The Purposeful Position of PhET Simulations in a 5E Model: A Rationale for PhET Integration in the Explore (Introduction), Explain (Core Instruction) and Elaborate (Assessment) Phases of NYS Chemistry Units

Zackary D. Waile
The College at Brockport, zwail1@brockport.edu

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The Purposeful Position of PhET Simulations in a 5E Model: A Rationale for PhET Integration in the Explore (Introduction), Explain (Core Instruction) and Elaborate (Assessment) Phases of NYS Chemistry Units

By

Zackary D. Waild

A thesis submitted to the Department of Education of The College at Brockport, State University of New York, in partial fulfillment of the requirements for the degree of Master of Science

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Contemporary Issues in Science Education

Literacy

Literacy is an important aspect of education and is imperative to working and living in the real world. Because of this importance, new sets of standards, including the CCSS and the NGSS, have begun to include literacy in the requirements for science classrooms (Drew & Thomas, 2017). The NGSS and CCSS also seek to lower the literacy gap in the population of the United States, and the literacy aspect of them were created to improve literacy for all students. These requirements have necessitated a shift in teaching styles for science educators in order to include literacy in the curriculum, including both science literacy and general literacy. Science literacy, as described by the NGSS, includes students’ abilities to read, write and debate science content using visual, auditory and digital media. This description of literacy is in slight contrast to that described in the CCSS standards, which may influence the way science educators teach literacy to their students (Drew & Thomas, 2017).

Findings indicate that, for the CCSS standards, educators responded on the entire range of the scale, from never to always, for how often the practices outlined were used (Drew & Thomas, 2017). Of the outlined practices, the most implemented was the use of symbols, vocabulary terms and content specific language, with 61% of participants responding with very often or more frequently. The next highest, following the similar requirement of very often or more frequently, was the use of procedures to carry out experiments at 46%. By far the lowest implemented practice was analysis of the author’s purpose for writing a text, with over 80% of the participants responding with occasionally or less frequently. Similarly, the NGSS aspect of the survey found varied results with the most frequent literacy related task being the analysis and interpretation of data, with 59% of the participants responding that it was used often. Only 39%
of teacher respondents responded that they required students to construct arguments and critique others about their reasoning. As for the final question, implementation of literacy based practices in the science classroom was significantly more frequent with practices that were believed by science educators to be the most relevant to science. Due to this, the NGSS was seen as more relevant, and thus more important, to science educators than the CCSS (Drew & Thomas, 2017).

In conclusion, very little literacy training was noted by educators in the study, making it difficult for them to actually teach literacy in the classroom. With an increased importance of literacy in the NGSS and CCSS, literacy classes are being implemented into teacher preparation programs but much of these deal with literacy overall and not scientific literacy specifically. Current educators should also be aware of the necessity of scientific literacy and should reflect on their own practices to ensure that students are learning what they need and are required to learn.

**Wait-Time**

Higher order thinking is an important aspect of education and has been stressed throughout a large portion of educational history, specifically in regards to Bloom’s Taxonomy. To develop these skills, educators most often rely on wait-time, time between when a question is asked and either an answer is received or additional prompting is given (Gilliam, Baker, Rayfield, Ritz, & Cummins, 2018). It has often been suggested that educators utilize between 3 and 5 seconds of wait time, allowing for students to process the information or question they receive (Gilliam et al., 2018).

Results regarding the first part of the central research question, effects of difficulty after a five second wait time, were similar for both low order and higher order questions (Gilliam et al., 2018). In both cases, participants’ heart rates tended to decrease through the first three seconds, a
side effect of cognitive processing, and then an increase back to the normal, resting heart rate. When questions requiring higher order thinking were used, it was found that, in general, heart rates were slightly lower than those after a lower order question was asked, but the increase back to the normal, resting heart rate followed a similar pattern. For the second half of the research question, the use of a ten second period of wait time, similar results were found. Heart rates tended to drop for the first few seconds and then increase back to baseline levels, with higher order questions causing heart rates to drop slightly lower. However, it was also seen that after eight seconds of the wait time had passed, the heart rates of participants started to decrease again, suggesting cognitive reengagement, likely as a result of the reconsideration of the initial thoughts of participants. Overall, it was seen that higher order questions require slightly deeper and more intense cognitive processing than low order questions, but that students appear to come to an answer in a very similar amount of time (Gilliam et al., 2018).

There are several weaknesses for this study, the first being the nature of the participants themselves. Since participants were undergraduate students, the findings are somewhat limited in their applicability to secondary school students. It is possible that findings with high school juniors and seniors would be similar, but it is unknown at what point, if at all, the accuracy of these findings begins to drop off. The participants were also all college students with above average GPAs, indicating that they were likely to have been at least slightly in the “gifted” range of students while in high school, again limiting the generalizability of the findings. It is entirely possible that students may exhibit lower heart rates for longer or shorter periods of time, especially students with cognitive disabilities and those in special education programs.

While this study does not involve high school students, there are implications for high school educators. Based on the conclusions drawn from this study, wait time is an important
aspect of information processing for students of all ages and, thus, wait time is essential to
student learning and engagement in content dialogue and discourse. It should also be noted that
three seconds appears to be the absolute minimum amount of wait time required for students to
engage with the question cognitively, indicating that it may be most beneficial for educators to
wait slightly longer in order for students to form their thoughts into a coherent answer. With the
second wave of cognitive processing that seems to occur after eight seconds, educators may wish
to implement even longer periods of wait time if they find students’ initial responses incorrect to
allow for reconsideration.

Collaboration

Collaboration is an important aspect of real world science which is lacking, somewhat, in
the high school chemistry curriculum (Patchen & Smithenry, 2015). Science education should
become more authentic, in that it mimics how science actually occurs in the workplace and
encourages participation, argumentation and cooperation. Participation is one of the main ways
in which information is exchanged between individuals in the classroom and is structured in a
few ways. The first being direct instruction (DI), in which the teacher has full authority over
what students learn and how they learn it, creating a more passive learning experience for
students. Small group work (SGW) is another structure of participation which is more active than
DI and involves students working in groups while whole class inquiry (WCI) in which students
take over almost complete control of their learning (Patchen & Smithenry, 2015).

Patchen and Smithenry (2015) sought to answer the question of how the use of a complex
participation structure affects student understanding of what science is in the classroom. To do so
they compared student achievement and perceptions of the students of two different chemistry
educators, one who utilized the WCI structure and the other who did not. Students were given an
achievement test to collect quantitative data, and qualitative data was collected through the use of observations and interviews with the educators. Students were also given a two part survey in the second phase of the study. There were 117 student participants during the first phase of the study, which lasted one entire school year, and 111 participants in the second phase the following year. Student participants were in an honors chemistry course at an affluent suburb in which much of the population was considered upper-middle class (Patchen & Smithenry, 2015).

The class which engaged in WCI found initial difficulties in coming to a consensus about whatever they were learning, or planning to learn about (Patchen & Smithenry, 2015). As students became more familiar with the process, however, difficulties in collaboration began to resolve themselves and students produced a quality learning product. The other class, which did not engage in WCI, did not have any of the same collaborative difficulties as the teacher maintained authority in the classroom. A pre-test was given at the beginning of the school year, before WCI was implemented, and both classes scored similarly, indicating no difference between them in terms of initial content understanding. When the post-test was taken, students in the WCI class scored significantly higher than their peers. Even with the difficulties associated with WCI, the students still performed better, supporting the idea that, even though the WCI structure may take longer, student achievement was not negatively affected (Patchen & Smithenry, 2015).

In the phase 2 survey, students reported no significant differences in perception of their teacher or in their perception of self-efficacy (Patchen & Smithenry, 2015). There were differences in other fields, however. Students in the WCI class reported better feelings of community, agency, and participation than students who were not in the WCI class. In contrast to this, the WCI students did report feeling significantly more uncomfortable with this learning
style than their peers. Students in the WCI class also reported that they believed they were being taught collaborative skills rather than chemistry content, while the reverse was true for the non-WCI class (Patchen & Smithenry, 2015).

While this study does have its strengths, namely in the amount of time devoted to it (two full school years), there are several weaknesses. The first weakness is that there were only two different chemistry teacher participants and they were both in the same school. Because of this, there was little to no differences in SES and the amount of diversity of the participants. It is highly possible that students from different SES, those with more diverse backgrounds, and even those from smaller or larger schools, may have different thoughts about the effectiveness of the WCI approach. Another weakness is the selection of the chemistry classes. Both classes were honors classes, which limits the generalizability of the findings. Students in honors classes will have significantly different opinions on styles of learning than students who are not in honors classes.

Implications from this study are significant, although somewhat limited. With the findings from the quantitative aspect of this study educators should at least consider using more student-directed and active approaches to learning in the chemistry classroom. There is certainly no negative impact, as far as achievement, to allowing more collaboration in the classroom and engaging students in collaborative practices will certainly help prepare them for authentic science experiences in the real world. While the academic benefits for WCI are apparent, students also reported greater feelings of discomfort in this environment. Due to this, it may be beneficial for educators to slowly integrate WCI into their classroom by handing over more control to students over the course of the school year, rather than all at one time. Educators could
also use WCI for certain topics or activities to increase collaborative skills and use DI and SGW for other topics or activities, to gain the benefits of both structures of participation.

Scientific Argumentation

Scientific argumentation is another major factor of authentic science learning and can increase scientific literacy for students (Sampson & Clark, 2009). While scientific argumentation is useful in aiding student achievement, it is a difficult task for most students. Most students struggle to propose, support, critique and refine their arguments. It has been suggested that when students engage in collaborative group work, they are also engaging in scientific argumentation. The arguments produced by groups have the possibility to be better because students can pool their knowledge together to come up with a sufficient argument. (Sampson & Clark, 2009).

Sampson and Clark (2009) looked into three different questions about the impact of collaboration on argumentative skills of students in science classrooms: (1) Do groups create better arguments than individuals? (2) Do individuals internalize and understand the argument they created in their group? And (3) Does group work lead to an increase in learning as compared to individual work? Participating students were from a large public high school and were randomly assigned to the two conditions: group work or individual work. There were 168 participating students in total, from six different chemistry classes, with two participating educators. The students engaging in group work were in groups of three of the same gender. Student participants were asked to solve a complex task that required some form of argumentation to explain. They were asked to pick from six possible explanations to the phenomenon and then create a written argument justifying their choice. After coming up with their argument, students from both groups were required to create their own written argument about a similar problem, involving the same content explanations but a different scenario, to the
one they had worked on previously. All data collection occurred over a four day, consecutive, period, consisting of 50 minute classes. The students who were assigned to the individual work condition were separated into three levels: the top scoring students, the middle scoring students and the bottom scoring students (Sampson & Clark, 2009).

Findings from analysis of the data indicate that the students working in the group setting produced significantly better arguments than the bottom scoring individual students, comparable arguments to the middle scoring individual students and significantly worse arguments than the top scoring individuals (Sampson & Clark, 2009). The less successful triads were observed to discuss fewer content relevant ideas and were more likely to accept ideas without any critical conversation. They also did not use the data available to them to support their argument as evidence. Data collected to support the second posed question, whether students internalized their arguments, lead to interesting results. A majority (54%) of students who worked individually produced the same arguments when required to respond to the second scenario, while only 28% of the students who worked in groups produced the same arguments. As for the quality of these arguments, 88% of students who worked individually produced arguments of equal or better quality, whereas only 65% of students who worked in groups produced arguments of equal quality. Interestingly, students who participated in the collaborative condition produced superior arguments on their own after collaboration when answering mastery or transfer problems (Sampson & Clark, 2009).

This study does have its weaknesses. The first being the limited sample size of the student participants. While there was a relatively large amount of participating students, they all came from one school and there were only two educators, with two different teaching styles, participating. With such varied styles of learning and teaching, some educators may find that the
collaborative argument creation lends itself better to their classroom environment, while other educators may not, somewhat limiting the findings. Another weakness was in the creation of the triads. For one, it is not always possible for a teacher to create equal groups of only one gender. The academic achievement and ability of group members was also not taken into account at all during the study. The final weakness is in the overall time taken to conduct the study. With such a short amount of time with only a single topic for argumentation, the results of this study are limited in regards to their application for the entire curriculum.

Implications from this study are significant. While group work tends to lead to comparable or better arguments for most students, the top students still create better arguments in an individual setting. Because of this, it is possible that students who know how to create arguments are limited due to the requirement of working with others. Perhaps giving students the choice of working individually or in a group would result in the greatest overall arguments. Educators should also emphasize the use of data to support arguments to students and should be sure to keep students in groups on task to improve their argument quality. Educators should also be aware that students who work in groups may not fully understand the argument their group is making and may need to make another assignment students need to complete on their own to assess understanding. It is also worth noting, that students do produce better arguments after bouncing ideas off of each other during collaborative efforts and get a greater understanding of what an argument is. Based on findings, educators should be willing to allow collaborative efforts between students to aid in student understanding of what constitutes a high quality argument but should also give students chances to create arguments individually. A balance between individual efforts and group efforts should be achieved to give students the best chance of creating successful and quality arguments.


Laboratories

Lab work is a staple of high school science education, especially in chemistry. Its importance and relevance to content standards, textbooks and curriculum requirements cannot be understated and it may even be seen as the defining characteristic of the science classroom (Hogstrom, Ottander, & Benckert, 2010). Lab work is believed to be the key process that links the chemistry content and theory with real world practices. It has been said that lab work helps students learn the chemistry concepts and increases student motivation, engagement, practical skills and problem solving skills. The lab work also allows students to interact with chemistry knowledge that is already known and accepted in the scientific community, allowing some connection between school work and the real world. There are several difficulties that have been continuously associated with lab work including: the lack of time, lack of money and the issue of the social involvement of students during lab sessions (Hogstrom, Ottander, & Benckert, 2010).

For the purpose of this study, four different questions were posed to guide the research: (1) What does the teacher want students to learn in a laboratory environment, (2) How do interactions between students and between the teacher and student groups contribute to the learning environment, (3) What do students think their teacher wants them to learn from the laboratory experience and (4) To what extent are the teacher created goals met by students after the lab work has completed (Hogstrom, Ottander, & Benckert, 2010). To meet these objectives, an explanatory case study was conducted in a single classroom in an urban secondary school in Sweden. There were 16, eighth grade student participants and the single teacher participant. Data was collected via audio and video recording over four lessons. There was also an interview conducted before and after the laboratory work with the participating teacher and another with
students directly after they finished the laboratory exercise (Hogstrom, Ottander, & Benckert, 2010).

Findings from this study indicate that educators want students to learn most about the chemistry behind the experiment during lab exercises and to extend understanding of the content to the practical application they are working on (Hogstrom, Ottander, & Benckert, 2010). The teacher participant also wanted students to discover the content themselves rather than being told about it. During the lab exercise, students were encouraged to work together to solve their task without much interference from the teacher. It was seen that many student groups understood what to do throughout the lab by following the laboratory manual handout but would often check back with the teacher to make sure they were doing it right. These check-ins with the teacher appeared to be the most significant tool for student learning, as it allowed students to expand upon what they were learning and clarify the connection to the content by receiving probing questions from the teacher. Interestingly, most students believed that their teacher wanted them to learn ideas that were different from what the teacher actually wanted them to learn. Students believed that the important thing for them to take away from the lab was lab safety. Many students cited concerns when dealing with the chemicals due to their hazardous nature and some had adverse reactions to their use which negatively affected their learning. Only about half of the student groups felt that their teacher wanted them to actually learn the chemistry content behind what they were doing in the lab. For the last posed question, that of whether or not the teacher goals were met, it appeared that the goals were partially fulfilled (Hogstrom, Ottander, & Benckert, 2010).

There are a few weaknesses to this study, mainly stemming from the participants themselves. The first of these weaknesses being the location the study was conducted in,
Sweden. All information collected from studies conducted in a different country should be considered less relevant to another country depending on the differences in their education system. The participants were only from a single classroom and there were only 16 students who actually participated in the study, as some students chose to not participate. Again, this limits these findings to being relevant to only that single classroom, although the suggestions and conclusions drawn may be, at least somewhat, applied to other contexts. The data collected was only qualitative in nature and the actual effect of student grades before and after conducting the lab exercise are unknown.

Implications for this study revolve mainly around the creation and implementation of labs themselves. Educators should be aware of, and take into consideration, the fact that students seem to focus on ideas that do not meet the goals set by the teacher. Because of this, educators may want to more explicitly state and reiterate what the goals for the lab activity are. If students are focusing more on lab safety, which is important but not the main purpose for the exercise, rather than the content, then they are not learning what they should be and connections will not be made. Considering that much of the learning that was done by students required interactions with the teacher, educators should focus more on either creating better scaffolds for their students during lab exercises, so that teacher interactions are unnecessary, or on interacting with each student group equally so that all students gain the most from the lab that they can. Educators may also wish to choose or create labs that involve less use of hazardous chemicals so that students are less worried about the chemicals they are using and more focused on learning the content. If educators wish to do labs that involve hazardous chemicals, it may be more beneficial for student learning if the teacher does the lab as a sort of demonstration for the class rather than having each student group working on it.
Inquiry

For much of the history of education, students have taken on the role of passive learners, sitting and absorbing information as their teacher lectures to them. They are trained to take information from their class, memorize it and then write it down on assessments and assignments. Often, students who fail to see the relevance and application of what they are learning become disengaged and unmotivated to learn. In more recent years, with the creation and implementation of the NGSS, the idea of inquiry based lessons and education has begun to arise to deal with this problem (Bassett, Martinez & Martin, 2014; Mumba, Banda, Chabelengula, & Dolenc, 2015; Vanhala, 2018).

To look into how inquiry effected her own students, Vanhala (2018) engaged in an action research project to answer two separate questions: (1) How does using inquiry-based learning affect student understanding of chemistry and (2) How does using inquiry affect the motivation of students to learn chemistry. The study was conducted in the author’s classroom in a rural school with low diversity and mainly middle class students. Three classes participated in this study with around 30 students in each (Vanhala, 2018).

Vanhala implemented inquiry by rephrasing the learning objectives for the unit as questions rather than statements (2018). The purpose of this was to allow students to work towards answering the main question throughout the unit, making better connections between what students were learning and the main topic they were supposed to be learning about. Students were encouraged to work with one another to answer this question, rather than being told the answer by Vanhala directly. To determine the effectiveness of her inquiry based unit, Vanhala compared the scores of the student participants with the scores of students who took the same unit, but without the inquiry approach, in the previous school year (2018).
Findings indicate that students did perform better on assessments regarding the stated learning objectives under the inquiry-based approach rather than the traditional, lecture style approach of the previous year (Vanhala, 2018). This increase was seen throughout each and every learning objective that was covered in the unit. After the completion of the unit, students were also asked to respond to a question about how well they understood the chemistry content. In comparison to before the inquiry based unit occurred, students tended to state that they had a better understanding of chemistry and no students responded that they had a low or very low understanding of chemistry, indicating that the inquiry-based unit increased student self-efficacy in regards to chemistry (Vanhala, 2018).

Students were also asked to respond to a prompt about how engaged and interested they were in learning the chemistry content before and after the implementation of the inquiry-based unit (Vanhala, 2018). Interestingly, a dramatic decrease in student responses of very engaged and very interested were seen after the unit. A shift towards the middle of the spectrum occurred with many students responding that they were only somewhat engaged or neutral. In contrast to student responses about engagement in the chemistry content, students did respond very positively to working with partners during the inquiry based unit with nearly 70% of students responding that they were very engaged in working with their group members. Students also stated both formally, in the form of exit slips, and informally, in the form of comments to Vanhala and other students, that they were more engaged during this inquiry-based unit than other units (2018).

Vanhala also found that students who struggled to pay attention during note-taking sessions, benefited greatly from being able to interact with group members when participating throughout the unit (2018). While some students thrived with this different approach to teaching,
other students were frustrated and struggled. Students who were traditionally successful in the class, expressed the greatest frustration with inquiry and many found that the inquiry based approach, in which they learned themselves rather than being taught by the teacher, to be pointless and difficult (Vanhala, 2018).

This study had a few weaknesses, mostly stemming from the fact that it was an action research project. Because of this, what Vanhala (2018) found was mostly only relevant to her own classroom and school district. Findings from the study were limited due to them coming from a single teacher in a single district, restricting the generalizability of the findings. It is highly possible that other educators would have found different results if they had conducted this project in their own classroom. The assessment measures limited this study as well. The assessments used were subjective and so the success of the inquiry based lesson was mainly based on the opinion of the researcher rather than concrete data. Because of this, it is possible that Vanhala had some form of bias in recording the data (2018).

Bassett, Martinez and Martin (2014), suggest an approach to teaching that creates active, rather than passive, learners similar to that of inquiry. Students and educators create a sort of partnership in the classroom with students taking more control over their own learning. Active learning has the potential to allow students to learn more about the process of learning and the actual concepts of the content they are learning about, rather than just the facts that are required to be memorized. Basset et al. (2014) put forth two types of active learning: self-directed learning (SDL) and activity-based learning (ABL).

When engaging in SDL, students take more responsibility for what they are actually learning (Bassett et al., 2014). Students are given the learning targets and standards they are expected to understand and then are required to choose their own learning tasks to help them
meet those goals. Building off of SDL, ABL is a style of active learning in which students are
given a choice about what activities they wish to engage in (Bassett et al., 2014).

The researchers sought to examine the relationship between student-directed activity-
based learning (SDABL) and student learning and achievement in a high school chemistry
classroom (Bassett et al., 2014). To do so: Bassett, Martinez and Martin posed three research
questions: (1) Will there be a significant difference for student achievement in SDABL classes as
opposed to traditional lecture style classes, (2) Will students respond more positively to SDABL
and (3) Will student participation increase with the more active learning style of SDABL. The
study was conducted in two classrooms containing 24 students each in a suburban high school.
One of these classes was focused on SDABL and the other was focused on teacher-centered
instruction (Bassett et al., 2014).

Students in both classes were given the same pretest before beginning the learning
segment and the same posttest at the end of the study (Bassett et al., 2014). Results indicated that
both classes showed significant improvement from the pretest to the posttest, as expected,
illustrating that students gained a significant amount of content knowledge from both the
SDABL learning style and the teacher-led instruction (TLI) learning style. Interestingly, the
scores of students in the TLI class were significantly higher than those of the students in the
SDABL class and students in the TLI group had much greater gains in chemistry knowledge as
opposed to those in the SDABL class (Basset et al, 2014).

Following a similar pattern to the quantitative data collected, qualitative data indicates
students’ preference for the traditional TLI approach over the SDABL approach (Bassett et al.,
2014). A survey was given at the end of the instructional period to students in both classes.
Students in the SDABL class agreed with the statements which related to a preference for TLI
over SDABL. Over half of the student participants in the SDABL class stated that they learned better when the teacher was available to explain the content, rather than learning the content on their own and showed a preference for TLI over SDABL in general. Student participation was also observed throughout the study and data indicated that student participation was the same or less for students in the SDABL class as compared to those in the TLI class (Bassett et al., 2014).

There are several weaknesses associated with this study. The first is the small sample size. Having only two classes of 24 students with the same teacher severely limits the results, as it is highly likely that the educators’ personal teaching style has some impact on student academic success. The study was also limited on time and, thus, on content covered. Since chemistry content is so varied and diverse in terms of the levels of abstractness and complexity, perhaps the topic covered was simply too difficult for students to take control of their learning on.

Findings from this study have interesting implications for science educators, especially chemistry educators. With such an emphasis on student centered learning and inquiry-based education to increase student engagement and participation, seeing results that indicate the opposite may lead educators to rethink some of their lessons. Bassett et al. (2014) also stated that their findings contradicted earlier findings, so it is possible that the issue of active learning vs. passive learning is something that should be considered on a case by case basis. Perhaps a blend of active learning and passive learning will result in the greatest increase in achievement, attitude and participation in the science classroom for all students.

Increasing the achievement, attitude and participation of all students is even more important with the update of IDEA in 2007, which required students with disabilities to receive their education with traditional students, making teaching approaches that benefit all students
even more important in the classroom (Mumba, Banda, Chabelengula, & Dolenc, 2015). In using inquiry-based instruction, it is possible for educators to effectively teach both students with disabilities and general education students while maintaining the fairness and equality required by IDEA. However, due to the relative newness of the NGSS many educators do not fully understand and comprehend what inquiry is and how it can be used in the inclusive classroom.

To determine what high school chemistry educators felt about the use of inquiry in the inclusive classroom, Mumba, Banda, Chabelengula and Dolenc (2015) collected data from a sample of 61 high school chemistry educators from across the United States. In collecting this data, Mumba et al. sought to answer two distinct questions: (1) What do these educators know about teaching in inclusive classrooms and (2) What are the benefits and challenges that these educators perceive about the use of inquiry in inclusive classrooms. In collecting data, Mumba et al. used a modified questionnaire that included two short answer, open-ended questions about the educators opinions of the benefits and challenges of using inquiry and two sections asking similar questions using a Likert-scale in which educators were asked to either select Strongly Agree, Agree, Neutral, Disagree or Strongly Disagree (Mumba et al., 2015).

Findings indicate that a vast majority of the educators believed that they were both benefits and challenges associated with the use of inquiry in the classroom (Mumba et al., 2015). For example, 87% of educators stated in the open-ended response that student engagement was increased through the use of inquiry, 65% of educators stated that inquiry sparks interest and 56% of educators stated that students were required to take ownership of the results of their inquiry based activity. As for the challenges associated with inquiry, 82% of teacher participants cited problems with meeting prior curricular goals, especially with regards to the amount of time and planning involved in creating inquiry-based learning opportunities; while 41% and 25% of
participant educators stated that the difference in student competence and achievement and the difficulty in creating effective student pairs, respectively, made it difficult to integrate inquiry into their learning segments. Overall, participating educators reported more benefits for students and more challenges for themselves in integrating inquiry (Mumba, et al., 2015).

There were several weaknesses to this study that may have influenced the results. The first was how the data was collected. While there were a fairly large amount of teacher participants from a wide range of demographics, the data that they provided was purely subjective and qualitative in nature. There was no concrete and significant data that was collected and presented that shows how inquiry effects student learning. Having educators fill out a survey and answer two open-ended questions also limits the findings of the study. With such a limited sample size of information, it is likely that there was more to teacher opinions than was presented, especially in regards to the Likert-scale survey. A further weakness is the lack of student voice in the study. It is possible that educators may misinterpret the way their students feel about the use of inquiry in the classroom. Student voice certainly matters in the implementation of the more innovative and unique types of teaching, as student perceptions of different types of teaching styles are what really matters.

There are certainly implications for educators as a result of the work of Mumba et al. (2015). While no concrete data was provided that could be used to sway educators either towards inquiry or away from it, the sentiments of the educators in the benefits of using inquiry based education is worth noting. The fact that there were little to no stated detriments to students and their academic performance, indicates that, at worse, students will be no worse off than they are under the traditional teaching styles. Many educators noted significant benefits in student behavior and engagement with the content material, which could translate to an increase in
academic performance. Educators should also be aware of the time and planning issues that come with creating inquiry based lessons, but should not be opposed to implementing inquiry as it is of benefit to their students.

**Spatial Ability**

Much of chemistry revolves around atoms and molecules, objects that are far too small to visualize without the use of a computer or other similar technological device or with high levels of spatial ability (Al-Balushi, Al-Musawi, Ambusaidi, & Al-Hairi, 2017). These topics are, for the most part, at the micro and symbolic level, rather than the more easily observable macro level. A high spatial ability allows students to mentally visualize and manipulate abstract ideas, reducing the need for computer simulations and animations. With higher levels of spatial ability, students may be better able to understand chemistry content (Al-Balushi et al., 2017).

This study investigates the effect that interacting with animations and simulations at the submicroscopic level have on student spatial thinking and reasoning ability (Al-Balushi et al., 2017). The two main questions to guide this research were: (1) What is the effect of using animations and simulations when studying chemistry content on students’ spatial ability and (2) What is the effect of using animations and simulations when studying chemistry content on students’ reasoning ability. There were 60 12th grade student participants that were considered middle to high achievers from middle class families in Oman. There were two different groups, one with 32 participants and one with 28 participants, which were taught by different educators. The study lasted 9 weeks with two lessons per day. The experimental group used tablets to interact with related simulations and animations, while the control group was taught using traditional teaching methods. Data was collected in the form of interviews, as well as from spatial ability and reasoning ability tools (Al-Balushi et al., 2017).
Findings from this study indicate that the experimental group, the group which used the animations and simulations, significantly outperformed the control group in regards to the spatial ability test (Al-Balushi et al., 2017). This difference, however, was not seen regarding differences in reasoning ability. Students with high spatial ability tended to use mental imaging and tracing, while those with low spatial ability tended to resort to physical motions such as rotating the test paper itself or drawing on other sheets of paper. For the second question, that of effect on reasoning ability, students tended to follow three different strategies in answering the questions. These strategies were the use of mathematical calculations, the manipulation of variables and the implementation of ideas involving probability. Participating students noted several reasons behind their perceived increase in understanding of the material. These reasons include: the use of different stimuli for learning, the organized and rich information presented, the use of modern technology and the diversity in assessment questions and exercises based on the simulations and animations (Al-Balushi et al, 2017).

There are several weaknesses to this study. The first involves the participants themselves. The participating students were all either mid or high achieving. These students may naturally have more spatial or reasoning ability than low achieving students, possibly skewing the results. The observed increase in spatial ability may be much more or much less significant for lower achieving students, so a more varied sample of students should have been taken. Another weakness is the use of two different teacher participants. These educators may have significantly different teaching styles and one style may just be better the other, or meet the needs of more students than the other. The length of the study does provide strong support but there was a relatively small sample size of students and they were all of similar populations. With a more diverse population, there may or may not have been different results.
There are several implications as a result of this study that educators should take into consideration. The first is that the use of animations and simulations are beneficial to students and should be implemented, if possible, in classrooms. The increased accessibility of technology for students allows more students to engage in these types of exercises. The fact that spatial ability significantly increases when using these simulations is also important, and it may be beneficial for students to begin working with these simulations and animations at a young age in order to build these abilities up throughout their schooling career.

In addition to the work done by Al-Balushi et al. (2017), Urhahne, Nick and Schanze (2009) also examined spatial ability and its relation to the use of three-dimensional computer simulations. These simulations have been shown to increase student learning and spatial ability when working with chemistry content more than traditional visualizations, such as ball-and-stick models or wire models. Increasing spatial ability is vital for achievement as it is a pre-requisite for understanding three-dimensional representations of chemical phenomena. This study sought to examine the effects of using three-dimensional representations, including simulations, on student understanding of chemistry (Urhahne, Nick, & Schanze, 2009).

Within this article, three different studies from the authors are discussed. For all of the studies, there were two guiding research questions: (1) Is student learning and achievement higher through the use of three-dimensional simulations or through the use of two-dimensional illustrations and (2) Do other factors, including spatial ability or cognitive load, effect the amount of learning that occurs in a computer-based learning environment (Urhahne, Nick, & Schanze, 2009). For the first study, 41 students taking a freshman chemistry course in college participated. Students worked through a computer-assisted learning unit about the modifications of carbon, as they had already had some prior exposure to this content. Students were given a
pre-test and a post-test for data collection purposes. Students also completed a brief survey before beginning to work with the simulation. The results of this first study indicate that students who used 3D-simulations did not gain a higher level of conceptual knowledge than did those who used 2D-figures and that the cognitive load requirement of learning the content was almost the same when using 3D simulations (Urhahne, Nick, & Schanze, 2009).

The second study was conducted with 155 students from eight different class of five different high schools (Urhahne, Nick, & Schanze, 2009). Students were randomly assigned into an experimental group, 76 students, that used simulations and into a control group, 79 students, that did not use simulations. The study was conducted over a 90 minute period and data was collected based on a questionnaire and a pre-test and post-test. Results from this study indicate that students in the experimental group outperformed students in the control group in terms of conceptual knowledge but there was no difference in factual knowledge between the groups (Urhahne, Nick, & Schanze, 2009).

The final study had 51 student participants who were in a chemistry or biochemistry program at a university (Urhahne, Nick, & Schanze, 2009). The students followed the same procedure as participants in the other studies. Similar to the first study, participants showed no increase in learning through the use of 3D simulations. However, in this study, spatial ability was a predictor of performance, with students having high spatial abilities consistently scoring better than those with low spatial ability (Urhahne, Nick, & Schanze, 2009).

A weakness of the first study is that it was only done over a period of 25 minutes, which may have significantly skewed the results one way or another. Another weakness of this study is that it was conducted on students taking a university chemistry class, indicating that they would likely have already taken a chemistry class in high school and, possibly, may be highly skilled in
chemistry already. These weaknesses were also found in the third study. In the second study, however, the only similar weakness was with the amount of time the study was conducted in. The sample size was relatively small, but larger enough that the results may be somewhat generalized. The population of the students was excellent, though, and the findings from this study may be generalized to almost any student population effectively.

There are several important implications from these studies. The first is that students who may be considered “experts” in the chemistry content, in these example the university students, gain very little from the use of simulations. Because of this, educators of AP or other advanced classes may find these types of results when working with their students. Simulations do not hurt students’ understanding of chemistry content, however, and even if working with experts, educators should still consider using simulations in the classroom.
Focused Literature

The 5E Model

Learning models are a common device for educators to use when planning lessons for their students. These learning models offer different suggestions for creating the best possible lessons. One of these models, the 5E model, is perhaps one of the most respected and useful models of learning, especially for those in the science field. This research-based model offers five distinct phases within a lesson to provide students with the greatest chance of success: Engage, Explore, Explain, Elaborate and Evaluate (Bybee, 2015; Bybee, 2019). Each phase has its own goal and can be done in any sequence, though the above sequence is generally recommended.

The Engage phase attempts to engage students in the material and is typically the first phase students go through in a learning segment. Students are given some sort of situation or problem that piques their interest and curiosity (Bybee, 2015; Bybee, 2019). This activity should allow students to use their own personal, real world experiences or past learning experiences to make connections to the new content while still requiring students to think about the phenomena behind the content. Activities can range from simply group and class discussions to interactive laboratory experiments and simulations, anything that encourages students to think about the content they will learn (Bybee, 2015; Bybee, 2019).

The Explore phase usually follows the Engage phase and requires students to think more deeply about the content they interacted with in the Engage phase. This phase is also used as a means to identify the current knowledge and skills students have in a somewhat formative manner (Bybee, 2015; Bybee, 2019). Students typically complete activities that further connect
prior knowledge to new material and generate new ideas and explore new questions about the content (Bybee, 2015; Bybee, 2019).

The Explain phase is typically the third phase in a learning segment following the 5E model and is where most of the traditional teaching is done. This phase focuses student attention on the important aspects of their experiences in the Engage and Explore phases (Bybee, 2015; Bybee, 2019). Students will construct meaning from their experiences in the first two phases and any relevant concepts or skills will be clarified by the teacher. Educators should also seek to gather data from some sort of informal assessment to help guide them in the final two phases. In essence, the Explain phase is the phase in which students gain a deeper understanding of the content (Bybee, 2015; Bybee, 2019).

The fourth phase, Elaborate, seeks to extend and challenge students understanding of the content they have learned in the previous three phases (Bybee, 2015; Bybee, 2019). Students work through additional activities to develop an even broader and deeper understanding of the content. Students should also directly apply what they learned in the Explain phase in a new way (Bybee, 2015; Bybee, 2019).

The final phase, Evaluate, is the culmination of the four previous phases. In this phase, students’ understanding of the content, along with any skills they have learned, are assessed (Bybee, 2015; Bybee, 2019). This allows for educators to determine student progress towards any targeted learning goals or standards. It is important for educators to take the information they receive during this phase and reflect upon it for future lessons or for re-teaching, if re-teaching is deemed necessary.

The 5E model is a highly effective, research-based model that should be used, or at least considered, by educators in any subject, especially the sciences. Following this model can help to
increase student learning and understanding of the material and can lead to better, more effective lessons and learning segments.

**Visualizations**

Students in high school tend to be “turned off” by learning science content, a fact that is consistent across most of the developed nations of the world (Geelan, Mahaffy, & Mukherjee, 2014). To solve this issue, the idea of using visualizations in the science classroom has arisen. These visualizations help to create connections between what students are learning, the science content, and their real world environment and their own mental images of this content. Visualizations can also come in the form of interactive, computer based simulations and animations and may allow students to develop more appropriate and accurate mental images on the content. Simulations tend to contribute to the processes by which students construct their own mental models and can help students overcome existing misconceptions about the content and create new, more accurate conceptions (Geelan, Mahaffy, & Mukherjee, 2014). A blend of visual and verbal learning has become the norm in many science classrooms, with concrete visual representations being crucial for visualizing phenomena that is too complex to mentally visualize (Cook, 2006). While visual representations are critical to student learning, it is highly possible that students may not be able to actually understand what they are seeing, due to a lack of prior information and background knowledge (Cook, 2006).

The study by Geelan, Mahaffy and Mukherjee (2014) was conducted in eleven chemistry classrooms in Australia. These classes were in both public and private schools that were mainly from the more affluent areas of Brisbane with student participants falling into the middle class category of SES. Each class had between 12 and 20 student participants, for a total of 129 student participants, with a vast majority, 101, being female. A crossover design was used for this
study, allowing each class to be its own control group. Each class completed one segment with
the use of visualizations and one segment without. Most of the participating classes had students
working themselves with the computer simulations while the remaining had the teacher
demonstrating the visualization. A pencil and paper based test was administered after the learning
segment (Geelan, Mahaffy, & Mukherjee, 2014).

Findings from this study indicate that there was no significant difference in student
achievement between lessons involving visualizations and lessons involving traditional, lecture
style teaching approaches (Geelan, Mahaffy, & Mukherjee, 2014). Interestingly, the female
students showed almost no gain in learning while the male students showed a much higher, but
not significant, gain in learning. A similar idea was observed when taking into consideration the
prior achievement level of the student participants. Lower and middle achieving students showed
little to no increase in achievement, while higher achieving students showed a larger, but again
not significant, increase in achievement (Geelan, Mahaffy, & Mukherjee, 2014).

There are several weaknesses to this study. The first is in the student participants. With
such a large proportion of the students being female, the applicability of the findings of this
study are mainly limited to all female schools and classes. The data itself shows that male
students show an increase in achievement when using visualizations while there is no change for
female students. It is entirely possible that the overall results of the study, the idea that there is no
change in learning outcomes from using visualizations, would be different if the gender of
students was more equal. Participating students were also all from the same type of school in the
same area of Australia, potentially limiting the diversity of the student population, especially in
regards to SES. Another weakness comes from the crossover design of the study. While there are
benefits to having each class act as its own control group, chemistry concepts can be so complex
that certain topics are more easily accessible for students without the use of visualizations than others. A stronger sample of data, while more difficult and time consuming, would be to compare student achievement over two entire school years, with one introducing visualizations and the other using the traditional approach. A further weakness is in the assessment used. A traditional pencil and paper based test may not be the best or most efficient method of assessing student understanding of material covered by a visualization.

There are only a few implications for educators from this study but they are important. The most important implication for educators is that visualizations have no negative effect on overall student achievement, while male students in particular show some improvement in achievement from the use of visualizations. For this reason, educators should certainly use visualizations, as there are no negative impacts in achievement for students and, if there are male students, there may actually be a more significant increase in student achievement than reported in this study. It is also possible that students are more engaged and motivated to learn when visualizations are used, a concept that was not explored in this study.

While the benefits of dynamic visualizations are numerous, there are also several difficulties associated with them and the demands they place on students (Ploetzner, Lippitsch, Galmbacher, Heuer & Scherrer, 2009). When using these visualizations, students are required to process an enormous amount of content information that is continuously changing as the dynamic visualization proceeds. With the lack of prior knowledge of the content associated with being a novice learner, students may have serious issues when attempting to learn from dynamic visualizations. To fully grasp the content in dynamic visualizations, students need to know the information behind what they are looking at, how what they see is related to the actual, real-
world phenomena and how the information they are seeing in dynamic visualizations relate to information they have seen or will see in other dynamic visualizations (Ploetzner et al., 2009).

The article by Ploetzner et al. (2009) describes two similar studies that were conducted by the authors. Both studies were conducted to determine what the best technique, as far as dynamic visualizations go, for student learning of kinematic line graphs in a physics classroom. The first study involved 111 11\textsuperscript{th} grade students who were split into three groups. The first group, Group S, had motion phenomena simulated with line graphs dynamically displayed. The second group, Group S+DIR, had the same features as Group S but with dynamic iconic representations of vectors added to the simulations with the final group, Group S+DIR+Stamps, having all of the above plus dynamic stamp diagrams as well. The number of students in each group was 39, 33 and 39 respectively. Students were given a worksheet that created a structured approach to the use of simulations, which were introduced step by step to prevent students from being overwhelmed. Data was collected from a pre and post-test. The post-test consisted of 30 multiple choice questions and eight free response questions. Results from this first study indicated that there were no significant differences between the groups on pre-test scores, indicating that there was no achievement difference before the study was conducted. Interestingly, there was no significant difference between students of any group after the experiment. There was slightly higher learning gain from those students who were in the S+DIR+Stamps Group than students from Group S. In addition to these findings, students who were classified as having high visual-spatial abilities had a much larger increase in learning than students with low visual-spatial abilities. Students with low-visual spatial ability actually scored worse on the post-test than the pre-test if they were in the S+DIR or S Groups (Ploetzner et al., 2009).
For the second study, only 24 students participated and were grouped into two groups, Group S and Group S+DIR+Stamps (Ploetzner et al., 2009). These groups were under the same conditions as their respective groups in the first study. Again, students took a pre-test and a post-test on kinematics. The post-test, however, had a much larger quantity of questions than the post-test in the first study, with 30 multiple choice questions and 36 free response questions. There were no significant differences in student achievement based on pre-test scores. There was a significant increase in both groups on the post-test, but there was no relationship between visual-spatial ability and achievement on the post-test. The increase in learning was much higher for students in the S+DIR+Stamps Group than Group S, and this increase was the greatest on the most difficult topics (Ploetzner et al., 2009).

For the first study, the weaknesses lie in the post-test. With such a heavy emphasis on multiple choice questions rather than free response questions, it is difficult to pinpoint the exact correlation between the use of dynamic visualizations and student achievement. The sample of students was also relatively small as there was less than 40 student participants for each group. With such a small size, every student has a more significant impact on the overall data than if there was a larger sample of students, which may have slightly skewed the results one way or the other. The second study resolves the post-test issue but has even less student participants. With only around a quarter of the students participating in the second study as compared to the first, the issues of small sample size of participants is significantly exacerbated.

Educators should take some of the findings of this study into consideration when using simulations and other dynamic visualizations. Dynamic visualizations can, potentially, have enormous positive benefits for student learning and achievement, but if they are not properly scaffolded or students do not have the necessary prior knowledge to prevent becoming
overwhelmed, dynamic visualizations may actually decrease student achievement, as was seen in the S or S+DIR groups. Spatial ability also has a significant impact on the effectiveness of dynamic visualizations on student learning, so finding some way to increase this ability may help student learning overall and make dynamic visualizations even more useful, while also limiting the negatives of their uses.

Cognitive load requirements and, by extension, the negative effects of learning through visualizations can be reduced through a few different concepts (Cook, 2006). These concepts include: multiple representations, dual-mode effect, modality effect and animations (Cook, 2006).

Multiple representations are a common teaching and learning strategy in chemistry due to the symbolic, microscopic, and macroscopic nature of the chemistry content (Cook, 2006). Symbolic and microscopic concepts are extremely difficult to understand and students may not be gaining the full amount of information from simply looking at a graphic or other visual representation alone. Due to this, multiple representations can complement one another and help students work toward an understanding of the content (Cook, 2006).

Dual-mode effect refers to the tendency for better learning when both visual and verbal representations of information are used in tandem, rather than individually (Cook, 2006). Similar to the ideas presented in the earlier multiple representations section, students may not fully understand the content if they are only looking at it or only reading about it; therefore, a blend of both strategies will lead to the most learning and to the most complete understanding of chemistry content for students. A similar effect, the modality effect, deals with the idea that when auditory information is presented, the cognitive load on students is reduced, decreasing the cognitive load and allowing more mental resources to be focused on learning (Cook, 2006).
Yet another strategy to reduce cognitive load and increase student learning through the use of visualizations is the use of animations (Cook, 2006). For the purposes of this review, animations are anything that present multiple images over time, which can be used to represent dynamic phenomena as it occurs in the real world, but which cannot be interacted with. Learners tend to react favorably to the use of animations but, there is not a clear increase in conceptual learning through the use of animations as compared to traditional methods. This problem comes from the requirement of students to have sufficient background information about what the animation is representing, so that they do not have to devote a significant amount of cognitive resources towards interpreting what is happening (Cook, 2006).

This article does not have the same limitations as most articles due to its nature as a review rather than a study with methods and data. However, being a compilation and review of numerous other studies, it is entirely possible that there is a large amount of bias in the conclusions that have been drawn. The author would have selected which articles and studies to draw from and it is unknown how these articles were selected. Due to this, the studies and findings discussed in this article should be considered separately to view the whole picture.

There are several implications from this article regardless of the fact that it is not a study with concrete data. The first is that visual representations are an effective way to reduce cognitive load on student learners and to, thus, increase their capacity for learning. It should be noted, however, that students need to have sufficient background knowledge on what the visualizations are representing in order to gain the most out of the visualizations that they can. It may be best for educators to scaffold visualizations for students or engage in an entire class discussion about a visualization to ensure that all students are fully grasping the chemistry content. Educators should also take note of the ideas of multiple representations and the dual-
mode effect. Giving students multiple ways to learn the material is imperative to making sure all students are given equal access to learning and to engage all students in the chemistry content regardless of their learning style.

There are four main effects that can explain the positive benefits visualizations have on student learning, namely: (1) the picture superiority effect, (2) the noticing effect, (3) the structuring effect and (4) the tuning effect (Lindgren & Schwartz, 2009). In addition to these effects, the practicality of simulations is unmatched. They save money and resources over physical experiments and allow student access to activities that could not be represented otherwise (Lindgren & Schwartz, 2009).

The picture superiority effect refers to the idea that people learn and remember visuals better than purely verbal or textual information (Lindgren & Schwartz, 2009). Visual images and other spatial type information have a unique location in memory which allows for this greater level of learning. It has been shown that the accuracy in recall memory is around 98% for images as compared to 90% for single words, which is a significant difference. This difference is increased even more when the images used are vivid and stand out more than other images or with images that are unexpected. These images are only remembered correctly and add to understanding if they can be interpreted by the learner eventually, through some type of external learning. It has been proposed that the picture superiority effect occurs because people create two different memory paths, one for the image itself and one for their verbal interpretation of it (Lindgren & Schwartz, 2009).

The noticing effect refers to the idea that, as one learns, they become more adept at noticing related content and noticing deeper aspects of the content itself (Lindgren & Schwartz, 2009). This is one of the reasons that experts tend to notice things that novices do not, a factor
that contributes heavily to the effectiveness of simulations. The noticing effect itself relates to the idea of perceptual learning, which can be promoted by exposing students to variability. In doing so, learners are able to distinguish between what is important for them to learn and what is not relevant for their learning. This variability is most easily accessed through the use of simulations, due to their nature of being extremely controllable (Lindgren & Schwartz, 2009).

The structuring effect refers to the idea that the image of a whole may be interpreted differently than the image of its individual parts (Lindgren & Schwartz, 2009). Because of this, visuals may be more useful to learners as they will be able to see the entire content as a whole and how it interacts together, rather than just reading or talking about each part separately. This is especially true for topics that are impossible to see without the use of images and simulations. These topics can be broken into three different categories: invisible, temporal and thought, all of which are more easily understood through the use of simulations. The idea that simulations can purify the science phenomena has also been put forth, which makes it easier for learners to see the exact information they need to, without getting lost in an overwhelming array of data (Lindgren & Schwartz, 2009).

The tuning effect is similar to muscle memory, in that people are better able to make predictions about things when they have done it before (Lindgren & Schwartz, 2009). This process is referred to as recalibration and is heavily involved in perceptual learning. Muscle memory may be able to be created through the use of simulations, although at the time of this article, this concept has not be explored. However, it has been seen that students who engage in virtual laboratory and simulations are better able to perform their physical counterparts (Lindgren & Schwartz, 2009).
The only weakness of this article lies in the fact that it is not a true “study.” There is no concrete data that has been collected and analyzed by the authors prior to writing this article, and so all the information within it is secondhand. While this is not a significant weakness, it should at least be noted, as there may be some slight bias in the conclusions drawn based on which article were selected to write about.

Educators should take the different effects discussed in this article into consideration when planning lessons for their students. It appears that visualizations can have significant positive effects on student learning and simulations, specifically, may show the best results, at least in terms of the previously discussed effects. Educators should also take note of the idea that learning similar content in different ways may lead to greater overall student understanding than simply covering content in only a single way. Visualizations, especially simulations, are an extremely effective means of educating students and should be at least considered for every science classroom.

Visual Literacy

Chemistry requires a great deal of visualization on the part of learners for full understanding of the content. While mental visualizations can be constructed by some learners in order to represent the chemistry content, many cannot create these mental images. Due to this, students of chemistry struggle with learning the chemistry content and may become disengaged and unmotivated to learn. However, using actual visualizations, such as images, animations, models, and simulations, can replace these mental images and make chemistry more accessible to all students. These physical and digital visualizations reduce the cognitive load required to understand the content, allowing students to focus more on the learning than the interpretation (Avgerinou & Ericson, 1997). Visualizations are limited due to the necessity for visual literacy, a
concept which refers to the ability of people to interpret visible objects, symbols, and interactions and comprehend them. The exact definition of visual literacy is up to the interpretation of whoever is dealing with it at the time and has undergone a variety of different changes and iterations over the years (Avgerinou & Ericson, 1997).

In this article Avgerinou and Ericson (1997) attempt to come up with an all-encompassing definition for visual literacy using definitions provided by authors of previous studies and articles and discuss what exactly visual literacy is and why it is beneficial in student learning, especially in complex and abstract topics, such as chemistry. Two of the studies that were discussed in this article are the most important in defining visual literacy. The first was one in which a large amount of organizers for an education conference were asked to define visual literacy. In total, 62 different definitions of the term visual literacy were received, indicating a vast degree of difference in interpretations. There was, however, a consensus as to what visual literacy refers to, namely: teaching strategies, the promotion of ideas, and human abilities. The other study, known as the Delphi Study, also found consensus between individuals on the general idea of visual literacy. These general ideas, as they pertain to education are: visual literacy refers to the use of visuals to communicate, think and learn, visual literacy may be seen with the eyes or in the mind, and visuals can be either man-made or natural objects and symbols (Avgerinou & Ericson, 1997).

Visual literacy, as it pertains to education, is an extremely important aspect of learning, as the use of visuals has a significant impact on understanding (Avgerinou & Ericson, 1997). A very high proportion of sensory learning is visual and the sense of vision is the most dominant and important sense. Because of the dominance of vision, educators should focus and concentrate on developing the visual literacy of students, so that they can fully engage in learning with their
most prominent sense. Visualizations have become more and more prominent in the current era, but students still need to learn how to use these visualizations to learn. While the most basic skills of visual literacy are learned by students through simply looking at and watching visualizations, the more complex and higher order skills need to be identified and taught by educators. Finally, Avgerinou and Ericson cite six different benefits of developing visual literacy for students: (1) increasing verbal skills, (2) improving self-expression of ideas, (3) increasing motivation and engagement, (4) reaching students who are not learning in traditional ways, (5) improving self-image and (6) improving self-reliance, confidence and independence (1997).

A weakness of this article is the lack of data to support the benefits of visual literacy. Due to the nature of the article as a sort of literature review of visual literacy, it is to be expected that there would be no data. However, it should be noted that bias may be present within the article. The authors selected which definitions of visual literacy to discuss and which articles to use for their own review, which may lead to some bias. It should be noted that the information provided and conclusions drawn from this information appears to have little to no bias within it, but this idea of bias should still be taken into consideration.

The main implication of this article is in the teaching of visual literacy and the extent to which visual literacy impacts student learning. Educators should be aware that students need to be taught how to effectively use and engage in visualizations and, thus, should have some sort of guidance or discussion surrounding any visuals that are used in the classroom. Educators should also be encouraged to use visuals in their classroom due to the benefits for students discussed in this article. These benefits go beyond simply learning and understanding and improving visual literacy benefits students throughout their life, not just in the classroom.
Computer Based Education

The TIMSS assessment is a study that compares student data from a wide range of participating countries (House, 2011). This data can be used to identify relationships and trends between teaching styles, including the use of simulations, and student achievement. Many instructional designs and strategies to improve student learning outcomes rely on hands-on activities and real world examples, two approaches that can easily be incorporated into and expanded upon through the use of computer simulations. In fact, computer simulations have been shown to improve student outcomes in science, especially when used in conjunction with other instructional strategies like cooperative learning. Through the data collected from the 2003 TIMSS assessment, it was seen that the highest student scores in science were received by students who described widespread use of computers in their classrooms, an idea that was further expanded upon in the 2007 TIMSS assessment (House, 2011).

The purpose of this study was to determine and analyze the relationships between student achievement and the use of computers and other instructional strategies in the classroom for eighth grade students in the United States (House, 2011). There were 239 schools in the United States who participated in the TIMSS assessment in 2007. Special education students and students with disabilities who were in general education classes were excluded from the test, resulting in 6,853 student participants who were around the age of 13. Student responses to a survey with questions regarding their frequency of use of computers and their perception of science were compared with the TIMSS score of the student to determine any relation (House, 2011).

Findings from this study indicate that students who frequently used a computer at home or at school tended to earn the highest science test scores (House, 2011). A similar finding was
found with students who frequently used a computer for schoolwork in science. Interestingly, not all computer use resulted in increased science test scores. Students who received low test scores reported frequently using the internet or playing computer games before or after school. The study also found that students who believed they did well in science tended to earn high scores whereas those who believed that science was not their strong suit tended to earn lower scores. Students with high science scores also reported that they frequently worked through science questions on their own and actively listened during lecture style learning segments. In contrast to what many prior studies have shown, this study found that students who related their learning in science to their daily lives tended to earn lower science test scores (House, 2011).

There were only a couple weaknesses to this study, and they are related to the data collection techniques. The TIMSS assessment is an assessment that is created for many countries to participate in. While this can help to rank countries worldwide, there are limitations to the assessment itself. Because of this, the assessment does not necessarily have a true link between what students in the United States learn about science and what is assessed in the science portion of the TIMSS assessment. Students could score better or worse than others depending simply on what content they covered in their specific science class. While the scores are a good measure overall, they should not be taken as a completely accurate representation of student learning. The use of a survey is also a weakness in data collection as students may answer differently than they would in a person-to-person interview. These weaknesses are not significant enough to completely dispute the claims in this study, however, as the wide variety of student participants makes the data collected viable for most classrooms across the United States.

There are some implications from the findings of this study. The first is that computer based education seems to have significant benefit on student achievement but what students are
doing on these computers should be at least somewhat monitored. Students in some schools are
now given their own computers to use throughout the school day, which should, based on the
findings of this study, increase their scholastic achievement. Educators should also be aware that
computers have the limitation of allowing students to freely browse the internet or play computer
games, which could actually lead to a decrease in student achievement rather than an increase.
The idea that students create a sort of self-fulfilling prophecy with their perception of their
scientific ability should also be noted, and educators should attempt to increase student
engagement and motivation to get students more confident in their abilities in the science
classroom. The final implication deals with the interesting finding that students who related
science content to their real world tended to have lower scores than those who do not. This
appears to be in stark contrast to a large amount of studies that have been conducted that deal
with this issue. Due to this, educators may want to plan to make useful connections for students
rather than any connection, as any connection may lead to lower student achievement.

Virtual Laboratories

Typically, computers are used in the laboratory as a supplement to traditional laboratory
equipment and are used to collect and display data. However, computer simulations can also be
used to completely replace laboratory equipment and provide a virtual lab experience for
students while still providing the benefits discussed by Hogstrom, Ottander and Benckert (2010).
Studies show that students who use computers to prepare for laboratory experiences tend to show
greater conceptual gains and that computer simulations can be as productive a learning tool as
hands-on equipment (Finkelstein et al., 2005).

For this study, the authors sought to examine the effectiveness of completely replacing
traditional, hands-on laboratory experiments with computer simulations (Finkelstein et al., 2005).
To guide them, three research questions were created: (1) Can simulations be used to replace physical lab equipment, (2) How well will students learn the concepts when using simulations as compared to traditional methods and (3) Will students develop understanding of the use of real equipment while working with simulations (Finkelstein et al., 2005).

The study was conducted at a research university using a PhET simulation (Finkelstein et al., 2005). There were two instructors and seven TAs who participated in the study with a total of 363 students in a 15-week physics course. In addition to these participants, 107 students from another physics class which did not engage in laboratory experiments were used as a second control group. Student participants were split into two groups: the CCK group consisting of 99 students who used simulations, and the TRAD group consisting of 132 students who engaged in the traditional laboratory experience. The laboratory write-ups and handouts were exactly the same for both groups except for the use of simulations in the CCK group. Students worked through a lab on DC circuits and were required to complete a challenge problem at the end of the laboratory session. Data was collected based on observational notes from TAs and the researchers, timing data on how long it took each group to complete the challenge problem, the write-ups related to the challenge question and scores on questions related to DC circuits on the final exam of the course (Finkelstein et al., 2005).

Results from the study indicate that the use of simulations lead to greater achievement than the use of traditional laboratory experiences and that laboratory experiences lead to greater achievement than not using labs in the curriculum at all (Finkelstein et al., 2005). Students in the CCK section completed the challenge question in significantly shorter amounts of time than those in the TRAD section with the control group requiring significantly longer amounts of time to complete the challenge question compared to both groups. Students in the CCK group also
showed a statistically significant shift in the scores of their challenge write-up scores in comparison to those of the TRAD group. Similar results were seen in the scores of the questions on the final exam related to DC circuits. Data collected from observations tended to show that virtual laboratories reduce the likelihood of students misinterpreting data from hands-on labs. For example, a lightbulb would light up when students correctly completed a part of the lab, but some students thought it hadn’t lit up even though they had set up the circuit correctly, a factor that did not limit those students in the CCK group. A drawback of the use of simulations was also seen in one of the CCK group sections, but was resolved on subsequent sessions. Technical difficulties occurred that caused students to be unable to complete the virtual lab activity until it was fixed by the TA, limiting the amount of time they had to work and requiring the TA to spend less time helping students learn and more time on fixing these issues (Finkelstein et al., 2005).

This study was very strong overall, with a large sample size of participants and a very isolated experimental variable due to the use of the same laboratory handouts and write-ups that students were required to complete. There is a weakness in the population of the student participants for high school educators, however. Because the participants in the study were in higher education, they may be more experienced with content than students who would be found in high school science classrooms. This factor only slightly limits the results of this study and the results should still be taken into consideration by high school science educators.

The findings of this study have interesting implications for high school science educators. The idea of completing replacing laboratory experiences with computer simulations may seem against traditional approaches to teaching, but the benefits are certainly there. Not only is student conceptual understanding significantly increased, virtual labs are much cheaper, faster and easier to implement into a curriculum than traditional labs. Educators may not want to replace some of
their traditional labs but using virtual labs to supplement content that does not have a traditional lab component due to lack of time may greatly increase student understanding of not only that specific content but understanding of the course content as well.

Simulations

As technology and computers become more advanced and prevalent in society, more and more students will have access to some sort of computer, most likely in the form of a laptop or tablet, in the classroom. With this ever increasing prevalence of computers, simulations have become part of many science curricula, especially in the more abstract disciplines like chemistry and physics (Rutten, van Joolingen, & van der Veen, 2012). Computer simulations are defined as any computer-generated model of the processes that occur in the real world (Smetana & Bell, 2014). These simulations may enhance, supplement or even replace some aspects of a traditional learning segment, and their flexibility is unmatched. Benefits of the use of simulations include: the ability to explore content, interact with a simplified version of a phenomena or process, alter time-scale of the events and practice tasks and solve problems without the stresses normally associated with physical, real-world laboratories (Rutten, van Joolingen, & van der Veen, 2012).

While the benefits for students are numerous, the benefits for educators are also important to discuss. Simulations save time and money and allow educators greater control over the content and materials students are working with (Rutten, van Joolingen, & van der Veen, 2012). These simulations help chemistry educators meet the needs of students engaging in authentic science practices by aiding students in making sense of macro, submicro and symbolic representations of chemistry (Smetana & Bell, 2014). In addition to observing that which is not typically observable, simulations also allow educators to slow down and manipulate the phenomena in order to further explain and explore the content with their students (Bell &
Smetana, 2008). Students may interact with computer simulations in both small-group and whole class settings (Smetana & Bell, 2014). For all these reasons, simulations are an excellent tool for students in the classroom and are especially useful in inquiry (Rutten, van Joolingen, & van der Veen, 2012).

In general, most studies conducted on the use of simulations in the classroom have reported positive outcomes (Bell & Smetana, 2008). The findings from these studies indicate that simulations are effective in developing content knowledge and processing skills. Simulations are also useful in promoting more complicated and involved goals such as student-led inquiry. Findings also indicate that gains in student understanding and achievement have been reported across all science classes, including chemistry. In comparison to traditional methods of teaching, the use of computer simulations has been shown to be equal to or more valuable in regards to student learning and achievement. Interestingly, computer simulations also tend to lead to greater student achievement in virtual labs as compared to traditional, hands-on laboratory experiments. In addition to these benefits, simulations have also been shown to be useful in highlighting student misconceptions and resolving these misconceptions by showing students the actual science phenomena. Finally, simulations have been shown to increase student enthusiasm, engagement and on-task behavior in science classes as compared to traditional approaches to teaching (Bell & Smetana, 2008).

Along with these findings regarding the effects of using computer simulations in the classroom, Bell and Smetana (2008) also suggest a set of guidelines for educators who wish to integrate simulations into their curriculum. The first is to use computer simulations as supplementary materials rather than in isolation. Studies have shown that using simulations without using other materials may prove ineffective in engaging students in learning the content.
Using simulations as supplements also ensure that they are connected to the overall curriculum and prior content that has been learned by students. The second guideline is to keep instruction focused around the student and to allow students to explore and work through the simulations themselves. If a teacher wishes to lead a simulation as a demonstration, Bell and Smetana suggest engaging students throughout the process with higher-level thinking questions and discussion. The third guideline is to point out any limitations associated with simulations. It is possible that students believe that how phenomena happen in simulations is exactly how it happens in the real world rather than a representation, which may even lead to more misconceptions rather than eliminating them. The final guideline is to ensure that the focus of simulations is on the content they represent rather than the simulation itself. Students should be able to understand how to use and operate the simulation themselves before fully engaging in the simulation, so that they can focus on learning rather than on trying to figure out how to work the simulation. To achieve this, educators may wish to demonstrate the simulation themselves before students begin working with it or provide sufficient scaffolding to support students as they work (Bell & Smetana, 2008).

The only real weakness of this article lies in its nature. As more of a literature review than a study, there is a certain amount of bias associated with the content discussed. The authors select which studies they use and do not use which may slightly alter the overall impression of the effectiveness of simulations. For example, much of this article discusses the benefits of using simulations in the classroom, and the studies discussed support this idea, with little discussion of challenges and detriments.

Implications of this article involve the use of simulations in the classroom. Educators should implement simulations as supplements to their current teaching styles in order to increase
student achievement and engagement in science content. Educators should be aware, however, that some scaffolding is required for students to be able to work through the simulations without getting stuck on their nuances. Overall, simulations are a useful and effective means of supplementing any curriculum.

In a later article, Smetana and Bell (2014) sought to answer three separate questions regarding the ways simulations are integrated into varied classroom settings: (1) How does student performance on assessments compare when simulations are used in a whole class setting versus a small group setting, (2) How do student discussions and conversation differ between whole class settings and small group settings and (3) How do students and educators experience with simulations change based on the classroom setting? To answer these questions, a case study was done with one participating teacher and her two honors chemistry classes. The study occurred over a 4-week unit covering atomic structure with simulations acting as review of prior knowledge, introductions to new chemistry content and practice for students. For the small group settings, students were given a guide to work through with a partner that aided in manipulating the simulations and provided guiding questions throughout the process. In comparison, the whole class setting involved one student manipulating the simulation while other students offered input and engage in discussion. After the unit, an open-ended assessment was given and, throughout the unit, classroom observations were recorded. In addition to these methods of data collection, informal interviews with the teacher and students, as well as, an open-ended questionnaire were collected (Smetana & Bell, 2014).

Findings indicate that both groups of students improved their understanding of the chemistry material throughout the unit (Smetana & Bell, 2014). It should be noted, however, that most students had a basic understanding of the concepts before the learning segment. The
differences in assessment scores between the two groups were minimal. In both the whole class setting and the small group setting, conversations were useful for drawing out student ideas. In the whole class setting, students were more likely to engage in collaborative conversations, in which multiple students added their ideas to the discussion of the content. There was back and forth between students in the small group setting to come to a conclusive understanding, but there were also occasions in which one student took complete control over the simulation and the other student(s) added little to nothing to the conversation. The whole class setting also allowed for the teacher to ask probing questions to extend the learning of the students and to engage them in higher order thinking. Both students and the teacher responded in interviews and the questionnaire that they preferred sharing and exploring ideas about the simulations and related content with more of their peers in the whole class setting as opposed to only their partner in the small group setting (Smetana & Bell, 2014).

There are a few weaknesses of this study. Being a case study, the findings of this study are only truly relevant to the participating teacher and her classes. It is highly likely that other educators and other classes may prefer one style over the other, so further research into this area is necessary for the drawing of any significant conclusions. The participating classes were also both honors classes, which further limits the findings of this study as students in honor classes, generally, are more likely to be active participants in both whole class and small group settings. There was also only one unit covered, the atomic structure unit. It is possible that certain units are more effectively learned in small group settings as opposed to whole class settings and vice versa.

There are a few implications for chemistry educators as a result of the findings of this study. The first is that there are merits to both small group and whole class instructional
strategies in the use of simulations. Perhaps the best strategy would be to use both settings throughout a unit so that all students can feel like they can actively participate, as it is possible for quieter students to get lost in the crowd of the whole class. A whole class setting may be most effective for introducing a topic, while small group settings may be most effective for practicing a topic, although more research would have to be done to draw any conclusions about this. Another implication would be in regards to how small group simulations are implemented. The activity guide helped students work through the simulation but there were no probing questions from the teacher, as was the case in the whole class setting, which could potentially limit student understanding of the deeper processes of chemistry. A teacher may need to engage more with their students during these settings to probe deeper understandings from students or they may need to ask more questions in the activity guide that require higher order thought and collaboration. Overall, the use of computer based simulations in both small group settings and whole class settings are effective to aid in student learning and achievement.

A study by Rutten, van Joolingen, & van der Veen (2012) investigated the effects that computer simulations had on student learning in science classrooms. Two research questions provided a focus for this study: (1) How can traditional approaches to teaching be enhanced and/or supplemented through the use of simulations and (2) what is the best way simulations can be used to support student learning. This study involved collecting data from a variety of studies published in the past 10 years (as based on the time of the publication of this article) which focused on computer simulations in the science disciplines for students between 12 and 20 years old. After narrowing down the options, the authors focused on 51 different publications, 48 of which were empirical studies and 3 of which were reviews. Qualitative data was coded into different themes, namely: traditional instruction, laboratory activities, representation, immersion,
instructional support, engagement, teacher guidance and collaboration. Statistical analysis was done on any quantitative data present in the 51 publications as well (Rutten, van Joolingen, & van der Veen, 2012).

Data was broken down into four major categories: enhancement of traditional instruction, different kinds of visualization, different kinds of instructional support, and classroom settings and lesson scenarios (Rutten, van Joolingen, & van der Veen, 2012). Results indicate that traditional approaches to instruction can be enhanced through the use of computer simulations. Simulations show improved learning outcomes for students and facilitate student conceptual understanding. Students are also more likely to correctly predict the results of experiments when they use simulations and are more likely to be engaged in the content material and have a positive outlook on learning science. Simulations do require some sort of support, however, or their effectiveness may be significantly reduced. Students should use simulations in an environment that gives them freedom but also provides them with any of the necessary supports or scaffolds for full understanding of the content. Within this idea of freedom, learning activities should be active and student-centered so as to foster high levels of engagement (Rutten, van Joolingen, & van der Veen, 2012).

The only weakness this article has lies in its nature as a review rather than a formal study. However, the data used and discussed was properly selected without any obvious bias. With such a large sample of data the conclusions drawn in this article can be generalized. It is likely that within the studies discussed in this article, there was sufficient sample sizes and data collection techniques to make this review thorough.

There are a multitude of implications for educators based on the information provided in this review. The first is that simulations should be used in the classroom and are extremely useful
and effective tools to supplement almost any curriculum. Because of their flexibility, simulations can be put into learning segments without losing any significant amount of time or can be used to completely replace some aspects of the traditional classroom. While simulations have benefits, they should be scaffolded and supports should be provided to students, as discussed in this review. A balance between freedom and structure needs to be achieved to maximize student learning and engagement. Finally, educators may wish to use simulations as an introduction to, or even replacement for, physical science labs. They can provide considerable support for students before they begin working through a lab, which may make the lab run more smoothly or, potentially, increase student learning of the content of the lab.

Going along with the idea of simulations, a study conducted by Han-Chin, Andre and Greenbowe (2008) sought to examine the relationship between student prior knowledge and computer simulations, and how prior knowledge effects students as they work collaboratively on these simulations. The previously discussed authors performed a study in which two main questions were the focus (1) How students with different levels of prior knowledge interacted with computer simulations and their peers and (2) What effects computer simulations have on students’ understanding of chemistry concepts. The study was conducted at a university in the United States and consisted of three pairs of female volunteers who participated in the case study. The pairs were selected based on ACS test scores, with one group being higher than average, another being lower than average and the final having one student who scored above average and one who scored below. Student pairs worked through a simulation about electrochemistry and completed worksheets. Their interactions with their partners and the simulations were recorded and transcribed. The interactions were coded and two major themes
were found: the impact of prior knowledge on interaction with a partner and the impact of prior knowledge on solving problems (Han-Chin, Andre, & Greenbowe, 2008).

Findings from this study indicate that simulations can increase student learning for both high scoring students and low scoring students (Han-Chin, Andre, & Greenbowe, 2008). Students who have lower levels of prior knowledge devoted less time to meaningful interactions when working through simulations than those who had higher levels of prior knowledge. These students did not delve into deeper discussions about the chemistry content and interactions between them were limited in comparison to those of students in the other groups. The group of students with one student scoring above average and the other below average, had similar findings, where the student who scored higher tended to dominate discussions about the content, while their partner just seemed to accept their reasoning. The final group, the group in which both partners scored above average, had data that indicated they used their prior knowledge more than the simulation to answer questions on the worksheet. In general, the higher scoring students provided more verbal explanations about the content when working through the simulation than did the lower scoring students and tended to discuss the content material more than their peers (Han-Chin, Andre, & Greenbowe, 2008).

A weakness of this study is in its nature as a case study. With a case study, the sample size is relatively low in comparison to other types of studies, which potentially limits the conclusions drawn. While students who scored above and who scored below average were participants in the study, there were no students who scored at the average. Considering the average score will be around where most students lie, the findings from this study lie in the extremes. This study is also limited due to the fact that student participants were at a university level. These students
likely have more prior knowledge than students in high school, so it would be interesting to see what interactions would be like between students with an even lower level of prior knowledge.

This study has one very important implication for educators wishing to implement simulations into their classroom. The data provided and conclusions drawn from this study support the benefits of simulations, but educators should consider the best ways to partner students when using simulations. It seems that, when achievement levels are significantly different, the higher achieving student dominates group discussions. When one student dominates, it may be difficult for the lower achieving student to actually learn anything and engage in discussion. For this reason, it may be best to group students of similar skill levels together or to group both low and high achieving students with the average achieving students, so that all students may participate in thoughtful discussions.

A perfect example of a chemistry topic enhanced through the use of simulations is the kinetic molecular theory. The kinetic molecular theory is a very important concept for modern chemistry and it is imperative in understanding the motions and interactions of particles (Stern, Barnea, & Shauli, 2008). Without a proper understanding of the kinetic molecular theory, it is almost impossible to understand the chemistry concepts that follow, especially the more complex and abstract topics in high school chemistry and beyond. Because of the importance of this theory, it is taught in almost every physical science curriculum, but, yet, students continue to struggle with this concept. Particulate matter, along with other micro level content, is impossible for students to physically see and visualize and, so, another tool is needed for complete understanding. Computer simulations are one of those tools (Stern, Barnea, & Shauli, 2008).

The purpose of this study was to determine the effect that the use of a computer simulation had on 7th grade students’ understanding of the kinetic molecular theory (Stern,
Barnea, & Shauli, 2008). The focus of the simulation was on basic particle theory, the idea that particles are invisible and are in constant motion. Along with the content, the researchers also sought to explore any potential differences in the effects of simulations on learning based on gender. Participants in the study were from two different middle schools and consisted of three educators and 133 students. Of these students, 62 were placed into the control group and 71 into the experimental group, the group using the simulation. Each teacher was assigned a control group and an experimental group to limit the impact of individual teaching styles and abilities on the data. Data was collected in the form of a pre-test and a post-test, as well as from interviews with five students from the control group and five students from the experimental group (Stern, Barnea, & Shauli, 2008).

Findings of the study indicated that both the experimental groups and the control groups improved their understanding of the content over the course of the learning segment (Stern, Barnea, & Shauli, 2008). However, the experimental group showed a significantly larger improvement in scores, at nearly double the average score gain between the pre-test and post-test. Not surprisingly, the students in the experimental group scored significantly higher than their control group peers on the post-test as well. The results of the quantitative portion of this study also indicated no significant differences in post-test scores of students in the experimental group based on gender, indicating that both genders receive seemingly equal benefits from the use of simulations in the classroom. The interviews indicate that students in the experimental group gained a better understanding of the microscopic nature of particles than the students in the control group. For example, students in the control group believed that particles were still and only began to move when they were heated up, while students in the experimental group believed that particles were always in motion. The authors suggest that the way the simulation
explicitly shows particles continuously moving may be the explanation for this difference in beliefs (Stern, Barnea, & Shauli, 2008).

This study does suffer from the issue of a small sample size for both the quantitative data that was collected, the scores on the post-test, and the qualitative data that was collected, the interview. While the researchers did account for differences in teaching styles and school environment by having multiple educators and two different schools, the sample of student participants was relatively small. Regardless of this, the quantitative data can still be generalized and should be considered when altering learning segments. The qualitative data, however, is extremely limited and may only be relevant to those students who were interviewed. The achievement levels of the students interviewed was unknown, but it would be interesting to see whether or not high-achieving students understood more about particle motion without seeing the simulation than low-achieving students who saw the simulation did.

There are two important implications of this study that science educators considering the use of simulations should take into account. The first is that simulations greatly improve student understanding of kinetic molecular theory, and most likely would improve student understanding of other chemistry topics. Therefore, simulations should be implemented into chemistry curricula where desired. The second implication is that there appears to be no gender differences in how much learning is gained from simulations and so simulations can be used with all students without fear of leaving certain students behind, at least based on gender.

**PhET Simulations**

PhET simulations are a group of simulations created by the University of Colorado Boulder that deal with a variety of science topics across numerous disciplines, including chemistry, biology and physics. These simulations have a wide range of potential uses in the
classroom and, if implemented effectively, can have numerous benefits for student learning (Perkins, Moore & Chasteen, 2015). Implicit scaffolding within the design of the simulation can help students work through them and gain content knowledge without getting lost in the nuances of simulation itself. Some of the goals that PhET simulations can be used for include: engagement in scientific exploration, development of greater conceptual understanding of content, the making of connections between content and the real world, increased overall engagement and enjoyment of learning science and the ability to take control of one’s learning.

PhET simulations also have the benefit for educators and schools of being free and highly flexible. In this study, the authors surveyed over 1,500 educators to answer four research questions: (1) to identify who uses PhET simulations, (2) to identify what population of students use or are exposed to PhET simulations (3) to identify the goals educators have in using PhET simulations and (4) to identify the different instructional approaches that are used by these educators (Perkins, Moore, & Chasteen, 2015).

The study was conducted as an online survey of K-12 educators and college professors who used PhET simulations in their classroom (Perkins, Moore, & Chasteen, 2015). The survey was multiple choice and long-answer, however, this article only deals with the multiple choice portion of the survey. The survey asked questions such as: what are the demographics of the students, what do students like and dislike about PhET simulations, what impacts do PhET simulations have on student learning, what goals are meant for PhET simulations to achieve and how PhET simulations were actually used and implemented in the classroom. There was no incentive to complete the survey, and so participants were self-selected. There were 1,233 high school physics educators and 276 college physics professors who responded to the survey (Perkins, Moore, & Chasteen, 2015).
Findings from this survey reveal that a wide range of educators use PhET simulations in their classroom (Perkins, Moore & Chasteen, 2015). Educators who have been teaching for a long time and newer educators both use PhET simulations in their classroom. Of these educators, about 70% of them used between 6 and 10 simulations throughout their curriculum, 20% used less than 6 simulations and 10% used 16 or more simulations in their teaching. Responses of student demographics indicated that PhET simulations were used for a wide range of students, spanning every achievement level and every student population. Many teacher respondents used PhET simulations to meet a variety of goals, mainly involving inquiry and exploration of science content and ideas. Around 50% of the high school educators responded that they used simulations to increase interest and engagement in science and approximately 97% of educators, including both high school and college educators, stated that students enjoyed using PhET simulations in the classroom. As for the last question, that of instructional approaches, educators indicated a wide range of potential uses for simulations ranging from homework to demonstrations to labs (Perkins, Moore, & Chasteen, 2015).

There are a few weaknesses to this study, mainly stemming from the data collection and reporting procedures. The main issue is that participation in the survey was optional and participants were self-selected. While it may be difficult to require educators to respond to a research survey, those who do respond are most likely those who greatly enjoy using PhET simulations in their classroom, skewing the results of this study greatly towards positive interactions with simulations. Another weakness is the use of multiple choice questions on the survey and the lack of data analysis, at least in this article, of the long-answer questions. Multiple-choice questions are easily misinterpreted and may lead to differences in responses simply because educators are not sure how to respond to certain questions. The use of long-
answer questions also allows for a much deeper understanding of teacher opinions on PhET simulations, and the fact that they were not discussed significantly weakens this study, as it is unknown why they were not included.

Even with the weaknesses discussed above, this study does provide insight into PhET simulations and their use in the science classroom. Educators working with all types of students and who have a wide range of years of experience choose to use PhET simulations in the classroom, indicating that educators who have not yet begun to use simulations may find benefits in their use. Students also seem to greatly enjoy the use of simulations in the classroom and simulations tend to lead to greater understanding because of this increased enjoyment and engagement in the content. Educators should definitely consider using PhET simulations in their classroom, if they have not already, to increase both student learning and engagement in science content.

In an article by Price, Wieman, & Perkins (2019) data was compiled from over 1,500 educators who use PhET simulations in their classroom and who offered lesson suggestions and guidance for integrating PhET simulations into the classroom (Price, Wieman, & Perkins, 2019). Two main questions were used to guide responses: (1) What learning goals can simulations address in the classroom and (2) How can simulations be used for instruction (Price, Wieman, & Perkins, 2019).

For the first question, what learning goals can be addressed with simulations, the educators questioned stated that they used simulations to address many goals and they can be used to address multiple goals at once (Price, Wieman, & Perkins, 2019). Educators noted that simulations often were used to help students visualize the science phenomena and to develop conceptual understanding of the required content. Simulations also were seen as means to engage
students in exploring and discovering ideas and to participate in inquiry and simulations were also seen as effective means of increasing enjoyment and engagement in the content. Of the educators surveyed, 69% said simulations were used because they exposed students to science, 52% said that simulations were used for an increase in student engagement in the content and 32% noted improved motivation as a reason for the use of simulations. Teacher participants also cited the benefits of visualizations, like simulations, in the classroom as a way to see aspects of science that are normally unable to be seen, a factor that is significant in abstract topics like chemistry where much of the content is at the molecular level. Students can also manipulate aspects of the simulation and receive feedback on how what they are manipulating influences the overall content of the simulation, allowing students to exploring the content in a visual, safe and contained manner (Price, Wieman, & Perkins, 2019).

For the second question, that of how simulations can be used in instruction, most educators stated that they used PhET simulations for in-class activities and virtual labs, especially ones in which students engaged in inquiry practices (Price, Wieman, & Perkins, 2019). Simulations are especially effective when they are student-centered and students are given the opportunity to explore their own questions about the content. Examples of how PhET simulations were used in the classroom were also provided to support this question. One of the lessons dealt with gas pressure and the simulation was used to help students visualize movement of the molecules and make connections between the molecular or micro level of gas pressure and macroscopic scenarios. Another example lesson used simulations to allow students to see the polarity of molecules and to visually compare different molecules. Overall, the use of PhET simulations is only limited by the creativity of the teacher using them, as their flexibility in the classroom is unmatched (Price, Wieman, & Perkins, 2019).
A weakness of this article is the lack of concrete data. Much of the data used to draw the conclusions was collected by Perkins, Moore and Chasteen during a previously conducted study in 2015. Because this article is not a stand-alone article, the study itself cannot be analyzed for any limitations. However, the article by Price, Wieman, and Perkins may still suffer from a slight bias as the data was selected by the authors, who may have only selected data that supported their own beliefs. The lack of discussion of the challenges and detriments of using simulations also weakens the strength of the conclusions drawn in this article.

Based on this study, educators should be implementing simulations into their classroom. The flexibility of simulations allow educators to put them into their curriculum and lesson plans without disrupting their overall plans. PhET simulations can also aid students in meeting certain learning goals and educators may wish to use these simulations in topics which students normally struggle with. Educators may also wish to use simulations as a replacement for labs that are either too hazardous, too time consuming or too expensive to use in the traditional classroom but which would greatly increase student learning outcomes. Overall, PhET simulations are a great tool for educators to use in the science classroom to increase student learning, engagement and motivation without significantly altering previously created curricula or plans.

A study performed by Herrington, Sweeder and VandenPlas (2017) sought to explore the effectiveness of PhET simulations on student learning in online classes and flipped classrooms. Two questions were the focus of this study: (1) What impact does usage of simulations or screencasts outside of the classroom have on students’ conceptual understanding of ionic and covalent compounds and (2) What are the differences between how and where students allocate attention when using simulations as compared to screencasts. Students used the sugar and salt solution PhET simulation that contained three different tabs: one that involved macroscopic
content, one that represented microscopic content and the final tab that dealt with particle interactions between water and a solute. Students were administered a pre-test and post-test with the same five questions. Students also answered three follow-up questions which required students to apply what they learned from the simulation. There were 239 participating students from an introductory chemistry lecture course at a university. Two groups were created, one where students worked through the simulation on their own and another where students worked through the simulation while watching a screencast of their instructor leading them through it. Data from the assignments was analyzed and coded and eye-tracking technology was used to answer the second research question that was posed (Herrington, Sweeder, & VandenPlas, 2017).

Results from this study indicate that students gained the content knowledge and conceptual understanding regardless of whether or not they use screencasts (Herrington, Sweeder, & VandenPlas, 2017). However, students who viewed the screencast were better able to explain and identify electrolytes, explain the dissolving process and to depict what would happen at a microscopic level when a substance dissolves in water. Analysis of the pre-test scores indicated that there was no significant difference in student understanding of the content before the study began. The students in the simulation only group did not show significant increases in scores on the post-test as compared to the pre-test, whereas there was a significant increase for students in the screencast group, however, there was no significant difference between the groups when scores were normalized. Results from the eye-tracking portion of the study suggest that neither group spent a statistically significant amount of time focusing on the assignment, but there was a difference in where this time was spent. The screencast group tended to spend more time focusing on the electronic resource (Herrington, Sweeder, & VandenPlas, 2017).
A weakness of this study is that it was conducted with university students. These students tend to have a much better understanding of chemistry content as a whole than high school students and so suffer from different challenges or receive different benefits from the usage of simulations than high school students. It does appear that simulations help students learn the content material, but since there was no real control group, it is difficult to determine where the increase in learning came from.

Educators should consider the results of this study regardless of whether or not they use a flipped classroom or assign simulations for students to work through on their own. Even at the university level, students do gain some benefits from being guided when working through simulations. This idea may be even more prevalent for high school students, as they are less familiar with the content. When educators incorporate simulations into their curriculum, they should be sure to provide some sort of guidance or scaffolding to maximize student learning and achievement.

**NetLogo vs. Flash Simulations**

The prevalence of laptops in the classroom allow for the potential use of computer-based models and simulations rather than physical models. There are additional benefits for these electronic models over the physical models. The first being the accessibility of them to students. Since all students in a district will have a laptop, provided the district has moved towards this idea, all students will have access to these models at all times, regardless of whether or not they are actually in their chemistry classroom. Previous studies and observations have shown that dynamic representations of chemistry content, such as the aforementioned electronic models, improve chemistry learning (Waigh & Gillmeister, 2014). Computer based models are a useful supplement to aid in student understanding of chemistry content. They allow for students to
visualize complex chemistry content that could not be represented through physical models. With many districts incorporating laptops or tablets into the materials for every student, the use of computer based models could, potentially, allow for even greater accessibility to the chemistry content.

While computer based models have the potential to aid student learning, there are some challenges associated with them as well. For example, students may find the models difficult to understand without proper scaffolding. Due to this, it is important to note the process of creating computer based models, in order to allow for greater ease of use for students.

Waight and Gillmeister (2014), sought to answer three general questions about what educators and students think about the use of electronic models in the classroom: (a) What are students’ and educators’ conceptions and opinions about two different types of electronic models, Flash and NetLogo, (b) How do the opinions of students and educators address the idea of multiple representations for chemistry content, and (c) What are the benefits and challenges associated with using electronic models in the high school chemistry classroom? Another, somewhat hidden, question that was indirectly explored in the study regarded the challenges of using computer based models to their maximum benefits between experts (educators) and novices (students) (Waight & Gillmeister, 2014).

Waight and Gillmeister (2014) conducted interviews with students and educators to gain their insight into the practicality of computer based models and the differences in usability between Flash and NetLogo models. There were eight Flash models and eight NetLogo models that were used in eight different high school chemistry classrooms. These classrooms represented various demographics, including suburban, urban and rural schools. For the purpose of the study, students were not told how to use the models but were given a guide sheet regarding the features
of each model, which they could use to aid them in individual or group based exercises (Waight & Gillmeister, 2014).

Results indicate that students in all eight of the classrooms enjoyed and found benefit in the use of both models (Waight & Gillmeister, 2014). Many of the students, more than 80%, believed that the models were exact recreations of what occurs in the real world. The majority of them, 75%, expressed the sentiment that the more aesthetic, visual features of the models made them more useful. Because of this, most of the students preferred the Flash models, which are easier to use and understand and deal with macro concepts, rather than the NetLogo models, which deal with submicro and symbolic content. It was also noted that students struggled when given full, exploratory control over their learning and the use of the models, suggesting that there needs to be some sort of balance between how much freedom students are given in their learning and the scaffolding and guidance provided to them. Going along with this idea, students stated that they preferred the more interactive and visible teaching of the models over the traditional lecture and reading style of teaching (Waight & Gillmeister, 2014).

The educators interviewed expressed concerns with the models due to the role of background knowledge required for full comprehension (Waight & Gillmeister, 2014). Similar to the views of the students, educators highlighted the more hands-on interactivity of the models as opposed to traditional teaching styles as a benefit of models. Three out of the six educators who participated in the interview process were aware of the benefits and challenges associated with the overwhelming amount of information that can be provided through the use of models, an idea not much different from what students thought. In essence, much of the difference in the use of these models between students and educators was a result of the amount of prior knowledge and experiences educators had with the chemistry content. If students had the same level of
background knowledge, it is likely that they would not become overwhelmed with the sheer amount of information provided in models (Waight & Gillmeister, 2014).

There is only one, glaring, weakness to this study, the lack of concrete, quantitative data. While the methods of the study, including the diverse participants, do lead to more widely applicable findings, the use of interviews limits the findings to subjectivity rather than objectivity. The opinions of students and educators regarding the use of computer based models are important, of course, but without any real assessment data, there is no concrete evidence of the benefits and challenges of using these models.

Some of the implications of this study by Waight and Gillmeister (2014), involve how computer based models should be used in the classroom. The first, and perhaps most important, implication of the findings is the amount of scaffolding students need when using these types of models. It is important, at least initially, to provide students with guidelines so that they may have some understanding of the content, especially when using the more complex NetLogo models, before they are required to engage in the higher-order thinking involved with exploring the nuances of the models. The role of background information is another vital implication from this study. Students need to have at least a decent grasp of the content before they can be expected to fully comprehend what is happening in the models. As suggested in this article, educators may need to use models as an introduction to content and then use them again after students understand the content as a supplement to their understanding (Waight & Gillmeister, 2014).

The use of computer based simulations and models can also aid students in developing their visual literacy skills, skills that allow for students to think visually (Waight, Liu, Gregorius, Smith & Park, 2014). These skills help students make connections between the sometimes
difficult and complex chemistry content and the real world, a factor that can, potentially, increase student learning, conceptual understanding and motivation. While computer based simulations may seem like they are purely beneficial as they increase student learning, they do take immense amounts of time and dedication on both the part students and educators in order to fully explore their benefits (Waight et. al, 2014).

To determine the opinions and perceived effectiveness of computer based simulations and models by educators, Waight et. al present a case study focused on one teacher, chosen due to her prior understanding of and experience with models (2014). The teacher was given two different sets of models, one from NetLogo and the other from Flash, to use as a supplement to her traditional course instruction. The data collected consisted of classroom observations by the researchers, a teacher interview and student interviews across an entire school year. (Waight et. al, 2014).

There were five main questions that Waight et. al. were seeking to answer throughout the study: (1) How do students and educators define models, (2) What are the overall perceived benefits of models, (3) How are instructional approaches adapted for the addition of models, (4) How are assessments impacted by the use of models and (5) What are student reactions to the use of models in the classroom (2014). The teacher, denoted as T1, reinforced the idea that models were used as tools to allow visualization of abstract concepts, allowing students to create images of what is happening and, thus, improve conceptual understanding. In the opinion of T1, models were best used as introductory content to aid students in shaping their prior understandings and background knowledge. T1 also stated that students became less interested in the use of models as the school year went on (Waight et. al, 2014).
While T1 expressed models as beneficial, students’ opinions were more diverse, especially during assessment (Waight et. al, 2014). Due to the nature of the models used, correct answers to the assessments were more abstract and required higher order thinking, as there were no explicit answers. As an explanation to this sentiment, T1 suggested that students were too familiar with the traditional style of teaching and learning to be able to be successful in these types of model-based assessments. Because of this, students were likely to be frustrated with the models even though students do see them as beneficial and useful (Waight et. al, 2014). It is possible that with more exposure to models throughout a student’s schooling career, this issue may be resolved.

An additional question that was more indirectly observed by Waight et. al (2014) was the comparison between the two types of computer models used, NetLogo and Flash. NetLogo models tend to be more complex and useful for microscopic ideas, while Flash models deal with more macro scale ideas. Overwhelmingly, students preferred Flash models as they are simply easier to use and deal with simpler and more observable phenomenon (Waight et. al, 2014).

The most influential weaknesses of this study are found mainly in data collection. One of these weaknesses is the use of only a single teacher for data collection. Due to the nature of education, with differences in teaching styles and learning styles, relying on only a single teacher, in a single classroom, in a single school environment severely limits the universality of the results. The use of more subjective and qualitative means of data collection also limits the findings of this study. Without concrete data, it is difficult to determine the actual effectiveness of using computer based models in the classroom. While students may have been frustrated with the models, they may also have had increased test scores because of the models, a factor that is not assessed in a qualitative research model.
There are some relevant implications for chemistry educators from the study by Waight et. al (2014). The first being that models should be used in the classroom, but should be used sparingly in order to prevent students from becoming frustrated with their use. Assessments based on information presented in models should be scaffolded to prevent students from becoming overwhelmed due to the jarring difference between traditional learning and assessments and model based learning and assessment. A final implication of the findings by Waight et. al (2014) involves the uses for different types of models. Due to the difference in what Flash and NetLogo models portray and their ease of use, it may be beneficial for educators to walk the class as a whole through the more complex NetLogo models and explain what is happening. In contrast, Flash models may be more useful for educators desiring to let their students explore the content freely and engage in higher order thinking.

In addition to the effects of using NetLogo and Flash models on students, Waight, Liu and Gregorius sought to explore the nuances of designing, developing and implementing computer based models for high school chemistry (2015). An interdisciplinary team of experts was studied as they worked through the creation of a computer based model. There were ten participants of the planning team working on creating the model consisting of: chemical engineers, polymer, physics and chemistry scientists and science educators. The models created were then implemented into the chemistry classrooms of two different educators and their students. Educators were interviewed at the start and end of the academic year, while students were interviewed at the mid-point of the semester (Waight, Liu, & Gregorius, 2015).

Results of the study indicate concerns between the specialists during the creation of the models (Waight, Liu, & Gregorius, 2015). The models would be created in both the Flash style and the NetLogo style. The scientific engineers and scientists sought to create models that were
highly accurate and specific to the actual phenomenon, regardless of the requirements and expectations for high school students. Because of this, students would have to engage in higher-level content knowledge to understand what is happening, potentially causing confusion and frustration for these students. In essence, the large degree of difference between the expectations for the models of the science specialists and the education specialists represent difficulties in the creation of these models (Waight, Liu, & Gregorius, 2015).

Implementation of these models by high school chemistry educators indicated that students and educators preferred the Flash model due to its ease of use and better visuals of the abstract, complicated content (Waight, Liu, & Gregorius, 2015). These models focus more on the macro level of chemistry and so are more easily understood and explained by educators and are more consistent with the high school chemistry expectations, allowing for greater exchange of knowledge between student and teacher. Flash models help decrease the cognitive loads required of students to understand the chemistry content by allowing them to focus on actual images, rather than those they create in their own mind. In contrast to the Flash models, the NetLogo models were seen as containing too much information for students to comprehend on their own and many students expressed confusion and frustration because of this (Waight, Liu, & Gregorius, 2015).

The weaknesses of this study lie in the method of data collection, as well as the participants themselves. While the first part of the study, the creation of the models, was accurately portrayed due to the wide variety of members on the planning team, it was only a single team. Different teams may have different personalities and perspectives that may or may not affect the creation process. The implementation part of the study also exhibited the similar issue of only having two educators of two classes taking part. With such a low sample size, it is
difficult to generalize any of the information presented during the implementation phase of the study. The information provided is also qualitative in nature, focusing more on student and teacher opinion than the actual data associated with implementing computer based models, such as assessment data.

The implications for this study are focused mainly on which type of model is most useful in the high school chemistry classroom. Similar to other studies that have discussed this same issue, students and educators both prefer to use the simpler Flash models. Planning teams may need to take this factor into account when creating models to either make the NetLogo models slightly easier to use and understand or to make Flash models that cover more complex topics. Educators may also take these factors into account when planning lessons by providing less scaffolding for Flash models and more for NetLogo models or by using Flash models to introduce chemistry topics and NetLogo models to expand upon the basics illustrated by the Flash models.

**Scaffolding**

Chemistry is a complex and abstract topic that many students have difficulties in during their high school years. Chemistry concepts tend to fall into three different levels of knowledge: macro, micro and symbolic (Li & Black, 2016). Macro concepts are those which are observable and experiential. The micro level refers to particulate models that explain macro level phenomena, while the symbolic level refers to symbols, equations and formulas that describe relationships within chemistry. Of these levels, macro concepts are the only physically observable phenomena and, so, educators rely on simulations to help students understand micro and symbolic content through visualization. However, simulations are not without their
challenges, as students can become bogged down in the content or struggle with understanding the simulation without proper scaffolding (Li & Black, 2016).

Types of scaffolding for simulations can be broken down into different categories, the first of which is inter-level scaffolding (Li & Black, 2016). In this category, scaffolding occurs across the different levels of chemistry content, allowing students to make connections between macro, micro and symbolic level content and increase student learning and understanding of the content itself. Another category, intra-level scaffolding refers to the creation of scaffolding within one specific level of chemistry content. The final category of scaffolding is known as procedural scaffolding, in which students work through the levels to gain full understanding of the chemistry content, meaning that students work through macro content then micro content then symbolic content in a concrete to abstract sequence (Li & Black, 2016).

For this study, Li and Black (2016) sought to answer two main questions: (1) Does inter-level scaffolding or intra-level scaffolding benefit student learning more and (2) What is the best sequence of representational activities for student learning of a chemistry topic. Two urban middle schools participated in the study, creating a sample of 129 seventh graders with most, nearly 85%, of the participants being from minority populations from low SES families. Student participants engaged in a simulation depending on which level and group they were assigned to and were given a pre and post assessment to determine the effectiveness of the scaffolds. The study used a 2x3 factorial design and was conducted over two class session on two consecutive days for a total instructional time of 100 minutes. Each student was paired up and then assigned to a condition with their partner (Li & Black, 2016).

Findings from this study indicate that inter-level scaffolding, scaffolding between the macro, micro and symbolic levels, benefits students more than intra-level scaffolding in
remembering and understanding the factual knowledge of chemistry (Li & Black, 2016). Along with this, introducing the macro content first produced marginally better scores on the posttest than the micro first. Introducing the symbolic content first had the least benefit on student learning as compared to the other two sequences. However, all three sequences showed significant improvement from the pretest to the posttest, indicating that learning did occur in all three sequences. Interestingly, students who were in the micro first, inter-level scaffolding group outperformed the rest of their peers. It is possible that, with enough scaffolding, analyzing a primitive model before learning an aggregate model may prove to be the best condition for student learning (Li & Black, 2016).

The weaknesses of this study come from the data collection. The first weakness is in the small sample size of participants and their homogeneity. Without a larger and more diverse population, the applicability of this study is somewhat limited. The fact that the study was conducted over two class periods also limits the study, as only one topic was briefly covered for the study and the long term effects of implementing scaffolding into a curriculum was not seen. Some topics in chemistry may be more or less impacted by the use of scaffolded simulations than the topic that was covered in this study.

This study has one extremely important and relevant implication, the use of scaffolding for simulations. Many studies have noted that students may struggle and become overwhelmed when using simulations in the classroom and the idea of scaffolding simulations should be seriously taken into consideration. The most important conclusion from this paper, is that a concrete to abstract or macro to micro to symbolic level of scaffolding is the most effective for student learning and should be used whenever a simulation is used.
Podolefsky, Moore, and Perkins (2013) state that scaffolding can either be explicit, that which is written down or said aloud in a step by step manner by an expert or teacher, or implicit, that which is built into the assignment so that students are at least somewhat guided while still allowing students to have some freedom and control over their learning. In essence, implicit scaffolding support students’ learning while still allowing students to maintain a sense of agency and control (Podolefsky, Moore, & Perkins, 2013).

This idea of implicit scaffolding can be found within PhET simulations (Podolefsky, Moore, & Perkins, 2013). These simulations are created to engage students in exploring science content, develop understanding of science concepts, make connections to the real world, increase enjoyment in learning and working with science and take greater ownership of one’s own learning. The simulations allow students to learn actively rather than passively and build their understanding of the content through exploration, a key component of inquiry-based learning. PhET simulations are created in order to maximize exploration and limit the potential challenges students may face when working through the content. They increase the sense of agency of students and allow students to take more control over their learning by affording and constraining interactions, allowing students to do exactly what they need to do without limiting the sense of exploration or without overwhelming students with options. These factors of PhET simulations allow students to be guided implicitly through the simulation itself, rather than from an external source like a teacher or a handout. It has been shown that PhET simulations, through the use of implicit scaffolding, engage students in the content and increase student learning outcomes (Podolefsky, Moore, & Perkins, 2013).

This article discussed the way in which PhET simulations are created based on student feedback, and a case study of one 6th grade student is provided as support for the discussed
benefits of PhET simulations and implicit scaffolding (Podolefsky, Moore, & Perkins, 2013). While this student was working through a simulation, they were asked to think aloud, with only prompts to continue talking given by the researchers. The student was able to interact with the simulation in an extremely short amount of time, less than 10 seconds, and, within this time frame, was already attempting to understand what was happening in the simulation. This factor was used to draw a conclusion that the simulation the students was using was easy to use due to the implicit scaffolding provided by the simulation. Another conclusion that was drawn from the case study was that the parameters that are added to the simulation, such as temperature or pressure, cue students into what they are supposed to be paying attention to, which can be seen as another example of an implicit scaffold (Podolefsky, Moore, & Perkins, 2013).

This article has a massive weakness in that it only provides a small amount of data from a case study of one student. There is only one data collection tool, an observation of the student working through the simulation, and no real data analysis methods. There is such a wide variance in the abilities of students, whether it is their level of knowledge surrounding the content or something not related to achievement such as technological prowess, that only discussing data from one student makes the findings extremely limited. The case study also only used one form of data collection, again limiting the findings, and the data supported what the authors were looking for in terms of support for the implicit scaffolding they created in the PhET simulation, further limiting the findings.

Implications from this article are fairly limited. While other studies have supported the idea that simulations and scaffolding can increase student engagement and achievement, this article only discusses how one student perceived a PhET simulation and its ease of use. The article contributes little to the actual field of education, but does give educators who use PhET
simulations a behind the scenes look at their creation and the reasons that certain decisions about what to include and exclude are made, which may help educators from lessons and activities around PhET simulations.
Simulations

Acid-Base Solutions

Simulation Link: https://phet.colorado.edu/en/simulation/acid-base-solutions

NYS Content Standards:

3.1rr. An electrolyte is a substance which, when dissolved in water, forms a solution capable of conducting an electric current. The ability of a solution to conduct an electric current depends on the concentration of ions.

3.1vv. Arrhenius acids yield H⁺ (aq), hydrogen ion as the only positive ion in an aqueous solution. The hydrogen ion may also be written as H₃O⁺ (aq), hydronium ion.

3.1ww. Arrhenius bases yield OH⁻ (aq), hydroxide ion as the only negative ion in an aqueous solution.

3.1uu. Behavior of many acids and bases can be explained by the Arrhenius theory. Arrhenius acids and bases are electrolytes.

Learning Goals:

1) Students will be able to define and distinguish between Arrhenius acids and Arrhenius bases.

2) Students will be able to explain the difference between strong acids and weak acids and strong bases and weak bases.

3) Students will be able to explain conductivity.

Key Vocabulary and Concepts for Simulation:

1) **pH** – measure of hydrogen ion concentration, ranges from 0 to 14, values < 7 are acidic, >7 are basic, 7 is neutral

2) **Arrhenius Acid** – molecule that yields an H⁺ atom in solution

3) **Arrhenius Base** – molecule that yields OH⁻ in solution
4) **Conductivity** – the ability of a solution to conduct an electrical current

5) **Electrolyte** – chemical compound that conducts electricity by turning into ions in solution

### Stimulating Aspects of the Simulation:

1) Variety of tools to use within the simulation – pH value, pH strips and lightbulb with batteries

2) Ability to visualize molecules in solution

3) Ability to visualize the concept that strong acids/bases completely dissociate in solution and weak acids/bases do not

4) Multiple means of seeing information – graph and physical molecules

### Planning Considerations for Simulation:

1) Very easy to rush through and miss many of the critical aspects of information within the simulation

2) Many small illustrations may make it difficult for students to distinguish between different molecules

3) Molecules are color coded which may make it difficult for students with visual impairments to distinguish
Simulation Parts Explained:

**Screen 1: Introduction**

- Tool Display
- pH
- Molecules
- Reaction Equation
- Solution Options
- View Options
- Tool Options
- Reset Button

**Screen 2: My Solution**

- Solution
- Acid
- Base
- Initial Concentration
- Strength
- Views
- Molecules
- Solvent
- Graph
- Hide Views
- Tools
**Reaction Equation** – the equation of the reaction shown in the main beaker display, molecules are color coded and look as they would in traditional models

**Molecules** – display of the molecules shown in the reaction equation, note that water molecules are not shown unless the solvent option in “View Options” is toggled on

**Tool Display** – shows whichever tool you have selected in the “Tool Options” menu

**Screen Options** – switches between the “Introduction” and “My Solution” screens

**Solution Options** – switches between a variety of solutions in the main beaker display, the molecules within the beaker display will change in accordance to whatever solution is selected

**View Options** – changes the way the simulation is viewed, the default view is the one shown in “Screen 1” the solvent option shows the water molecules if selected, the graph option simply shows a bar graph of the number of molecules in solution and the hide view option should not be used as it gets rid of anything in the main beaker display

**Tool Options** – selects which tool to use, the first option is a pH probe which can be dragged into the beaker and shows the numerical value of the pH, the second option is a litmus strip which changes color according to the pH, again this can be dragged into the beaker and a strip of all potential colors and values is also shown, the final options shows a battery, a light bulb, and two electrodes such as the tool shown in “Screen 2,” if ions are present, the lightbulb will light up corresponding to the idea of electrolytes

**Reset Button** – resets the screen to the default screen shown in the screenshot

**My Solution Options** – allows you to adjust the strength and concentration of an acid or base, this solution is then shown in the reaction equation and within the main beaker display

### Suggestions for Supplemental Material:

**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged in this activity because it gives students an opportunity to see and interact with acid-base content and connect their prior knowledge to what they will be learning in this learning segment. Students can use a variety of tools to see what is happening in the solution and can alter different aspects of the solution as well. The activity is fully student centered and informal, giving students a low-risk means of experiencing the content. It may also be useful for the teacher to use data collected from this activity to tailor this learning segment to their classes. It should be noted that this activity could be handed out to students to collect more formal data or could be simply displayed on a SmartBoard to start conversations between students.

**Explore** – This activity allows students to explore both the concept of acid-base solutions and the simulation on their own with little prompting on instruction on the part of the teacher. The simulation is a hands-on representation of the content and allows students to select a variety of different solutions and use a few different tools to experiment with and collect data from.

**Activity** -

**Introduction to Acid-Base Solutions**

In this activity we will be working through a simulation activity that deals with acid-base solutions and strong acids and bases. Before we begin, list some of the things you know about acid-base solutions in the space below. Some things to think about include: pH, strong acids, weak acids, electrolytes, conductivity, acids and bases.

Now, open up the “Acid-Base Solutions” simulation found at [https://phet.colorado.edu/en/simulation/acid-base-solutions](https://phet.colorado.edu/en/simulation/acid-base-solutions). You should open up to the “Home” screen and see two different boxes labeled “Introduction” and “My Solution.” We will be sticking with the “Introduction” screen for this assignment. Click on the box and you should see a beaker of water with a magnifying glass over it. Play around with this screen and note any observations in the
space below. Be sure to try all three tools and all five solution options. See how they are the same and how they are different.

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**Simulation Usage in Core Instruction**

**Explain** – In the explain phase, students learn more about the content they explored previously in a more formal manner. The key vocabulary for this learning segment, acid-base solutions, is explained in an in-depth manner in the introductory section of this activity. It is advised that the teacher read this section aloud to students and answer any questions students may have about acid-base solutions before they delve more deeply into the content. Students will also learn how to predict reactants and products of acid-base solutions and how to predict whether or not a solution will conduct electricity. In addition, students will learn the definitions of Arrhenius acids and Arrhenius bases and the differences between them.

**Elaborate** – In the elaborate phase, students continue to practice working with the concept of acid-base solutions and expand upon this idea by relating it to electrical conductivity. This allows students to actually see how the ideas of strong acids and bases forming ions and becoming electrolytes effects the real world. Acid-base solutions are put into context and allow students to make connections between the content and real world phenomena they may experience.

**Activity - (adapted from**

https://chem.libretexts.org/Bookshelves/PhysicalandTheoreticalChemistryTextbookMaps/SupplementalModules(PhysicalandTheoreticalChemistry)/AcidsandBases/Acid/OverviewofAcidsandBases)

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**Arrhenius Acids & Bases**

Acids and bases are common solutions that exist everywhere. Almost every liquid that we encounter in our daily lives consists of acidic and basic properties, with the exception of water. They have completely different
properties and are able to neutralize to form H\textsubscript{2}O. Acids and bases can be defined by their physical and chemical observations.

<table>
<thead>
<tr>
<th>General Properties of Acids and Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACIDS</strong></td>
</tr>
<tr>
<td>produce a piercing pain in a wound.</td>
</tr>
<tr>
<td>taste sour.</td>
</tr>
<tr>
<td>are colorless when placed in phenolphthalein (an indicator).</td>
</tr>
<tr>
<td>are red on blue litmus paper (a pH indicator).</td>
</tr>
<tr>
<td>have a pH&lt;7.</td>
</tr>
<tr>
<td>produce hydrogen gas when reacted with metals.</td>
</tr>
</tbody>
</table>
When acids and bases are dissolved in an aqueous solution, certain ions are released into the solution. Acids and bases in aqueous solutions will conduct electricity because they contain these dissolved ions. Therefore, acids and bases are **electrolytes**. Strong acids and bases will be strong electrolytes. Weak acids and bases will be weak electrolytes. This affects the amount of conductivity.

In 1884, Svante Arrhenius, a Swedish chemist, proposed the idea that acids and bases differ in what they do in solution. An Arrhenius acid is a compound that increases the concentration of **H⁺ ions** that are present when added to water. These H⁺ ions form the hydronium ion (H₃O⁺) when they combine with water molecules. This process is represented in a chemical equation by adding H₂O to the reactants side.

\[ \text{HCl(aq)} \rightarrow \text{H}^+(aq) + \text{Cl}^-(aq) \]

In this reaction, hydrochloric acid (HCl) dissociates completely into hydrogen (H⁺) and chlorine (Cl⁻) ions when dissolved in water, thereby releasing H⁺ ions into solution. Formation of the hydronium ion equation:

\[ \text{HCl(aq)} + \text{H₂O(l)} \rightarrow \text{H₃O}^+(aq) + \text{Cl}^-(aq) \]

An Arrhenius base is a compound that increases the concentration of **OH⁻ ions** that are present when added to water. The dissociation is represented by the following equation:

\[ \text{NaOH(aq)} \rightarrow \text{Na}^+(aq) + \text{OH}^- (aq) \]

In this reaction, sodium hydroxide (NaOH) disassociates into sodium (Na⁺) and hydroxide (OH⁻) ions when dissolved in water, thereby releasing OH⁻ ions into solution.
Getting Started

1. Log into a computer and open up Google Chrome.

2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/acid-base-solutions](https://phet.colorado.edu/en/simulation/acid-base-solutions).

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start with the “Introduction” section by selecting the first option.

Introduction

1. You should see a beaker with a magnifying glass over it. If you do not, ensure that you have followed the directions in the “Getting Started” section correctly.

CiQ 1: Check the box next to “Solvent.” What do you think this solvent is? Based on what we read above, why do you think that?

2. Drag the pH probe into the solution in the beaker. Record the pH in the corresponding box in the table on the next page.

3. Click the second option in the “Tools” menu. This tool is a litmus test. Drag the litmus paper into the solution and record the color of the litmus paper in the corresponding box in the table on the next page.

4. Do the same with the last option in the “Tools” menu. This is a conductivity test. Think about what it would mean if a solution were to conduct electricity and fill in the corresponding box in the table on the next page.

5. Repeat steps 2-4 with each of the available solutions.
<table>
<thead>
<tr>
<th>Solution</th>
<th>Reaction Equation</th>
<th>pH</th>
<th>Litmus Paper Color</th>
<th>Conducts?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strong Acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weak Acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strong Base</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weak Base</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CiQ 2: HCl is a strong acid. Would you expect it to conduct? Explain.

CiQ3: What would you predict the reaction equation for HCl to be?

6. Now, check the box next to “Graph” in the views option. Ensure that you are on the lightbulb tool and switch between each solution, then answer the Check in Question below.

CiQ4: What do you notice about the equilibrium concentrations of the products and reactants for the solutions that conducted (pay attention to the brightness of the lightbulb)? What does this tell you?

Wrap-Up Questions:

1) What is an Arrhenius acid?
   a. An H\(^+\) donor
   b. An OH\(^-\) donor
   c. An \(\text{H}_2\text{O}^+\) donor
   d. An \(\text{H}_2\text{O}\) donor
2) What is an Arrhenius base?
   a. An H\(^+\) donor
   b. An OH\(^-\) donor
   c. An H\(_3\)O\(^+\) donor
   d. An H\(_2\)O donor

3) What does a strong acid/base do that a weak acid/base doesn’t?

4) Do strong acids/bases or weak acids/bases conduct electricity better?

5) How does a solution conduct electricity?

6) Write the reaction equation for a strong acid in water.

---

**Simulation Usage as an Expansionary Assessment**

**Evaluate** – In the evaluate phase, students put what they have learned in the previous phases into action. For the purposes of this activity, students are using what they have learned about acid-base solutions so far in this learning segment, as well as what they have learned about how to use the simulation itself to answer a variety of questions.

**Activity** –

**Acid-Base Solutions Assessment**

1. Create a solution that will strongly conduct electricity.
   a. Is it an acid or a base? ________
b. Is it strong or weak? __________

c. What is its pH? ______

2. Create a solution that will weakly conduct electricity.
   a. Is it an acid or a base? __________
   b. Is it strong or weak? __________
   c. What is its pH? ______

3. Create a solution with a pH of 0.
   a. Is it an acid or a base? __________
   b. Is it strong or weak? __________
   c. What is its concentration? ______
   d. Does it conduct? ______
   e. What color is the litmus test? ______

   a. Is it an acid or a base? __________
   b. Is it strong or weak? __________
   c. What is its concentration? ______
   d. Does it conduct? ______
   e. What color is the litmus test? ______

5. What is the concentration of products of a weak acid with a pH of 5.50?

6. What is the concentration of reactants of a weak base with a pH of 12.5?
7. What is the concentration of reactants of a strong acid with a pH of 3.0?

8. What is the concentration of products of a strong base with a pH of 11.0?

9. What does conductivity mean?

10. Why do acids and bases conduct electricity?

11. Why do strong acids and bases conduct electricity better than weak acids and bases?

12. Which of the following would be an Arrhenius base?
   a. HNO₃
   b. Mg(OH)₂
   c. H₃O⁺
   d. C₆H₁₂O₆

13. Which of the following would be an Arrhenius acid?
   a. CH₃COOH
   b. KOH
   c. NH₃
   d. LiOH
14. Which of the following would be an Arrhenius base?
   a. NH₃  
   b. CH₃COOH  
   c. HCl  
   d. NaOH

15. Which of the following would be an Arrhenius acid?
   a. H₃O⁺  
   b. Mg(OH)₂  
   c. HCl  
   d. C₃H₇OH

16. Challenge: Write your own question using the simulation and what you have learned about acids and bases.

Activity Guide

Preliminary Activity

Introduction to Acid-Base Solutions

In this activity we will be working through a simulation activity that deals with acid-base solutions and strong acids and bases. Before we begin, list some of the things you know about acid-base solutions in the space below. Some things to think about include: pH, strong acids, weak acids, electrolytes, conductivity, acids and bases.

Dependent on student

Now, open up the “Acid-Base Solutions” simulation found at https://phet.colorado.edu/en/simulation/acid-base-solutions. You should open up to the “Home” screen and see two different boxes labeled “Introduction” and “My
Solution.” We will be sticking with the “Introduction” screen for this assignment. Click on the box and you should see a beaker of water with a magnifying glass over it. Play around with this screen and note any observations in the space below. Be sure to try all three tools and all five solution options. See how they are the same and how they are different.

Dependent on student

Core Activity

Arrhenius Acids & Bases

Acids and bases are common solutions that exist everywhere. Almost every liquid that we encounter in our daily lives consists of acidic and basic properties, with the exception of water. They have completely different properties and are able to neutralize to form H₂O. Acids and bases can be defined by their physical and chemical observations.

<table>
<thead>
<tr>
<th>General Properties of Acids and Bases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACIDS</strong></td>
</tr>
<tr>
<td>produce a piercing pain in a wound.</td>
</tr>
<tr>
<td>taste sour.</td>
</tr>
<tr>
<td>are colorless when placed in phenolphthalein (an indicator).</td>
</tr>
<tr>
<td><strong>BASES</strong></td>
</tr>
<tr>
<td>give a slippery feel.</td>
</tr>
<tr>
<td>taste bitter.</td>
</tr>
<tr>
<td>are pink when placed in phenolphthalein (an indicator).</td>
</tr>
<tr>
<td>Acid Properties</td>
</tr>
<tr>
<td>------------------------------------------</td>
</tr>
<tr>
<td>are red on blue litmus paper (a pH indicator).</td>
</tr>
<tr>
<td>have a pH&lt;7.</td>
</tr>
<tr>
<td>produce hydrogen gas when reacted with metals.</td>
</tr>
<tr>
<td>produce carbon dioxide when reacted with carbonates.</td>
</tr>
<tr>
<td>Common examples: Lemons, oranges, vinegar, urine, sulfuric acid, hydrochloric acid</td>
</tr>
</tbody>
</table>

When acids and bases are dissolved in an aqueous solution, certain ions are released into the solution. Acids and bases in aqueous solutions will conduct electricity because they contain these dissolved ions. Therefore, acids and bases are **electrolytes**. Strong acids and bases will be strong electrolytes. Weak acids and bases will be weak electrolytes. This affects the amount of conductivity.

In 1884, Svante Arrhenius, a Swedish chemist, proposed the idea that acids and bases differ in what they do in solution. An Arrhenius acid is a compound that increases the concentration of **H⁺ ions** that are present when added to water. These H⁺ ions form the hydronium ion (H₃O⁺) when they combine with water molecules. This process is represented in a chemical equation by adding H₂O to the reactants side.

$$\text{HCl(aq)} \rightarrow \text{H}^+(aq) + \text{Cl}^-(aq)$$
In this reaction, hydrochloric acid (HCl) dissociates completely into hydrogen (H\(^+\)) and chlorine (Cl\(^-\)) ions when dissolved in water, thereby releasing H\(^+\) ions into solution. Formation of the hydronium ion equation:

\[
HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)
\]

An Arrhenius base is a compound that increases the concentration of OH\(^-\) ions that are present when added to water. The dissociation is represented by the following equation:

\[
NaOH(aq) \rightarrow Na^+(aq) + OH^-(aq)
\]

In this reaction, sodium hydroxide (NaOH) disassociates into sodium (Na\(^+\)) and hydroxide (OH\(^-\)) ions when dissolved in water, thereby releasing OH\(^-\) ions into solution.

**Getting Started**

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/acid-base-solutions](https://phet.colorado.edu/en/simulation/acid-base-solutions).
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.
4. Start with the “Introduction” section by selecting the first option.

**Introduction**

1. You should see a beaker with a magnifying glass over it. If you do not, ensure that you have followed the directions in the “Getting Started” section correctly.

**CiQ 1:** Check the box next to “Solvent.” What do you think this solvent is? Based on what we read above, why do you think that?

   **Solvent is water, dissociation of acids/bases in water**
2. Drag the pH probe into the solution in the beaker. Record the pH in the corresponding box in the table on the next page.

For this guide, we will be focusing on the strong acid solution available in the simulation. Note that the reaction on the bottom of the screen coincides with the fact that we have selected a strong acid. The pH value can be shown on the probe, in this case it is 2.00. You can also see the molecules in the beaker. Notice that there are no HA molecules in solution due to the fact that strong acids completely dissociate in water.

3. Click the second option in the “Tools” menu. This tool is a litmus test. Drag the litmus paper into the solution and record the color of the litmus paper in the corresponding box in the table on the next page.
4. Do the same with the last option in the “Tools” menu. This is a conductivity test. Think about what it would mean if a solution were to conduct electricity and fill in the corresponding box in the table on the next page.
5. Repeat steps 2-4 with each of the available solutions.

As discussed in the previous example, the bulb appears less bright in comparison to the bulb in the strong acid as the solution is now a weak acid. You can also see that the “Solvent” box has been checked and you can now see the gray molecules in the beaker that represent the solvent, water.
<table>
<thead>
<tr>
<th>Solution</th>
<th>Reaction Equation</th>
<th>pH</th>
<th>Litmus Paper Color</th>
<th>Conducts?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>$2\text{H}_2\text{O} \leftrightarrow \text{H}_3\text{O}^+ + \text{OH}^-$</td>
<td>7.00</td>
<td>Light Orange</td>
<td>No</td>
</tr>
<tr>
<td>Strong Acid</td>
<td>$\text{HA} + \text{H}_2\text{O} \rightarrow \text{A}^- + \text{H}_3\text{O}^+$</td>
<td>2.00</td>
<td>Dark Red</td>
<td>Yes, strongly</td>
</tr>
<tr>
<td>Weak Acid</td>
<td>$\text{HA} + \text{H}_2\text{O} \leftrightarrow \text{A}^- + \text{H}_3\text{O}^+$</td>
<td>4.50</td>
<td>Dark orange</td>
<td>Yes, weakly</td>
</tr>
<tr>
<td>Strong Base</td>
<td>MOH $\rightarrow$ M$^+$ + OH$^-$</td>
<td>12.00</td>
<td>Dark Blue</td>
<td>Yes, strongly</td>
</tr>
<tr>
<td>Weak Base</td>
<td>B + H$_2$O $\leftrightarrow$ BH$^+$ + OH$^-$</td>
<td>9.50</td>
<td>Dark Green</td>
<td>Yes, weakly</td>
</tr>
</tbody>
</table>

CiQ 2: HCl is a strong acid. Would you expect it to conduct? Explain.

Yes, dissociates completely into ions, the other strong acid in the simulation conducts

CiQ3: What would you predict the reaction equation for HCl to be?

$$\text{HCl} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^-$$

6. Now, check the box next to “Graph” in the views option. Ensure that you are on the lightbulb tool and switch between each solution, then answer the Check in Question below.
CiQ4: What do you notice about the equilibrium concentrations of the products and reactants for the solutions that conducted (pay attention to the brightness of the lightbulb)? What does this tell you?

Strong conducting solutions have acids/bases that dissociate completely to have no reactants and only products, weakly conducting solutions have some reactants and some products in solution

Wrap-Up Questions:

1. What is an Arrhenius acid?
   a. An $H^+$ donor
   b. An $OH^-$ donor
   c. An $H_3O^+$ donor
   d. An $H_2O$ donor
2. What is an Arrhenius base?
   a. An H⁺ donor
   b. An OH⁻ donor
   c. An H₃O⁺ donor
   d. An H₂O donor

3. What does a strong acid/base do that a weak acid/base doesn’t?
   Dissociates completely

4. Do strong acids/bases or weak acids/bases conduct electricity better?
   Strong

5. How does a solution conduct electricity?
   Ions in solution, electrolytes

6. Write the reaction equation for a strong acid in water.
   \[ HA + H₂O \rightarrow H₃O⁺ + A⁻ \]
Assessment Activity

Acid-Base Solutions Assessment

For these questions, there is a lot of playing around with options to get the desired results. Use of judgement makes this process much easier. Note that the biggest factors will be concentration and the strength of the solution.

1. Create a solution that will strongly conduct electricity.
   a. Is it an acid or a base? Either
   b. Is it strong or weak? Strong
   c. What is its pH? <7.5 if base for “a” and <6.5 if acid for “a”

2. Create a solution that will weakly conduct electricity.
   a. Is it an acid or a base? Either
   b. Is it strong or weak? weak
   c. What is its pH? <7.5 if base for “a” and <6.5 if acid for “a”

3. Create a solution with a pH of 0.
a. Is it an acid or a base? **acid**

b. Is it strong or weak? **strong**

c. What is its concentration? **1.0 mol/L**

d. Does it conduct? **yes**

e. What color is the litmus test? **Very dark red**


a. Is it an acid or a base? **base**

b. Is it strong or weak? **strong**

c. What is its concentration? **1.0 mol/L**

d. Does it conduct? **yes**

e. What color is the litmus test? **Black**

For these questions, make sure you have the “Graph” option selected in the “Views” section. Again, this involves playing around with the simulation and using best judgement to find the correct pH. Once the correct pH is found, you can find the concentrations within the graph.
5. What is the concentration of products of a weak acid with a pH of 5.50?

\[ 3.17 \times 10^{-6} \text{ H}_3\text{O}^+ \text{ and A}^- \]

6. What is the concentration of reactants of a weak base with a pH of 12.5?

\[ 9.68 \times 10^{-1} \text{ B and 55.6 H}_2\text{O} \]

7. What is the concentration of reactants of a strong acid with a pH of 3.0?

0/negligible for HA, 55.6 for H\(_2\)O

8. What is the concentration of products of a strong base with a pH of 11.0?

1x10\(^{-3}\)

9. What does conductivity mean?

Ability to conduct electricity, if something can conduct electricity a lightbulb can be light in the solution

10. Why do acids and bases conduct electricity?

Presence of ions, they are electrolytes

11. Why do strong acids and bases conduct electricity better than weak acids and bases?

Higher concentration of ions because strong acids/bases dissociate completely

12. Which of the following would be an Arrhenius base?

a. HNO\(_3\)

b. Mg(OH)\(_2\)

c. H\(_3\)O\(^+\)

d. C\(_6\)H\(_{12}\)O\(_6\)

13. Which of the following would be an Arrhenius acid?

a. CH\(_3\)COOH
14. Which of the following would be an Arrhenius base?
   a. NH₃
   b. CH₃COOH
   c. HCl
   d. NaOH

15. Which of the following would be an Arrhenius acid?
   a. H₃O⁺
   b. Mg(OH)₂
   c. HCl
   d. C₃H₇OH

16. Challenge: Write your own question using the simulation and what you have learned about acids and bases.

   Dependent on student
Alpha Decay

Simulation Link: [https://phet.colorado.edu/en/simulation/legacy/alpha-decay](https://phet.colorado.edu/en/simulation/legacy/alpha-decay)

NYS Content Standards:

3.1p Spontaneous decay can involve the release of alpha particles, beta particles, positrons and/or gamma radiation from the nucleus of an unstable isotope. These emissions differ in mass, charge, and ionizing power, and penetrating power.

4.4a Each radioactive isotope has a specific mode and rate of decay (half-life).

Learning Goals:

1) Students will be able to define alpha decay.
2) Students will be able to write equations for alpha decay.
3) Students will be able to define half-life.
4) Students will be able to determine the isotope of a molecule.

Key Vocabulary and Concepts for Simulation:

1) **Alpha Decay** – radioactive decay of a molecule in which two protons and two neutrons are released in the form of an alpha particle
2) **Half-Life** – the time it takes for a radioactive isotope to decrease to 50% of its original value
3) **Atomic Mass** – the average of the sum of the number of protons and neutrons in an atom and its isotopes
4) **Isotope** – two or more forms of the same element that have the same number of protons and electrons but different numbers of neutrons so that they have the same charge but not the same atomic mass
5) **Proton** – a subatomic particle with a positive charge that is the same size as a neutron
6) **Neutron** – a subatomic particle with no charge that is the same size as a proton
7) **Electron** - a relatively small subatomic particle with a negative charge
### Stimulating Aspects of the Simulation:

1. Ability to visualize radioactive decay when an alpha particle/electron is released
2. Records the amount of time for a decay to occur
3. Decay times are not at the exact half-life to show a more realistic visualization of radioactivity
4. The initial and final identity of the atom before and after radioactive decay has occurred are shown

### Planning Considerations for Simulation:

1. Little hands-on interaction
2. Students may rush through without observing everything the simulation has to offer
3. Fairly small amount of actual content in the simulations
Simulation Parts Explained:

Screen 1: Alpha Decay – Multiple Atoms

- Decay Timer
- Reset Button
- Pause/Play Button
- Nucleus Selector
- Nucleus Bucket

Screen 2: Alpha Decay – Single Atom

- Single Decay Timer
- Energy Graph
**Decay Timer** – shows the average half-life, in seconds, for the nucleus selected, also shows how many of each nucleus are still present, at the beginning it will be entirely the radioactive nucleus and after decay has occurred it will be entirely the more stable nucleus, as nuclei decay they will appear on the timer so you will end up with various nuclei decayed at various times averaged around the half-life line.

**Pause/Play Button** – pauses or plays the simulation, in addition, the button to the right of the pause/play button allows you to control frame by frame if you press it while paused.

**Reset Button** – resets all nuclei on the screen to their unstable form, starting the simulation over again.

**Nucleus Selector** – selects which nucleus to use in the simulation, with the custom option selected, you will be able to drag the half-life line to wherever you wish.

**Nucleus Bucket** – allows you to control how many nuclei are on the screen undergoing decay, you may drag one out at a time or press the “Add 10” button below the bucket to add 10 nuclei at one time, you may also drag any nuclei back into the bucket to remove it from the simulation.

**Energy Graph** – shows the energy of the nucleus, it will remain at the same level (the red line) until it decays, at which point the decaying particle will shoot off to one of the sides, dropping the energy down below the black line.

**Single Decay Timer** – similar to the decay timer on the “Multiple Atoms” tab, however, this timer displays the time in milliseconds on the left side of the timer, in addition, when you reset the nucleus on this screen it will decay and then an indicator will appear on the timer corresponding to the time the nucleus decayed, to completely clear this simply press the “Clear Chart” button on the bottom left side of the timer.

**Suggestions for Supplemental Material:**

[https://chem.libretexts.org/Courses/can/intro/17%3ARadioactivityandNuclearChemistry/17.03%3ATypesofRadioactivity%3AAAlpha%2CBeta%2CandGammaDecay](https://chem.libretexts.org/Courses/can/intro/17%3ARadioactivityandNuclearChemistry/17.03%3ATypesofRadioactivity%3AAAlpha%2CBeta%2CandGammaDecay)
Simulation Usage in the Preliminary Period

**Engage** – Students will be engaged during this segment because they will be required to think back to what they have previously learned about subatomic particles and nuclear decay and then apply this knowledge to a new topic and device for learning, the simulation. Students can drag different nuclei into the simulation and watch as they decay and alpha particles shoot off. The simulation itself greatly adds to the engagement of this part of the learning segment as it gives students the opportunity to play around on their own in a low-stakes environment with only a few prompting questions guiding them, allowing them to take greater control of their own learning. While this activity is formally written out as a handout, there are numerous benefits to using it simply as a guide to spark class discussion on the topic of alpha decay.

**Explore** – As was discussed in the previous section about the engage phase, the use of this activity gives students the opportunity to explore the content within the simulation on their own, without being constrained by a more formal assignment. Students will be able to see alpha decay as it is happening through the simulation and have the opportunity to relate what they are seeing to what they have learned previously.

**Activity -**

**Introduction to Alpha Decay**

Alpha decay is a specific example of nuclear decay. Nuclear decay occurs when an unstable atom releases some type of particle so that it can become stable again. Write some things you know about nuclear chemistry in the below.

1.
2.
3.
Nuclear chemistry deals with many different types of subatomic particles. We have talked about some of these previously. Using what you have learned about subatomic particles, define the following terms:

4. **Nucleus** –
5. **Proton** –
6. **Neutron** –
7. **Electron** –

Now that you have thought about subatomic particles again, open up the “Alpha Decay” simulation found at [https://phet.colorado.edu/en/simulation/legacy/alpha-decay](https://phet.colorado.edu/en/simulation/legacy/alpha-decay). Spend a few minutes playing around with these simulations. Write down some of the things you notice in the space below. Pay close attention to things like half-life, the initial and final atom and the number and types of subatomic particles.

8. 
9. 
10. 

**Simulation Usage in the Core Instruction Period**

**Explain** – For this assignment, the explain phase is covered mainly in the introductory reading. It is suggested that the teacher read this introductory information to the class aloud and address any student questions that arise and any misconceptions students may have. Much of the information that will be needed for the full understanding of this learning segment is found here, and students will use this information throughout the remainder of the learning segment to answer various questions.

**Elaborate** – The elaborate phase of this learning segment happens when students answer the wrap-up questions at the end of this assignment. For these questions, students will be connecting what they learned in the explain phase of
this assignment to the questions they will have to answer. These questions will require students to take what they learned and apply it to a new, more challenging situation.

Activity (adapted from https://chem.libretexts.org/Courses/can/intro/17%3A_Radioactivity_and_Nuclear_Chemistry/17.03%3A_Types_of_Radioactivity%3A_Alpha%2C_Beta%2C_and_Gamma_Decay) –

### Alpha Decay

Many nuclei are radioactive; that is, they decompose by emitting particles and in doing so, become a different nucleus. In our studies up to this point, atoms of one element were unable to change into different elements. That is because in all other types of changes we have talked about only the electrons were changing. In these changes, the nucleus, which contains the protons which dictate which element an atom is, is changing. All nuclei with 84 or more protons are radioactive and elements with less than 84 protons have both stable and unstable isotopes. All of these elements can go through nuclear changes and turn into different elements. This nuclear change occurs around the half-life of the atom. The half-life is the time it takes for half of the atoms in a radioactive sample to undergo a type of nuclear change.

One of these types of nuclear changes is alpha decay. Alpha decay occurs when an alpha particle is released from a radioactive nuclei. This alpha particle has been identified as a helium-4 nuclei. An example of a nucleus that undergoes alpha decay is uranium-238. The alpha decay of U-238 is

\[
\text{U}^{238} \rightarrow \text{He}^4 + \text{Th}^{234}
\]

As you can see from this equation, the uranium-238 is changed into thorium-234 through the release of an alpha particle. Notice that an alpha particle will have an atomic mass of 4, as denoted by the number in the top right of the element, and that the thorium-234 atom has an atomic mass that is 4 less than the original uranium-238 atom. This means that the alpha particle has two protons in it which were lost by the uranium atom. The two protons also
have a charge of +2. The top number, 4, is the mass number or the total of the protons and neutrons in the particle.

Because it has 2 protons, and a total of 4 protons and neutrons, alpha particles must also have two neutrons. Alpha particles always have this same composition: two protons and two neutrons.

Another alpha particle producer is thorium-230.

\[ \text{Th}^{230} \rightarrow \text{He}^{4} + \text{Ra}^{226} \]

Because the only thing given off by alpha decay is the alpha particle, you can easily predict what the ending atom will be if given the starting atom, or you could easily find out what the original atom was if given the ending atom and, thus, will be able to write out the appropriate equation for any alpha decay situation. These types of equations are called nuclear equations and are similar to the chemical equivalent discussed through the previous chapters.

**Getting Started**

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/legacy/alpha-decay](https://phet.colorado.edu/en/simulation/legacy/alpha-decay).
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.
4. Start the “Alpha Decay” simulation.

**Multiple Atoms**

1. Begin by dragging one of the atoms from the “Bucket o’ Polonium” into the middle of the screen.
   a. What subatomic particles leave the initial atom? (you may wish to pause the simulation to make it easier to see)
b. What atom does the initial atom become after alpha decay?

CiQ 1: Do you think this atom is more or less stable than Polonium? Why?

c. What is the decay time you found for your atom?

d. Is it to the right or to the left of the “Half Life” line that is around 0.5 seconds?

2. Now add 10 nuclei to the simulation. Record their decay times in the table below (use your best judgement).

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
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<tr>
<td>#3</td>
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<td>#4</td>
<td></td>
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<tr>
<td>#5</td>
<td></td>
</tr>
<tr>
<td>#6</td>
<td></td>
</tr>
<tr>
<td>#7</td>
<td></td>
</tr>
</tbody>
</table>
**CiQ 2:** Was your average decay time close to the half-life of 0.5 seconds?

3. Reset the simulation by pressing the “Reset All Nuclei” button in the middle right of the screen. Repeat Step 2 with another 10 nuclei.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
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<td>#4</td>
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<td>#5</td>
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<td>#6</td>
<td></td>
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<tr>
<td>#7</td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td></td>
</tr>
<tr>
<td>#9</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td></td>
</tr>
</tbody>
</table>

**Average Decay Time**

---

1. **CiQ 2:** Was your average decay time close to the half-life of 0.5 seconds?

3. Reset the simulation by pressing the “Reset All Nuclei” button in the middle right of the screen. Repeat Step 2 with another 10 nuclei.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
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<td>#4</td>
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<td>#5</td>
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<td>#7</td>
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<td>#8</td>
<td></td>
</tr>
<tr>
<td>#9</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td></td>
</tr>
</tbody>
</table>

**Average Decay Time**
**CiQ 3:** How does this value for the average decay time compare to the first value you calculated? How does it compare to the half-life value of 0.5 seconds?

**CiQ 4:** If you added more nuclei what do you think would happen to your average decay time?

---

**Single Atom**

1. Switch over to the “Single Atom” tab.

2. Wait for the nucleus to decay and then record the decay time in the table below.

3. Run 10 different samples, clicking the “Reset Nucleus” button after recording each decay time.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (milliseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
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<tr>
<td>#4</td>
<td></td>
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<td>#5</td>
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<td>#6</td>
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<tr>
<td>#7</td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td></td>
</tr>
<tr>
<td>#9</td>
<td></td>
</tr>
</tbody>
</table>
CiQ 5: How does your average decay time compare to the average decay time you found in the “Multiple Atoms” section?

Class Data

1. Now we will calculate the overall class average decay time for the Polonium atom. Based on what we have talked about regarding the half-life of atoms, this value should be even closer to the half-life for Polonium, as the half-life is the average time it takes for 50% of a radioactive sample to decay into a non-radioactive substance.

<table>
<thead>
<tr>
<th>Group</th>
<th>Average Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
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<td>#5</td>
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<td>#7</td>
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<td>#8</td>
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<tr>
<td>#9</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td></td>
</tr>
<tr>
<td>Class Average Decay Time</td>
<td></td>
</tr>
</tbody>
</table>
Wrap-Up Questions

1. If you tested a radioactive sample with 6 atoms, what would the half-life of the atom be if the atoms decay after 1.2 seconds, 0.4 seconds, 1.9 seconds, 0.8 seconds, 2.4 seconds and 1.5 seconds?

2. You are given an atom of radon-222 and are told it is a byproduct of alpha decay. What would the original atom be?

3. Write a nuclear equation for the alpha decay of platinum-175.

4. Find an example of an atom that undergoes alpha decay, which we have not talked about yet in this assignment. What is its nuclear equation?

5. For the same atom you found in question 4, what is its half-life?

Simulation Usage as an Expansionary Assessment

Evaluate – The evaluate phase will occur in this assessment. Students will use both the content knowledge they have learned throughout this learning segment and their knowledge of the simulation to answer a variety of questions regarding alpha decay. This questions will give students the opportunity to apply and reflect upon what they have learned.

Activity –
1. Using the “Alpha Decay” simulation, find the decay time of five atoms with a half-life of 1.0 seconds.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
</tr>
</tbody>
</table>

**Average Decay Time**

2. Using the “Alpha Decay” simulation, find the average decay time of five atoms with a half-life of 1.5 seconds.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
</tr>
</tbody>
</table>

**Average Decay Time**

3. Calculate the half-life of an atom if samples decayed at 3.2 seconds, 1.4 seconds, 2.3 seconds, 2.2 seconds, 0.9 seconds, and 1.8 seconds.
4. Test your calculated half-life from question 3 in the “Alpha Decay” simulation. Record the decay time of 5 samples in the table below.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
</tr>
<tr>
<td>Average Decay Time</td>
<td></td>
</tr>
</tbody>
</table>

5. Write the definition of half-life in your own words.

6. How many neutrons are found in an alpha particle?

7. How many protons are found in an alpha particle?

8. Write the nuclear equation for the alpha decay of Astatine 214.
9. Write the nuclear equation if the atom, after alpha decay, is Thallium-206.

10. Write the nuclear equation for the alpha decay of Lead-210.

---

**Activity Guide**

**Preliminary Activity**

**Introduction to Alpha Decay**

Alpha decay is a specific example of nuclear decay. Nuclear decay occurs when an unstable atom releases some type of particle so that it can become stable again. Write some things you know about nuclear chemistry in the space below.

For this assignment, there will be a few things of importance to note in the simulation. As you can see here, the simulation is paused and 10 nuclei have been added to the simulation. Notice that some of the nuclei have undergone decay and changed from Po-211 to Pb-207 before the half-life, some have after, and some have yet to decay. You can also see that the nuclei on the right side of the screen has just undergone decay as it is emitting light and an alpha particle which, if you look closely, consists of 2 neutrons and 2 protons.

1. Dependent on student
Nuclear chemistry deals with many different types of subatomic particles. We have talked about some of these previously. Using what you have learned about subatomic particles, define the following terms:

4. **Nucleus** – positively charged central core of an atom, consisting of protons and neutrons and containing nearly all its mass

5. **Proton** – a positively charged subatomic particle, about the same size as a neutron

6. **Neutron** – a neutrally charged subatomic particle, about the same size as a proton

7. **Electron** – a small, negatively charged subatomic particle

Now that you have thought about subatomic particles again, open up the “Alpha Decay” simulation found at https://phet.colorado.edu/en/simulation/legacy/alpha-decay. Spend a few minutes playing around with these simulations. Write down some of the things you notice in the space below. Pay close attention to things like half-life, the initial and final atom, the number and types of subatomic particles and what happens to the unstable atoms.

8. Dependent on student

9. Dependent on student

10. Dependent on student

**Core Activity**

**Alpha Decay**

Many nuclei are radioactive; that is, they decompose by emitting particles and in doing so, become a different nucleus. In our studies up to this point, atoms of one element were unable to change into different elements. That is because in all other types of changes we have talked about only the electrons were changing. In these changes, the
nucleus, which contains the protons which dictate which element an atom is, is changing. All nuclei with 84 or more protons are radioactive and elements with less than 84 protons have both stable and unstable isotopes. All of these elements can go through nuclear changes and turn into different elements. This nuclear change occurs around the half-life of the atom. The half-life is the time it takes for half of the atoms in a radioactive sample to undergo a type of nuclear change.

One of these types of nuclear changes is alpha decay. Alpha decay occurs when an alpha particle is released from a radioactive nuclei. This alpha particle has been identified as a helium-4 nuclei. An example of a nucleus that undergoes alpha decay is uranium-238. The alpha decay of U-238 is

$$^{238}U \rightarrow ^{4}He + ^{234}Th$$

As you can see from this equation, the uranium-238 is changed into thorium-234 through the release of an alpha particle. Notice that an alpha particle will have an atomic mass of 4, as denoted by the number in the top right of the element, and that the thorium-234 atom has an atomic mass that is 4 less than the original uranium-238 atom. This means that the alpha particle has two protons in it which were lost by the uranium atom. The two protons also have a charge of +2. The top number, 4, is the mass number or the total of the protons and neutrons in the particle. Because it has 2 protons, and a total of 4 protons and neutrons, alpha particles must also have two neutrons. Alpha particles always have this same composition: two protons and two neutrons.

Another alpha particle producer is thorium-230.

$$^{230}Th \rightarrow ^{4}He + ^{226}Ra$$

Because the only thing given off by alpha decay is the alpha particle, you can easily predict what the ending atom will be if given the starting atom, or you could easily find out what the original atom was if given the ending atom and, thus, will be able to write out the appropriate equation for any alpha decay situation. These types of
equations are called nuclear equations and are similar to the chemical equivalent discussed through the previous chapters.

**Getting Started**

1. Log into a computer and open up Google Chrome.

2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/legacy/alpha-decay](https://phet.colorado.edu/en/simulation/legacy/alpha-decay).

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Alpha Decay” simulation.

**Multiple Atoms** – For the purposes of this guide, all questions will be answered based on information found in the screenshots, note that this will be different for everyone

4. Begin by dragging one of the atoms from the “Bucket o’ Polonium” into the middle of the screen.
a. What subatomic particles leave the initial atom? (you may wish to pause the simulation to make it easier to see)

   **Alpha particle, 2 protons and 2 neutrons**

b. What atom does the initial atom become after alpha decay?

   **Lead/Pb-207**

**CiQ1:** Do you think this atom is more or less stable than Polonium? Why?
c. What is the half-life you found for your atom?

A little under 0.5 seconds, ~ 0.475 seconds (data dependent)

d. Is it to the right or to the left of the “Half Life” line that is around 0.5 seconds?

Left (data dependent)

5. Now add 10 nuclei to the simulation. Record their half-lives in the table below (use your best judgement).

For this section, 10 Polonium nuclei have been added to the simulation and allowed to fully decay. Notice that each nuclei will drop off at the time that they decay and there is a wide range of half-life times. This will look different for any run of the simulation and so the following table will be related to this screenshot. All decay times will also be rough estimates for this section.
<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0.1</td>
</tr>
<tr>
<td>#2</td>
<td>0.2</td>
</tr>
<tr>
<td>#3</td>
<td>0.5</td>
</tr>
<tr>
<td>#4</td>
<td>0.6</td>
</tr>
<tr>
<td>#5</td>
<td>0.6</td>
</tr>
<tr>
<td>#6</td>
<td>0.75</td>
</tr>
<tr>
<td>#7</td>
<td>0.75</td>
</tr>
<tr>
<td>#8</td>
<td>1.1</td>
</tr>
<tr>
<td>#9</td>
<td>1.4</td>
</tr>
<tr>
<td>#10</td>
<td>1.5</td>
</tr>
<tr>
<td>Average Decay Time</td>
<td>0.75</td>
</tr>
</tbody>
</table>

CiQ 2: Was your calculated average half-life close to the accepted half-life of 0.5 seconds?

Relatively close but actually about 50% higher than the accepted value (data dependent)

6. Reset the simulation by pressing the “Reset All Nuclei” button in the middle right of the screen. Repeat Step 2 with another 10 nuclei.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#2</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#3</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#4</td>
<td>See above table and explanation</td>
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<tr>
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<td>See above table and explanation</td>
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<td>#8</td>
<td></td>
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<tr>
<td>#9</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td></td>
</tr>
<tr>
<td><strong>Average Decay Time</strong></td>
<td>See above table and explanation</td>
</tr>
</tbody>
</table>

**CiQ 3:** How does this value for the average half-life compare to the first value you calculated? How does it compare to the accepted value of 0.5 seconds?

Data dependent

**CiQ 4:** If you added more nuclei what do you think would happen to your average half-life?

Get closer to the accepted value of 0.5 seconds

**Single Atom**

1. Switch over to the “Single Atom” tab.

2. Wait for the nucleus to decay and then record the decay time in the table below.
3. Run 10 different samples, clicking the “Reset Nucleus” button after recording each decay time.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (milliseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>330</td>
</tr>
<tr>
<td>#2</td>
<td>400</td>
</tr>
<tr>
<td>#3</td>
<td>45</td>
</tr>
<tr>
<td>#4</td>
<td>1100</td>
</tr>
<tr>
<td>#5</td>
<td>1500</td>
</tr>
<tr>
<td>#6</td>
<td>225</td>
</tr>
</tbody>
</table>
CiQ 5: How does your average half-life compare to the average half-life you found in the “Multiple Atoms” section?

Pretty close (data dependent)

Class Data

1. Now we will calculate the overall class average decay time for the Polonium atom. Based on what we have talked about regarding the half-life of atoms, this value should be even closer to the half-life for Polonium, as the half-life is the average time it takes for 50% of a radioactive sample to decay into a non-radioactive substance.

<table>
<thead>
<tr>
<th>Group</th>
<th>Average Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Dependent on class data</td>
</tr>
<tr>
<td>#2</td>
<td>Dependent on class data</td>
</tr>
<tr>
<td>#3</td>
<td>Dependent on class data</td>
</tr>
<tr>
<td>#4</td>
<td>Dependent on class data</td>
</tr>
<tr>
<td>#5</td>
<td>Dependent on class data</td>
</tr>
<tr>
<td>#6</td>
<td>Dependent on class data</td>
</tr>
<tr>
<td>#7</td>
<td>Dependent on class data</td>
</tr>
<tr>
<td>#8</td>
<td>Dependent on class data</td>
</tr>
</tbody>
</table>
Wrap-Up Questions

1. If you tested a radioactive sample with 6 atoms, what would the half-life of the atom be if the atoms decay after 1.2 seconds, 0.4 seconds, 1.9 seconds, 0.8 seconds, 2.4 seconds and 1.5 seconds?

   1.37 seconds

2. You are given an atom of radon-222 and are told it is a byproduct of alpha decay. What would the original atom be?

   Radium-226

3. Write a nuclear equation for the alpha decay of platinum-175.

   \[ \text{Pt-175} \rightarrow \text{He-4} + \text{Os-171} \]

4. Find an example of an atom that undergoes alpha decay, which we have not talked about yet in this assignment. What is its nuclear equation?

   Dependent on student

5. For the same atom you found in question 4, what is its half-life?

   Dependent on student

Assessment Activity

Alpha Decay Assessment

1. Using the “Alpha Decay” simulation, find the decay time of five atoms with a half-life of 1.0 seconds.
For this section, you will need to switch to the “Custom” nuclei on the right side of the screen. You will then be able to drag the target half-life anywhere you want by dragging the green arrow. Notice that it states there are 6 nuclei present. For some reason, nuclei may not decay until they are off the chart so you will not be able to see the time they decay. Because of this, I would advise just ignoring those nuclei and adding another to get 5 solid samples for the table.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>0.8</td>
</tr>
<tr>
<td>#2</td>
<td>1.2</td>
</tr>
<tr>
<td>#3</td>
<td>1.3</td>
</tr>
<tr>
<td>#4</td>
<td>1.4</td>
</tr>
<tr>
<td>#5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Average Decay Time: 1.34
2. Using the “Alpha Decay” simulation, find the decay time of five atoms with a half-life of 1.5 seconds.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#2</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#3</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#4</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#5</td>
<td>See above table and explanation</td>
</tr>
</tbody>
</table>

Average Decay Time

See above table and explanation

3. Calculate the half-life of an atom if samples decayed at 3.2 seconds, 1.4 seconds, 2.3 seconds, 2.2 seconds, 0.9 seconds, and 1.8 seconds.

1.18 seconds

4. Test your calculated half-life from question 3 in the “Alpha Decay” simulation. Record the half-lives of 5 samples in the table below.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#2</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#3</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#4</td>
<td>See above table and explanation</td>
</tr>
<tr>
<td>#5</td>
<td>See above table and explanation</td>
</tr>
</tbody>
</table>

Average Decay Time

See above table and explanation
5. Write the definition of half-life in your own words.

   Time it takes for 50% of a radioactive sample to decay

6. How many neutrons are found in an alpha particle?

   2

7. How many protons are found in an alpha particle?

   2

8. Write the nuclear equation for the alpha decay of Astatine 214.

   As-214 → He-4 + Ga-210

9. Write the nuclear equation if the atom, after alpha decay, is Thallium-206.

   Bi-210 → He-4 + Tl-206

10. Write the nuclear equation for the alpha decay of Lead-210.

    Pb-210 → He-4 + Hg-206
Balancing Chemical Equations

Simulation Link: https://phet.colorado.edu/en/simulation/balancing-chemical-equations

NYS Content Standards:

3.3c. A balanced chemical equation represents conservation of atoms. The coefficients in a balanced chemical equation can be used to determine mole ratios in the reaction.

Learning Goals:

1) Students will be able to accurately balance a chemical equation.

Key Vocabulary and Concepts for Simulation:

1) Empirical Formula – the simplest positive integer ratio of atoms present in a compound

2) Molecular Formula – the number of atoms of each element present in a molecule

Stimulating Aspects of the Simulation:

1) Multiple means of visualizing the quantity of each element in a molecule

2) Games of varying difficulty that give instant feedback

Planning Considerations for Simulation:

1) Possible to get correct answers by purely guessing on the game

Simulation Parts Explained:
Screen 1: Introduction

Screen 2: Game Home Menu

Screen Selector – selects which screen you are on
**Reaction Selector** – selects which reaction you would like to balance in the reaction equation section of the simulation.

**Molecule Display** – displays the molecules you have indicated in the reaction equation section.

**Tool Options** – allows you to select different tools to aid in visualizing the reaction, the tool appears directly above the molecule display windows, a scale and a graph can be selected that show the numbers of molecules relative to one another, when the coefficients are correct, the tools will appear balanced.

**Reaction Equation** – the equation for the reaction you have selected, you can alter the coefficients by either clicking on the up and down arrows or by clicking the number itself.

**Reset Button** – resets the simulation to the default state shown in the above screenshots.

**Game Options** – toggle various options for use within the game, sound may be enabled or disabled (a noise when you are correct and a different noise when you are incorrect) and a timer can be enabled or disabled.

**Difficulty Selector** – selects the difficulty of the game, the reaction that needs to be balanced becomes more complex the higher the level of difficulty.

**Suggestions for Supplemental Material:**

https://chem.libretexts.org/Courses/UniversityofBritishColumbia/CHEM100%3AFoundationsofChemistry/07%3AChemicalReactions/7.04%3AHowtoWriteBalancedChemicalEquations

**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged in this activity because it gives them an opportunity to interact with the content in a low-risk, game setting. Students may also compete with one another or with themselves to get better scores, and the randomness of the game allows for some replayability. Students will also be able to connect some of their prior learning about chemical reactions to the content within the simulation and see where they stand with this knowledge.
**Explore** – Like the engage phase, students will be exploring the content on their own when playing through the game. They will be given instant feedback and will be able to take this feedback into consideration to improve their abilities within the game.

**Activity** –

**Introduction to Balancing Chemical Equations**

Balancing chemical equations is an extremely important skill for the aspiring chemist. Since atoms can neither be created nor destroyed, the atoms you start with before a reaction occurs have to be the same as the atoms you end with after the reaction. For this assignment, you will begin to work through balancing chemical equations using the simulation found at [https://phet.colorado.edu/en/simulation/balancing-chemical-equations](https://phet.colorado.edu/en/simulation/balancing-chemical-equations). Navigate to the “Game” screen of the simulation and click on “Level 1.” Complete this game and write the completed reaction equations, including coefficients, below.

1. 

2. 

3. 

4. 

5.
Simulation Usage in the Core Instruction Period

**Explain** – For this assignment, the explain phase is covered mainly in the introductory reading. It is suggested that the teacher read this introductory information to the class aloud and address any student questions that arise and any misconceptions students may have. Much of the information that will be needed for the full understanding of this learning segment is found here, and students will use this information throughout the remainder of the learning segment to answer various questions.

**Elaborate** – The elaborate phase of this learning segment happens when students answer the wrap-up questions at the end of this assignment. For these questions, students will be connecting what they learned in the explain phase of this assignment to the questions they will have to answer. These questions will require students to take what they learned and apply it to a new, more challenging situation.

**Activity (adapted from**
https://chem.libretexts.org/Courses/University_of_British_Columbia/CHEM_100%3A_Foundations_of_Chemistry/07%3A_Chemical_Reactions/7.04%3A_How_to_Write_Balanced_Chemical_Equations) –

**Balancing Chemical Equations**

Even though chemical compounds are broken up and new compounds are formed during a chemical reaction, atoms in the reactants do not disappear nor do new atoms appear to form the products. In chemical reactions, atoms are never created or destroyed. The same atoms that were present in the reactants are present in the products - they are merely reorganized into different arrangements. In a complete chemical equation, the two sides of the equation must be present on the reactant and the product sides of the equation.
**Coefficients and Subscripts**

There are two types of numbers that appear in chemical equations. There are subscripts, which are part of the chemical formulas of the reactants and products and there are coefficients that are placed in front of the formulas to indicate how many molecules of that substance is used or produced.

The subscripts are part of the formulas and once the formulas for the reactants and products are determined, the subscripts may not be changed. The coefficients indicate the number of each substance involved in the reaction and may be changed in order to balance the equation. The equation above indicates that one mole of solid copper is reacting with two moles of aqueous silver nitrate to produce one mole of aqueous copper (II) nitrate and two atoms of solid silver.

**Balancing Equations**

Because the identities of the reactants and products are fixed, the equation cannot be balanced by changing the subscripts of the reactants or the products. To do so would change the chemical identity of the species being described.

The simplest and most generally useful method for balancing chemical equations is “inspection,” better known as trial and error. The following is an efficient approach to balancing a chemical equation using this method.

**Steps in Balancing a Chemical Equation**

1. Identify the most complex substance.
2. Beginning with that substance, choose an element(s) that appears in only one reactant and one product, if possible. Adjust the coefficients to obtain the same number of atoms of this element(s) on both sides.
3. Balance polyatomic ions (if present on both sides of the chemical equation) as a unit.

4. Balance the remaining atoms, usually ending with the least complex substance and using fractional coefficients if necessary. If a fractional coefficient has been used, multiply both sides of the equation by the denominator to obtain whole numbers for the coefficients.

5. Count the numbers of atoms of each kind on both sides of the equation to be sure that the chemical equation is balanced.

Getting Started

1. Log into a computer and open up Google Chrome.

2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/balancing-chemical-equations.

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Balancing Chemical Equations” simulation.

Introduction

1. For this assignment, you will be working exclusively with the “Introduction” screen of the “Balancing Chemical Equations” simulation. Open the simulation and navigate to this screen.

2. Click on the “Tools” drop down menu and select the first option, the scale. This will show you the balance of atoms between the products and reactants.

3. Using this tool, balance the making of ammonia reaction equation and write it, including coefficients, in the space below.
4. Now, select the second option in the tool menu, the graph. This will show you a graphical representation of the amount of atoms in the products and reactants of the equation.

5. Using this tool, balance the separate water equation and write it, including coefficients, in the space below.

6. Now, remove all tools and balance the combust methane reaction on your own and write it, including coefficients, in the space below.

Wrap-Up Questions

Balance the following chemical equations:

1. \(\_\_\_\text{Al} + \_\_\_\text{O}_2 \rightarrow \_\_\_\text{Al}_2\text{O}_3\)

2. \(\text{\_\_NaClO}_3 \rightarrow \_\_\text{NaCl} + \_\_\text{O}_2\)

3. \(\text{\_\_AgNO}_3 + \_\_\text{K}_3\text{PO}_4 \rightarrow \_\_\text{Ag}_3\text{PO}_4 + \_\_\text{KNO}_3\)

4. \(\_\_\text{S}_8 + \_\_\text{O}_2 \rightarrow \_\_\text{SO}_2\)

5. \(\_\_\text{Al} + \_\_\text{Br}_2 \rightarrow \_\_\text{AlBr}_3\)

6. \(\_\_\text{C}_2\text{H}_2 + \_\_\text{O}_2 \rightarrow \_\_\text{CO}_2 + \_\_\text{H}_2\text{O}\)

7. \(\_\_\text{SnO}_2 + \_\_\text{H}_2 \rightarrow \_\_\text{Sn} + \_\_\text{H}_2\text{O}\)

8. \(\text{\_\_KNO}_3 + \text{\_\_H}_2\text{CO}_3 \rightarrow \text{\_\_K}_2\text{CO}_3 + \_\_\text{HNO}_3\)

9. \(\_\_\text{Ba}_3\text{N}_2 + \_\_\text{H}_2\text{O} \rightarrow \_\_\text{Ba(OH)}_2 + \_\_\text{NH}_3\)

10. Find your own example of a real world chemical equation and balance it.
Simulation Usage in the Assessment Period

Evaluate – The activity for this section will assess students’ knowledge of both the simulation itself and the content within the simulation, the balancing of chemical equations. Students will be required to take what they have learned in the core instruction period and use it to complete the games within the simulation and answer the pencil and paper questions found in this activity. Students will also be able to self-evaluate their own learning as they complete the games.

Activity –

Balancing Chemical Equations Assessment

Part I:

Use the “Balancing Chemical Equations” simulation found at [https://phet.colorado.edu/en/simulation/balancing-chemical-equations](https://phet.colorado.edu/en/simulation/balancing-chemical-equations) to complete this part. Navigate to the “Game” screen of this simulation and complete “Level 2.”

Write down your completed and balanced reactions below.

1.

2.

3.

4.
Part II:

Use the “Balancing Chemical Equations” simulation found at https://phet.colorado.edu/en/simulation/balancing-chemical-equations to complete this part. Navigate to the “Game” screen of this simulation and complete “Level 3.”

Write down your completed and balanced reactions below.

6.

7.

8.

9.

10.

Part III:

Balance the following equations.

11. \( \text{Fe}_2\text{O}_3 + \text{C} \rightarrow \text{Fe} + \text{CO}_2 \)

12. \( \text{NH}_3 + \text{H}_2\text{SO}_4 \rightarrow (\text{NH}_4)\text{SO}_4 \)
13. \( \text{Na}_3\text{PO}_4 + \text{CaCl}_2 \rightarrow \text{NaCl} + \text{Ca}_3(\text{PO}_4)_2 \)

14. \( \text{CF}_4 + \text{Br}_2 \rightarrow \text{CBr}_4 + \text{F}_2 \)

15. Find and balance your own real world chemical reaction.

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**Activity Guide**

**Preliminary Activity**

**Introduction to Balancing Chemical Equations**

Balancing chemical equations is an extremely important skill for the aspiring chemist. Since atoms can neither be created nor destroyed, the atoms you start with before a reaction occurs have to be the same as the atoms you end with after the reaction. For this assignment, you will begin to work through balancing chemical equations using the simulation found at [https://phet.colorado.edu/en/simulation/balancing-chemical-equations](https://phet.colorado.edu/en/simulation/balancing-chemical-equations). Navigate to the “Game” screen of the simulation and click on “Level 1.” Complete this game and write the completed reaction equations, including coefficients, below.
The equations for the games in the simulation are randomly drawn from a pool so, for the purposes of this example, this screenshot, and the complete game that followed, will be used to answer the questions. You can increase and decrease the coefficients at any time using the up and down arrows. The number of molecules you have indicated is shown in the boxes to aid in visualization. When you think you have the correct answer, you can press the check button to check your answer. Hints will be given if the balancing is off.

6. \( 1\text{C}_2\text{H}_2 + 2\text{H}_2 \rightarrow 1\text{C}_2\text{H}_6 \)
7. \( 2\text{NO} \rightarrow 1\text{N}_2 + 1\text{O}_2 \)
8. \( 2\text{N}_2 + 1\text{O}_2 \rightarrow 2\text{N}_2 \)
9. \( 1\text{P}_4 + 6\text{F}_2 \rightarrow 4\text{PF}_3 \)
10. \( 1\text{CH}_3\text{OH} \rightarrow 1\text{CO} + 2\text{H}_2 \)
Core Activity

Balancing Chemical Equations

Even though chemical compounds are broken up and new compounds are formed during a chemical reaction, atoms in the reactants do not disappear nor do new atoms appear to form the products. In chemical reactions, atoms are never created or destroyed. The same atoms that were present in the reactants are present in the products - they are merely reorganized into different arrangements. In a complete chemical equation, the two sides of the equation must be present on the reactant and the product sides of the equation.

Coefficients and Subscripts

There are two types of numbers that appear in chemical equations. There are subscripts, which are part of the chemical formulas of the reactants and products and there are coefficients that are placed in front of the formulas to indicate how many molecules of that substance is used or produced.

The subscripts are part of the formulas and once the formulas for the reactants and products are determined, the subscripts may not be changed. The coefficients indicate the number of each substance involved in the reaction and may be changed in order to balance the equation. The equation above indicates that one mole of solid copper is reacting with two moles of aqueous silver nitrate to produce one mole of aqueous copper (II) nitrate and two atoms of solid silver.

Balancing Equations
Because the identities of the reactants and products are fixed, the equation cannot be balanced by changing the subscripts of the reactants or the products. To do so would change the chemical identity of the species being described.

The simplest and most generally useful method for balancing chemical equations is “inspection,” better known as trial and error. The following is an efficient approach to balancing a chemical equation using this method.

**STEPS IN BALANCING A CHEMICAL EQUATION**

1. Identify the most complex substance.
2. Beginning with that substance, choose an element(s) that appears in only one reactant and one product, if possible. Adjust the coefficients to obtain the same number of atoms of this element(s) on both sides.
3. Balance polyatomic ions (if present on both sides of the chemical equation) as a unit.
4. Balance the remaining atoms, usually ending with the least complex substance and using fractional coefficients if necessary. If a fractional coefficient has been used, multiply both sides of the equation by the denominator to obtain whole numbers for the coefficients.
5. Count the numbers of atoms of each kind on both sides of the equation to be sure that the chemical equation is balanced.

**Getting Started**

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/balancing-chemical-equations](https://phet.colorado.edu/en/simulation/balancing-chemical-equations)
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

**Introduction**

1. For this assignment, you will be working exclusively with the “Introduction” screen of the “Balancing Chemical Equations” simulation. Open the simulation and navigate to this screen.

2. Click on the “Tools” drop down menu and select the first option, the scale. This will show you the balance of atoms between the products and reactants.

For this example, we will be using the scale tool. This tool provides a scale that adjusts as you change the coefficients of both the products and reactants. Notice that each atom has its own scale, and that, when balanced, the scale will also be balanced. This is a useful tool to quickly visualize how many of each atom you have present in your own reaction equation. Notice that when the balance is completed, a yellow face appears in the top middle of the screen to indicate that you are correct.

3. Using this tool, balance the making of ammonia reaction equation and write it, including coefficients, in the space below.
1N₂ + 3H₂ → 2NH₃

4. Now, select the second option in the tool menu, the graph. This will show you a graphical representation of the amount of atoms in the products and reactants of the equation.

5. Using this tool, balance the separate water equation and write it, including coefficients, in the space below:

\[ 2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2 \]

6. Now, remove all tools and balance the combust methane reaction on your own and write it, including coefficients, in the space below:

\[ \text{1CH}_4 + 2\text{O}_2 \rightarrow \text{1CO}_2 + 2\text{H}_2\text{O} \]

**Wrap-Up Questions**

Balance the following chemical equations:
1. $\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$

2. $2\text{NaClO}_3 \rightarrow 2\text{NaCl} + 3\text{O}_2$

3. $3\text{AgNO}_3 + 1\text{K}_3\text{PO}_4 \rightarrow 1\text{Ag}_3\text{PO}_4 + 3\text{KNO}_3$

4. $\text{S}_8 + 8\text{O}_2 \rightarrow 8\text{SO}_2$

5. $2\text{Al} + 3\text{Br}_2 \rightarrow 2\text{AlBr}_3$

6. $2\text{C}_2\text{H}_2 + 5\text{O}_2 \rightarrow 4\text{CO}_2 + 2\text{H}_2\text{O}$

7. $\text{SnO}_2 + 2\text{H}_2 \rightarrow 1\text{Sn} + 2\text{H}_2\text{O}$

8. $2\text{KNO}_3 + 1\text{H}_2\text{CO}_3 \rightarrow 1\text{K}_2\text{CO}_3 + 2\text{HNO}_3$

9. $1\text{Ba}_3\text{N}_2 + 6\text{H}_2\text{O} \rightarrow 3\text{Ba(OH)}_2 + 2\text{NH}_3$

10. Find your own example of a real world chemical equation and balance it.

    Student dependent answer

Assessment Activity

Balancing Chemical Equations Assessment

Part I:

Use the “Balancing Chemical Equations” simulation found at [https://phet.colorado.edu/en/simulation/balancing-chemical-equations](https://phet.colorado.edu/en/simulation/balancing-chemical-equations) to complete this part. Navigate to the “Game” screen of this simulation and complete “Level 2.”

Write down your completed and balanced reactions below.
The equations for the games in the simulation are randomly drawn from a pool so, for the purposes of this example, this screenshot, and the complete game that followed, will be used to answer the questions. You can increase and decrease the coefficients at any time using the up and down arrows. The number of molecules you have indicated is shown in the boxes to aid in visualization. When you think you have the correct answer, you can press the check button to check your answer. Hints will be given if the balancing is off.

1. $\text{SO}_2 + 3\text{H}_2 \rightarrow \text{H}_2\text{S} + 2\text{H}_2\text{O}$
2. $\text{CH}_4 + 4\text{S} \rightarrow \text{CS}_2 + 2\text{H}_2\text{S}$
3. $\text{CH}_4 + \text{H}_2\text{O} \rightarrow 3\text{H}_2 + \text{CO}$
4. $2\text{C} + 2\text{H}_2\text{O} \rightarrow \text{CH}_4 + \text{CO}_2$
5. $\text{C}_2\text{H}_6 + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_5\text{Cl} + \text{HCl}$

**Part II:**

Use the “Balancing Chemical Equations” simulation found at [https://phet.colorado.edu/en/simulation/balancing-chemical-equations](https://phet.colorado.edu/en/simulation/balancing-chemical-equations) to complete this part. Navigate to the “Game” screen of this simulation and complete “Level 3.”

Write down your completed and balanced reactions below.
The equations for the games in the simulation are randomly drawn from a pool so, for the purposes of this example, this screenshot, and the complete game that followed, will be used to answer the questions. You can increase and decrease the coefficients at any time using the up and down arrows. The number of molecules you have indicated is shown in the boxes to aid in visualization. When you think you have the correct answer, you can press the check button to check your answer. Hints will be given if the balancing is off.

6. \(4 \text{NH}_3 + 7 \text{O}_2 \rightarrow 4 \text{NO}_2 + 6 \text{H}_2\text{O}\)
7. \(2 \text{C}_2\text{H}_6 + 7 \text{O}_2 \rightarrow 4 \text{CO}_2 + 6 \text{H}_2\text{O}\)
8. \(5 \text{N}_2 + 6\text{H}_2\text{O} \rightarrow 4 \text{NH}_3 + 6 \text{NO}\)
9. \(4 \text{CO}_2 + 2\text{H}_2\text{O} \rightarrow 4 \text{NH}_3 + 6 \text{NO}\)
10. \(2 \text{CO}_2 + 3\text{H}_2\text{O} \rightarrow 1 \text{C}_2\text{H}_5\text{OH} + 3 \text{O}_2\)

**Part III:**

Balance the following equations.

11. \(\text{Fe}_2\text{O}_3 + \text{C} \rightarrow \text{Fe} + \text{CO}_2\)

\[2\text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 4\text{Fe} + 3\text{CO}_2\]
12. \( \text{NH}_3 + \text{H}_2\text{SO}_4 \rightarrow (\text{NH}_4)_2\text{SO}_4 \)

\[
2\text{NH}_3 + \text{H}_2\text{SO}_4 \rightarrow (\text{NH}_4)_2\text{SO}_4
\]

13. \( \text{Na}_3\text{PO}_4 + \text{CaCl}_2 \rightarrow \text{NaCl} + \text{Ca}_3(\text{PO}_4)_2 \)

\[
2\text{Na}_3\text{PO}_4 + 3\text{CaCl}_2 \rightarrow 6\text{NaCl} + \text{Ca}_3(\text{PO}_4)_2
\]

14. \( \text{CF}_4 + \text{Br}_2 \rightarrow \text{CBr}_4 + \text{F}_2 \)

\[
\text{CF}_4 + 2\text{Br}_2 \rightarrow \text{CBr}_4 + 2\text{F}_2
\]

15. Find and balance your own real world chemical reaction.

Dependent on student
Beta Decay

Simulation Link: https://phet.colorado.edu/en/simulation/legacy/beta-decay

NYS Content Standards:

3.1p Spontaneous decay can involve the release of alpha particles, beta particles, positrons and/or gamma radiation from the nucleus of an unstable isotope. These emissions differ in mass, charge, and ionizing power, and penetrating power.

4.4a Each radioactive isotope has a specific mode and rate of decay (half-life).

Learning Goals:

1) Students will be able to define beta decay.

2) Students will be able to write the equation for beta decay.

3) Students will be able to define half-life.

4) Students will be able to determine the isotope of a molecule.

Key Vocabulary and Concepts for Simulation:

1) Beta Decay – radioactive decay of a molecule in which an electron is emitted

2) Half-Life – the time it takes for a radioactive isotope to decrease to 50% of its original value

3) Atomic Mass – the average of the sum of the number of protons and neutrons in an atom and its isotopes

4) Isotope – two or more forms of the same element that have the same number of protons and electrons but different numbers of neutrons so that they have the same charge but not the same atomic mass

5) Proton – a subatomic particle with a positive charge that is the same size as a neutron

6) Neutron – a subatomic particle with no charge that is the same size as a proton

7) Electron - a relatively small subatomic particle with a negative charge

Stimulating Aspects of the Simulation:
1) Ability to visualize radioactive decay when an alpha particle/electron is released

2) Records the amount of time for a decay to occur

3) Decay times are not at the exact half-life to show a more realistic visualization of radioactivity

4) The initial and final identity of the atom before and after radioactive decay has occurred are shown

**Planning Considerations for Simulation:**

1) Little hands-on interaction

2) Students may rush through without observing everything the simulation has to offer

3) Fairly small amount of actual content in the simulations

**Simulation Parts Explained:**

**Screen 1: Multiple Atoms**

- Decay Timer
- Reset Button
- Nucleus Bucket
- Nucleus Selector
- Pause/Play Button

**Screen 2: Single Atom**
Decay Timer – shows the average half-life, in seconds, for the nucleus selected, also shows how many of each nucleus are still present, at the beginning it will be entirely the radioactive nucleus and after decay has occurred it will be entirely the more stable nucleus, as nuclei decay they will appear on the timer so you will end up with various nuclei decayed at various times averaged around the half-life line.

Pause/Play Button – pauses or plays the simulation, in addition, the button to the right of the pause/play button allows you to control frame by frame if you press it while paused.

Reset Button – resets all nuclei on the screen to their unstable form, starting the simulation over again.

Nucleus Selector – selects which nucleus to use in the simulation, with the custom option selected, you will be able to drag the half-life line to wherever you wish.
**Nucleus Bucket** – allows you to control how many nuclei are on the screen undergoing decay, you may drag one out at a time or press the “Add 10” button below the bucket to add 10 nuclei at one time, you may also drag any nuclei back into the bucket to remove it from the simulation.

**Single Decay Timer** – similar to the decay timer on the “Multiple Atoms” tab, however, this timer displays the time in milliseconds on the left side of the timer, in addition, when you reset the nucleus on this screen it will decay and then an indicator will appear on the timer corresponding to the time the nucleus decayed, to completely clear this simply press the “Clear Chart” button on the bottom left side of the timer.

**Suggestions for Supplemental Material:**

https://chem.libretexts.org/Courses/can/intro/17%3ARadioactivityandNuclearChemistry/17.03%3ATypesofRadioactivity%3AAArrow%3ABeta%2CBeta%2CandGammaDecay

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**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged during this segment because they will be required to think back to what they have previously learned about subatomic particles and nuclear decay and then apply this knowledge to a new topic and device for learning, the simulation. The simulation itself greatly adds to the engagement of this part of the learning segment as it gives students the opportunity to play around on their own in a low-stakes environment with only a few prompting questions guiding them, allowing them to take greater control of their own learning. Students can drag different nuclei into the simulation and watch as they decay. While this activity is formally written out as a handout, there are numerous benefits to using it simply as a guide to spark class discussion on the topic of beta decay.

**Explore** – As was discussed in the previous section about the engage phase, the use of this activity gives students the opportunity to explore the content within the simulation on their own, without being constrained by a more formal
assignment. Students will be able to see beta decay as it is happening through the simulation and have the opportunity to relate what they are seeing to what they have learned previously.

**Activity -**

**Introduction to Beta Decay**

Beta decay is another specific example of nuclear decay. Nuclear decay occurs when an unstable atom releases some type of particle so that it can become stable again. Write some things you know about nuclear chemistry and about the differences between alpha and beta decay in the space below.

1. 
2. 
3. 

Nuclear chemistry deals with many different types of subatomic particles. We have talked about some of these previously. Using what you have learned about subatomic particles, define the following terms:

4. Nucleus –
5. Proton –
6. Neutron –
7. Electron –

Now that you have thought about subatomic particle again, open up the Beta Decay simulation found at [https://phet.colorado.edu/en/simulation/legacy/beta-decay](https://phet.colorado.edu/en/simulation/legacy/beta-decay). Spend a few minutes playing around with this simulation. Write down some of the things you notice in the space below. Pay close attention to things like half-life, the initial and final atom, the number and types of subatomic particles and what happens to the unstable atoms.

8. 
9. 
Simulation Usage in the Core Instruction Period

**Explain** – For this assignment, the explain phase is covered mainly in the introductory reading. It is suggested that the teacher read this introductory information to the class aloud and address any student questions that arise and any misconceptions students may have. Much of the information that will be needed for the full understanding of this learning segment is found here, and students will use this information throughout the remainder of the learning segment to answer various questions.

**Elaborate** – The elaborate phase of this learning segment happens when students answer the wrap-up questions at the end of this assignment. For these questions, students will be connecting what they learned in the explain phase of this assignment to the questions they will have to answer. These questions will require students to take what they learned and apply it to a new, more challenging situation

*Activity (adapted from)*

https://chem.libretexts.org/Courses/can/intro/17%3A_Radioactivity_and_Nuclear_Chemistry/17.03%3A_Types_of_Radioactivity%3A_Alpha%2C_Beta%2C_and_Gamma_Decay

**Beta Decay**

Recall that many nuclei are radioactive; that is, they decompose by emitting particles and in doing so, become a different nucleus. In these changes, the nucleus, which contains the protons which dictate which element an atom is, is changing. Remember that all nuclei with 84 or more protons are radioactive and elements with less than 84 protons have both stable and unstable isotopes. All of these elements can go through nuclear changes and turn into different elements. We previously discussed alpha decay, in which an alpha particle, a He\(^4\) atom, is emitted from a radioactive nuclei. Another type of nuclear decay is beta decay.
In beta decay, a beta particle is emitted. A beta particle is simply a high energy electron that is emitted from the nucleus. It may occur to you that we have a logically difficult situation here. Nuclei do not contain electrons and yet during beta decay, an electron is emitted from a nucleus. At the same time that the electron is being ejected from the nucleus, a neutron is becoming a proton. It is tempting to picture this as a neutron breaking into two pieces with the pieces being a proton and an electron. For the purpose of this assignment, we will treat beta decay as a neutron splitting into a proton and an electron. The proton stays in the nucleus, increasing the atomic number of the atom by one. The electron is ejected from the nucleus and is the particle of radiation called beta.

To insert an electron into a nuclear equation and have the numbers add up properly, an atomic number and a mass number had to be assigned to an electron. The mass number assigned to an electron is zero (0) which is reasonable since the mass number is the number of protons plus neutrons and an electron contains no protons and no neutrons. The atomic number assigned to an electron is negative one (-1), because that allows a nuclear equation containing an electron to balance atomic numbers. Therefore, the nuclear symbol representing an electron (beta particle) is

\[ ^0_e \text{ or } ^0_\beta \]

Thorium-234 is a nucleus that undergoes beta decay. Here is the nuclear equation for this beta decay.

\[ ^{234}_0Th \to ^0_e + ^{234}_{-1}Pa \]

**Getting Started**

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/legacy/beta-decay.
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.
4. Start the “Beta Decay” simulation.

**Multiple Atoms**

1. Begin by dragging one of the atoms from the “Bucket o’ Atoms” into the middle of the screen. Make sure that you have the hydrogen nucleus selected!
   a. What subatomic particles leave the initial atom? (you may wish to pause the simulation to make it easier to see)
   b. What atom does the initial atom become after beta decay?

**CiQ1**: Do you think this atom is more or less stable than Hydrogen? Why?

c. What is the decay time you found for your atom?

d. Is it to the right or to the left of the “Half Life” line that is around 12 years?

2. Now add 10 nuclei to the simulation. Record their decay time in the table below (use your best judgement).

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
</tbody>
</table>
### CiQ 2: Was your calculated average decay time close to the half-life of 12 years?

3. Repeat step 2 using the carbon nucleus.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
</tr>
<tr>
<td>#6</td>
<td></td>
</tr>
<tr>
<td>#7</td>
<td></td>
</tr>
</tbody>
</table>
CiQ 3: How does this value for the average decay time compare to the accepted value of 5,730 years?

CiQ 4: If you added more nuclei what do you think would happen to your average decay time?

**Single Atom**

1. Switch over to the “Single Atom” tab.
2. Wait for the nucleus to decay and then record the decay time in the table below.
3. Run 10 different samples, clicking the “Reset Nucleus” button after recording each decay time.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
</tr>
<tr>
<td>#6</td>
<td></td>
</tr>
</tbody>
</table>
CiQ 5: How does your average decay time compare to the average decay time you found in the “Multiple Atoms” section for hydrogen?

4. Repeat steps 1-3 with the carbon nucleus.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
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<tr>
<td>#5</td>
<td></td>
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<tr>
<td>#6</td>
<td></td>
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<tr>
<td>#7</td>
<td></td>
</tr>
<tr>
<td>#8</td>
<td></td>
</tr>
<tr>
<td>#9</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td></td>
</tr>
</tbody>
</table>

Average Decay Time
CiQ 6: How does this average decay time compare to the half-life value for carbon and the average decay time you found in the “Multiple Atoms” section.

**Class Data**

1. Now we will calculate the overall class average decay time for both the hydrogen and carbon atoms. Based on what we have talked about regarding the half-life of atoms, this value should be even closer to the half-life values for our nuclei, as the half-life is the average time it takes for 50% of a radioactive sample to decay into a non-radioactive substance.

<table>
<thead>
<tr>
<th>Hydrogen - Group</th>
<th>Average Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
</tr>
<tr>
<td>#5</td>
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<td>#6</td>
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<tr>
<td>#7</td>
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<tr>
<td>#8</td>
<td></td>
</tr>
<tr>
<td>#9</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td></td>
</tr>
<tr>
<td>Class Average Decay Time</td>
<td></td>
</tr>
<tr>
<td>Carbon - Group</td>
<td>Average Decay Time (years)</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
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<td>#4</td>
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<td>#7</td>
<td></td>
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<tr>
<td>#8</td>
<td></td>
</tr>
<tr>
<td>#9</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td></td>
</tr>
<tr>
<td>Class Average Decay Time</td>
<td></td>
</tr>
</tbody>
</table>

**Wrap-Up Questions**

1. If you tested a radioactive sample with 6 atoms, what would the half-life of the atom be if the atoms decay after 350 years, 436 years, 320 years, 153 years, 75 years and 279 years?

2. You are given an atom of $^6_{\text{Li}}$ and are told it is a byproduct of beta decay. What would the original atom be?

3. Write a nuclear equation for the beta decay of $^{24}_{11}\text{Na}$. 
4. Find an example of an atom that undergoes beta decay, which we have not talked about yet in this assignment. What is its nuclear equation?

5. For the same atom you found in question 4, what is its half-life?

---

**Simulation Usage as an Expansionary Assessment**

**Evaluate** – The evaluate phase will occur in this assessment. Students will use both the content knowledge they have learned throughout this learning segment and their knowledge of the simulation to answer a variety of questions regarding beta decay. This questions will give students the opportunity to apply and reflect upon what they have learned.

**Activity** –

**Beta Decay Assessment**

1. Using the “Beta Decay” simulation, find the decay time of five atoms with a half-life of 10 years.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
</tr>
</tbody>
</table>

Average Decay Time
2. Using the “Beta Decay” simulation, find the decay time of five atoms with a half-life of 5 years.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
</tr>
</tbody>
</table>

**Average Decay Time**

3. Calculate the half-life of an atom if samples decayed at 4 years, 7.5 years, 10 years, 3.2 years, 1.4 years, and 0.5 years.

4. Test your calculated half-life from question 3 in the “Beta Decay” simulation. Record the decay time of five samples in the table below.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td></td>
</tr>
<tr>
<td>#5</td>
<td></td>
</tr>
</tbody>
</table>

**Average Decay Time**
5. Write the definition of half-life in your own words.

6. How many neutrons are found in a beta particle?

7. How many protons are found in a beta particle?

8. Write the symbol associated with beta particles.

9. Write the nuclear equation if the atom, after beta decay, is $^{41}_{20}$Ca.

10. Write the nuclear equation for the alpha decay of $^{52}_{26}$Fe.

Activity Guide

Preliminary Activity

Introduction to Beta Decay

Beta decay is another specific example of nuclear decay. Nuclear decay occurs when an unstable atom releases some type of particle so that it can become stable again. Write some things you know about nuclear chemistry and about the differences between alpha and beta decay in the space below.

1. Dependent on student

2. Dependent on student
Nuclear chemistry deals with many different types of subatomic particles. We have talked about some of these previously. Using what you have learned about subatomic particles, define the following terms:

4. Nucleus – positively charged core of the atom
5. Proton – positively charged subatomic particle found in the nucleus, roughly the same size as a neutron
6. Neutron – neutral subatomic particle found in the nucleus, roughly the same size as a proton
7. Electron – small, negatively charged subatomic particle

Now that you have thought about subatomic particle again, open up the “Beta Decay” simulation found at https://phet.colorado.edu/en/simulation/legacy/beta-decay. Spend a few minutes playing around with this simulation. Write down some of the things you notice in the space below. Pay close attention to things like half-life, the initial and final atom, the number and types of subatomic particles and what happens to the unstable atoms.

8. Dependent on student
9. Dependent on student
10. Dependent on student

Core Activity

Beta Decay

Recall that many nuclei are radioactive; that is, they decompose by emitting particles and in doing so, become a different nucleus. In these changes, the nucleus, which contains the protons which dictate which element an atom is, is changing. Remember that all nuclei with 84 or more protons are radioactive and elements with less than 84 protons
have both stable and unstable isotopes. All of these elements can go through nuclear changes and turn into different elements. We previously discussed alpha decay, in which an alpha particle, a He\textsuperscript{4} atom, is emitted from a radioactive nuclei. Another type of nuclear decay is beta decay.

In beta decay, a beta particle is emitted. A beta particle is simply a high energy electron that is emitted from the nucleus. It may occur to you that we have a logically difficult situation here. Nuclei do not contain electrons and yet during beta decay, an electron is emitted from a nucleus. At the same time that the electron is being ejected from the nucleus, a neutron is becoming a proton. It is tempting to picture this as a neutron breaking into two pieces with the pieces being a proton and an electron. For the purpose of this assignment, we will treat beta decay as a neutron splitting into a proton and an electron. The proton stays in the nucleus, increasing the atomic number of the atom by one. The electron is ejected from the nucleus and is the particle of radiation called beta.

To insert an electron into a nuclear equation and have the numbers add up properly, an atomic number and a mass number had to be assigned to an electron. The mass number assigned to an electron is zero (0) which is reasonable since the mass number is the number of protons plus neutrons and an electron contains no protons and no neutrons. The atomic number assigned to an electron is negative one (-1), because that allows a nuclear equation containing an electron to balance atomic numbers. Therefore, the nuclear symbol representing an electron (beta particle) is

\[ _{\text{-1}}^{0}e \text{ or } _{\text{-1}}^{0}\beta \]

Thorium-234 is a nucleus that undergoes beta decay. Here is the nuclear equation for this beta decay.

\[ ^{234}_{0}\text{Th} \rightarrow ^{0}_{\text{-1}}e + ^{234}_{\text{-1}}\text{Pa} \]

**Getting Started**

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/legacy/ beta-decay.

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Beta Decay” simulation.

Multiple Atoms

1. Begin by dragging one of the atoms from the “Bucket o’ Atoms” into the middle of the screen. Make sure that you have the hydrogen nucleus selected!

For the following section, all data is based on this screenshot. Make sure that the hydrogen nuclei option is selected, then drag one of the atoms from the “Bucket o’ Atoms” into the simulation screen. It will begin to shake until it decays and releases an electron, the blue dot near the middle of the screen. The nuclei will also drop when it decays so that you can see when the half-life of that nuclei is.

a. What subatomic particles leave the initial atom? (you may wish to pause the simulation to make it easier to see)
b. What atom does the initial atom become after beta decay?

He$^3$

CiQ1: Do you think this atom is more or less stable than Hydrogen? Why?

More, doesn’t decay further

c. What is the decay time you found for your atom?

7 years

d. Is it to the right or to the left of the “Half Life” line that is around 12 years?

left
2. Now add 10 nuclei to the simulation. Record their decay times in the table below (use your best judgement).

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1</td>
</tr>
<tr>
<td>#2</td>
<td>2</td>
</tr>
<tr>
<td>#3</td>
<td>2</td>
</tr>
<tr>
<td>#4</td>
<td>3</td>
</tr>
<tr>
<td>#5</td>
<td>9</td>
</tr>
<tr>
<td>#6</td>
<td>12</td>
</tr>
<tr>
<td>#7</td>
<td>22</td>
</tr>
<tr>
<td>#8</td>
<td>26</td>
</tr>
</tbody>
</table>

The following data will be based on this screenshot. If you press the “Add 10” button, you can add 10 nuclei at a time. Make sure that you have selected the hydrogen nucleus and then let the nuclei decay. They will drop when they decay so that you will be able to see what decay time each nuclei has.
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>#9</td>
<td>26</td>
</tr>
<tr>
<td>#10</td>
<td>29</td>
</tr>
<tr>
<td><strong>Average Decay Time</strong></td>
<td><strong>13.2</strong></td>
</tr>
</tbody>
</table>

**CiQ 2:** Was your calculated average decay time close to the half-life of 12 years?

Yes

3. Repeat step 2 using the carbon nucleus.

<table>
<thead>
<tr>
<th><strong>Nuclei</strong></th>
<th><strong>Decay Time (years)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>See above</td>
</tr>
<tr>
<td>#2</td>
<td>See above</td>
</tr>
<tr>
<td>#3</td>
<td>See above</td>
</tr>
<tr>
<td>#4</td>
<td>See above</td>
</tr>
<tr>
<td>#5</td>
<td>See above</td>
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<tr>
<td>#6</td>
<td>See above</td>
</tr>
<tr>
<td>#7</td>
<td>See above</td>
</tr>
<tr>
<td>#8</td>
<td>See above</td>
</tr>
<tr>
<td>#9</td>
<td>See above</td>
</tr>
<tr>
<td>#10</td>
<td>See above</td>
</tr>
<tr>
<td><strong>Average Decay Time</strong></td>
<td><strong>See above</strong></td>
</tr>
</tbody>
</table>

**CiQ 3:** How does this value for the average decay time compare to the half-life of 5,730 years?

See above
CiQ 4: If you added more nuclei what do you think would happen to your average decay time?

Get closer to the accepted half-life value

**Single Atom**

1. Switch over to the “Single Atom” tab.
2. Wait for the nucleus to decay and then record the decay time in the table below.
3. Run 10 different samples, clicking the “Reset Nucleus” button after recording each decay time.

Like the previous section, all answers and data below will refer to this screenshot. When you switch to this screen, the nuclei will immediately begin to decay. Make sure you have the hydrogen nucleus selected. Once it does decay, the exact time in years will be shown. Be sure to record this before resetting, as otherwise you will have to rely on estimations from the chart.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>2</td>
</tr>
</tbody>
</table>


### CiQ 5: How does your average half-life compare to the average half-life you found in the “Multiple Atoms” section for hydrogen?

**Significantly lower**

4. Repeat steps 1-3 with the carbon nucleus.

<table>
<thead>
<tr>
<th>Nuclei</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>See above</td>
</tr>
<tr>
<td>#2</td>
<td>See above</td>
</tr>
<tr>
<td>#3</td>
<td>See above</td>
</tr>
<tr>
<td>#4</td>
<td>See above</td>
</tr>
<tr>
<td>#5</td>
<td>See above</td>
</tr>
<tr>
<td>#6</td>
<td>See above</td>
</tr>
</tbody>
</table>
CiQ 6: How does this average decay time compare to the half-life value for carbon and the average decay time you found in the “Multiple Atoms” section.

See above

Class Data

1. Now we will calculate the overall class average decay time for both the hydrogen and carbon atoms. Based on what we have talked about regarding the half-life of atoms, this value should be even closer to the half-life values for our nuclei, as the half-life is the average time it takes for 50% of a radioactive sample to decay into a non-radioactive substance.

<table>
<thead>
<tr>
<th>Hydrogen - Group</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Based on student data</td>
</tr>
<tr>
<td>#2</td>
<td>Based on student data</td>
</tr>
<tr>
<td>#3</td>
<td>Based on student data</td>
</tr>
<tr>
<td>#4</td>
<td>Based on student data</td>
</tr>
<tr>
<td>#5</td>
<td>Based on student data</td>
</tr>
<tr>
<td>#6</td>
<td>Based on student data</td>
</tr>
<tr>
<td>#7</td>
<td>Based on student data</td>
</tr>
<tr>
<td>#8</td>
<td>Based on student data</td>
</tr>
</tbody>
</table>
Wrap-Up Questions

1. If you tested a radioactive sample with 6 atoms, what would the half-life of the atom be if the atoms decay after 350 years, 436 years, 320 years, 153 years, 75 years and 279 years?

   268.8

2. You are given an atom of $^8$Li and are told it is a byproduct of beta decay. What would the original atom be?
3. Write a nuclear equation for the beta decay of $^{24}_{11}\text{Na}$.

$$^{24}_{11}\text{Na} \rightarrow ^{24}_{12}\text{Mg} + ^0_{-1}\text{e}$$

4. Find an example of an atom that undergoes beta decay, which we have not talked about yet in this assignment. What is its nuclear equation?

Dependent on student

5. For the same atom you found in question 4, what is its half-life?

Dependent on student
Assessment Activity

Beta Decay Assessment

1. Using the “Beta Decay” simulation, find the decay time of five atoms with a half-life of 10 years.

For the following table, all data is from this screenshot. To select a desired half-life, simply drag the green arrow to whichever half-life you want. Then, you can add the five nuclei from the bucket. Ensure that the “Custom” nucleus is selected. Each nuclei will drop at the time it took for it to decay. So, using this, you can find the decay times for the table below.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>3</td>
</tr>
<tr>
<td>#2</td>
<td>9</td>
</tr>
<tr>
<td>#3</td>
<td>17</td>
</tr>
<tr>
<td>#4</td>
<td>19</td>
</tr>
<tr>
<td>#5</td>
<td>27</td>
</tr>
</tbody>
</table>
2. Using the “Beta Decay” simulation, find the decay time of five atoms with a half-life of 5 years.

<table>
<thead>
<tr>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
</tr>
<tr>
<td>#2</td>
</tr>
<tr>
<td>#3</td>
</tr>
<tr>
<td>#4</td>
</tr>
<tr>
<td>#5</td>
</tr>
<tr>
<td>Average Decay Time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
</tbody>
</table>

3. Calculate the half-life of an atom if samples decayed at 4 years, 7.5 years, 10 years, 3.2 years, 1.4 years, and 0.5 years.

4.43 years

4. Test your calculated half-life from question 3 in the “Beta Decay” simulation. Record the decay time of five samples in the table below.

<table>
<thead>
<tr>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
</tr>
<tr>
<td>#2</td>
</tr>
<tr>
<td>#3</td>
</tr>
<tr>
<td>#4</td>
</tr>
<tr>
<td>#5</td>
</tr>
<tr>
<td>Average Decay Time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decay Time (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
<tr>
<td>See above</td>
</tr>
</tbody>
</table>
5. Write the definition of half-life in your own words.

   Time for 50% of a radioactive sample to decay

6. How many neutrons are found in a beta particle?

   0

7. How many protons are found in a beta particle?

   0

8. Write the symbol associated with beta particles.

   \( _{-1}^0 e \)

9. Write the nuclear equation if the atom, after beta decay, is Ca\(^{41}_{20} \).

   \( \frac{42}{19}K \rightarrow \frac{42}{20}Ca + _{-1}^0 e \)

10. Write the nuclear equation for the alpha decay of Fe\(^{52}_{26} \).

    \( \frac{52}{26}Fe \rightarrow \frac{52}{27}Co + _{-1}^0 e \)
## Build an Atom

<table>
<thead>
<tr>
<th>Build an Atom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation Link:</strong> <a href="https://phet.colorado.edu/en/simulation/build-an-atom">https://phet.colorado.edu/en/simulation/build-an-atom</a></td>
</tr>
</tbody>
</table>

### NYS Content Standards:

**3.1a** The modern model of the atom has evolved over a long period of time through the work of many scientists.

**3.1b** Each atom has a nucleus, with an overall positive charge, surrounded by negatively charged electrons.

**3.1c** Subatomic particles contained in the nucleus include protons and neutrons.

**3.1d** The proton is positively charged, and the neutron has no charge. The electron is negatively charged.

**3.1e** Protons and electrons have equal but opposite charges. The number of protons equals the number of electrons in an atom.

**3.1g** The number of protons in an atom (atomic number) identifies the element. The sum of the protons and neutrons in an atom (mass number) identifies an isotope. Common notations that represent isotopes include: 14C, 14C, carbon-14, C-14

### Learning Goals:

1. Students will be able to construct a model of an atom.
2. Students will be able to identify an element based on its number of protons, neutrons and electrons.
3. Students will be able to calculate the overall charge of an atom based on its number of protons, neutrons and electrons.
4. Students will be able to calculate the atomic mass of an atom given its number of protons, neutrons and electrons.

### Key Vocabulary and Concepts for Simulation:

1. **Atom** – smallest component of an element
2. **Nucleus** – positively charged center of the atom consisting of protons and neutrons
3) **Proton** – a subatomic particle with a positive charge that is the same size as a neutron

4) **Neutron** – a subatomic particle with no charge that is the same size as a proton

5) **Electron** - a relatively small subatomic particle with a negative charge

**Stimulating Aspects of the Simulation:**

1) Ability to manipulate and build atoms, as well as see how the number of subatomic particles effects mass, stability, and charge

2) Games of varying types with instant feedback

**Planning Considerations for Simulation:**

1) Possible to get correct answers by purely guessing on the game

**Simulation Parts Explained:**

**Screen 1: Atom**

![Diagram of an atom with labels for Protons, Neutrons, Electrons, Particle Count, Particle Bucket, Screen Selector, Model View, Display Options, Reset Button, Net Charge, Mass Number, Periodic Table.](image-url)
Particle Count – shows the total number of subatomic particles in the atom
**Particle Bucket** – contains subatomic particles which can be added to the atom by clicking and dragging them into the atom

**Atom** – shows the atom that is being manipulated, the dotted circles represent electron orbitals

**Screen Selector** – selects which screen you are on

**Model View** – switches between an orbital view or a cloud view for the atom, the cloud view will show a blue splash around the nucleus which changes in size according to the number of electrons in the atom

**Display Options** – toggles between a number of display options, checking the element box will show the element name, checking the neutral/ion box will show whether or not the atom is neutral or has a charge, selecting the stable/unstable box will show whether or not the atom is stable in its current form

**Periodic Table** – shows the known elements, the element corresponding to the element you have made will be highlighted and its atomic symbol will be shown in the box above the table

**Net Charge** – shows the net charge of the atom you have created

**Mass Number** – shows the mass number of the element you have created

**Reset Button** – resets the simulation to the default state shown in the above screenshots

**Atomic Symbol** – shows the atomic symbol of the element you have created, including charge, atomic mass and atomic number

**Game Options** – toggle various options for use within the game, sound may be enabled or disabled (a noise when you are correct and a different noise when you are incorrect) and a timer can be enabled or disabled

**Game Selector** – selects from a variety of games to choose from, the first game will have the user select the element on the periodic table when given the number of protons, neutrons and electrons, the second game will have the user find the mass number when given the number of protons, neutrons and electrons, the third game will have the user find the net charge when given the number of protons, neutrons and electrons and the final game will have a variety of different questions using a variety of formats, including creating an atom given its subatomic particle count and
“Check” button will need to be pressed, you can also go back to the game home menu by pressing the “Start Over” button in the top right of the screen.

**Suggestions for Supplemental Material:**

https://chem.libretexts.org/Bookshelves/GeneralChemistry/Map%3AChemistry-TheCentralScience(Brownetal.)/02.Atoms%2CMolecules%2CandIons/2.3%3ATheModernViewofAtomicStructure

**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged in this activity because it gives them an opportunity to interact with the content in a low-risk setting. Students will also be able to connect some of their prior learning about atoms to the content within the simulation and see where they stand with this knowledge. Students can drag subatomic particles into the simulation and create their own atoms. These atoms will tell students what the element is.

**Explore** – Like the engage phase, students will be exploring the content on their own when interacting with the simulation.

**Activity** –

**Introduction to Structure of Atoms**

Atoms are the building blocks of everything in the world. Within these atoms are smaller particles that combine together to form specific elements. These subatomic particles consist of protons, neutrons and electrons. Each element on the Periodic Table has its own, specific combination of protons, neutrons and electrons that provide the properties the element is known for. For this assignment, you will begin to work with subatomic particles to build atoms of a variety of different elements through the “Atom” screen of the “Build an Atom” simulation found at [https://phet.colorado.edu/en/simulation/build-an-atom](https://phet.colorado.edu/en/simulation/build-an-atom). Spend a few minutes messing around with this simulation and build five different atoms. Which atoms did you build and how many of each subatomic particle did they have?
Simulation Usage in the Core Instruction Period

**Explain** – For this assignment, the explain phase is covered mainly in the introductory reading. It is suggested that the teacher read this introductory information to the class aloud and address any student questions that arise and any misconceptions students may have. Much of the information that will be needed for the full understanding of this learning segment is found here, and students will use this information throughout the remainder of the learning segment to answer various questions.

**Elaborate** – The elaborate phase of this learning segment happens when students answer the wrap-up questions at the end of this assignment. For these questions, students will be connecting what they learned in the explain phase of this assignment to the questions they will have to answer. These questions will require students to take what they learned and apply it to a new, more challenging situation.
Activity (adapted from https://chem.libretexts.org/Courses/Howard_University/General_Chemistry%3A_An_Atoms_First_Approach/Unit_1%3A__Atomic_Structure/Chapter_1%3A_Introduction/Chapter_1.5%3A_The_Atom) –

Structure of Atoms

To date, about 115 different elements have been discovered; by definition, each is chemically unique. To understand why they are unique, you need to understand the structure of the atom (the fundamental, individual particle of an element) and the characteristics of its components.

Atoms consist of electrons protons, and neutrons. This is an oversimplification that ignores the other subatomic particles that have been discovered, but it is sufficient for our discussion of chemical principles. There are three important points to remember about these subatomic particles with additional information provided in the table that follows.

1. Electrons and protons have electrical charges that are identical in magnitude but opposite in sign. No particle with any fraction charge has ever been discovered although many have tried. For historical reasons having to do with the earliest studies of electricity, scientists have assigned charges of $-1$ and $+1$ to the electron and proton, respectively.

2. Neutrons have approximately the same mass as protons but no charge. They are electrically neutral.

3. The mass of a proton or a neutron is about 1836 times greater than the mass of an electron. Protons and neutrons constitute by far the bulk of the mass of atoms.
<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (g)</th>
<th>Atomic Mass (amu)</th>
<th>Electrical Charge (coulombs)</th>
<th>Relative Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td>$9.109 \times 10^{-28}$</td>
<td>0.0005486</td>
<td>$-1.602 \times 10^{-19}$</td>
<td>-1</td>
</tr>
<tr>
<td>proton</td>
<td>$1.673 \times 10^{-24}$</td>
<td>1.007276</td>
<td>$+1.602 \times 10^{-19}$</td>
<td>+1</td>
</tr>
<tr>
<td>neutron</td>
<td>$1.675 \times 10^{-24}$</td>
<td>1.008665</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Getting Started**

1. Log into a computer and open up Google Chrome.

2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/build-an-atom](https://phet.colorado.edu/en/simulation/build-an-atom).

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Build an Atom” simulation.

**Atom**

1. Navigate to the “Atom” screen of the simulation.

2. Create all the atoms available (10 total) by dragging different combinations of protons, neutrons and electrons into the simulation from the buckets at the bottom of the screen.

3. Fill in the following table after creating each different neutral element. The first has been done for you.
<table>
<thead>
<tr>
<th>Element</th>
<th>Abbreviation</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

**CiQ 1:** If you add an extra electron to a neutral atom, what happens to its charge?

**CiQ 2:** When you add an extra electron to a neutral atom, what does the atom become?

**CiQ 3:** If you add an extra neutron to a neutral atom, what happens to the atom’s stability?

**Symbol**

1. Navigate to the “Symbol” screen of the simulation.

2. Use this screen to help you draw the symbol for the following neutral elements:
   a. Lithium
   b. Hydrogen
c. Neon

d. Boron

e. Nitrogen

Find the Element

1. Navigate to the “Game” screen of the simulation.

2. Select the first game option.

3. Fill in the table below with your specific questions and answers.

<table>
<thead>
<tr>
<th>Element</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
<th>Ion or Neutral?</th>
</tr>
</thead>
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</tbody>
</table>

Wrap-Up Questions

1. How many protons are in an atom of Sodium?

2. How many electrons are found in an atom of Boron if it has a charge of -1?
3. How many protons are found in an atom of Neon if it has a charge of +1?

4. How many neutrons are in an atom of Aluminum?

5. How many electrons are found in an atom of Carbon if it has a charge of -2?

Simulation Usage as an Expansionary Assessment

Evaluate – The activity for this section will assess students’ knowledge of both the simulation itself and the content within the simulation. Students will be required to take what they have learned in the core instruction period and use it to complete the questions related to the simulation and answer the pencil and paper questions found in this activity.

Activity –

Structure of Atoms Assessment

Part I

Directions: Use the “Game” screen of the “Build an Atom” simulation found at https://phet.colorado.edu/en/simulation/build-an-atom to complete this assignment. For each section, start and complete the respective game, recording all relevant information in the tables below.

Total Charge – Game 2

<table>
<thead>
<tr>
<th>Element</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
<th>Net Charge</th>
</tr>
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<tbody>
<tr>
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</table>
Symbols – Game 3

<table>
<thead>
<tr>
<th>Element</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
<th>Net Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>

Challenge – Game 4

<table>
<thead>
<tr>
<th>Element</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
<th>Net Charge</th>
</tr>
</thead>
<tbody>
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</tr>
</tbody>
</table>

Part II

**Directions:** Use the Periodic Table to help you answer the following questions.
1. How many protons are in a neutral atom of Nickel?

2. How many neutrons are in an atom of Calcium with a charge of -1?

3. How many electrons are in an atom of Hydrogen with a charge of +1?

4. How many electrons are in a neutral atom of Phosphorous?

5. How many electrons are in an atom of Gallium with a charge of -2?

6. How many protons are in an atom of Chlorine with a charge of +2?

7. How many protons are in a neutral atom of Sulphur?

8. How many electrons are in a neutral atom of Barium?

9. How many protons are in an atom of Platinum with a charge of -2?

10. How many electrons are in an atom of Tellurium with a charge of +1?
Activity Guide

Preliminary Activity

Introduction to Structure of Atoms

Atoms are the building blocks of everything in the world. Within these atoms are smaller particles that combine together to form specific elements. These subatomic particles consist of protons, neutrons and electrons. Each element on the Periodic Table has its own, specific combination of protons, neutrons and electrons that provide the properties the element is known for. For this assignment, you will begin to work with subatomic particles to build atoms of a variety of different elements through the “Atom” screen of the “Build an Atom” simulation found at https://phet.colorado.edu/en/simulation/build-an-atom. Spend a few minutes messing around with this simulation and build five different atoms. Which atoms did you build and how many of each subatomic particle did they have?

For this activity, you just need to create five atoms of your choice and record the number of subatomic particles within said atom. For this example, the Helium atom was created, as indicated by the name appearing in the center of the screen. This was done by dragging two protons, two neutrons and two electrons into the center of the screen from the buckets at the bottom of the screen. You can also see that two of each were added by looking towards the top left of the screen at the particle count tab.
Core Activity

Structure of Atoms

To date, about 115 different elements have been discovered; by definition, each is chemically unique. To understand why they are unique, you need to understand the structure of the atom (the fundamental, individual particle of an element) and the characteristics of its components.

Atoms consist of electrons protons, and neutrons. This is an oversimplification that ignores the other subatomic particles that have been discovered, but it is sufficient for our discussion of chemical principles. There are three important points to remember about these subatomic particles with additional information provided in the table that follows.

4. Electrons and protons have electrical charges that are identical in magnitude but opposite in sign. No particle with any fraction charge has ever been discovered although many have tried. For historical reasons having to do with the earliest studies of electricity, scientists have assigned charges of $-1$ and $+1$ to the electron and proton, respectively.

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<td>(+1.602 \times 10^{-19})</td>
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**Getting Started**

1. Log into a computer and open up Google Chrome.
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3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.
4. Start the “Build an Atom” simulation.

**Atom**

1. Navigate to the “Atom” screen of the simulation.
2. Create all the atoms available (10 total) by dragging different combinations of protons, neutrons and electrons into the simulation from the buckets at the bottom of the screen.
3. Fill in the following table after creating each different **neutral** element. The first has been done for you.

For this section, you need to build the first 10 elements of the Periodic Table. To do so, drag the subatomic particles from the buckets on the bottom into the atom in the center of the screen. Make sure that the atom is neutral. The number of protons, neutrons and electrons can be seen near the top of the screen. In this example, a neutral atom of Neon was created by adding 10 protons, 12 neutrons and 10 electrons to the atom in the center of the screen. Note that this is an isotope of Neon and that multiple responses for the # of neutrons are possible because of this.

<table>
<thead>
<tr>
<th>Element</th>
<th>Abbreviation</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Helium</td>
<td>He</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Be</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Boron</td>
<td>B</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Carbon</td>
<td>C</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>
If you add an extra electron to a neutral atom, what happens to its charge?

**Becomes -1**

When you add an extra electron to a neutral atom, what does the atom become?

**An ion**

If you add an extra neutron to a neutral atom, what happens to the atom’s stability?

**Becomes unstable**

Symbol

1. Navigate to the “Symbol” screen of the simulation.

2. Use this screen to help you draw the symbol for the following neutral elements:
Find the Element

1. Navigate to the “Game” screen of the simulation.
2. Select the first game option.
3. Fill in the table below with your specific questions and answers.
For all games in this simulation, the ordering of questions and the questions themselves differ from student to student. For the purposes of this example, the first row of the table has been filled out in accordance with the question shown in this screenshot. A sample atom was given, and you must find whichever element it is. In this case, the atom had one proton so it was found to be hydrogen. You are then asked to decide whether it is a neutral atom or an ion. In this case, because there were two electrons to only one proton, the charge of the atom was -1 and, therefore, it is an ion. When the answer is correct, the yellow face shown in this screenshot will appear and you may move on to the next question. Note however, that you cannot go back to the previous question so must record the information in the table as you work through the game.

<table>
<thead>
<tr>
<th>Element</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
<th>Ion or Neutral?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>Ion</td>
</tr>
<tr>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
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<tr>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Wrap-Up Questions**

1. How many protons are in an atom of Sodium?
   
   11

2. How many electrons are found in an atom of Boron if it has a charge of -1?
   
   6

3. How many protons are found in an atom of Neon if it has a charge of +1?
   
   10

4. How many neutrons are in an atom of Aluminum?
   
   14

5. How many electrons are found in an atom of Carbon if it has a charge of -2?
   
   8

**Assessment Activity**

**Structure of Atoms Assessment**

**Part I**

**Directions:** Use the “Game” screen of the “Build an Atom” simulation found at [https://phet.colorado.edu/en/simulation/build-an-atom](https://phet.colorado.edu/en/simulation/build-an-atom) to complete this assignment. For each section, start and complete the respective game, recording all relevant information in the tables below.

**Total Charge – Game 2**
For this game, you must determine the total charge of the atom based on information you are given. Information may come in the form of a picture of an atom, as it is in this example, or as words and numbers stating the number of each subatomic particle. You are then tasked with using this information to determine the total charge of the molecule. In this case, there is one proton in the atom and no electrons so the charge must be +1. The atom must then be determined based on the number of protons and number of neutrons. Because this example has one proton and one neutron, it must be a hydrogen molecule, specifically the deuterium isotope. Again, isotopes are possible so should be taken into consideration. Note that the ordering of questions in the game are randomized and the questions themselves are randomly selected from a pool of questions.

<table>
<thead>
<tr>
<th>Element</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
<th>Net Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>+1</td>
</tr>
<tr>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
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<td>Dependent on student</td>
</tr>
</tbody>
</table>
Symbols – Game 3

For this game, you must use the information provided to complete the atomic symbol of whichever element you are given. In this case, a picture of the atom was given with one proton and one neutron. Using this information, you can determine that the atomic number of the atom must be 1, due to there being only one proton.

<table>
<thead>
<tr>
<th>Element</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
<th>Net Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>+1</td>
</tr>
<tr>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
</tr>
<tr>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
</tr>
</tbody>
</table>
For this game, the types of questions are randomized and you must answer a variety of different types of questions. For this example, the symbol was given and the atom was to be constructed based on this symbol. Note that this is only one type of question that may appear in this game.

<table>
<thead>
<tr>
<th>Element</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
<th>Net Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>-1</td>
</tr>
<tr>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
<td>Dependent on student</td>
</tr>
</tbody>
</table>
Part II

Directions: Use the Periodic Table to help you answer the following questions.

11. How many protons are in a neutral atom of Nickel?

    7

12. How many neutrons are in an atom of Calcium with a charge of -1?

    20

13. How many electrons are in an atom of Hydrogen with a charge of +1?

    0

14. How many electrons are in a neutral atom of Phosphorous?

    15

15. How many electrons are in an atom of Gallium with a charge of -2?

    33

16. How many protons are in an atom of Chlorine with a charge of +2?

    17
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. How many protons are in a neutral atom of Sulphur?</td>
<td>16</td>
</tr>
<tr>
<td>18. How many electrons are in a neutral atom of Barium?</td>
<td>58</td>
</tr>
<tr>
<td>19. How many protons are in an atom of Platinum with a charge of -2?</td>
<td>78</td>
</tr>
<tr>
<td>20. How many electrons are in an atom of Tellurium with a charge of +1?</td>
<td>51</td>
</tr>
</tbody>
</table>
## Build a Molecule

<table>
<thead>
<tr>
<th>Build a Molecule</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation Link:</strong> <a href="https://phet.colorado.edu/en/simulation/legacy/build-a-molecule">https://phet.colorado.edu/en/simulation/legacy/build-a-molecule</a></td>
</tr>
</tbody>
</table>

### NYS Content Standards:

- **3.3d.** The empirical formula of a compound is the simplest whole-number ratio of atoms of the elements in a compound. It may be different from the molecular formula, which is the actual ratio of atoms in a molecule of that compound.

- **5.2l.** Molecular polarity can be determined by the shape of the molecule and distribution of charge.

### Learning Goals:

1. Students will be able to construct a molecule given a variety of different atoms and a chemical formula.

### Key Vocabulary and Concepts for Simulation:

1. **Molecule** – a group of atoms bonded together
2. **Atom** – smallest component of an element

### Stimulating Aspects of the Simulation:

1. Game-like
2. Fairly easy and straightforward to understand and work with

### Planning Considerations for Simulation:

1. The first two screens are very easy and students may complete the collections without actually thinking about what they are doing

### Simulation Parts Explained:
Screen 1: Make Molecules

Molecule Kit

Collection

Reset Collection
Screen 2: Collect Multiple
Screen 3: Larger Molecules

Molecule Kit – shows atoms for the construction of a molecule, as atoms are put together the name of the molecule will be shown, pressing the “3D” button to the top right of the molecule will show the molecule in 3D using either a space filling or ball and stick model, pressing the blue cross next to the “3D” button will separate the molecule into its respective atoms, note that you may also press the “Refill Kit” button at the top left of this section to remove all the molecules from the screen and place them back in their respective buckets, each kit will construct a different molecule that can be dragged into the “Collection”

Collection – the collection of all the molecules that can be created from the kits, when a collection is completed, you can press the yellow arrow that appears at the top of this section to switch to another collection and another set of molecule kits

Reset Collection – removes all the molecules from the screen and from the “Collection”
Suggestions for Supplemental Material:

https://chem.libretexts.org/Bookshelves/GeneralChemistry/Map%3AChemistry-TheCentralScience(Brownetal.)/02.Atoms%2CMolecules%2CandIons/2.3%3ATheModernViewofAtomicStructure

Simulation Usage in the Preliminary Period

Engage – Students will be engaged in this activity because it gives them an opportunity to interact with the content in a low-risk setting. Students will also be able to connect some of their prior learning about atoms to the content within the simulation and see where they stand with this knowledge. Students can drag different atoms into the simulation and combine them into a variety of different molecules. The collection aspect of the simulation is also engaging for students because it gives students a goal to accomplish while playing with the simulation.

Explore – Like the engage phase, students will be exploring the content on their own when interacting with the simulation.

Activity –

Introduction to Structure of Molecules

Molecules are a collection of atoms of elements. These atoms can be the same element, as in the case of O₂, or different elements, in the case of H₂O. For this assignment, you will be looking at how atoms can be put together through the “Build a Molecule” simulation found at https://phet.colorado.edu/en/simulation/legacy/build-a-molecule. Navigate to the “Make Molecules” screen and use the three kits at the bottom of the screen to fill “Collection 1” on the right side of the screen. Draw and label the molecules below.

1. H₂O

2. O₂
3. $\text{H}_2$

4. $\text{CO}_2$

5. $\text{N}_2$

**Simulation Usage in the Core Instruction Period**

**Explain** – For this assignment, the explain phase is covered mainly by the actual content of the simulation itself. Students will be able to see what molecules are actually legitimate through the simulation and students will be able to determine why some molecules work and some don’t. The teacher should also be aware that students may have questions about the molecules and these questions should be used to further explain the content as needed.

**Elaborate** – The elaborate phase of this learning segment happens when students answer the wrap-up questions at the end of this assignment. For these questions, students will be connecting what they learned in the explain phase of this assignment to the questions they will have to answer. These questions will require students to take what they learned and apply it to a new, more challenging situation.

**Activity** –

**Building Molecules**

**Getting Started**

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/legacy/build-a-molecule.

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Build a Molecule” simulation.

5. Navigate to the “Collect Multiple” screen.

**Molecule Collection**

**Directions:** Complete the first 5 collections of the “Collect Multiple” screen and fill in the table below. The first has been done for you.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Name</th>
<th>Sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
<td></td>
</tr>
</tbody>
</table>
Wrap-Up Questions:

**Directions:** For each of the following molecules, predict and sketch the structure.

1. HF

2. CH₄

3. CH₆

4. Cl₂O₇
Simulation Usage as an Expansionary Assessment

Evaluate – The activity for this section will assess students’ knowledge of both the simulation itself and the content within the simulation. Students will be required to take what they have learned in the core instruction period and use it to complete the questions related to the simulation.

Activity –

Structure of Molecules Assessment

Directions: Use the “Larger Molecules” screen of the “Build a Molecule” simulation found at https://phet.colorado.edu/en/simulation/legacy/build-a-molecule to help you sketch the following molecules.

1. Acetic Acid

2. Nitric Acid

3. Hydrogen Chloride

4. Dichloromethane

5. Methane
6. Dichlorodifluoromethane

7. Borane

8. Borylidynesilicon (Hint: Contains Boron and Silicon)

9. Hydrogen Sulfide

10. Bromine

**Bonus:** Build and label your own molecule using the simulation.

---

**Activity Guide**

**Preliminary Activity**

**Introduction to Structure of Molecules**

Molecules are a collection of atoms of elements. These atoms can be the same element, as in the case of O₂, or different elements, in the case of H₂O. For this assignment, you will be looking at how atoms can be put together through the “Build a Molecule” simulation found at [https://phet.colorado.edu/en/simulation/legacy/build-a-](https://phet.colorado.edu/en/simulation/legacy/build-a-).
Navigate to the “Make Molecules” screen and use the three kits at the bottom of the screen to fill “Collection 1” on the right side of the screen. Draw and label the molecules below.

For this assignment, you need to construct the molecules shown on the right using the kits on the bottom of the screen. To do so, simply drag the atoms from each bucket into the center of the simulation to create the corresponding molecule. In this case, two hydrogen atoms and one oxygen atom have been dragged into the center of the screen to create a water molecule. This molecule must then be dragged into the corresponding spot on the right to add it to the collection. The completed collection is shown in this screenshot and the answers for the following questions should be drawings similar to those shown in the collection.

1. $\text{H}_2\text{O}$

   See screenshot

2. $\text{O}_2$

   See screenshot

3. $\text{H}_2$

   See screenshot
Core Activity

Building Molecules

Getting Started

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/legacy/build-a-molecule.
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.
4. Start the “Build a Molecule” simulation.
5. Navigate to the “Collect Multiple” screen.

Molecule Collection

Directions: Complete the first 5 collections of the “Collect Multiple” screen and fill in the table below. The first has been done for you.
For this assignment, you will need to create the first five collections of molecules. Each collection has its own set of kits, which will switch once you complete the collection. For each of the molecules stated on the right, construct the correct molecule by dragging the atoms from the bucket. They will automatically attach if compatible and the name of the molecule will appear. In this case, the molecule is CO$_2$ otherwise known as Carbon Dioxide as shown. This molecule should then be dragged into the field in which the arrow is pointing to add it to the collection.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Name</th>
<th>Sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$</td>
<td>Carbon Dioxide</td>
<td>O-C-O</td>
</tr>
<tr>
<td>O$_2$</td>
<td>Oxygen</td>
<td>O-O</td>
</tr>
<tr>
<td>H$_2$</td>
<td>Hydrogen</td>
<td>H-H</td>
</tr>
<tr>
<td>NH$_3$</td>
<td>Ammonia</td>
<td>H-N-H-H</td>
</tr>
<tr>
<td>N$_2$</td>
<td>Nitrogen</td>
<td>N-N</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>Carbon Dioxide</td>
<td>O-C-O</td>
</tr>
<tr>
<td>C$_2$H$_4$</td>
<td>Ethylene</td>
<td>H-C=H-C=H</td>
</tr>
</tbody>
</table>

**Sketch**

- CO$_2$: O-C-O
- O$_2$: O-O
- H$_2$: H-H
- NH$_3$: H-N-H-H
- N$_2$: N-N
- CO$_2$: O-C-O
- C$_2$H$_4$: H-C=H-C=H
<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H2O2</td>
<td>Hydrogen Peroxide</td>
<td>H-O-O-H</td>
<td></td>
</tr>
<tr>
<td>CH3Cl</td>
<td>Chloromethane</td>
<td>Cl-H-C-H-H</td>
<td></td>
</tr>
<tr>
<td>N2O</td>
<td>Nitrous Oxide</td>
<td>N-N-O</td>
<td></td>
</tr>
<tr>
<td>N2</td>
<td>Nitrogen</td>
<td>N-N</td>
<td></td>
</tr>
<tr>
<td>H2O</td>
<td>Water</td>
<td>H-O-H</td>
<td></td>
</tr>
<tr>
<td>O2</td>
<td>Oxygen</td>
<td>O-O</td>
<td></td>
</tr>
<tr>
<td>SiH4</td>
<td>Silane</td>
<td>H-H-Si-H</td>
<td></td>
</tr>
<tr>
<td>CH3F</td>
<td>Fluoromethane</td>
<td>F-H-C-H</td>
<td></td>
</tr>
<tr>
<td>CH3Cl</td>
<td>Chloromethane</td>
<td>Cl-H-C-H</td>
<td></td>
</tr>
<tr>
<td>PH3</td>
<td>Phosphine</td>
<td>H-P-H</td>
<td></td>
</tr>
<tr>
<td>N2O</td>
<td>Nitrous Oxide</td>
<td>N-N-O</td>
<td></td>
</tr>
<tr>
<td>BH3</td>
<td>Borane</td>
<td>H-B-H</td>
<td></td>
</tr>
<tr>
<td>C2H2</td>
<td>Acetylene</td>
<td>H-C-C-H</td>
<td></td>
</tr>
</tbody>
</table>

**Wrap-Up Questions:**

**Directions:** For each of the following molecules, predict and sketch the structure.

1. HF
   
   [H-F]

2. CH₄
   
   [H-H-C-H-H]

3. CH₆
   
   [H-H-C-C-H-H]
4. $\text{Cl}_2\text{O}_7$

\[
\text{O}^\text{=}=\text{O}=\text{Cl}-\text{O}-\text{Cl}=\text{O}^\text{=}=\text{O}
\]

5. $\text{S}_2\text{Cl}_2$

\[
\text{Cl}-\text{S}-\text{S}-\text{Cl}
\]

**Assessment Activity**

**Structure of Molecules Assessment**

**Directions:** Use the “Larger Molecules” screen of the “Build a Molecule” simulation found at [https://phet.colorado.edu/en/simulation/legacy/build-a-molecule](https://phet.colorado.edu/en/simulation/legacy/build-a-molecule) to help you sketch the following molecules.

For this assessment, you will need to construct a variety of different molecules using the provided kits. The name of the molecule is given and you must construct the molecule based on just the name. For this example, acetic acid was chosen. As you can see, two molecules of carbon, two molecules of oxygen and four molecules of hydrogen were combined to make the molecule. The simulation will tell you if the molecule you have made is a real molecule and will tell you the name of the molecule so that you may check yourself as you work through this assignment.
1. Acetic Acid
   
   \[
   H^-H\cdot C\cdot C\cdot O\cdot H\cdot O
   \]

2. Nitric Acid
   
   \[
   O\cdot N\cdot O\cdot H\cdot O
   \]

3. Hydrogen Chloride
   
   \[
   H\cdot Cl
   \]

4. Dichloromethane
   
   \[
   H\cdot Cl\cdot C\cdot Cl\cdot H
   \]

5. Methane
   
   \[
   H\cdot H\cdot C\cdot H\cdot H
   \]

6. Dichlorodifluoromethane
   
   \[
   Cl\cdot F\cdot C\cdot F\cdot Cl
   \]

7. Borane
   
   \[
   H\cdot H\cdot B\cdot H
   \]

8. Borylidynesilicon (**Hint: Contains Boron and Silicon**)
   
   \[
   B\cdot Si
   \]

9. Hydrogen Sulfide
   
   \[
   H\cdot S\cdot H
   \]

10. Bromine
    
    \[
    Br\cdot Br
    \]
<table>
<thead>
<tr>
<th><strong>Bonus:</strong> Build and label your own molecule using the simulation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependent on student</td>
</tr>
</tbody>
</table>
Density

Simulation Link: https://phet.colorado.edu/en/simulation/legacy/density

NYS Content Standards:

3.1w: Elements can be differentiated by physical properties. Physical properties of substances, such as density, differ among elements.

Learning Goals:

1) Students will be able to manipulate the density formula to calculate density, mass or volume.
2) Students will be able to calculate volume of a substance due to water displacement.
3) Students will be able to determine between different substances based on density.

Key Vocabulary and Concepts for Simulation:

1) Density – the degree of compactness of a substance, does not change with size, if \( d > 1.0 \text{ kg/L} \) object sinks in water, (kg/L)
2) Mass – measure of the amount of matter in an object (kg)
3) Volume – quantity of three-dimensional space occupied by a liquid, solid, or gas (L)
4) Density of Water - ~1.0 kg/L, objects with a higher density sink, objects with a lower density float
5) Water Displacement – object placed into water takes the space of some of the water, causing the water level to rise in parallel to the volume of the object; volume of object = final volume of water – initial volume of water
6) Unique Properties of Substances – each substance has its own distinct density that DOES NOT change with changes in size, volume, shape or mass

Stimulating Aspects of Simulation:

1) Multiple variables to manipulate
2) Water level rises in real time in accordance with the concept of water displacement
3) Multiple substances to experiment with
4) Fairly simple in what it deals with and explains, allowing students to get right down to the content without being bogged down by complexities

<table>
<thead>
<tr>
<th>Planning Considerations for Simulation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Students cannot physically feel the blocks of different substances to confirm that they are different</td>
</tr>
<tr>
<td>2) Blocks look the same regardless of substance on the “Mystery” screen</td>
</tr>
<tr>
<td>3) Possible for students to rush through as the depth of content is relatively low</td>
</tr>
<tr>
<td>4) Dependent on color</td>
</tr>
</tbody>
</table>

Simulation Parts Explained:
Screen 1: Custom

Simulation Tabs

Custom

Blocks

Volume

Water

2.00 kg

102.00 L

0.40 kg/L

Reset Button

My Block Material Wood

Mass 2.00 kg

Volume 5.00 L

Density Wood Ice Brick Aluminum

Blocks

Custom

Same Mass

Same Volume

Same Density

Mystery

Reset All
Screen 2: Same Mass/Volume/Density
**Screen 3: Mystery**

**Blocks** – Main interactable aspect of the simulation, can be dragged around the screen and placed in the water

**Water** – Static default volume value of 100 L unless a block is placed into it

**Volume Measurement** – Changes when blocks are placed into the water, indicates the volume of the block through displacement

**Simulation Tabs** – Can be switched between five different options, “Screen 1” is the first option, “Screen 2” is the second through fourth options, and “Screen 3” is the fifth option

**Reset Button** – Can be used to instantly restore the simulation to its default status
**Custom Options** – allows you to change the mass and volume of the block, the density indicator, as well as the block itself, change as the mass and volume variables are changed, a variety of substances can be chosen which will auto adjust the mass and volume sliders to create the correct density value of the substance

**Table** – provides density values for a variety of substances, each block corresponds to one of the options in the table

**Scale** – displays the mass of blocks that are dragged on to it

**Suggestions for Supplemental Material:**

https://chem.libretexts.org/Bookshelves/IntroductoryChemistry/Map%3AIntroductoryChemistry(Tro)/02%3AMEasurementandProblemSolving/2.09%3ADensity

---

**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged in this activity because it gives students an opportunity to see and interact with density content and connect their prior knowledge to what they will be learning in this learning segment. The activity is fully student centered and informal, giving students a low-risk means of experiencing the content. It may also be useful for the teacher to use data collected from this activity to tailor this learning segment to their classes. Students can drag different blocks into the container of water and see how water displacement works.

**Explore** – This activity allows students to explore both the concept of density and the simulation on their own with little prompting on instruction on the part of the teacher. The simulation is a hands-on representation of the content and allows students to manipulate the mass, volume and density of the block to observe how all three variables are connected.

**Activity**

**Introduction to Density**
In this activity we will be working through a simulation activity that deals with density. Before we begin, list some of the things you know about density in the space below. Think about what density means, how to find density and what its units are.

Now, open up the density simulation found at https://phet.colorado.edu/en/simulation/legacy/density. You should see a block floating in water with a dialog box in the top right and an option menu in the top right. Make sure that you have the “Custom” option filled in. Mess around with this screen and write down any initial observations, questions or comments you have in the space below.

Simulation Usage in Core Instruction

**Explain** – In the explain phase, students learn more about the content they explored previously in a more formal manner. The key vocabulary for this learning segment, density, is explained in an in-depth manner in the introductory section of this activity. It is advised that the teacher read this section aloud to students and answer any questions students may have about density before they delve more deeply into the content. Students will also learn how to calculate density and to demonstrate this knowledge.

**Elaborate** – In the elaborate phase, students continue to practice working with the concept of density and expand upon this idea by determining whether or not the blocks in the simulation float or sink. This not only allows students to put what density actually means into context but also allows students to make connections between the content and real world phenomena they may experience.

**Activity** (adapted from https://www.thoughtco.com/what-is-density-definition-and-calculation-2698950) –

**Density**
Density is a measure of mass per unit of volume. The average density of an object equals its total mass divided by its total volume, meaning that density is the ratio of mass to volume. An object made from a comparatively dense material (such as iron) will have less volume than an object of equal mass made from some less dense substance (such as water).

One of the most common uses of density is in how different materials interact when mixed together. Wood floats in water because it has a lower density, while an anchor sinks because the metal has a higher density. Helium balloons float because the density of the helium is lower than the density of the air.

When your automotive service station tests various liquids, like transmission fluid, it will pour some of the fluid into a hydrometer. The hydrometer has several calibrated objects, some of which float in the liquid. By observing which of the objects float, the service station employees can determine the density of the liquid. In the case of the transmission fluid, this test reveals whether service station employees need to replace it immediately, or whether the fluid still has some life in it.

To calculate the density (usually represented by the Greek letter "$\rho$") of an object, take the mass ($m$) and divide by the volume ($v$):

$$\rho = \frac{m}{v}$$

The SI unit of density is kilogram per cubic meter ($\text{kg/m}^3$) or kilogram per liter ($\text{kg/L}$).

Density allows you to solve for mass and volume if given the other quantity. Since the density of common substances is known, this calculation is fairly straightforward, in the form.
Getting Started

1. Log into a computer and open up Google Chrome.

2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/legacy/density](https://phet.colorado.edu/en/simulation/legacy/density)

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start with the “Same Mass” section by selecting the second option.

Same Mass

1. Before you begin, predict which blocks will sink and which blocks will float. Explain your reasoning in the space below.

2. Drag each block individually into the water and find the volume (Remember units!). Note whether each block sinks in the table below.

3. Calculate the density (Remember units!) of each block using the mass you were given and the volume you found.

<table>
<thead>
<tr>
<th>Color</th>
<th>Mass</th>
<th>Volume</th>
<th>Density</th>
<th>Sinks?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>5.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>5.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>5.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>5.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. Why do you think some of the blocks floated and some of the blocks sunk?

### Same Volume

1. Before you begin, predict which blocks will sink and which blocks will float. Explain your reasoning in the space below.

2. Drag each block individually into the water and find the volume (Remember units!). Note whether each block sinks in the table below.

3. Calculate the density (Remember units!) of each block using the mass you were given and the volume you found.

<table>
<thead>
<tr>
<th>Color</th>
<th>Mass</th>
<th>Volume</th>
<th>Density</th>
<th>Sinks?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>6.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>8.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>4.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>2.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Why do you think some of the blocks floated and some of the blocks sunk (same idea as the question in the “Same Mass” section)?
5. Now, place all four blocks into the water at the same time. Note any observations and possible explanations for those observations in the space below.

**Same Density**

1. Before you begin, predict which blocks will sink and which blocks will float. Explain your reasoning in the space below.

2. Drag each block individually into the water and find the volume (Remember units!). Note whether each block sinks in the table below.

3. Calculate the density (Remember units!) of each block using the mass you were given and the volume you found.

<table>
<thead>
<tr>
<th>Color</th>
<th>Mass</th>
<th>Volume</th>
<th>Density</th>
<th>Sinks?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>3.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>4.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>2.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>1.00 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Wrap-Up Questions

1) Are there any interesting trends between density and whether or not the block sinks? Explain.

2) Do you think it is possible to determine whether or not a block will float or sink before placing it into water? Why or why not?

3) Does the size of the block determine whether or not it will sink or float?

4) If you placed the blocks in the “Same Volume” section into a liquid with a density of 2.0 kg/L, which blocks would float and which would sink? What about if the density of the liquid was 0.5 kg/L?

Wrap Up Questions

For each question, calculate the value of the unknown variable and determine whether it will float or sink in water.

Remember units!

1. Mass = 2.50 kg, Volume = 5.00 L, Density =?
<table>
<thead>
<tr>
<th></th>
<th>Mass</th>
<th>Volume</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>6.75 kg</td>
<td>1.50 L</td>
<td>?</td>
</tr>
<tr>
<td>3</td>
<td>3.00 kg</td>
<td>?</td>
<td>1.50 kg/L</td>
</tr>
<tr>
<td>4</td>
<td>?</td>
<td>6.00 L</td>
<td>4.25 kg/L</td>
</tr>
<tr>
<td>5</td>
<td>1.35 kg</td>
<td>3.46 L</td>
<td>?</td>
</tr>
</tbody>
</table>

**Simulation Usage as an Expansionary Assessment**

**Evaluate** – In the evaluate phase, students put what they have learned in the previous phases into action. For the purposes of this activity, students are using what they have learned about density and how to calculate it, as well as how to use the simulation itself to answer a variety of questions.

**Activity** –

**Density**

**Part I**

**Directions**: For this assignment, you will be working on your own to determine the identity of five different blocks. Be sure to show all work in the space to the side and include the values of the volume and mass you
determine for each block. Remember units! Be sure to click on the “Show Table” button when you are ready to identify the block.

1. Block Letter:_______
   a. Volume:_______
   b. Mass:_______
   c. Density:_______
   d. Identity:_______

2. Block Letter:_______
   a. Volume:_______
   b. Mass:_______
   c. Density:_______
   d. Identity:_______

3. Block Letter:_______
   a. Volume:_______
   b. Mass:_______
   c. Density:_______
   d. Identity:_______

4. Block Letter:_______
   a. Volume:_______
   b. Mass:_______
   c. Density:_______
   d. Identity:_______

5. Block Letter:_______
Part II

Directions: For this section, you will be using the “Custom” section of the simulation to identify more substances using the table on the “Mystery” screen. Make sure you are on the “My Block” tab!

6. Unknown 1
   a. Volume: 2.64 L
   b. Mass: 9.32 kg
   c. Density: ________
   d. Identity: ________

7. Unknown 2
   e. Volume: 7.06 L
   f. Mass: 4.52 kg
   g. Density: ________
   h. Identity: ________

Part III

Directions: For this section, calculate the missing variable using whatever information you are provided. Remember to show work and use units!

8. Density: ________
   i. Mass: 6.54 kg
   j. Volume: 9.63 L
9. Mass: _______
   k. Volume: 63.49
   l. Identity of Substance: Wood

10. Volume: _______
    m. Density: 2.70 kg/L
    n. Mass: 6.93 kg

**Challenge Question** – Create and solve your own version of a Part II question (questions 6 & 7).

---

**Activity Guide**

**Preliminary Activity**

**Introduction to Density**

In this activity we will be working through a simulation activity that deals with density. Before we begin, list some of the things you know about density in the space below. Think about what density means, how to find density and what its units are.

Dependent on student

Now, open up the density simulation found at https://phet.colorado.edu/en/simulation/legacy/density. You should see a block floating in water with a dialog box in the top right and an option menu in the top right. Make sure that you have the “Custom” option filled in. Mess around with this screen and write down any initial observations, questions or comments you have in the space below.

Dependent on student
Core Activity

Density

Density is a measure of mass per unit of volume. The average density of an object equals its total mass divided by its total volume, meaning that density is the ratio of mass to volume. An object made from a comparatively dense material (such as iron) will have less volume than an object of equal mass made from some less dense substance (such as water).

One of the most common uses of density is in how different materials interact when mixed together. Wood floats in water because it has a lower density, while an anchor sinks because the metal has a higher density. Helium balloons float because the density of the helium is lower than the density of the air.

When your automotive service station tests various liquids, like transmission fluid, it will pour some of the fluid into a hydrometer. The hydrometer has several calibrated objects, some of which float in the liquid. By observing which of the objects float, the service station employees can determine the density of the liquid. In the case of the transmission fluid, this test reveals whether service station employees need to replace it immediately, or whether the fluid still has some life in it.

To calculate the density (usually represented by the Greek letter "\( \rho \)") of an object, take the mass \( (m) \) and divide by the volume \( (v) \):

\[
\rho = \frac{m}{v}
\]

The SI unit of density is kilogram per cubic meter \( (\text{kg/m}^3) \) or kilogram per liter \( (\text{kg/L}) \).
Density allows you to solve for mass and volume if given the other quantity. Since the density of common substances is known, this calculation is fairly straightforward, in the form.

**Getting Started**

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/legacy/density](https://phet.colorado.edu/en/simulation/legacy/density)
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.
4. Start with the “Same Mass” section by selecting the second option.

**Same Mass**

1. Before you begin, predict which blocks will sink and which blocks will float. Explain your reasoning in the space below.
2. Drag each block individually into the water and find the volume (Remember units!). Note whether each block sinks in the table below.
3. Calculate the density (Remember units!) of each block using the mass you were given and the volume you found.

<table>
<thead>
<tr>
<th>Color</th>
<th>Mass</th>
<th>Volume</th>
<th>Density</th>
<th>Sinks?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>5.00 kg</td>
<td>5.00 L</td>
<td>1.00 kg/L</td>
<td>Yes</td>
</tr>
<tr>
<td>Yellow</td>
<td>5.00 kg</td>
<td>5.00 L</td>
<td>1.00 kg/L</td>
<td>No</td>
</tr>
<tr>
<td>Green</td>
<td>5.00 kg</td>
<td>2.5 L</td>
<td>2.00 kg/L</td>
<td>Yes</td>
</tr>
<tr>
<td>Red</td>
<td>5.00 kg</td>
<td>1.25 L</td>
<td>4.00 kg/L</td>
<td>Yes</td>
</tr>
</tbody>
</table>

When you pick up a block with your mouse and drop it into the water, this is what you see. The volume level on the right of the screen will increase depending on the volume of the block. The default level of water is 100.00L. The volume of the block would be the total, in this case 101.25, minus the initial water level, or 101.25-100 = 1.25 L = volume of the block. The blocks all have their mass written on them, so to find the density you simply need to find the volume as discussed and divide the given mass by it. This screen will look the same for the remaining uses of the simulation in this activity. The blocks will also sink or float depending on their density, which could be a useful check to ensure that the density calculations are correct.
4. Why do you think some of the blocks floated and some of the blocks sunk?

Density > Density of water = sink

**Same Volume**

1. Before you begin, predict which blocks will sink and which blocks will float. Explain your reasoning in the space below.

Green and Red float

2. Drag each block individually into the water and find the volume (Remember units!). Note whether each block sinks in the table below.

3. Calculate the density (Remember units!) of each block using the mass you were given and the volume you found.

<table>
<thead>
<tr>
<th>Color</th>
<th>Mass</th>
<th>Volume</th>
<th>Density</th>
<th>Sinks?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>6.00 kg</td>
<td>5.00 L</td>
<td>1.20 kg/L</td>
<td>Yes</td>
</tr>
<tr>
<td>Yellow</td>
<td>8.00 kg</td>
<td>5.00 L</td>
<td>1.60 kg/L</td>
<td>Yes</td>
</tr>
<tr>
<td>Green</td>
<td>4.00 kg</td>
<td>5.00 L</td>
<td>0.80 kg/L</td>
<td>No</td>
</tr>
<tr>
<td>Red</td>
<td>2.00 kg</td>
<td>5.00 L</td>
<td>0.40 kg/L</td>
<td>No</td>
</tr>
</tbody>
</table>
4. Why do you think some of the blocks floated and some of the blocks sunk (same idea as the question in the “Same Mass” section)?

Density > Density of water = sink

5. Now, place all four blocks into the water at the same time. Note any observations and possible explanations for those observations in the space below.

Red block floats higher than green block, lower density, lower density means floats higher in water

**Same Density**

1. Before you begin, predict which blocks will sink and which blocks will float. Explain your reasoning in the space below.

   All float

2. Drag each block individually into the water and find the volume (Remember units!). Note whether each block sinks in the table below.

3. Calculate the density (Remember units!) of each block using the mass you were given and the volume you found.

<table>
<thead>
<tr>
<th>Color</th>
<th>Mass</th>
<th>Volume</th>
<th>Density</th>
<th>Sinks?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>3.00 kg</td>
<td>3.00 L</td>
<td>1.00 kg/L</td>
<td>No</td>
</tr>
<tr>
<td>Yellow</td>
<td>4.00 kg</td>
<td>4.00 L</td>
<td>1.00 kg/L</td>
<td>No</td>
</tr>
<tr>
<td>Green</td>
<td>2.00 kg</td>
<td>2.00 L</td>
<td>1.00 kg/L</td>
<td>No</td>
</tr>
<tr>
<td>Red</td>
<td>1.00 kg</td>
<td>1.00 L</td>
<td>1.00 kg/L</td>
<td>No</td>
</tr>
</tbody>
</table>
Wrap-Up Questions

1. Are there any interesting trends between density and whether or not the block sinks? Explain.

They are the same or lower density than water at 1.00 kg/L so float

2. Do you think it is possible to determine whether or not a block will float or sink before placing it into water? Why or why not?

Yes, calculate density, if density <= 1.00 kg/L it will float

3. Does the size of the block determine whether or not it will sink or float?

No

4. If you placed the blocks in the “Same Volume” section into a liquid with a density of 2.0 kg/L, which blocks would float and which would sink? What about if the density of the liquid was 0.5 kg/L?

Higher = All float ; Lower = Only red would float

Wrap Up Questions

For each question, calculate the value of the unknown variable and determine whether it will float or sink in water.

Remember units: \( d = \frac{m}{V} \), \( V = \frac{m}{D} \), \( m = VD \)
1. Mass = 2.50 kg, Volume = 5.00 L, Density =? 

   \[ D = 0.5 \text{ kg/L ; float} \]

2. Mass = 6.75 kg, Volume = 1.50 L, Density =? 

   \[ D = 4.5 \text{ kg/L ; sink} \]

3. Mass = 3.00 kg, Volume = ?, Density = 1.50 kg/L 

   \[ V = 2.0 \text{ L ; sink} \]

4. Mass = ?, Volume = 6.00 L, Density = 4.25 kg/L 

   \[ M = 25.5 \text{ kg, sink} \]

5. Mass = 1.35 kg, Volume = 3.46 L, Density =? 

   \[ D = 0.390 \text{ kg/L ; float} \]

Assessment Activity

Density

Part I

Directions: For this assignment, you will be working on your own to determine the identity of five different blocks. Be sure to show all work in the space to the side and include the values of the volume and mass you determine for each block. Remember units! Be sure to click on the “Show Table” button when you are ready to identify the block.
To ultimately find the identity of the unknown blocks, you will need to find the density of each one and compare it to a given table of densities. The first step is to find the mass. To find the mass, drag one of the blocks onto this scale on the left side of the screen, as shown, and record the mass.

Next, you can find the volume by dragging the block into the water and calculating the volume of the block through the concept of water displacement, as was done in the core activity. In this case, the volume is 3.38L. Since we found the mass previously, 65.14kg, we can now find the density by dividing mass by volume or 65.14kg/3.38L = 19.27 kg/L.
Now that we know the density is 19.27 kg/L, we can click on the show table option and compare it to the density of the known materials. Since our number is closest to 19.3 kg/L, we can safely assume that block ‘A’ is made of gold. Repeat for the other blocks.

1. Block Letter: A
   a. Volume: 3.38L
   b. Mass: 65.14 kg
   c. Density: 19.27 kg/L
   d. Identity: Gold

2. Block Letter: B
   a. Volume: 0.64L
   b. Mass: 0.64kg
   c. Density: 1.0 kg/L
   d. Identity: Ice/Water (it does have the density of water but it is a solid so it’s assumed to be ice)
3. Block Letter: C
   a. Volume: 4.08L
   b. Mass: 4.08kg
   c. Density: 1.0kg/L
   d. Identity: Ice (see above)

4. Block Letter: D
   a. Volume: 3.10L
   b. Mass: 3.10kg
   c. Density: 1.0kg/L
   d. Identity: Ice (see above)

5. Block Letter: E
   a. Volume: 1.0L
   b. Mass: 3.53kg
   c. Density: 3.53kg/L
   d. Identity: Diamond

Part II

Directions: For this section, you will be using the “Custom” section of the simulation to identify more substances using the table on the “Mystery” screen. Make sure you are on the “My Block” tab!

6. Unknown 1 \[ D = \frac{m}{v} = \frac{9.32\text{kg}}{2.64\text{L}} = 3.53\text{kg/L} \]
   a. Volume: 2.64 L
   b. Mass: 9.32 kg
   c. Density: 3.53kg/L
   d. Identity: Diamond
7. Unknown 2 \[ D = \frac{m}{V} = \frac{4.52\text{kg}}{7.06\text{L}} = \frac{0.64\text{kg}}{\text{L}} \]
   a. Volume: 7.06 L
   b. Mass: 4.52 kg
   c. Density: 0.64 kg/L
   d. Identity: Apple

**Part III**

**Directions:** For this section, calculate the missing variable using whatever information you are provided. Remember to show work and use units!

8. Density: 0.68 kg/L \[ D = \frac{m}{V} = \frac{6.54\text{kg}}{9.63\text{L}} = \frac{0.68\text{kg}}{\text{L}} \]
   a. Mass: 6.54 kg
   b. Volume: 9.63 L

9. Mass: 25.40 kg \[ D = \frac{m}{V} \frac{0.40\text{kg}}{L} = \frac{m}{9.63\text{L}} \quad m = 25.40\text{kg} \]
   a. Volume: 9.63 L
   b. Identity of Substance: Wood

10. Volume: 2.57 L \[ D = \frac{m}{V} \frac{2.70\text{kg}}{L} = \frac{6.93\text{kg}}{V} \quad V = 2.57\text{L} \]
    a. Density: 2.70 kg/L
    b. Mass: 6.93 kg

**Challenge Question** – Create and solve your own version of a Part II question (questions 6 & 7).

Dependent on student
Isotopes and Atomic Mass

| Simulation Link: | https://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass |

**NYS Content Standards:**

3.1g The number of protons in an atom (atomic number) identifies the element. The sum of the protons and neutrons in an atom (mass number) identifies an isotope. Common notations that represent isotopes include: 14C, 14C, carbon-14, C-14

3.1m Atoms of an element that contain the same number of protons but a different number of neutrons are called isotopes of that element.

3.1n The average atomic mass of an element is the weighted average of the masses of its naturally occurring isotopes.

**Learning Goals:**

1) Students will be able to identify elements based on mass number.

2) Students will be able to find the atomic mass of an element.

3) Students will be able to define the term isotope.

**Key Vocabulary and Concepts for Simulation:**

1) **Atomic Number** – the number of protons in the nucleus of an atom

2) **Atomic Mass** – the average of the sum of the number of protons and neutrons in an atom and its isotopes

3) **Isotope** – two or more forms of the same element that have the same number of protons and electrons but different numbers of neutrons so that they have the same charge but not the same atomic mass

4) **Proton** – a subatomic particle with a positive charge that is the same size as a neutron

5) **Neutron** – a subatomic particle with no charge that is the same size as a proton

6) **Electron** - a relatively small subatomic particle with a negative charge

**Stimulating Aspects of the Simulation:**
1) Ability to see the nucleus of an atom

2) Ability to manipulate the atomic mass of an element

3) Wide variety of elements to experiment with

4) Ability to visualize the actual composition of isotopes in nature of a variety of elements

5) Ability to alter the composition of isotopes to see how it affects the atomic mass of an element

**Planning Considerations for Simulation:**

1) Can easily become cluttered, especially in the “Mixtures” screen

2) Relies on color to distinguish between protons and neutrons, limiting usefulness for students with visual impairments

3) While there are a variety of elements to test, you cannot test every element in the Periodic Table

**Simulation Parts Explained:**

**Screen 1: Isotopes**
**Screen 2: Mixtures**

**Subatomic Counter** – visually displays the number of subatomic particles (protons, neutrons, electrons) in the selected isotope

**Neutron Bucket** – a bucket of spare neutrons that can be added to the isotope, neutrons can also be taken off the isotope and placed into the bucket, doing either of these will make the isotope unstable

**Mass Toggle** – used to switch between either the “Mass Number” (a whole integer) or the “Atomic Mass” (a decimal that will only be displayed if the isotope is actually found in nature)

**Periodic Table** – a small subset of the Periodic Table, you may select which isotope you would like to observe by clicking on the corresponding symbol

**Isotope** – the isotope you have selected, shows the isotope name, the stability and the nucleus of the isotope you have selected

**Screen Selector** – switches between the screens of the simulation

**Reset Button** – resets the screen to the default as shown in the screenshots above
**Isotope Bucket** – samples of the isotopes available in nature for the selected element, note that some elements will only have one of these buckets while others may have 2 or more, these can also be switched to sliders by clicking on the slider button on the bottom right of the main display, you can drag these isotopes into the main display if the “My Mix” option is selected in the “Isotope Mixture” area to the left of the reset button

**Percent Composition** – the percent composition of each isotope, this can be toggled to how the element is found in nature by clicking on the “Nature’s Mix” button to the left of the reset button, this will also change depending on what isotopes you have placed into the main display

**Average Atomic Mass** – the average atomic mass of all the isotopes found in the main display

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**Suggestions for Supplemental Material:**

https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry_-_The_Central_Science_(Brown_et_al.)/02._Atoms%2C_Molecules%2C_and_Ions/2.4%3A_ATOMIC_MASS

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**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged in this activity because it gives them an opportunity to interact with the content in a low-risk setting. Students will also be able to connect some of their prior learning about atoms to the content within the simulation and see where they stand with this knowledge. Students can drag neutrons into the simulation to add them to the atom and see how doing so effects the atomic mass of an atom.

**Explore** – Like the engage phase, students will be exploring the content on their own when interacting with the simulation.

**Activity** –

**Introduction to Atomic Mass and Isotopes**
For this activity, you will be working through the “Atomic Mass and Isotopes” simulation found at https://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass, Before opening the simulation, define the vocabulary terms below to the best of your ability.

1. Neutron –
2. Proton –
3. Electron –
4. Atomic Number –
5. Atomic Mass –
6. Element –

Now, open the simulation. Spend a few minutes playing around with the simulation. Be sure to interact with all the variables possible on both the “Isotopes” screen and the “Mixtures” screen. After playing with the simulation, write four things you notice about this simulation and the content it represents.

7. 
8. 
9. 
10. 

Simulation Usage in the Core Instruction Period

**Explain** – For this assignment, the explain phase is covered mainly in the introductory reading. It is suggested that the teacher read this introductory information to the class aloud and address any student questions that arise and any misconceptions students may have. Much of the information that will be needed for the full understanding of this learning segment is found here, and students will use this information throughout the remainder of the learning segment to answer various questions.
Elaborate – The elaborate phase of this learning segment happens when students answer the wrap-up questions at the end of this assignment. For these questions, students will be connecting what they learned in the explain phase of this assignment to the questions they will have to answer. These questions will require students to take what they learned and apply it to a new, more challenging situation.

Activity (adapted from https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry_-_The_Central_Science_(Brown_et_al.)/02. Atoms%2C_Molecules%2C_and_Ions/2.4%3A_Atomic_Mass)

Atomic Mass and Isotopes

The arbitrary standard that has been established for describing atomic mass is the atomic mass unit (amu or u), defined as one-twelfth of the mass of one atom of $^{12}\text{C}$. Because the masses of all other atoms are calculated relative to the $^{12}\text{C}$ standard, $^{12}\text{C}$ is the only atom whose exact atomic mass is equal to the mass number. Experiments have shown that 1 amu = $1.66 \times 10^{-24}$ g.

The periodic table lists the atomic masses of all the elements. However, the atomic masses given in the periodic table never correspond exactly to those of any of its isotopes. Because most elements exist as mixtures of several stable isotopes, the atomic mass of an element is defined as the weighted average of the masses of the isotopes. For example, naturally occurring carbon is largely a mixture of two isotopes: 98.89% $^{12}\text{C}$ (mass = 12 amu by definition) and 1.11% $^{13}\text{C}$ (mass = 13.003355 amu). The percent abundance of $^{14}\text{C}$ is so low that it can be ignored in this calculation. The average atomic mass of carbon is then calculated as follows:

$$
(0.9889 \times 12\text{amu}) + (0.0111 \times 13.003355\text{amu}) = 12.01\text{amu}
$$
Carbon is predominantly $^{12}\text{C}$, so its average atomic mass should be close to 12 amu, which is in agreement with this calculation.

The value of 12.01 is shown under the symbol for C in the periodic table, although without the abbreviation amu, which is customarily omitted. Thus the tabulated atomic mass of carbon or any other element is the weighted average of the masses of the naturally occurring isotopes.

**Getting Started**

1. Log into a computer and open up Google Chrome.

2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass.

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Isotopes and Atomic Mass” simulation.

**Elements**

1. For this activity, we will focus on the “Isotopes” screen of the simulation.

2. Open the symbol and abundance in nature tabs by clicking on the green plus on the right side of the tab.

3. Record the mass number, atomic mass, number of protons, number of neutrons, number of electrons and the symbol of the Hydrogen isotope in the table below.

4. Repeat step 3 for the remaining elements.
<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Mass #</th>
<th>Atomic Mass</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helium</td>
<td></td>
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</tr>
<tr>
<td>Lithium</td>
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<td></td>
</tr>
<tr>
<td>Beryllium</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Nitrogen</td>
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</tr>
<tr>
<td>Oxygen</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Fluorine</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Neon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CiQ 1: What do you notice about the atomic mass and the mass number?

CiQ 2: What relationship do you see between the number of protons and neutrons in the isotope and the mass number?

Isotopes

1. Remaining on the “Isotope” screen, find all isotopes of each element option in the periodic table (you can add or remove neutrons to achieve isotopes).
2. Record the abundance in nature of each isotope in the table below. The first set of isotopes has been done for you. **HINT:** There are 17 possible isotopes you can find in this simulation.

<table>
<thead>
<tr>
<th>Isotope Name</th>
<th>Abundance in Nature (%)</th>
<th>Change in Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen-1</td>
<td>99.9885</td>
<td>0</td>
</tr>
<tr>
<td>Hydrogen-2</td>
<td>0.0115</td>
<td>+1</td>
</tr>
</tbody>
</table>
**Wrap-Up Questions**

1. For each of the isotope sets below, calculate the atomic mass. Be sure to show work!
   
   a. H-1 at 99.985% ; H-2 at 0.015%

   b. Cl-35 at 75.77% ; Cl-37 at 24.23%

   c. Cu-63 at 69.17% ; Cu-65 at 30.83%

   d. Mg-24 at 78.99% ; Mg-25 at 10.00% ; Mg-26 at 11.01% abundance

   e. Ag-107 at 51.86% ; Ag-109 at 48.14%

---

**Simulation Usage as an Expansionary Assessment**

**Evaluate** – The activity for this section will assess students’ knowledge of both the simulation itself and the content within the simulation. Students will be required to take what they have learned in the core instruction period and use it to complete the questions related to the simulation and answer the pencil and paper questions found in this activity.

**Activity** –
Atomic Mass and Isotopes Assessment

Part I

Use the “Isotopes and Atomic Mass” simulation found at https://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass to answer the questions below:

1. What Argon isotopes are found in nature and what is the percent composition of these isotopes?

2. Which element(s) found in the simulation have no other isotope(s)?

3. What is the average atomic mass of Silicon?

4. What is the percent composition in nature of the Magnesium-26 isotope?

5. What is the least abundant isotope found in this simulation?

Part II

Use the Periodic Table to answer the following questions:

6. What element has an atomic mass of 107.87?

7. Which element has 87 protons and 136 neutrons?
8. Which element has 21 protons? What is its mass number?

9. How many protons and neutrons does a Calcium atom have?

10. Which element has the smallest atomic mass?

**Part III**

Define the following terms:

11. Isotope – 

12. Atomic Mass – 

13. Atomic Number – 

14. Proton – 

15. Neutron –
Activity Guide

Preliminary Activity

Introduction to Atomic Mass and Isotopes

For this activity, you will be working through the “Atomic Mass and Isotopes” simulation found at https://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass. Before opening the simulation, define the vocabulary terms below to the best of your ability.

1. Neutron – neutrally charged particle found in the nucleus, similar mass to proton
2. Proton – positively charged particle found in the nucleus, similar mass to neutron
3. Electron – negatively charged particle found outside the nucleus, much smaller than proton and neutron
4. Atomic Number – number of protons in the nucleus
5. Atomic Mass – approximately equal to the number of protons and neutrons in an atom, the average of the relative abundance of different isotopes found in the nature
6. Element – chemical that cannot be broken down into simple substances

Now, open the simulation. Spend a few minutes playing around with the simulation. Be sure to interact with all the variables possible on both the “Isotopes” screen and the “Mixtures” screen. After playing with the simulation, write four things you notice about this simulation and the content it represents.
For this preliminary activity, there are no concrete directions. The main purpose of this activity is to explore the simulations. Some important things to note in the simulation, however, are the subatomic particle counter, the toggle between mass number and atomic mass, the periodic table with element options and the expansionary button for the symbol and abundance in nature tabs. The symbol is the most important for this activity as it allows students to see the atomic number and atomic mass of the element as it would appear in the periodic table.
Similar to the first screenshot and explanation, this section is purely for exploration. Important things to notice for this screen are the isotope buckets and the isotope mixture options. You can drag different isotopes into the simulation and the percent composition of the isotopes you have placed in the simulation will be shown in the middle right of the screen under the percent composition tab. You can also switch to the nature’s mix option which shows a visual representation of how the isotopes actually appear in the real world.

7. Based on student

8. Based on student

9. Based on student

10. Based on student
Core Activity

Atomic Mass and Isotopes

The arbitrary standard that has been established for describing atomic mass is the atomic mass unit (amu or u), defined as one-twelfth of the mass of one atom of \(^{12}\text{C}\). Because the masses of all other atoms are calculated relative to the \(^{12}\text{C}\) standard, \(^{12}\text{C}\) is the only atom whose exact atomic mass is equal to the mass number. Experiments have shown that 1 amu = \(1.66 \times 10^{-24}\) g.

The periodic table lists the atomic masses of all the elements. However, the atomic masses given in the periodic table never correspond exactly to those of any of its isotopes. Because most elements exist as mixtures of several stable isotopes, the atomic mass of an element is defined as the weighted average of the masses of the isotopes. For example, naturally occurring carbon is largely a mixture of two isotopes: 98.89% \(^{12}\text{C}\) (mass = 12 amu by definition) and 1.11% \(^{13}\text{C}\) (mass = 13.003355 amu). The percent abundance of \(^{14}\text{C}\) is so low that it can be ignored in this calculation. The average atomic mass of carbon is then calculated as follows:

\[
(0.9889 \times 12 \text{amu}) + (0.0111 \times 13.003355 \text{amu}) = 12.01 \text{amu}
\]

Carbon is predominantly \(^{12}\text{C}\), so its average atomic mass should be close to 12 amu, which is in agreement with this calculation.

The value of 12.01 is shown under the symbol for C in the periodic table, although without the abbreviation amu, which is customarily omitted. Thus the tabulated atomic mass of carbon or any other element is the weighted average of the masses of the naturally occurring isotopes.
Getting Started

1. Log into a computer and open up Google Chrome.

2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass.

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Isotopes and Atomic Mass” simulation.

Elements

1. For this activity, we will focus on the “Isotopes” screen of the simulation.

2. Open the symbol and abundance in nature tabs by clicking on the green plus on the right side of the tab.

3. Record the mass number, atomic mass, number of protons, number of neutrons, number of electrons and the symbol of the Hydrogen isotope in the table below.

4. Repeat step 3 for the remaining elements.
For this activity, you will be looking for all the important data provided by the simulation. This data includes: the subatomic particle counter, the toggle between mass number and atomic mass, the periodic table with element options and the atomic symbol. For this example, you can see that there are no neutrons and there is single proton and a single electron in the Hydrogen-1 isotope. This isotope has a mass number of 1 and an atomic mass of 1.00783 amu.

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Mass #</th>
<th>Atomic Mass</th>
<th># Protons</th>
<th># Neutrons</th>
<th># Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>$\frac{1}{1}H$</td>
<td>1</td>
<td>1.00783</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Helium</td>
<td>$\frac{2}{4}He$</td>
<td>4</td>
<td>4.00260</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lithium</td>
<td>$\frac{2}{3}Li$</td>
<td>7</td>
<td>7.01600</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Beryllium</td>
<td>$\frac{9}{4}Be$</td>
<td>9</td>
<td>9.01218</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Boron</td>
<td>$\frac{11}{5}B$</td>
<td>11</td>
<td>11.00931</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Carbon</td>
<td>$\frac{12}{6}C$</td>
<td>12</td>
<td>12.00000</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>$\frac{14}{7}N$</td>
<td>14</td>
<td>14.00307</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Element</td>
<td>Isotope</td>
<td>Mass Number</td>
<td>Atomic Mass</td>
<td>Protons</td>
<td>Neutrons</td>
<td>Charge</td>
</tr>
<tr>
<td>----------</td>
<td>---------</td>
<td>-------------</td>
<td>-------------</td>
<td>---------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>Oxygen</td>
<td>$^{16}_{8}O$</td>
<td>16</td>
<td>15.99491</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Fluorine</td>
<td>$^{19}_{9}F$</td>
<td>19</td>
<td>18.99840</td>
<td>9</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Neon</td>
<td>$^{20}_{10}Ne$</td>
<td>20</td>
<td>19.99244</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

**CiQ 1:** What do you notice about the atomic mass and the mass number?

Similar but different due to the atomic mass being an average atomic mass of all isotopes

**CiQ 2:** What relationship do you see between the number of protons and neutrons in the isotope and the mass number?

Mass number = # of protons + # of neutrons

**Isotopes**

1. Remaining on the “Isotope” screen, find all isotopes of each element option in the periodic table (you can add or remove neutrons to achieve isotopes).

2. Record the abundance in nature of each isotope in the table below. The first set of isotopes has been done for you. **HINT:** There are 17 possible isotopes you can find in this simulation.
For this section of the activity, you will be focusing purely on the relative abundance of different isotopes. To find the different isotopes, you will have to either drag neutrons from the neutron bucket or drag them away from the nucleus. In this case, a neutron has been dragged into the Hydrogen-1 isotope, turning it into the Hydrogen-2 isotope. You can then see the abundance in nature of this isotope is 0.0115%.

<table>
<thead>
<tr>
<th>Isotope Name</th>
<th>Abundance in Nature (%)</th>
<th>Change in Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen-1</td>
<td>99.9885</td>
<td>0</td>
</tr>
<tr>
<td>Hydrogen-2</td>
<td>0.0115</td>
<td>+1</td>
</tr>
<tr>
<td>Helium-4</td>
<td>99.9999</td>
<td>0</td>
</tr>
<tr>
<td>Helium-3</td>
<td>0.0001</td>
<td>-1</td>
</tr>
<tr>
<td>Lithium-7</td>
<td>92.41</td>
<td>0</td>
</tr>
<tr>
<td>Lithium-6</td>
<td>7.59</td>
<td>-1</td>
</tr>
<tr>
<td>Beryllium-9</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Boron-11</td>
<td>80.1</td>
<td>0</td>
</tr>
<tr>
<td>Isotope</td>
<td>Mass</td>
<td>Charge</td>
</tr>
<tr>
<td>--------------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Boron-10</td>
<td>19.9</td>
<td>-1</td>
</tr>
<tr>
<td>Carbon-12</td>
<td>98.93</td>
<td>0</td>
</tr>
<tr>
<td>Carbon-13</td>
<td>1.07</td>
<td>+1</td>
</tr>
<tr>
<td>Nitrogen-14</td>
<td>99.636</td>
<td>0</td>
</tr>
<tr>
<td>Nitrogen-15</td>
<td>0.364</td>
<td>+1</td>
</tr>
<tr>
<td>Oxygen-16</td>
<td>99.757</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen-17</td>
<td>0.038</td>
<td>+1</td>
</tr>
<tr>
<td>Fluorine-19</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Neon-20</td>
<td>90.48</td>
<td>0</td>
</tr>
<tr>
<td>Neon-21</td>
<td>0.27</td>
<td>+1</td>
</tr>
<tr>
<td>Neon-22</td>
<td>9.25</td>
<td>+2</td>
</tr>
</tbody>
</table>

**Wrap-Up Questions**

1. For each of the isotope sets below, calculate the atomic mass based on the mass numbers given. Be sure to show work!

   \[
   \text{atomic mass} = (\text{percent abundance in decimal form of isotope 1})(\text{mass number isotope 1}) + (\text{percent abundance in decimal form of isotope 2})(\text{mass number isotope 2})
   \]

   a. H-1 at 99.985% ; H-2 at 0.015%

   \[
   (0.99985)(1) + (0.00015)(2) = 1.00015
   \]

   b. Cl-35 at 75.77% ; Cl-37 at 24.23%

   \[
   (0.7577)(35) + (0.2423)(37) = 35.4846
   \]

   c. Cu-63 at 69.17% ; Cu-65 at 30.83%

   \[
   (0.6917)(63) + (0.3083)(65) = 63.6166
   \]
d. Mg-24 at 78.99% ; Mg-25 at 10.00% ; Mg-26 at 11.01% abundance

\[(0.7899)(24) + (0.1000)(25) + (0.1101)(26) = 24.3202\]

e. Ag-107 at 51.86% ; Ag-109 at 48.14%

\[(0.5186)(107) + (0.4814)(109) = 107.9628\]

**Assessment Activity**

**Atomic Mass and Isotopes Assessment**

**Part I**

Use the “Isotopes and Atomic Mass” simulation found at [https://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass](https://phet.colorado.edu/en/simulation/isotopes-and-atomic-mass) to answer the questions below:

For these question, ensure that you have selected the Nature’s Mix option. Then select whichever element the question is asking for in the Periodic Table, in this case Argon. Then you can see useful information, like the percent composition and average atomic mass, in the sections below the periodic table. For question 1, the isotopes of Argon, as seen in this screenshot, are Argon-36, Argon-38 and Argon-40 and their percent compositions are 0.3365%, 0.0632% and 99.603% respectively, as shown in this screenshot.
1. What Argon isotopes are found in nature and what is the percent composition of these isotopes?

   Argon-36 (0.3365%); Argon-38 (0.0632%) and Argon-40 (99.6003%)

2. Which element(s) found in the simulation have no other isotope(s)?

   Beryllium, Fluorine, Sodium, Aluminum, Phosphorus,

3. What is the average atomic mass of Silicon?

   28.08550 amu

4. What is the percent composition in nature of the Magnesium-26 isotope?

   11.01%

5. What is the least abundant isotope found in this simulation?

   Helium-3 at 0.0001%

**Part II**

Use the Periodic Table to answer the following questions:

6. What element has an atomic mass of 107.87?

   Silver

7. Which element has 87 protons and 136 neutrons?

   Francium

8. Which element has 21 protons? What is its mass number?

   Scandium, 45

9. How many protons and neutrons does a Calcium atom have?

   Protons = 20, Neutrons = 20
10. Which element has the smallest atomic mass?

Hydrogen

Part III

Define the following terms:

11. Isotope – two or more forms of the same element that have the same number of protons but different numbers of neutrons so that they have the same charge but not the same mass

12. Atomic Mass – the average of the sum of the number of protons and neutrons in an element

13. Atomic Number – the number of protons in the nucleus of an atom

14. Proton – a subatomic particle with a positive charge that is the same size as a neutron

15. Neutron – a subatomic particle with no charge that is the same size as a proton
### Molarity

|------------------|--------------------------------------------------------------------------------------------------|

#### NYS Content Standards:

3.1pp The concentration of a solution may be expressed in molarity (M), percent by volume, percent by mass, or parts per million (ppm) and calculate solution concentration in molarity (M), percent mass, and parts per million (ppm).

#### Learning Goals:

1. Students will be able to visually distinguish between a saturated and unsaturated solution.
2. Students will be able to define concentration and molarity.
3. Students will be able to calculate concentration and molarity.

#### Key Vocabulary and Concepts for Simulation:

1. **Concentration** – the amount of substance per defined space
2. **Molarity** – a measure of concentration, moles solute per liter solution
3. **Moles** – unit for the amount of a substance, one mole is $6.022 \times 10^{23}$ (Avogadro’s number)
4. **Unsaturated** – solute concentration is lower than equilibrium solubility, solution can hold more solute
5. **Saturated** – solute concentration is equal to the equilibrium solubility, the solution holds as much solute as possible
6. **Supersaturated** – solution that contains more of a solute than normally possible

#### Stimulating Aspects of the Simulation:

1. Many different colorful options of solute
2. Multiple variables to change
3) Easy to see changes in concentration

**Planning Considerations for Simulation:**

1) Easy to rush through

2) Not very deep in content, requires supplemental material

**Simulation Parts Explained:**

**Screen 1: Concentration**
**Evaporation Slider** – removes the water solvent without removing any of the solute, solute can be removed by clicking on the “Remove Solute” button to the right of this slider.

**Faucet** – pull the blue knob to add water to the solution.

**Solute Shaker** – grab and move the shaker back and forth to add solute to the solution, note that if the “Solution” option is selected in the solute options, this will be a pipet which you press the red button in the top middle of it to add the solute in solution form.

**Concentration Probe** – must be dragged into the solution to display the concentration in moles per liter (molarity).

**Drain** – pull the blue knob to remove both water and solute from the beaker.

**Solute Options** – select from a variety of different solutes to add to the solution, also is used to toggle between solid solute or solute in solution form.

**Reset Button** – resets the screen to its default state as shown in the screenshots above.

**Solute Slider** – used to select how much solute is in the beaker.
**Solution Slider** – used to select how much solvent (water) is in the beaker

**Concentration Display** – displays the concentration of the solution, dependant on your selections in the solute and solution sliders

**Suggestions for Supplemental Material:**

https://chem.libretexts.org/Bookshelves/General_Chemistry/Book%3A_Chemistry_(OpenSTAX)/03%3A_Composition_of_Substances_and_Solutions/3.3%3A_Molarity

---

**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged in this activity because it gives them an opportunity to interact with the content in a low-risk setting. Concentration, by its nature, is very difficult to see and visualize in the physical environment and this simulation solves much of this problem. Students can add solute to the solution in a multiple ways and can see how adding solute effects concentration and the color of the solution itself. Students will also be able to connect some of their prior learning about concentration to the content within the simulation and see where they stand with this knowledge.

**Explore** – Like the engage phase, students will be exploring the content on their own when interacting with the simulation. They will be able to instantly see what effects the variables that can manipulate have on a solution and its concentration.

**Activity** –

**Introduction to Molarity**

Concentration is a way to describe how much of something, the solute, is in a solution. There are many ways to express concentration, but the most common you will see in chemistry is molarity. Molarity uses the units of moles per liter, which means that it’s a measure of the moles of solute per liter of solution. For this assignment, we
will be focusing on the “Concentration” simulation found at https://phet.colorado.edu/en/simulation/concentration.

Open up the simulation and play around with it for a few minutes before answering the questions below.

1. How can you increase concentration in the simulation?

2. How can you decrease concentration in the simulation?

3. How does the solution look different at higher concentrations than at lower concentrations?

4. What happens when all the solvent (the liquid portion of the solution) evaporates?

5. Does adding solute to the solution increase the overall volume of the solution? Why or why not?

---

**Simulation Usage in the Core Instruction Period**

**Explain** – For this assignment, the explain phase is covered mainly in the introductory reading. It is suggested that the teacher read this introductory information to the class aloud and address any student questions that arise and any misconceptions students may have. Much of the information that will be needed for the full understanding of this learning segment is found here, and students will use this information throughout the remainder of the learning segment to answer various questions.

**Elaborate** – The elaborate phase of this learning segment happens when students answer the wrap-up questions at the end of this assignment. For these questions, students will be connecting what they learned in the explain phase of
Activity (adapted from
https://chem.libretexts.org/Bookshelves/General_Chemistry/Book%3A_Chemistry_(OpenSTAX)/03%3A_Composition_of_Substances_and_Solutions/3.3%3A_Molarity) –

**Molarity**

Mixtures are samples of matter containing two or more substances physically combined. These mixtures are more common in nature than seeing a pure substance. Similar to a pure substance, the relative composition of a mixture plays an important role in determining its properties. The relative amount of oxygen in a planet’s atmosphere determines its ability to sustain aerobic life. The relative amounts of iron, carbon, nickel, and other elements in steel (a mixture known as an “alloy”) determine its physical strength and resistance to corrosion. The relative amount of the active ingredient in a medicine determines its effectiveness in achieving the desired pharmacological effect. The relative amount of sugar in a beverage determines its sweetness. In this section, we will describe one of the most common ways in which the relative compositions of mixtures may be quantified.

The relative amount of a given solution component is known as its **concentration**. Often, though not always, a solution contains one component with a concentration that is significantly greater than that of all other components. This component is called the solvent and may be viewed as the medium in which the other components are dispersed, or dissolved. Solutions in which water is the solvent are, of course, very common on our planet. A solution in which water is the solvent is called an aqueous solution.

A solute is a component of a solution that is typically present at a much lower concentration than the solvent. Solute concentrations are often described with qualitative terms such as dilute (of relatively low concentration)
and concentrated (of relatively high concentration). When the maximum amount of solute that the solution can hold is reached, the solution is said to be saturated. All other quantities of solute before this point indicate that the solution is unsaturated.

Concentrations may be quantitatively assessed using a wide variety of measurement units, each convenient for particular applications. Molarity ($M$) is a useful concentration unit for many applications in chemistry. Molarity is defined as the number of moles of solute in exactly 1 liter (1 L) of the solution:

$$M = \frac{\text{mol solute}}{L\text{ solution}}$$

**Getting Started**

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/concentration](https://phet.colorado.edu/en/simulation/concentration).
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.
4. Start the “Concentration” simulation.

**Solid**

1. Start with the solid sample of your solute. You should see a salt shaker in the top middle of the screen. To add solute to the solution, simply “shake” the salt shaker by dragging it around on the screen.
2. Drag the purple cursor into the solution in order to see the current concentration of the solution.
3. Keep the solution at ½ L and add solute into the solution until it becomes saturated (it will say “Saturated!” at the bottom of the beaker).
4. Record the concentration at which the solution becomes saturated.
5. Repeat steps 1-4 with the remaining solutes.

<table>
<thead>
<tr>
<th>Solute Name</th>
<th>Solute Chemical Formula</th>
<th>Saturated Concentration (mol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drink Mix</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt (II) Nitrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt (II) Chloride</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium Dichromate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium Chromate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickel (II) Chloride</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper (II) Sulfate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potassium Permanganate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CiQ 1:** What did you notice about the color of the solution as the solution become more concentrated?

**CiQ 2:** Do you notice any similarities between the solutes that caused the solution to become saturated at relatively low concentrations?

**Solution**

1. Now switch over to the solution sample of the solute. You should see a pipet with the selected solute in it near the top middle of the simulation.

2. Ensure that the purple cursor is in the solution so that you will be able to see the current concentration.

3. Ensure that the volume of the solution starts at $\frac{1}{2}$ L.
4. Add the solute until the solution reaches a volume of 1 L (you will not be able to add anymore at this point).

5. Record the concentration in the table below.

6. Repeat steps 1-5 for the remaining solutes.

<table>
<thead>
<tr>
<th>Solute Name</th>
<th>Solute Chemical Formula</th>
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</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Potassium Chromate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nickel (II) Chloride</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper (II) Sulfate</td>
<td></td>
<td></td>
</tr>
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<td>Potassium Permanganate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CiQ 3:** Calculate the molar mass of the solute that had the lowest saturated concentration and the solute that had the highest saturated concentration. Do you notice any relationship between molar mass and the concentration at 1 L? If so, what was the relationship?

**CiQ 4:** What is left behind if all the liquid is removed from a solution?

**Wrap-Up Questions**

1. Which of the following molecules do you expect would need the lowest concentration before the solution became saturated: C₆H₁₂O₆, N₂, NaCl, CaO, or O₃?
2. What would be the molarity of a 1 L solution containing 0.25 moles of NaCl?

3. A 1.0M solution of HCl contains 0.5 moles of HCl. What is the volume of the solution?

4. A 0.75M solution of H₂SO₄ fills a 0.5L beaker. How many moles of H₂SO₄ are in the solution?

5. For a laboratory experiment, you are required to create a 0.25M solution of CH₃COOH. How many grams of CH₃COOH should you add to 1L of solvent to create this 0.25M solution?

**Simulation Usage as an Expansionary Assessment**

**Evaluate** – The activity for this section will assess students’ knowledge of both the simulation itself and the content within the simulation, molarity. Students will be required to take what they have learned in the core instruction period and use it to complete the questions related to the simulation and answer the pencil and paper questions found in this activity.

**Activity** –

**Molarity Assessment**

**Part I**

For each of the following questions, find the molarity of Drink mix using the “Molarity” simulation found at https://phet.colorado.edu/en/simulation/molarity.
1. \( V = 0.552 \text{ L} \), Solute = 0.460 mol

2. \( V = 0.830 \text{ L} \), Solute = 0.197 mol

3. \( V = 1.000 \text{ L} \), Solute = 1.000 mol

4. \( V = 0.607 \text{ L} \), Solute = 0.806 mol

5. \( V = 0.200 \text{ L} \), Solute = 1.00 mol

6. \( V = 0.323 \text{ L} \), Solute = 0.195 mol

7. \( V = 0.646 \text{ L} \), Solute = 0.728 mol

**Part II**

For each of the following questions, calculate the missing variable. Be sure to show your work and use correct units!

8. \( M = 2.30M \), \( V = 0.232\text{L} \), mol =?

9. \( M = ? \), \( V = 1.42\text{L} \), mol = 0.54 mol
10. $M = ?, V = 0.75L, \text{mol} = 1.3 \text{ mol}$

11. $M = 5.76M, V = 0.12L, \text{mol} = ?$

12. $M = 0.12M, V = ?, \text{mol} = 0.05 \text{ mol}$

13. $M = 0.30M, V = ?, \text{mol} = 1.23 \text{ mol}$

14. $M = ?, V = 0.35L, \text{mol} = 0.25 \text{ mol}$

15. $M = 1.23M, V = 1.2L, \text{mol} = ?$

Activity Guide

Preliminary Activity

Introduction to Molarity

Concentration is a way to describe how much of something, the solute, is in a solution. There are many ways to express concentration, but the most common you will see in chemistry is molarity. Molarity uses the units of moles per liter, which means that it’s a measure of the moles of solute per liter of solution. For this assignment, we will be focusing on the “Concentration” simulation found at [https://phet.colorado.edu/en/simulation/concentration](https://phet.colorado.edu/en/simulation/concentration). Open up the simulation and play around with it for a few minutes before answering the questions below.
The purpose of this assignment is to play around with the simulation and begin to understand what happens when variables are manipulated. The most important thing to note, at this point, is that the purple cursor must be dragged into the solution in order to see the concentration and solute can be added by dragging the shaker near the top middle of the screen.

1. How can you increase concentration in the simulation?
   
   Add more solute

2. How can you decrease concentration in the simulation?
   
   Remove solute or add more solvent

3. How does the solution look different at higher concentrations than at lower concentrations?
   
   Darker/more vibrant color

4. What happens when all the solvent (the liquid portion of the solution) evaporates?
   
   Left with solid solute/precipitate
5. Does adding solute to the solution increase the overall volume of the solution? Why or why not?

No, added solute dissolves in solution

Core Activity

Molarity

Mixtures are samples of matter containing two or more substances physically combined. These mixtures are more common in nature than seeing a pure substance. Similar to a pure substance, the relative composition of a mixture plays an important role in determining its properties. The relative amount of oxygen in a planet’s atmosphere determines its ability to sustain aerobic life. The relative amounts of iron, carbon, nickel, and other elements in steel (a mixture known as an “alloy”) determine its physical strength and resistance to corrosion. The relative amount of the active ingredient in a medicine determines its effectiveness in achieving the desired pharmacological effect. The relative amount of sugar in a beverage determines its sweetness. In this section, we will describe one of the most common ways in which the relative compositions of mixtures may be quantified.

The relative amount of a given solution component is known as its concentration. Often, though not always, a solution contains one component with a concentration that is significantly greater than that of all other components. This component is called the solvent and may be viewed as the medium in which the other components are dispersed, or dissolved. Solutions in which water is the solvent are, of course, very common on our planet. A solution in which water is the solvent is called an aqueous solution.

A solute is a component of a solution that is typically present at a much lower concentration than the solvent. Solute concentrations are often described with qualitative terms such as dilute (of relatively low concentration) and concentrated (of relatively high concentration). When the maximum amount of solute that the solution can hold is
reached, the solution is said to be **saturated**. All other quantities of solute before this point indicate that the solution is **unsaturated**.

Concentrations may be quantitatively assessed using a wide variety of measurement units, each convenient for particular applications. **Molarity** ($M$) is a useful concentration unit for many applications in chemistry. Molarity is defined as the number of moles of solute in exactly 1 liter (1 L) of the solution:

$$M = \frac{\text{mol solute}}{L_{\text{solution}}}$$

**Getting Started**

1. Log into a computer and open up Google Chrome.

2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/concentration](https://phet.colorado.edu/en/simulation/concentration).

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Concentration” simulation.

**Solid**

1. Start with the solid sample of your solute. You should see a salt shaker in the top middle of the screen. To add solute to the solution, simply “shake” the salt shaker by dragging it around on the screen.

2. Drag the purple cursor into the solution in order to see the current concentration of the solution.

3. Keep the solution at ½ L and add solute into the solution until it becomes saturated (it will say “Saturated!” at the bottom of the beaker).

4. Record the concentration at which the solution becomes saturated.

5. Repeat steps 1-4 with the remaining solutes.
For this section of the assignment, you will be solely working with the “Solid” solute, as indicated by the presence of this salt shaker like object. You can add the solid solute to the solution by moving the shaker back and forth. As you do so, you will be able to see a solid, powder like form of the solute leave the shaker and go into the solution. As you continue to do this, the concentration will increase and the solution will become saturated, as indicated by the word “Saturated!” in the bottom of the beaker. Once this point is achieved, be sure to check the concentration by dragging the purple cursor into the solution, if you have not already done so. The concentration will appear in the purple box, in this case 5.960 mol/L, which should then be recorded in the table below for each solute sample. Note that you will have to reset the simulation after every solute.

<table>
<thead>
<tr>
<th>Solute Name</th>
<th>Solute Chemical Formula</th>
<th>Saturated Concentration (mol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drink Mix</td>
<td></td>
<td>5.96</td>
</tr>
<tr>
<td>Cobalt (II) Nitrate</td>
<td>Co(NO$_3$)$_2$</td>
<td>5.64</td>
</tr>
<tr>
<td>Cobalt (II) Chloride</td>
<td>CoCl$_2$</td>
<td>4.33</td>
</tr>
<tr>
<td>Potassium Dichromate</td>
<td>K$_2$Cr$_2$O$_7$</td>
<td>0.51</td>
</tr>
<tr>
<td>Potassium Chromate</td>
<td>K$_2$CrO$_4$</td>
<td>3.35</td>
</tr>
<tr>
<td>Nickel (II) Chloride</td>
<td>NiCl$_2$</td>
<td>5.21</td>
</tr>
<tr>
<td>Solute</td>
<td>Formula</td>
<td>Concentration</td>
</tr>
<tr>
<td>------------------------------</td>
<td>------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Copper (II) Sulfate</td>
<td>CuSO₄</td>
<td>1.38</td>
</tr>
<tr>
<td>Potassium Permanganate</td>
<td>KMnO₄</td>
<td>0.48</td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td>NaCl</td>
<td>6.15</td>
</tr>
</tbody>
</table>

**CiQ 1:** What did you notice about the color of the solution as the solution become more concentrated?

   Color was more vibrant, more red or whatever color the solute is

**CiQ 2:** Do you notice any similarities between the solutes that caused the solution to become saturated at relatively low concentrations?

   Smaller molecules tend to need larger concentrations before they become saturated and vice versa for larger molecules

**Solution**

1. Now switch over to the solution sample of the solute. You should see a pipet with the selected solute in it near the top middle of the simulation.
2. Ensure that the purple cursor is in the solution so that you will be able to see the current concentration.
3. Ensure that the volume of the solution starts at ½ L.
4. Add the solute until the solution reaches a volume of 1 L (you will not be able to add anymore at this point).
5. Record the concentration in the table below.
6. Repeat steps 1-5 for the remaining solutes.
For the next section, you will be using the liquid solution for the solute. If you press the button on the pipet, you will begin to dispense the solute solution into the solution. Continue to do so until you reach 1L (you will not be able to add any more after this). Record the concentration in the table below, in this case the concentration for Drink mix is 2.75 mol/L. Ensure that the purple cursor is dragged into the solution so that the concentration will be displayed.

<table>
<thead>
<tr>
<th>Solute Name</th>
<th>Solute Chemical Formula</th>
<th>Concentration (mol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drink Mix</td>
<td></td>
<td>2.75</td>
</tr>
<tr>
<td>Cobalt (II) Nitrate</td>
<td>Co(NO₃)₂</td>
<td>2.50</td>
</tr>
<tr>
<td>Cobalt (II) Chloride</td>
<td>CoCl₂</td>
<td>2.00</td>
</tr>
<tr>
<td>Potassium Dichromate</td>
<td>K₂Cr₂O₇</td>
<td>0.25</td>
</tr>
<tr>
<td>Potassium Chromate</td>
<td>K₂CrO₄</td>
<td>1.50</td>
</tr>
<tr>
<td>Nickel (II) Chloride</td>
<td>NiCl₂</td>
<td>2.50</td>
</tr>
<tr>
<td>Copper (II) Sulfate</td>
<td>CuSO₄</td>
<td>0.50</td>
</tr>
<tr>
<td>Potassium Permanganate</td>
<td>KMnO₄</td>
<td>0.20</td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td>NaCl</td>
<td>2.75</td>
</tr>
</tbody>
</table>

**CiQ 3:** Calculate the molar mass of the solute that had the lowest saturated concentration and the solute that had the highest saturated concentration. Do you notice any relationship between molar mass and the concentration at 1 L? If so, what was the relationship?

\[
KMnO_4 = 158.034 \text{ g/mol} \; ; \; NaCl = 58.44 \text{ g/mol} \; ; \; \text{larger molecules were less concentrated}
\]

**CiQ 4:** What is left behind if all the liquid is removed from a solution?

precipitate

To remove all liquid from the solution, you can drag the Evaporation slider until the screen looks like the screen in this screenshot. Notice that you are left with a solid precipitate on the bottom of the beaker. Also notice that the concentration will not be read, as it is no longer a solution.
Wrap-Up Questions

1. Which of the following molecules do you expect would need the lowest concentration before the solution became saturated: C₆H₁₂O₆, N₂, NaCl, CaO, or O₃?

   C₆H₁₂O₆

2. What would be the molarity of a 1 L solution containing 0.25 moles of NaCl?

   \[ M = \frac{mol}{L} = \frac{0.25 \text{ mol}}{1 \text{ L}} = 0.25 \text{M} \]

3. A 1.0M solution of HCl contains 0.5 moles of HCl. What is the volume of the solution?

   \[ M = \frac{mol}{L}; 1 \text{M} = 0.5 \frac{mol}{L}; \frac{0.5 \text{ mol}}{1 \text{M}} = L; L = 0.5 \text{L} \]

4. A 0.75M solution of H₂SO₄ fills a 0.5L beaker. How many moles of H₂SO₄ are in the solution?

   \[ M = \frac{mol}{L}; 0.75 \text{M} = \frac{mol}{0.5 \text{L}}; (0.75 \text{M})(0.5 \text{L}) = \text{mol}; 0.375 = \text{mol} \]

5. For a laboratory experiment, you are required to create a 0.25M solution of CH₃COOH. How many grams of CH₃COOH should you add to 1L of solvent to create this 0.25M solution?

   \[ M = \frac{mol}{L}; 0.25 \text{M} = \frac{mol}{1 \text{L}}; 0.25 = \text{mol} \]

   \[ g = \left( \frac{g}{\text{mol}} \right) (\text{mol}) = \left( 60.052 \frac{g}{\text{mol}} \right) (0.25 \text{mol}) = 15.013 \text{g} \]
Assessment Activity

Molarity Assessment

Part I

For each of the following questions, find the molarity of Drink mix using the Molarity simulation found at https://phet.colorado.edu/en/simulation/molarity.

1. \( V = 0.552 \text{ L} \), Solute = 0.460 mol
   
   \[ M = 0.832 \text{M} \]

2. \( V = 0.830 \text{ L} \), Solute = 0.197 mol
   
   \[ M = 0.237 \text{M} \]
3. \( V = 1.000 \text{ L}, \text{ Solute} = 1.000 \text{ mol} \)  
   \[ M = 1.326 \text{M} \]

4. \( V = 0.607 \text{ L}, \text{ Solute} = 0.806 \text{ mol} \)  
   \[ M = 5.000 \text{M} \]

5. \( V = 0.200 \text{ L}, \text{ Solute} = 1.00 \text{ mol} \)  
   \[ M = 0.605 \text{M} \]

6. \( V = 0.323 \text{ L}, \text{ Solute} = 0.195 \text{ mol} \)  
   \[ M = 1.127 \text{M} \]

7. \( V = 0.646 \text{ L}, \text{ Solute} = 0.728 \text{ mol} \)  
   \[ M = 1.127 \text{M} \]

**Part II**

For each of the following questions, calculate the missing variable. Be sure to show your work and use correct units!

8. \( M = 2.30 \text{M}, V = 0.232 \text{L}, \text{ mol} =? \)  
   \[ \text{Mol} = 0.534 \text{ mol} \]

9. \( M = ?, V = 1.42 \text{L}, \text{ mol} = 0.54 \text{ mol} \)  
   \[ M = 0.380 \text{M} \]

10. \( M = ?, V = 0.75 \text{L}, \text{ mol} = 1.3 \text{ mol} \)  
    \[ M = 1.733 \text{M} \]

11. \( M = 5.76 \text{M}, V = 0.12 \text{L}, \text{ mol} =? \)  
    \[ \text{Mol} = 0.680 \text{ mol} \]
12. \( M = 0.12\text{M}, V = ?, \text{mol} = 0.05 \text{mol} \)

\[ V = 0.416\text{L} \]

13. \( M = 0.30\text{M}, V = ?, \text{mol} = 1.23 \text{mol} \)

\[ V = 4.1\text{L} \]

14. \( M = ?, V = 0.35\text{L}, \text{mol} = 0.25 \text{mol} \)

\[ M = 0.714\text{M} \]

15. \( M = 1.23\text{M}, V = 1.2\text{L}, \text{mol} =? \)

\[ \text{Mol} = 1.476 \text{mol} \]
### Molecule Shape and Polarity

|-------------------|---------------------------------------------------------------------------------------------------------------|

### NYS Content Standards:

5.2l Molecular polarity can be determined by the shape of the molecule and distribution of charge. Symmetrical (nonpolar) molecules include CO₂, CH₄, and diatomic elements. Asymmetrical (polar) molecules include HCl, NH₃, and H₂O.

### Learning Goals:

1. Students will be able to identify the shape of a molecule based on bonding pairs and lone pairs.
2. Students will be able to determine the polarity of a molecule.

### Key Vocabulary and Concepts for Simulation:

1. **Bonding Pairs** – electrons between two atoms that form a bond between them
2. **Lone Pairs** – pair of valence electrons that are not shared with another atom
3. **Polarity** – separation of electric charge that causes a molecule to have an electric dipole moment with a negatively charged end and a positively charged end
4. **Electronegativity** – measure of the tendency of an atom to attract a bonding pair of electrons
5. **Partial Charges** – charge within a molecule created from unequal distribution of electrons due to electronegativity differences

### Stimulating Aspects of the Simulation:

1. Ability to see and manipulate a 3D model of molecular shapes
2. Ability to see and manipulate a 3D model of actual molecules
3. Ability to manipulate electronegativity of atoms to see how partial charges are effected by electronegativity
4) Ability to see partial charges of actual molecules

**Planning Considerations for Simulation:**

1) Easy to rush through

2) Heavily relies on color for full effect of simulation

**Simulation Parts Explained:**

**Screen 1: Model (Molecule Shapes)**

- Molecule
- Bonding Pairs
- Lone Pairs
- Molecule Information
- Options
- Reset Button
- Screen Selector
Screen 2: Real Molecules (Molecule Shapes)

Molecule Selector

Screen 3: Two Atoms (Molecule Polarity)

Electronegativity Options

Molecule Electronegativity

Electronegativity Control
Screen 4: Three Atoms (Molecule Polarity)
Screen 5: Real Molecules (Molecule Polarity)

**Molecule** – shows the molecule you have built, you may drag the bonds to manipulate the molecule or drag the base of the molecule (the purple sphere in the center) to rotate the entire molecule.

**Molecule Information** – shows the molecule geometry and electron geometry of the molecule you have built, if the checkboxes are both checked.

**Bonding Pairs** – allows you to add certain bond types to the molecule, you may drag up to 6 bonding or lone pairs total to the molecule, you may remove pairs by clicking on the red X to the right of the pairs, you may also click the “Remove All” button below the lone pair box.

**Lone Pairs** – allows you to add lone pairs to the molecule, you may drag up to 6 bonding or lone pairs total to the molecule, you may remove pairs by clicking on the red X to the right of the pairs, you may also click the “Remove All” button below the lone pair box.
Options – toggles between various options, you may choose to hide or show lone pairs and bond angles on the molecule

Screen Selector – selects which screen you are on

Reset Button – resets the screen to its default state as shown in the screenshots above

Molecule View – switches between a model view of the molecule and a real view of the molecule, the real view will show each separate atom as a different color, while the model view will only color the base atom in the center

Molecule Selector – selects from a variety of molecules to experiment with

Molecule Electronegativity – shows the molecule you have selected along with the electron distribution

Electronegativity Control – allows you to manipulate the electronegativity of each atom in the molecule, electrons will trend towards the atom with more electronegativity

Electronegativity Options – toggles between a variety of options for the molecule, the bond dipole and partial charges options will show which atom the electrons are trending towards and the partial charge of each atom respectively, the bond character option will show whether the molecule is more covalent or more ionic (molecules with closer electronegativity values will be more covalent), the electrostatic potential option will show clouds around the atoms which change color depending on the level of partial charge, a similar view is shown with the electron density option, the atom with the higher electronegativity will have a deeper color in accordance with having more electrons around it, the electric field option will create an electric field which will align the molecule according to the partial charges

Suggestion for Supplemental Information:

https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_A_Molecular_Approach_(Tro)/10%3A_Chemical_Bonding%2C_Molecular_Shapes%2C_Valance_Bond_Theory%2C_and_Molecular_Orbital_Theory
**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged in this activity because it gives them an opportunity to interact with the content in a low-risk setting. Students will also be able to connect some of their prior learning about atoms to the content within the simulation and see where they stand with this knowledge. Students can manipulate the different molecules to see a more accurate 3D representation of molecules than they could without a simulation.

**Explore** – Like the engage phase, students will be exploring the content on their own when interacting with the simulation.

**Activity** –

**Introduction to Molecule Shape and Polarity**

Molecules come in all different shapes and sizes. The shape is heavily influenced by the number of bonding pair electrons, electrons that form a bond between two atoms, and lone pair electrons, electrons that are part of an atom and do not create a bond with another atom. For this activity, you will be observing how these pairs effect the shape of molecules by working with the “Molecule Shape” simulation found at [https://phet.colorado.edu/en/simulation/molecule-shapes](https://phet.colorado.edu/en/simulation/molecule-shapes). Open the simulation and navigate to the “Model” screen. Use this screen to answer the following questions.

1. What is the molecule geometry of the initial molecule in the simulation? Draw and label it in the space below.

2. Add one lone pair of electrons. What is the shape now and how did it change from the initial molecule? Draw and label the molecule in the space below.
3. Add a single bonded electron pair to the molecule. What is the shape now and how did it change from the molecule in question 2? Draw and label the molecule in the space below.

4. Add another single bonded electron pair to the molecule. What is the shape now and how did it change from the molecule in question 3? Draw and label the molecule in the space below.

5. Add another lone pair of electrons. What is the shape now and how did it change from the molecule in question 2? Draw and label the molecule in the space below.

Simulation Usage in the Core Instruction Period

**Explain** – For this assignment, the explain phase is covered mainly in the introductory reading. It is suggested that the teacher read this introductory information to the class aloud and address any student questions that arise and any misconceptions students may have. Much of the information that will be needed for the full understanding of this learning segment is found here, and students will use this information throughout the remainder of the learning segment to answer various questions.

**Elaborate** – The elaborate phase of this learning segment happens when students answer the wrap-up questions at the end of this assignment. For these questions, students will be connecting what they learned in the explain phase of this assignment to the questions they will have to answer. These questions will require students to take what they learned and apply it to a new, more challenging situation.
Molecule Shape and Polarity

Valence shell electron-pair repulsion theory (VSEPR theory) enables us to predict the molecular structure, including approximate bond angles around a central atom, of a molecule from an examination of the number of bonds and lone electron pairs in its Lewis structure. The VSEPR model assumes that electron pairs in the valence shell of a central atom will adopt an arrangement that minimizes repulsions between these electron pairs by maximizing the distance between them. The electrons in the valence shell of a central atom form either bonding pairs of electrons, located primarily between bonded atoms, or lone pairs. The electrostatic repulsion of these electrons is reduced when the various regions of high electron density assume positions as far from each other as possible.

As a simple example of VSEPR theory, let us predict the structure of a gaseous BeF$_2$ molecule. The Lewis structure of BeF$_2$ shows only two electron pairs around the central beryllium atom. With two bonds and no lone pairs of electrons on the central atom, the bonds are as far apart as possible, and the electrostatic repulsion between these regions of high electron density is reduced to a minimum when they are on opposite sides of the central atom. The bond angle is 180°.
Electron positioning is also heavily influenced by the electronegativity of the atoms in a molecule. Differences in electronegativity of the atoms within a molecule cause the molecule to become polar. Electronegativity is defined as the ability of an atom in a molecule or an ion to attract electrons to itself. Thus there is a direct correlation between electronegativity and bond polarity.

A bond is nonpolar if the bonded atoms have equal electronegativity’s. If the electronegativity’s of the bonded atoms are not equal, however, the bond is polarized toward the more electronegative atom. A bond in which the electronegativity of B is greater than the electronegativity of A, for example, is indicated with the partial negative charge on the more electronegative atom:

\[ \text{A}^{\delta^-} \rightarrow \text{B}^{\delta^+} \]

These partial charges create a dipole moment. The dipole moment can be represented by writing an arrow above the molecule. This arrow shows the direction of electron flow by pointing toward the more electronegative atom.

Getting Started

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/molecule-shapes](https://phet.colorado.edu/en/simulation/molecule-shapes).
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Molecule Shapes” simulation.

**Molecule Shapes**

1. Navigate to the “Model” screen.

2. Check the “Molecule Geometry” and “Show Bond Angles” boxes.

3. Use this screen to help you fill in the table below, the first has been done for you.

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Bonding Pairs</th>
<th>Lone Pairs</th>
<th>Bond Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>2</td>
<td>0</td>
<td>180</td>
</tr>
</tbody>
</table>

**CiQ 1:** Is it possible to have the same molecular geometry with different numbers of lone pairs and bonding pairs of electrons?
Molecule Polarity


2. Navigate to the “Two Atoms” screen.

3. Where does the dipole moment point initially?

4. Set the electronegativity of both atoms to the far left of the slider. What happens?

5. Set the electronegativity of both atoms to the far right of the slider. What happens?

6. Decrease the electronegativity of atom B. What happens?

7. Switch to the “Three Atoms” screen.

8. Where does the dipole moment point initially?

9. Increase the electronegativity of atom A. What happens?

10. Increase the electronegativity of atom B. What happens?

Wrap-Up Questions

1. Draw a Linear molecule.
2. Draw a T-Shaped molecule.

3. Draw a Seesaw shaped molecule.

4. Draw a Bent molecule.

5. Draw a tetrahedral molecule.

6. Where would the dipole moment point in an HF molecule?

7. Where would the dipole moment point in an NH$_3$ molecule?

8. Where would the dipole moment point in an H$_2$O molecule?

9. Where would the dipole moment point in a CH$_4$ molecule?

10. Where would the dipole moment point in an HCl molecule?

---

**Simulation Usage as an Expansionary Assessment**

**Evaluate** – The activity for this section will assess students’ knowledge of both the simulation itself and the content within the simulation. Students will be required to take what they have learned in the core instruction period and use it to complete the questions related to the simulation and answer the pencil and paper questions found in this activity.
Activity –

**Molecule Shape and Polarity Assessment**

**Part I**

**Directions:** Use the “Real Molecules” screen of the “Molecule Shapes” simulation found at [https://phet.colorado.edu/en/simulation/molecule-shapes](https://phet.colorado.edu/en/simulation/molecule-shapes) to fill in the following table.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Geometry</th>
<th>Bonding Pairs</th>
<th>Lone Pairs</th>
<th>Bond Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XeF₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ClF₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₃</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF₄</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>XeF₄</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BrF₅</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCl₅</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF₆</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part II**
**Directions:** Use the “Real Molecules” screen of the “Molecule Polarity” simulation found at [https://phet.colorado.edu/en/simulation/molecule-polarity](https://phet.colorado.edu/en/simulation/molecule-polarity) to fill in the following table. The first one has been done for you.

<table>
<thead>
<tr>
<th>Name</th>
<th>Atom Dipole Moment Points Towards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Fluoride</td>
<td>Fluorine</td>
</tr>
</tbody>
</table>
Activity Guide

Preliminary Activity

Introduction to Molecule Shape and Polarity

Molecules come in all different shapes and sizes. The shape is heavily influenced by the number of bonding pair electrons, electrons that form a bond between two atoms, and lone pair electrons, electrons that are part of an atom and do not create a bond with another atom. For this activity, you will be observing how these pairs effect the shape of molecules by working with the “Molecule Shape” simulation found at https://phet.colorado.edu/en/simulation/molecule-shapes. Open the simulation and navigate to the “Model” screen. Use this screen to answer the following questions.

1. What is the molecule geometry of the initial molecule in the simulation? Draw and label it in the space below.
2. Add one lone pair of electrons. What is the shape now and how did it change from the initial molecule? Draw and label the molecule in the space below.

3. Add a single bonded electron pair to the molecule. What is the shape now and how did it change from the molecule in question 2? Draw and label the molecule in the space below.
4. Add another single bonded electron pair to the molecule. What is the shape now and how did it change from the molecule in question 3? Draw and label the molecule in the space below.

5. Add another lone pair of electrons. What is the shape now and how did it change from the molecule in question 2? Draw and label the molecule in the space below.
**Core Activity**

**Molecule Shape and Polarity**

Valence shell electron-pair repulsion theory (VSEPR theory) enables us to predict the molecular structure, including approximate bond angles around a central atom, of a molecule from an examination of the number of bonds and lone electron pairs in its Lewis structure. The VSEPR model assumes that electron pairs in the valence shell of a central atom will adopt an arrangement that minimizes repulsions between these electron pairs by maximizing the distance between them. The electrons in the valence shell of a central atom form either bonding pairs of electrons, located primarily between bonded atoms, or lone pairs. The electrostatic repulsion of these electrons is reduced when the various regions of high electron density assume positions as far from each other as possible.

As a simple example of VSEPR theory, let us predict the structure of a gaseous BeF$_2$ molecule. The Lewis structure of BeF$_2$ shows only two electron pairs around the central beryllium atom. With two bonds and no lone pairs of electrons on the central atom, the bonds are as far apart as possible, and the electrostatic repulsion between these regions of high electron density is reduced to a minimum when they are on opposite sides of the central atom. The bond angle is 180°.

![BeF2 molecule diagram]

Electron positioning is also heavily influenced by the electronegativity of the atoms in a molecule. Differences in electronegativity’s of the atoms within a molecule cause the molecule to become polar. Electronegativity is defined...
as the ability of an atom in a molecule or an ion to attract electrons to itself. Thus there is a direct correlation between electronegativity and bond polarity.

A bond is nonpolar if the bonded atoms have equal electronegativity’s. If the electronegativity’s of the bonded atoms are not equal, however, the bond is polarized toward the more electronegative atom. A bond in which the electronegativity of B is greater than the electronegativity of A, for example, is indicated with the partial negative charge on the more electronegative atom:

Aδ⁺→ Bδ⁻

These partial charges create a dipole moment. The dipole moment can be represented by writing an arrow above the molecule. This arrow shows the direction of electron flow by pointing toward the more electronegative atom.

Getting Started

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/molecule-shapes.
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.
4. Start the “Molecule Shapes” simulation.

Molecule Shapes

1. Navigate to the “Model” screen.
2. Check the “Molecule Geometry” and “Show Bond Angles” boxes.

3. Use this screen to help you fill in the table below, the first has been done for you.

For this section of the activity, you simply need to add bond pairs of electrons and lone pairs of electrons and see how adding these electrons effect the geometry of the molecule and the bond angles within it. For this example, you can see that it is named as linear in the bottom of the screen and the bond angle is shown on the molecule itself at 180°.

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Bonding Pairs</th>
<th>Lone Pairs</th>
<th>Bond Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>2</td>
<td>0</td>
<td>180</td>
</tr>
<tr>
<td>Trigonal Planar</td>
<td>3</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>Tetrahedral</td>
<td>4</td>
<td>0</td>
<td>109.5</td>
</tr>
<tr>
<td>Trigonal Bipyramidal</td>
<td>5</td>
<td>0</td>
<td>90, 120</td>
</tr>
<tr>
<td>Octahedral</td>
<td>6</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Bent</td>
<td>2</td>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>Trigonal Pyramidal</td>
<td>3</td>
<td>1</td>
<td>109.5</td>
</tr>
<tr>
<td>Molecule</td>
<td>#Bonding Pairs</td>
<td>#Lone Pairs</td>
<td>Bonding Angle</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------</td>
<td>-------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Seesaw</td>
<td>4</td>
<td>1</td>
<td>90, 120</td>
</tr>
<tr>
<td>Square Pyramidal</td>
<td>5</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td>T-Shaped</td>
<td>3</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>Square Planar</td>
<td>5</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>T-Shaped</td>
<td>3</td>
<td>3</td>
<td>90</td>
</tr>
</tbody>
</table>

**CiQ 1:** Is it possible to have the same molecular geometry with different numbers of lone pairs and bonding pairs of electrons?

Yes, multiple options but check T-shaped in the table above

**Molecule Polarity**


2. Navigate to the “Two Atoms” screen.
This section deals solely with manipulating the electronegativity of the atoms in the molecule and observing how the dipole moment changes as you do so. To change electronegativity, simply drag the slider to the left to decrease it and to the right to increase it for each atom respectively. The dipole moment is shown as an arrow above the molecule and points towards the more electronegative atom, in this case, the more electronegative atom is B, but this will change as you manipulate the electronegativity throughout the questions.

3. Where does the dipole moment point initially?
   
   Towards B

4. Set the electronegativity of both atoms to the far left of the slider. What happens?
   
   No dipole moment, electronegativity’s are equal

5. Set the electronegativity of both atoms to the far right of the slider. What happens?
   
   No dipole moment, electronegativity’s are equal

6. Decrease the electronegativity of atom B. What happens?
   
   Dipole moment points towards A, the bigger difference in EN the larger the arrow
7. Switch to the “Three Atoms” screen.

8. Where does the dipole moment point initially?

   **Straight up from B**

9. Increase the electronegativity of atom A. What happens?

   **Arrow begins to rotate down towards A, sticks straight out to the left from B if A has max EN**

10. Increase the electronegativity of atom B. What happens?

   **Arrow is pulled back up towards B, arrow sticks out from B in line with the bond to C if B has max EN**

**Wrap-Up Questions**

1. Draw a Linear molecule.

   ![Linear molecule](image1)

2. Draw a T-Shaped molecule.

   ![T-shaped molecule](image2)
3. Draw a Seesaw shaped molecule.

4. Draw a Bent molecule.
5. Draw a tetrahedral molecule.

6. Where would the dipole moment point in an HF molecule?
   \[ \text{F} \]

7. Where would the dipole moment point in an NH\(_3\) molecule?
   \[ \text{N} \]

8. Where would the dipole moment point in an H\(_2\)O molecule?
   \[ \text{O} \]

9. Where would the dipole moment point in a CH\(_4\) molecule?
   \[ \text{C} \]

10. Where would the dipole moment point in an HCl molecule?
    \[ \text{Cl} \]
Assessment Activity

Molecule Shape and Polarity Assessment

Part I

Directions: Use the “Real Molecules” screen of the “Molecule Shapes” simulation found at https://phet.colorado.edu/en/simulation/molecule-shapes to fill in the following table.

For this section, you will simply need to switch the molecule and record the important information provided. Ensure that the molecule geometry, lone pair, and bond angles boxes are all checked and that the Real option is selected. Then record the molecule geometry from the bottom of the screen, the number of lone pairs and bonding pairs off the molecule itself and the bond angle shown underneath the molecule. In this case, the H₂O atom is bent, with 2 bonding pairs, 2 lone pairs and a bond angle of 104.5°.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Geometry</th>
<th>Bonding Pairs</th>
<th>Lone Pairs</th>
<th>Bond Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>Bent</td>
<td>2</td>
<td>2</td>
<td>104.5°</td>
</tr>
<tr>
<td>CO₂</td>
<td>Linear</td>
<td>2</td>
<td>0</td>
<td>180</td>
</tr>
<tr>
<td>SO₂</td>
<td>Bent</td>
<td>4</td>
<td>1</td>
<td>119</td>
</tr>
<tr>
<td>Molecule</td>
<td>Shape</td>
<td>Bonds</td>
<td>Lone Pairs</td>
<td>Angle</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>-------</td>
<td>------------</td>
<td>--------</td>
</tr>
<tr>
<td>XeF₂</td>
<td>Linear</td>
<td>2</td>
<td>3</td>
<td>180</td>
</tr>
<tr>
<td>BF₃</td>
<td>Trigonal Planar</td>
<td>3</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>ClF₃</td>
<td>T-Shaped</td>
<td>3</td>
<td>2</td>
<td>87.5</td>
</tr>
<tr>
<td>NH₃</td>
<td>Trigonal Pyramidal</td>
<td>3</td>
<td>1</td>
<td>107.8</td>
</tr>
<tr>
<td>CH₄</td>
<td>Tetrahedral</td>
<td>4</td>
<td>0</td>
<td>109.5</td>
</tr>
<tr>
<td>SF₄</td>
<td>Seesaw</td>
<td>4</td>
<td>1</td>
<td>87.8</td>
</tr>
<tr>
<td>XeF₄</td>
<td>Square Planar</td>
<td>4</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>BrF₅</td>
<td>Square Pyramidal</td>
<td>5</td>
<td>1</td>
<td>84.8</td>
</tr>
<tr>
<td>PCl₅</td>
<td>Trigonal Bipyramidal</td>
<td>5</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>SF₆</td>
<td>Octahedral</td>
<td>6</td>
<td>0</td>
<td>90</td>
</tr>
</tbody>
</table>

**Part II**

**Directions:** Use the “Real Molecules” screen of the “Molecule Polarity” simulation found at [https://phet.colorado.edu/en/simulation/molecule-polarity](https://phet.colorado.edu/en/simulation/molecule-polarity) to fill in the following table. The first one has been done for you.
There are a number of different options to determine which direction the dipole moment arrow points towards but the easiest is simply checking the “Bond Dipoles” box. Whichever way the arrow for this option points is the answer to the table. In this case, the arrow points towards the F atom, so the F atom is the more electronegative and the dipole moment happens towards the F.

<table>
<thead>
<tr>
<th>Name</th>
<th>Atom Dipole Moment Points Towards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>Neither</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Neither</td>
</tr>
<tr>
<td>Oxygen</td>
<td>Neither</td>
</tr>
<tr>
<td>Fluorine</td>
<td>Neither</td>
</tr>
<tr>
<td>Hydrogen Fluoride</td>
<td>Fluorine</td>
</tr>
<tr>
<td>Water</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Compound</td>
<td>Element</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Hydrogen Cyanide</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Ozone</td>
<td>None</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Borane</td>
<td>Boron</td>
</tr>
<tr>
<td>Boron Trifluoride</td>
<td>Fluorine</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Methane</td>
<td>Carbon</td>
</tr>
<tr>
<td>Fluoromethane</td>
<td>Fluorine</td>
</tr>
<tr>
<td>Difluoromethane</td>
<td>Fluorine</td>
</tr>
<tr>
<td>Trifluoromethane</td>
<td>Fluorine</td>
</tr>
<tr>
<td>Tetrafluoromethane</td>
<td>Fluorine</td>
</tr>
<tr>
<td>Chloroform</td>
<td>Chlorine</td>
</tr>
</tbody>
</table>
pH

<table>
<thead>
<tr>
<th>pH Scale</th>
</tr>
</thead>
</table>

Simulation Link: [https://phet.colorado.edu/en/simulation/ph-scale](https://phet.colorado.edu/en/simulation/ph-scale)

NYS Content Standards:

3.1ss: The acidity or alkalinity of an aqueous solution can be measured by its pH value.

Learning Goals:

1) Students will be able to define acid and base in terms of pH value.

2) Students will be able to predict what the proportion of H⁺: OH⁻ is for a solution based on pH value.

3) Students will be able to use a simulation to examine and predict phenomena about pH and concentration of H⁺ and OH⁻

Key Vocabulary and Concepts for Simulation:

1) **pH** – measure of hydrogen ion concentration, ranges from 0 to 14, values < 7 are acidic, >7 are basic, 7 is neutral

2) **Acidity** – the percentage of H⁺ ions in a solution

3) **Concentration** – amount of substance in a defined space, usually mass per unit volume

4) **Molarity** – type of concentration, moles of solute per liter of solution

5) **Dilution** – decreasing the concentration of a solute, usually done by adding more solvent

6) **H₃O⁺/OH⁻** - two ions formed by water in solution, solutions with more H₃O⁺ are more acidic, more OH⁻ are more basic

Stimulating Aspects of Simulation:

1) Great way for students to explore pH without dealing with actual chemicals

2) Wide variety of solutions allows for greater connections to be made with the real world

3) Allows students to see the H₃O⁺ and OH⁻ molecules and create a visual connection with the content
4) Complex features can be toggled to cater to a range of academic ability

**Planning Considerations for Simulation:**

1) Relies heavily on use of color and has small components, limiting students with visual impairments

2) Requires a fairly large amount of background knowledge for full comprehension of content

**Simulation Parts Explained:**

**Screen 1: Macro**
Screen 2: Micro

- Unit Slider
- pH value
- Ion Indicator
- Type of Scale
- Molecule Options

The pH value is 5.80, indicating a slightly acidic solution.
Screen 3: My Solution

**pH Scale** – a visual representation of the pH of the solution, also indicates whether pH values are acidic or basic

**pH Probe** – tool used to measure the pH value of the solution, must be dragged into the solution for a reading to be obtained

**Solution Selector** – drop down menu that allows the user to pick between a variety of solutions of varying pH values

**Drain** – used to remove some of the solution, the blue knob must be pulled in order for the solution to begin draining

**Pipet** – used to add some of the chosen solution

**Screen Selector** – used to switch between the screens at any point

**Water Faucet** – used to add water, the blue knob must be pulled for the water to be added

**Volume Indicator** – shows the volume of solution in the container

**Reset Button** – used to reset the screen to its default
**Unit Slider** – used to change what the displayed value is, either molarity or moles

**Type of Scale** – used to change between a linear or logarithmic scale

**pH value** – shows the pH value of the current solution in the container

**Molecule Options** - choose whether to show the molecules in the container and whether to show the ratio of ions in the container

**Suggestions for Supplemental Material:**

https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Acids_and_Bases

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**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged in this activity because it gives students an opportunity to see and interact with the pH scale along with different solutions in a safe environment and connects their prior knowledge to what they will be learning in this learning segment. The activity is fully student centered and informal, giving students a low-risk means of experiencing the content. It may also be useful for the teacher to use data collected from this activity to tailor this learning segment to their classes. Students can add a variety of different solutions in different volumes and see how pH is affected.

**Explore** – This activity allows students to explore both the basic concepts of pH and the simulation on their own with little prompting on instruction on the part of the teacher. The simulation is a hands-on digital representation of the content and allows students to experiment with concentration and different solutions.

**Activity:**

**Introduction to the pH Scale**

The pH scale is a useful tool for determining the acidity or basicity of a solution. It ranges from 0-14, with lower numbers being more acidic and higher numbers being more basic. A pH of 7 is considered neutral on the pH
scale. For this introductory assignment, you will spend a few minutes playing around with a simulation found at https://phet.colorado.edu/en/simulation/ph-scale.

1. Download and open the pH Scale simulation.
2. Click on the button labeled “Macro.”
3. Drag the green cursor into the beaker.
4. Add different types of solutions and different amounts of water to the beaker and observe how the pH changes.

**CiQ 1:** Do you notice anything about the pH when you add more water? What about when you add more solution?

**CiQ 2:** Do you notice anything about the type of solutions that are basic and the type of solutions that are acidic?

Think about them in terms of how the solution is used in the real world.

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**Simulation Usage in Core Instruction**

**Explain** – In the explain phase, students learn more about the content they explored previously in a more formal manner. The key concept for this learning segment, pH, is explained in an in-depth manner in the introductory section of this activity. It is advised that the teacher read this section aloud to students and answer any questions students may have about pH before they delve more deeply into the content. Students will also learn how a pH value is found.

**Elaborate** – In the elaborate phase, students continue to practice working with the concept of pH and acidity and basicity and expand upon these ideas by relating them to their real world experiences.
Simulating pH

The pH scale is a scale used to specify how acidic or basic a water-based solution is. This scale runs from 1-14, with acidic solutions having lower pH values and basic solutions having higher pH values. Water is typically associated with being neutral on the scale with a pH of 7. What a pH value really indicates is the concentration of an ion called hydronium in the solution. This ion is typically written as $H_3O^+$ but can also be written as simply $H^+$. The more hydronium ions that are found in a solution, the more acidic it is. Because of this, the lower the pH value of something is, the higher it’s concentration of hydronium ions is. To calculate a pH value, you should take the negative log of the concentration of this ion or, in equation form, $pH = -\log ([H_3O^+])$. The pH scale is logarithmic, meaning that a solution with a pH value that is 1 lower than another solution will have 10 times the concentration of hydronium ion! This is true throughout the scale. For example, a solution with a pH of 5 will have 100 times the concentration of hydronium ion as a solution with a pH of 7 will and a solution with a pH of 3 will have 100 times the concentration of hydronium ion as a solution with a pH of 5 and 10,000 times the concentration of hydronium ion as a solution with a pH of 7! To get a better idea of pH and how it is effected by the concentration of hydronium ion in solution, we will look at a simulation.

Getting Started

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/ph-scale
3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and it will open in the web browser.
4. Start with the “Macro” section by clicking in the middle of the box.

**Macro**

1. Start by dragging the green cursor at the bottom of the pH scale into the liquid that is shown in the box that looks like a beaker. For chicken soup, you should see an indication that the pH is 5.80.

2. You will repeat this for each solution that you can select from the top drop down menu of the simulation. You will only need to click on the solution from the drop down menu and then drag the cursor over. **Do not press anything else.**

3. Fill out the following table with the pH values you find for each solution. Also be sure to record whether you think it is acidic, basic or neutral in the far right column. Be sure to answer the check in question after the table!

<table>
<thead>
<tr>
<th>Solution</th>
<th>pH Value</th>
<th>Acidic/Basic/Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain Cleaner</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand Soap</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spit</td>
<td></td>
<td></td>
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<tr>
<td>Milk</td>
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<td></td>
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<tr>
<td>Chicken Soup</td>
<td></td>
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<tr>
<td>Coffee</td>
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<td></td>
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<tr>
<td>Orange Juice</td>
<td></td>
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<tr>
<td>Soda Pop</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vomit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery Acid</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**CiQ 1:** Do you notice anything in common with the solutions that you labeled acidic? Anything in common with the basic solutions?

4. Now select one of the basic solutions. You may add more of the solution into the container by clicking on the button on top of the pipet and remove solution by pulling out the blue nozzle of the bottom faucet. Experiment with different volumes of solution and observe their pH and then answer the following check-in question.

**CiQ 2:** Does adjusting the volume of solution affect its pH? Why do you think this is the case?

5. Now, select the same solution you used in step 4. Reset your volume to 0.50L by clicking on the orange reset button to the bottom right of the beaker. You can add more water to the solution by pulling the grey nozzle of the top faucet. Do so now and answer the next check-in question.

**CiQ 3:** What happened to the pH value when you added more water to your basic solution? Why do you think this happened?

6. Follow the same procedure as in steps 4 and 5 for an acidic solution and then answer the following question.

**CiQ 4:** Did you observe the same results for an acidic solution as you did for a basic solution? What were the similarities and/or differences?

**Micro**

1. Switch over to the “Micro” section of the simulation by pressing the “Micro” icon at the bottom of the screen. You will notice that you have the same selection of solutions available to you as in the “Macro” section, however you no longer need to drag the cursor into the beaker, as the pH is always shown to you at the top of
the screen. If you cannot see a number for your pH value, click the orange plus sign in the top right of the pH box.

2. Fill out the following table like you did in step 3. Take note of the new, rightmost column. You can determine the concentration of each of the molecules by looking at the scale to the left of the beaker or the quantity of the molecules can also be found by checking the box next to “Molecule count” near the bottom of the screen. Once you finish filling out the table, answer the next check-in question.

<table>
<thead>
<tr>
<th>Solution</th>
<th>pH Value</th>
<th>Acidic/Basic/Neutral</th>
<th>More H$_3$O$^+$ or OH$^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain Cleaner</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Hand Soap</td>
<td></td>
<td></td>
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<tr>
<td>Blood</td>
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<td>Spit</td>
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<td>Milk</td>
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<tr>
<td>Chicken Soup</td>
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<td>Coffee</td>
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<tr>
<td>Orange Juice</td>
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<td>Soda Pop</td>
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<td></td>
</tr>
<tr>
<td>Vomit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Battery Acid</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**CiQ 5:** Do you notice any similarities between the solutions you labeled acids? Are there any similarities between the solutions you labeled bases?

3. Select an acidic solution and adjust its volume like you did in step 4. Do the same for a basic solution.
CiQ 6: What happened to the amount of molecules that were in the solution when you added more solution? Did the pH change?

4. Add more water to your beaker like you did in step 5.

CiQ 7: What happened to the amount of molecules when you added more water to the acidic solution? Be sure to pay attention to the ratio of molecules and its relation to pH!!!

Wrap Up Questions

1. Which of the following would be the likely pH value for acetic acid?
   a. 14.5
   b. 7.0
   c. 10.7
   d. 2.4

2. Which of the following would be the likely pH value for a cleaning solution such as Windex?
   a. 14.5
   b. 7.0
   c. 10.7
   d. 2.4

3. Which of the following would be the likely pH value for water?
   a. 14.5
   b. 7.0
   c. 10.7
   d. 2.4
4. You are required to add sulfuric acid to a battery you just bought for your car. You decide to test the pH value of the solution and find it to be 10.4. Does this value make sense? Why or why not?

5. Which of the following statements is true for **basic** solutions?
   a. \([H^+] > [OH^-]\)
   b. \([H^+] < [OH^-]\)
   c. \([H^+] = [OH^-]\)

6. Which of the following statements is true for **neutral** solutions?
   a. \([H^+] > [OH^-]\)
   b. \([H^+] < [OH^-]\)
   c. \([H^+] = [OH^-]\)

7. Which of the following statements is true for **acidic** solutions?
   a. \([H^+] > [OH^-]\)
   b. \([H^+] < [OH^-]\)
   c. \([H^+] = [OH^-]\)

8. What does the value of pH actually mean?

9. What are some common acids and bases? List at least 3 of each.

10. What are three things you know about acids, bases and pH?
Simulation Usage as an Expansionary Assessment

Evaluate – In the evaluate phase, students put what they have learned in the previous phases into action. For the purposes of this activity, students are using what they have learned about pH and the relationship between pH, the concentration of OH\(^-\) and the concentration of H\(_3\)O\(^+\) in a solution, as well as how to use the simulation itself to answer a variety of questions.

Activity –

pH Assessment

Directions: For this assignment, you will be working with the pH simulation found at [https://phet.colorado.edu/en/simulation/ph-scale](https://phet.colorado.edu/en/simulation/ph-scale). Download and open the simulation before you start. You will be working exclusively with the “My Solution” section. Use the simulation to help you answer the following questions.

1. Make a neutral pH and find the following values.
   a. pH:_____
   b. Concentration of OH\(^-\):_____
   c. Concentration of H\(_3\)O\(^+\):_____
   d. Quantity of OH\(^-\) Molecules:_____
   e. Quantity of H\(_3\)O\(^+\) Molecules:_____

2. Make an acidic pH and find the following values.
   a. pH:_____
   b. Concentration of OH\(^-\):_____
   c. Concentration of H\(_3\)O\(^+\):_____
   d. Quantity of OH\(^-\) Molecules:_____
   e. Quantity of H\(_3\)O\(^+\) Molecules:_____


3. Make a basic pH and find the following values.
   a. pH:_____
   b. Concentration of OH\(^-\):_____
   c. Concentration of H\(_3\)O\(^+\):_____
   d. Quantity of OH\(^-\) Molecules:_____
   e. Quantity of H\(_3\)O\(^+\) Molecules:_____

4. What would the pH value be of a solution with 1.79 \times 10^{22} \text{ molecules of OH}^-? 

5. What would the pH value be of a solution with an H\(_3\)O\(^+\) concentration of 7.2 \times 10^{-4} \text{ mol/L}? 

6. Tomato juice has a pH of 4.00. What would the concentration of OH\(^-\) be in a solution of 0.50L tomato juice? 

7. Eggs have a pH of 8.00. What would the concentration of H\(_3\)O\(^+\) be in a solution of 0.50L eggs? 

8. Would you expect the concentration of OH\(^-\) to be higher or lower than the concentration of H\(_3\)O\(^+\) in a basic solution? 

9. Would you expect the number of OH\(^-\) molecules to be higher or lower than the number of H\(_3\)O\(^+\) molecules in a basic solution? 

10. Use the internet to find a solution of your choice and answer the following questions.
    a. pH:_____
    b. Concentration of OH\(^-\):_____

Activity Guide

Preliminary Activity

Introduction to the pH Scale

The pH scale is a useful tool for determining the acidity or basicity of a solution. It ranges from 0-14, with lower numbers being more acidic and higher numbers being more basic. A pH of 7 is considered neutral on the pH scale. For this introductory assignment, you will spend a few minutes playing around with a simulation found at https://phet.colorado.edu/en/simulation/ph-scale.

1. Download and open the pH Scale simulation.
2. Click on the button labeled “Macro.”
3. Drag the green cursor into the beaker.
4. Add different types of solutions and different amounts of water to the beaker and observe how the pH changes.

CiQ 1: Do you notice anything about the pH when you add more water? What about when you add more solution?

Adding more water to a basic solution lowers pH, adding water to an acidic solution raises pH, goes towards a pH of 7.

Adding more of a basic solution raises pH, more of an acidic solution lowers pH, get farther from a pH of 7

CiQ 2: Do you notice anything about the type of solutions that are basic and the type of solutions that are acidic?

Think about them in terms of how the solution is used in the real world.

c. Concentration of H₃O⁺:______
d. Quantity of OH⁻ Molecules:______
e. Quantity of H₃O⁺ Molecules:______
Core Activity

Simulating pH

The pH scale is a scale used to specify how acidic or basic a water-based solution is. This scale runs from 1-14, with acidic solutions having lower pH values and basic solutions having higher pH values. Water is typically associated with being neutral on the scale with a pH of 7. What a pH value really indicates is the concentration of an ion called hydronium in the solution. This ion is typically written as $\text{H}_3\text{O}^+$ but can also be written as simply $\text{H}^+$. The more hydronium ions that are found in a solution, the more acidic it is. Because of this, the lower the pH value of something is, the higher it’s concentration of hydronium ions is. To calculate a pH value, you should take the negative log of the concentration of this ion or, in equation form, \( \text{pH} = -\log ([\text{H}_3\text{O}^+]) \). The pH scale is logarithmic, meaning that a solution with a pH value that is 1 lower than another solution will have 10 times the concentration of hydronium ion! This is true throughout the scale. For example, a solution with a pH of 5 will have 100 times the concentration of hydronium ion as a solution with a pH of 7 will and a solution with a pH of 3 will have 100 times the concentration of hydronium ion as a solution with a pH of 5 and 10,000 times the concentration of hydronium ion as a solution with a pH of 7! To get a better idea of pH and how it is effected by the concentration of hydronium ion in solution, we will look at a simulation.

Getting Started

1. Log into a computer and open up Google Chrome.
2. Type the following address into the address bar: https://phet.colorado.edu/en/simulation/ph-scale
3. You may either download the simulation and open in from the Download section of the files on your computer or simply press the play button and it will open in the web browser.
4. Start with the “Macro” section by clicking in the middle of the box.

**Macro**

1. Start by dragging the green cursor at the bottom of the pH scale into the “liquid” that is shown in the box that looks like a beaker. For chicken soup, you should see an indication that the pH is 5.80.

2. You will repeat this for each solution that you can select from the top drop down menu of the simulation. You will only need to click on the solution from the drop down menu and then drag the cursor over. Do not press anything else.

For this section of the activity, you need to drag the green pH probe into the solution as shown. To select your solution, click on the drop down menu at the top of the screen. It will then show you the pH value of this solution in the green box labeled “pH.” In this case, the drain cleaner was selected and the pH was determined to be 13.00, indicating that it is basic as it is a value above 7. Repeat for each solution.

3. Fill out the following table with the pH values you find for each solution. Also be sure to record whether you think it is acidic, basic or neutral in the far right column. Be sure to answer the check in question after the table!

<table>
<thead>
<tr>
<th>Solution</th>
<th>pH Value</th>
<th>Acidic/Basic/Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain Cleaner</td>
<td>13.00</td>
<td>Basic</td>
</tr>
<tr>
<td>Hand Soap</td>
<td>10.00</td>
<td>Basic</td>
</tr>
<tr>
<td>------------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Blood</td>
<td>7.40</td>
<td>Basic</td>
</tr>
<tr>
<td>Spit</td>
<td>7.40</td>
<td>Basic</td>
</tr>
<tr>
<td>Milk</td>
<td>6.50</td>
<td>Acidic</td>
</tr>
<tr>
<td>Chicken Soup</td>
<td>5.80</td>
<td>Acidic</td>
</tr>
<tr>
<td>Coffee</td>
<td>5.00</td>
<td>Acidic</td>
</tr>
<tr>
<td>Orange Juice</td>
<td>3.50</td>
<td>Acidic</td>
</tr>
<tr>
<td>Soda Pop</td>
<td>2.50</td>
<td>Acidic</td>
</tr>
<tr>
<td>Vomit</td>
<td>2.00</td>
<td>Acidic</td>
</tr>
<tr>
<td>Battery Acid</td>
<td>1.00</td>
<td>Acidic</td>
</tr>
</tbody>
</table>

**CiQ 1:** Do you notice anything in common with the solutions that you labeled acidic? Anything in common with the basic solutions?

Basic solutions: cleaning supplies and bodily fluids; Acidic solutions: drinks, stomach acid for breaking down food, battery supply

4. Now select one of the basic solutions. You may add more of the solution into the container by clicking on the button on top of the pipet and remove solution by pulling out the blue nozzle of the bottom faucet.

Experiment with different volumes of solution and observe their pH and then answer the following check-in question.

**CiQ 2:** Does adjusting the volume of solution affect its pH? Why do you think this is the case?

No, you are adding more of the same, no change in concentration

5. Now, select the same solution you used in step 4. Reset your volume to 0.50L by clicking on the orange reset button to the bottom right of the beaker. You can add more water to the solution by pulling the grey nozzle of the top faucet. Do so now and answer the next check-in question.
CiQ 3: What happened to the pH value when you added more water to your basic solution? Why do you think this happened?

Adding more water to a basic solution lowers pH, adding water to an acidic solution raises pH, goes towards a pH of 7.

Adding more of a basic solution raises pH, more of an acidic solution lowers pH, get farther from a pH of 7.

6. Follow the same procedure as in steps 4 and 5 for an acidic solution and then answer the following question.

CiQ 4: Did you observe the same results for an acidic solution as you did for a basic solution? What were the similarities and/or differences?

Adding more water to a basic solution lowers pH, adding water to an acidic solution raises pH, goes towards a pH of 7.

Adding more of a basic solution raises pH, more of an acidic solution lowers pH, get farther from a pH of 7.

Micro

1. Switch over to the “Micro” section of the simulation by pressing the “Micro” icon at the bottom of the screen.

You will notice that you have the same selection of solutions available to you as in the “Macro” section, however you no longer need to drag the cursor into the beaker, as the pH is always shown to you at the top of the screen. If you cannot see a number for your pH value, click the orange plus sign in the top right of the pH box.
Fill out the following table like you did in step 3. Take note of the new, rightmost column. You can determine the concentration of each of the molecules by looking at the scale to the left of the beaker or the quantity of the molecules can also be found by checking the box next to “Molecule count” near the bottom of the screen. Once you finish filling out the table, answer the next check-in question.

<table>
<thead>
<tr>
<th>Solution</th>
<th>pH Value</th>
<th>Acidic/Basic/Neutral</th>
<th>More H₃O⁺ or OH⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain Cleaner</td>
<td>13.00</td>
<td>Basic</td>
<td>OH⁻</td>
</tr>
<tr>
<td>Hand Soap</td>
<td>10.00</td>
<td>Basic</td>
<td>OH⁻</td>
</tr>
<tr>
<td>Blood</td>
<td>7.40</td>
<td>Basic</td>
<td>OH⁻</td>
</tr>
<tr>
<td>Spit</td>
<td>7.40</td>
<td>Basic</td>
<td>OH⁻</td>
</tr>
<tr>
<td>Milk</td>
<td>6.50</td>
<td>Acidic</td>
<td>H₃O⁺</td>
</tr>
<tr>
<td></td>
<td>pH</td>
<td></td>
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</tr>
<tr>
<td>----------------</td>
<td>------</td>
<td>----</td>
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</tr>
<tr>
<td>Chicken Soup</td>
<td>5.80</td>
<td>Acidic</td>
<td>H₃O⁺</td>
</tr>
<tr>
<td>Coffee</td>
<td>5.00</td>
<td>Acidic</td>
<td>H₃O⁺</td>
</tr>
<tr>
<td>Orange Juice</td>
<td>3.50</td>
<td>Acidic</td>
<td>H₃O⁺</td>
</tr>
<tr>
<td>Soda Pop</td>
<td>2.50</td>
<td>Acidic</td>
<td>H₃O⁺</td>
</tr>
<tr>
<td>Vomit</td>
<td>2.00</td>
<td>Acidic</td>
<td>H₃O⁺</td>
</tr>
<tr>
<td>Battery Acid</td>
<td>1.00</td>
<td>Acidic</td>
<td>H₃O⁺</td>
</tr>
</tbody>
</table>

CiQ 5: Do you notice any similarities between the solutions you labeled acids? Are there any similarities between the solutions you labeled bases?

Acids – lower pH, more H₃O⁺

2. Select an acidic solution and adjust its volume like you did in step 4. Do the same for a basic solution.

Notice that when the volume of the acid is increased, the molecule count of all three molecules increases accordingly, but the concentration on the scale remains constant. This is because the molecular ratio remains constant, as no new solution is added.

CiQ 6: What happened to the amount of molecules that were in the solution when you added more solution? Did the pH change?
3. Add more water to your beaker like you did in step 5.

Like before, add more water to the solution by pulling the blue knob at the top right corner. Notice now that the quantities of molecules as well as the concentration of molecules has changed. Because more water was added, the solution became more dilute and so the concentrations of $\text{H}_3\text{O}^+$ and $\text{OH}^-$ decreased. The solution also became more basic, as indicated by the increased pH and the increased quantity of $\text{OH}^-$ molecules in solution, as well as the decreased quantity of $\text{H}_3\text{O}^+$ molecules.

**CiQ 7:** What happened to the amount of molecules when you added more water to the acidic solution? Be sure to pay attention to the ratio of molecules and its relation to pH!!!

More molecules, pH increases and more OH$^-$ molecules

**Wrap Up Questions**

1. Which of the following would be the likely pH value for acetic acid?
   a. 14.5
   b. 7.0
   c. 10.7
   d. 2.4
2. Which of the following would be the likely pH value for a cleaning solution such as Windex?
   a. 14.5
   b. 7.0
   c. 10.7
   d. 2.4

3. Which of the following would be the likely pH value for water?
   a. 14.5
   b. 7.0
   c. 10.7
   d. 2.4

4. You are required to add sulfuric acid to a battery you just bought for your car. You decide to test the pH value of the solution and find it to be 10.4. Does this value make sense? Why or why not?
   No, it should be a low pH since it is acidic

5. Which of the following statements is true for basic solutions?
   a. \([H^+] > [OH^-]\)
   b. \([H^+] < [OH^-]\)
   c. \([H^+] = [OH^-]\)

6. Which of the following statements is true for neutral solutions?
   a. \([H^+] > [OH^-]\)
   b. \([H^+] < [OH^-]\)
   c. \([H^+] = [OH^-]\)
7. Which of the following statements is true for **acidic** solutions?

   a. \([H+] > [OH^-]\)
   
   b. \([H+] < [OH^-]\)
   
   c. \([H+] = [OH^-]\)

8. What does the value of pH actually mean?

   **Negative log of the concentration of hydrogen ions in solution**

9. What are some common acids and bases? List at least 3 of each.

   **Acid:** Milk, Chicken Soup, Soda, battery acid, etc.

   **Base:** Drain cleaner, Windex, Hand soap, blood, spit

10. What are three things you know about acids, bases and pH?

    Anything goes here, up to the discretion of the teacher, just a way for students to self-check themselves and take some control of their learning
Assessment Activity

pH Assessment

Directions: For this assignment, you will be working with the pH simulation found at https://phet.colorado.edu/en/simulation/ph-scale. Download and open the simulation before you start. You will be working exclusively with the “My Solution” section. Use the simulation to help you answer the following questions.

For this section, the only parts that can be manipulated are the pH value and the concentration values. All three options are related and will all change accordingly when one variable is altered. For the first question, the arrows on the right side of the pH box were used to get a value of 7.00. The concentrations and quantities of the molecules in solution changed to the value they are now. Alternatively, if given a concentration, you could drag a concentration box to the desired value and then observe the pH value and the concentration of the other molecule in solution.

1. Make a neutral pH and find the following values.
   a. pH: 7
   b. Concentration of OH⁻: 1x10⁻⁷
c. Concentration of H$_3$O$^+$: 1x10$^7$

d. Quantity of OH$^-$ Molecules: 3.01x10$^{16}$

e. Quantity of H$_3$O$^+$ Molecules: 3.01x10$^{16}$

2. Make an acidic pH and find the following values. Will be different depending on what pH value is picked.

a. pH: 2

b. Concentration of OH$^-$: 1.0x10$^{-12}$

c. Concentration of H$_3$O$^+$: 1.0x10$^{-2}$

d. Quantity of OH$^-$ Molecules: 3.01x10$^{11}$

e. Quantity of H$_3$O$^+$ Molecules: 3.01x10$^{21}$

3. Make a basic pH and find the following values. Will be different depending on what pH value is picked.

a. pH: 11

b. Concentration of OH$^-$: 1.0x10$^{-3}$

c. Concentration of H$_3$O$^+$: 1.0x10$^{-11}$

d. Quantity of OH$^-$ Molecules: 3.01x10$^{20}$

e. Quantity of H$_3$O$^+$ Molecules: 3.01x10$^{12}$

4. What would the pH value be of a solution with 1.79 x 10$^{22}$ molecules of OH$^-$?

12.77

5. What would the pH value be of a solution with an H$_3$O$^+$ concentration of 7.2 x 10$^{-4}$ mol/L?

3.14

6. Tomato juice has a pH of 4.00. What would the concentration of OH$^-$ be in a solution of 0.50L tomato juice?

1x10$^{-10}$

7. Eggs have a pH of 8.00. What would the concentration of H$_3$O$^+$ be in a solution of 0.50L eggs?

1x10$^{-8}$
8. Would you expect the concentration of OH⁻ to be higher or lower than the concentration of H₃O⁺ in a basic solution?

higher

9. Would you expect the number of OH⁻ molecules to be higher or lower than the number of H₃O⁺ molecules in a basic solution?

higher

10. Use the internet to find a solution of your choice and answer the following questions. Depends on chosen solution.

   a. pH:_____
   b. Concentration of OH⁻:_____
   c. Concentration of H₃O⁺:_____
   d. Quantity of OH⁻ Molecules:_____
   e. Quantity of H₃O⁺ Molecules:_____


Properties of Gases


NYS Content Standards:

3.1kk The three phases of matter (solids, liquids, and gases) have different properties.

3.4a The concept of an ideal gas is a model to explain the behavior of gases. A real gas is most like an ideal gas when the real gas is at low pressure and high temperature.

3.4b Kinetic molecular theory (KMT) for an ideal gas states that all gas particles: • are in random, constant, straight-line motion. • are separated by great distances relative to their size; the volume of the gas particles is considered negligible. • have no attractive forces between them. • have collisions that may result in a transfer of energy between gas particles, but the total energy of the system remains constant.

3.4c Kinetic molecular theory describes the relationships of pressure, volume, temperature, velocity, and frequency and force of collisions among gas molecules

Learning Goals:

1) Students will be able to define an ideal gas.

2) Students will be able to define and work with the kinetic molecular theory (PV=nRT).

Key Vocabulary and Concepts for Simulation:

1) Gas – a state of matter consisting of particles with neither a defined volume nor a defined shape

2) Temperature – a measure of how much the molecules of a substance are moving

3) Pressure – the force that a gas exerts on the walls of its container

4) Volume – quantity of 3D space occupied by a gas
5) **Ideal Gas** – a gas with molecules of negligible size with an average molar kinetic energy dependent only on temperature, follows \( PV = nRT \)

6) **Kinetic Molecular Theory (KMT)** – gas particles are in constant motion and exhibit perfectly elastic collisions

**Stimulating Aspects of the Simulation:**

1) Ability to visualize gas particles in motion

2) Ability to manipulate volume, amount of molecules and temperature to see effect on particle motion

**Planning Considerations for Simulation:**

1) Needs background information to understand KMT in regards to the simulation

**Simulation Parts Explained:**

**Screen 1: Gases Intro (Introduction Simulation)**
Screen 2: Gas Laws (Introduction Simulation)

Screen 3: Energy (Gas Properties Simulation)
**Volume Control** – changes the size and volume of the container, you may drag the handle to the left to increase the size or to the right to decrease the size of the container

**Pause/Play Button** – pauses or plays the simulation, in addition, the button to the right of the pause/play button allows you to control frame by frame if you press it while paused

**Temperature Control** – changes the temperature within the container, you may drag the center up to heat the container or down to cool the container

**Screen Selector** – selects which screen you are on

**Gas Release** – releases gas particles within the container, drag the handle to the left to open the container and to the right to close the container, note that not all the particles will escape at one time as there will be a fairly steady stream of released particles until the container is empty

**Instrumentation** – shows the current temperature and pressure within the container, you may change between K and C for temperature and atm and kPa for pressure by clicking the arrow on the drop down menu

**Particle Pump** – releases gas particles into the container, you may choose between two different colors underneath the pump, to add particles simply pull up and then down on the pump, note that if you press the eraser to the left of the pump, all the particles in the container will be deleted by the simulation will not be reset, the larger, purple molecules are heavier while the smaller, orange particles are lighter

**Display Options** – allows you to view various additional information about the container and the particles within it, each option can be enabled by clicking on the check boxes to the left of their labels, the “Width” option shows the width of the container in nm below the container itself, the “Stopwatch” option creates a stopwatch in the top left of the screen, the “Collision Counter” option counts the number of times a gas particle collides with the inside wall of the container in a set period of time

**Particle Information** – shows information about how many particles of each type are in the container at the current time
**Reset Button** – resets the screen to its default state as shown in the screenshots above

**Constants Options** – shows which, if any, variable (PVT) is held constant at the current time, selecting “Volume” removes the “Volume Control” handle, selecting “Temperature” removes the “Temperature Control” handle, selecting “Pressure V” holds volume and pressure constant while selecting “Pressure T” holds temperature and pressure constant

**Speed Display** – shows the average speed of each type of particle in the container in both numerical (top) and graphical (bottom) form

**Kinetic Energy Display** – shows the kinetic energy of the particles in the container

**Precision Temperature Control** – changes the temperature at which new particles are at when added to the container

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td><a href="https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry-%25">https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry-%</a></td>
</tr>
<tr>
<td><em>The_Central_Science</em>(Brown_et_al.)/10%3A_Gases/10.5%3A_Gases_(Summary)</td>
</tr>
</tbody>
</table>

**Simulation Usage in the Preliminary Period**

**Engage** – Students will be engaged in this activity because it gives them an opportunity to interact with the content in a low-risk setting. Students will also be able to connect some of their prior learning about atoms to the content within the simulation and see where they stand with this knowledge. Students can use the bicycle pump to add molecules into the container and then manipulate different variables to see how they affect each other and the speed of the gas particles in the container.

**Explore** – Like the engage phase, students will be exploring the content on their own when interacting with the simulation.

**Activity** –
Introduction to Gases

Gases are, perhaps, the most important state of matter for life. They constitute the air we breathe and the air plants use to create energy through photosynthesis. Gases tend to all have the same basic properties, which you will see in the simulation found at https://phet.colorado.edu/en/simulation/gases-intro. Open up the Gases Intro simulation and navigate to the intro screen. Spend a few minutes playing around with this simulation and then write down three things you notice about gases below. The key question you will be exploring in this simulation is how do the different variables (temperature, pressure, volume, amount of gas particles) effect how the gas particles move and interact with their surroundings.

1.

2.

3.

Simulation Usage in the Core Instruction Period

Explain – For this assignment, the explain phase is covered mainly in the introductory reading. It is suggested that the teacher read this introductory information to the class aloud and address any student questions that arise and any misconceptions students may have. Much of the information that will be needed for the full understanding of this learning segment is found here, and students will use this information throughout the remainder of the learning segment to answer various questions.
**Elaborate** – The elaborate phase of this learning segment happens when students answer the wrap-up questions at the end of this assignment. For these questions, students will be connecting what they learned in the explain phase of this assignment to the questions they will have to answer. These questions will require students to take what they learned and apply it to a new, more challenging situation.

**Activity** (adapted from [https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry_-_The_Central_Science_(Brown_et_al.)/10%3A_Gases/10.5%3A_Gases_(Summary)](https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_Chemistry_-_The_Central_Science_(Brown_et_al.)/10%3A_Gases/10.5%3A_Gases_(Summary)) –

**Gases**

Bulk matter can exist in three states: gas, liquid, and solid. Gases have the lowest density of the three, are highly compressible, and fill their containers completely. Elements that exist as gases at room temperature and pressure are clustered on the right side of the periodic table; they occur as either monatomic gases (the noble gases) or diatomic molecules (some halogens, N₂, O₂).

- Gases expand spontaneously to fill containers in which they are held, equaling their volume. Consequently, they are highly compressible.
- Gases form homogeneous mixtures with each other regardless of the identities or relative proportions of the component gases.
- The characteristic properties of gases arise because the individual molecules are relatively far apart, hence, acting largely as though they were alone.

The volume of a gas is inversely proportional to its pressure and directly proportional to its temperature and the amount of gas. Boyle showed that the volume of a sample of a gas is inversely proportional to pressure (Boyle’s law), Charles and Gay-Lussac demonstrated that the volume of a gas is directly proportional to its temperature at constant
pressure (Charles’s law), and Avogadro showed that the volume of a gas is directly proportional to the number of moles of gas (Avogadro’s law).

The empirical relationships among the volume, the temperature, the pressure, and the amount of a gas can be combined into the ideal gas law, \( PV = nRT \). The proportionality constant, \( R \), is called the gas constant. The ideal gas law describes the behavior of an ideal gas, a hypothetical substance whose behavior can be explained quantitatively by the ideal gas law and the kinetic molecular theory of gases. Standard temperature and pressure (STP) is 0°C and 1 atm.

\[
PV=nRT
\]

Where \( P = \) pressure, \( V = \) volume, \( n = \) number of moles, \( R = \) gas constant, \( T = \) Temperature (always expressed on absolute-temperature scale, usually Kelvin).

The Gas constant (\( R \)) is the constant of proportionality in the ideal-gas equation. Some values of \( R \) are given below:

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<td>8.314</td>
</tr>
<tr>
<td>M³-Pa/mol-K</td>
<td>8.314</td>
</tr>
</tbody>
</table>
Getting Started

1. Log into a computer and open up Google Chrome.

2. Type the following address into the address bar: [https://phet.colorado.edu/en/simulation/gases-intro](https://phet.colorado.edu/en/simulation/gases-intro).

3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.

4. Start the “Gases Intro” simulation.

Laws

1. Navigate to the “Laws” screen of the simulation.

2. Pull up and push down the pump on the right side of the screen to release gas molecules into the container.

3. Hold volume constant and increase the temperature.
   a. What happens to the pressure?
   b. What happens to the speed of the gas particles?
   c. What happens to the volume?
d. What happens to the number of gas particles in the container?

4. Now, hold temperature constant and increase the amount of gas particles in the container.
   a. What happens to the pressure?
   b. What happens to the speed of the gas particles?
   c. What happens to volume?
   d. What happens to temperature?

5. Continue to hold temperature constant and increase the volume of the container.
   a. What happens to the pressure?
   b. What happens to the speed of the gas particles?
c. What happens to the temperature?

d. What happens to the number of gas particles in the container?

6. Reset the simulation and then add gas particles to the container.

7. Hold Pressure $V$ constant and increase the temperature.
   a. What happens to the volume of the container?

8. Hold Pressure $V$ constant and increase the number of gas particles in the container.
   a. What happens to the volume of the container?

9. Hold Pressure $T$ constant and increase the number of gas particles in the container.
   a. What happens to the temperature of the container?

   b. What happens to the speed of the gas particles in the container?
Energy


3. Add gas particles to the container.

4. Click the green “+” next to “Kinetic Energy.”

5. Record the initial speed in the table below.

6. Increase the temperature in the container. Record what happens to the speed and kinetic energy in the table below.

7. Increase the amount of gas particles in the container. Record what happens to the speed and kinetic energy in the table below.

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<td></td>
<td></td>
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CiQ 1: What do you think would happen to both speed and kinetic energy if you decreased the temperature in step 6, instead of increasing it?

CiQ 2: What do you think would happen to both speed and kinetic energy if you reduced the number of gas particles in step 7, instead of increasing them?
Wrap Up Questions

1. A sample of gas is found to have a pressure of 0.75 atm when held in a 1.3L balloon at 23°C. How many moles of gas are in the balloon?

2. A container is filled with 0.25 moles of a gas. What is the volume of the container if the pressure and temperature are held at 0.85 atm and 30°C, respectively?

3. What is the pressure of a gas if 0.3 moles of it completely fill a 2L container at 15°C?

4. You find the pressure of 0.6 moles of a gas to be 0.25 atm when it is in a 1.5L container. What is the temperature of the container?

5. A 15L balloon is filled with 100g of N₂ at 20°C, what is its pressure?

Simulation Usage as an Expansionary Assessment

Evaluate – The activity for this section will assess students’ knowledge of both the simulation itself and the content within the simulation. Students will be required to take what they have learned in the core instruction period and use it to complete the questions related to the simulation and answer the pencil and paper questions found in this activity.
Activity –

Gases Assessment

Part I

Directions: Use the “Laws” screen of the “Gases Intro” simulation found at https://phet.colorado.edu/en/simulation/gases-intro to answer the following questions. Be sure to add a single pump of gas particles to the container and hold nothing constant.

1. What is the pressure in the container at 300K?

2. What is the pressure in the container at 400K?

3. What is the pressure in the container at 550K?

4. What is the pressure in the container at 300K if the width of the container is reduced to 5.0 nm?

5. What is the pressure in the container at 550K if the width of the container is reduced to 5.0 nm?

6. What is the pressure in the container at 300K if the width of the container is increased to 15.0 nm?

7. What is the pressure in the container at 550K if the width of the container is increased to 15.0 nm?
8. At what temperature is the pressure in the container 12.7 atm at a width of 10.0 nm?

9. At what temperature is the pressure in the container 12.7 atm at a width of 15.0 nm?

10. At what temperature is the pressure in the container 12.7 atm at a width of 5.0 nm?

Part II

Directions: Calculate the missing variable.

11. Pressure = ?, moles gas = 1.45 mol, Temperature = 273K, Volume = 2.75L

12. Pressure = 15.4 atm, moles gas = ?, Temperature = 432K, Volume = 1.86L

13. Pressure = 22.3 atm, moles gas = 0.65 mol, Temperature = ?, Volume = 4.32L

14. Pressure = 30.5 atm, moles gas = 0.98 mol, Temperature = 190K, Volume = ?

15. Pressure = ?, moles gas = 1.0 mol, Temperature = 300K, Volume = 5.0l
**Activity Guide**

**Preliminary Activity**

**Introduction to Gases**

Gases are, perhaps, the most important state of matter for life. They constitute the air we breathe and the air plants use to create energy through photosynthesis. Gases tend to all have the same basic properties, which you will see in the simulation found at [https://phet.colorado.edu/en/simulation/gases-intro](https://phet.colorado.edu/en/simulation/gases-intro). Open up the Gases Intro simulation and navigate to the intro screen. Spend a few minutes playing around with this simulation and then write down three things you notice about gases below. The key question you will be exploring in this simulation is how do the different variables (temperature, pressure, volume, amount of gas particles) effect how the gas particles move and interact with their surroundings.

There are no stated goals for this preliminary activity as it is solely exploratory in nature. Some key features to note, however, are the pump which allows you to add gas particles to the simulation, the burner at the bottom of the screen that can adjust temperature and the handle on the left side of the container which can be used to manipulate the width of the container and, thus, the volume.
1. Dependent on student

2. Dependent on student

3. Dependent on student

Core Activity

Gases

Bulk matter can exist in three states: gas, liquid, and solid. Gases have the lowest density of the three, are highly compressible, and fill their containers completely. Elements that exist as gases at room temperature and pressure are clustered on the right side of the periodic table; they occur as either monatomic gases (the noble gases) or diatomic molecules (some halogens, N₂, O₂).

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Where \( P \) = pressure, \( V \) = volume, \( n \) = number of moles, \( R \) = gas constant, \( T \) = Temperature (always expressed on absolute-temperature scale, usually Kelvin).

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3. You may either download the simulation and open it from the Download section of the files on your computer or simply press the play button and the simulation will open in the web browser.
4. Start the “Gases Intro” simulation.

Laws

1. Navigate to the “Laws” screen of the simulation.
2. Pull up and push down the pump on the right side of the screen to release gas molecules into the container.
For this section, multiple variables within the simulation will be manipulated, and their impact on the other variables will be observed. For example, the first question has volume being held constant, which removes the handle from the left of the container, and has the temperature being increased. To increase the temperature, the blue piece of the burner was pulled to the top and the temperature was increased, as shown by the thermometer. Notice that the pressure has changed from the initial example as a result.

3. Hold volume constant and increase the temperature.
   a. What happens to the pressure?
      
      Increases
   
   b. What happens to the speed of the gas particles?
      
      Increases
   
   c. What happens to the volume?
      
      Constant, remains the same
d. What happens to the number of gas particles in the container?

   Remains the same

4. Now, hold temperature constant and increase the amount of gas particles in the container.
   a. What happens to the pressure?

      Increase

   b. What happens to the speed of the gas particles?

      Remains the same

   c. What happens to volume?

      Remains the same

   d. What happens to temperature?

      Remains the same

5. Continue to hold temperature constant and increase the volume of the container.
   a. What happens to the pressure?

      decreases

   b. What happens to the speed of the gas particles?

      No effect
c. What happens to the temperature?

Remains the same

d. What happens to the number of gas particles in the container?

Remains the same

6. Reset the simulation and then add gas particles to the container.

7. Hold Pressure $V$ constant and increase the temperature.
   a. What happens to the volume of the container?

   Increases

8. Hold Pressure $V$ constant and increase the number of gas particles in the container.
   a. What happens to the volume of the container?

   Increases

9. Hold Pressure $T$ constant and increase the number of gas particles in the container.
   a. What happens to the temperature of the container?

   Decreases

   b. What happens to the speed of the gas particles in the container?

   Decreases
Energy


3. Add gas particles to the container.

4. Click the green “+” next to “Kinetic Energy.”

5. Record the initial speed in the table below.

For this section, the important aspects shown in the simulation are the average speed and the kinetic energy. This example shows the initial average speed of the particles at the standard temperature. As temperature and number of particles are changed, so too will the kinetic energy and average speed.

6. Increase the temperature in the container. Record what happens to the speed and kinetic energy in the table below.
7. Increase the amount of gas particles in the container. Record what happens to the speed and kinetic energy in the table below.

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</tr>
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<tbody>
<tr>
<td>Initial</td>
<td>Student dependent</td>
<td>****</td>
</tr>
<tr>
<td>Temperature</td>
<td>Student dependent, should increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Number of particles</td>
<td>Student dependent, should decrease</td>
<td>decrease</td>
</tr>
</tbody>
</table>

CiQ 1: What do you think would happen to both speed and kinetic energy if you decreased the temperature in step 6, instead of increasing it?

Decrease

CiQ 2: What do you think would happen to both speed and kinetic energy if you reduced the number of gas particles in step 7, instead of increasing them?

Increase

Wrap Up Questions

\[ PV = nRT \]

1. A sample of gas is found to have a pressure of 0.75 atm when held in a 1.3L balloon at 23°C. How many moles of gas are in the balloon?

\[ n = \frac{PV}{RT} = \frac{(0.75 \text{ atm})(1.3L)}{(0.08206 \frac{\text{Latm}}{\text{molK}})(300K)} = 0.40 \text{ mol} \]
2. A container is filled with 0.25 moles of a gas. What is the volume of the container if the pressure and temperature are held at 0.85 atm and 30°C, respectively?

\[
V = \frac{nRT}{P} = \frac{(0.25\,\text{mol}) \left(\frac{0.08206\,\text{Latm}}{\text{molK}}\right)(303\,\text{k})}{0.85\,\text{atm}} = 7.31L
\]

3. What is the pressure of a gas if 0.3 moles of it completely fill a 2L container at 15°C?

\[
P = \frac{nRT}{V} = \frac{(0.3\,\text{mol}) \left(\frac{0.08206\,\text{Latm}}{\text{molK}}\right)(288\,\text{k})}{2\,\text{L}} = 3.54\,\text{atm}
\]

4. You find the pressure of 0.6 moles of a gas to be 0.25 atm when it is in a 1.5L container. What is the temperature of the container?

\[
T = \frac{PV}{nR} = \frac{(0.25\,\text{atm})(1.5\,\text{L})}{(0.6\,\text{mol}) \left(\frac{0.08206\,\text{Latm}}{\text{molK}}\right)} = 7.62\,\text{K}
\]

5. A 15L balloon is filled with 100g of N \(_2\) at 20°C, what is its pressure?

\[
P = \frac{nRT}{V} = \frac{\left(\frac{\text{mass}}{\text{mm}}\right)RT}{V} = \frac{\left(\frac{100g}{28g/\text{mol}}\right) \left(\frac{0.08206\,\text{Latm}}{\text{molK}}\right)(293\,\text{K})}{15\,\text{L}} = 5.72\,\text{atm}
\]
Assessment Activity

Gases Assessment

Part I

Directions: Use the “Laws” screen of the “Gases Intro” simulation found at https://phet.colorado.edu/en/simulation/gases-intro to answer the following questions. Be sure to add a single pump of gas particles to the container and hold nothing constant.

1. What is the pressure in the container at 300K?
   
   5.8 atm

2. What is the pressure in the container at 400K?
   
   7.8 atm

3. What is the pressure in the container at 550K?
   
   10.7 atm

4. What is the pressure in the container at 300K if the width of the container is reduced to 5.0 nm?
   
   11.7 atm

5. What is the pressure in the container at 550K if the width of the container is reduced to 5.0 nm?
   
   21.4 atm

6. What is the pressure in the container at 300K if the width of the container is increased to 15.0 nm?
   
   3.9 atm

7. What is the pressure in the container at 550K if the width of the container is increased to 15.0 nm?
   
   7.1 atm
8. At what temperature is the pressure in the container 12.7 atm at a width of 10.0 nm?

650K

9. At what temperature is the pressure in the container 12.7 atm at a width of 15.0 nm?

975K

10. At what temperature is the pressure in the container 12.7 atm at a width of 5.0 nm?

325K

Part II

Directions: Calculate the missing variable.

\[ PV = nRT \]

11. Pressure = ?, moles gas = 1.45 mol, Temperature = 273K, Volume = 2.75L

\[ P = \frac{nRT}{V} = \frac{(1.45\text{mol})(0.08206\text{Latm/molK})(273K)}{2.75L} = 11.8\text{atm} \]

12. Pressure = 15.4 atm, moles gas = ?, Temperature = 432K, Volume = 1.86L

\[ n = \frac{PV}{RT} = \frac{(15.4\text{atm})(1.86L)}{(0.08206\text{Latm/molK})(432K)} = 0.81\text{mol} \]

13. Pressure = 22.3 atm, moles gas = 0.65 mol, Temperature = ?, Volume = 4.32L

\[ T = \frac{PV}{nR} = \frac{(22.3\text{atm})(4.32L)}{(0.65\text{mol})(0.08206\text{Latm/molK})} = 1806\text{K} \]

14. Pressure = 30.5 atm, moles gas = 0.98 mol, Temperature = 190K, Volume =?

\[ V = \frac{nRT}{P} = \frac{(0.98\text{mol})(0.08206\text{Latm/molK})(190K)}{30.5\text{atm}} = 0.50L \]
15. Pressure = ?, moles gas = 1.0 mol, Temperature = 300K, Volume = 5.0l

\[
P = \frac{nRT}{V} = \frac{(1.0 \text{ mol}) \left(\frac{0.08206 \text{ Latm}}{\text{molK}}\right)(300 \text{ K})}{5.0 \text{ L}} = 4.92 \text{ atm}
\]


