5. Harry Moseley: Numbering the Elements

Dmitri Mendeleev (identified on screen) works on the Periodic Table, writes down the atomic weights of the elements.

NARR: Previously on *The Mystery of Matter…*

HISTORIAN MICHAEL GORDIN VO
He figures out something rather extraordinary about the elements.

DMITRI MENDELEEV, partly in VO
The eye is immediately struck by a pattern within the horizontal rows and the vertical columns.

Mendeleev's first table morphs into the familiar modern Periodic Table.

AUTHOR ERIC SCERRI VO
He found an absolutely fundamental principle of nature.

Humphry Davy (identified on screen) performs an experiment with his voltaic pile.

HISTORIAN DAVID KNIGHT VO
Somehow the particles of matter have to be glued together to form molecules. What Davy has had is a big idea. Perhaps electricity could be this kind of glue.

Marie Curie (identified on screen) sits down at the spectroscope and peers into the eyepiece.

NARR: The spectroscope kicked off a whole new round in the discovery of elements.

The spectra of four elements appear on screen, along with their names.

PHYSICIST DAVID KAISER VO
It's almost like each element has its own bar code.

Marie and Pierre enter their lab at night and see vials of radium glowing on the shelves.

MARIE TO PIERRE
Don't light the lamps! Look!

PHYSICIST DAVID KAISER VO

Radioactivity was a sign that the atom itself was unstable. It could break apart.

Marie and Pierre look in wonder at their radiant element.

NARR: Scientists now had a pressing new question to answer: What's inside the atom?

Fade to black

ANNOUNCER: Major funding for *The Mystery of Matter: Search for the Elements* was provided by the National Science Foundation, where discoveries begin. Additional funding provided by the Arthur Vining Davis Foundations – dedicated to strengthening America's future through education. And by the following.

Episode Title: Into the Atom

CHAPTER 1: The Discovery of the Electron

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure of Atoms

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.

F: Science and Technology in Local, National, and Global Challenges

- Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them.

G: History and Nature of Science

Science as a Human Endeavor

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.

Nature of Scientific Knowledge

- Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.
- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. … In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Historical Perspectives

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.

Alignment with the Next Generation Science Standards

Science and Engineering Practices

1. Asking Questions and Defining Problems

- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

2. Developing and Using Models

- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

3. Planning and Carrying Out Investigations

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- Select appropriate tools to collect, record, analyze, and evaluate data.

4. Analyzing and Interpreting Data

- Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.

6. Constructing Explanations and Designing Solutions

- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena.

Disciplinary Core Ideas

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

Fade up to Host doing a demonstration with Geissler tubes.

HOST

In the late 1800s, tubes like this were a staple of the popular science lecture.

Host turns on the tube, and we see the beam of electricity and the crowd-pleasing glow.

HOST

When electricity was applied to the metal at this end, it would give off a glow that thrilled crowds still mystified by electricity.

CONCEPT IN BRIEF: electricity

STOP AND THINK 1: What is electricity? What particles are associated with electricity?

Possible Student Answers: Many students may know that electricity refers to the movement of electrons, and some students may know that electricity refers to the movement of both electrons and ions.

EVERYDAY APPLICATION 1: A Geissler tube is a kind of cathode ray tube (CRT). CRTs have served many purposes over the years. They have been used to help scientists understand the structure of the atom, to show electrical signals, to make the first television monitors, as part of electron scanning microscopes (which can "see" atoms), and as parts in other imaging devices. While CRTs are no longer the first choice for televisions due to the development of LCD flat panel technology, CRTs are still used professionally in printing, broadcasting, video, photography, and graphics because they have better color fidelity, better contrast, and a wider viewing angle.

Host motions to a photo of J. J. Thomson behind him.

HOST

In 1897, physicist J.J. Thomson of England's Cambridge University set out to find out what these mysterious rays were.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

Host moves a magnet into place; we see the beam of electricity bend.

CONCEPT IN BRIEF: magnetism

HOST VO

When Thomson moved a magnet near a tube modified to reveal the rays, he saw that it bent the path of that beam.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

EVERYDAY APPLICATION 2: When charges move**,** such as a stream of electrons, they create a magnetic field and act as a magnet. Likewise, a moving magnet creates an electric field and acts as a charged object. The invention of the generator and the motor were made possible by understanding the interaction between electricity and magnetism. Generators are used to generate household electricity. Generators use a source of energy, such as moving air or water, to rotate a magnet; the rotating magnet creates an electric field that moves the electrons in a nearby metal wire.

HOST

Electricity, he realized, must be made up of *negatively-charged* particles – what soon came to be called "electrons." But electrons weren't just the unit of electricity. Thomson found that even when he used different metals to generate the rays, the resulting electrons were always the same. His bold conclusion was that the electron must be a tiny piece of every atom – thousands of times smaller than the atom itself.

Animation showing size of the electron relative to the hydrogen atom – about 1/2000th the size.

PHYSICIST DAVID KAISER, partly in VO

These things were much, much smaller than anyone had ever thought a kind of physical thing could be. But over time, people began to agree that this was a piece of every atom in the universe, that all of matter had these little parts inside them.

Photo of participants in the early Solvay conferences, including Curie, Einstein and Rutherford

NARR: Now the race was on to identify the rest of the atom's pieces and understand how they fit together. This challenge drew many of the best minds in science...

Pan from flowers to Moseley writing letter

NARR: … including a 22-year-old physicist from one of England's leading scientific families.

CONCEPT IN BRIEF: atom

CONCEPT IN DETAIL: electricity

CONCEPT IN DETAIL: electron

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

EXAMPLE OF SCIENCE PRACTICE: constructing explanations and designing solutions

EXAMPLE OF SCIENCE PRACTICE: developing and using models

CONCEPT IN BRIEF: matter

Notes from the Field:

My students and I discussed the fact that new scientific discoveries are often not accepted right away and why they think that is.

CONCEPT IN BRIEF: contributions of individuals and teams to the scientific enterprise

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

CHAPTER 2: Harry Moseley

Alignment with the NRC's National Science Education Standards
G: History and Nature of Science
Science as a Human Endeavor

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.

Cut to shot of mother reading the letter as VO begins.

On screen: **Words spoken by the characters in this film are drawn from their writings.**

HARRY MOSELEY VO

My dear Mother,

Two letters from you, so here a second from me …

Photo of young Moseley among his classmates at Trinity College Oxford

NARR: Henry Gwyn Jeffreys Moseley – Harry to his friends – was born with science in his blood.

Image of a Royal Society meeting

NARR: Both his grandfathers had been members of the Royal Society.

Photo of his father, Henry Nottidge Moseley

NARR: And his father was a famous naturalist and Oxford professor.

Photo of Moseley as a boy

NARR: But he died when Harry was just three ...

Photo of his mother, Amabel Gwyn Jeffreys

NARR: ... leaving him to be raised by his mother, Amabel.

Moseley continues writing the letter. Cut to shots of mother working in the garden.

HARRY MOSELEY VO

Firstly, the garden. Please occupy yourself in taking many hundreds of rose cuttings … Put them quite close together and ram the earth round them.

NARR: Harry and his mother grew very close. Together they laid out a garden alongside their country cottage. And throughout his life, his letters home were filled with instructions.

HARRY MOSELEY VO

Such Penstemons as the mole killed must be replaced … The Quamashes would like to be planted …

BIOGRAPHER JOHN HEILBRON, partly in VO

As any good gardener, he knew what he wanted planted where, and he told people what to do. He got to be very good at telling people what to do.

HARRY MOSELEY, partly in VO

… I hope the burrowing progresses and that it is being done with reference to our pretty ground plan.

Photo of young Moseley at Oxford

NARR: Moseley earned a degree in physics at Trinity College Oxford, and then elected to pursue graduate studies …

Photo of smoggy Manchester in 1910. Drawing of physics building at Owens College. Shot of the same building today.

NARR: … two hundred miles to the north, in smoggy Manchester, whose industrialists had generously endowed the local university.

NEIL TODD, MANCHESTER UNIVERSITY, partly in VO

The laboratory that Moseley came to in 1910 was, at that time, one of the most advanced physical institutes in the world.

Footage of Moseley working in the lab, then zoom to Rutherford in the center of group photo of the lab

NARR: But for Moseley, the real attraction was that it was run by the brightest star in physics – an irrepressible New Zealander named Ernest Rutherford.

STOP AND THINK 2: In Moseley's time, Manchester was one of most populous cities in the world. The reason was Manchester's diversified economy that included engineering, chemical, and electrical industries. Why would the people who ran these industries encourage scientific research?

Possible Student Answers: Some students may explain that advances in science often have industrial applications or can be used to create new inventions.

EVERYDAY APPLICATION 3: There is a strong connection between scientific research and industry. A study of U.S. industrial patents in 1997 showed that the majority of the papers cited in the patents were derived from publically supported scientific research.

CHAPTER 3: Rutherford's Boys

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure of Atoms

- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation. The decay of any one nucleus cannot be predicted, but a large group of identical nuclei decay at a predictable rate. This predictability can be used to estimate the age of materials that contain radioactive isotopes.

G: History and Nature of Science

Science as a Human Endeavor

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.

Nature of Scientific Knowledge

- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. … In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Alignment with the Next Generation Science Standards
Science and Engineering Practices
1. Asking Questions and Defining Problems
- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

3. Planning and Carrying Out Investigations
- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- Select appropriate tools to collect, record, analyze, and evaluate data.

Disciplinary Core Ideas
- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.

Photo of Rutherford

NARR: Rutherford had leapt into the study of radioactivity as soon as Marie and Pierre Curie announced their findings.

CONCEPT IN BRIEF: radioactive decay

Animation showing alpha and beta particles given off during radioactive decay

NARR: And he had already won the Nobel Prize for his discovery that radioactive atoms give off different kinds of rays and particles as they decay.

STOP AND THINK 3: What kinds of rays and particles do radioactive atoms give off as they decay?

Possible Student Answers: Some students may know that radioactive-decay products are gamma rays, alpha particles, and beta particles. A few students may know that gamma rays are high-energy electromagnetic waves, alpha particles are helium nuclei, and beta particles are either electrons or their positively charged counterparts, positrons.

Photo of Rutherford with his instruments

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

PHYSICIST DAVID KAISER, partly in VO
So by 1910 he was undoubtedly among the great physical scientists, thinking hard about the nature of radioactivity, about how to understand atoms and their parts.

Moseley is working at his equipment. In the background we hear Rutherford approaching, singing "Onward Christian Soldiers" – badly. Rutherford enters the lab and comes over to speak to him.

NARR: Moseley was soon assigned a research project on radioactivity, and Rutherford kept close tabs on his progress.

ERNEST RUTHERFORD

Good morning, Moseley! Well, how's it all going?

NEIL TODD, MANCHESTER UNIVERSITY, partly in VO

He would daily make a round and visit all of the young workers where they were carrying out their experiments.

We hear bits of their conversation about a problem Moseley is having with the instrument.

HARRY MOSELEY (TO RUTHERFORD)

The tube is giving off alpha and gamma rays.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

ERNEST RUTHERFORD (TO MOSELEY)

They're producing secondary electrons. Have you tried shielding?

NARR: "Papa," as they called him, would pour out advice – often seeing right to the heart of the matter.

ERNEST RUTHERFORD (TO MOSELEY)

That should do it. That should help.

Rutherford and Moseley continue discussing the problem.

PHYSICIST DAVID KAISER, partly in VO

He was constantly at the elbows and shoulders of his young students, coaxing them on, offering advice on the nitty-gritty of experimental technique. He seemed to have the magic hands to get things to work.

Rutherford claps him on the shoulder and leaves singing. Moseley returns to his work with a wry smile.

ERNEST RUTHERFORD
Carry on ... ward Christian Soldiers, marching as to war ...

NEIL TODD, MANCHESTER UNIVERSITY, partly in VO
It was a very happy atmosphere in his laboratory, because it was like a band of brothers, almost.

Photo of Rutherford's lab members in 1912. The people mentioned are highlighted.

NARR: Rutherford's band of brothers was one of the finest groups of young scientists ever assembled in one place. Among them were Hans Geiger, who would invent the radiation detector known as the Geiger counter; Charles G. Darwin, grandson of the great biologist, and James Chadwick, a future Nobel Prize winner.

CONCEPT IN DETAIL: contributions of individuals and teams to the scientific enterprise

Photo of young scientists at work, then shot of Manchester lab today

PHYSICIST DAVID KAISER, partly in VO
He had a very active group, of young researchers who were wondering about ultimate questions of "What is the nature of matter?" – with new discoveries practically every week.

STOP AND THINK 4: Rutherford's personality was an important factor in creating a scientific team and attracting talented people like Harry Moseley. Why does having a strong team matter in science? Why is personality important to forming a team?

Possible Student Answers: Many students may know that most scientific research is carried out by teams of people. A strong or attractive personality can convince some of the best people to join together in pursuit of a scientific goal.

CHAPTER 4: The Discovery of the Nucleus

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure of Atoms

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons.
- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation. The decay of any one nucleus cannot be predicted, but a large group of identical nuclei decay at a predictable rate. This predictability can be used to estimate the age of materials that contain radioactive isotopes.

G: History and Nature of Science

Science as a Human Endeavor

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.

Nature of Scientific Knowledge

- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Historical Perspectives

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.

Alignment with the Next Generation Science Standards

Science and Engineering Practices

1. Asking Questions and Defining Problems

- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

2. Developing and Using Models

- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

3. Planning and Carrying Out Investigations
- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- Select appropriate tools to collect, record, analyze, and evaluate data.

4. Analyzing and Interpreting Data
- Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.

6. Constructing Explanations and Designing Solutions
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena.

Disciplinary Core Ideas
- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.
- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.

Pull back from group lab photo

NARR: One of the most exciting discoveries came just a few months after Moseley's arrival, as Rutherford's team continued to probe the structure of the atom.

CONCEPT IN DETAIL: scientific knowledge evolves by using new evidence to build on earlier knowledge

Reprise animation of electron

NARR: They knew that J.J. Thomson's tiny, negatively-charged electron was one piece of the puzzle. But that left two big unanswered questions.

PHYSICIST JIM GATES

Since atoms are generally neutral, that meant that the atom itself had to somehow have a positive charge to balance the negative charge out.

Animation with a plus sign and big question mark over the atom

NARR: But where in the atom were the positive charges needed to offset those negative electrons?

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

PHYSICIST DAVID KAISER

And a related question, since people knew by this point that electrons were so much less massive than the atoms themselves, where was the mass distributed?

Photo of Rutherford with Geiger

CONCEPT IN DETAIL: radioactive decay

NARR: Rutherford and his students had been trying to answer these questions …

Reprise of Rutherford's radioactive decay illustration, alpha particle labeled

NARR: … with the help of the positively-charged alpha particles that poured out of radium during radioactive decay.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

Animation of the gold foil experiment

NARR: They aimed a beam of alpha particles at an ultrathin sheet of gold foil.

PHYSICIST DAVID KAISER, partly in VO

Most of the time, these alpha particles would sail right through. But every now and then, some of these projectiles would actually bounce practically right back in their faces. And that was really, really unexpected.

ERNEST RUTHERFORD

It was the most incredible thing that has ever happened to me. It was almost as if you had fired a 15-inch shell at a piece of tissue paper and it came back and hit you.

EXAMPLE OF SCIENCE PRACTICE: constructing explanations and designing solutions

Shot of the lab exterior today

NARR: In late 1910, Rutherford came into the lab one day and announced he knew what this surprising result meant.

CHEMIST GREG PETSKO

It meant that the atom must be mostly empty space but have some incredibly dense, hard center.

Animation showing the atom transforming as the mass and positive charge are squashed down into the center. Red alpha particles veer off as they approach the center.

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

NARR: If the atom's positive charge and most of its mass were concentrated in a tiny central core, it would let most particles sail through but repel any positive charge that came near the center.

One alpha approaches the center straight on and is kicked straight back.

BIOGRAPHER JOHN HEILBRON, partly in VO

Then you can give the incoming alpha particle a real kick and sometimes turn it all the way around.

CONCEPT IN DETAIL: atom

EXAMPLE OF SCIENCE PRACTICE: developing and using models

Animation reveals the new picture of the atom. The nucleus is labeled with a plus sign.

PHYSICIST DAVID KAISER, partly in VO

So with that we had this really quite, brand new vision of the structure of the atom. Almost all of its mass was concentrated very very tightly in a minute, little space, in what we would now call the nucleus. And then, separated by mostly nothing, you have these negatively charged electrons, sort of whizzing around, but at a great, great distance on the scale of the atom.

Notes from the Field:

This content is pretty abstract and can be tough for students to understand. I pause the video during the animations and go through it at my own pace, making sure my kids are getting the key points.

PHYSICIST JIM GATES

One of the most remarkable things about the atom is that it is mostly made of nothing!

Manchester lab group shot

PHYSICIST DAVID KAISER, partly in VO

I think the feeling in those hallways, the laboratories of Manchester, was one of great excitement. They could sense that Rutherford and his team had literally cracked open a new view of matter.

CONCEPT IN DETAIL: contributions of individuals and teams to the scientific enterprise

STOP AND THINK 5: The gold foil experiment helped scientists determine a model of atomic structure. Why might a model of atomic structure be helpful for understanding other phenomena?

Possible Student Answers: Some students may consider the connection among atomic structure, chemical bonding, and observable properties of materials. Some students may consider the connection among atomic structure, radioactivity, atomic fusion, and atomic fission.

CHAPTER 5: X-Ray Diffraction

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure of Atoms:

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.

Interactions of Energy and Matter

- Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. … Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance.

G: History and Nature of Science

Science as a Human Endeavor

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.

Nature of Scientific Knowledge

- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Historical Perspectives

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.

Alignment with the Next Generation Science Standards

Science and Engineering Practices

1. Asking Questions and Defining Problems

- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

3. Planning and Carrying Out Investigations
- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- Select appropriate tools to collect, record, analyze, and evaluate data.

4. Analyzing and Interpreting Data
- Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.

Disciplinary Core Ideas
- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

Crosscutting Concepts
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Zoom to Moseley in Manchester group photo

NARR: But while all this was going on around him, Moseley was consigned to plugging away on radioactivity research projects.

HARRY MOSELEY, partly in VO
I'm repeating someone else's experiment to please Rutherford, so the work is not very exciting. I'm hoping to be through with it soon.

Footage of Moseley working in the lab, not thrilled. He sighs.

CHEMIST RUSSELL EGDELL, partly in VO
From his correspondence, I think he found it actually slightly mundane just to be following on behind other people and not really making his own distinctive mark.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

Moseley is frustrated with a broken piece of equipment. Dissolve to shot of him reading a German physics journal.

NARR: So in the spring of 1912, when a piece of his radioactivity equipment broke, Moseley seized the opportunity to strike out in a new direction.

Mother reads letter in the garden.

HARRY MOSELEY VO

My dear Mother,

I'm sorry that I didn't answer your letter sooner, but I was very busy. Last Thursday we got the result we were searching for, using the X-rays.

Moseley reads about the German work. Close-up of the article he's reading.

NARR: Moseley had turned his attention to some exciting news out of Germany.

Images of X-ray excitement from the 1890s

NARR: X-rays – the same rays that had so captivated the world 15 years earlier – had been found to have properties like those of light.

CONCEPT IN BRIEF: X-rays

Illustration of Newton and the prism

NARR: Ever since Newton, it had been known that a prism could split light into a series of distinct colors, each with its own wavelength or frequency.

STOP AND THINK 9: What is light? Why does a prism separate white light into different colors?

Possible Student Answers: Some students may know that light is electromagnetic radiation. Some students may know that white light is a mixture of different colors of different frequencies of electromagnetic radiation, and that a prism separates this mixture into different colors because each frequency of light bends at a slightly different angle when it moves into the prism.

Photo of Max von Laue, animation of diffraction by crystal

NARR: What the German scientists had discovered was that X-rays could be split up, or "diffracted," in the same way … with the help of a crystal.

CONCEPT IN DETAIL: X-rays

Image of von Laue's spots

NARR: Only the resulting image was not a rainbow but a symmetrical pattern of spots on a photographic plate.

Moseley and Darwin work together in the lab on X-rays, chattering away.

CHARLES G. DARWIN (TO MOSELEY)
Power on.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

HARRY MOSELEY (TO DARWIN)
Fifteen volts and steady.

EVERYDAY APPLICATION 4: X-ray diffraction is an important tool for looking at the fine detail of materials. X-rays are a kind of electromagnetic radiation, and they travel in waves. X-rays have very short wavelengths (the distance between two adjacent wave peaks); therefore, X-ray waves are small enough to interact with atoms. Visible light, another kind of electromagnetic radiation, has much longer wavelengths; therefore, people use visible light to see objects much larger than atoms. X-ray diffraction looks at how X-rays are scattered when bounced off an object. The directions in which X-rays are scattered depend on several factors. For many years, X-ray diffraction has been used to obtain information about crystal structure, chemical composition, and the physical properties of materials and thin films. Recently, because of improvements to diffraction methods, X-ray diffraction has been used to obtain information about the internal structures of biological organisms.

Photo of Darwin

NARR: Intrigued, Moseley asked Charles G. Darwin to join him in investigating this curious X-ray pattern.

Moseley and Darwin continue working together in the lab.

CONCEPT IN DETAIL: contributions of individuals and teams to the scientific enterprise

CHARLES G. DARWIN (TO MOSELEY)
220 degrees, 10 minutes.

PHYSICIST JUSTIN WARK, partly in VO
Darwin was actually a mathematician, and that's really why Moseley got hold of his services, because he knew that this was going to imply some complex mathematics.

Animation showing how planes of atoms could reflect X-rays to create the pattern of spots

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

NARR: Moseley and Darwin concluded that the atoms inside the crystal were neatly arrayed in rows that reflected the X-rays to create the pattern of spots.

Rutherford meets with Moseley and Darwin in the lab. Rutherford is skeptical.

NARR: Excited by this discovery, Moseley and Darwin asked Rutherford for permission to devote all their time to this new project.

ERNEST RUTHERFORD

I don't really think that we are equipped – we don't really have the supervision for this sort of thing.

BIOGRAPHER JOHN HEILBRON, partly in VO

Rutherford, who knew nothing about X-rays, was not very enthusiastic about this new departure. So he at first opposed it.

ERNEST RUTHERFORD

Are you absolutely sure this is something you want to do?

CHARLES G. DARWIN

We were fired by our interest in this unexplored field, and had no idea where it would lead. At the time, X-rays were still mysterious. We simply wanted to know what they really were.

Rutherford reluctantly assents. Moseley and Darwin exchange glances, relieved to have been given the chance to move forward.

CHARLES G. DARWIN VO

Finally, we persuaded him to let us try.

ERNEST RUTHERFORD

Okay, well, on the condition that if you run into trouble of any kind, you do ...

NEIL TODD, MANCHESTER UNIVERSITY, PARTLY IN VO

I think it was essentially their enthusiasm for the subject, which convinced Rutherford that, yeah, this was worth a shot.

ERNEST RUTHERFORD

And keep me informed all along the way.

HARRY MOSELEY

Certainly sir.

CHAPTER 6: The Hardest Worker

Alignment with the NRC's National Science Education Standards

G: History and Nature of Science

Science as a Human Endeavor

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.

Nature of Scientific Knowledge

- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. … In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Historical Perspectives

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.

Alignment with the Next Generation Science Standards

Science and Engineering Practices

3. Planning and Carrying Out Investigations

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- Select appropriate tools to collect, record, analyze, and evaluate data.

8. Obtaining, Evaluating, and Communicating Information

- Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.

Disciplinary Core Ideas

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

Shots of Moseley and Darwin at work in the lab. They chatter away.

CHARLES G. DARWIN (TO MOSELEY)
220 degrees, 20 minutes.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

HARRY MOSELEY (TO DARWIN)
Fifteen volts and steady.

NARR: For six months, the two young researchers holed up in the laboratory.

Shot of Mom working in the spring garden. Then back to Moseley and Darwin working together.

HARRY MOSELEY VO
I wish I were with you to see all the fresh spring, but here it's all work. I'm like a gnome after a long winter of darkness, longing for some light.

Notes from the Field:

I like to point out to my students that hard work is just as important as being "smart," as demonstrated by Moseley's work ethic.

Moseley works alone in the lab late at night.

CHARLES G. DARWIN, partly in VO
Working with Moseley is one of the most strenuous things I've ever done. He is without exception the hardest worker I've ever known.

ERNEST RUTHERFORD, partly in VO
I'd arrive at the laboratory in the morning and meet Moseley just as he was leaving. He'd been at it all through the night – 15 straight hours.

CHARLES G. DARWIN
Indeed, one of Moseley's skills was knowing where in Manchester you could get a meal at three in the morning.

Moseley eats fruit while he reviews the manuscript to be submitted to Nature.

HARRY MOSELEY VO
We've sent a letter off to *Nature* describing what we have found so far. But we must keep on with the work. Many others are on the same track.

EXAMPLE OF SCIENCE PRACTICE: obtaining, evaluating, and communicating information

Photos of two Braggs, father and son

PHYSICIST DAVID KAISER, partly in VO

Moseley was not alone in realizing this was exciting. There was some pretty steep competition, like William Bragg and his son William Lawrence Bragg, who were already working hard and fast on similar techniques.

Moseley and Darwin discuss things in the lab.

NARR: Aware of this competition and anxious to return to Rutherford's work on the atom ...

CHARLES G. DARWIN

I thought I'd come by to bid you farewell.

NARR: ... Darwin decided to leave the partnership in the summer of 1913.

HARRY MOSELEY VO

I suppose this makes sense. You were always a better theoretician than you were a lab tinkerer.

CHARLES G. DARWIN

Will you go on alone?

HARRY MOSELEY VO

Oh, certainly. I think this might lead to something.

NARR: Rather than abandoning the work ...

CHARLES G. DARWIN

Well, I wish you all the best.

They shake hands and Darwin leaves. Moseley returns to work as Darwin looks back.

NARR: ... Moseley changed his approach, leaving basic research on X-rays to others.

BIOGRAPHER JOHN HEILBRON VO

Moseley, says, "We'll, okay. I'm not quite sure what these things are, but I know perfectly well how to use them."

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

Moseley works alone in the lab.

NEIL TODD, MANCHESTER UNIVERSITY, partly in VO
Having done the basic work with Darwin, he decided to use the method as a tool to investigate the nature of the elements.

BIOGRAPHER JOHN HEILBRON, partly in VO
And that is when his brilliant discoveries began.

CHAPTER 7: X-Ray Spectroscopy

Alignment with the NRC's National Science Education Standards
B: Physical Science
Structure of Atoms

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.

Structure and Properties of Matter:

- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.

Interactions of Energy and Matter

- Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance.

Alignment with the Next Generation Science Standards
Science and Engineering Practices
1. Asking Questions and Defining Problems

- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.
- Ask questions to clarify and refine a model, an explanation, or an engineering problem.

3. Planning and Carrying Out Investigations
- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- Select appropriate tools to collect, record, analyze, and evaluate data.

Disciplinary Core Ideas
- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

Crosscutting Concepts
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Moseley ponders an X-ray tube.

NARR: Moseley set out to learn if each element had a unique X-ray spectrum – a bar code like the ones that had been discovered a half century earlier using light. To find out, he placed a sample of an element inside an X-ray tube.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

Animation of the tube in Moseley's hands shows how the X-rays are created.

NARR: When a beam of electrons struck the sample, the element gave off X-rays. Moseley could then determine the element's X-ray spectrum.

The resulting X-ray spectrum of platinum, shot of Moseley in the lab.

HARRY MOSELEY, partly in VO

The whole subject of X-rays is opening up wonderfully. When we fire electrons at a target made of platinum, we get a sharp line spectrum of five wavelengths. Tomorrow I will search for the X-ray spectra of other elements.

I believe they will prove much more important and fundamental than the ordinary light spectra.

CONCEPT IN BRIEF: spectroscopy

Reprise image of light spectra

NARR: While the light spectra had been invaluable in identifying new elements, they hadn't solved certain puzzles about the *ordering* of the elements in the Periodic Table.

CONCEPT IN DETAIL: importance of scientific tools

Pan along the Periodic Table, highlighting the increase in atomic weights

NARR: The elements were arranged in columns with similar chemical properties, but they also tended to fall in order of increasing atomic weight – the amount a single atom of an element weighed.

CONCEPT IN BRIEF: element

CONCEPT IN BRIEF: atomic weight

PHYSICIST DAVID KAISER, partly in VO

But it's not perfect. Every now and then there seemed to be anomalies, little reversals, where chemical properties seemed to suggest one kind of ordering but their weights suggested the opposite order.

CONCEPT IN DETAIL: Periodic Table

CU of cobalt and nickel in the table, highlighting their inverted atomic weights.

AUTHOR ERIC SCERRI, partly in VO

For example, there was cobalt and nickel. Chemically speaking cobalt, should occur before nickel, and yet its weight is higher. And nobody knew why these inversions were happening.

In the PTE, the 10 metals of Moseley's study are highlighted: 11 metals from calcium to zinc, a continuous series missing only scandium.

NARR: To find out if X-rays could solve this riddle, Moseley set out to test ten neighboring elements in the Periodic Table, including that troublesome pair, cobalt and nickel.

Moseley studies his X-ray tube, realizing he will need something different.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

NARR: But Moseley quickly realized he had a problem: For each element he tested, he had to use the lab's vacuum pump to empty the tube of air.

PHYSICIST JUSTIN WARK

Vacuum pumps were jealously guarded devices. Lots of people in the lab needed a vacuum to do their research, and you had to join the queue.

Moseley begins sketching a new design.

PHYSICIST JUSTIN WARK VO

But Moseley realized that if he could put lots of these little elements at once in the same tube, then he could really make progress.

Drawing of Moseley's train, drawn from his paper. Dissolve to the actual device. Moseley has placed his metal samples at intervals along a track that has wheels. It's like a tiny freight train.

NARR: So he designed a long X-ray tube and built a tiny railroad car to carry his samples along inside it.

PHYSICIST JUSTIN WARK, partly in VO
And tied a little piece of silk fishing line to them and then tied that line to a little bobbin.

CONCEPT IN DETAIL: importance of scientific tools

Moseley turns the bobbin to move a new element into position, then turns on the electron beam.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

NARR: By turning the bobbin, Moseley could bring his samples … one after the other … into the line of fire.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

PHYSICIST JUSTIN WARK, partly in VO
And so he could do all of these elements in one go, if you like, with the same vacuum tube.

Moseley places a piece of film in the film holder, covers it, closes the chamber and switches on the electron beam tube to start the generation of X-rays. An animation shows how the device works. The X-rays bounce off a crystal, creating an image on the strip of film.

NARR: As each metal was struck by the electron beam, it gave off X-rays. When diffracted by a crystal, they created a series of lines on a strip of film.

Moseley enters his dark room – a tent of black cloth behind his work station. There, in the red glow, the spectral lines appear on the film strip.

HARRY MOSELEY VO
I've worked out a simple way of finding the wavelengths of my different elements.

BIOGRAPHER JOHN HEILBRON, partly in VO
Once he got it up and running he said, "It's so easy, it's almost a sin to snatch the bread from those hungry Germans."

HARRY MOSELEY, partly in VO

In five minutes I can get a strong, sharp photograph of the x-ray spectrum.

Animation shows the spectra of the six elements he mentions.

CONCEPT IN DETAIL: spectroscopy

NARR: Moseley found – just as he had hoped – that each element had a unique X-ray spectrum.

HARRY MOSELEY, partly in VO

In just four days I've got the spectrum of chromium, manganese, iron, cobalt, nickel and copper.

There is here a whole new branch of spectroscopy.

CHAPTER 8: Moseley's Staircase

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure of Atoms

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.

Structure and Properties of Matter:

- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.

Interactions of Energy and Matter

- Each kind of atom or molecule can gain or lose energy only in particular discrete amounts and thus can absorb and emit light only at wavelengths corresponding to these amounts. These wavelengths can be used to identify the substance.

G: History and Nature of Science
Nature of Scientific Knowledge

- Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.
- Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public.

Alignment with the Next Generation Science Standards
Science and Engineering Practices
4. Analyzing and Interpreting Data

- Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.

5. Using Mathematics and Computational Thinking

- Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations.

Disciplinary Core Ideas

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

Crosscutting Concepts

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Moseley sits down and lays out his strips of film on a light table, making sure to align them properly so that they accurately reflect the wavelengths of the spectral lines.

NARR: But not even Moseley expected what he found when he compared the spectra of all ten elements in his series.

BIOGRAPHER JOHN HEILBRON

The result of these measurements was absolutely extraordinary.

Moseley continues laying out his strips of film on the light table. The staircase is traced out by a red line.

PHYSICIST JUSTIN WARK, partly in VO

He decided to simply take his photographic film and to arrange the film according to its frequency.

NARR: Each piece of film represented a different element in his series.

PHYSICIST JUSTIN WARK VO
The frequencies of the X-rays that came out had an amazingly simple relationship.

NARR: As he laid them out, one after the other, Moseley found that their dominant X-ray lines rose in frequency, step by step.

When he's through, he sees that the strips form a perfectly regular "staircase."

PHYSICIST JUSTIN WARK VO
And that produces this beautiful staircase.

JOHN HEILBRON, partly in VO
He had no idea when he started to measure these frequencies that the result, now known as Moseley's staircase, would come about. That was a great surprise.

CONCEPT IN DETAIL: use of empirical standards, logical arguments, and skepticism to form scientific explanations

PHYSICIST JUSTIN WARK, partly in VO
I think he must have been astonished. And I think the scientific world was astonished that it was that simple.

Moseley looks down at the staircase, realizing he has discovered something remarkable.

NARR: It would be years before scientists understood the reason for this striking pattern. But Moseley knew at once he had made a fundamental discovery.

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

He sits back and thinks about it.

PHYSICIST JUSTIN WARK, partly in VO
He thought, "Ah! Now I have a means, for the first time, to really tell which element is which, and to put them in a proper order."

Zoom to and highlight the cobalt and nickel steps, then reprise of their out-of-order weights in the Periodic Table

NARR: Moseley's X-ray lines showed that cobalt and nickel were just where they should be, even though their atomic weights were out of order.

Moseley looks down at the light table.

NARR: The conclusion was inescapable: The X-ray spectra of the elements didn't depend on their atomic weights but on something even simpler.

PHYSICIST DAVID KAISER, partly in VO

There was a remarkably simple relationship between the wavelength or the frequency of that X-ray that came out and something they came to call the atomic number of the element.

CONCEPT IN BRIEF: atomic number

CHAPTER 9: Atomic Number (the Proton)

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure and Properties of Matter:

- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.

G: History and Nature of Science

Nature of Scientific Knowledge

- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. … In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Historical Perspectives

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.

Alignment with the Next Generation Science Standards

Science and Engineering Practices

2. Developing and Using Models

- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

4. Analyzing and Interpreting Data
- Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.

6. Constructing Explanations and Designing Solutions
- Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena.

Disciplinary Core Ideas
- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

Crosscutting Concepts
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Periodic Table – the numbers light up one after the other, indicating an element's place in the table.

CONCEPT IN BRIEF: Periodic Table

NARR: Up to now, "atomic number" had simply referred to the number of an element's box in the Periodic Table.

CHEMIST GREG PETSKO (MOTIONING)

All the way back to Mendeleev, it's where in the row you are. It's counting one by one.

Pan of Periodic Table with atomic numbers highlighted

NARR: But Moseley's results showed atomic number was much more than a convenient label.

CONCEPT IN DETAIL: scientific knowledge evolves by using new evidence to build on earlier knowledge

Reprise of staircase, with atomic numbers filling in

EXAMPLE OF SCIENCE PRACTICE: constructing explanations and designing solutions

HARRY MOSELEY, partly in VO

What we have here is proof that there's a fundamental quantity in the atom which increases by regular steps as we pass from one element to the next. This fundamental quantity can only be the charge on the central positive nucleus.

Animation: A nitrogen atom pops out of the Periodic Table. Its nucleus – an amorphous blob labeled +7 – transforms into a collection of seven positive particles. Next the oxygen atom pops out alongside it. Its nucleus contains eight positive particles. Fluorine pops out with 9 positive particles.

CONCEPT IN BRIEF: proton

NARR: Moseley had discovered that the nucleus was not one big positive blob … but a collection of positively charged particles that increased in number with each heavier element. Building on Moseley's work, Rutherford would soon discover this next piece of the atom – the proton – and show that each element in the Periodic Table is defined by the number of protons in its nucleus: its atomic number.

CONCEPT IN BRIEF: atom

CONCEPT IN DETAIL: atomic number

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

HARRY MOSELEY

Our experiments show that the atomic number always increases by a single unit from element to element. For hydrogen, the atomic number is 1; for helium, 2; for lithium, 3, and so on.

Periodic Table highlighting increasing atomic weight

NARR: Moseley's discovery put the Periodic Table in a whole new light. For the most part, elements were arranged in increasing atomic weight.

PHYSICIST DAVID KAISER, partly in VO

But that's not the real reason for that tremendous order that we find among all the elements. It really is marching along atomic number, the amount of positive electric charge on that nucleus, none of which was known in Mendeleev's own day.

CONCEPT IN DETAIL: use of empirical standards, logical arguments, and skepticism to form scientific explanations

EXAMPLE OF SCIENCE PRACTICE: developing and using models

CONCEPT IN DETAIL: element

CHEMIST GREG PETSKO

Weights didn't matter. Something fundamental that was deeper in the atom was what mattered.

ERNEST RUTHERFORD

Moseley's proof that the properties of an element are determined by its atomic *number*, not its atomic *weight*, ranks in importance with the discovery of the periodic law itself. In some respects it's even more fundamental.

HISTORIAN LAWRENCE PRINCIPE

Moseley and atomic number … that's really the crucial moment where we find out what an element really is.

CHAPTER 10: Calling the Roll of the Elements

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure of Atoms

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.

Structure and Properties of Matter:

- Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element.
- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.

G: History and Nature of Science

Nature of Scientific Knowledge

- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. … In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Historical Perspectives

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.

Alignment with the Next Generation Science Standards

Science and Engineering Practices

2. Developing and Using Models

- Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.

3. Planning and Carrying Out Investigations
- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.
- Select appropriate tools to collect, record, analyze, and evaluate data.

4. Analyzing and Interpreting Data
- Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.

Disciplinary Core Ideas
- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

Crosscutting Concepts
- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Composite image of proposed new elements emerging from Moseley's X-ray device, with voicings of their unfamiliar names

NARR: Armed with his X-ray machine, Moseley could quickly sort through the dozens of supposed new elements chemists had claimed to have found, separating the real from the imagined.

CONCEPT IN BRIEF: spectroscopy

PHYSICIST DAVID KAISER, partly in VO

He could distinguish between types of matter, with a brand new technique, not dependent on their chemical properties, but by measuring the atomic number based on these X-rays.

CONCEPT IN DETAIL: importance of scientific tools

STOP AND THINK 10: Moseley found that he could quickly identify the elements present in a sample using his technique. How might his method be used?

Possible Student Answers: Students might discuss applications to crime detection or health.

Moseley works in the lab.

NARR: Moseley's X-rays allowed him not only to rule out elements that *didn't* exist but also to predict what new elements would eventually be found.

Animated graph from Moseley's second paper showing a straight-line relationship among the elements. In the animation, we highlight the gap at 61.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

NARR: In 1914, Moseley measured the X-ray spectra of 30 additional elements beyond the first ten. They, too, fell into line according to atomic number, clearly revealing where elements were missing … and where no new ones could fit.

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

Dissolve to Periodic Table. It is gradually filled in, as if the elements were answering a roll call. A question mark appears in box 43, which doesn't answer the roll call.

NARR: "For the first time," one scientist marveled, "it was possible to call the roll of the chemical elements – to determine how many there were and how many remained to be discovered."

EXAMPLE OF SCIENCE PRACTICE: developing and using models

BIOGRAPHER JOHN HEILBRON

The idea that somebody could know how many elements God created, that was terrific.

Wide shot of Periodic Table with all seven missing elements highlighted.

NARR: After Moseley's work, it was clear that there were seven *and only seven* elements remaining to be discovered.

HARRY MOSELEY

But since we can now predict the X-ray spectra of these elements, they should not be difficult to find.

CHAPTER 10: Moseley's Death

Alignment with the NRC's National Science Education Standards
G: History and Nature of Science
Science as a Human Endeavor

- Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society.

Mother opens a letter.

NARR: In 1914, Moseley's continuing work on the elements was interrupted when his country called.

Photo of Moseley in uniform

HARRY MOSELEY VO

My dearest Mother,

I am now a second lieutenant in the Royal Engineers …

CONCEPT IN BRIEF: influence of society and culture on science

NARR: England had been drawn into war by events in Europe.

Reprise of photo of Moseley with Trinity College classmates

NARR: Like many others of his generation, Moseley felt a duty to serve.

HARRY MOSELEY VO

… I was very lucky to get into the army so quickly because RE commissions are much in demand.

Archival photo of World War 1 troops

CHEMIST RUSSELL EGDELL, partly in VO

He had a bit of a difficulty actually getting into the army, because he wasn't an engineer and the Royal Engineers wanted engineers.

Photo of Moseley

BIOGRAPHER JOHN HEILBRON, partly in VO

He badgered the recruiting officers to allow him in.

Photo of soldiers bathing at the beach

NARR: By the summer of 1915, Moseley was stationed in Turkey.

HARRY MOSELEY VO

It gets hotter here by the day, and only cool nights and sea bathing keep life tolerable.

ERNEST RUTHERFORD, partly in VO

I had mixed feelings about the enlistment of so many young men of science – pride over their ready response to the country's call, apprehension about irreparable losses to science.

Moseley writes in the tent. On the table beside him is the latest care package from home, which includes a jar of precious Tiptree jam. His mother reads the letter in the garden.

NARR: On August 3, 1915, he wrote from Gallipoli.

HARRY MOSELEY VO

My insides returned to duty and let me once more enjoy the good things which are sent us, foremost among them your Tiptree jam.

Moseley hears a bugle call, puts on his cap, jots down a final word and leaves the tent. Image and sounds of World War I battle at Gallipoli.

NARR: One week later, as they attempted to take a ridge, Moseley's brigade was overwhelmed by Turkish troops.

Reprise photo of Moseley in uniform

NARR: The 27-year-old communications offer was shot in the head and killed.

Amabel grieves in the garden. Cut to shot of Moseley's name on a memorial list of war dead at Manchester.

NEIL TODD, MANCHESTER UNIVERSITY, partly in VO

The news of Moseley's death was a terrible shock at Manchester, because by that time it was already clear that Moseley was one of the most brilliant, young physicists of his generation.

Photo of Moseley, Headline about Moseley's death: TOO VALUABLE TO DIE.

CHEMIST RUSSELL EGDELL, partly in VO

In the scientific community, there was a big sense of outrage, particularly from Rutherford, because he did feel Moseley was someone special.

Notes from the Field:

My students were surprised by how much Moseley accomplished in his 27 years and wondered what else he could have done if war hadn't ended his life so young.

ERNEST RUTHERFORD

The services he could have performed for his country … Instead they exposed him to the chances of a Turkish bullet.

Photo of Rutherford and Millikan at a Solvay Conference

NARR: Tributes poured in from around the world, none more moving than that of American physicist Robert Millikan, who had met Moseley during a visit to Rutherford's lab.

PHYSICIST ROBERT MILLIKAN

He threw open the windows through which we can glimpse the sub-atomic world with a clarity never dreamt of before.

Iconic photo of Moseley at Oxford

PHYSICIST ROBERT MILLIKAN VO

Twenty-seven years old … If the European War had done nothing worse than snuff out this one young life, that alone would make it one of most hideous crimes in history.

ACTIVITY IDEAS

Investigation of Electric Charge

All materials are made up of atoms, which contain electrons. In this activity, students will transfer electrons between ordinary items like balloons, wool, and plastic wrap, and this transfer will result in negatively and positively charged balloons. Carry out this investigation on a dry day.

NOTE: Do not allow students who have a pacemaker, cochlear implant, or similar device to work with electricity.

Set up two or three lab areas that contain six inflated balloons, 3–6 meters of fishing line, one piece of wool cloth or fur, one piece of plastic wrap, and one structure that can be used to suspend the balloons. Ask students to set up their lab areas by suspending 6 balloons, arranged in three sets of two adjacent balloons that are close but not touching. Ensure that the balloons are not close to any metal. Ask student groups to carry out the following steps and then end with a discussion about students' observations and inferences.

1. Rub both balloons in the first set of two adjacent balloons with wool cloth or fur. Let the balloons hang freely and then record what happens.
2. Rub both balloons in the second set of two adjacent balloons with plastic wrap. Let the balloons hang freely and then record what happens.
3. Rub one of the balloons in the third set of two adjacent balloons with the wool cloth or fur, and rub the other balloon with the plastic wrap. Let the balloons hang freely and then record what happens.

Demonstration of the Electrical Nature of Water

This demonstration shows that a charged object affects water. Have on hand a faucet or burette, 1 rubber rod, 1 acrylic rod, and wool. If using a burette, have a source of water available for refilling. Carry out the following steps.

1. Use a sink or burette to deliver a thin continuous stream of water at least six inches tall.
2. Negatively charge a rubber rod by rubbing it with wool.
3. Bring the negatively charged rod slowly toward the stream of water and hold it as close as possible without touching the water.
4. Put away the rubber rod and positively charge an acrylic rod by rubbing it with wool.
5. Bring the positively charged rod slowly toward the stream of water and hold it as close as possible without touching the water.
6. Ask students to speculate about the cause of the motion of the water. After discussion, explain that water molecules have charge because of the uneven sharing of electrons among the atoms that make up the molecules.

Recreating the Gold Foil Experiment

The first experiment that gave evidence about the structure of the atom was the gold foil experiment carried out by Hans Geiger and Ernest Marsden in Ernest Rutherford's laboratory. The results of this experiment led to the conclusion that atoms contain mostly empty space and a very small dense nucleus. Have students reproduce this experiment using a piece of paper with simple illustrations of atoms that represents the gold foil, a marble that represents the alpha particles fired through the gold foil, and a piece of carbon paper that represents the detection system.

To make the simple illustrations of atoms, draw about 24 circles that do not overlap but that cover most of the area of a piece of paper. Inside each circle, draw smaller identical circles about 2 centimeters in diameter to represent the nuclei of the atoms.

Introduce this experiment to students as a re-creation of the gold foil experiment. Then ask student groups of three to carry out the following steps:

1. Place the carbon paper face up on the floor.
2. Place the atom paper template face down on top of the carbon paper so that you do not see the atoms.
3. Have one student drop the marble from a height of 8 inches onto the paper. Have a second student catch the marble after it bounces so that only one hit occurs per drop. Have a third student count.
4. Make about 100 drops onto the piece of paper, with students switching their jobs after every 25 drops.
5. Examine the atom side of the paper. First record the number of marks on the piece of paper in all locations and then record the number of marks that are only fully inside the small nuclei.
6. Determine an indirect measurement of the area of all the nuclei by using the following equation:

$$\text{Area of all nuclei} = \frac{\text{(Number of marks in nuclei)(Area of the paper)}}{\text{(Total number of marks on the paper)}}$$

7. Count the number of nuclei on the paper and then calculate the area of one nucleus by dividing the area of all nuclei by the number of nuclei.
8. Check the accuracy of your indirect measurement by making a direct measurement of the area of one nucleus. Determine the area of one nucleus by using the following equation:
   $A = \pi \text{ (radius)}^{2.}$

If you have computer access, also have students download and run the PhET Simulation: Rutherford Scattering at http://phet.colorado.edu/en/simulation/rutherford-scattering (note that this activity is also referenced in Web Resources).

TEACHER NOTES

IN-DEPTH INVESTIGATION: ATOMS AND X-RAYS

Context

In *Numbering the Elements*, scientists use new tools and methods to probe and elucidate the structure of the atom. The endeavor required many contributions from different scientists, with each one studying different phenomena. Harry Moseley was one of the scientists who contributed to understanding the structure of the atom. When Moseley bombarded specific elements with electrons, he observed a pattern of emitted X-ray wavelengths that was the result of each element's atomic structure.

Overview

Students read about atomic structure and learn how atoms emit X-rays when they are bombarded with electrons. Students view the pattern of wavelengths that Moseley observed and develop an explanation for that pattern using what they have learned about atomic structure.

Next Generation Science Standards Alignment

Science and Engineering Practices

2. Developing and Using Models
    - Use a model based on evidence to illustrate the relationships between systems or between components of a system.
5. Using Mathematics and Computational Thinking
    - Use mathematical representations of phenomena to support claims.
6. Constructing Explanations and Designing Solutions
    - Apply scientific principles and evidence to provide an explanation of phenomena.
    - Apply scientific reasoning and models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation
7. Engaging in Argument from Evidence
    - Evaluate the evidence and reasoning behind currently accepted explanations to determine the merits of arguments.

Disciplinary Core Ideas

- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons.

Crosscutting Concepts

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Understanding Goals

Students should understand:

- Atoms are made up of three kinds of subatomic particles: electrons, protons, and neutrons.
- Electric charge is associated with subatomic particles. Protons have positive electric charge and electrons have negative electric charge.
- Each element has one more proton than the previous element in the Periodic Table; the atomic number is the number of protons and the number of electrons found in a neutral atom of that element.
- The structure of an atom is composed of a dense nucleus consisting of protons and neutrons and layers that contain specified number of electrons. The electrons move around within the layers, which take up most of the space of the atom. The layers are called energy levels or shells.
- Each electron energy level corresponds to a row in the Periodic Table and can contain as many electrons as there are elements in that row. Therefore, energy level 2 corresponds to the second row in the Periodic Table and can hold up to 8 electrons.
- Within an atom, there is an electric attractive force between the negative electrons and the positive nucleus.
- Energy is needed to dislodge an electron from an atom, and energy is released when an electron returns to an atom. The released energy is in the form of electromagnetic radiation, including X-rays.
- The wavelength of electromagnetic radiation is inversely related to the energy of the wave. The larger the wavelength, the less energy the wave carries.
- The amount of energy that is released when an electron falls from a higher level to a lower level in an atom varies according to the element's placement in the row of the Periodic Table. Across a row of the Periodic Table, the increasing number of protons in the nucleus of each element exerts an increasing amount of attraction on the electrons in a particular energy level. Therefore, across a row, an increasing amount of energy is released even if the electron falls between the same two energy levels.

Student Materials

You will find on the following pages a reading and activity.

Activity Facilitation

- Circulate around to students as they work on the activity.
- Make sure the students can determine the correct relationship between energy of X-ray and atomic number. Reading Figure 3 from left to right, wavelength increases as atomic number decreases. Because the wavelength is inversely related to the energy of the wave, energy of the emitted X-ray decreases as atomic number decreases. This relationship can also be stated as energy of the emitted X-ray increases as atomic number increases.
- Make sure that students understand that all the elements are found in the fourth row.
- Review the concepts of model, claim, evidence, and reasoning

Activity Rubric

Criteria	Not evident	Limited	Developing	Competent	Accomplished
Explain the jump in emitted X-ray wavelength values between elements Ti and Ca	No explanation	Explanation did not refer to regular pattern of X-ray values	Explanation referred to regular pattern of increasing energy of X-rays across the row, but explanation was not convincing	Explanation referred to regular pattern of increasing energy of X-rays across the row, and explanation was somewhat convincing	Explanation referred to regular pattern of increasing energy of X-rays across the row, and explanation was completely convincing
Does X-ray evidence support these aspects of the atomic model: electron energy levels correlate to row, and a proton is added to the nucleus as atomic number increases by one?	No explanation	Explanation did not refer to pull of the nucleus on electrons or to the energy of emitted X-rays	Explanation referred to pull of the nucleus on electrons and to the energy of emitted X-rays, but the reasoning that linked atomic model and evidence was not convincing	Explanation referred to pull of the nucleus on electrons and to the energy of emitted X-rays, and the reasoning that linked atomic model and evidence was somewhat convincing	Explanation referred to pull of the nucleus on electrons and to the energy of emitted X-rays, and the reasoning that linked atomic model and evidence was completely convincing

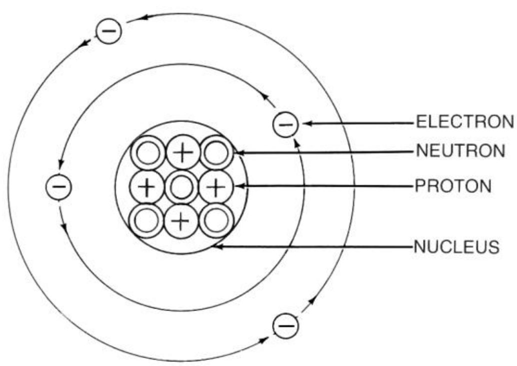
IN-DEPTH INVESTIGATION: ATOMS AND X-RAYS

READING: Why Did Moseley's Experiment Cause Atoms to Emit X-Rays?

Structure of the Atom

You have learned that atoms are not a single unit but are made up of smaller particles. In *Moseley: Numbering the Elements*, you learned part of the story of scientists' endeavor to identify the subatomic particles and to understand how they are arranged inside atoms. Their work resulted in a model of the structure of the atom that is still used today.

Each atom is made up of three kinds of subatomic particles: electrons, protons, and neutrons. The subatomic particles are arranged in a specific way inside each atom. The atom has a dense nucleus consisting of protons and neutrons. Layers that contain the electrons encircle the nucleus. Because the protons in the nucleus are positive and the electrons in the levels are negative, there is an electric attractive force between the electrons and the nucleus that holds the atom together. Figure 1 shows the atomic structure.



Source: http://commons.wikimedia.org/wiki/File%3AAtom_(PSF).png By Pearson Scott Foresman [Public domain], via Wikimedia Commons

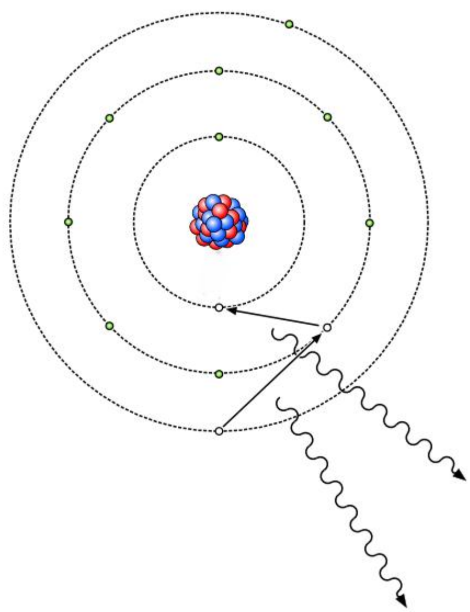
Figure 1: *An atom consists of a nucleus with protons and neutrons and electrons arranged in levels. This is a simplified two-dimensional diagram. An actual atom is three-dimensional, and the electron levels have more complex shapes.*

Energy and Electrons

These layers that contain the electrons are called energy levels. Each energy level corresponds to a row in the Periodic Table and can contain as many electrons as there are elements in that row. Electrons in an energy level have a specific amount of energy, and the energy increases as distance of the level from the nucleus increases.

In his X-ray experiment, Moseley bombarded elements with cathode rays. Cathode rays contain streams of fast-moving electrons that can sometimes knock an electron away from an atom. Once an electron is knocked away from the atom, there is an empty space in one of the energy levels. The nucleus of the atom will pull another electron from a higher energy level into the empty space. This creates a second empty space, and again the nucleus of the atom will pull an electron from a higher energy level into the second empty space.

Just as an object accelerating to the ground releases energy, an electron accelerating towards the nucleus releases energy. The energy released by an accelerating electron is in the form of electromagnetic waves, including X-rays. Refer to Figure 2.



Source: http://commons.wikimedia.org/wiki/File%3AElectron_capture_NT.PNG By Tosaka [CC-BY-3.0 (http://creativecommons.org/licenses/by/3.0)], via Wikimedia Commons

Figure 2: *When Moseley bombarded atoms with cathode rays, one of the fast-moving electrons in a ray would occasionally knock an electron out of an atom. The diagram shows what happens when an electron is knocked out of the layer closest to the nucleus. Electrons in other levels then fall, or accelerate, toward the empty spot in a domino-like event. Each falling electron releases energy in the form of electromagnetic waves, in this case, X-rays. The two electromagnetic waves—represented by the wavy lines—have different wavelengths because one electron is falling from energy level 2 to level 1 and one electron is falling from energy level 3 to level 2.*

The amount of energy released by the electron that falls from a higher level to a lower level is not always the same. One factor that affects the energy is the amount of positive charge of the nucleus. A nucleus with greater positive charge will have a stronger attraction for an electron in a particular layer. As the number of protons and the nuclear positive charge increases, the energy released by a falling electron also increases.

Another factor that affects the energy released by the electron that falls toward a nucleus is the distance that it falls. An electron might fall from an adjacent level of electrons or from a level that is farther away. As the distance of falling increases, the energy released by a falling electron also increases.

Moseley was able to detect the energy released by accelerating electrons. He used a method that allowed him to measure the wavelengths of the X-rays emitted from the elements that he was testing. Wavelength is inversely related to the energy of the wave. The larger the wavelength, the less energy the wave carries.

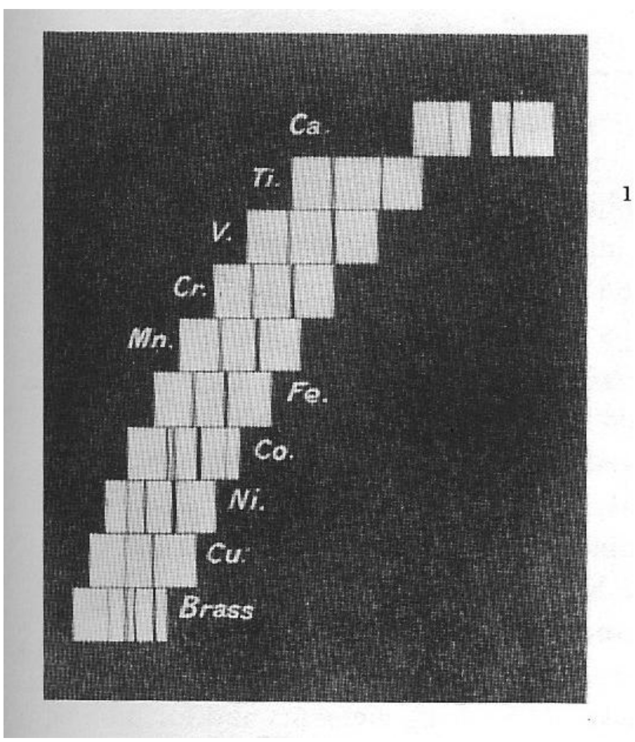
ACTIVITY: Explaining Moseley's Staircase

When Moseley bombarded specific elements with electrons, he observed a pattern of emitted X-ray wavelengths that was the result of each element's atomic structure. That pattern was called "Moseley's staircase." In this activity, you will examine Moseley's staircase and develop an explanation for the pattern that Moseley observed.

Procedure

Carry out the following steps with your group and record all work in your notebook.

1. Study the wavelength data and caption for Moseley's staircase in Figure 3. What is the relationship between energy of emitted X-rays and atomic number? Share your conclusion with the class.



Source: https://commons.wikimedia.org/wiki/File%3AMoseley_step_ladder.jpg By Henry Moseley (1887 - 1915) [Public domain], via Wikimedia Commons

***Figure 3:** Moseley's staircase. In this drawing, Moseley recorded the wavelengths of X-rays emitted by nine elements that were bombarded by cathode rays. He also included the alloy brass for comparison with the elements. The dark lines in the white rectangles show the size of the wavelengths emitted for each element and for brass. The wavelength increases and atomic number decreases as you move from left to right in Moseley's data presentation.*

2. Identify where the nine elements in Figure 3 are in the Periodic Table. Are they in the same row?
3. In Figure 3, why is there a jump in wavelength values between elements Ti and Ca?
4. Does X-ray evidence support these aspects of the atomic model: electron energy levels are correlated to rows, and there is an addition of a proton to the nucleus as element atomic number increase by one? Refer to the pull of the nucleus on electrons and the energy of emitted X-rays in your answer.

Web Resources

The Story of Moseley and X-rays

http://www.physics.ox.ac.uk/history.asp?page=Moseley

A concise biographical sketch and explanation of Henry J. G. Moseley's research. Includes a link to The Museum of the History of Science in Oxford, UK. Site maintained by the Physics Department of the University of Oxford.

H.G.J. Moseley

http://www.uh.edu/engines/epi717.htm

A revealing look at Henry J. G. Moseley and his relationship with Ernest Rutherford, produced by KUHF-FM. Includes streaming audio of the text with music. Site maintained by Engines of Our Ingenuity and The University of Houston's College of Engineering.

Moseley's Discovery - The Modern Concept of Atomic Number

http://www.chemteam.info/AtomicStructure/AtNum-Moseley.html

A history of Henry J. G. Moseley's discovery of the concept of atomic number, with a section about Moseley's research. Puts his work in a larger context. From the Chem Team website. Site maintained by John Park of Diamond Bar High School, Calif.

Moseley's Plot of Characteristic X-rays and Moseley's Modeling of X-ray Frequencies

http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/moseley.html

The actual computations carried out by Henry J. G. Moseley as well as a description of the origin of the "Moseley plot." Site maintained by C. R. Nave.

This Month in Physics History: August 10, 1915: Henry G.J. Moseley Killed in Action

http://www.aps.org/publications/apsnews/201208/physicshistory.cfm

The importance of Henry J. G. Moseley's work is described in this American Physical Society article.

Clarendon Laboratory, University of Oxford

http://www.rsc.org/Education/EiC/issues/2007Nov/MoseleyLandmark.asp

This website commemorates the Royal Chemical Society's awarding of Chemical Landmark status to the laboratory where Henry J. G. Moseley carried out the experiments that led to his discovery of atomic number.

PhET Simulation: Build an Atom

http://phet.colorado.edu/en/simulation/build-an-atom

Students can download this simulation and drag protons, neutrons, and electrons to construct an atom. As particles are moved into place, the simulation automatically displays the net charge, atomic mass number, atomic symbol, and name of the element. Site created and maintained by the PhET™ project at the University of Colorado.

PhET Simulation: Rutherford Scattering

http://phet.colorado.edu/en/simulation/rutherford-scattering

How did Ernest Rutherford and his colleagues figure out the structure of the atom without being able to see it? Students can download this simulation and carry out the famous experiment in which Hans Geiger and Ernest Marsden observed alpha particles bouncing off atoms. Site created and maintained by the PhET™ project at the University of Colorado.

Rutherford—The Road to the Nuclear Atom

http://cerncourier.com/cws/article/cern/45748

Ernest Rutherford assembled a team of scientists in his lab in Manchester, including Henry G. J. Moseley, which would change history with its discoveries. This online article in the *Cern Courier* describes Rutherford's career.

The High Frequency Spectra of the Elements

http://web.mit.edu/8.13/www/pdf_files/moseley-1913-high-freq-spectra-elements-part2.pdf

This is a reprint of the paper that Henry J. G. Moseley published explaining his work with the emission of X-rays by various elements that had been bombarded with a stream of fast-moving electrons.