format?
2. How do high school chemistry students who use the Science Writing Heuristic during laboratory activities compare on the Science Reasoning Test of the ACT with students who use a more traditional laboratory worksheet format?

Chapter Three

Methods

Participants

For this action research study, the participants attended a private Mid-western high school within a large city (population > 150,000). On average, this high school has an annual enrollment of approximately 1200 students, composed primarily of European-American students from predominantly middle-class backgrounds. Based on the returned consent forms, this study included 72 students (total enrollment = 105), where 57 were in grade 11 (juniors) and 15 were in grade 12 (seniors). In addition, 50 of the consenting participants were female, whereas 22 were male. At the time of data analysis, only those participants with complete pre-post data sets (n=67) were included. Of those participants excluded, two students were from the Control group and three were from the SWH group. All five participants were excluded from the analysis because their pre-post data sets were not complete due to their absence on assessment days.

The study participants were students who were enrolled in an "academic" track chemistry class, which was the middle track of a three tracked curriculum for this high school. This three tracked program included a "general" level which typically contained the students who were identified as "at-risk", an "academic" level which typically contained the students of average academic achievement, and an "honors" level which typically contained students identified as "gifted". Each incoming freshman was required to take an independently administered placement test, where reading and math scores were used to determine student placement within this three track system. Parental override of the administrative recommended placement was an available option upon matriculation. Also, parents were permitted to override any administrative placement recommendation throughout all four years of student attendance.

To determine future student placement within each curricular discipline, faculty recommendations were made based upon each student's academic achievement within that discipline (i.e. sophomores are recommended for chemistry based upon their achievement in biology and geometry). To be enrolled in "academic" chemistry within this system, students were required to have taken biology and geometry. Due to the math co-requisite, this "academic" chemistry classroom had a mixed enrollment of juniors and seniors.

Study Design

To address the two research questions posited, a quasi-experimental study was performed using a pre-post test design with two groups: a Control group and a SWH Treatment group. Based on the tracked curriculum of the high school, the study participants were divided among four sections of "academic" chemistry (A, B, C and D). Study group assignment was based on individual student performances of the pre-Science Reasoning Test (pre-SRT) of the 2010 practice ACT (Appendix A). This pre-test score was used to determine if there were any pre-existing differences between the four sections of "academic" chemistry based on the participants' scientific reasoning ability. The means of the students' total pre-SRT scores were used to establish a base-line reasoning ability level for each section of "academic" chemistry. Using the means of their total pre-SRT scores, the study participants were divided as follows: 2 sections chosen as the control group (n = 31), and 2 sections chosen for the treatment group (n = 36). The two "academic" chemistry sections (A and D) chosen for the control group displayed the higher mean values on the pre-SRT, and the remaining two sections of "academic" chemistry (B and C) were then placed in the SWH treatment group. Further details of the sample size can be seen in

Table 1.

Sample Sizes of Participants' Characteristics in Both Groups

Category	Subcategory	Control Group	SWH Group
Grade	Grade 11 (Jrs)	26	28
	Grade 12 (Srs)	5	8
Gender	Male	9	13
	Female	22	23
Total		**31**	**36**

Procedure

To begin the study, both groups watched a World of Chemistry Video: *Episode 17 The Precious Envelope* that introduced the importance of gases in our natural world. After watching the video, both groups were given a teacher-constructed pre-test covering the knowledge and application of the gas laws of Boyle, Charles, and Gay-Lussac (Appendix B). Following the gas law pre-test, both the treatment and the control groups received a lecture series on the gas laws based on their textbook, Holt-Rinehart-Winston's *Modern Chemistry* (2002) which was presented in 6 segments of 20 minute MS PowerPoint presentations. For both groups, conceptual reinforcement was accomplished through the use of small group collaborative worksheets completed during instructional time. Upon completion of the lecture series, both groups took a "practice quiz" on the gas laws and time was allowed for review of their performances.

For this study, the two groups diverged when they began their laboratory experience: the Control group used a structured inquiry laboratory exercise, while the SWH Treatment group used a teacher created guided inquiry laboratory exercise. Upon completion of the laboratory activities, both groups were provided with a review day and then were administered a teacher generated Post-test of the gas laws. To conclude the study, the participants in both groups were given a Post-SRT test (ACT 2010) to be used to assess any improvement in reasoning abilities as inquired by the first research question.

The Gas Laws Unit

To begin a study of the nature and behavior of gases, instructional time was spent on defining the Kinetic Molecular Theory. This theory is a nice starting point that connects the gas law unit to previous chemistry concepts like states of matter and atomic theory. According to several high school chemistry texts, the concept of pressure, its relationship to force and area, and how it is measured in different units is a necessary foundational construct for students to begin to understand the gas laws. During this study, the concept of pressure was given an entire lecture period with reinforcement in the area of unit conversions for pressure. Because the gas laws involve the Kelvin temperature scale, instructional time was also dedicated to unit conversions between Celsius, Fahrenheit, and Kelvin temperature measurements. Additionally, the concept of Standard Temperature and Pressure (STP) was also defined to ensure that students understood this scientific vernacular used when speaking about gases.

After defining pressure, temperature and volume, instructional time was then spent of each of the gas laws, including the combined gas law. For each gas law, half of an instructional period (approximately 20 minutes) was dedicated to introducing, clarifying, and applying it through a MS PowerPoint presentation. After each lecture, the students were broken into their "study groups" where they would collaboratively complete a reinforcement worksheet of problems utilizing the gas law that was taught in lecture. Review of the worksheets was done the next instructional day. For the gas law unit, there were a total of 6 MS PowerPoint lectures presented in as many instructional days. The culminating activity was a “practice quiz” that was administered at the end of the lecture/worksheet series.

To help the students move from knowledge to application to synthesis, the next three instructional days were dedicated towards a laboratory exercise that was meant to encourage the students to apply what they learned about the gas laws. In other words, the students were provided an educational opportunity to go beyond just understanding the gas laws as mathematical equations and to personally experience the relationships between pressure, temperature and volume of a gas. Upon completion of the lab exercises, instructional time was allotted for review of all the presented material the day before the test. Based on prior classroom experience, students in the “academic” level of chemistry perform better on unit assessments when provided with dedicated instructional time toward concept review the day before the actual assessment. A summary of the activities involved in the gas law unit can be seen in Table 2.

Table 2.

Timeline of Study Activities

Day	**Activity**
Day 1 (Monday)	Administration of pre-test Science Reasoning Test (SRT) 2010
Day 2	World of Chemistry Video: Episode 17 The Precious Envelope
Day 3	Administration of Pre-test of Gas Laws Lecture 1: Kinetic Molecular Theory (KMT)
Days 4 – 8	Lectures 2 - 6: Pressure, Boyle's Gas Law, Charles' Law, Gay-Lussac's Law, and Combined Gas Law
Day 9	Review Day: Practice Quiz
Day 10 - 12	*Laboratory Activities:* o SWH Group: CanCo Inquiry Activity ○ Control Group: Charles' Law textbook activity
Day 13	Review Day
Day 14	Post-test of Gas Laws
Day 15 (Monday)	Post-test of Science Reasoning Test (SRT) 2010

Using the WI Department of Public Instruction's website, the following state standards were applied for both the control group and the SWH treatment group for the duration of this study:

- *Science Connections Performance Standards Grade 12*
    - A.12.6 Identify and, using evidence learned or discovered, replace inaccurate personal models and explanations of science-related events.
    - A.12.7 Re-examine the evidence and reasoning that led to conclusions drawn from investigations, using the science themes.
    - D.12.11 Using the science themes*, explain* common occurrences in the physical world.

In addition to the above listed WI DPI standards, the SWH treatment group applied these standards to their experience:

- *Science Inquiry Performance Standards Grade 12*
    - C.12.6 Present the results of investigations* to groups concerned with the issues, explaining* the meaning and implications of the results, and answering questions in terms the audience can understand.
- *Science Application Performance Standards Grade 12*
    - G.12.2 Design, build, evaluate, and revise models and explanations related to the earth and space, life and environmental, and physical sciences.

Study Groups

For the laboratory portion of this gas law unit, the control group performed a traditional directed inquiry laboratory activity about Charles' law that was generated from the teacher resources associated with the students' chemistry text, Holt-Rinehart-Winston's *Modern Chemistry* (2002). This activity included 5 pre-lab questions, a step-by-step activity that demonstrated the application of Charles' Law, creation of a data table, generation of a graph of activity results, and 2 post-lab questions about "Real-World" applications of Charles' Law (Appendix C). For the duration of the laboratory activity, the control group students were directed to answer the pre-lab questions in their lab notebook, follow the experimental procedure provided, collect data in their lab notebook, and generate a graph as per the post-lab questions on their handout. For the duration of the study, the control group followed the schedule specified in Table 2, with the only difference being that they utilized a "cookbook" approach for their lab on Days 10-12. The control group completed the activity in assigned pairs, without any large group discussion of data interpretation or analysis.

The treatment group, however, experienced a guided inquiry laboratory that utilized the Science Writing Heuristic (SWH) in lieu of a copied worksheet and created posters to present their work group's solution to the proposed problem. Based on the premise of teaching science as inquiry, the gas law laboratory for the treatment groups was set up as a process-oriented activity where each section was randomly divided into three work groups. Each student work group was assigned to a "corporation" that had a problem that needed to be solved:

- The *GoGreen Recycling Center*, where workers are threatening to go "On Strike" because they want a new method of rinsing and crushing empty aluminum cans (focus on the application of Boyle's gas law);
- The *Simply Elegant Food Processing Plant*, where their production of their new prepared salads is very low because there is serious lag from the egg peeler to the egg slicer (focus on the application of Gay-Lussac's gas law); and
- The *Happy Times Party Supply Factory*, where their new product, the "Memory Maker Balloon", has been leaving their warehouse under-filled (focus on the application of Charles' gas law).

Each group received an information sheet that described the problem in detail, listed the required jobs to complete the project, and a timeline for project completion (Appendix D). Within each work group, jobs were assigned according to student vote and/or student volunteerism.

Instead of a traditional worksheet format, the student work groups in the treatment sections utilized the following SWH template as they worked on their projects (Figure 3):

*Figure 3***.** The SWH template used by the treatment group (Hand & Keys, 1999).

1. ***Beginning Ideas***….What questions do I have?	*Students were guided to write testable questions and to make predictions accordingly.*
2. ***Tests….***what did I do? (How did you test to answer your questions?)	*Students were asked to provide a step-by-step method of how they would perform their tests.*
3. ***Observations….***what did I find? (What did you find when you tested?)	*Students were directed to record any and all observable, measureable data; even if nothing happened!*
4. ***Claims….***what inferences can I make? (Explain what you think happened.)	*Students were asked to interpret their observations and provide explanations as to why they happened.*
5. ***Evidence….***how do I know? (Justify your claims by providing evidence…"Show me the data!")	*Students were guided to justify their claims with specific data collected and recorded.*
6. ***Reading….***how do my ideas compare with others?	*Students were asked to compare their ideas with at least two other sources; citations were to be provided.*
7. ***Reflection***….how have my ideas changed?	*Students were prompted to reflect on their original ideas and to provide an explanation if they had changed.*

For both the treatment and the control groups of this classroom study, the laboratory experience lasted three full instructional days (45 minutes/day), where two days were dedicated to experimentation and one day was dedicated to laboratory write-up. All work was completed within the time constraints of the classroom, with only one exception: the treatment group was required to do the "Reading" section of the SWH on their own time. The treatment groups either assigned one person for the job, or they all helped in acquiring the necessary information.

Instrumentation

Due to the nature of the two research questions posited for this study, the use of two test instruments was required. To measure the effects of the treatment (SWH) on student conceptual understanding of the gas laws (research question #1), a teacher constructed test derived from the gas law unit presented in the study during Days 3-8 was utilized as the testing instrument. This instrument was administered in a pre-test/post-test format, where the pre-test Gas Laws was given on Day 2 of the study and the post-test Gas Laws was given on Day 14, at the conclusion of the unit and its subsequent laboratory activities. This teacher constructed test was designed as an 11 question multiple choice test, where 5 questions were targeted towards knowledge (lower Bloom) and 6 questions were targeted towards application (middle Bloom) [See Appendix B]. Thus, this instrument established the dependent variables as post-GasK based on the 5 knowledge questions, and post-GasA based on the 6 application questions.

Within this first testing instrument, the language and learning outcomes of the 11 questions remained identical from pre-test to post-test. However, in an attempt to protect the internal validity of this instrument, the order of the questions was altered during the post-test Gas Laws due to the small number of test items involved and the proximity of administration dates between pre-test Gas Laws and post-test Gas Laws (see Table 2). Additionally, this instrument was administered in a timed-format of 20 minutes allotted. The students were allowed to use a calculator and a “ChemHelper” (see Appendix E) as aids toward successful completion of both the pre-test Gas Laws and the post-test Gas Laws. This accommodation was made due to the nature of assessment in this classroom throughout the 2010-2011 academic year, where the participants were allowed the use of both aids on each and every test taken.

For the second research question posited, the Science Reasoning Test (SRT) of the 2010 practice ACT was utilized as the testing instrument. When administered as a pre-test, the SRT was used as an indicator of participants' reasoning ability. After being administered on Day 1, means of pre-SRT's total scores were used to establish baseline measurements of reasoning ability on behalf of the study participants. This baseline measurement was used to create the two groups for the study: the Control group and the SWH Treatment group. To accurately measure the possible growth in reasoning ability, the SRT was administered again as a post-test on Day 15, at the conclusion of the study. Both the pre-SRT and the post-SRT were administered as complete tests (see Appendix A) of 40 multiple choice questions with the same time limit of 35 minutes. These 40 questions were broken down into 7 different passages:

- **3 Data Representation passages with 5 questions each:** Tested the students' knowledge of graphs, scatterplots, and interpretation of information in tables, diagrams, and figures.
- **3 Research Summaries passages with 6 questions each:** Tested the ability of the students to interpret results from given experiments.
- **1 Conflicting Viewpoints passage with 7 questions:** Presented the students with an observable phenomenon and asked them to understand differences and similarities in the hypotheses.

For both the pre-test and the post-test SRT, the same 40 questions were administered in the same order, and no additional testing aids were allowed (calculators, cheat sheets, ChemHelper, etc.) Consequently, the dependent variable for this instrument was the total score on the test, post-SRT.

Method of Analysis

All analyses to address the two research questions were performed using the Predictive Analytics Software (PASW Statistics 18), where the significance level was $p = 0.05$. A two-step analysis was executed with this study's data. First, a one-way ANOVA was performed to investigate the pre-existing differences in the pre-SRT total scores between the four different sections of "academic" chemistry. Although this analysis was reported after implementation of the study, the results supported the grouping of study participants that was determined based on the difference in means of total scores on the pre-SRT. A second ANOVA was conducted to determine if there were other pre-existing differences between both the Control group and the SWH group based on prior knowledge of the Gas laws: GasK and GasA.

In addressing both research questions, paired sample t-tests were conducted comparing students' performances on pre- and post-test measures for both the SRT and the Gas Laws test to explore whether there were any learning gains within the instructional content. Correlational analysis was performed on pre- and post-test items to identify relevant pre-test variables for inclusion in the post-test model. Based on the pre-measure analyses, a more conservative analysis of covariance was used for the Post-test measures (with pre-SRT and pre-GasK as covariates in the ANCOVA model). Specifically, this ANCOVA model was conducted using post-test scores as the dependent variable, the pre-test scores as the covariate, and the study groups as the independent variable. This statistical method was chosen because it is often difficult to attribute any differences on groups to any one single variable when performing educational research. Mertler and Vannatta (2002) suggest that statistical analysis of variance (ANOVA) tends to ignore the effect of other variables on the dependent variable. Based on the many factors involved in student learning, the use of an ANCOVA model as a statistical method of analysis was preferred.

Chapter Four

Results

Results are reported based on the sequence of data analysis. The first ANOVA analysis performed used the pre-SRT scores of the all study participants. These pre-SRT scores were used as a baseline comparison to see if there were any pre-existing differences of science reasoning ability among the four sections of "academic" chemistry students participating in the study (Table 3). Once pre-existing differences were identified, the participants were placed in the two study groups, control (traditional) or treatment (SWH).

Table 3.

Comparison of Classes on the Baseline Pre-Science Reasoning Test (Pre-SRT)

	Section A		Section B		Section C		Section D	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pre-SRT	24.25	5.27	20.60	4.82	23.67	3.75	23.40	5.11
N	16		15		21		15	

Results from comparisons in this ANOVA indicated no significant differences between class sections prior to the intervention [F (3, 66) = 1.858, p = .146]. However, post-hoc LSD comparisons indicated that there was a significant difference between section A and B (p = .034), thus suggesting that these two sections be placed in separate groups (Section A in Control and Section B in SWH). Fortunately, the means of the total scores on the pre-SRT also hinted at this anomaly and the segregation of Section A into the Control group and Section B into the SWH treatement group did occur prior to implementation of the study.

The second ANOVA analysis performed was to determine if there were any other pre-existing differences based on the conceptual understanding of the gas laws prior to the implementation of the SWH intervention (Table 4).

Table 4.

Descriptive Statistics of Pre-study measures for the Control group and the Science Writing Heuristic (SWH) treatment group

	Control		SWH	
	M	*SD*	*M*	*SD*
Pre-SRT	23.84	5.13	22.39	4.44
Pre-GasK	2.64	1.38	2.86	1.10
Pre-GasA	3.00	1.06	3.19	0.89
N	31		36	

Results from this second ANOVA showed no pre-existing differences between the Control group and the SWH treatment group on any of conceptual understanding pre-test measures collected prior to the intervention (Table 4).

Before analyses of post-test data were conducted to determine answers to both research questions, Paired Samples t-tests were performed to compare students' performances on pre- and post-test measures (Table 5). This analysis was executed to see if any content learning had indeed occurred within the participant population.

Table 5.

Overall (both groups) results for pre-post test measures

	Pre-test		Post-test				
	M	*SD*	*M*	*SD*	*t*	*df*	*p*
SRT	23.06	4.79	22.20	6.08	-1.33	66	.187
GasK	2.76	1.23	4.03	0.92	8.47	66	.000
GasA	3.10	0.97	5.22	0.87	15.11	66	.000
N	67		67				

According to this secondary analysis, students scored significantly better on the Gas Law post-test compared to the Gas Law pre-test for two measures, knowledge (GasK), and application (GasA). These results indicate that there were positive learning gains based on the gas law unit. No significant difference was found between the Pre-SRT and the Post-SRT scores.

Based on the ANCOVA models used to address both research questions, no differences were found between students in the Control Group and students in the SWH treatment group (Table 6) on any of the post-test measures.

Table 6.

Post-study measures for the Control group and the Science Writing Heuristic (SWH) group

	Control		SWH	
	adj. M	*SE*	*adj. M*	*SE*
Post-SRT	21.65	1.07	22.61	0.88
Post-GasK	3.86	0.18	3.99	0.15
Post-GasA	5.42	0.18	5.25	0.14
N	31		36	

To eliminate the effect of the significant pre-exsting difference found between Section A and Section B in the initial ANOVAs performed, adjusted means were utilized for this analysis.

To summarize, the results from this quasi-experimental study indicated that there were no significant differences found between the SWH treatment group and the control group with regards to both research questions posited. Based on the first question of gas law conceptual understanding, findings show that there were no significant differences between the SWH treatment group and the control group as seen in the participants' scores on the pre-post Gas Laws test. As far as the second research question of scientific reasoning ability, there were no significant differences found between the control group and the SWH treatment group as demonstrated by the participants' pre-post total SRT scores.

Chapter Five

Discussion

Summary

Results addressing the two research questions indicated that there was no significant difference in post-test performance (Table 6) between students who completed laboratories in a traditional format (Control group) and students who completed a guided inquiry laboratory activity using the Science Writing Heuristic (SWH group). This lack of significant difference may be attributed to the length of time that the study was implemented, only 15 days. This short time duration limited the SWH experiences to only one guided inquiry activity. Due to such a short study duration, the participants may not have had enough time to truly develop their critical thinking skills to the point of detection through the summative testing instruments utilized. In *Negotiating Science: The Critical role of Argument in Student Inquiry*, Hand et al. (2009) explain that the development of competency with the cognitive elements of the SWH takes time. In Chapter 7, “Reading and Reflection”, the authors suggest that improvement in higher ordered thinking becomes perceptible and measurable after at least three implementations of the Science Writing Heuristic within a science laboratory setting (p. 141-153).

Findings were promising in that the results showed that students did learn the focus concepts of the Gas Law unit (Table 5), performing significantly better on post test measures compared to pre-test measures on the Gas Laws test items. It was interesting that students did not significantly gain in terms of the reasoning ability measure, the SRT. This might be explained by the nature of this standardized assessment. In the National Science Teacher Association publication, *Science as Inquiry in the Secondary Setting* (2008), the authors suggest that assessment of student learning within an inquiry setting must be balanced between three format types in order to successfully measure conceptual understanding and improvement of scientific reasoning. These three format types are: (1) endpoint assessments, which evaluate what students know at a single point in time, (2) dynamic assessments, which determine how students respond to changing prompts, and (3) conceptual framework assessments, which provide insight into the way that students store, retrieve and store knowledge (p. 109-110). When inquiry assessments possess a balance between all three types of assessment, conceptual understanding and scientific reasoning can be adequately measured for improvement. Based on this evidence, it is hypothesized that the lack of significant difference between the two study groups could be attributed toward the nature of the SRT as an endpoint assessment.

Signifcant Observations of Student Behaviors

Although the statistical analyses performed did not indicate a significant difference in student conceptual understanding or scientific reasoning ability, it should be noted that there were a few considerable differences seen between the SWH treatment group and the control group with regards to student engagement, student effort, and student use of scientific language – both written and spoken. In comparing the traditional format (Appendix C) with the SWH format (Appendix D), it is evident that the inherent design of the the SWH allows the students to clarify, argue and negotiate their conceptual understandings of the laboratory exercise performed, and to practice the use of scientific reasoning to validate their evidence, claims, and conclusions. For the students in the treatment group, the SWH template was specifically designed with a culminating meta-cognitive activity based on its “Reflection” piece, where students are asked, “How have my ideas changed?” (Figure 3).

However, this meta-cognitive step was missing from the traditional laboratory worksheet format (Appendix D). Students in the control group (Sections A and D), who used the traditional worksheet format, did not have a similar opportunity to summarize their learning through a collaborative, culminating writing task. Throughout their directed inquiry activity, it was evident that participants were simply driven to complete the worksheet, sometimes through copying answers from a lab partner or through a textbook resource. Due to the nature of the traditional worksheet format, it was observed that the students were motivated to simply perform the lab, fill in the data tables, and complete the post-lab questions. In addition, the students in the control group were not inclined to collaborate or to ask probing questions to make sense of their data, to clarify their conceptual understanding, or to answer the post-lab questions. Typically, the control group students' inquiries were based on what specifically they needed to do to "complete the worksheet", such as "Do we need to do the graph?", "Are the Real-World questions due as well?", and "Should we write the answers on a separate sheet of paper?".

In addition, formative assessment of the control group was limited to merely the assessment of laboratory skills, rather than gas law conceptual understanding or scientific reasoning. Because the laboratory procedure was laid out for them step-by-step, the control group students were not apt to verbally clarify conceptual understanding, rather they were motivated to ensure that they were following the directions accurately. Also, it was observed that the students did not clarify the data as it was collected; there was no evidence of critical thinking about whether or not the data "made sense". Based on these observations, it is hypothesized that the worksheet activity was too far removed from the control groups' gas law conceptual understanding. Without the opportunity to apply their gas law knowledge in a way that fit where they were "cognitively", it was assumed that the control group students were disconnected from their learning. Without a connection between prior learning and new learning goals, the control group students had no hope of improving their scientific literacy skills. These hypotheses are supported by Hand et al. (2009) when the authors state:

> when procedures are uniform for all students, where data collected are similar, and where claims match expected outcomes, then the reportage of results and conclusions often seems meaningless to students and lacks opportunities for deeper student learning about the topic or for developing scientific reasoning skills (p. 13).

On the other hand, the four negotiation phases of the SWH template (Figure 2) allowed for several opportunities for formative assessment of the treatment group's gas law conceptual understanding and their use of scientific reasoning. Also, the open question design of the SWH worksheet (Figure 3) increased the number of formative assessment opportunities during the implementation of this study. Because the treatment group had to work collaboratively to solve the problem and to negotiate their own meaning about the gas laws, this learning environment allowed for immediate clarification of misconceptions and for increased use of both written and spoken science vocabulary.

Because the treatment group was only given a "framework" of the guided inquiry activity, the students were allowed freedom of choice in how to solve the given problem. With such intellectual freedom permitted, the students were more engaged in the activity and motivated to understand the gas law concepts in order to successfully complete the project (NRC, 2000). Prior to beginning the guided laboratory exercise, each SWH lab group member had to assigned a participatory role. Based on this design, each lab group member was held responsible for a particular aspect of the culminating project; therefore, resulting in an marked increase in student participation and individual student effort for the duration of the study. Additionally, at the time of group presentations, each lab group seemed genuinely invested in the final product, demonstrated great pride in their creation, and made sure to accurately and precisely represent their solution to the problem presented. From the review of literature, support for these observations can be found in Hand et al. (2004) and Rudd et al. (2001). All in all, the SWH group seemed to truly enjoy their learning experience, more so than the control group who simply turned in their completed worksheet. As a final note, the percentage of task completion for the SWH group was at calculated at 95.3% (presentation, poster, completed template worksheet), as compared to the 73.8% completion for the control group (textbook generated worksheet, graph).

Limitations

The original intent of the research was to determine, if possible, the relevant impact of the SWH laboratory approach on both student content learning and reasoning ability as compared to the traditional laboratory approach. As Table 5 indicates, students in both groups experienced significant gains in conceptual knowledge and application but not in scientific reasoning ability. As Table 6 indicates, there were no significant differences across all three post-test measures between the SWH treatment group and the Control group. As discussed previously, this lack of significance may be attributed to several factors such as the timing of the study, the nature of the assessments, and duration of the study.

The timing of the study could have affected the amount of student motivation and application towards improving achievement. With the study being conducted late in the fourth quarter, students may have been less inclined to participate to their academic potential in laboratory activities and testing instruments. In addition, the study concluded after the administration of the April 2011 ACT, when approximately 95% of this high school's students had taken that standardized test. With the administration of the post-SRT after the April 2011 test date, participants may not have been motivated to engage fully due to the possibility of "burn-out" regarding standardized testing.

With the duration of the study being considerably short (15 days), more instructional time should have been allotted for this study so that the participants could have experienced the SWH treatment for more than one inquiry-based activity. Lengthening the duration of the study might have resulted in measurable improvements in participants' scientific reasoning abilities. As stated previously from Hand et al. (2009), development of higher order thinking within an inquiry setting takes time.

As mentioned previously, assessments of student learning within an inquiry setting need to be balanced between endpoint, dynamic, and conceptual framework types. After critical analysis of the teacher-created Gas Law pre-post test, it was found that the instrument may not been designed to accurately measure improvement in scientific reasoning and conceptual understanding. Had the pre-post Gas Law unit test been more critically aligned with the nature of the science as inquiry, perhaps the results would have clearly differentiated between the two groups, the Control group and the SWH treatment group.

Future Research Questions

Based on the body of research dedicated toward the impact of the Science Writing Heuristic on student learning, repeating this study using more than one inquiry-based activity in the high school chemistry classroom might be a worthwhile endeavor. If the duration of the study were to include at least three inquiry-based activities, would there be more measurable improvement in content learning and reasoning ability on behalf of the participants? With an increase in instructional time spent with the SWH, the results should clearly indicate the benefits of this student-centered pedagogy: increase of student conceptual awareness and understanding, improvement of critical thinking skills, and further development of scientific literacy (Hand et al., 2009).

Implications for Teaching

As established by the body of educational research cited in this study's review of literature, implementation of the SWH within a science classroom can benefit students towards the acquisition of conceptual understanding, critical thinking skills, and scientific literacy. However, to reap such benefits within individual student populations, Hand et al. (2009) emphatically state that the quality of implementation is the key factor:

> The SWH approach is a combination of teacher quality and embedded-language -based science inquiry experiences. One by itself will not lead to the same results as the combination. Embedded-language practices, scientific argumentation, or teacher implementation alone will not give the same benefits as integrating all these together (p. 192).

Several authors who have conducted research using the SWH have discovered many benefits of the implementation of the SWH based on the aforementioned design. These benefits include: (1) closing the achievement gap, (2) closing the gender gap, (3) improved performance on standardized tests, (4) improved academic performance of students with Individualized educational Plans (IEPs), and (5) improved academic performance of students with a low socio-economic status (SES). With such strong evidence, it is possible that the SWH is one of the strongest candidates toward improving the nation's scientific literacy among its entire population.

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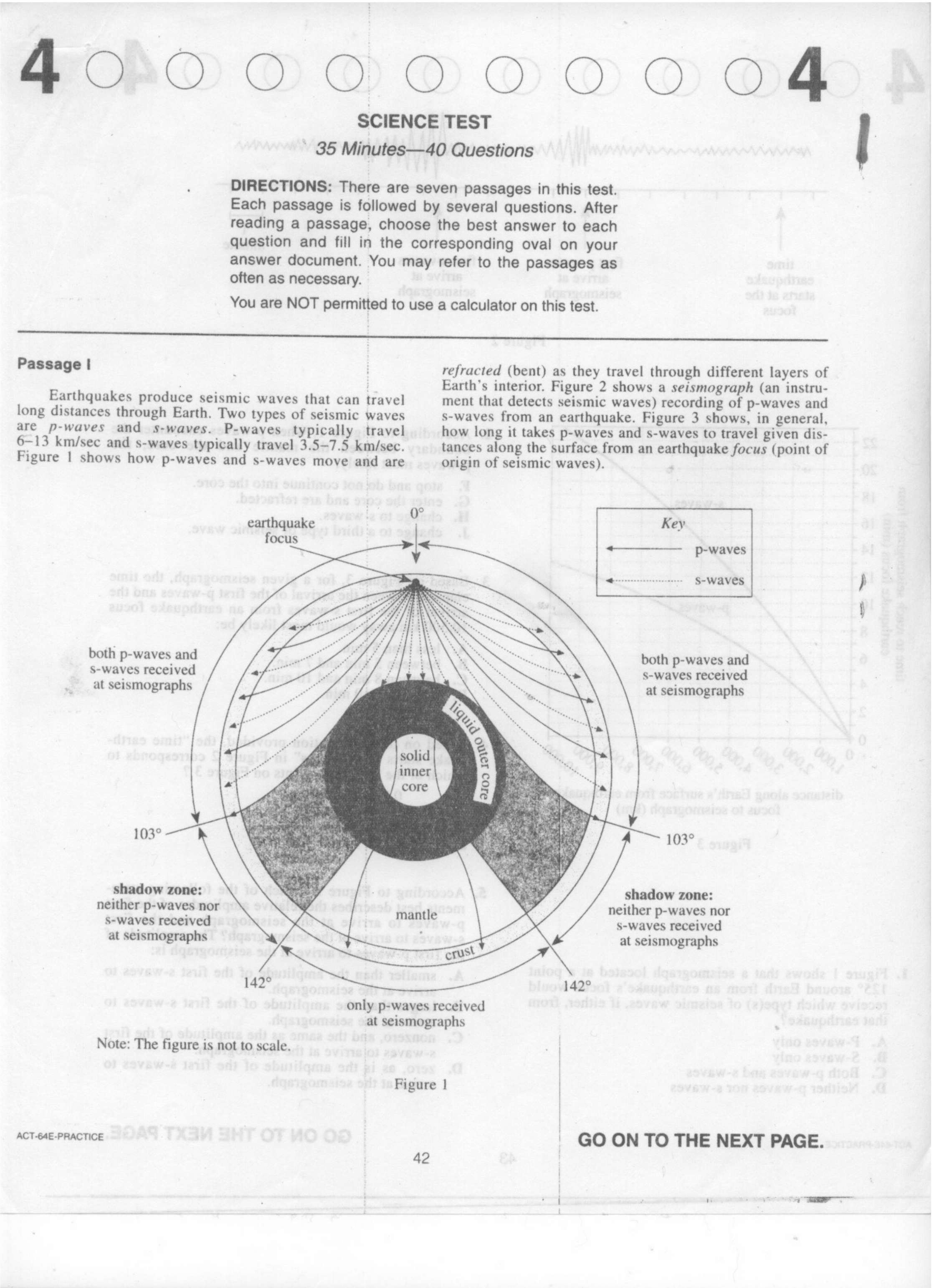
Appendix A

Science Reasoning Test (2010 Practice ACT)



4 ○ ○ ○ ○ ○ ○ ○ ○ ○ 4

SCIENCE TEST

35 Minutes—40 Questions

DIRECTIONS: There are seven passages in this test. Each passage is followed by several questions. After reading a passage, choose the best answer to each question and fill in the corresponding oval on your answer document. You may refer to the passages as often as necessary.

You are NOT permitted to use a calculator on this test.

Passage I

Earthquakes produce seismic waves that can travel long distances through Earth. Two types of seismic waves are *p-waves* and *s-waves*. P-waves typically travel 6–13 km/sec and s-waves typically travel 3.5–7.5 km/sec. Figure 1 shows how p-waves and s-waves move and are *refracted* (bent) as they travel through different layers of Earth's interior. Figure 2 shows a *seismograph* (an instrument that detects seismic waves) recording of p-waves and s-waves from an earthquake. Figure 3 shows, in general, how long it takes p-waves and s-waves to travel given distances along the surface from an earthquake *focus* (point of origin of seismic waves).

Note: The figure is not to scale.

Figure 1

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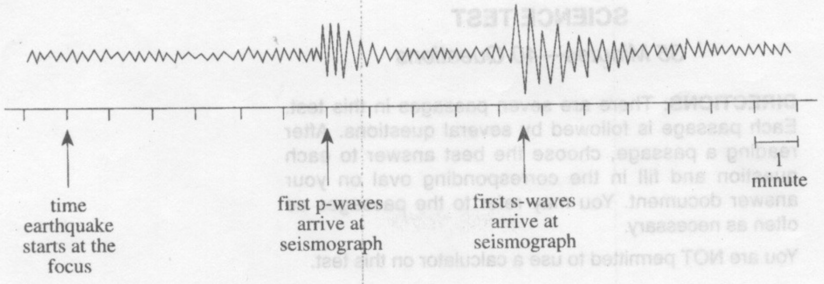

Figure 2

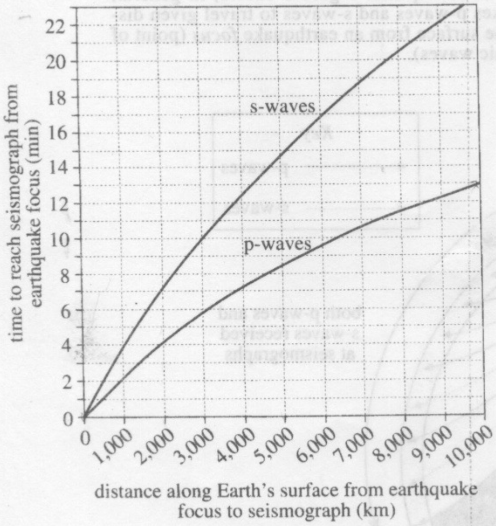

Figure 3

1. Figure 1 shows that a seismograph located at a point 125° around Earth from an earthquake's focus would receive which type(s) of seismic waves, if either, from that earthquake?

   A. P-waves only
   B. S-waves only
   C. Both p-waves and s-waves
   D. Neither p-waves nor s-waves

2. According to Figure 1, when p-waves encounter the boundary between the mantle and the core, the p-waves most likely:

   F. stop and do not continue into the core.
   G. enter the core and are refracted.
   H. change to s-waves.
   J. change to a third type of seismic wave.

3. Based on Figure 3, for a given seismograph, the time elapsed between the arrival of the first p-waves and the arrival of the first s-waves from an earthquake focus 10,500 km away would most likely be:

   A. less than 5 min.
   B. between 5 min and 7 min.
   C. between 8 min and 10 min.
   D. more than 10 min.

4. Based on the information provided, the "time earthquake starts at the focus" in Figure 2 corresponds to which of the following points on Figure 3 ?

F.	0 km,	0 min
G.	2,000 km,	5 min
H.	5,000 km,	12 min
J.	10,000 km,	20 min

5. According to Figure 2, which of the following statements best describes the relative amplitudes of the first p-waves to arrive at the seismograph and the first s-waves to arrive at the seismograph? The amplitude of the first p-waves to arrive at the seismograph is:

   A. smaller than the amplitude of the first s-waves to arrive at the seismograph.
   B. larger than the amplitude of the first s-waves to arrive at the seismograph.
   C. nonzero, and the same as the amplitude of the first s-waves to arrive at the seismograph.
   D. zero, as is the amplitude of the first s-waves to arrive at the seismograph.

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Passage II

Lake Agassiz existed between 11,700 and 9,500 years ago in North America (see Figure 1). The lake was formed when a large glacier dammed several rivers. Groundwater trapped in lake and glacial sediments provides information about the climate at the time the sediments were deposited. Figure 2 shows a cross section of the sediments (lake clay and glacial till) and bedrock in the area. Figure 3 shows the $\delta^{18}O$ values of groundwater taken from samples of the top 40 m of sediment at 3 sites along the same cross section. $\delta^{18}O$ is calculated from a ratio of 2 oxygen isotopes (^{18}O and ^{16}O) in the groundwater. Smaller $\delta^{18}O$ values indicate cooler average temperatures.

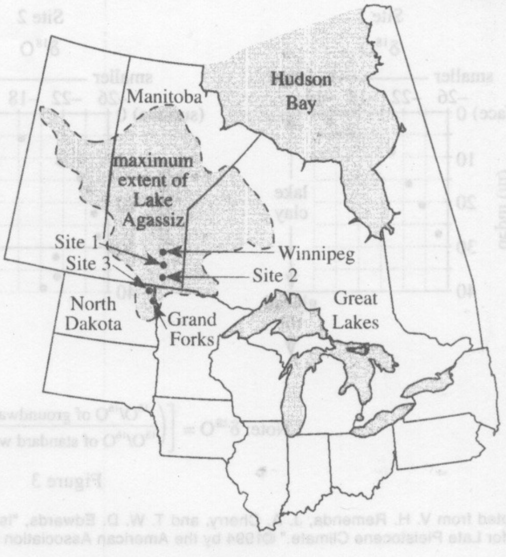

Figure 1

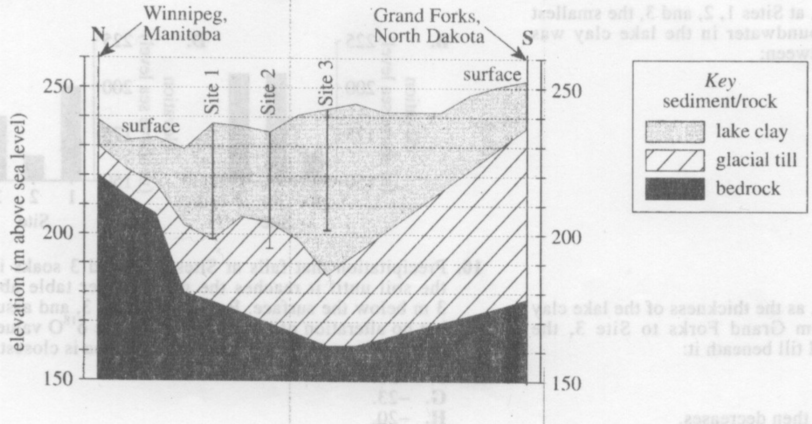

Figure 2

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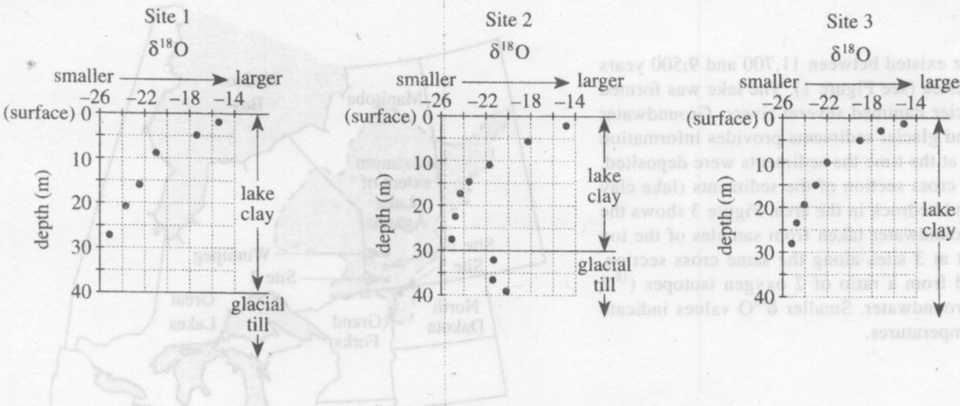


Note: $$\delta^{18}O = \left[\left(\frac{^{18}O/^{16}O \text{ of groundwater sample}}{^{18}O/^{16}O \text{ of standard water sample}}\right) - 1\right] \times 1{,}000$$

Figure 3

igures adapted from V. H. Remenda, J. A. Cherry, and T. W. D. Edwards, "Isotopic Composition of Old Ground Water from Lake Agassiz: nplications for Late Pleistocene Climate." ©1994 by the American Association for the Advancement of Science.

6. According to Figure 2, the lake clay deposit is thinnest at which of the following cities or sites?

F. Winnipeg
G. Site 1
H. Site 2
J. Grand Forks

7. According to Figure 3, at Sites 1, 2, and 3, the smallest $\delta^{18}O$ value of the groundwater in the lake clay was recorded at a depth between:

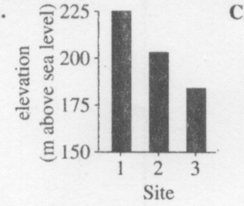
A. 0 m and 10 m.
B. 10 m and 20 m.
C. 20 m and 30 m.
D. 30 m and 40 m.

8. According to Figure 2, as the thickness of the lake clay deposit increases from Grand Forks to Site 3, the thickness of the glacial till beneath it:

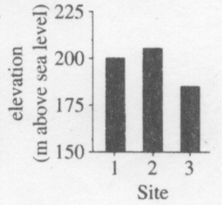
F. increases.
G. remains the same.
H. first increases and then decreases.
J. decreases.

9. According to Figure 2, which of the following graphs best represents the *elevations*, in m above sea level, of the top of the glacial till layer at Sites 1, 2, and 3 ?

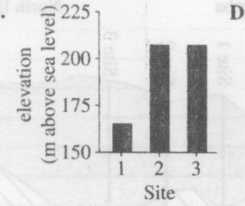
A.



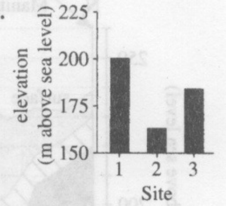
C.



B.

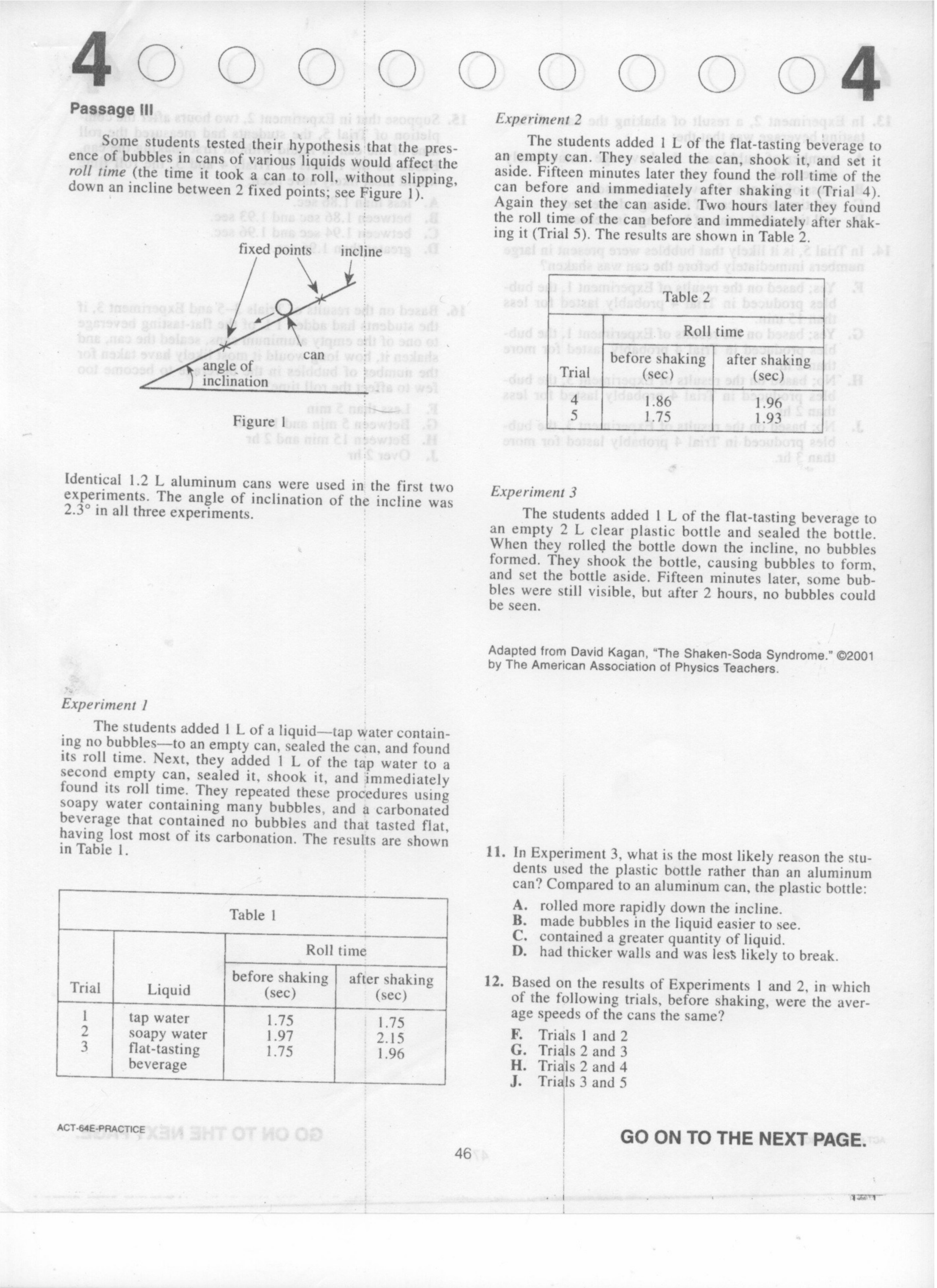


D.



10. Precipitation that falls at Sites 1, 2, and 3 soaks into the soil until it reaches the groundwater table about 3 m below the surface. Based on Figure 3, and assuming no alteration of the precipitation, the $\delta^{18}O$ value of present-day precipitation in the study area is closest to:

F. −26.
G. −23.
H. −20.
J. −15.



Passage III

Some students tested their hypothesis that the presence of bubbles in cans of various liquids would affect the *roll time* (the time it took a can to roll, without slipping, down an incline between 2 fixed points; see Figure 1).

Figure 1

Identical 1.2 L aluminum cans were used in the first two experiments. The angle of inclination of the incline was 2.3° in all three experiments.

Experiment 1

The students added 1 L of a liquid—tap water containing no bubbles—to an empty can, sealed the can, and found its roll time. Next, they added 1 L of the tap water to a second empty can, sealed it, shook it, and immediately found its roll time. They repeated these procedures using soapy water containing many bubbles, and a carbonated beverage that contained no bubbles and that tasted flat, having lost most of its carbonation. The results are shown in Table 1.

Table 1

Trial	Liquid	Roll time	
		before shaking (sec)	after shaking (sec)
1	tap water	1.75	1.75
2	soapy water	1.97	2.15
3	flat-tasting beverage	1.75	1.96

Experiment 2

The students added 1 L of the flat-tasting beverage to an empty can. They sealed the can, shook it, and set it aside. Fifteen minutes later they found the roll time of the can before and immediately after shaking it (Trial 4). Again they set the can aside. Two hours later they found the roll time of the can before and immediately after shaking it (Trial 5). The results are shown in Table 2.

Table 2

Trial	Roll time	
	before shaking (sec)	after shaking (sec)
4	1.86	1.96
5	1.75	1.93

Experiment 3

The students added 1 L of the flat-tasting beverage to an empty 2 L clear plastic bottle and sealed the bottle. When they rolled the bottle down the incline, no bubbles formed. They shook the bottle, causing bubbles to form, and set the bottle aside. Fifteen minutes later, some bubbles were still visible, but after 2 hours, no bubbles could be seen.

Adapted from David Kagan, "The Shaken-Soda Syndrome." ©2001 by The American Association of Physics Teachers.

11. In Experiment 3, what is the most likely reason the students used the plastic bottle rather than an aluminum can? Compared to an aluminum can, the plastic bottle:

- **A.** rolled more rapidly down the incline.
- **B.** made bubbles in the liquid easier to see.
- **C.** contained a greater quantity of liquid.
- **D.** had thicker walls and was less likely to break.

12. Based on the results of Experiments 1 and 2, in which of the following trials, before shaking, were the average speeds of the cans the same?

- **F.** Trials 1 and 2
- **G.** Trials 2 and 3
- **H.** Trials 2 and 4
- **J.** Trials 3 and 5

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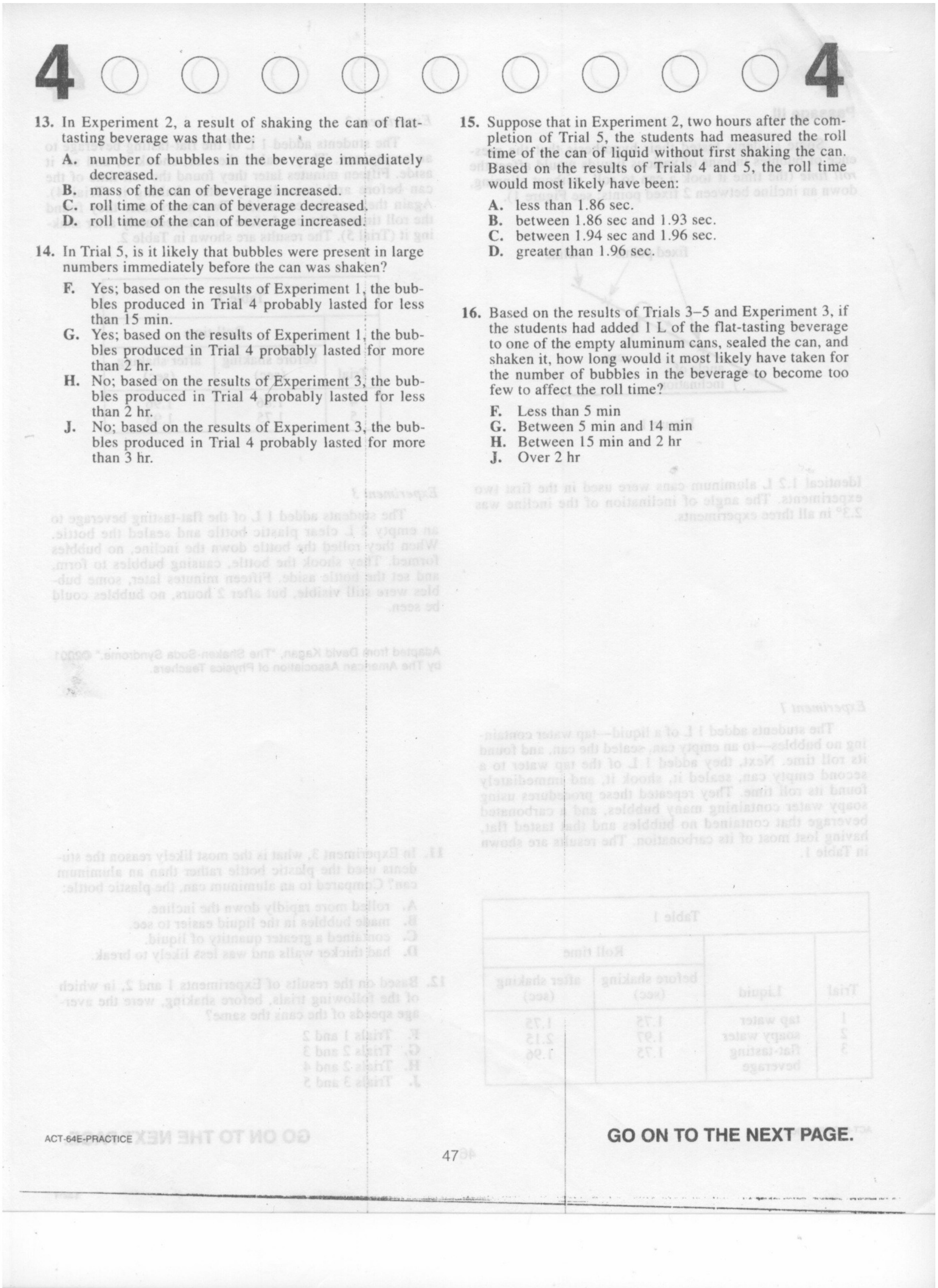

13. In Experiment 2, a result of shaking the can of flat-tasting beverage was that the:

A. number of bubbles in the beverage immediately decreased.
B. mass of the can of beverage increased.
C. roll time of the can of beverage decreased.
D. roll time of the can of beverage increased.

14. In Trial 5, is it likely that bubbles were present in large numbers immediately before the can was shaken?

F. Yes; based on the results of Experiment 1, the bubbles produced in Trial 4 probably lasted for less than 15 min.
G. Yes; based on the results of Experiment 1, the bubbles produced in Trial 4 probably lasted for more than 2 hr.
H. No; based on the results of Experiment 3, the bubbles produced in Trial 4 probably lasted for less than 2 hr.
J. No; based on the results of Experiment 3, the bubbles produced in Trial 4 probably lasted for more than 3 hr.

15. Suppose that in Experiment 2, two hours after the completion of Trial 5, the students had measured the roll time of the can of liquid without first shaking the can. Based on the results of Trials 4 and 5, the roll time would most likely have been:

A. less than 1.86 sec.
B. between 1.86 sec and 1.93 sec.
C. between 1.94 sec and 1.96 sec.
D. greater than 1.96 sec.

16. Based on the results of Trials 3–5 and Experiment 3, if the students had added 1 L of the flat-tasting beverage to one of the empty aluminum cans, sealed the can, and shaken it, how long would it most likely have taken for the number of bubbles in the beverage to become too few to affect the roll time?

F. Less than 5 min
G. Between 5 min and 14 min
H. Between 15 min and 2 hr
J. Over 2 hr

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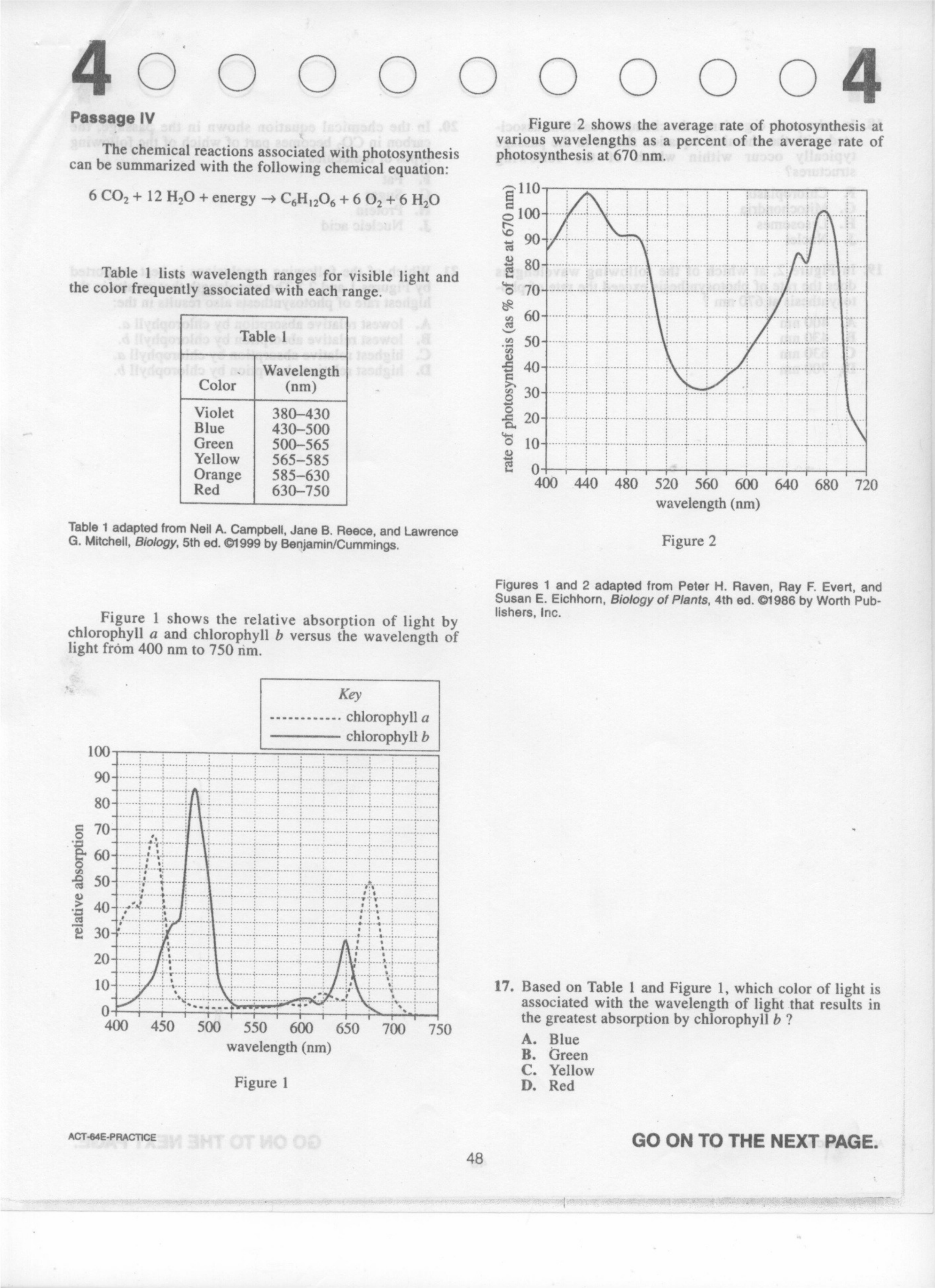

Passage IV

The chemical reactions associated with photosynthesis can be summarized with the following chemical equation:

$$6\ CO_2 + 12\ H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

Table 1 lists wavelength ranges for visible light and the color frequently associated with each range.

Table 1

Color	Wavelength (nm)
Violet	380–430
Blue	430–500
Green	500–565
Yellow	565–585
Orange	585–630
Red	630–750

Table 1 adapted from Neil A. Campbell, Jane B. Reece, and Lawrence G. Mitchell, *Biology*, 5th ed. ©1999 by Benjamin/Cummings.

Figure 1 shows the relative absorption of light by chlorophyll *a* and chlorophyll *b* versus the wavelength of light from 400 nm to 750 nm.

Figure 1

Figure 2 shows the average rate of photosynthesis at various wavelengths as a percent of the average rate of photosynthesis at 670 nm.

Figure 2

Figures 1 and 2 adapted from Peter H. Raven, Ray F. Evert, and Susan E. Eichhorn, *Biology of Plants*, 4th ed. ©1986 by Worth Publishers, Inc.

17. Based on Table 1 and Figure 1, which color of light is associated with the wavelength of light that results in the greatest absorption by chlorophyll *b* ?
   - **A.** Blue
   - **B.** Green
   - **C.** Yellow
   - **D.** Red

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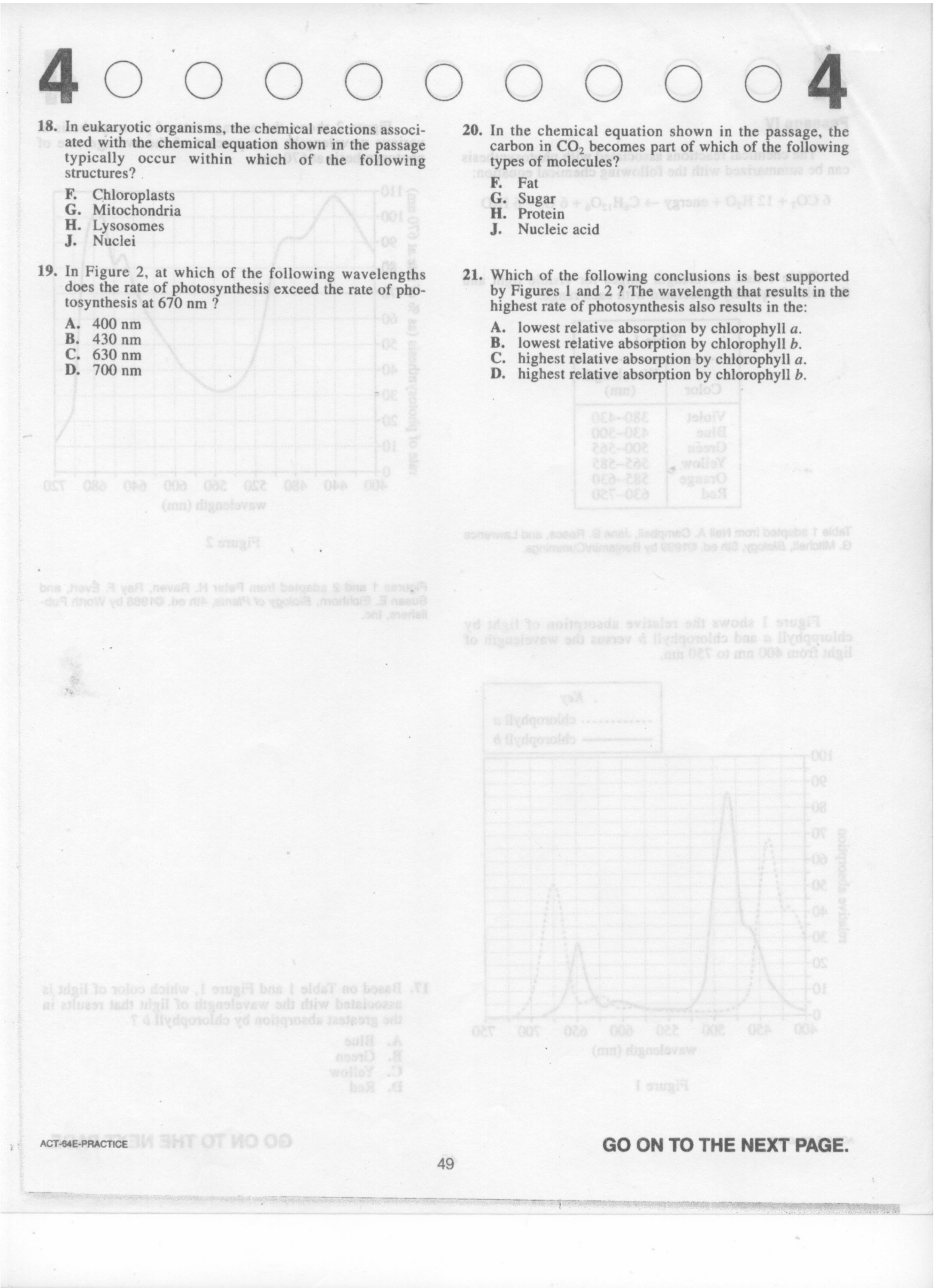

18. In eukaryotic organisms, the chemical reactions associated with the chemical equation shown in the passage typically occur within which of the following structures?

F. Chloroplasts
G. Mitochondria
H. Lysosomes
J. Nuclei

19. In Figure 2, at which of the following wavelengths does the rate of photosynthesis exceed the rate of photosynthesis at 670 nm ?

A. 400 nm
B. 430 nm
C. 630 nm
D. 700 nm

20. In the chemical equation shown in the passage, the carbon in CO_2 becomes part of which of the following types of molecules?

F. Fat
G. Sugar
H. Protein
J. Nucleic acid

21. Which of the following conclusions is best supported by Figures 1 and 2 ? The wavelength that results in the highest rate of photosynthesis also results in the:

A. lowest relative absorption by chlorophyll *a*.
B. lowest relative absorption by chlorophyll *b*.
C. highest relative absorption by chlorophyll *a*.
D. highest relative absorption by chlorophyll *b*.

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Passage V

Students performed the following experiments to determine the density of common plastics.

Experiment 1

A dry 100 mL graduated cylinder was placed on an electronic balance and *tared* (the balance was reset to 0.000 g). H_2O was added to the graduated cylinder until a certain mass was obtained. Ethanol was added to the graduated cylinder until the volume of liquid was 50.0 mL. The density of the liquid was then calculated. The procedure was repeated with different amounts of ethanol and H_2O (see Table 1).

Table 1

Liquid	Mass of H_2O (g)	Mass of ethanol (g)	Total mass (g)	Density (g/mL)
1	0	39.67	39.67	0.793
2	10.24	32.43	42.67	0.853
3	19.79	25.23	45.02	0.900
4	35.42	12.47	47.89	0.958
5	49.96	0	49.96	0.999

Experiment 2

A known mass of potassium iodide (KI) was dissolved in a known mass of H_2O. A dry 100 mL graduated cylinder was placed on the balance and tared. The solution was added to the graduated cylinder until the volume was 50.0 mL. The density of the liquid was then calculated. The procedure was repeated with different amounts of KI and H_2O (see Table 2).

Table 2

Liquid	Mass of H_2O in solution (g)	Mass of KI in solution (g)	Mass of solution in graduated cylinder (g)	Density (g/mL)
6	97.66	7.36	52.51	1.05
7	95.41	15.52	55.70	1.11
8	94.38	20.68	57.53	1.15
9	92.18	29.08	60.63	1.21
10	87.77	41.31	64.64	1.29

Experiment 3

A solid plastic bead was placed at the bottom of a sample of each of Liquids 1–10 from Experiments 1 and 2. If the bead stayed at the bottom, "S" was recorded in Table 3. If the bead rose, "R" was recorded in Table 3. The procedure was repeated for various plastics.

Table 3

Plastic	Liquid									
	1	2	3	4	5	6	7	8	9	10
Polybutylene	R	R	R	R	R	R	R	R	R	R
VLDPE	S	R	R	R	R	R	R	R	R	R
LDPE	S	S	S	R	R	R	R	R	R	R
HDPE	S	S	S	S	R	R	R	R	R	R
PA-11	S	S	S	S	S	R	R	R	R	R
PA-6	S	S	S	S	S	S	S	R	R	R
Polycarbonate	S	S	S	S	S	S	S	S	R	R
PVC	S	S	S	S	S	S	S	S	S	S

22. In Experiment 1, the density of ethanol was found to be:

F. less than 0.793 g/mL.
G. 0.793 g/mL.
H. 0.999 g/mL.
J. greater than 0.999 g/mL.

23. Based on the results of Experiments 1–3, the density of PA-11 is most likely:

A. less than 0.793 g/mL.
B. between 0.853 g/mL and 0.958 g/mL.
C. between 0.999 g/mL and 1.05 g/mL.
D. greater than 1.11 g/mL.

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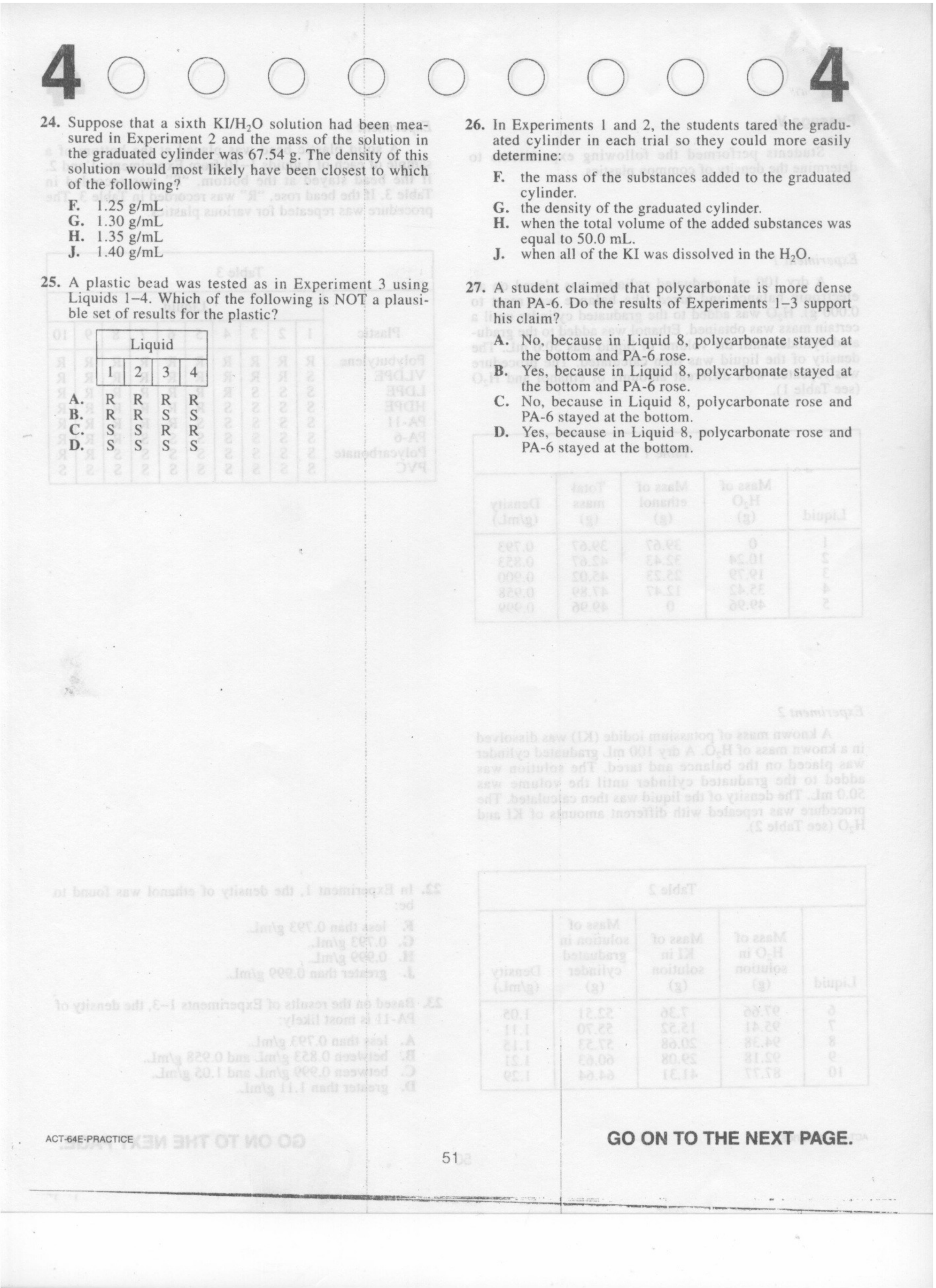

24. Suppose that a sixth KI/H_2O solution had been measured in Experiment 2 and the mass of the solution in the graduated cylinder was 67.54 g. The density of this solution would most likely have been closest to which of the following?

- **F.** 1.25 g/mL
- **G.** 1.30 g/mL
- **H.** 1.35 g/mL
- **J.** 1.40 g/mL

25. A plastic bead was tested as in Experiment 3 using Liquids 1–4. Which of the following is NOT a plausible set of results for the plastic?

	Liquid			
	1	2	3	4
A.	R	R	R	R
B.	R	R	S	S
C.	S	S	R	R
D.	S	S	S	S

26. In Experiments 1 and 2, the students tared the graduated cylinder in each trial so they could more easily determine:

- **F.** the mass of the substances added to the graduated cylinder.
- **G.** the density of the graduated cylinder.
- **H.** when the total volume of the added substances was equal to 50.0 mL.
- **J.** when all of the KI was dissolved in the H_2O.

27. A student claimed that polycarbonate is more dense than PA-6. Do the results of Experiments 1–3 support his claim?

- **A.** No, because in Liquid 8, polycarbonate stayed at the bottom and PA-6 rose.
- **B.** Yes, because in Liquid 8, polycarbonate stayed at the bottom and PA-6 rose.
- **C.** No, because in Liquid 8, polycarbonate rose and PA-6 stayed at the bottom.
- **D.** Yes, because in Liquid 8, polycarbonate rose and PA-6 stayed at the bottom.

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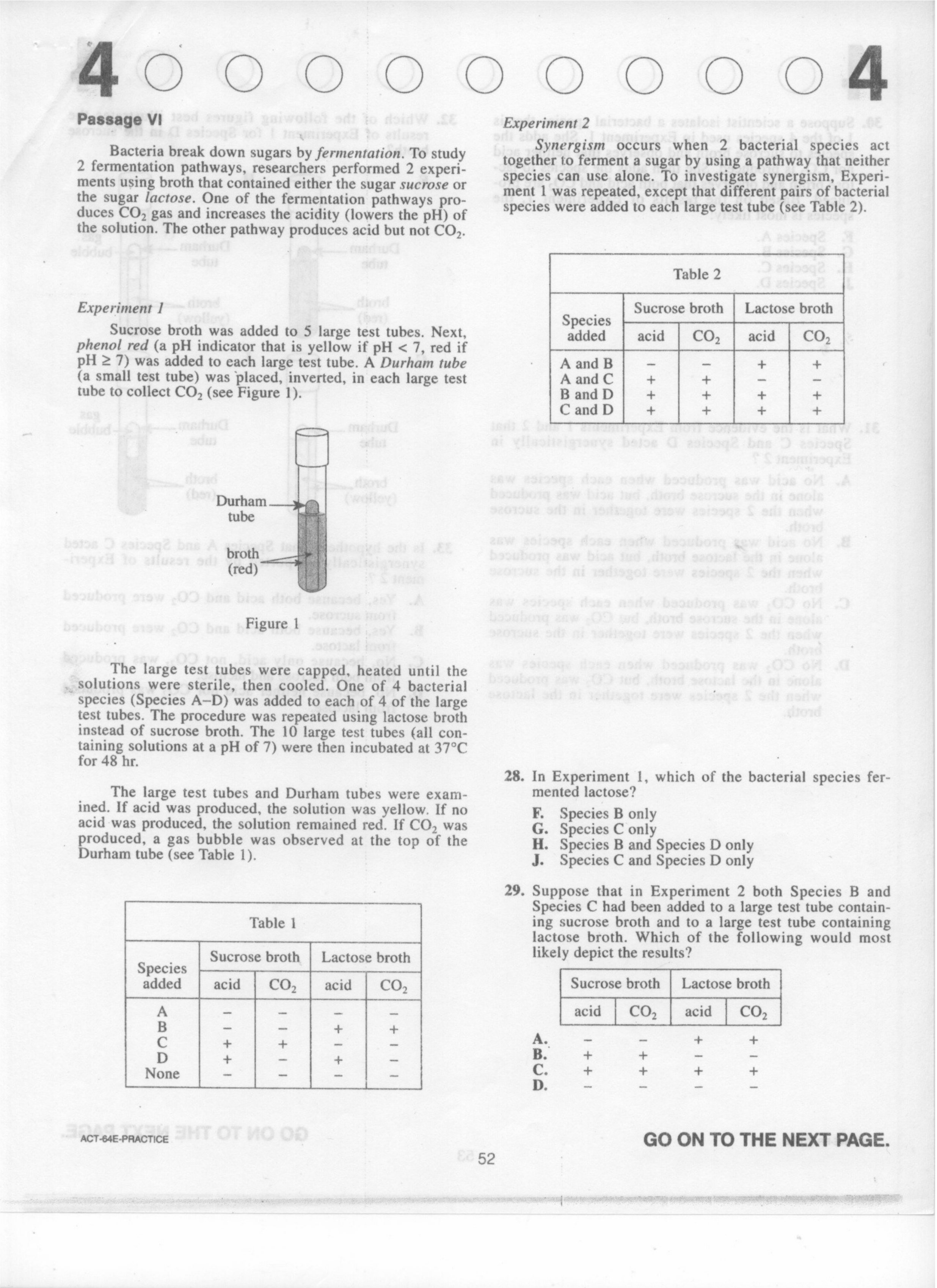

Passage VI

Bacteria break down sugars by *fermentation*. To study 2 fermentation pathways, researchers performed 2 experiments using broth that contained either the sugar *sucrose* or the sugar *lactose*. One of the fermentation pathways produces CO_2 gas and increases the acidity (lowers the pH) of the solution. The other pathway produces acid but not CO_2.

Experiment 1

Sucrose broth was added to 5 large test tubes. Next, *phenol red* (a pH indicator that is yellow if pH < 7, red if pH ≥ 7) was added to each large test tube. A *Durham tube* (a small test tube) was placed, inverted, in each large test tube to collect CO_2 (see Figure 1).

Figure 1

The large test tubes were capped, heated until the solutions were sterile, then cooled. One of 4 bacterial species (Species A–D) was added to each of 4 of the large test tubes. The procedure was repeated using lactose broth instead of sucrose broth. The 10 large test tubes (all containing solutions at a pH of 7) were then incubated at 37°C for 48 hr.

The large test tubes and Durham tubes were examined. If acid was produced, the solution was yellow. If no acid was produced, the solution remained red. If CO_2 was produced, a gas bubble was observed at the top of the Durham tube (see Table 1).

Table 1

Species added	Sucrose broth		Lactose broth	
	acid	CO_2	acid	CO_2
A	−	−	−	−
B	−	−	+	+
C	+	+	−	−
D	+	−	+	−
None	−	−	−	−

Experiment 2

Synergism occurs when 2 bacterial species act together to ferment a sugar by using a pathway that neither species can use alone. To investigate synergism, Experiment 1 was repeated, except that different pairs of bacterial species were added to each large test tube (see Table 2).

Table 2

Species added	Sucrose broth		Lactose broth	
	acid	CO_2	acid	CO_2
A and B	−	−	+	+
A and C	+	+	−	−
B and D	+	+	+	+
C and D	+	+	+	+

28. In Experiment 1, which of the bacterial species fermented lactose?

F. Species B only
G. Species C only
H. Species B and Species D only
J. Species C and Species D only

29. Suppose that in Experiment 2 both Species B and Species C had been added to a large test tube containing sucrose broth and to a large test tube containing lactose broth. Which of the following would most likely depict the results?

	Sucrose broth		Lactose broth	
	acid	CO_2	acid	CO_2
A.	−	−	+	+
B.	+	+	−	−
C.	+	+	+	+
D.	−	−	−	−

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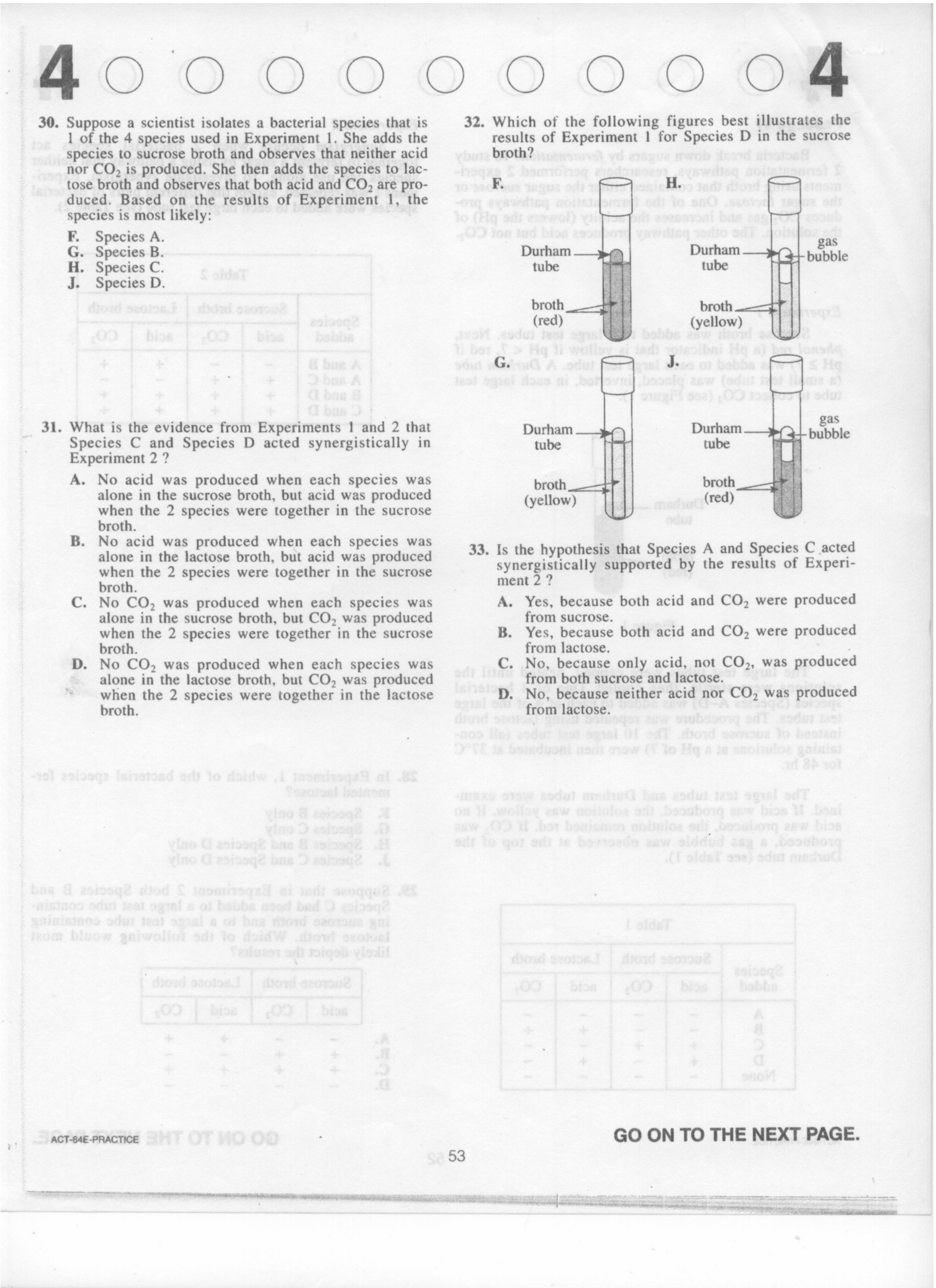

30. Suppose a scientist isolates a bacterial species that is 1 of the 4 species used in Experiment 1. She adds the species to sucrose broth and observes that neither acid nor CO_2 is produced. She then adds the species to lactose broth and observes that both acid and CO_2 are produced. Based on the results of Experiment 1, the species is most likely:

F. Species A.
G. Species B.
H. Species C.
J. Species D.

31. What is the evidence from Experiments 1 and 2 that Species C and Species D acted synergistically in Experiment 2 ?

A. No acid was produced when each species was alone in the sucrose broth, but acid was produced when the 2 species were together in the sucrose broth.
B. No acid was produced when each species was alone in the lactose broth, but acid was produced when the 2 species were together in the sucrose broth.
C. No CO_2 was produced when each species was alone in the sucrose broth, but CO_2 was produced when the 2 species were together in the sucrose broth.
D. No CO_2 was produced when each species was alone in the lactose broth, but CO_2 was produced when the 2 species were together in the lactose broth.

32. Which of the following figures best illustrates the results of Experiment 1 for Species D in the sucrose broth?

33. Is the hypothesis that Species A and Species C acted synergistically supported by the results of Experiment 2 ?

A. Yes, because both acid and CO_2 were produced from sucrose.
B. Yes, because both acid and CO_2 were produced from lactose.
C. No, because only acid, not CO_2, was produced from both sucrose and lactose.
D. No, because neither acid nor CO_2 was produced from lactose.

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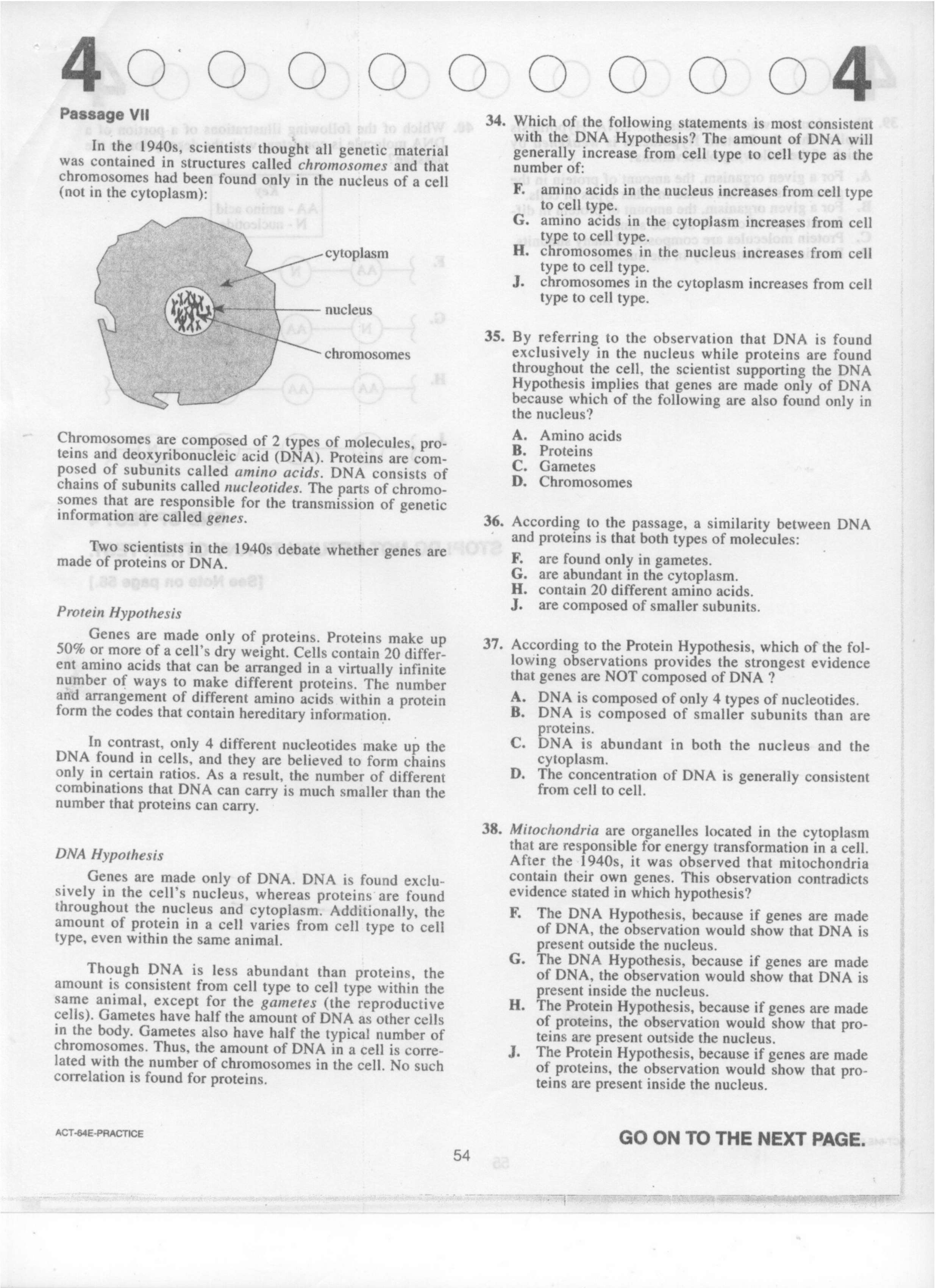

4 ○ ○ ○ ○ ○ ○ ○ ○ ○ **4**

Passage VII

In the 1940s, scientists thought all genetic material was contained in structures called *chromosomes* and that chromosomes had been found only in the nucleus of a cell (not in the cytoplasm):

Chromosomes are composed of 2 types of molecules, proteins and deoxyribonucleic acid (DNA). Proteins are composed of subunits called *amino acids*. DNA consists of chains of subunits called *nucleotides*. The parts of chromosomes that are responsible for the transmission of genetic information are called *genes*.

Two scientists in the 1940s debate whether genes are made of proteins or DNA.

Protein Hypothesis

Genes are made only of proteins. Proteins make up 50% or more of a cell's dry weight. Cells contain 20 different amino acids that can be arranged in a virtually infinite number of ways to make different proteins. The number and arrangement of different amino acids within a protein form the codes that contain hereditary information.

In contrast, only 4 different nucleotides make up the DNA found in cells, and they are believed to form chains only in certain ratios. As a result, the number of different combinations that DNA can carry is much smaller than the number that proteins can carry.

DNA Hypothesis

Genes are made only of DNA. DNA is found exclusively in the cell's nucleus, whereas proteins are found throughout the nucleus and cytoplasm. Additionally, the amount of protein in a cell varies from cell type to cell type, even within the same animal.

Though DNA is less abundant than proteins, the amount is consistent from cell type to cell type within the same animal, except for the *gametes* (the reproductive cells). Gametes have half the amount of DNA as other cells in the body. Gametes also have half the typical number of chromosomes. Thus, the amount of DNA in a cell is correlated with the number of chromosomes in the cell. No such correlation is found for proteins.

34. Which of the following statements is most consistent with the DNA Hypothesis? The amount of DNA will generally increase from cell type to cell type as the number of:

F. amino acids in the nucleus increases from cell type to cell type.
G. amino acids in the cytoplasm increases from cell type to cell type.
H. chromosomes in the nucleus increases from cell type to cell type.
J. chromosomes in the cytoplasm increases from cell type to cell type.

35. By referring to the observation that DNA is found exclusively in the nucleus while proteins are found throughout the cell, the scientist supporting the DNA Hypothesis implies that genes are made only of DNA because which of the following are also found only in the nucleus?

A. Amino acids
B. Proteins
C. Gametes
D. Chromosomes

36. According to the passage, a similarity between DNA and proteins is that both types of molecules:

F. are found only in gametes.
G. are abundant in the cytoplasm.
H. contain 20 different amino acids.
J. are composed of smaller subunits.

37. According to the Protein Hypothesis, which of the following observations provides the strongest evidence that genes are NOT composed of DNA ?

A. DNA is composed of only 4 types of nucleotides.
B. DNA is composed of smaller subunits than are proteins.
C. DNA is abundant in both the nucleus and the cytoplasm.
D. The concentration of DNA is generally consistent from cell to cell.

38. *Mitochondria* are organelles located in the cytoplasm that are responsible for energy transformation in a cell. After the 1940s, it was observed that mitochondria contain their own genes. This observation contradicts evidence stated in which hypothesis?

F. The DNA Hypothesis, because if genes are made of DNA, the observation would show that DNA is present outside the nucleus.
G. The DNA Hypothesis, because if genes are made of DNA, the observation would show that DNA is present inside the nucleus.
H. The Protein Hypothesis, because if genes are made of proteins, the observation would show that proteins are present outside the nucleus.
J. The Protein Hypothesis, because if genes are made of proteins, the observation would show that proteins are present inside the nucleus.

ACT-64E-PRACTICE

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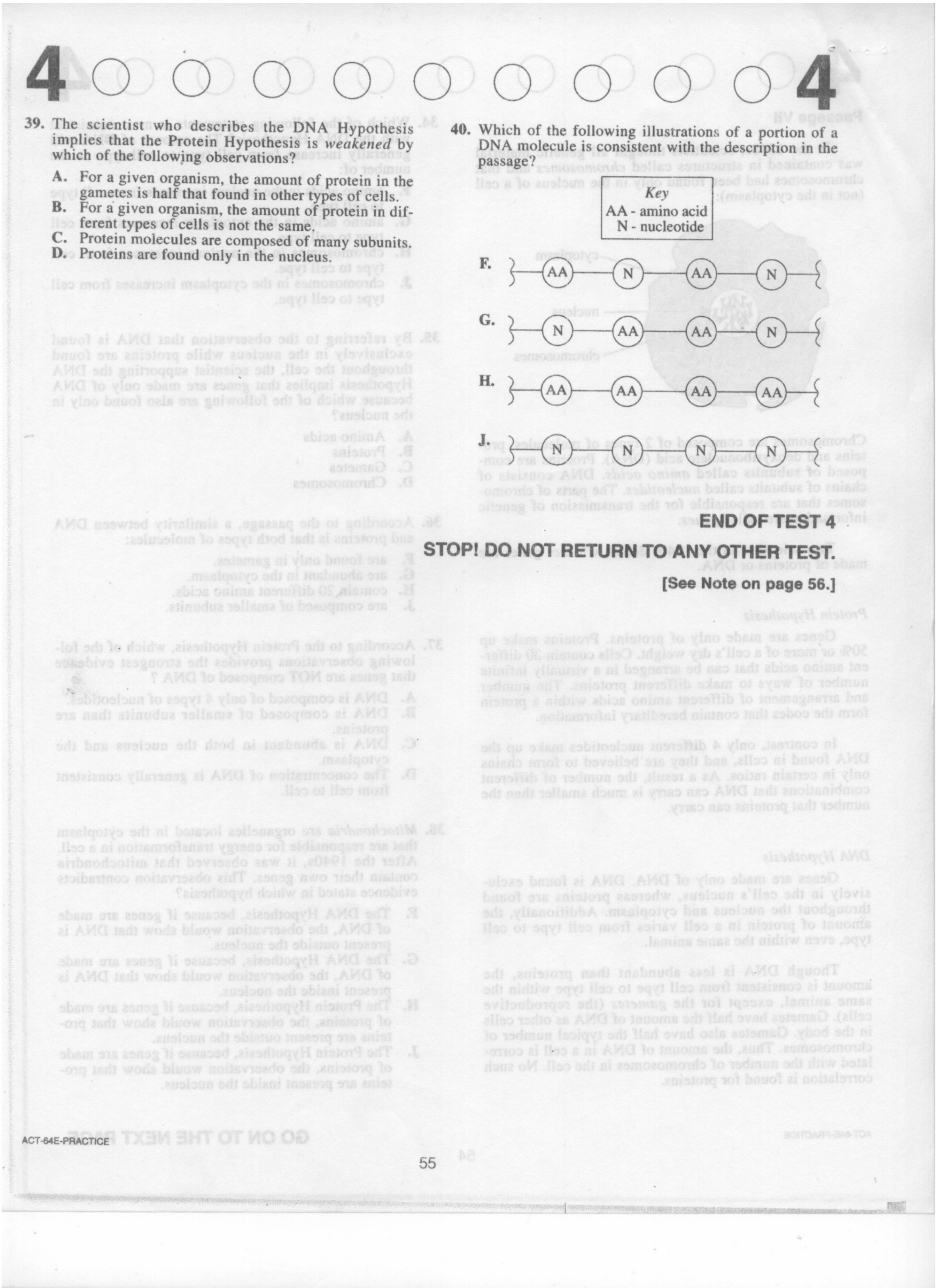


39. The scientist who describes the DNA Hypothesis implies that the Protein Hypothesis is *weakened* by which of the following observations?

A. For a given organism, the amount of protein in the gametes is half that found in other types of cells.
B. For a given organism, the amount of protein in different types of cells is not the same.
C. Protein molecules are composed of many subunits.
D. Proteins are found only in the nucleus.

40. Which of the following illustrations of a portion of a DNA molecule is consistent with the description in the passage?

Key
AA - amino acid
N - nucleotide

F. AA — N — AA — N
G. N — AA — AA — N
H. AA — AA — AA — AA
J. N — N — N — N

END OF TEST 4

STOP! DO NOT RETURN TO ANY OTHER TEST.

[See Note on page 56.]

Appendix B

Gas Law Unit Pre-test

Multiple Choice. *Identify the choice that best completes the statement or answers the question.*

____ 1. According to the kinetic molecular theory, particles of matter are in motion in
a. gases only. c. solids, liquids and gases.
b. gases and liquids. d. solids only.

____ 2. An ideal gas is an imaginary gas
a. not made of particles.
b. that conforms to all of the assumptions of the kinetic molecular theory.
c. whose particles have zero mass.
d. made of motionless particles.

____ 3. The density of a substance undergoes the greatest change when the substance changes from a
a. liquid to gas c. solid to liquid
b. liquid to solid d. a molecular solid to an ionic solid

____ 4. Pressure is the force per unit of
a. Volume c. length
b. surface area d. depth

____ 5. Which instrument measures atmospheric pressure
a. Manometer c. vacuum pump
b. Barometer d. torrometer

____ 6. Convert the pressure of 0.75 atm to mm Hg.
a. 101.325 mm Hg c. 570 mm Hg
b. 430 mm Hg d. 760 mm Hg

____ 7. The pressure of a sample of helium is 2.0 atm in a 200 ml container. If the container is compressed to 10 ml without changing the temperature, what is the new pressure?
a. 200 atm c. 100 atm
b. 0.10 atm d. 40. atm

____ 8. Why would the pressure of a sample of gas at a constant volume fall 75 mm Hg?
a. The contained exploded. c. The temperature decreased.
b. The temperature increased d. Few particles were present.

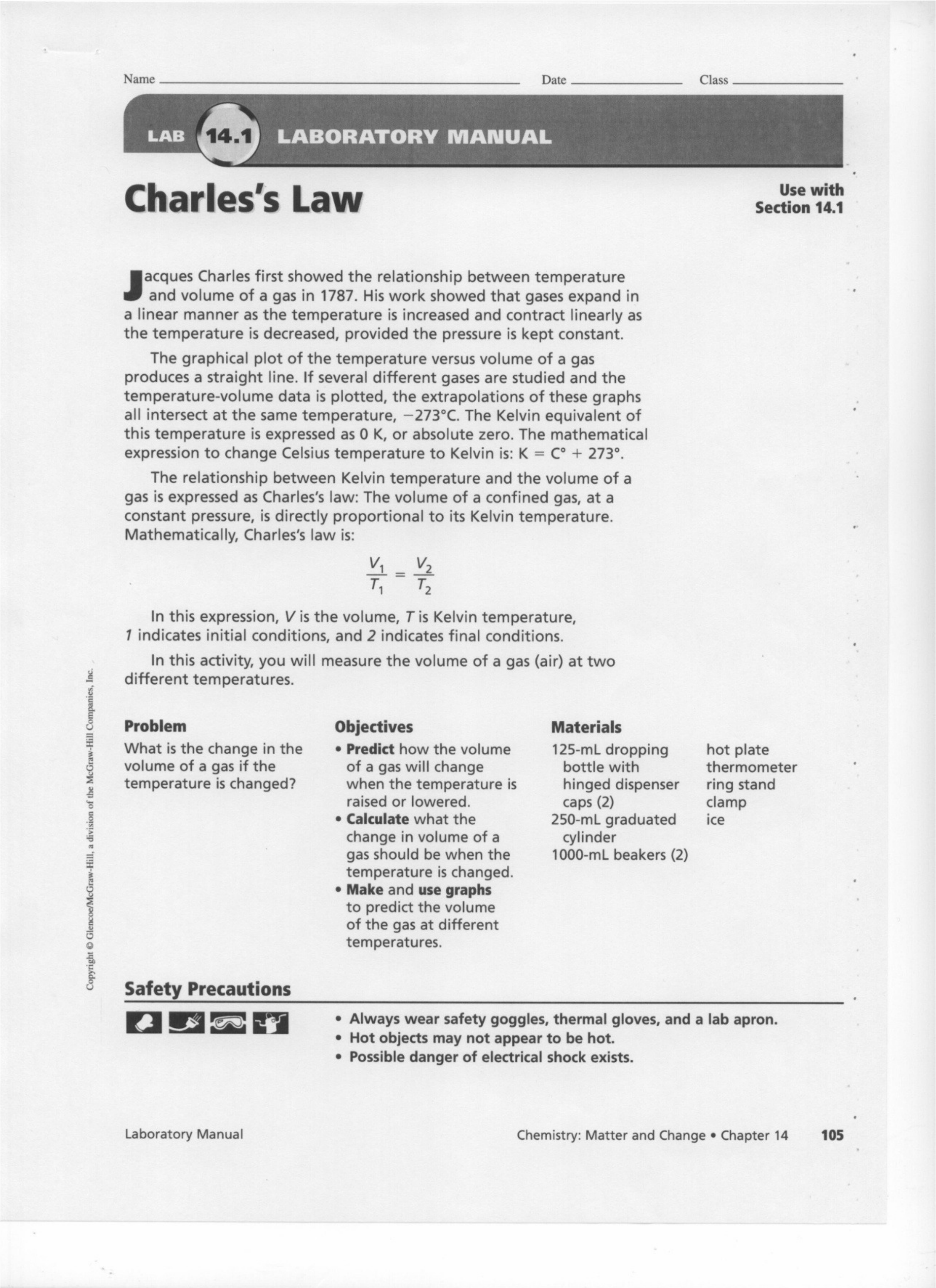
____ 9. The pressure of a sample of gas at a constant volume is 2.00 atm at 300. K. What is the pressure of the sample at 293 K?
a. 1.00 atm c. 2.10 atm
b. 1.95 atm d. 20.1 atm

____ 10. The volume of a sample of oxygen is 300.0 mL when the pressure is 1 atm and the temperature is 300 K. At what temperature is the volume 1.00 L and the pressure 0.500 atm?
a. 273 K c. 318 K
b. 295 K d. 500 K

____ 11. At 0.500 atm and 15.0 ^{o}C, a sample of gas occupies 120. L. what volume does it occupy at 0.250 atm and 10.0 ^{o}C.
a. 60 L c. 236 L
b. 111 L d. 480 L

Appendix C

Traditional Format Laboratory Exercise



Name ______________________ Date __________ Class __________

LAB 14.1 LABORATORY MANUAL

Charles's Law

Use with Section 14.1

Jacques Charles first showed the relationship between temperature and volume of a gas in 1787. His work showed that gases expand in a linear manner as the temperature is increased and contract linearly as the temperature is decreased, provided the pressure is kept constant.

The graphical plot of the temperature versus volume of a gas produces a straight line. If several different gases are studied and the temperature-volume data is plotted, the extrapolations of these graphs all intersect at the same temperature, −273°C. The Kelvin equivalent of this temperature is expressed as 0 K, or absolute zero. The mathematical expression to change Celsius temperature to Kelvin is: $K = C° + 273°$.

The relationship between Kelvin temperature and the volume of a gas is expressed as Charles's law: The volume of a confined gas, at a constant pressure, is directly proportional to its Kelvin temperature. Mathematically, Charles's law is:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

In this expression, V is the volume, T is Kelvin temperature, *1* indicates initial conditions, and *2* indicates final conditions.

In this activity, you will measure the volume of a gas (air) at two different temperatures.

Problem

What is the change in the volume of a gas if the temperature is changed?

Objectives

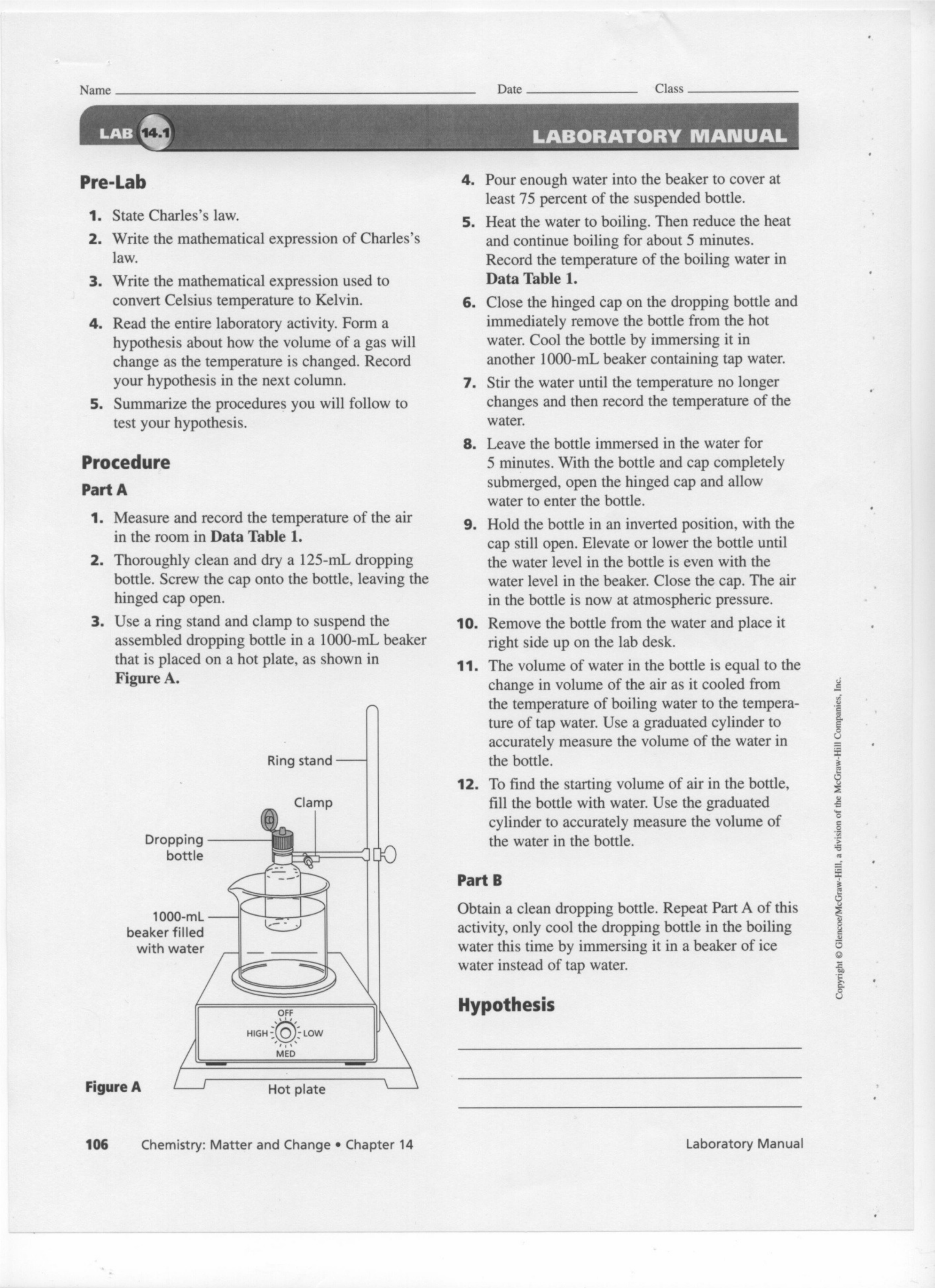
- **Predict** how the volume of a gas will change when the temperature is raised or lowered.
- **Calculate** what the change in volume of a gas should be when the temperature is changed.
- **Make** and **use graphs** to predict the volume of the gas at different temperatures.

Materials

125-mL dropping bottle with hinged dispenser caps (2)
250-mL graduated cylinder
1000-mL beakers (2)
hot plate
thermometer
ring stand
clamp
ice

Safety Precautions

- **Always wear safety goggles, thermal gloves, and a lab apron.**
- **Hot objects may not appear to be hot.**
- **Possible danger of electrical shock exists.**



Name ____________________ Date __________ Class __________

LAB 14.1 **LABORATORY MANUAL**

Pre-Lab

1. State Charles's law.
2. Write the mathematical expression of Charles's law.
3. Write the mathematical expression used to convert Celsius temperature to Kelvin.
4. Read the entire laboratory activity. Form a hypothesis about how the volume of a gas will change as the temperature is changed. Record your hypothesis in the next column.
5. Summarize the procedures you will follow to test your hypothesis.

Procedure

Part A

1. Measure and record the temperature of the air in the room in **Data Table 1.**
2. Thoroughly clean and dry a 125-mL dropping bottle. Screw the cap onto the bottle, leaving the hinged cap open.
3. Use a ring stand and clamp to suspend the assembled dropping bottle in a 1000-mL beaker that is placed on a hot plate, as shown in **Figure A.**

Figure A

4. Pour enough water into the beaker to cover at least 75 percent of the suspended bottle.
5. Heat the water to boiling. Then reduce the heat and continue boiling for about 5 minutes. Record the temperature of the boiling water in **Data Table 1.**
6. Close the hinged cap on the dropping bottle and immediately remove the bottle from the hot water. Cool the bottle by immersing it in another 1000-mL beaker containing tap water.
7. Stir the water until the temperature no longer changes and then record the temperature of the water.
8. Leave the bottle immersed in the water for 5 minutes. With the bottle and cap completely submerged, open the hinged cap and allow water to enter the bottle.
9. Hold the bottle in an inverted position, with the cap still open. Elevate or lower the bottle until the water level in the bottle is even with the water level in the beaker. Close the cap. The air in the bottle is now at atmospheric pressure.
10. Remove the bottle from the water and place it right side up on the lab desk.
11. The volume of water in the bottle is equal to the change in volume of the air as it cooled from the temperature of boiling water to the temperature of tap water. Use a graduated cylinder to accurately measure the volume of the water in the bottle.
12. To find the starting volume of air in the bottle, fill the bottle with water. Use the graduated cylinder to accurately measure the volume of the water in the bottle.

Part B

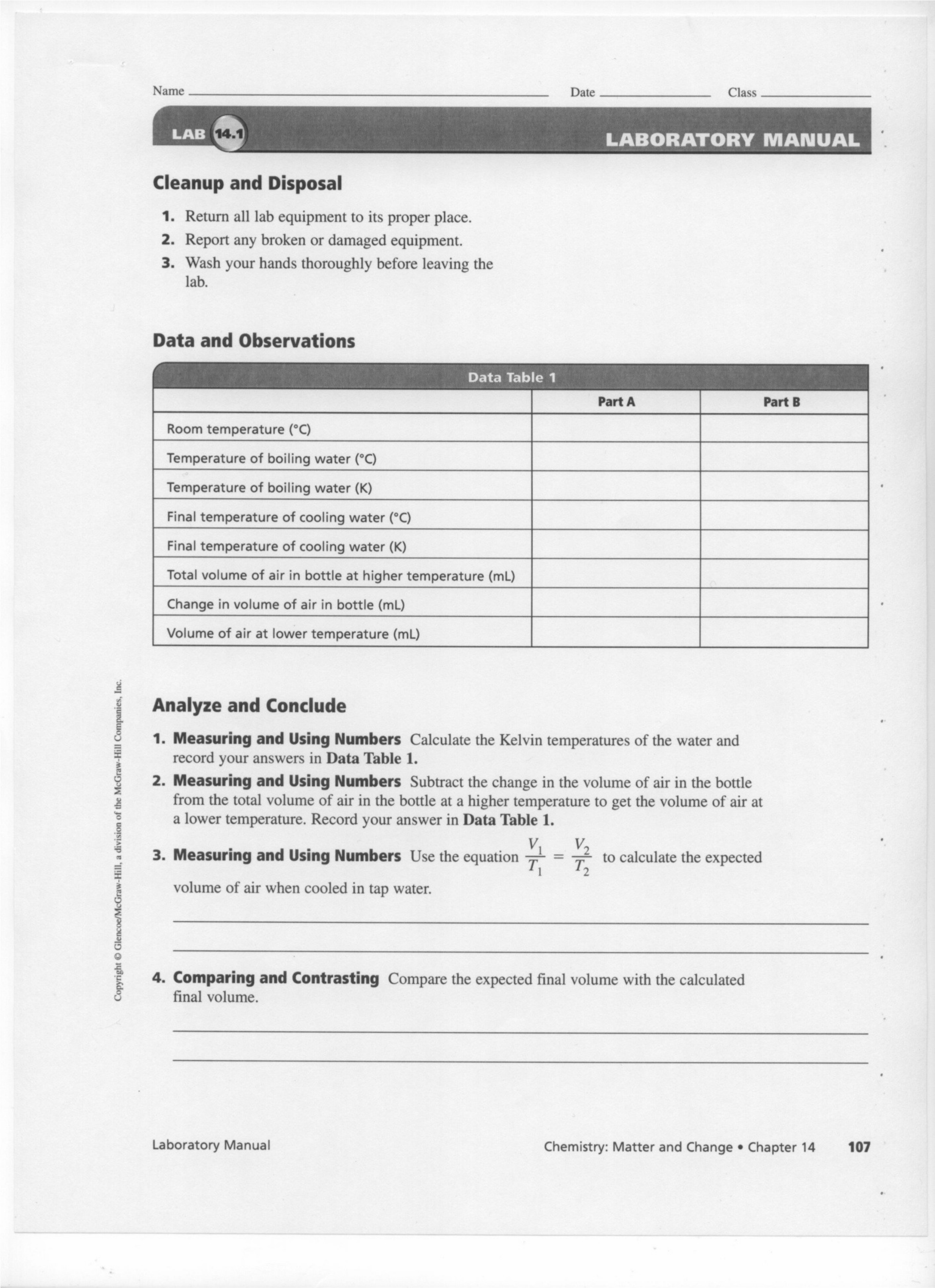
Obtain a clean dropping bottle. Repeat Part A of this activity, only cool the dropping bottle in the boiling water this time by immersing it in a beaker of ice water instead of tap water.

Hypothesis

____

____

____



Name ____________ Date ________ Class ________

Cleanup and Disposal

1. Return all lab equipment to its proper place.
2. Report any broken or damaged equipment.
3. Wash your hands thoroughly before leaving the lab.

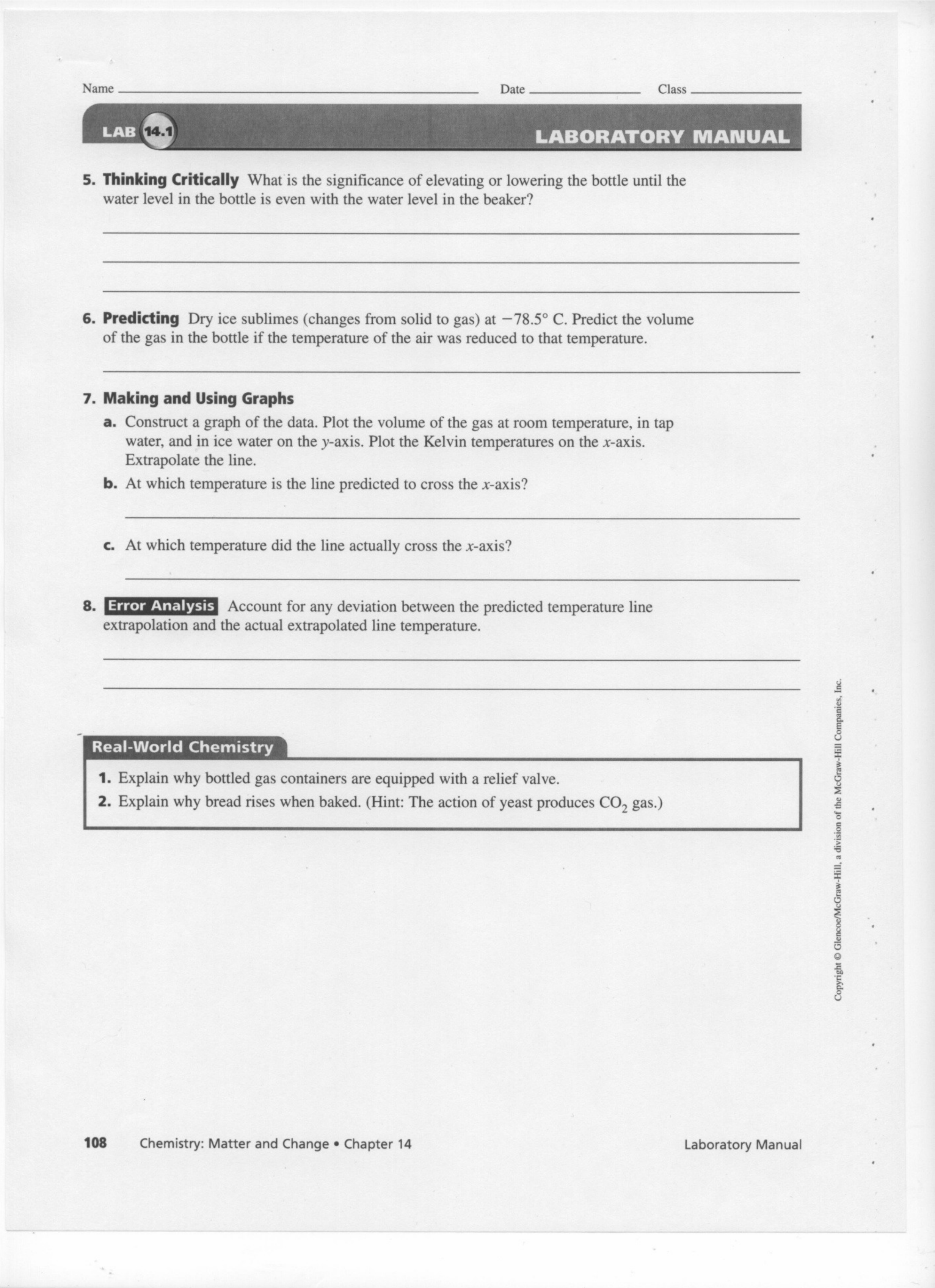
Data and Observations

Data Table 1

	Part A	Part B
Room temperature (°C)		
Temperature of boiling water (°C)		
Temperature of boiling water (K)		
Final temperature of cooling water (°C)		
Final temperature of cooling water (K)		
Total volume of air in bottle at higher temperature (mL)		
Change in volume of air in bottle (mL)		
Volume of air at lower temperature (mL)		

Analyze and Conclude

1. **Measuring and Using Numbers** Calculate the Kelvin temperatures of the water and record your answers in **Data Table 1.**
2. **Measuring and Using Numbers** Subtract the change in the volume of air in the bottle from the total volume of air in the bottle at a higher temperature to get the volume of air at a lower temperature. Record your answer in **Data Table 1.**
3. **Measuring and Using Numbers** Use the equation $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ to calculate the expected volume of air when cooled in tap water.
4. **Comparing and Contrasting** Compare the expected final volume with the calculated final volume.



Name ________________________ Date ____________ Class ____________

5. **Thinking Critically** What is the significance of elevating or lowering the bottle until the water level in the bottle is even with the water level in the beaker?

____

____

____

6. **Predicting** Dry ice sublimes (changes from solid to gas) at −78.5° C. Predict the volume of the gas in the bottle if the temperature of the air was reduced to that temperature.

____

7. **Making and Using Graphs**
   a. Construct a graph of the data. Plot the volume of the gas at room temperature, in tap water, and in ice water on the *y*-axis. Plot the Kelvin temperatures on the *x*-axis. Extrapolate the line.
   b. At which temperature is the line predicted to cross the *x*-axis?

   ____

   c. At which temperature did the line actually cross the *x*-axis?

   ____

8. **Error Analysis** Account for any deviation between the predicted temperature line extrapolation and the actual extrapolated line temperature.

____

____

Real-World Chemistry

1. Explain why bottled gas containers are equipped with a relief valve.
2. Explain why bread rises when baked. (Hint: The action of yeast produces CO_2 gas.)

Appendix D

"It's a Gas!" Information Sheet

THE CHALLENGE:
The GoGreen Recycling Center has a problem. Their workers are threatening to go "On Strike" because they want a new method of rinsing and crushing empty aluminum cans. Their employees think there is an easier, more efficient way of getting their job done. So, your team has been chosen to design a more efficient process of rinsing and crushing aluminum cans for the GoGreen Recycling Company. The GoGreen Recycling Company needs a proposal by next Wednesday, April 20 to keep their workers from going "On Strike".

BIG QUESTION: How does your "new" process demonstrate the application of the gas laws?

JOB ASSIGNMENTS:
Activity Manager (1) = ____

- Checking with the "Experts", presenter

Graphic Designer (2) = ____

- Presentation Poster

Reporter (2) = ____

- Claims and Evidence, data collection and analysis

Photographer (1-2) = ____

- visual presentation of experimental procedure and results

Testers (2) = ____

- Perform the experiment

Teacher Signature:______________________________

PROJECT TIMELINE:
Day 1 (Friday, April 15):

- Job Assignments
- Experimental procedure
- Begin testing
- Rough draft of presentation poster

Day 2 (Monday, April 18):

- Finish Testing
- Collecting Data and analysis
- Making claims, supporting claims with evidence from testing
- Revision of presentation poster
- HW: Checking with the "Experts"

Day 3 (Tuesday, April 19):

- Making Claims, Providing Evidence, Checking the experts
- Final Draft of presentation poster

Day 4 (Wednesday, April 20):

- READY OR NOT = Presentation of demonstration: How does it show the application of the gas laws?

THE CHALLENGE:

The Simply Elegant Food Processing Plant has a problem. Their production of their new prepared salads is very low and they can't meet the demands of their customers. Their engineers figured out that there is serious lag in production at the egg slicer. Currently, the hard-boiled eggs are transported by hand from the peeler to the slicer, causing a serious lag in production of the prepared salads. In addition, employees have been getting hurt when they put the eggs in the slicer. The employees know there is a way to connect the machines and have the eggs move between these two machines so that the slicing process occurs faster and safer. The Simple Elegant Food processing engineers don't think the eggs will move through the connection they designed and cannot figure out a way to get the hard-boiled eggs through the connection without using worker's hands or tools. Your team has been chosen to design a process of getting the eggs through the connection between the peeler and the slicer without the use of workers hands or tools. The Simple Elegant CFO needs a proposal by next Wednesday, April 20 to keep their customers from finding another vender for their prepared salads.

BIG QUESTION: How does your "new" connection demonstrate the application of the gas laws?

JOB ASSIGNMENTS:

Activity Manager (1) = ____

- Checking with the "Experts", presenter

Graphic Designer (2) = ____

- Presentation Poster

Reporter (2) = ____

- Claims and Evidence, data collection and analysis

Photographer (1-2) = ____

- visual presentation of experimental procedure and results

Testers (2) = ____

- Perform the experiment

Teacher Signature:____________________________________

PROJECT TIMELINE:

Day 1 (Friday, April 15):

- Job Assignments
- Experimental procedure
- Begin testing
- Rough draft of presentation poster

Day 2 (Monday, April 18):

- Finish Testing
- Collecting Data and analysis
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- Revision of presentation poster
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Day 3 (Tuesday, April 19):

- Making Claims, Providing Evidence, Checking the experts
- Final Draft of presentation poster

Day 4 (Wednesday, April 20):

- READY OR NOT = Presentation of demonstration: How does it show the application of the gas laws?

THE CHALLENGE:

The Happy Times Party Supply Factory has a problem. Their new product, the "Memory Maker Balloon", has been leaving their warehouse under- filled. It seems that the final product is not filled with the required amount of treats and toys that are advertised on their website. Their factory engineers found that the "presenter" machines are not opening the balloons wide enough, nor deep enough for the "filler" machines to place the required amount of treats and toys into each Memory Maker balloon. Their employees think there is a simple answer to getting the "presenter" machines to open the balloons wide enough and deep enough. So, your team of factory workers has been chosen to design a more efficient process of opening and widening the balloons for the "filler" machine so that the Happy Times Party Supply Factory can ship the correctly advertized Memory Maker Balloon. The CEO needs a proposal by next Wednesday, April 20 to keep the on-line customers satisfied and for you to keep your job.

BIG QUESTION: How does your "new" process demonstrate the application of the gas laws?

JOB ASSIGNMENTS:

Activity Manager (1) = ____________________
- Checking with the "Experts", presenter

Graphic Designer (2) = ____________________
- Presentation Poster

Reporter (2) = ____________________
- Claims and Evidence, data collection and analysis

Photographer (1-2) = ____________________
- visual presentation of experimental procedure and results

Testers (2) = ____________________
- Perform the experiment

Teacher Signature:____________________

PROJECT TIMELINE:

Day 1 (Friday, April 15):
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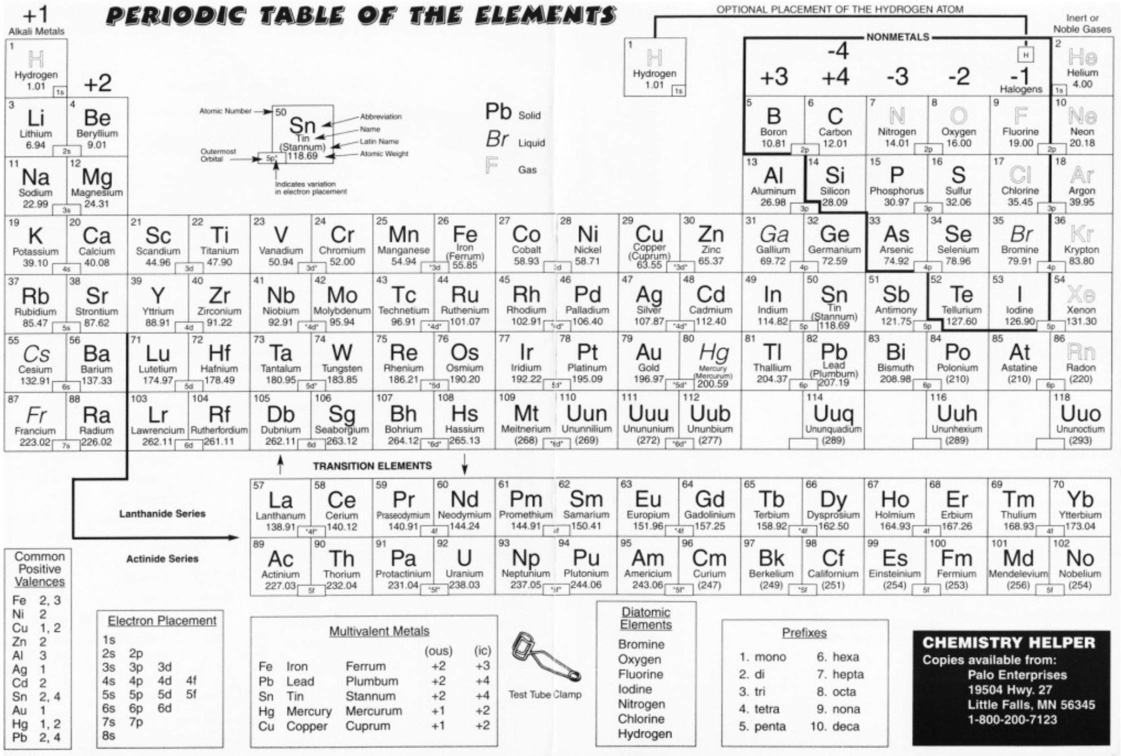
- Making Claims, Providing Evidence, Checking the experts
- Final Draft of presentation poster

Day 4 (Wednesday, April 20):
- READY OR NOT = Presentation of demonstration: How does it show the application of the gas laws?

Appendix E

Chemistry Helper



PERIODIC TABLE OF THE ELEMENTS

OPTIONAL PLACEMENT OF THE HYDROGEN ATOM

NONMETALS

Atomic Number → 50; Sn ← Abbreviation; Tin ← Name; (Stannum) ← Latin Name; 118.69 ← Atomic Weight; Outermost Orbital → 5p"; Indicates variation in electron placement

Pb Solid
Br Liquid
F Gas

+1 Alkali Metals	+2											+3	-4 +4	-3	-2	H -1 Halogens	Inert or Noble Gases
1 H Hydrogen 1.01 1s																	2 He Helium 4.00 1s
3 Li Lithium 6.94 2s	4 Be Beryllium 9.01											5 B Boron 10.81 2p	6 C Carbon 12.01	7 N Nitrogen 14.01 2p	8 O Oxygen 16.00	9 F Fluorine 19.00 2p	10 Ne Neon 20.18
11 Na Sodium 22.99 3s	12 Mg Magnesium 24.31											13 Al Aluminum 26.98 3p	14 Si Silicon 28.09	15 P Phosphorus 30.97 3p	16 S Sulfur 32.06	17 Cl Chlorine 35.45 3p	18 Ar Argon 39.95
19 K Potassium 39.10 4s	20 Ca Calcium 40.08	21 Sc Scandium 44.96 3d	22 Ti Titanium 47.90	23 V Vanadium 50.94 3d"	24 Cr Chromium 52.00	25 Mn Manganese 54.94 '3d	26 Fe Iron (Ferrum) 55.85	27 Co Cobalt 58.93 3d	28 Ni Nickel 58.71	29 Cu Copper (Cuprum) 63.55 "3d"	30 Zn Zinc 65.37	31 *Ga* Gallium 69.72 4p	32 Ge Germanium 72.59	33 As Arsenic 74.92 4p	34 Se Selenium 78.96	35 *Br* Bromine 79.91 4p	36 Kr Krypton 83.80
37 Rb Rubidium 85.47 5s	38 Sr Strontium 87.62	39 Y Yttrium 88.91 4d	40 Zr Zirconium 91.22	41 Nb Niobium 92.91 "4d"	42 Mo Molybdenum 95.94	43 Tc Technetium 96.91 "4d"	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91 "4d"	46 Pd Palladium 106.40	47 Ag Silver 107.87 "4d"	48 Cd Cadmium 112.40	49 In Indium 114.82 5p	50 Sn Tin (Stannum) 118.69	51 Sb Antimony 121.75 5p	52 Te Tellurium 127.60	53 I Iodine 126.90 5p	54 Xe Xenon 131.30
55 *Cs* Cesium 132.91 6s	56 Ba Barium 137.33	71 Lu Lutetium 174.97 5d	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95 5d"	74 W Tungsten 183.85	75 Re Rhenium 186.21 '5d	76 Os Osmium 190.20	77 Ir Iridium 192.22 5d"	78 Pt Platinum 195.09	79 Au Gold 196.97 "5d"	80 *Hg* Mercury (Mercurum) 200.59	81 Tl Thallium 204.37 6p	82 Pb Lead (Plumbum) 207.19	83 Bi Bismuth 208.98 6p	84 Po Polonium (210)	85 At Astatine (210) 6p	86 Rn Radon (220)
87 *Fr* Francium 223.02 7s	88 Ra Radium 226.02	103 Lr Lawrencium 262.11 6d	104 Rf Rutherfordium 261.11	105 Db Dubnium 262.11 6d	106 Sg Seaborgium 263.12	107 Bh Bohrium 264.12 "6d"	108 Hs Hassium 265.13	109 Mt Meitnerium (268) "6d"	110 Uun Ununnilium (269)	111 Uuu Unununium (272) "6d"	112 Uub Ununbium (277)		114 Uuq Ununquadium (289)		116 Uuh Ununhexium (289)		118 Uuo Ununoctium (293)

TRANSITION ELEMENTS

Lanthanide Series	57 La Lanthanum 138.91 "4f"	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91 4f	60 Nd Neodymium 144.24	61 Pm Promethium 144.91 4f	62 Sm Samarium 150.41	63 Eu Europium 151.96 '4f	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92 '4f	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93 4f	68 Er Erbium 167.26	69 Tm Thulium 168.93 4f	70 Yb Ytterbium 173.04
Actinide Series	89 Ac Actinium 227.03 5f	90 Th Thorium 232.04	91 Pa Protactinium 231.04 "5f"	92 U Uranium 238.03	93 Np Neptunium 237.05 "5f"	94 Pu Plutonium 244.06	95 Am Americium 243.06 "5f"	96 Cm Curium (247)	97 Bk Berkelium (249) "5f	98 Cf Californium (251)	99 Es Einsteinium (254) 5f	100 Fm Fermium (253)	101 Md Mendelevium (256) 5f	102 No Nobelium (254)

Common Positive Valences

Fe	2, 3
Ni	2
Cu	1, 2
Zn	2
Al	3
Ag	1
Cd	2
Sn	2, 4
Au	1
Hg	1, 2
Pb	2, 4

Electron Placement

1s
2s 2p
3s 3p 3d
4s 4p 4d 4f
5s 5p 5d 5f
6s 6p 6d
7s 7p
8s

Multivalent Metals

			(ous)	(ic)
Fe	Iron	Ferrum	+2	+3
Pb	Lead	Plumbum	+2	+4
Sn	Tin	Stannum	+2	+4
Hg	Mercury	Mercurum	+1	+2
Cu	Copper	Cuprum	+1	+2

Test Tube Clamp

Diatomic Elements

Bromine
Oxygen
Fluorine
Iodine
Nitrogen
Chlorine
Hydrogen

Prefixes

1. mono
2. di
3. tri
4. tetra
5. penta
6. hexa
7. hepta
8. octa
9. nona
10. deca

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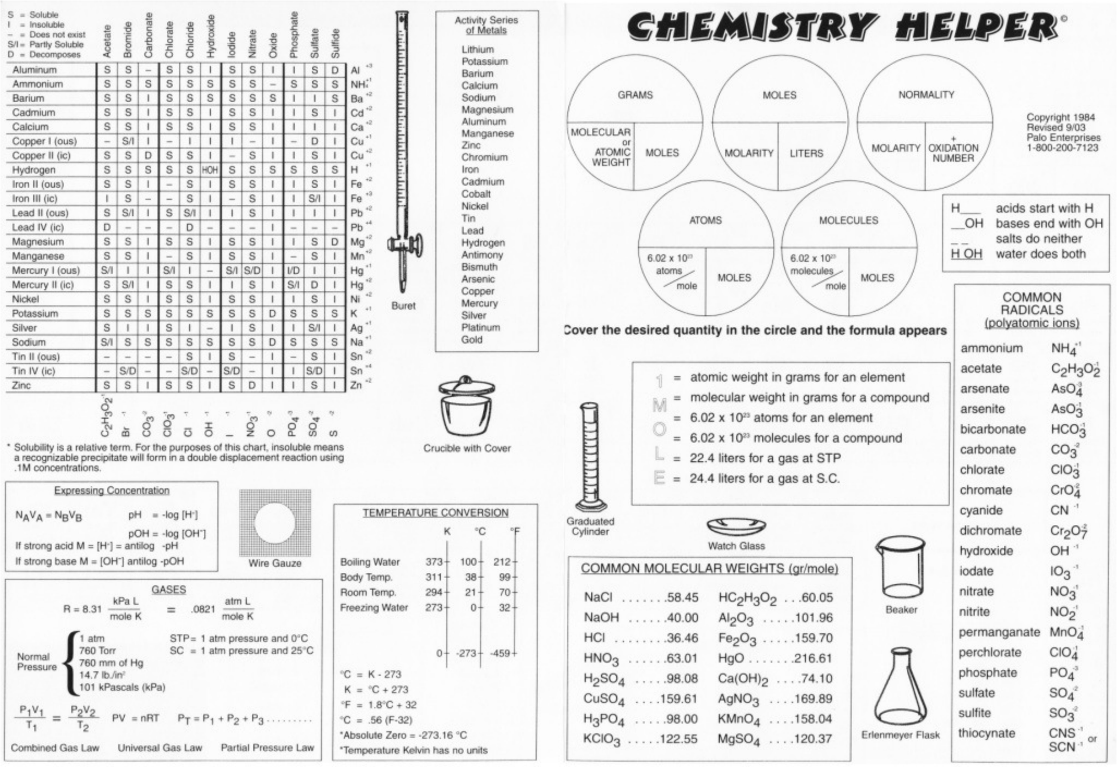

S = Soluble
I = Insoluble
– = Does not exist
S/I = Partly Soluble
D = Decomposes

	Acetate	Bromide	Carbonate	Chlorate	Chloride	Hydroxide	Iodide	Nitrate	Oxide	Phosphate	Sulfate	Sulfide	
Aluminum	S	S	–	S	S	I	S	S	I	I	S	D	Al^{+3}
Ammonium	S	S	S	S	S	S	S	S	–	S	S	S	NH_4^{+1}
Barium	S	S	I	S	S	S	S	S	S	I	I	S	Ba^{+2}
Cadmium	S	S	I	S	S	I	S	S	I	I	S	I	Cd^{+2}
Calcium	S	S	I	S	S	I	S	S	I	I	I	I	Ca^{+2}
Copper I (ous)	–	S/I	I	–	I	I	I	–	I	–	D	I	Cu^{+1}
Copper II (ic)	S	S	D	S	S	I	–	S	I	I	S	I	Cu^{+2}
Hydrogen	S	S	S	S	S	HOH	S	S	S	S	S	S	H^{+1}
Iron II (ous)	S	S	I	–	S	I	S	S	I	I	S	I	Fe^{+2}
Iron III (ic)	I	S	–	–	S	I	–	S	I	I	S/I	I	Fe^{+3}
Lead II (ous)	S	S/I	I	S	S/I	I	I	S	I	I	I	I	Pb^{+2}
Lead IV (ic)	D	–	–	–	D	–	–	–	I	–	–	–	Pb^{+4}
Magnesium	S	S	I	S	S	I	S	S	I	I	S	D	Mg^{+2}
Manganese	S	S	I	–	S	I	S	S	I	–	S	I	Mn^{+2}
Mercury I (ous)	S/I	I	I	S/I	I	–	S/I	S/D	I	I/D	I	I	Hg^{+1}
Mercury II (ic)	S	S/I	I	S	S	I	I	S	I	S/I	D	I	Hg^{+2}
Nickel	S	S	I	S	S	I	S	S	I	I	S	I	Ni^{+2}
Potassium	S	S	S	S	S	S	S	S	D	S	S	S	K^{+1}
Silver	S	I	I	S	I	–	I	S	I	I	S/I	I	Ag^{+1}
Sodium	S/I	S	S	S	S	S	S	S	D	S	S	S	Na^{+1}
Tin II (ous)	–	–	–	–	S	I	S	–	I	–	S	I	Sn^{+2}
Tin IV (ic)	–	S/D	–	–	S/D	–	S/D	–	I	I	S/D	I	Sn^{+4}
Zinc	S	S	I	S	S	I	S	D	I	I	S	I	Zn^{+2}
	$C_2H_3O_2^{-1}$	Br^{-1}	CO_3^{-2}	ClO_3^{-1}	Cl^{-1}	OH^{-1}	I^{-1}	NO_3^{-1}	O^{-2}	PO_4^{-3}	SO_4^{-2}	S^{-2}	

* Solubility is a relative term. For the purposes of this chart, insoluble means a recognizable precipitate will form in a double displacement reaction using .1M concentrations.

Buret

Activity Series of Metals

Lithium
Potassium
Barium
Calcium
Sodium
Magnesium
Aluminum
Manganese
Zinc
Chromium
Iron
Cadmium
Cobalt
Nickel
Tin
Lead
Hydrogen
Antimony
Bismuth
Arsenic
Copper
Mercury
Silver
Platinum
Gold

Crucible with Cover

Expressing Concentration

$N_AV_A = N_BV_B$

pH = -log [H^+]

pOH = -log [OH^-]

If strong acid M = [H^+] = antilog -pH

If strong base M = [OH^-] antilog -pOH

Wire Gauze

GASES

$$R = 8.31\ \frac{\text{kPa L}}{\text{mole K}} = .0821\ \frac{\text{atm L}}{\text{mole K}}$$

Normal Pressure:
1 atm
760 Torr
760 mm of Hg
14.7 lb./in²
101 kPascals (kPa)

STP = 1 atm pressure and 0°C
SC = 1 atm pressure and 25°C

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \qquad PV = nRT \qquad P_T = P_1 + P_2 + P_3 \ldots\ldots\ldots$$

Combined Gas Law — Universal Gas Law — Partial Pressure Law

TEMPERATURE CONVERSION

	K	°C	°F
Boiling Water	373	100	212
Body Temp.	311	38	99
Room Temp.	294	21	70
Freezing Water	273	0	32
	0	-273	-459

°C = K - 273
K = °C + 273
°F = 1.8°C + 32
°C = .56 (F-32)
*Absolute Zero = -273.16 °C
*Temperature Kelvin has no units

CHEMISTRY HELPER©

GRAMS / MOLECULAR or ATOMIC WEIGHT | MOLES

MOLES / MOLARITY | LITERS

NORMALITY / MOLARITY | + OXIDATION NUMBER

ATOMS / 6.02 x 10²³ atoms/mole | MOLES

MOLECULES / 6.02 x 10²³ molecules/mole | MOLES

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H___	acids start with H
__OH	bases end with OH
_ _	salts do neither
H OH	water does both

Cover the desired quantity in the circle and the formula appears

1 MOLE
= atomic weight in grams for an element
= molecular weight in grams for a compound
= 6.02 x 10²³ atoms for an element
= 6.02 x 10²³ molecules for a compound
= 22.4 liters for a gas at STP
= 24.4 liters for a gas at S.C.

Graduated Cylinder

Watch Glass

Beaker

Erlenmeyer Flask

COMMON MOLECULAR WEIGHTS (gr/mole)

NaCl	58.45	$HC_2H_3O_2$	60.05
NaOH	40.00	Al_2O_3	101.96
HCl	36.46	Fe_2O_3	159.70
HNO_3	63.01	HgO	216.61
H_2SO_4	98.08	$Ca(OH)_2$	74.10
$CuSO_4$	159.61	$AgNO_3$	169.89
H_3PO_4	98.00	$KMnO_4$	158.04
$KClO_3$	122.55	$MgSO_4$	120.37

COMMON RADICALS (polyatomic ions)

ammonium	NH_4^{+1}
acetate	$C_2H_3O_2^{-1}$
arsenate	AsO_4^{-3}
arsenite	AsO_3^{-1}
bicarbonate	HCO_3^{-1}
carbonate	CO_3^{-2}
chlorate	ClO_3^{-1}
chromate	CrO_4^{-2}
cyanide	CN^{-1}
dichromate	$Cr_2O_7^{-2}$
hydroxide	OH^{-1}
iodate	IO_3^{-1}
nitrate	NO_3^{-1}
nitrite	NO_2^{-1}
permanganate	MnO_4^{-1}
perchlorate	ClO_4^{-1}
phosphate	PO_4^{-3}
sulfate	SO_4^{-2}
sulfite	SO_3^{-2}
thiocynate	CNS^{-1} or SCN^{-1}