

4. Marie Curie: Unlikely Revolutionary

CHAPTER 1: Polish Origins

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure of Atoms:

- Matter is made up of minute particles called atoms, and atoms are composed of even smaller components.

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.

F: Science in Personal and Social Perspectives

Science and Technology in Local, National, and Global Challenges

- Progress in science and technology can be affected by social issues and challenges.

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.

Host with the Periodic Table behind him

HOST

As the 19th century drew to a close, the **Periodic Table's** ability to corral the **elements** contributed to a growing sense that the work of science was just about complete. Most of nature's building blocks had been found, measured and cataloged. Chemists agreed these elements had been, and always would be, the same – forever fixed, unchanging. All that remained was to fill in the few remaining blanks.

CONCEPT IN BRIEF: matter

CONCEPT IN BRIEF: element

CONCEPT IN BRIEF: Periodic Table

STOP AND THINK 1: What do you think the host means when he says that elements are unchanging?

Possible Student Answers: Students' answers to this question will most likely reflect their prior instruction and information they have gained through their own interests. Use this question as an opportunity to find out whether students understand that elements are made up of one kind of atom.

Note: “Element” is one of those scientific words that has other meanings in everyday language. This varied usage can cause confusion among students and create misconceptions. However, even among chemists the word element has several meanings. The word element is used to refer to both a material substance that is an element and to atoms of that element. It may be useful to discuss the two scientific meanings of the word and to clearly distinguish between its uses when referring to a material substance and when referring to an atom.

Host steps forward to reveal a photo of our next character: Marie Curie.

HOST

Or so it seemed. In fact, this smug sense of satisfaction was about to be shattered by something – and someone – completely unexpected.

CONCEPT IN BRIEF: influence of society and culture on science

Marie uses wash bottle in the lab, then strolls down a “Paris” street.

NARR: She was the unlikeliest of revolutionaries – a graduate student ... a woman ... from Poland ... who had left her homeland to pursue her passion for science in Paris.

Photo of Marie

NARR: Yet in four short years, her discoveries would transform our understanding of matter and make her one of the most famous women in the world.

Photo of Marie in the lab

CHEMIST DAGMAR RINGE, partly in VO

She worked on something that was relatively obscure and turned it into a blockbuster. New elements, new properties and a whole new way to look at the world.

Photos of young Marie and the Sklodowski family. Photo of square with ranks of Russian troops.

NARR: The world would know her as Marie Curie, but she was born Maria Sklodowska, into a family of Polish patriots, at a time when Warsaw was under Russian rule.

On a graphic map, Poland is swallowed up by three surrounding countries, and Warsaw becomes part of Russia.

NARR: Poland had been literally wiped off the map, its residents forbidden to speak their own language or teach their own history.

Photos of Marie's parents and their five children

NARR: But Maria's family secretly defied the czar, speaking Polish at home and reciting patriotic poetry to preserve their Polish heritage.

Photo of Warsaw with Russian obelisk

BIOGRAPHER SUSAN QUINN, partly in VO

She used to go by an obelisk erected in honor of the Russian people and spit on the obelisk on the way to school. So you can see Maria learned early to be a fighter and resister.

Photo of young Maria

NARR: The daughter of two teachers, Maria excelled in science and math.

Photo of down-trodden Poles

NARR: But in Russian-ruled Poland, women were not allowed to attend university, let alone become scientists.

STOP AND THINK 2: Historically, some groups of people have been discouraged from becoming scientists. How do you think this restriction has influenced or hindered scientific developments?

Possible Student Answers: Students' answers to this question will vary. Students may understand that such a restriction meant that fewer competent people were working on scientific developments and progress is slower.

HISTORIAN DAVID KAISER

Very, very few places in Europe, or elsewhere, had opportunities for young women to study science. So one of the few places that she could was, in fact, in Paris.

Photo of Wladyslaw Sklodowski and his three daughters

NARR: But because her family was too poor to send her, Maria would first have to work for six long years as a governess to support her older sister's studies.

Notes from the Field:

My students were really appalled by the injustices Marie Curie suffered just because she was a woman. I used this as a springboard for a conversation about social injustice and the effect it can have on science.

Photo of Marie and her older sister

NARR: Only at age 24 did she finally get her chance.

BIOGRAPHER SUSAN QUINN

She waited her turn and she didn't give up. And when the turn came she took it.

CHAPTER 2: Marie in Paris

Alignment with the NRC's National Science Education Standards

F: Science in Personal and Social Perspectives

Science and Technology in Local, National, and Global Challenges

- Progress in science and technology can be affected by social issues and challenges.

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.

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.

Archival photos of Paris in the 1890s

MARIE CURIE, partly in VO

I was lost in the great city, but the feeling of living there alone – taking care of myself without any help – didn't depress me at all. I had been waiting for this opportunity for a long time.

Paris archival photos, emphasizing technology

CONCEPT IN DETAIL: influence of society and culture on science

NARR: Paris in the 1890s was like no other place on earth – a living showcase for the wonders of science and technology.

Streetcar photo

NARR: The city boasted such modern marvels as electric streetcars and telephone exchanges.

Photos of the Pasteur Institut

NARR: At the laboratories of Louis Pasteur, scientists were conquering diseases that had plagued humanity for centuries.

Lumiere brothers film footage

NARR: The Lumiere Brothers were thrilling crowds with their new invention: pictures that actually moved.

Pull back on photo to reveal the Eiffel Tower

NARR: And rising above it all was the brand new Eiffel Tower, which would remain the world's tallest structure for nearly half a century.

HISTORIAN DAVID KAISER

Here was Paris, the kind of intellectual, artistic, technological capital of the universe. This was where the modern age was born.

Photo of Paris night life

BIOGRAPHER SUSAN QUINN, partly in VO

She felt this precious sense of liberty. She could say whatever she wanted, go wherever she wanted. And she took it all in and loved it.

MARIE CURIE

Everything I saw and learned was a new delight to me. I had only one regret – the days were too short and went by too quickly.

Photos of Marie and the Sorbonne ca 1891

NARR: Adopting the French form of her name, “Marie,” she enrolled at Paris’ pre-eminent university, the Sorbonne, where she could study under the leading lights of French science.

Photo of Lippmann

NARR: One of them was Gabriel Lippmann, a future Nobel Prize winner.

Photos of Poincare, other Sorbonne teachers

BIOGRAPHER SUSAN QUINN VO

Another was Henri Poincare, who was one of the leading mathematicians of the 19th century. One of her math instructors was a mountain climber. Another was an aviator. These were exciting people, scientists who had exciting lives.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

MARIE CURIE

It was like a new world open to me, the world of science, which I was at last permitted to know in all liberty.

Photos of Sorbonne classroom, Lippmann

CONCEPT IN BRIEF: magnetism

NARR: Marie graduated first in her class in physics and, with Professor Lippmann's help, received a grant to do research on **magnetism**.

Photo of Pierre Curie in classroom

NARR: A friend suggested she seek out a French physicist who had studied the subject and might have some lab space for her. The meeting would change her life.

CHAPTER 3: Pierre

Alignment with the NRC's National Science Education Standards

B: Physical Science

Motions and Forces

- Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces.

F: Science in Personal and Social Perspectives

Science and Technology in Local, National, and Global Challenges

- Progress in science and technology can be affected by social issues and challenges.

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.

Photo of young Pierre Curie

MARIE CURIE, partly in VO

Pierre Curie seemed to me very young, though he was 35 at the time.

BIOGRAPHER SUSAN QUINN, PARTLY IN VO

I think it was pretty much electric from the beginning.

Photo of young Marie

PIERRE CURIE, partly in VO

With all my heart I thank you for your photograph. I showed it to my brother Jacques -- was I wrong? He finds you very fine but he also said, "She has a very decisive look, maybe even stubborn."

Photos of young Pierre Curie and the School of Industrial Physics and Chemistry, where he worked

NARR: Pierre Curie was a first-rate researcher, but he had never bothered to complete his dissertation and was content teaching at an industrial college.

STOP AND THINK 3: A science teacher needs science knowledge. What other careers require science knowledge?

Possible Student Answers: Students might think of careers in electronics, medical settings, science journalism, pharmacies, biochemistry, aerospace, engineering, machining, electricity, and farming.

Curie family photo

BIOGRAPHER SUSAN QUINN, partly in VO

He was diffident, modest and shy. He was very much an outsider. He had been homeschooled by his politically radical father, along with his brother Jacques.

MARIE CURIE VO

In a family photograph you see him with his brother. His head is resting on his hand. It's a pose of ... dreaming, as if he is looking at some inner vision.

NARR: Pierre was a man of ideas, not action.

Photo of Marie

NARR: But he was galvanized by this young woman and pursued her as he had nothing else in his life.

Photo of Pierre and Marie in the lab

PIERRE CURIE, partly in VO

It would be a beautiful thing if we could spend our lives near each other, true to our dream – in science, where every discovery, no matter how small, lives on.

Photos of the Sorbonne and Marie's father

NARR: Pierre's proposal posed a dilemma for Marie. She had planned to get a first-rate scientific education in Paris and then return to her beloved Poland to teach and care for her aging father.

BIOGRAPHER SUSAN QUINN

Her mother had died of TB early on, and he was counting on Marie coming back.

Marie and Pierre walk along a "Paris" street.

NARR: Now this ardent young man was offering her an exciting life as a working scientist.

MARIE CURIE

It was a decision that would mean abandoning my family and my country.

BIOGRAPHER SUSAN QUINN

Marie had all those feelings of responsibility for her father, for her family, and then for Poland on top of that.

Photo of Marie and Pierre together, arms linked

NARR: In the end, their mutual devotion – to each other and to science – overcame Marie's resistance.

BIOGRAPHER SUSAN QUINN, partly in VO

She wrote one of her friends: “Fate has brought us together, and we simply can’t bear to be apart.”

Photo of the two of them with their bikes

NARR: The newlyweds left on a cycling honeymoon after a simple ceremony in 1895.

CHAPTER 4: Mysterious Rays

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.

Interactions of Energy and Matter

- Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays.

Structure of Atoms:

- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation.

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.

Disciplinary Core Ideas

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.

Photo of Marie and Pierre with young Irene

NARR: By 1897, even with a toddler to care for, Marie had set her sights on getting what no other woman had ever received in France: a doctorate in physics.

Selection of X-ray images

NARR: At the time, the world was abuzz with excitement over a new discovery: mysterious rays that had the power to "see through" solid objects.

STOP AND THINK 4: What do you know about X-rays? How can X-rays pass through parts of the body?

Possible Student Answers: There is a common misconception that the different frequency ranges of electromagnetic radiation (light, microwaves, X-rays, and so on) are separate phenomena. Students may therefore not know that X-rays are electromagnetic radiation and they may not know how X-rays are created. They may know that X-rays have high energy. They may also know that this energy is absorbed in different amounts when it passes through the body, which is why X-rays can be used to create medical images.

X-ray of hand

PHYSICIST JIM GATES, partly in VO

You could by this process look at the bones inside of your living hand. It's as if you had a magical set of glasses that lets you see inside of living creatures. And that sparks the public imagination.

CONCEPT IN BRIEF: X-rays

CONCEPT IN BRIEF: impact of scientific technologic progress on society

Archival images showing the potential medical applications

NARR: Doctors instantly recognized X-rays as an invaluable diagnostic tool.

Images of the scientific interest

HISTORIAN DAVID KAISER, partly in VO

There was a great rush of excitement from working scientists, as well. In that first year there were about a thousand scientific articles published, at a time when the entire physics community in the world was only a thousand members.

EVERYDAY APPLICATION 1: The name "X-rays" was created as a temporary name and meant "unknown radiation." However, the name stuck, and now almost everyone is familiar with the use of X-rays to see broken bones, swallowed coins and keys, and parts of the body like the lungs. X-rays are made up of high-energy electromagnetic waves. When X-rays go through a person's body and onto a film, the waves pass around smaller atoms but are absorbed by larger atoms—leaving a dark outline on the film. Since bones contain calcium, a larger atom, the dark outline shows the person's bones.

Photo of Marie and Pierre

NARR: But with so many others doing research on X-rays, Marie felt it would be hard to make an original contribution.

CHEMIST DAGMAR RINGE

And so she picked something that she could work on where there was less competition – in fact, no competition.

Photo of Henri Becquerel, Periodic Table with U highlighted.

NARR: Just a year earlier, a French physicist named Henri Becquerel had discovered a different kind of ray given off by the element uranium.

CONCEPT IN BRIEF: radioactivity

Photo of Becquerel's cross

NARR: These “uranic rays” were powerful enough to penetrate thick black paper and create an image on a photographic plate.

Becquerel's cross image slides over for comparison with a much sharper X-ray image.

NARR: But the images were not nearly as striking as those created by X-rays, and they seemed to have no practical value.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

Animated montage of Becquerel's papers

NARR: So after writing a few papers about this scientific curiosity, Becquerel dropped the subject, thinking it had been “squeezed dry.”

MATERIALS SCIENTIST AINISSA RAMIREZ

Marie just thought that this was a tremendous thing to work on, particularly as a graduate student.

MARIE CURIE

The subject was attractive to me because it was entirely new – little had been written about it.

STOP AND THINK 5: Most scientists' research builds on prior experiments and theories. Based on what you have learned about Marie Curie, why do you think she was attracted by an entirely new phenomenon?

Possible Student Answers: Marie Curie had not received encouragement to pursue science. She may have thought that by working on an entirely new phenomenon, she would have more control over the work she would be doing. She also may have thought that the work might be an opportunity to contribute to scientific knowledge.

Host stands at a bench with a battery, a wire and a small light bulb in front of him.

CONCEPT IN BRIEF: electricity

HOST

There was another reason Becquerel's uranic rays appealed to Marie:

CU of the electric bulb connected by wire to the battery. The bulb is lit. He cuts the wire and the light goes off.

HOST

She had spotted a clue that might reveal more about them.

He holds the two ends an inch apart.

HOST

As you can see, air is normally a poor conductor of **electricity**. The current can't jump this gap, so the bulb doesn't light. But Becquerel had noticed his uranic rays had the mysterious power to charge the air around them, allowing electricity to leak across.

CONCEPT IN BRIEF: ionization

CONCEPT IN BRIEF: importance of scientific tools

CU: Bulb lights up as host touches the two ends of the wire together.

HOST

The amount of electricity was incredibly small – about a trillionth the amount needed to light this little bulb. No meter of the day could measure it. But Marie had a secret weapon Becquerel didn't.

Notes from the Field:

I use this opportunity to emphasize how important careful measurements are, especially with such small amounts.

STOP AND THINK 6: What materials conduct electricity? What is the different between materials that do and materials that do not conduct electricity?

Possible Student Answers: Students' answers to this question will most likely reflect their prior instruction and information they have gained through their own interests. Conductive materials are materials that have mobile electric charges, such as electrons in metals. Non-conductive materials do not have mobile electric charges.

CHAPTER 5: The Curies' Instruments

Alignment with the NRC's National Science Education Standards

B: Physical Science

Motions and Forces:

- Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces, and moving magnets produce electric forces.
- The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel.
- Most observable forces such as those exerted by a coiled spring or friction may be traced to electric forces acting between atoms and molecules.

Structure of Atoms:

- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation.

Interactions of Energy and Matter

- Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays.

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.

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.

Disciplinary Core Ideas

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.
- 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.

Pierre shows Marie the equipment.

HISTORIAN DAVID KAISER VO

Right in Marie’s own household was perhaps *the* world expert in how to measure tiny little electrical effects. The two of them, Pierre and Marie Curie, designed this really quite ingenious instrument to measure these very subtle electrical effects from her samples.

CONCEPT IN DETAIL: electricity

Pierre places a test substance on the bottom plate of the ionization chamber as Marie watches.

NARR: They placed a layer of uranium on a metal plate, then charged the plate with a battery.

Animation shows leaking of electricity from the bottom plate to the top.

NARR: As expected, electricity leaked across the gap to the plate above.

Pierre and Marie at the quartz generator

NARR: To measure this tiny current, the Curies would use this second device to create a matching amount of electricity.

STOP AND THINK 7: Often, careful measurements of a phenomena can reveal new information. What might Marie and Pierre Curie learn about “uranic rays” by measuring how much electricity leaked across the gap between the charged plates?

Possible Student Answers: Students may suggest several ideas. The Curie team could determine if the ionization of the air varied according to the amount of uranium. They could test other substances for an ability to ionize air.

Cutaway animation revealing crystal inside

NARR: Inside was a special crystal that could generate its own tiny charge, thanks to a phenomenon called piezoelectricity.

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

Old photo of Pierre at a lab bench with the quartz generator matching ours

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

NARR: More than 20 years earlier, Pierre and his brother Jacques had discovered that certain crystals give out electricity in response to pressure.

Animation shows how crystals give out electricity when squeezed or stretched.

HISTORIAN DAVID KAISER, partly in VO

The amount of electricity generated when you squeeze or stretch that crystal depends precisely on how hard you press on that crystal. And that means you have a way to make a very, very sensitive measurement of minute little electrical currents.

CU: Marie places a weight on the pan.

NARR: By placing a weight on the pan below

Animation showing the electrical connections among the three instruments and the passage of two currents to the electrometer.

NARR: ... Marie stretched the piezoelectric crystal inside the device. Then, by slowly *relieving* the tension – unstretching the crystal – she could generate a charge exactly offsetting the one coming from her uranium sample.

In lab footage, Pierre moves to the electrometer and calibrates the spot with Marie's help. We see a spot of light reflected onto the graduated scale Marie is watching. The spot is near 0.

NARR: She could tell the two charges were equal when the spot of light from this third instrument was at zero on the scale.

HISTORIAN DAVID KAISER, partly in VO

Though it didn't look very pretty, this sort of pulled together little contraption was exquisitely accurate and could allow them to make measurements like no one else in the world.

CONCEPT IN DETAIL: importance of scientific tools

CU of starting the stop watch. Wide shot of Pierre instructing Marie how to use the instruments.

NARR: But *using* these instruments required extraordinary concentration and dexterity.

CU of Marie's fingers on the weight

NARR: Ever so gradually, Marie relieved the tension on the crystal ...

CU of her eyes, then CU of what she's following: a beam of light that moves back and forth along a graduated scale, staying close to zero.

NARR: ... while carefully watching the spot of light to keep the two charges in balance ...

CU of Marie's face

NARR: ... and timing how long it took to lift the weight entirely off the pan.

CU of hand on weight, two-shot of Marie and Pierre

NARR: The faster she had to remove the weight, the stronger the activity of her test sample.

Photo of Curie in her lab, holding a stop watch

BIOGRAPHER SUSAN QUINN, partly in VO

And that's why, when you see pictures of Marie Curie in this experiment, she is sitting there with a stop watch.

She lifts the weight from the tray, then stops the watch. "Tres bien" moment between Marie and Pierre.

MARIE CURIE, partly in VO

I never dreamt that I was about to embark on a new science that Pierre and I would follow for the rest of our days.

STOP AND THINK 8: Scientific work is done by collaborative teams. Think about your experience in doing science. What kinds of skills are needed to hypothesize, experiment, draw conclusions, and communicate science work?

Possible Student Answers: Students should list a number of skills, which may include prior knowledge of science, familiarity with existing laboratory equipment, ability to create new laboratory equipment, ability to design experiments, ability to understand data, ability to represent data, ability to communicate well in writing, analytical ability, synthetic ability, and openness to new ideas.

CHAPTER 6: Discovering Radioactivity

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure of Atoms:

- Matter is made up of minute particles called atoms, and atoms are composed of even smaller components.
- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation.

Structure and Properties of Matter:

- An element is composed of a single type of atom.
- A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms.

F: Science in Personal and Social Perspectives

Science and Technology in Local, National, and Global Challenges

- Progress in science and technology can be affected by social issues and challenges.

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.

Historical Perspectives

- The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge.

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.

6. Constructing Explanations and Designing Solutions

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

Disciplinary Core Ideas

- 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.

Marie continues her measurements, drinking tea to stay warm, adding new samples to the ionization chamber and repeating the process of measuring their effects.

CONCEPT IN DETAIL: element

NARR: Day after day, working in a cramped, unheated storeroom, Marie painstakingly carried out her measurements. She compiled data on uranium, then went on to test the other known elements to see if any of them could also electrify the air.

HISTORIAN DAVID KAISER, partly in VO

She was not expecting to make any sort of earth-shattering discoveries.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

BIOGRAPHER SUSAN QUINN, partly in VO

She thought she would do some sort of diligent work on a whole lot of elements, and she would measure their power.

HISTORIAN DAVID KAISER VO

Exactly what you would expect for a perfectly legitimate PhD dissertation.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

Marie continues her measurements.

NARR: And for a while, the results were predictably dull. No other elements showed this strange property.

CONCEPT IN DETAIL: ionization

Pierre works in the background.

BIOGRAPHER SUSAN QUINN, partly in VO

Things were going along pretty routinely until one day in February of 1898. And that was the day that everything changed.

Marie is puzzled, calls over Pierre.

NARR: In the course of a single week, Marie made two startling discoveries.

Zoom to thorium in the periodic table of the 1890s

NARR: She found that the element thorium could also make air a better conductor.

HISTORIAN DAVID KAISER, partly in VO

That was the first, real solid indication that this was not unique to uranium. This might be a property of **matter**, not a curiosity of one particular element.

CONCEPT IN DETAIL: radioactivity

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

MARIE CURIE, partly in VO

It was necessary to find a new term to define this new property of matter. I proposed the word “radioactivity**.”**

STOP AND THINK 9: What do you already know about radioactivity?

Possible Student Answers: If students have recently studied radioactivity, they may know that radioactivity is the emission of high-energy electromagnetic waves and particles by unstable nuclei as they undergo nuclear transformation. Students may know that this process results in the formation of more stable nuclei. Students may know that only certain isotopes emit radiation and that the number of neutrons may be an important factor in determining radioactivity.

Marie and Pierre puzzle over the results. CU of notebook shows pitchblende’s readings are four times as high as uranium’s. Marie and Pierre chatter in French.

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

NARR: The next surprise came when Marie tested **pitchblende** – the raw ore from which uranium is taken. Something was very wrong. Pitchblende seemed to be four times as radioactive as uranium itself.

Marie watches as Pierre looks for the source of the strange reading. He removes the housing and brushes off the crystal inside.

CHEMIST DAGMAR RINGE, partly in VO

When I find a result like that, as a scientist my first reaction is, “I made a mistake,” or, “The machine isn’t working.”

HISTORIAN DAVID KAISER, partly in VO

She did what every good scientist should do, which was doubt it, be extremely skeptical, and check every last step of that chain.

STOP AND THINK 10: Why did Marie Curie check the equipment she was using to measure radioactivity at this point in her experiments?

Possible Student Answers: Marie Curie had tested all the elements and knew that only uranium and thorium emitted “uranic rays.” When she found that pitchblende, the material from which uranium was isolated, was a stronger source of “uranic rays” than either uranium or thorium, she had no explanation for this result. Before she could propose a reason for this unexpected result, she needed to make sure that the measurement was real and not a result of the equipment not working correctly.

EVE CURIE VO

So my mother made her measurements over again ...

EVE CURIE

– ten times, twenty times – until she was forced to accept the results.

Marie repeats her measurements again and again. The results keep coming out the same. Pierre joins her for the final confirmation. The stopwatch keeps coming up 20 seconds. Marie looks at Pierre: This is real.

EXAMPLE OF SCIENCE PRACTICE: constructing explanations and designing solutions

NARR: In time, the Curies realized this was no mistake. The readings from pitchblende were real.

MATERIALS SCIENTIST AINISSA RAMIREZ

A light bulb went off, and they said, “Well, maybe there is something else in there.”

CONCEPT IN DETAIL: radioactivity

Marie writes in her notebook.

BIOGRAPHER SUSAN QUINN, partly in VO

Very soon, they began to suspect that there was another element in pitchblende, which was producing this enormous radioactivity.

CONCEPT IN DETAIL: element

HISTORIAN DAVID KAISER

There must be some new thing under the sun, some new element that had never been seen before.

MARIE CURIE

And it must be intensely radioactive, since it was present in amounts so small that no one had ever detected it.

CHAPTER 7: Two New Elements

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.

Structure of Atoms:

- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation.

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.

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.

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.

4. Analyzing and Interpreting Data

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

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

- 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.

CU of Marie and Pierre working side by side at the instrument. Photo of Lippmann.

NARR: Since neither Marie nor Pierre was a member of the Academy of Sciences, they asked Marie's mentor, Gabriel Lippmann, to deliver the paper announcing this discovery.

CONCEPT IN DETAIL: influence of society and culture on science

Shot of the paper's title page: Rays Emitted by the Compounds of Uranium and Thorium, by Madame Sklodowska Curie.

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

CHEMIST GREG PESTSKO, partly in VO

This was one of the most important papers in the history of chemistry. And yet it was almost universally ignored.

STOP AND THINK 11: Beliefs and stereotypes about groups of people can affect the acceptance of their ideas. What are the possible outcomes of these kinds of beliefs?

Possible Student Answers: An important idea or discovery by a person might be discounted or ignored due to beliefs and stereotypes about that person.

Photo of Marie and Pierre. Footage of Marie being helped by younger male scientist.

HISTORIAN ALAN ROCKE, partly in VO

Who was this Marie Curie? She was a graduate student. She spoke French with a Polish accent. She was married to a teacher in an industrial school. And she was a woman.

Notes from the Field:

This is a good example of how society's views can influence science. Because Marie was Polish and a woman, her findings weren't taken seriously.

MATERIALS SCIENTIST AINISSA RAMIREZ, partly in VO

These are strikes that are definitely against you. And so her ideas just weren't embraced, because she was so different.

Marie and Pierre work in the chemistry lab.

NARR: But Marie knew she was onto something important.

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

BIOGRAPHER SUSAN QUINN VO

She had lit upon, almost by accident, an extremely exciting discovery. And as soon as he figured that out, Pierre abandoned his work on crystals and joined her.

STOP AND THINK 12: Scientists often work together on important problems. Why is the search for a new element important?

Possible Student Answers: Students should be able to describe the important role of elements—they are the building blocks of all matter on Earth.

NARR: To track down their mystery element, Marie and Pierre subjected pitchblende to a battery of chemical procedures.

CHEMIST DAGMAR RINGE, partly in VO

You break up your rock. You try to dissolve it. You treat it with all kinds of other chemicals.

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

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

NARR: The goal is to separate the ore into portions with different chemical properties, all the while tracking the radioactive signal.

CHEMIST GREG PETSKO, partly in VO

She then throws away everything that isn't radioactive. It's getting more and more concentrated as she goes through these steps.

NARR: The Curies soon discovered that two distinct parts of the pitchblende, with different chemical properties, were *both* radioactive. That meant not one but *two* new elements might be hidden in the ore.

CONCEPT IN DETAIL: element

EVE CURIE

By July 1898, they were able to announce the discovery of one of those substances with certainty.

Pierre approaches Marie with coffee pot in the lab. He pours. They talk.

PIERRE

Marie, you will have to name it.

EVE CURIE, partly in VO

The former Mademoiselle Skłodowska thought of her occupied native country, whose very name had been erased from the map of the world.

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

MARIE CURIE

Could we call it polonium?

BIOGRAPHER SUSAN QUINN, partly in VO
Poland, remember, was still not a country. This was one way of putting it on the map.

PIERRE CURIE

Eh bien, voila. Polonium it is.

Marie places another sample in the ionization chamber.

NARR: Marie next turned her attention to the second mystery element.

CU of Marie looking at results

HISTORIAN DAVID KAISER, partly in VO
She finds the activity is through the roof. It is nearly a thousand times more active than even her uranium sample had been.

In another laboratory, Eugene Demarçay tests her sample with a simple spectroscope while Marie and Pierre look on.

NARR: Marie's polonium sample had not been pure enough to yield a unique spectral line. Would this new, more powerful element pass the test?

CONCEPT IN DETAIL: spectroscopy

HISTORIAN DAVID KAISER VO
By 1900 spectroscopy was often seen as the gold standard for identifying the materials you're working with. And if Marie Curie wanted to make some claim that she found in fact a whole new element, she was going to have to meet the chemists on their own terms. She'd need spectroscopic evidence.

Demarçay pulls back from the instrument and, in a book, points to the part of the spectrum where he's seen new lines.

EUGENE DEMARCAY

Regarde ici. Il ya une ligne ...

He invites Marie to look. She sits and looks into the eyepiece.

NARR: Marie's sample showed the presence of the well-known element barium.

Cut to the spectrum of barium as she might have seen it, and below it the spectrum of a new element.

NARR: But it also revealed a pattern of spectral lines never seen before – strong evidence that she and Pierre had tracked down their mystery element.

STOP AND THINK 13: Spectral lines are a characteristic property of an element. How can properties be used to identify an element?

Possible Student Answers: As part of their prior study of the Periodic Table, students have already been introduced to the idea that elemental substances are grouped by their properties. Although students may not know the phrase “characteristic property,” they should be able to explain that every substance, including elemental substances, has a group of properties that are unique.

Marie looks up and receives congratulations from the two men.

CHEMIST DAGMAR RINGE, partly in VO

She could tell that she had an element that hadn't been seen before, because the spectral lines she got were different.

CONCEPT IN BRIEF: importance of scientific tools

Shot of the notebook page from Dec. 20, 1898: The word “Radium” is written in heavy ink at the top of the page.

BIOGRAPHER SUSAN QUINN, partly in VO

And in the notebook Pierre writes in very bold ink the name they decided to give the new element: Radium.

CHAPTER 8: Isolating Radium

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure of Atoms:

- Matter is made up of minute particles called atoms, and atoms are composed of even smaller components.

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

- 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.

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.

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.

Spectroscopy scene continues.

HISTORIAN ALAN ROCKE, partly in VO

But in the 19th century there had been scores of claims of elements that later proved not to be elements at all. You needed to do more.

AUTHOR OLIVER SACKS, partly in VO

To satisfy the chemical community, a spectral line wasn't enough. They had to see the real stuff, which could be weighed, which could be measured.

BIOGRAPHER SUSAN QUINN

It was important, as you would with any other element, to isolate this element, to weigh it and to place it on the Periodic Table.

CHEMIST DAGMAR RINGE

So in order to be absolutely certain, she had to have pure material, and that is what she set out to do.

EVE CURIE

It was my mother who had no fear of throwing herself into that daunting task – without personnel, without money, without supplies.

Marie squeezes by Pierre in their cramped lab.

NARR: To isolate even a speck of radium, Marie would need to process huge quantities of pitchblende – a job too big for her tiny laboratory.

Photos of the crude shed where the radium isolation was carried out

NARR: The only space available for this work was a drafty old shed once used as a dissecting room for the school's medical students.

Movie poster for Madame Curie

NARR: As Greer Garson and Walter Pidgeon showed in the 1943 film *Madame Curie* ...

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

Notes from the Field:

I always point out that Marie's workspace had been a morgue but wasn't even deemed usable for that purpose anymore.

Radium isolation scenes from the 1943 feature film Madame Curie. Greer Garson as Marie Curie stirs a huge cauldron with a long rod.

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

NARR: ... the Curies worked tirelessly to separate the radium from tons of pitchblende residue they had shipped from a mine in Bohemia.

MARIE CURIE VO

Sometimes I had to spend the whole day mixing a boiling mass with a heavy iron rod nearly as big as I was. I would be broken with fatigue by the end of the day. And yet we spent the happiest days of our lives in this miserable old shed. An entirely new field was opening before us.

Notes from the Field:

The way that Marie persevered and diligently worked is a wonderful example of how scientists must verify their findings.

Movie isolation scenes continue.

NARR: Marie soon realized that radium was a smaller part of the pitchblende than she ever imagined – less than a millionth of one percent. Isolating it was going to be an enormous job.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

BIOGRAPHER SUSAN QUINN, partly in VO

Marie's daughter said that, had it been up to Pierre, he might not have taken the next step.

Excerpt from movie – Pierre expresses frustration over how long it's taking.

WALTER PIDGEON AS PIERRE CURIE

The world has done without radium up to now. What does it matter if it isn't isolated for another hundred years?

GREER GARSON AS MARIE CURIE

I can't give it up.

AUTHOR OLIVER SACKS

There is a special passion which goes with the discovery of elements, and a line in the spectrum is not enough.

HISTORIAN DAVID KAISER

She was after an understanding of nature. And there was very, very little that would stand in her way.

Photo of resolute Marie. CU of pinch of table salt in a watch glass.

CONCEPT IN DETAIL: Periodic Table

NARR: In 1902, after four years of arduous work, Marie finally succeeded in isolating one-tenth of a gram of radium chloride from *ten tons* of pitchblende residue.

EXAMPLE OF SCIENCE PRACTICE: using mathematics and computational thinking

MARIE CURIE

– four years to produce the kind of evidence that chemical science demands.

HISTORIAN DAVID KAISER, partly in VO

All of this effort so that she could actually convince the remaining chemists that this was a real, honest-to-goodness element.

EXAMPLE OF SCIENCE PRACTICE: developing and using models

CU of Curie notebook showing atomic weight calculation.

NARR: She measured radium's atomic weight at 225.9 – very close to the current value of 226.

CONCEPT IN BRIEF: atomic weight

Radium appears in the Periodic Table.

NARR: And she placed it correctly in the Periodic Table.

EVE CURIE, PARTLY IN VO

Radium officially existed. The incredulous chemists – and there were still a few – could now only bow before the facts, before the superhuman obstinacy of a woman.

STOP AND THINK 14: Based on what you learned about Marie Curie's work, how difficult was it to find and prove the existence of new elements?

Possible Student Answers: The work was very difficult. First, scientists had to find and recognize evidence that there was an element that had not been identified. For the Curies, that evidence was the very high level of "uranic rays" in pitchblende. Second, scientists had to carry out many procedures and tests to isolate and identify the new element.

STOP AND THINK 15: What does the atomic weight of an element measure?

Possible Student Answers: Students may recall that atomic weight is related to the mass of the nucleus (the neutrons and protons) in an atom. You may want to explain or review the concept of isotopes, nuclear variants of elements that have different numbers of neutrons. Then explain that atomic weight shown on the Periodic Table is the average weight of all of the isotopes of each element.

CHAPTER 9: The Nobel Prize

Alignment with the NRC's National Science Education Standards

F: Science in Personal and Social Perspectives

Science and Technology in Local, National, and Global Challenges

- Progress in science and technology can be affected by social issues and challenges.

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.

Photo of Marie

HISTORIAN DAVID KAISER, partly in VO

Here she was, still basically a graduate student, and the whole world was beginning to talk about her discoveries. In just these four years, she has now discovered two brand new elements. Even more important, she has shown that this strange emanation, this radioactivity, is a feature of matter, not specific to one quirky little substance. And she's also developed a quite impressive technique for finding more.

BIOGRAPHER SUSAN QUINN

This was the beginning of identifying elements by their radioactive power.

CONCEPT IN DETAIL: impact of scientific and technologic progress on society

Graphic: Actinium and radon take their places in the Periodic Table

NARR: The same technique would soon be used by others to identify more new radioactive elements.

Shot of Marie's dissertation: "Radioactive Substances"

NARR: In 1903, Marie Sklodowska Curie became the first female scientist ever awarded a doctorate in France.

Photo of Marie

NARR: By then it was clear radioactivity was a pivotal scientific discovery, deserving of recognition.

HISTORIAN DAVID KAISER, partly in VO

There's no doubt that Marie Curie had done the lion's share of this work. And yet, when the time came to recognize this work, it very nearly went to other people.

Shot of the letter nominating Becquerel and Pierre Curie for the Nobel Prize. It gives credit to the two men.

BIOGRAPHER SUSAN QUINN, partly in VO

A number of prominent French scientists nominated Pierre Curie and Henri Becquerel for the Nobel Prize in 1903. And in this letter, they didn't mention Marie Curie at all.

Shot of Lippmann's signature, then photo of Lippmann

NARR: One of the nominators was Gabriel Lippmann.

BIOGRAPHER SUSAN QUINN, partly in VO

It's quite remarkable since Gabriel Lippmann was her teacher, her mentor. He actually presented her very first paper to the Academy. So he knew about her importance in this work and how central she was to these discoveries.

Composite photos of four "cabal" members who signed the letter

BIOGRAPHER SUSAN QUINN

And yet his cabal of Frenchmen just left her off the list. The idea that she could be an important scientist just didn't occur to them. She was totally invisible.

STOP AND THINK 16: What role did the social and cultural context Marie Curie lived in play in her initial exclusion from the nomination for the Nobel Prize?

Possible Student Answers: The people who thought the discovery of radioactivity was worthy of a Nobel Prize were aware of the work that Marie Curie had done. However, they excluded her from the nominating letter for the Nobel Prize because of the wide-spread belief that women should not be scientists.

Pierre angrily writes a letter.

CHEMIST DAGMAR RINGE, partly in VO

Pierre – and we have to give him total credit for this – turned around and said, “I did not conceive of this idea. I helped with the work, but it was someone else’s idea that made it possible, and that’s Marie Curie.”

BIOGRAPHER SUSAN QUINN, partly in VO

Pierre was adamant that Marie needed to be included. He immediately wrote back and said, “Wouldn’t it be better, from an artistic point of view, to award the prize to Marie Curie and to me?”

Images of Marie’s two Nobel Prizes

NARR: In the end, Marie did share in the Nobel with Pierre and Henri Becquerel. She would go on to win a second all her own.

CHAPTER 10: What’s Inside the Atom?

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.
- 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.

Structure and Properties of Matter:

- An element is composed of a single type of atom.

G: History and Nature of Science

Historical Perspectives

- The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge.

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.

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.

Crosscutting Concepts

- The total amount of energy and matter in closed systems is conserved.
- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.

Page from Le Radium with picture of Curies in the lab

NARR: But the real prize was the magical substance for which she would always be known. Some nights the Curies would stop by the laboratory to admire the element Marie called “my child.”

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

Cut to door of darkened laboratory being opened with a squeak

EVE CURIE, partly in VO

They arrived in the Rue Lhomond. Pierre put the key in the lock. The door squeaked and admitted them to their world.

Marie and Pierre enter and see the (fake) radium samples glowing on the shelves.

AUTHOR OLIVER SACKS VO

Eve Curie in her biography of her mother ...

MARIE CURIE TO PIERRE

Don't light the lamps! Look!

AUTHOR OLIVER SACKS, partly in VO

... describes the wonder of the Curies as they went into their lab one night and saw these glowing vials.

MARIE CURIE VO

From all sides, we could see gleamings suspended in darkness, like faint fairy lights.

MARIE CURIE TO PIERRE

Do you remember the day you said to me, “I would like radium to be a beautiful color?”

EVE CURIE, partly in VO

Radium had something better than a beautiful color. It was spontaneously luminous.

Footage of the glowing samples

CHEMIST GREG PETSKO, partly in VO

The fact that radium glowed in the dark seemed magical. But it was also troubling, because it almost seemed to violate some kind of fundamental, physical law.

PHYSICIST JIM GATES, partly in VO

Scientists had known for some time that light is a form of energy, so if you distill something and it suddenly glows in the dark, you have to ask the question: Where does that energy come from?

STOP AND THINK 17: What questions were raised by Marie Curie’s discovery of radioactivity?

Possible Student Answers: What feature of an element makes it radioactive? Do the atoms of radioactive elements change in some way when they emit energy?

MATERIALS SCIENTIST AINISSA RAMIREZ, partly in VO

It’s not changing shape. It’s not interacting with the environment to get this energy. But it is just glowing, infinitely, and we had no idea why it did that.

CONCEPT IN BRIEF: atom

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

Animation of atoms breaking down and changing identities

NARR: It was Marie who had the flash of insight: Perhaps some kinds of matter were changing from one kind to another, their atoms splitting apart and releasing energy in the process.

CONCEPT IN DETAIL: matter

MARIE CURIE

This theory of the source of the energy is very seductive; it explains radioactivity very well.

EXAMPLE OF SCIENCE PRACTICE: constructing explanations and designing solutions

STOP AND THINK 18: What evidence led Marie Curie to propose the idea that atoms could split?

Possible Student Answers: The evidence that radioactive elements released an unknown form of energy led to Marie Curie's proposal.

Photo of doubtful Russian chemists, arms crossed, Mendeleev in the corner

CONCEPT IN BRIEF: radioactive decay

NARR: But it was an idea many chemists refused to accept.

CONCEPT IN DETAIL: element

DMITRI MENDELEEV

Tell me, please, how much radium salt is there in the entire earth? A few grams! On this shaky foundation they want to overturn our understanding of the nature of matter!

CONCEPT IN DETAIL: atom

Photo of the Curies

NARR: Even the Curies were reluctant to accept it.

PHYSICIST JIM GATES, partly in VO

The Curies themselves, they wanted to think of elements as immutable, unchangeable parts of nature.

Image of the Curies over glowing vessel

AUTHOR OLIVER SACKS, partly in VO

The idea that one could have **transmutation** from one element to another was very disturbing, even to her, at first.

Photo of Marie, head down, surrounded by men at a Solvay conference. Tilt up and widen out to reveal Rutherford and Einstein standing behind her.

NARR: But the Curies' discoveries inspired others around the world to pursue this daring theory.

Animation of the atom breaking apart – emphasis on fragments coming out.

HISTORIAN DAVID KAISER, partly in VO

The idea that finally got pieced together was that the energy was, in fact, coming from the disintegration of these atoms themselves. Radioactivity was a sign that the atom itself was unstable. It could break apart.

Host picks up an animated round ball labeled U, for uranium.

HOST

This discovery implied something even more profound. Up to then, most scientists had believed atoms were the smallest units of matter – “solid, unsplitable lumps.”

Now the ball begins throwing off animated heat, light and other products of radioactivity.

HOST

But if radioactivity was atoms falling apart, there must be even smaller pieces inside, still awaiting discovery.

STOP AND THINK 19: How do you think atoms break down?

Possible Student Answers: Most students will know that atoms are made of protons, neutrons, and electrons and have been introduced to atomic structure. They might theorize that the breakdown of atoms is related to the breaking apart of the nucleus. Students may or may not have studied the forces that affect the particles in the nucleus.

Host walks forward to reveal photo of Curie with her two daughters

HOST

Thanks to this Polish expatriate ... this graduate student ... this young mother ... scientists hoping to solve the mystery of matter now had a pressing new question to answer: What’s inside the atom?

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

STOP AND THINK 20: Knowledge of radioactivity encouraged new research into atoms. What discoveries about atoms have been made since Marie Curie's time?

Possible Student Answers: Students' answers to this question will most likely reflect their prior instruction and information they have gained through their own interests. Subatomic structure, quantum mechanics, detailed understanding of fission and fusion, atomic bombs, atomic energy, and how atoms were formed are some ideas that students might have knowledge of.

VO: Next time on *The Mystery of Matter* ...

Harry Moseley (identified on screen) at his x-ray machine.

HARRY MOSELEY VO

There's a fundamental quantity in the atom which increases by regular steps as we pass from one element to the next.

PHYSICIST JUSTIN WARK VO

I think he must have been astonished.

Physicist Luis Alvarez bursts into the UC Berkeley cyclotron control room and shouts to his graduate student, Phil Abelson, who is seated at the console.

PHYSICIST LUIS ALVAREZ

Phil, the Germans have split the uranium atom!

Glenn Seaborg (identified on screen) raises a narrow centrifuge tube and studies the small sample of plutonium in its pointed bottom.

PHYSICIST JIM GATES, partly in VO

Seaborg figured out how to turn it into a new element, plutonium.

Seaborg and graduate student Arthur Wahl perform a chemical test on plutonium. A mushroom cloud appears inside the flask as Seaborg mentions the changing world.

GLENN SEABORG, partly in VO

No matter what you do with the rest of your life, nothing will be as important as your work on this project. It will change the world.

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.

Production Credits/Web tag/DVD offer

ANNOUNCER: To learn more about the search for the elements and watch bonus videos on the featured scientists, visit [pbs.org/mystery of matter](http://pbs.org/mysteryofmatter). *The Mystery of Matter: Search for the Elements* is available on DVD. To order, visit ShopPBS.org or call 1-800-PLAY-PBS.

Banner: More from The Mystery of Matter

Photo of Marie Curie

MATERIALS SCIENTIST AINISSA RAMIREZ, partly in VO
For me, Marie Curie is a story of perseverance. She just said, “Hey! You don’t like what I’m doing, I’m just going to work harder and prove you wrong.”

Marie and Pierre in the lab. Photo of Marie as a young girl.

BIOGRAPHER SUSAN QUINN, partly in VO
There is just so much about her and her stick-to-it-tiveness from the beginning. It’s so moving and so wonderful. Her courage throughout her life is an enormous inspiration to everyone, but especially to women.

Images and footage of Marie, including Pierre and kids

CHEMIST DAGMAR RINGE, partly in VO
She was certainly an inspiration to me. I come from a generation when it was also, not quite yet fashionable to be a scientist. And here was a woman who had achieved it – to not only be a scientist but to be a wife, a mother, a part of a community. Those are very hard to do all at once. She was able to do that. And as women came along, they could look at that and say, “Well, maybe I can do it, too.”

Footage of Marie in the lab

MATERIALS SCIENTIST AINISSA RAMIREZ, partly in VO

If you look a little different, if you are a different gender, a different race, there are many barriers to overcome. But you do what Marie did, which is, you put your head down and you work harder.

Footage of Marie

HISTORIAN DAVID KAISER, partly in VO

Curie's legacy is a many-fold. She changed cherished truths or notions about how the world seems to work, what's the universe made out of? She challenged equally steadfast notion of who should be contributing – who could play the game of science? She showed by example that there could be all kinds of people doing really, breathtakingly important science, all kinds of people could have a hand in pursuing the mystery of matter.

ACTIVITY IDEAS

Demonstration of Ionization

The Curies used an ionization chamber to measure radioactivity. The gases found in fluorescent bulbs are ionized so that they will fluoresce. An electric current causes the ionization. Show the connections between static electricity, electric current, and ionization by carrying out the following demonstration on a dry day. Obtain a tubular fluorescent bulb and carefully wash and thoroughly dry the bulb. Blow up a balloon and charge the balloon by rubbing it with a piece of wool. Hold the bulb in one hand and the balloon in the other hand. Darken your room. Move the balloon close to the tube with touching it and observe. Then move the balloon along the tube without touching it and observe.

Simulation of Radioactive Decay

Half-life can be demonstrated with pennies, which are proxies for the atoms of a radioactive element. Place 80 pennies in a cup. Shake the pennies in the cup for a set time (the half life). Spill the pennies onto a large table. Explain that pennies that have heads up are the atoms of a non-radioactive element, which are the decay products of the original radioactive element. Count these pennies and remove them. Explain that pennies that have tails up are the atoms of the radioactive element that have not yet decayed. Count these pennies and place them back in the cup. This sequence of steps is called sequence 1. Repeat all the steps, beginning with shaking the pennies in the cup for a set time (the half life). This sequence of steps is called sequence 2. Carry out five sequences in all and then have students graph the number of radioactive atoms formed during each sequence on the y-axis and the sequence numbers (which is correlated to the half-life) on the x-axis.

Calculate Your Radiation Dose

Everyone is exposed to radiation. Students can estimate their exposure to radiation by using a U.S. Environmental Protection Agency survey. A classroom version of this activity—integrated with “Mysterious Rays”—is described in the In-depth Investigation in this section. Or students can complete the survey on their own. The survey is found at:

<http://www.epa.gov/rpdweb00/understand/calculate.html>

Write Nuclear Equations

Describe alpha decay and beta decay to your students and introduce students to the notation used in nuclear equations. Present descriptions of radioactive decay and have students work in groups to write the accompanying nuclear equations.

TEACHER NOTES**IN-DEPTH INVESTIGATION: ANNUAL RADIATION EXPOSURE****Context**

Pierre and Marie Curie were not aware of the dangers of their laboratory work on radioactivity. Both showed symptoms typical of radiation sickness, an illness caused by exposure to radioactive substances. Pierre Curie died as an indirect result of radioactivity, and Marie Curie died as a direct result of radioactivity. Exposure to radioactive substances causes radiation sickness because radioactive substances are a source of ionizing radiation, which ionizes the cells in the body. Many people associate radiation sickness and ionizing radiation with radioactive substances like those studied by the Curies. However, there are many other natural and manmade sources of ionizing radiation.

Overview

In this activity, students read more about how Pierre and Marie Curie were affected by radiation sickness. They learn about ionizing radiation safety guidelines, measurements of ionizing radiation, common sources of ionizing radiation, average ionizing radiation exposure, and the maximum allowable ionizing radiation exposure. Students then calculate their own annual ionizing radiation exposure by answering a survey.

Next Generation Science Standards Alignment

Disciplinary Core Ideas

- 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.

Understanding Goals

Students should understand:

- Pierre and Marie Curie had health problems related to substantial exposure to ionizing radiation emitted by the radioactive substances they were studying.
- Substantial exposure to ionizing radiation could be harmful or fatal.
- People who now work with sources of ionizing radiation follow specific safety precautions, including measuring their radiation exposure.
- All people are exposed to low levels of ionizing radiation.
- Ionizing radiation exposure is measured in units called millirems (mrems).
- There are many sources of ionizing radiation in addition to radioactive substances studied in the laboratory, and these sources include space, the ground, the air, home appliances, medical equipment, and food and water.
- Radiation exposure can be estimated.

Student Materials

You will find on the following page a reading and a radiation exposure survey.

Activity Facilitation

- Circulate around to students as they work on the activity.

IN-DEPTH INVESTIGATION: ANNUAL RADIATION EXPOSURE

READING: Radiation Exposure—Then and Now

When Marie and Pierre Curie carried out their experiments with **radioactive** substances, they both had periodic episodes of poor health. In addition to the lesions and burns on their skin caused by contact with the substances, they were often tired and anemic, and their joints would hurt. These symptoms match the symptoms of **radiation sickness**, an illness that occurs when a person has substantial exposure to ionizing (high-energy) **radiation**. One source of ionizing radiation is radioactive substances.

Pierre and Marie were not aware that their work was compromising their health. This lack of knowledge would prove deadly for both of them. Pierre died in 1906, when weakness caused by radiation made him fall in the street, where he was hit by a horse-drawn cart. Marie died in 1934 of **aplastic anemia**, a disease directly caused by ionizing radiation.

As people have learned more about the negative effects of ionizing radiation exposure, safety guidelines have been developed. The Nuclear Regulatory Commission sums up the safety guidelines with the succinct phrase, “time, distance, and shielding.” This phrase refers to the three main ways to reduce exposure to ionizing radiation: minimize the time spent near a source of radiation, maximize the distance from a source of radiation, and shield a source of radiation with materials such as lead, concrete, and water that absorb the energy of the ionizing radiation.

To ensure that safety guidelines are working, there has to be a way to measure a person’s exposure to ionizing radiation. People who come into sustained contact with sources of ionizing radiation wear a **dosimeter**. The dosimeter measures the ionizing radiation in **millirems** (mrems), a unit that accounts for both the amount of ionizing radiation emitted by a source and the distinct health hazards faced by a particular person.

Even if you do not work with radioactive substances, you are still exposed to a small amount of ionizing radiation. People are exposed to ionizing radiation from materials on Earth, from naturally occurring radon in the air, from outer space, and from inside their own bodies (as a result of the food and water they consume that contain very small amount of radioactive substances). The average dose per person from all sources is about 360 mrems per year. However, it is not uncommon for some people to receive far more than that in a given year, largely due to certain medical procedures they undergo. International standards allow exposure to as much as 5,000 mrems a year for those who work with and around sources of ionizing radiation. When atomic bombs were dropped on Nagasaki and Hiroshima in Japan radiation exposure near the bomb detonation exceeded the fatal amount of 600,000 mrems. The radiation exposure for workers near the core of Chernobyl nuclear power plant in Ukraine that melted down also exceeded the fatal amount of 600,000 mrems.

SURVEY: Calculating Your Annual Radiation Exposure

[Source: "Estimate your personal annual radiation exposure." 2000. A publication of the American Nuclear Society. Available at <http://www.ans.org/pi/resources/dosechart/> (retrieved 2/29/2008).]

How much ionizing radiation are you exposed to? Complete the following survey to find out.

Procedure

Follow these steps to calculate how much radiation you were exposed to over the past year.

1. In your notebook, create a table with columns for sources of radiation, the amount of radiation you were exposed to from that source, and whether the source was human-made or natural.
2. To determine how much cosmic radiation (radiation from outer space) you were exposed to, find out the elevation of your hometown, and record in your notebook the appropriate radiation exposure:
 - a. If your hometown is at sea level, record an exposure of: 26 millirems (mrem)
 - b. 0–1000 ft: 28 mrem
 - c. 1000–2000 ft: 31 mrem
 - d. 2000–3000 ft: 35 mrem
 - e. 3000–4000 ft: 41 mrem
 - f. 4000–5000 ft: 47 mrem
 - g. 5000–6000 ft: 52 mrem
 - h. 6000–7000 ft: 66 mrem
 - i. 7000–8000 ft: 79 mrem
 - j. 8000–9000 ft: 96 mrem
3. To determine how much terrestrial radiation (radiation from the ground) you were exposed to, record in your notebook the appropriate radiation exposure:
 - a. If you live in a state that borders the Gulf or Atlantic coasts, record 16 mrem.
 - b. If you live in the Colorado Plateau area, record 63 mrem.
 - c. If you live anywhere else in the continental United States, record 30 mrem.
4. If you live in a stone, adobe, brick, or concrete building, record 7 mrem.
5. If you live within 50 miles of a nuclear or coal-fired power plant, record the appropriate radiation exposure:
 - a. Within 50 miles of a nuclear power plant: 0.01 mrem
 - b. Within 50 miles of a coal-fired power plant: 0.03 mrem
6. You are exposed to about 40 mrem every year from the food you eat and the water you drink. (Food contains the radioactive **isotopes** carbon-14 and potassium-40, and water contains dissolved radon.) Record this value in your notebook.
7. You are exposed to about 200 mrem every year from radon in the air. Record this value in your notebook.
8. You are exposed to 1 mrem or less of radiation from nuclear weapons test fallout. Record 1 mrem in your notebook.
9. Traveling in a jet plane exposes you to additional cosmic radiation. For every hour you spent in the air this past year, record 0.5 mrem.
10. If you have porcelain crowns or false teeth, record 0.07 mrem.
11. If you wear a luminous wristwatch, record 0.06 mrem.
12. If you went through luggage inspection at an airport, record 0.002 mrem.

13. Watching TV exposes you to 1 mrem or less of radiation. If you watch TV, record 1 mrem.
14. If you use a computer screen, record 1 mrem.
15. If you have a smoke detector in your home, record 0.0008 mrem.
16. If you use a gas camping lantern, record 0.2 mrem.
17. If you wear a plutonium-powered pacemaker, record 100 mrem.
18. If you underwent any of the following medical procedures, record the appropriate radiation exposure for each time you went through the procedure:
 - a. X-rays:
 - i. Of the arm, hand, foot, or leg: 1 mrem
 - ii. Dental: 1 mrem
 - iii. Chest: 6 mrem
 - iv. Pelvis/hip: 65 mrem
 - v. Skull/neck: 20 mrem
 - vi. Barium enema: 405 mrem
 - vii. Upper GI: 245 mrem
 - b. CAT scan: 110 mrem
 - c. Nuclear medicine (e.g., thyroid scan): 14 mrem
19. Now add up all the values you recorded in steps 2–18, and record the total in your notebook. This is how much radiation you were exposed to over the past year.

Questions

1. How does your total radiation exposure compare to the average exposure (360 mrems per year)?
2. What human-made sources of ionizing radiation and what natural sources of ionizing radiation were you exposed to?
3. Which source was the largest part of your exposure?
4. Why does elevation affect your exposure to ionizing radiation?

WEB RESOURCES

Atom Builder

<http://www.teachersdomain.org/resource/phy03.sci.phys.matter.atombuilder/>

Building a carbon atom from scratch, using subatomic particles as building blocks, is simply not something humans can do. Even with the most powerful microscopes, we cannot see subatomic particles, much less manipulate them. This interactive activity from the NOVA Web site provides users with a good approximation of what it would be like to build an atom if we could do it, and in the process demonstrates how ions and radioactive materials come to be.

Radiation: To Worry or Not to Worry

http://www.teachersdomain.org/resource/phy03.sci.phys.energy.lp_worry/

In this lesson, students work with several resources to help them distinguish safe forms of radiation from those that are dangerous. They watch a video segment about sources of radiation we encounter every day, and another video about potentially dangerous radon radiation found in many homes. They work with an interactive activity, which explains both natural and human-made sources of radiation, use facts about radiation to estimate their own annual radiation exposure, and, finally, take a survey of how nuclear phobic they are.

Sources of Radiation

<http://www.teachersdomain.org/resource/phy03.sci.phys.energy.radsourc/>

Radiation, like energy, comes in many different forms and from many different sources. This interactive activity from the NOVA Web site identifies common forms of radiation that people encounter throughout their lives and explains where they come from and what effects they might have on human health.

Help for the Wounded

https://www.aip.org/history/curie/brief/05_campaigns/campaigns_1.html

Read how Marie Curie brought X-ray machines to battlefield hospitals during World War One. The X-ray machines enabled doctors to save the lives of wounded soldiers by revealing bullets, shrapnel, and broken bones. The site includes excerpts from Marie Curie's *Autobiographical Notes*.