The Scholars' Academy

Mission Statement: To Prepare for College and Careers of the 21st Century
"Technology Today, Smarter Tomorrow: Removing Time and Place from Teaching and Learning"
27Q323 is an Accelerated College Preparatory School for Grades 6-12
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Course: Regents Chemistry
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Welcome to Regents Chemistry! We will start off our study of Chemistry by looking at the most fundamental particle in all of Chemistry… the atom. As an introduction to the atom, you will read an excerpt from A Short History of Nearly Everything by Bill Bryson.

Once you have read the excerpt you will imagine yourself to be a writer. Imagine you are writing an article for the Tuesday Science section of the *New York Times*. Your job is to convince the reader, **through careful use of details**, that the atom is truly a miraculous particle. Use the following guiding questions as information to make your case. Your response must be written in paragraph form and may not exceed one to two pages of text. **You will hand me only your one to two page paper, not the answers to these questions.**

This assignment is due Monday, September 16, 2013 and will count as a project grade in your first marking period grade.

Guiding Questions (the content from each of these questions should be addressed in your paper):

1. How many molecules are in a cubic centimeter of air?
2. What does the author mean when he says "atoms are so long-lived, atoms really get around"?
3. According to Bryson, what are some analogies to describe how small the atom really is?
4. What three particles make up an atom? What is the charge of each?
5. What particle gives an atom its "identity"? Which particle gives an atom it's "personality"?
6. How does the Cathedral analogy relate to the structure of the atom?
7. What is the majority of the atom made up of?
8. What does the author mean by the statement "when you are sitting in a chair, you are not actually sitting there but levitating above it …."? How does this statement relate to the structure of the atom?

In addition choose *two* of the following to address in your paper:

1. Describe Dalton's Theory of the atom.
2. Describe Rutherford's Gold Foil experiment. What were his conclusions about the atom?
3. How did Bohr contribute to our understanding of the model of the atom?

Describe the Heisenberg Uncertainty principle. How does it relate to the structure of the atom?

Standards

CCLS

- RST.9-10.1. Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
- RST.9-10.2. Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- WHST2: Write informative/explanatory texts

NYS Standards

Key Idea 3:
Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.

Teaching Task Rubric (Informational or Explanatory)

Scoring Elements	Not Yet		Approaches Expectations		Meets Expectations		Advanced
	1	1.5	2	2.5	3	3.5	4
Focus	Attempts to address prompt, but lacks focus or is off-task.		Addresses prompt appropriately, but with a weak or uneven focus.		Addresses prompt appropriately and maintains a clear, steady focus.		Addresses all aspects of prompt appropriately and maintains a strongly developed focus.
Controlling Idea	Attempts to establish a controlling idea| but lacks a clear purpose.		Establishes a controlling idea with a general purpose.		Establishes a controlling idea with a clear purpose maintained throughout the response.		Establishes a strong controlling idea with a clear purpose maintained throughout the response.
Reading/ Research	Attempts to present information in response to the prompt, but lacks connections or relevance to the purpose of the prompt. (L2) Does not address the credibility of sources as prompted.		Presents information from reading materials relevant to the purpose of the prompt with minor lapses in accuracy or completeness. (L2) Begins to address the credibility of sources when prompted.		Presents information from reading materials relevant to the prompt with accuracy and sufficient detail. (L2) Addresses the credibility of sources when prompted.		Accurately presents information relevant to all parts of the prompt with effective selection of sources and details from reading materials. (L2) Addresses the credibility of sources and identifies salient sources when prompted.
Development	Attempts to provide details in response to the prompt, including retelling, but lacks sufficient development or relevancy. (L2) Implication is missing, irrelevant, or illogical. (L3) Gap/unanswered question is missing or irrelevant.		Presents appropriate details to support the focus and controlling idea. (L2) Briefly notes a relevant implication or (L3) a relevant gap/unanswered question.		Presents appropriate and sufficient details to support the focus and controlling idea. (L2) Explains relevant and plausible implications, and (L3) a relevant gap/unanswered question.		Presents thorough and detailed information to strongly support the focus and controlling idea. (L2) Thoroughly discusses relevant and salient implications or consequences, and (L3) one or more significant gaps/unanswered questions.
Organization	Attempts to organize ideas, but lacks control of structure.		Uses an appropriate organizational structure to address the specific requirements of the prompt, with some lapses in coherence or awkward use of the organizational structure		Maintains an appropriate organizational structure to address the specific requirements of the prompt.		Maintains an organizational structure that intentionally and effectively enhances the presentation of information as required by the specific prompt.
Conventions	Attempts to demonstrate standard English conventions, but lacks cohesion and control of grammar, usage, and mechanics. Sources are used without citation.		Demonstrates an uneven command of standard English conventions and cohesion. Uses language and tone with some inaccurate, inappropriate, or uneven features. Inconsistently cites sources.		Demonstrates a command of standard English conventions and cohesion, with few errors. Response includes language and tone appropriate to the audience, purpose, and specific requirements of the prompt. Cites sources using an appropriate format with only minor errors.		Demonstrates and maintains a well-developed command of standard English conventions and cohesion, with few errors. Response includes language and tone consistently appropriate to the audience, purpose, and specific requirements of the prompt. Consistently cites sources using an appropriate format.
Content Understanding	Attempts to include disciplinary content in explanations, but understanding of content is weak; content is irrelevant, inappropriate, or inaccurate.		Briefly notes disciplinary content relevant to the prompt; shows basic or uneven understanding of content; minor errors in explanation.		Accurately presents disciplinary content relevant to the prompt with sufficient explanations that demonstrate understanding.		Integrates relevant and accurate disciplinary content with thorough explanations that demonstrate in-depth understanding.

Excerpt from Bill Bryson's book A Short History of Nearly Everything - Chapter 9 *The Mighty Atom*

WHILE EINSTEIN AND Hubble were productively unraveling the large-scale structure of the cosmos, others were struggling to understand something closer to hand but in its way just as remote: the tiny and ever- mysterious atom.

The great Caltech physicist Richard Feynman once observed that if you had to reduce scientific history to one important statement it would be "All things are made of atoms." They are everywhere and they constitute every thing. Look around you. It is all atoms. Not just the solid things like walls and tables and sofas, but the air in between. And they are there in numbers that you really cannot conceive.

The basic working arrangement of atoms is the molecule (from the Latin for "little mass"). A molecule is simply two or more atoms working together in a more or less stable arrangement: add two atoms of hydrogen to one of oxygen and you have a molecule of water. Chemists tend to think in terms of molecules rather than elements in much the way that writers tend to think in terms of words and not letters, so it is molecules they count, and these are numerous to say the least. At sea level, at a temperature of 32 degrees Fahrenheit, one cubic centimeter of air (that is, a space about the size of a sugar cube) will contain 45 billion billion molecules. And they are in every single cubic centimeter you see around you. Think how many cubic centimeters there are in the world outside your window—how many sugar cubes it would take to fill that view. Then think how many it would take to build a universe. Atoms, in short, are very abundant.

They are also fantastically durable. Because they are so long lived, atoms really get around. Every atom you possess has almost certainly passed through several stars and been part of millions of organisms on its way to becoming you. We are each so atomically numerous and so vigorously recycled at death that a significant number of our atoms—up to a billion for each of us, it has been suggested—probably once belonged to Shakespeare. A billion more each came from Buddha and Genghis Khan and Beethoven, and any other historical figure you care to name. (The personages have to be historical, apparently, as it takes the atoms some decades to become thoroughly redistributed; however much you may wish it, you are not yet one with Elvis Presley.)

So we are all reincarnations—though short-lived ones. When we die our atoms will disassemble and move off to find new uses elsewhere—as part of a leaf or other human being or drop of dew. Atoms, however, go on practically forever. Nobody actually knows how long an atom can survive, but according to Martin Rees it is probably about 10^{35}years—a number so big that even I am happy to express it in notation.

Above all, atoms are tiny—very tiny indeed. Half a million of them lined up shoulder to shoulder could hide behind a human hair. On such a scale an individual atom is essentially impossible to imagine, but we can of course try.

Start with a millimeter, which is a line this long: -. Now imagine that line divided into a thousand

equal widths. Each of those widths is a micron. This is the scale of microorganisms. A typical paramecium, for instance, is about two microns wide, 0.002 millimeters, which is really very small. If you wanted to see with your naked eye a paramecium swimming in a drop of water, you would have to enlarge the drop until it was some forty feet across. However, if you wanted to see the atoms in the same drop, you would have to make the drop fifteen *miles* across. Atoms, in other words, exist on a scale of minuteness of another order altogether. To get down to the scale of atoms, you would need to take each one of those micron slices and shave it into ten thousand finer widths. *That's* the scale of an atom: one ten-millionth of a millimeter. It is a degree of slenderness way beyond the capacity of our imaginations, but you can get some idea of the proportions if you bear in mind that one atom is to the width of a millimeter line as the thickness of a sheet of paper is to the height of the Empire State Building.

Dalton's simple insight was that at the root of all matter are exceedingly tiny, irreducible particles. "We might as well attempt to introduce a new planet into the solar system or annihilate one already in existence, as to create or destroy a particle of hydrogen," he wrote.

Neither the idea of atoms nor the term itself was exactly new. Both had been developed by the ancient Greeks. Dalton's contribution was to consider the relative sizes and characters of these atoms and how they fit together. He knew, for instance, that hydrogen was the lightest element, so he gave it an atomic weight of one. He believed also that water consisted of seven parts of oxygen to one of hydrogen, and so he gave oxygen an atomic weight of seven. By such means was he able to arrive at the relative weights of the known elements. He wasn't always terribly accurate—oxygen's atomic weight is actually sixteen, not seven—but the principle was sound and formed the basis for all of modern chemistry and much of the rest of modern science.

For a century after Dalton made his proposal, it remained entirely hypothetical, and a few eminent scientists—notably the Viennese physicist Ernst Mach, for whom is named the speed of sound—doubted the existence of atoms at all. "Atoms cannot be perceived by the senses . . . they are things of thought," he wrote. The existence of atoms was so doubtfully held in the German-speaking world in particular that it was said to have played a part in the suicide of the great theoretical physicist, and atomic enthusiast, Ludwig Boltzmann in 1906.

It was Einstein who provided the first incontrovertible evidence of atoms' existence with his paper on Brownian motion in 1905, but this attracted little attention and in any case Einstein was soon to become consumed with his work on general relativity. So the first real hero of the atomic age, if not the first personage on the scene, was Ernest Rutherford.

Rutherford was born in 1871 in the "back blocks" of New Zealand to parents who had emigrated from Scotland to raise a little flax and a lot of children (to paraphrase Steven Weinberg). Growing up in a remote part of a remote country, he was about as far from the mainstream of science as it was possible to be, but in 1895 he won a scholarship that took him to the Cavendish Laboratory at Cambridge University, which was about to become the hottest place in the world to do physics.

Rutherford was a lucky man—lucky to be a genius, but even luckier to live at a time when physics and chemistry were so exciting and so compatible (his own sentiments notwithstanding). Never again would they quite so comfortably overlap.

For all his success, Rutherford was not an especially brilliant man and was actually pretty terrible at mathematics. Often during lectures he would get so lost in his own equations that he would give up halfway through and tell the students to work it out for themselves. According to his longtime colleague James Chadwick, discoverer of the neutron, he wasn't even particularly clever at experimentation. He was simply tenacious and open-minded. For brilliance he substituted shrewdness and a kind of daring. His mind, in the words of one biographer, was "always operating out towards the frontiers, as far as he could see, and that was a great deal further than most other men." Confronted with an intractable problem, he was prepared to work at it harder and longer than most people and to be more receptive to unorthodox explanations. His greatest breakthrough came because he was prepared to spend immensely tedious hours sitting at a screen counting alpha particle scintillations, as they were known—the sort of work that would normally have been farmed out. He was one of the first to see—possibly the very first—that the power inherent in the atom could, if harnessed, make bombs powerful enough to "make this old world vanish in smoke."

By the early twentieth century it was known that atoms were made of parts—Thomson's discovery of the electron had established that—but it wasn't known how many parts there were or how they fit together or what shape they took. Some physicists thought that atoms might be cube shaped, because cubes can be packed together so neatly without any wasted space. The more general view, however, was that an atom was more like a currant bun or a plum pudding: a dense, solid object that carried a positive charge but that was studded with negatively charged electrons, like the currants in a currant bun.

In 1910, Rutherford (assisted by his student Hans Geiger, who would later invent the radiation detector that bears his name) fired ionized helium atoms, or alpha particles, at a sheet of gold foil.[2] To Rutherford's astonishment, some of the particles bounced back. It was as if, he said, he had fired a fifteen-inch shell at a sheet of paper and it rebounded into his lap. This was just not supposed to happen. After considerable reflection he realized there could be only one possible explanation: the

particles that bounced back were striking something small and dense at the heart of the atom, while the other particles sailed through unimpeded. An atom, Rutherford realized, was mostly empty space, with a very dense nucleus at the center. This was a most gratifying discovery, but it presented one immediate problem. By all the laws of conventional physics, atoms shouldn't therefore exist.

Let us pause for a moment and consider the structure of the atom as we know it now. Every atom is made from three kinds of elementary particles: protons, which have a positive electrical charge; electrons, which have a negative electrical charge; and neutrons, which have no charge. Protons and neutrons are packed into the nucleus, while electrons spin around outside. The number of protons is what gives an atom its chemical identity. An atom with one proton is an atom of hydrogen, one with two protons is helium, with three protons is lithium, and so on up the scale. Each time you add a proton you get a new element. (Because the number of protons in an atom is always balanced by an equal number of electrons, you will sometimes see it written that it is the number of electrons that defines an element; it comes to the same thing. The way it was explained to me is that protons give an atom its identity, electrons its personality.)

Neutrons don't influence an atom's identity, but they do add to its mass. The number of neutrons is generally about the same as the number of protons, but they can vary up and down slightly. Add a neutron or two and you get an isotope. The terms you hear in reference to dating techniques in archeology refer to isotopes—carbon-14, for instance, which is an atom of carbon with six protons and eight neutrons (the fourteen being the sum of the two).

Neutrons and protons occupy the atom's nucleus. The nucleus of an atom is tiny—only one millionth of a billionth of the full volume of the atom—but fantastically dense, since it contains virtually all the atom's mass. As Cropper has put it, if an atom were expanded to the size of a cathedral, the nucleus would be only about the size of a fly—but a fly many thousands of times heavier than the cathedral. It was this spaciousness—this resounding, unexpected roominess—that had Rutherford scratching his head in 1910.

It is still a fairly astounding notion to consider that atoms are mostly empty space, and that the solidity we experience all around us is an illusion. When two objects come together in the real world—billiard balls are most often used for illustration—they don't actually strike each other. "Rather," as Timothy Ferris explains, "the negatively charged fields of the two balls repel each other . . . were it not for their electrical charges they could, like galaxies, pass right through each other unscathed." When you sit in a chair, you are not actually sitting there, but levitating above it at a height of one angstrom (a hundred millionth of a centimeter), your electrons and its electrons implacably opposed to any closer intimacy.

The picture that nearly everybody has in mind of an atom is of an electron or two flying around a nucleus, like planets orbiting a sun. This image was created in 1904, based on little more than clever guesswork, by a Japanese physicist named Hantaro Nagaoka. It is completely wrong, but durable just the same. As Isaac Asimov liked to note, it inspired generations of science fiction writers to create stories of worlds within worlds, in which atoms become tiny inhabited solar systems or our solar system turns out to be merely a mote in some much larger scheme. Even now CERN, the European Organization for Nuclear Research, uses Nagaoka's image as a logo on its website. In fact, as physicists were soon to realize, electrons are not like orbiting planets at all, but more like the blades of a spinning fan, managing to fill every bit of space in their orbits simultaneously (but with the crucial difference that the blades of a fan only *seem* to be everywhere at once; electrons *are*).

One of the people working with Rutherford was a mild and affable young Dane named Niels Bohr. In 1913, while puzzling over the structure of the atom, Bohr had an idea so exciting that he postponed his honeymoon to write what became a landmark paper. Because physicists couldn't see anything so small as an atom, they had to try to work out its structure from how it behaved when they did things to it, as Rutherford had done by firing alpha particles at foil. Sometimes, not surprisingly, the results of these experiments were puzzling. One puzzle that had been around for a long time had to do with spectrum readings of the wavelengths of hydrogen. These produced patterns showing that hydrogen atoms emitted energy at certain wavelengths but not others. It was rather as if someone under surveillance kept turning up at particular locations but was never observed traveling between them. No one could understand why this should be.

It was while puzzling over this problem that Bohr was struck by a solution and dashed off his famous paper. Called "On the Constitutions of Atoms and Molecules," the paper explained how electrons could keep from falling into the nucleus by suggesting that they could occupy only certain well-defined orbits. According to the new theory, an electron moving between orbits would disappear from one and reappear instantaneously in another *without visiting the space between*. This idea—the famous "quantum leap"—is of course utterly strange, but it was too good not to be true. It not only kept electrons from spiraling catastrophically into the nucleus; it also explained hydrogen's bewildering wavelengths. The electrons only appeared in certain orbits because they only existed in certain orbits. It was a dazzling insight, and it won Bohr the 1922 Nobel Prize in physics, the year after Einstein received his.

Finally, in 1926, Heisenberg came up with a celebrated compromise, producing a new discipline that came to be known as quantum mechanics. At the heart of it was Heisenberg's Uncertainty Principle, which states that the electron is a particle but a particle that can be described in terms of

waves. The uncertainty around which the theory is built is that we can know the path an electron takes as it moves through a space or we can know where it is at a given instant, but we cannot know both.[3] Any attempt to measure one will unavoidably disturb the other. This isn't a matter of simply needing more precise instruments; it is an immutable property of the universe.

What this means in practice is that you can never predict where an electron will be at any given moment. You can only list its probability of being there. In a sense, as Dennis Overbye has put it, an electron doesn't exist until it is observed. Or, put slightly differently, until it is observed an electron must be regarded as being "at once everywhere and nowhere."

If this seems confusing, you may take some comfort in knowing that it was confusing to physicists, too. Overbye notes: "Bohr once commented that a person who wasn't outraged on first hearing about quantum theory didn't understand what had been said." Heisenberg, when asked how one could envision an atom, replied: "Don't try."

So the atom turned out to be quite unlike the image that most people had created. The electron doesn't fly around the nucleus like a planet around its sun, but instead takes on the more amorphous aspect of a cloud. The "shell" of an atom isn't some hard shiny casing, as illustrations sometimes encourage us to suppose, but simply the outermost of these fuzzy electron clouds. The cloud itself is essentially just a zone of statistical probability marking the area beyond which the electron only very seldom strays. Thus an atom, if you could see it, would look more like a very fuzzy tennis ball than a hard-edged metallic sphere (but not much like either or, indeed, like anything you've ever seen; we are, after all, dealing here with a world very different from the one we see around us).

It seemed as if there was no end of strangeness. For the first time, as James Trefil has put it, scientists had encountered "an area of the universe that our brains just aren't wired to understand." Or as Feynman expressed it, "things on a small scale behave *nothing* like things on a large scale." As physicists delved deeper, they realized they had found a world where not only could electrons jump from one orbit to another without traveling across any intervening space, but matter could pop into existence from nothing at all—"provided," in the words of Alan Lightman of MIT, "it disappears again with sufficient haste."