History Sheets
The History sheets are organized by units in the student text.

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Benjamin Banneker

Benjamin Banneker was a farmer, naturalist, civil rights advocate, self-taught mathematician, astronomer and surveyor who published his detailed astronomical calculations in popular almanacs. He was appointed by President George Washington as one of three surveyors of the territory that became Washington D.C.

Early times

Benjamin Banneker was born in rural Maryland in 1731. His family was part of a population of about two hundred free black men and women in Baltimore county. They owned a small farm where they grew tobacco and vegetables, earning a comfortable living.

A mathematician builds a clock

Benjamin’s grandmother taught him to read, and he briefly attended a Quaker school near his home. Benjamin enjoyed school and was especially fond of solving mathematical riddles and puzzles. When he was 22, Benjamin borrowed a pocket watch, took it apart, and made detailed sketches of its inner workings. Then he carved a large-scale wooden model of each piece, fashioned a homemade spring, and built his own clock that kept accurate time for over 50 years.

A keen observer of the night sky

As a young adult, Benjamin designed an irrigation system that kept his family farm prosperous even in dry years. The Bannekers sold their produce at a nearby store owned by a Quaker family, the Ellicotts. There, Benjamin became friends with George Ellicott, who loaned him books about astronomy and mathematics.

Banneker was soon recording detailed observations of the night sky. He performed complicated calculations to predict the positions of planets and the timing of eclipses. From 1791 to 1797, Banneker published his astronomical calculations along with weather and tide predictions, literature, and commentaries in six almanacs. The almanacs were widely read in Maryland, Delaware, Pennsylvania, and Virginia, bringing Banneker a measure of fame.

A keen observer of nature

Banneker was also a keen observer of the natural world and is believed to be the first person to document the cycle of the 17-year cicada, an insect that exists in the larval stage underground for 17 years, and then emerges to live for just a few weeks as a loud buzzing adult.

Banneker writes Thomas Jefferson

Banneker sent a copy of his first almanac to then-Secretary of State Thomas Jefferson, along with a letter challenging Jefferson’s ownership of slaves as inconsistent with his assertion in the Declaration of Independence that “all men are created equal.” Jefferson sent a letter thanking Banneker for the almanac, saying that he sent it onto the Academy of Sciences of Paris as proof of the intellectual capabilities of Banneker’s race. Although Jefferson’s letter stated that he “ardently wishes to see a good system commenced for raising the condition both of [our black brethren’s] body and mind,” he unfortunately never freed his own slaves.

Designing Washington D.C.

In 1791, George Ellicott’s cousin Andrew Ellicott asked him to serve as an astronomer in a large surveying project. George Ellicott suggested that he hire Benjamin Banneker instead. Banneker left his farm in the care of relatives and traveled to Washington, where he became one of three surveyors appointed by President George Washington to assist in the layout of the District of Columbia.

After his role in the project was complete, Banneker returned to his Maryland farm, where he died in 1806. Banneker Overlook Park, in Washington D.C., commemorates his role in the surveying project. In 1980, the U.S. Postal Service issued a stamp in Banneker’s honor.
Reading reflection

1. Benjamin Banneker built a working clock that lasted 50 years. Why would his understanding of mathematics have been helpful in building the clock?

2. Identify one of Banneker’s personal strengths. Justify your answer with examples from the reading.

3. Benjamin Banneker lived from 1731 to 1806. During his lifetime, he advocated equal rights for all people. Find out the date for each of the following “equal rights” events: (a) the Emacipation Proclamation, (b) the end of the Civil War, (c) women gain the right to vote, and (d) the desegregation of public schools (due to the landmark Supreme Court case, Brown versus the Board of Education).

4. Name three of Benjamin Banneker’s lifetime accomplishments.

5. What do you think motivated Banneker during his lifetime? What are some possible reasons that he was persistent in his scientific work?

6. Research: Find a mathematical puzzle written by Banneker. Try to solve it with your class.
Isaac Newton is one of the most brilliant figures in scientific history. His three laws of motion are probably the most important natural laws in all of science. He also made vital contributions to the fields of optics, calculus, and astronomy.

**Plague provides opportunity for genius**

Isaac Newton was born in 1642 in Lincolnshire, England. His childhood years were difficult. His father died just before he was born, and when he was three, his mother remarried and left her son to live with his grandparents. Newton bitterly resented his stepfather throughout his life.

An uncle helped Newton remain in school and in 1661, he entered Trinity College at Cambridge University. He earned his bachelor’s degree in 1665. Ironically, it was the closing of the university due to the bubonic plague in 1665 that ushered in the blossoming of Newton’s genius. He returned to Lincolnshire and spent the next two years in solitary academic pursuit. During this period, he made significant advances in calculus, worked on a revolutionary theory of the nature of light and color, developed early versions of his three laws of motion, and gained new insights into the nature of planetary motion.

**Revolutionary law of universal gravitation**

In the 1680s, Newton turned his attention to forces and motion. He worked on applying his three laws of motion to orbiting bodies, projectiles, pendulums, and free-fall situations. This work led him to formulate his famous law of universal gravitation.

According to legend, Newton thought of the idea while sitting in his Lincolnshire garden. He watched an apple fall from a tree, and wondered if the same force that caused the apple to fall toward the center of Earth (gravity) might be responsible for keeping the moon in orbit around Earth, and the planets in orbit around the sun.

This concept was truly revolutionary. Less than 50 years earlier, it was commonly believed that some sort of invisible shield held the planets in orbit.

**Important contributor in spite of conflict**

In 1687, Newton published his ideas in a famous work known as the *Principia*. He jealously guarded the work as entirely his. He bitterly resented the suggestion that he should acknowledge the exchange of ideas with other scientists (especially Hooke) as he worked on his treatise.

Newton left Cambridge to take a government position in London in 1696. His years of active scientific research were over. However, almost three centuries after his death in 1727, Newton remains one of the most important contributors to our understanding of how the universe works.

**Fear of criticism stifles scientist**

When Cambridge reopened in 1667, Newton was given a minor position at Trinity and began his academic career. His studies in optics led to his invention of the reflecting telescope in the early 1670s. In 1672, his first public paper was presented, on the nature of light and color. Newton longed for public recognition of his work but dreaded criticism. When another bright young scientist, Robert Hooke, challenged some of his points, Newton was incensed. An angry exchange of words left Newton reluctant to make public more of his work.
Reading reflection

1. Important phases of Newton’s education and scientific work occurred in isolation. Why might this have been helpful to him? On the other hand, why is working in isolation problematic for developing scientific ideas?

2. Newton began his academic career in 1667. For how long was he a working scientist? Was he a very productive scientist? Justify your answer.

3. Briefly state one of Newton’s three laws of motion in your own words. Give an explanation of how this law works.

4. Define the law of universal gravitation in your own words.

5. The orbit of a space shuttle is surprisingly like an apple falling from a tree to Earth. The space shuttle is simply moving so fast that the path of its fall is an orbit around our planet. Which of Newton’s laws helps explain the orbit of a space shuttle around Earth and the orbit of Earth around the sun?

6. Research: Newton was outraged when, in 1684, German mathematician Wilhelm Leibniz published a calculus book. Find out why, and describe how the issue is generally resolved today.
Agnes Pockels

Working in her kitchen, Agnes Pockels made significant strides in understanding surface tension. She developed new methods for measuring properties of films on the surface of water and other liquids. The study of these monolayer films laid the groundwork for the field of nanotechnology.

The start of a scientist

Agnes Pockels was born on Feb. 14, 1862 in Venice, Italy, where her father was serving in the Austrian army. When he became ill and retired in 1871, he moved the family to Brunswick, Lower Saxony (part of Germany).

Agnes attended the Municipal High School for Girls in Brunswick. The school’s science curriculum was rigorous and she acquired a strong background in the natural sciences. She especially liked physics and wanted to pursue her education, but women were not admitted to university. When they finally were, she was obligated to stay home to care for her parents who were both ill with complications from malaria.

Kitchen experiments

Agnes’s younger brother did attend university, in Göttingen, and he provided her with the textbooks she studied at home. At 19, she began experimenting in the kitchen, using household items to study oily films on the surface of water in a container.

Agnes invented a device for measuring the surface tension of liquids. First, she made a special water trough with a movable partition that allowed her to create a fresh, uncontaminated water surface for each measurement. Then, using some string and a balance, she measured the weight needed to separate a small button from the water’s surface. She compared her results for plain water with the results she obtained when salt, oils, flour, wax, and other contaminants were added. She kept careful records of all of her experiments.

A letter makes her known

After Pockels read about the work of Lord Rayleigh, a British physicist (and future Nobelist), in the study of water surfaces, she wrote him a letter describing her own observations. He was impressed and, after his wife translated the letter from German into English, Lord Rayleigh sent it to the journal Nature, where it was published in 1891.

After that, Pockels’s research methods became the standard for studying surface films; some of the techniques are still used, in fact. Using her methods, scientists learned that a small amount of oil will spread out on water until it is just one molecule thick, forming a monolayer film. Irving Langmuir, a researcher in the United States, studied Pockels's work and repeated many of her experiments. He credited her for providing the foundation that enabled him to make an important discovery: Molecules in a monolayer film line up in a common orientation. In 1932, Langmuir won the Nobel Prize in chemistry for this discovery.

The Pockels point

When her work became known, Pockels was invited by the university in Heidelberg to work in its physics lab, which she did for 40 years. In 1931, Pockels was awarded the Laura Leonard Prize for “Quantitative Investigation of the Properties of Surface Layers and Surface Films.” In 1932, she received an honorary doctorate from Carolina-Wilhelmina University at Brunswick. Pockels died in 1935. In recognition of her work, the minimum area occupied by a monolayer film is called the Pockels point.

Monolayers and nanotechnology

Recently, monolayer films have been of particular interest because nanotechnology research scientists have learned that data could be stored on stacked monolayers. Each atom in a monolayer would store a byte of data. Using atoms instead of chips for memory would allow us to store more that 100 billion billion bytes in a volume the size of a sugar cube. Computers that size could deliver a billion billion instructions per second.
Reading reflection

1. What subject did Agnes Pockels especially enjoy in high school?

2. Although Pockels work investigated the nature of fluids (something you will learn about in unit 3), Pockels relied on her understanding of simple machines to construct her device. The device that Pockels invented might have looked like this diagram.

   a. What are the pros and cons of this device?
   b. Do you think the device gave Pockels accurate data about the surface tension of water? Why or why not?

3. From the reading, what do you think the term *surface tension* of a liquid means? Write a definition in your own words.

4. List two reasons it was important for Pockels to write a letter describing her observations.

5. What is a *monolayer film*?

6. What is the *Pockels point*?

7. Research and list at least three uses for monolayer films other than data storage.

8. Even though Pockels could not attend the university, what do you think motivated her to keep trying scientific experiments?
Archimedes was a Greek mathematician who specialized in geometry. He figured out the value of pi and the volume of a sphere, and has been called “the father of integral calculus.” During his lifetime, he was famous for using compound pulleys and levers to invent war machines that successfully held off an attack on his city for three years. Today he is best known for the Archimedean principle, which was the first explanation of how buoyancy works.

**Archimedes’ screw**

Archimedes was born in Syracuse, on Sicily (then an independent Greek city-state), in 287 B.C. His letters suggest he studied in Alexandria, Egypt, as a young man. Historians believe it was there that he invented a device for raising water by means of a rotating screw or spirally bent tube within an inclined hollow cylinder. The device known as Archimedes’ screw is still used in many parts of the world.

**‘Eureka!’**

A famous Greek legend says that King Hieron II of Syracuse asked Archimedes to figure out if his new crown was pure gold or if the craftsman had mixed some less expensive silver into it. Archimedes had to determine the answer without destroying the crown. He thought about it for days and then, as he lowered himself into a bath, the method for figuring it out struck him. The legend says Archimedes ran naked through the streets, shouting “Eureka!”—meaning “I have found it.”

**A massive problem**

Archimedes realized that if he had equal masses of gold and silver, the denser gold would have a smaller volume. Therefore, the gold would displace less water than the silver when submerged.

Archimedes found the mass of the crown, and then made a bar of pure gold with the same mass. He submerged the gold bar and measured the volume of water it displaced. Next, he submerged the crown. He found that the crown displaced more water than the gold bar had and, therefore, could not be pure gold. The gold had been mixed with a less dense material. Archimedes had confirmed the king’s doubts.

**Why do things float?**

Archimedes wrote a treatise titled “On Floating Bodies,” further exploring density and buoyancy. He explained that an object immersed in a fluid is buoyed upward by a force equal to the weight of the fluid displaced by the object. Therefore, if an object weighs more than the fluid it displaces, it will sink. If it weighs less than the fluid it displaces, it will float. This statement is known as the Archimedean principle. Although we commonly assume the fluid is water, the statement holds true for any fluid, whether liquid or gas. A helium balloon floats because the air it displaces weighs more than the balloon filled with lightweight gas.

**Cylinders, circles, and exponents**

Archimedes wrote several other treatises, including “On the Sphere and the Cylinder,” “On the Measurement of the Circle,” “On Spirals,” and “The Sand Reckoner.” In this last treatise, he devised a system of exponents that allowed him to represent large numbers on paper—up to $8 \times 10^{63}$ in modern scientific notation. This was large enough, he said, to count the grains of sand that would be needed to fill the universe. This paper is even more remarkable for its astronomical calculations than for its new mathematics. Archimedes first had to figure out the size of the universe in order to estimate the amount of sand needed to fill it. He based his size calculations on the writings of three astronomers (one of them was his father). While his estimate is considered too small by today’s standard, it was much, much larger than anyone had previously suggested. Archimedes was the first to think on an “astronomical scale.”

Archimedes was killed by a Roman soldier during an invasion of Syracuse in 212 B.C.
Reading reflection

1. The boldface words in the article are defined in the glossary of your textbook. Look them up and then explain the meaning of each in your own words.

2. Imagine you are Archimedes and have to write your resume for a job. Describe yourself in a brief paragraph. Be sure to include in the paragraph your skills and the jobs you are capable of doing.

3. What was Archimedes’ treatise “The Sand Reckoner” about?

4. Why does a balloon filled with helium float in air, but a balloon filled with air from your lungs sinks?

5. Research one of Archimedes’ inventions and create a poster that shows how the device worked.
Ernest Rutherford

Ernest Rutherford initiated a radical new view of the atom. He explained the mysterious phenomenon of radiation as the spontaneous disintegration of atoms. He was the first to describe the atom’s internal structure and performed the first successful nuclear reaction.

Ambitious immigrants

Ernest Rutherford was born in rural New Zealand on August 31, 1871. His father was a Scottish immigrant, his mother English. Both valued education (he had had little and she was a teacher) and instilled a strong work ethic in their 12 children. Ernest enjoyed the family farm, but was encouraged by his parents and teachers to pursue scholarships, first to a secondary school, Nelson College, and then, in 1890, after twice taking the qualifying exam, to Canterbury College of the University of New Zealand.

Investigating radioactivity

After earning three degrees in his homeland, Rutherford traveled to Cambridge, England, to pursue graduate research under the guidance of the man who discovered the electron, J. J. Thomson. Through his research with Thomson, Rutherford became interested in studying radioactivity. In 1898 he described two kinds of particles emitted from radioactive atoms, calling them alpha and beta particles. He also coined the term half-life to describe the amount of time taken for radioactivity to decrease to half its original level.

An observer of transformations

Rutherford accepted a professorship at McGill University in Montreal, Canada, in 1898. It was there that he proved that atoms of a radioactive element could spontaneously decay into another element by expelling a piece of the atom. This was surprising to the scientific community—the idea that atoms could change into other atoms had been scorned as alchemy. In 1908 Rutherford received the Nobel Prize in chemistry for “his investigations into the disintegration of the elements and the chemistry of radioactive substances.” He considered himself a physicist and joked that, “of all the transformations I have seen in my lifetime, the fastest was my own transformation from physicist to chemist.”

Exploring atomic space

Rutherford had returned to England in 1907, to Manchester University. There, he and two students bombarded gold foil with alpha particles. Most of the particles passed through the foil, but a few bounced back. They reasoned these particles must have hit denser areas of foil. Rutherford hypothesized that the atom must be mostly empty space, through which the alpha particles passed, with a tiny dense core he called the nucleus, which some of the particles hit and bounced off. From this experiment he developed a new “planetary model” of the atom. The inside of the atom, Rutherford suggested, contained electrons orbiting a small nucleus the way the planets of our solar system orbit the sun.

‘Playing with marbles’

In 1917, Rutherford made another discovery. He bombarded nitrogen gas with alpha particles and found that occasionally an oxygen atom was produced. He concluded that the alpha particles must have knocked a positively charged particle (which he named the proton) from the nucleus. He called this “playing with marbles” but word quickly spread that he had become the first person to split an atom. Rutherford, who was knighted in 1914 (and later elevated to the peerage, in 1931) returned to Cambridge in 1919 to head the Cavendish Laboratory where he had begun his research in radioactivity. He remained there until his death at 66 in 1937.
Reading reflection

1. What are alpha and beta particles? Use your textbook to find the definitions of these terms. Make a diagram of each particle; include labels in your diagram.

2. The term “alchemy” refers to early pseudoscientific attempts to transform common elements into more valuable elements (such as lead into gold). For one kind of atom to become another kind of atom, which particles of the atom need to be expelled or gained?

3. Make a diagram of the “planetary model” of the atom. Include the nucleus and electrons in your diagram.

4. Compare and contrast Rutherford’s “planetary model” of the atom with our current understanding of an atom’s internal structure.

5. Why did Rutherford say that bombarding atoms with particles was like “playing with marbles”? What subatomic particle did Rutherford discover during this phase of his work?

6. Choose one of Rutherford’s discoveries and explain why it intrigues you.
**Chien-Shiung Wu**

_During World War II, Chinese-American physicist Chien-Shiung Wu played an important role in the Manhattan Project, the Army’s secret work to develop the atomic bomb. In 1957, she overthrew what was considered an indisputable law of physics, changing the way we understand the weak nuclear force._

Determined to learn

Chien-Shiung Wu was born on May 31, 1912, in a small town outside Shanghai, China. Her father had opened the region’s first school for young girls, which Chien-Shiung finished at age 10. She then attended a girls boarding school in Suzhou that had two sections—a teacher training school and an academic school with a standard Western curriculum. Chien-Shiung enrolled in teacher training, because tuition was free and graduates were guaranteed jobs.

Students from both sections lived in the dormitory, and as Chien-Shiung became friends with girls in the academic school, she learned that their science and math curriculum was more rigorous than hers. She asked to borrow their books and stayed up late teaching herself the material. She graduated first in her class and was invited to attend prestigious National Central University in Nanjing. After earning a bachelor’s degree in physics and doing research for two years, in 1936 Wu emigrated to the United States. She earned her doctorate from the University of California at Berkeley in 1940.

A key scientist in the Manhattan Project

Wu taught at Smith College and Princeton University until 1944, when she went to Columbia University as a senior scientist and researcher and was asked to join the Manhattan Project. There she helped develop the process to enrich uranium ore. In the course of the project, her renowned colleague Enrico Fermi turned to Wu for help when he ran into unexpected difficulties with a fission experiment. A rare gas which she had studied in graduate school was causing the problem; with Wu’s assistance, Fermi was able to continue his work.

Right and left in nature?

After the war, Wu continued her research in nuclear physics at Columbia. In 1956, she and two colleagues, Tsung-Dao Lee of Columbia and Chen Ning Yang of Princeton, reconsidered the _law of conservation of parity_, which said in effect that in nuclear reactions, nature does not distinguish between left and right. They wondered if the law might not be valid for interactions of subatomic particles involving the _weak nuclear force_.

Wu was a leading specialist in _beta decay_. She figured out a means of testing their theory. She cooled cobalt-60, a radioactive _isotope_, to 0.01 degree above absolute zero. Next, she placed the cobalt-60 in a strong magnetic field so that the cobalt nuclei lined up and spun along the same axis. She observed what happened as the cobalt-60 broke down and gave off electrons. According to the law of conservation of parity, equal numbers of electrons should have been given off in each direction. However, Wu found that many more electrons flew off in the direction opposite the spin of the cobalt-60 nuclei. She proved that in beta decay, nature does in fact distinguish between left and right.

Always a landmark achiever

Unfortunately, when Lee and Yang were awarded the Nobel Prize in physics in 1957, Wu’s contribution to the project was overlooked. However, among her many honors and awards, she later received the National Medal of Science, the nation’s highest award for science achievement. In 1973, she became the first female president of the American Physical Society. Wu died at 84 in 1997, leaving a husband and son who were both physicists.
Reading reflection

1. The boldface words in the article are defined in the glossary of your textbook. Look up and write the definitions of these words.

2. How did Chien-Shiung Wu’s work in graduate school help her with her work on the Manhattan Project?

3. From the reading, define the law of conservation of parity in your own words.

4. How many protons and neutrons does cobalt-60 have? List the nonradioactive isotopes of cobalt.

5. Briefly describe Wu’s elegant experiment that proved that nature distinguishes between right and left.

6. Research: Wu was the first woman recipient of the National Medal of Science in physical science. Two other women have since received this award. Who were they and what did they do?

7. What are three questions that you have about Wu and her work?

8. What might be the reason why Wu did not receive the Nobel Prize for her work?
Rosalyn Sussman Yalow

**Encouraged and inspired**

Rosalyn Sussman was born in 1921 in New York City. Neither of her parents attended school beyond eighth grade, but they encouraged Rosalyn and her older brother to value education. In the early grades, Rosalyn enjoyed math, but in high school her chemistry teacher encouraged her interest in science. She stayed in New York, studying physics and chemistry at Hunter College and, after her graduation in 1941, taking a job as a secretary at Columbia University. There were few opportunities for women to attend graduate school, and Sussman hoped that by working at Columbia, she might be able to sit in on some courses.

**A wartime opportunity**

However, as the United States began drafting large numbers of men in preparation for war, universities began to accept women rather than close down. In fall 1941, Sussman arrived at the University of Illinois with a teaching assistantship in the School of Engineering, where she was the only woman. She specialized in the construction and use of devices for measuring radioactive substances. By January 1945 she had earned her doctorate, with honors, in nuclear physics, and married Aaron Yalow, a fellow student.

**From medical physics to ‘radioimmunoassay’**

From 1946-50, Yalow taught physics at Hunter, which had only introduced it as a major her senior year and which now admitted men. In 1947, she also began working part time at the Veterans Administration Hospital in the Bronx, which was researching medical uses of radioactive substances. In 1950 she joined the hospital full time and began a research partnership with Solomon A. Berson, an internist. Together they developed the basic science, instruments, and mathematical analysis necessary to use radioactive isotopes to measure tiny concentrations of biological substances and certain drugs in blood and other body fluids. They called their technique radioimmunoassay, or RIA. (Yalow also had two children by 1954.)

**RIA helps diabetes research**

One early application of RIA was in diabetes research, which was especially significant to Yalow because her husband was diabetic. Diabetes is a condition in which the body is unable to regulate blood sugar levels. This is normally accomplished through the release of a hormone called insulin from the pancreas. Using RIA, they showed that adult diabetics did not always lack insulin in their blood, and that, therefore, something must be blocking their insulin’s normal action. They also studied the body’s immune system response to insulin injected into the bloodstream.

**Commercial applications, not commerce**

RIA’s current uses include screening donated blood, determining effective doses of medicines, detecting foreign substances in the blood, testing hormone levels in infertile couples, and treating certain children with growth hormones. Yalow and Berson changed theoretical immunology and could have made their fortunes had they chosen to patent RIA, but instead, Yalow explained, “Patents are about keeping things away from people for the purpose of making money. We wanted others to be able to use RIA.” Berson died unexpectedly in 1972; Yalow had their VA research laboratory named after him, and lamented later that his death had excluded him from sharing the team’s greatest recognition.

**A rare Nobel winner**

Yalow was awarded the Nobel Prize in physiology or medicine in 1977, only the second woman to win in that category, for her work on radioimmunoassay of peptide hormones.
Reading reflection

1. Rosalyn Yalow has said that Eve Curie’s biography of her mother, Marie Curie, helped spark her interest in science. Compare the lives of these two scientists.

2. Describe radioimmunoassay in your own words.

3. What information about adult diabetes was discovered using RIA?

4. Find out more about the role of patents in medical research. Do you agree or disagree with Yalow’s statement? Why?
Niels Bohr

Danish physicist Niels Bohr first proposed the idea that electrons exist in specific orbits around the atom’s nucleus. He showed that when an electron falls from a higher orbital to a lower one, it releases energy in the form of visible light.

At home among ideas
Niels Bohr was born October 7, 1885, in Copenhagen, Denmark. His father was a physiology professor at the University of Copenhagen, his mother the daughter of a prominent Jewish politician and businessman. His parents often invited professors over for dinners and leisurely discussions. Niels and his sister and brother were frequently invited to join this friendly exchange of ideas and learned to value the search for deeper understanding of the world. (Niels and his brother also shared a passion for soccer, which they both played, and for which Harald, later a world-famous mathematician, was to win an Olympic silver medal.)

Bohr entered the University of Copenhagen in 1903 to study physics. Because the university had no physics laboratory, Bohr conducted experiments in his father’s physiology lab. He graduated with a doctorate in 1911.

Meeting of great minds
In 1912, Bohr went to Manchester, England, to study under Ernest Rutherford, who became a lifelong friend. Rutherford had recently published his new planetary model of the atom, which explained that an atom contains a tiny dense core surrounded by orbiting electrons. Bohr began researching the orbiting electrons, hoping to describe their behavior in greater detail.

Electrons and the atom’s chemistry
Bohr studied the quantum ideas of Max Planck and Albert Einstein as he sought to describe the electrons’ orbits. In 1913 he published his results. He proposed that electrons traveled only in specific orbits. The orbits were like rungs on a ladder — electrons could move up and down orbits, but did not exist in between the orbital paths. He explained that outer orbits could hold more electrons than inner orbits, and that many chemical properties of the atom were determined by the number of electrons in the outer orbit.

Bohr also described how atoms emit light. He explained that an electron needs to absorb energy to jump from an inner orbit to an outer one. When the electron falls back to the inner orbit, it releases that energy in the form of visible light.

An institute, then a Nobel Prize
In 1916, Bohr accepted a position as professor of physics at the University of Copenhagen, which created the Institute of Theoretical Physics that Bohr directed for the rest of his life. In 1922, he was awarded the Nobel Prize in physics for his work in atomic structure and radiation.

In 1940, as World War II spread across Europe, Germany occupied Denmark. Though he had been baptized a Christian, Bohr’s family history and his own anti-Nazi sentiments made life difficult. In 1943, he escaped in a fishing boat to Sweden, where he convinced the king to offer sanctuary to all Jewish refugees from Denmark. The British brought him to England, where researchers were working on the atomic bomb. A few months later, the team went to Los Alamos, New Mexico, to continue their work.

A warrior for peace
Although Bohr believed the creation of the atomic bomb was necessary in the face of the Nazi threat, he was deeply concerned about its future implications. He promoted disarmament efforts through the United Nations and won the first U.S. Atoms for Peace Award in 1957, the same year his son Aage shared the Nobel Prize in physics. He died in 1962 in Copenhagen.
Reading reflection

1. How did Niels Bohr’s model of the atom compare with Ernest Rutherford’s?

2. Name two specific contributions Bohr made to our understanding of atomic structure.

3. Make a drawing of Bohr’s model of the atom.

4. In your own words describe how atoms emit light.

5. Why do you think Bohr was concerned with the future implications of his work on atomic bombs? Once you have answered this question, discuss your thoughts with a partner.
Lise Meitner

Lise Meitner identified and explained nuclear fission, proving it was possible to split an atom.

Prepared to learn

Lise Meitner was born in Vienna on November 7, 1878, one of eight children; her father was among the first Jews to practice law in Austria. At 13, she completed the schooling provided to girls. Her father hired a tutor to help her prepare for a university education, although women were not yet allowed to attend.

The preparation was worthwhile. When the University of Vienna opened its doors to women in 1901, Meitner was ready. She found a mentor there in physics professor Ludwig Boltzmann, who encouraged her to pursue a doctoral degree. Physicist Otto Robert Frisch, Meitner’s nephew, wrote that “Boltzmann gave her the vision of physics as a battle for ultimate truth, a vision she never lost.”

Pioneer in radioactivity

In 1906 after earning her doctorate, only the second in physics awarded to a woman by the university, Meitner went to Berlin where there was great interest in theoretical physics. There she began a 30-year collaboration with chemist Otto Hahn. Together, they studied radioactive substances. One of their first successes was the development of a new technique for purifying radioactive material.

During World War I, Meitner volunteered as an X-ray nurse-technician with the Austrian army. She pioneered cautious handling techniques for radioactive substances, and when she was off duty, continued her work with Hahn.

Elemental discoveries

In 1917, they discovered the element protactinium. Afterward, Meitner was appointed head of the physics department at the Kaiser Wilhelm Institute for Chemistry in Berlin, where Hahn was head of the chemistry department. The two continued their study of radioactivity, and Meitner became the first to explain how conversion electrons were produced when gamma rays were used to remove orbital electrons.

Atomic-age puzzles

In 1934, when Enrico Fermi produced radioactive isotopes of uranium by neutron bombardment, he was puzzled by the products. Meitner, Hahn, and German chemist Fritz Strassmann began looking for answers.

Their research was interrupted when Nazi Germany annexed Austria in 1938 and restrictions on “non-Aryan” academics tightened. Meitner, though she had been baptized and raised a Protestant, went into exile in Sweden. She continued to correspond with her collaborators and suggested that they perform further tests on a product of the uranium bombardment. When tests showed it was barium, the group was puzzled. Barium was so much smaller than uranium. Hahn wrote to Meitner that uranium “can’t really break into barium ... try to think of some other possible explanation.” Meitner and Frisch, who was also in Sweden, worked on the problem and proved that splitting the uranium atom was energetically possible. Using Niels Bohr’s model of the nucleus, they explained how the neutron bombardment could cause the nucleus to elongate into a dumbbell shape. Occasionally, they explained, the narrow center of the dumbbell could separate, leaving two nuclei. Meitner and Frisch called this process nuclear fission.

Meitnerium honors achievement

In 1944, Hahn received the Nobel Prize in chemistry for the discovery of nuclear fission, with Meitner’s role having been overlooked or obscured. In 1966, she, Hahn, and Strassman shared the Enrico Fermi Award, given by President Lyndon B. Johnson and the Department of Energy. Meitner died two years later, just days before her 90th birthday. In 1992, element 109 was named meitnerium to honor her work.
Reading reflection

1. **Research:** Ludwig Boltzmann was an important mentor to Lise Meitner. Who was Boltzmann? Research and list one of his contributions to science.

2. What element did Meitner and Otto Hahn discover? Using the periodic table, list the atomic number and mass number of this element. Does this element have stable isotopes?

3. What is nuclear fission? Explain this event in your own words and draw a diagram showing how fission occurs in a uranium nucleus.

4. **Research** and describe at least two ways nuclear fission was used in the twentieth century.

5. Meitner did not receive the Nobel Prize for her work on nuclear fission, though she was honored in other ways. List how she was honored for her work in physics.

6. On a separate sheet of paper, compose a letter to the Nobel Prize Committee explaining why Meitner deserved this prize for her work. Be sure to explain your reasoning clearly and be sure to use formal language and good grammar in your letter.
Marie and Pierre Curie’s pioneering studies of radioactivity had a profound impact on the development of twentieth-century science. Marie Curie’s bold assertion that uranium rays seemed to be an intrinsic part of uranium atoms encouraged physicists to explore the possibility that atoms might have an internal structure. Out of this idea the field of nuclear physics was born. Together the Curies discovered two radioactive elements, polonium and radium. Through Pierre Curie’s study of how living tissue responds to radiation, a new era in cancer treatment was born.

The allure of learning
Marya Sklodowska was born on November 7, 1867, in Russian-occupied Warsaw, Poland, the youngest of five children of two teachers, her father a teacher of physics and mathematics, her mother also a singer and pianist. Marya loved school, and especially math and science, but in Poland, as in much of the rest of the world, opportunities for higher education were limited for women. At 17, she and one of her sisters enrolled in an illegal, underground “floating university” in Warsaw.

After these studies, she worked for three years as a governess. Her employer allowed her to teach reading to the children of peasant workers at his beet-sugar factory, although this was forbidden under Russian rule. At the same time, she took chemistry lessons from the factory’s chemist, mathematics lessons from her father by mail, and studied on her own.

By fall 1891, Sklodowska had saved enough money to enroll at the University of Paris (also called the Sorbonne). She earned two master’s degrees, in physics and mathematics. A Polish friend introduced Marie, as she was called in French, to Pierre Curie, the laboratory chief at the Sorbonne’s Physics and Industrial Chemistry Schools.

The piezoelectric effect
Pierre Curie’s early research centered on properties of crystals. He and his brother Jacques discovered the piezoelectric effect, which describes how a crystal will oscillate when electric current is applied. The oscillation of crystals is now used to precisely control timing in computers and watches and many other devices.

Pierre Curie and Marie Sklodowska found that despite their different nationalities and backgrounds and the different paths by which they had arrived at the Sorbonne, they had the same passion for scientific research and shared the desire to use their discoveries to promote humanitarian causes. Their friendship deepened and in 1895 they married.

Crystals and uranium rays
Pierre continued his pioneering research in crystal structures, while Marie pursued a physics doctorate. As her research topic she chose uranium rays, which had been discovered only recently by French physicist Henri Becquerel. After reading Becquerel’s report that uranium compounds emitted some sort of ray that fogged photographic plates, Marie Curie decided to research the effect these rays had on the air’s ability to conduct electricity. To measure this effect, she adapted a device that Pierre and Jacques Curie had invented 15 years earlier.

Marie Curie confirmed that the electrical effects of uranium rays were similar to the photographic effects that Becquerel reported — both were present whether the uranium was solid or powdered, pure or in compound, wet or dry, exposed to heat or to light. She concluded that the emission of rays by uranium was not the product of a chemical reaction, but could be something built into the very structure of uranium atoms.

Allies behind a revolutionary idea
Marie Curie’s idea was revolutionary because atoms were still believed to be tiny, featureless particles. She decided to test every known element to see if any others would, like uranium, improve the air’s ability to conduct electricity. She found that the element thorium had this property.

Pierre Curie put aside his research on crystals and joined Marie after she found that two different
uranium ores (raw materials gathered from uranium mines) caused the air to conduct electricity much better than even pure uranium or thorium. They wondered if an undiscovered element might be mixed into each ore. They worked to separate the chemicals in the ores and found two substances that were responsible for the increased conductivity. They called these elements polonium, in honor of Marie’s native country, and radium, from the Greek word for ray.

A new field of medicine
While Marie Curie searched for ways to extract these pure elements from the ores, Pierre turned his attention to the properties of the rays themselves. He tested the radiation on his own skin and found that it damaged living tissue. As he published his findings, a whole new field of medicine developed, using targeted rays to destroy cancerous tumors and cure skin diseases. Unfortunately, both Curies became ill from overexposure to radiation.

Curies share the Nobel Prize
In June 1903, Madame Curie defended her thesis and became the first woman in Europe to receive a doctorate in science. In December of that year, the Curies and Becquerel shared the Nobel Prize in physics, the Curies for their work on the spontaneous radiation Becquerel had discovered (and which Marie Curie called “radioactivity.”) She was the first woman to win the Nobel in physics. And in 1904, her second daughter, Eve, was born. The elder, Irene, was 7.

Tragedy intrudes
In April 1906, Pierre was killed by a horse-drawn wagon in a Paris street accident. A month later, the Sorbonne asked Madame Curie to take over her husband’s position there. She agreed, in hopes of creating a state-of-the art research center in her husband’s memory.

Marie Curie threw herself into the busy academic schedule of teaching and conducting research (she was the first woman to lecture, the first to be named professor, and the first to head a laboratory at the Sorbonne), and found time to work on raising money for the new center. The Radium Institute of the University of Paris opened in 1914 and Madame Curie was named director of its Curie Laboratory.

The scientist-humanitarian
In 1911, Curie received a second Nobel Prize (the first person so honored), this time in chemistry for her work in finding elements and determining the atomic weight of radium.

With the start of World War I in 1914, she turned her attention to the use of radiation to help wounded soldiers. Assisted by Irene, she created a fleet of 20 mobile X-ray units to help medics quickly determine and then treat injuries in the field. Next, she set up nearly 200 X-ray labs in hospitals and trained 150 women to operate the equipment.

Legacy continues
After the war, Curie went back to direct the Radium Institute, which grew to two centers, one devoted to research and the other to treatment of cancer. In July 1934, she died at 66 of radiation-induced leukemia. The next year, Irene Joliot-Curie and her husband, Frederic Joliot-Curie, were awarded the Nobel Prize in chemistry for their discovery of artificial radiation.
Reading reflection

1. Why might Marie Curie have been motivated to teach the children of beet workers? Recall that this was forbidden by Russian rule. Discuss your answer to this question with a partner.

2. What fundamental change in our understanding of the atom was brought about by the work of Marie Curie?

3. Describe how Marie and Pierre Curie discovered two elements.

4. Name at least three new fields of science that stem from the work of Marie and/or Pierre Curie.

5. **Research:** In your own words, describe Marie Curie as a role model for women in science. Use your library or the Internet to research how she viewed balancing her scientific career and being a mother.
Albert Einstein

Looking for ‘something deeply hidden’

Albert Einstein was born in 1879 in Ulm, Germany, and his family moved several weeks later to Munich. He was a quiet child who spent hours building houses of cards and playing the violin. One story he told from his youth was of his first encounter with a magnetic compass: The needle seemed to him to be guided northward by an invisible force. He was convinced there had to be “something behind things, something deeply hidden.” The search for that “something” occupied him until his death in 1955.

Einstein was not fond of school until he entered secondary school in Aarau, Switzerland (his family had moved to Italy). There he found first-rate laboratory facilities and teachers who nurtured his interest in science. He went on to attend the Swiss Federal Institute of Technology in Zurich and graduated in 1900 with a teaching degree. His first permanent job was as a technician in the Patent Office in Bern. Einstein enjoyed evaluating patent claims, but the best part of the position was the stability it provided. He spent his evenings reading and thinking about current issues in theoretical physics.

Stepping into the spotlight

In 1905, Einstein published three papers that radically changed the way scientists understood the physical world. While most work in theoretical physics is accomplished through an extended dialogue among scientists, these papers had been written in relative isolation. The first described light as discrete bundles of radiation. Einstein’s description formed the basis for much of quantum mechanics. The second paper proposed his theory of special relativity. While Einstein was not the first scientist to generate all of the pieces of this theory, he was the first to unify them. The third paper showed that Brownian motion (the erratic motion of microscopic particles in a fluid) provided physical evidence for the existence of atoms and molecules. Until Einstein’s paper, scientists had only theoretical evidence of these tiny particles.

Einstein earned respect as one of Europe’s leading scientific thinkers as a result of these papers. In 1909 he became a professor first in Zurich, then Prague, and eventually again in Zurich. In 1914 he was appointed director of the Kaiser Wilhelm Physical Institute and professor at the University of Berlin.

Light bends in space

Einstein’s interests turned toward a theory of general relativity, which showed how inertia and gravity are connected. His theory predicted that light from distant stars should be bent by the curvature of space near the sun. During a solar eclipse in 1919, his prediction was proven correct. In 1921, he was awarded the Nobel Prize in physics for his work on the photoelectric effect.

War and peace

During World War I, Einstein, a pacifist, refused to support Germany’s war aims. In 1933, he left Germany to become a professor at Princeton University. In 1939, concerned about the rise of fascism, he decided force was necessary to face this threat. He sent a letter to President Franklin Roosevelt that urged the United States to develop an atomic bomb before Germany did. After the war, Einstein was a strong supporter of nuclear disarmament.

Unifying the forces of nature

Einstein’s scientific interests in his later years focused on finding a unified field theory, which he hoped could integrate all the known forces in nature in a single equation that would show they were all manifestations of a single fundamental force. While he never managed to find what he was looking for, his work fascinates theoretical physicists to this day.
**Reading reflection**

1. Look up the definition of each boldface word in the article. Write down the definitions and be sure to credit your source.

2. Imagine that you knew Albert Einstein when he was growing up. Write a brief description of him as a young person.

3. How did each of Einstein’s first three papers contribute to scientific understanding?

4. **Research** Brownian motion and prepare a demonstration for your classmates.

5. What event helped prove Einstein’s prediction that light bends near the sun?

6. **Research** how scientists tested Einstein’s theory of general relativity in 1919. Write a paragraph to explain their method.

7. The United States’ involvement in World War II lasted from 1941-45. What important thing did Einstein do before the war?

8. After World War II, why do you think Einstein argued for nuclear disarmament?

9. Define the term “unified field theory” in your own words.

10. Which of Einstein’s theories was most important? Why? Compare your answer to this question with others in your classroom or discussion group.
George Westinghouse

George Westinghouse was both an imaginative tinkerer and a bold entrepreneur. His inventions had a profound effect on nineteenth-century transportation and industrial development in the United States. His air brakes and signaling systems made railway systems safer at higher speeds, so that railroads became a practical method of transporting goods across the country. He promoted alternating current as the best means of providing electric power to businesses and homes, and his method became the worldwide standard. Westinghouse obtained 361 patents over the course of his life.

A boyhood among machines

George Westinghouse was born October 6, 1846, in Central Bridge, New York. When he was 10, his family moved to Schenectady, where his father opened a shop that manufactured agricultural machinery. George spent a great deal of time working and tinkering there. After serving in both the Union Army and Navy in the Civil War, Westinghouse attended college for three months. He dropped out after receiving his first patent in 1865, for a rotary steam engine he had invented in his father’s shop.

An inventive train of thought

In 1866, Westinghouse was aboard a train that had to come to a sudden halt to avoid colliding with a wrecked train. To stop the train, brakemen manually applied brakes to each individual car based on a signal from the engineer. Westinghouse believed there could be a safer way to stop these heavy trains. In April 1869, he patented an air brake that enabled the engineer to stop all the cars in tandem. That July he founded the Westinghouse Air Brake Company, and soon his brakes were used by most of the world’s railways.

The new braking system made it possible for trains to travel safely at much higher speeds. Westinghouse next turned his attention to improving railway signaling and switching systems. Combining his own inventions with others, he created the Union Switch and Signal Company.

Long-distance electricity

Next, Westinghouse became interested in transmitting electricity over long distances. He saw the potential benefits of providing electric power to individual homes and businesses, and in 1884 formed the Westinghouse Electric Company. Westinghouse learned that Nikola Tesla had developed alternating current and he persuaded Tesla to join the company. Initially, Westinghouse met with resistance from Thomas Edison and others who argued that direct current was a safer alternative. But direct current could not be transmitted over distances longer than three miles. Westinghouse demonstrated the potential of alternating current by lighting the streets of Pittsburgh, Pennsylvania, and, in 1893, the entire Chicago World’s Fair. Afterward, alternating current became the standard means of transmitting electricity.

From waterfalls to elevated railway

Also in 1893, Westinghouse began yet another new project: the construction of three hydroelectric generators to harness the power of Niagara Falls on the New York-Canada border. By November 1895, electricity generated there was being used to power industries in Buffalo, some 20 miles away.

Another Westinghouse interest was alternating current locomotives. He introduced this new technology first in 1905 with the Manhattan Elevated Railway in New York City, and later with the city’s subway system.

An always inquiring mind

The financial panic of 1907 caused Westinghouse to lose control of his companies. He spent much of his last years in public service. Westinghouse died in 1914 and left a legacy of 361 patents in his name—the final one received four years after his death.
Reading reflection

1. Where did George Westinghouse first develop his talent for inventing things?

2. How did Westinghouse make it possible for trains to travel more safely at higher speeds?

3. Why did Westinghouse promote alternating current over direct current for delivering electricity to businesses and homes?

4. How did Westinghouse turn public opinion in favor of alternating current?

5. Together with a partner, explain the difference between direct and alternating current. Write your explanation as a short paragraph and include a diagram.

6. How did Westinghouse provide electrical power to the city of Buffalo, New York?

7. Ordinary trains in Westinghouse’s time were coal-powered steam engines. How were Westinghouse’s Manhattan elevated trains different?

8. Research: Westinghouse had a total of 361 patents to his name. Use a library or the Internet to find out about three inventions not mentioned in this brief biography, and describe each one.
Ben Franklin

Benjamin Franklin overcame a lack of formal education to become a prominent businessman, community leader, inventor, scientist, and statesman. His study of “electric fire” changed our basic understanding of how electricity works.

An eye toward inventiveness

Benjamin Franklin was born in Boston in 1706. With only one year of schooling he became an avid reader and writer. He was apprenticed at 12 to his brother James, a printer. The siblings did not always see eye to eye, and at 17, Ben ran away to Philadelphia.

In his new city, Franklin developed his own printing and publishing business. Over the years, he became a community leader, starting the first library, fire department, hospital, and fire insurance company. He loved gadgets and invented some of his own: the Franklin stove, the glass armonica (a musical instrument), bifocal eyeglasses, and swim fins.

‘Electric fire’

In 1746, Franklin saw some demonstrations of static electricity that were meant for entertainment. He became determined to figure out how this so-called “electric fire” worked. Undeterred by his lack of science education, Franklin began experimenting. He generated static electricity using a glass rod and silk cloth, and then recorded how the charge could attract and repel lightweight objects. He read everything he could about this “electric fire” and became convinced that a lightning bolt was a large-scale example of the same phenomenon.

Father and son experiment

In June 1752, Franklin and his 21-year-old son, William, conducted an experiment to test his theory. Although there is some debate over the details, most historians agree that Franklin flew a kite on a stormy day in order to collect static charges. Franklin explained that he and his son constructed a kite of silk cloth and two cedar strips. They attached a metal wire to the top. Hemp string was used to fly the kite. A key was tied near the string’s lower end. A silk ribbon was affixed to the hemp, below the key.

Shocking results

It is probable that Franklin and his son were under some sort of shelter, to keep the silk ribbon dry. They got the kite flying, and once it was high in the sky they held onto it by the dry silk ribbon, not the wet hemp string. Nothing happened for a while. Then they noticed that the loose threads of the hemp suddenly stood straight up. The kite probably was not struck directly by lightning, but instead collected charge from the clouds. Franklin touched his knuckle to the key and received a static electric shock. He had proved that lightning was a discharge of static electricity.

Those are charged words

Through his experiments, Franklin determined that “electric fire” was a single “fluid” rather than two separate fluids, as European scientists had thought. He proposed that this “fluid” existed in two states, which he called “positive” and “negative.” Franklin was the first to explain that if there is an excess buildup of charge on one item, such as a glass rod, it must be exactly balanced by a lack of charge on another item, such as the silk cloth. Therefore, electric charge is conserved. He also explained that when there is a discharge of static electricity between two items, the charges become balanced again. Many of Franklin’s electrical terms remain in use today, including battery, charge, discharge, electric shock, condenser, conductor, plus and minus, and positive and negative.
Reading reflection

1. Although Ben Franklin had only one year of schooling, he became a highly educated person. Describe how Franklin learned about the world.

2. What hypothesis did Franklin test with his kite experiment?

3. Describe the results and conclusion of Franklin’s kite experiment.

4. Franklin’s kite experiment was dangerous. Explain why.

5. Silk has an affinity for electrons. When you rub a glass rod with silk, the glass is left with a positive charge. Make a diagram that shows the direction that charges move in this example. Illustrate and label positive and negative charges on the silk and glass rod in your diagram. Note: Show the same number of positive and negative charges in your diagram.

6. Research: Among Franklin’s many inventions is the lightning rod. Find out how this device works, and create a model or diagram to show how it functions.
Michael Faraday

Despite little formal schooling, Michael Faraday rose to become one of England’s top research scientists of the nineteenth century. He is best known for his discovery of electromagnetic induction, which made possible the large-scale production of electricity in power plants.

Reading his way to a job

Michael Faraday was born on September 22, 1791, in Surrey, England, the son of a blacksmith. His family moved to London, where Michael received a rudimentary education at a local school. At 14, he was apprenticed to a bookbinder. He enjoyed reading the materials he was asked to bind, and found himself mesmerized by scientific papers that outlined new discoveries. A wealthy client of the bookbinder noticed this voracious reader and gave him tickets to hear Humphry Davy, the British chemist who had discovered potassium and sodium, give a series of lectures to the public.

Faraday took detailed notes at each lecture. He bound the notes and sent them to Davy, asking him for a job. In 1812, Davy hired him as a chemistry laboratory assistant at the Royal Institution, London’s top scientific research facility.

Despite his lack of formal training in science or math, Faraday was an able assistant and soon began independent research in his spare time. In the early 1820s, he discovered how to liquefy chlorine and became the first to isolate benzene, an organic solvent with many commercial uses.

The first electric motor

Faraday also was interested in electricity and magnetism. After reading about the work of Hans Christian Oersted, the Danish physicist, chemist, and electromagnetist, he repeated Oersted’s experiments and used what he learned to build a machine that used an electromagnet to cause rotation—the first electric motor. Next, he tried to do the opposite, to use a moving magnet to cause an electric current. In 1831, he succeeded. Faraday’s discovery is called electromagnetic induction, and it is used by power plants to generate electricity even today.

The Faraday effect

Faraday first developed the concept of a field to describe magnetic and electric forces, and used iron filings to demonstrate magnetic field lines. He also conducted important research in electrolysis and invented a voltmeter. He was interested in finding a connection between magnetism and light. In 1845 he discovered that a strong magnetic field could rotate the plane of polarized light. Today this is known as the Faraday effect.

A scientist’s public education

Faraday was a teacher as well as a researcher. When he became director of the Royal Institution laboratory in 1825, he instituted a popular series of Friday Evening Discourses. Here paying guests (including Prince Albert, who was Queen Victoria’s husband) were entertained with demonstrations of the latest discoveries in science. A series of lectures on the chemistry and physics of flames, titled “The Natural History of a Candle,” was among the original Christmas Lectures for Children, which continue to this day.

Named in his honor

Faraday continued his work at the Royal Institution until just a few years before his death in 1867. Two units of measure have been named in his honor: the farad, a unit of capacitance, and the faraday, a unit of charge.
Reading reflection

1. What did Michael Faraday do to get a job with Humphry Davy? Why was this effort important in getting Faraday started in science?

2. Research benzene and list two modern-day commercial uses for this chemical.

3. Based on the reading, define electromagnetic induction.

4. In your own words, describe the Faraday effect. In your description, explain the term “polarized light.”

5. How did Faraday contribute to society during his time as the director of the Royal Institution laboratory?

6. Name two ways in which Faraday’s work affects your own life in the twenty-first century.

7. Imagine you could go back in time to see one of Faraday’s demonstrations. Explain why you would like to attend one of his demonstrations.

8. **Activity**: Use iron filings and a magnet to demonstrate magnetic field lines, or prepare a simple demonstration of electromagnetic induction for your classmates.
Stephen Hawking

**Origin and evolution**

Stephen Hawking was born on January 8, 1942, in Oxford, England, and grew up in and near London. As a child, he enjoyed making radio-controlled models, though they often looked sloppy. He was always more interested in how they worked than how they looked. As a teenager, he made up elaborate games with complicated maps, charts, and rules.

Hawking studied physics at Oxford, and after earning his degree (and because no one at Oxford was working in this area), went to Cambridge in 1962 to study cosmology, the branch of astrophysics that studies the origin, evolution, and structure of the universe.

**A shock to the system**

At Oxford, Hawking had noticed himself getting clumsy. After his first term at Cambridge, his parents sent him to a doctor; weeks of hospital tests produced a diagnosis of motor neuron disease (Lou Gehrig’s disease), which destroys the nerves that control muscles. Hawking was told he would become weaker, then paralyzed, and that he had only two years to live.

Absorbing this devastating diagnosis, Hawking was for a time sad and withdrawn. But then he realized there were things he wanted to do with the time he had left. He found he was enjoying his studies more and working harder than ever—and he had met a woman whom he wanted to marry. Hawking said his engagement to Jane Wilde gave him something to live for, and also meant that he needed to finish his doctorate and get a job.

**Black holes and singularities**

Hawking’s cosmology work centered on black holes and “space-time singularities.” Black holes are extremely dense space objects that were once massive stars that have collapsed inward because of their own gravitational force. **Singularities** are events where the laws of physics seem to break down. The singularity that most interested Hawking is thought to occur when a large star collapses. The star’s matter is compressed until even the subatomic particles are crushed. The result is a hugely massive object with an equally huge gravitational force—but zero size.

In his doctoral paper, Hawking suggested that if you think of the formation of this singularity as a movie and play it backward, you would see a huge explosion. Perhaps, he wrote, the universe began as such an explosion. This was a revolutionary idea that is now widely accepted. After earning his doctorate in 1965, Hawking stayed on at Cambridge as a professor.

**Mind over many matters**

By 1968 he was confined to a wheelchair; though the progress of his disease had slowed, his research had not. In 1974 Hawking showed through complicated calculations that black holes, in certain circumstances, could emit radiation. This startled physicists, who for years had believed that nothing, not even light, could escape a black hole’s gravitational pull.

Hawking’s recent studies have led to ways of linking two theories that were considered incompatible: Einstein’s theory of relativity and quantum mechanics. Since 1979, Hawking has been the Lucasian Professor of Mathematics at Cambridge, the very position held by Sir Isaac Newton 300 years earlier.

In 1985, Hawking came down with pneumonia. A breathing tube was inserted in his throat, which saved his life but took away his ability to speak. He now uses a computer with a voice synthesizer to communicate.

In 1988, Hawking wrote a book to explain his life work to the general public. “A Brief History of Time” became a surprise best-seller and the author a celebrity scientist—even appearing in an episode of “Star Trek: The Next Generation.” Hawking continues to write (“The Universe in a Nutshell” in 2001, among other works) and speaks to many groups each year, helping people better understand the universe.
Reading reflection

1. When Stephen Hawking entered graduate school at Cambridge, he had to decide whether to pursue experimental physics or theoretical physics. How might his childhood interests help explain his choice?

2. Research: In the United States, motor neuron disease (or amyotrophic lateral sclerosis) is often called Lou Gehrig’s disease, after a famous baseball player who died in 1941 from the condition. Use your library or the Internet to find out about new treatments being developed to slow the progress of this disease. Write a paragraph to explain your findings.

3. Research: In 1974, astronomers using a space-based telescope discovered two stars orbiting around each other. This star system was named Cygnus X-1. What was unusual about this star system? What do scientists believe it provides evidence for?

4. Research: Hawking and his colleagues enjoy giving their new ideas in cosmology witty titles. Choose one of these ideas to explain in a well-developed paragraph: the Big Crunch, Hawking radiation, wormholes, or string theory.

5. Imagine that Stephen Hawking was going to visit your school. Make a list of ten questions you have about black holes that you would want to ask him. Compare your questions with a partner. With your partner, choose the five best questions.
Thomas Edison

Thomas Alva Edison holds the record for the most patents issued to an individual in the United States: 1,093. He is famous for saying that “Genius is one percent inspiration and ninety-nine percent perspiration.” Edison’s hard work and imagination brought us the phonograph, practical incandescent lighting, motion pictures, and the alkaline storage battery.

The young entrepreneur

Thomas Alva Edison was born February 11, 1847, in Milan, Ohio, the youngest of seven children. His family moved to Port Huron, Michigan, in 1854 and Thomas attended school there—for a few months. He was taught reading, writing, and simple arithmetic by his mother, a former teacher, and he read widely and voraciously. The basement was his first laboratory.

When he was 13, Thomas started selling newspapers and candy on the train from Port Huron to Detroit. Waiting for the return train, he often read science and technology books. He set up a chemistry lab in an empty boxcar, until he accidentally set the car on fire.

At 16, Thomas learned to be a telegraph operator and began to travel the country for work. His interest in experiments and gadgets grew and he invented an automatic timer to send telegraph messages while he slept. About this time his hearing was deteriorating; he was left with only about 20 percent hearing in one ear.

First a patent, then business

In 1868 Edison arrived in Boston. His first patent was issued there for an electronic vote recorder. While the device worked very well, it was a commercial failure. Edison vowed that, in the future, he would only invent things he was certain the public would want.

He moved on to New York, where he invented a “Universal Stock Printer” for which he was paid $40,000, a huge sum he found hard to comprehend. After developing some devices to improve telegraph communications, Edison had enough money to build a research lab in Menlo Park, New Jersey.

The invention factory

Edison’s facility had everything he needed for inventing: machine and carpentry shops, a lab, offices, and a library. He hired assistants who specialized where he felt he was lacking, in mathematics, for instance. The concept of a commercial research facility—an “invention factory” of sorts—was new.

Some consider Menlo Park itself to be one of Edison’s most important inventions.

It was there Edison invented the tin foil phonograph, the first machine to record and play back sounds. Next, he developed a practical, safe, and affordable incandescent light. The company he formed to manufacture and market this invention eventually became General Electric.

In 1888, Edison opened an even larger research complex in West Orange, New Jersey. Here he improved the phonograph and created a device that “does for the eye what the phonograph does for the ear.” This was the first motion picture player.

Not a man to be discouraged

Not all of Edison’s ideas were successful. In the 1890s he sold all his stock in General Electric and invested millions to develop better methods of mining iron ore. He never was able to come up with a workable process and the investment was a loss.

One of the most remarkable aspects of Edison’s character was his refusal to be discouraged by failure. The 3,500 notebooks he kept illustrate his typical approach to inventing: brainstorm as many avenues as possible to create a product, try anything that seems remotely workable, and record everything. Failed experiments, he said, helped direct his thinking toward more useful designs.

Edison also worked to create an efficient storage battery to use in electric cars. By the time his alkaline battery was ready, electric cars were uncommon. But the invention proved useful in other devices, like lighting railway cars and miners’ lamps. Edison’s last patent was granted when he was 83, the year before he died, and his last big undertaking was an attempt, at Henry Ford’s request, to develop an alternative source of rubber. He was still working on the project when he died in 1931.
Name: ___________________________ Date: ______________________

**Reading reflection**

1. Name three different avenues by which Thomas Edison received an education.

2. What did Edison learn from his attempts to sell his first patented invention?

3. Describe Edison’s “invention factory.”

4. Name two important inventions that came out of Menlo Park.

5. Describe the process Edison used to invent things.

6. How did Edison view his projects that failed?

7. How do you think the tin foil phonograph worked? Discuss and compare your ideas with a fellow member of your class.

8. **Research:** Edison holds the record for the most patents issued to an individual in the United States. Use a library or the Internet to research three of his inventions that are not mentioned in this biography, and briefly describe each one.
**Galileo Galilei**

Galileo Galilei was a mathematician, scientist, inventor, and astronomer. His observations led to significant advances in our understanding of pendulum motion and free fall. He invented a thermometer, water pump, military compass, and microscope. He refined a Dutch invention, the telescope, and used it to revolutionize our understanding of the solar system.

**An incurable mathematician**

Galileo Galilei was born in Pisa, Italy, on February 15, 1564. His father, a musician and wool trader, hoped his son would find a more profitable career. He sent Galileo to a monastery school at age 11 to prepare for medical school. After four years there, Galileo decided to become a monk. The eldest of seven children, he had sisters who would need dowries in order to marry, and his father had planned on his financial help. Galileo was hastily withdrawn from the monastery school.

Two years later, he enrolled as a medical student at the University of Pisa, though his interests were mathematics and natural philosophy. It was evident soon enough that Galileo did not intend to apply himself to medical studies, and so his father finally agreed that he could study mathematics instead.

**Seeing through the ordinary**

Galileo was insatiably curious. At 20, he found himself watching a lamp swinging from a cathedral ceiling. He used his pulse as a makeshift stopwatch and discovered that the lamp’s long and short swings took the same amount of time. He wrote about this in an early paper titled “On Motion.” Years later, he drew up plans for an invention, a pendulum clock, based on this discovery.

**Inventions and experiments**

Galileo started teaching at the University of Padua in 1592 and stayed for 18 years. Here he invented a simple thermometer, a water pump, and a compass for accurately aiming cannonballs. He also performed experiments with falling objects, using an inclined plane to slow the object’s motion so it could be more accurately timed. Through these experiments, he realized that all objects fall at the same rate unless acted on by another force.

**Crafting better telescopes**

In 1609, Galileo heard that a Dutch eyeglass maker had invented an instrument that made things appear larger. Soon he had crafted his own 10-powered telescope. The senate in Venice was impressed with its potential military uses, and in a year, Galileo had refined his invention to a 30-powered telescope. He might well have enjoyed his acclaim and become a man of wealth and leisure for the rest of his life.

**Star gazing**

Using his powerful telescope, Galileo’s curiosity now turned skyward. He discovered craters on the moon, sunspots, Jupiter’s four largest moons, and the phases of Venus. His observations led him to conclude that Earth could not possibly be the center of the universe, as had been commonly accepted since the time of the Greco-Egyptian astronomer Ptolemy in the second century. Instead, Galileo was convinced that Polish astronomer Nicolaus Copernicus (1473-1543) must have been right: The sun is at the center of the universe and the planets revolve around it.

**House arrest**

The Roman Catholic Church held that Ptolemy’s theory was truth and Copernican theory was heresy. Galileo, who had been told by the Inquisition in 1616 to abandon Copernican theory and its promulgation, pursued his thinking and writing. In February 1632, he published his ideas in the form of a conversation between two characters, the one representing Ptolemy’s view seeming foolish and bullheaded, the other arguing Copernicus’s theory. This provoked the church, whose permission was needed for publishing books, to call Galileo before the Inquisition in Rome, where under formal threat of torture he renounced his error in promoting Copernican theory. He was sentenced to house arrest, and lived until his death in 1642 watched over by Inquisition guards.
Reading reflection

1. What scientific information was presented in Galileo’s paper “On Motion”?

2. Research one of Galileo’s inventions and draw a diagram showing how it worked.

3. How were Galileo’s views about the position of Earth in the universe supportive of Copernicus’s ideas?

4. Imagine you could travel back in time to January 1632 to meet with Galileo just before he publishes his “Dialogue Concerning the Two Chief World Systems.” What would you say to him?

5. In your opinion, which of Galileo’s ideas or inventions had the biggest impact on history? Why?
Arthur Walker

Arthur Walker pioneered several new space-based research tools that brought about significant changes in our understanding of the sun and its corona. He was instrumental in the recruitment and retention of minority students at Stanford University, and he advised the United States Congress on physical science policy issues.

Not to be discouraged

Arthur Walker was born in Cleveland in 1936. His father was a lawyer and his mother a social worker. When Arthur was 5, the family moved to New York. Arthur was an excellent student and his mother encouraged him to take the entrance exam for the Bronx High School of Science.

Arthur passed the exam, but when he entered school a faculty member told him that the prospects for a black scientist in the United States were bleak. Rather than allow him to become dissuaded from his aspirations, Arthur’s mother visited the school and told them that her son would pursue whatever course of study he wished.

Making his mark in space

Walker went on to earn a bachelor’s degree in physics, with honors, from Case Institute of Technology in Cleveland and, by 1962, his master’s and doctorate from the University of Illinois. He then spent three years’ active duty with the Air Force, where he designed a rocket probe and satellite experiment to measure radiation that affects satellite operation. This work sparked Walker’s lifelong interest in developing new space-based research tools.

After completing his military service, Walker worked with other scientists to develop the first X-ray spectrometer used aboard a satellite. Their device helped determine the temperature and composition of the sun’s corona and provided new information about how matter and radiation interact in plasma.

Snapshots of the sun

In 1974, Walker joined the faculty at Stanford University. There he pioneered the use of a new multilayer mirror technology in space observations. The mirrors selectively reflected X-rays of certain wavelengths, and enabled Walker to obtain the first high-resolution images showing different temperature regions of the solar atmosphere. He then worked to develop telescopes using the multilayer mirror technology, and launched them into space on rockets. The telescopes produced detailed photos of the sun and its corona. One of the pictures was featured on the cover of the journal Science in September 1988.

A model for student scientists

Walker was a mentor to many graduate students, including Sally Ride, who went on to become the first American woman in space. He worked to recruit and retain minority applicants to Stanford’s natural and mathematical science programs, and was instrumental in helping Stanford produce more black doctoral physicists than any university in the United States.

At work in other orbits

Public service was important to Walker, who served on several committees of the National Aeronautics and Space Administration (NASA), National Science Foundation, and National Academy of Science, working to develop policy recommendations for Congress. He was also appointed to the presidential commission that investigated the 1986 space shuttle Challenger accident.

Reading reflection

1. Use your textbook, an Internet search engine, or a dictionary to find the definition of each word in bold type. Write down the meaning of each word. Be sure to credit your source.

2. What have you learned about pursuing goals from Arthur Walker’s biography?

3. Why is a spectrometer a useful device for measuring the temperature and composition of something like the sun’s corona?

4. **Research:** Use a library or the Internet to find one of Walker’s revolutionary photos of the sun and its corona. Present the image to your class.

5. **Research:** Use a library or the Internet to find more about the commission that investigated the explosion of the space shuttle Challenger in 1986. Summarize the commission’s findings and recommendations in two or three paragraphs.
History Sheets Answer Keys

Unit 1

Benjamin Banneker

1. An understanding of gear ratios was necessary for building the clock. He used geometry skills to figure out how to create a large-scale model of each tiny piece of the watch he examined.
2. Personal strengths identified from the reading include strong spatial skills (building the clock), creativity and problem solving skills (irrigation system), curiosity and attention to detail (astronomical observations, cicada observations, and almanac), concern for others (letter to Jefferson).
3. Dates are as follows:
   a. 1863
   b. 1865
   c. 1920
   d. 1954
4. Any three of the following answers is correct. Banneker’s accomplishments include:
   a. Designed an irrigation system
   b. Documented cycle of 17-year cicada
   c. Published detailed astronomical calculations in popular almanacs
   d. Served as surveyor of territory that became Washington D.C.
5. Banneker evidently had a strong innate curiosity about the natural world. He was passionate about improving the welfare of the black men and women in the United States and his letter to Jefferson stated that he hoped his scientific work would be seen as proof that people of all races are created equal.
6. Banneker’s puzzles can be found on several web sites. Using an Internet search engine, look for “Benjamin Banneker” + puzzle. Some of the sites publish the answers while others do not. Here is one of Banneker’s puzzles taken from the web site www.thefriendsofbanneker.org. Note that the puzzle was written in the 1700’s and from Banneker’s personal journals.
THE PUZZLE ABOUT TRIANGLES
“Suppose ladder 60 feet long be placed in a Street so as to reach a window on the one side 37 feet high, and without moving it at bottom, will reach another window on the other side of the Street which is 23 feet high, requiring the breadth of the Street.” [No solution recorded in historic records.]

Isaac Newton

1. The isolation due to the Plague allowed Newton to focus on his scientific work, free from the distractions of university life. However, most scientists learn a great deal from discussing their ideas with peers. Collaboration also enables experimental scientists to test a greater number of hypotheses.
2. Newton was an active member of the scientific community at Cambridge for just under 30 years. In that time, he made great strides in understanding light and optics, planetary motion, universal gravitation, and calculus. He made extraordinary contributions to many scientific fields during those years.
3. Example answer: Newton’s first law says that unless you apply an unbalanced force to an object, the object will keep on doing what is was doing in the first place. So a rolling ball will keep on rolling until an unbalanced force changes its motion, while a ball that is not moving will stay still unless acted on by an unbalanced force.
4. Example answer: The law of universal gravitation says that the force of attraction between two objects is directly related to the masses of the objects and inversely related to the distance between them.
6. Newton claimed that 20 years earlier, he had invented the material that Leibnitz published. Newton accused Leibnitz of plagiarism. Most historians today agree that the two developed the material independently, and therefore they are known as co-discoverers.
Extra information: The famous legend of Newton’s apple tells of Newton sitting in his garden in Linconshire in 1666, watching an apple fall from a tree. He later noted that “In the same year, I began to think of gravity extending to the orb of the moon.” However, he did not make public his musings about gravity until the 1680’s, when he formulated his law of universal gravitation.

Unit 2

Agnes Pockels

1. Physics
2. Answers are:
   a. Answers will vary. Pros might include that the device is simple and inexpensive and that it produces quantitative data. Cons might include that the device might be fragile and results might be hard to replicate for that reason.
   b. Yes, she did make valid observations about surface tension, although she actually was measuring the adhesion between the button and the liquid rather than the attraction of liquid molecules for each other (which is known as cohesion). Because the button remained the same throughout the experiment, she could draw conclusions about how various contaminants affected the liquid’s adhesive properties.
3. In the context of Agnes Pockels’ work, surface tension refers to the tendency for molecules at the surface of a liquid to “stick to” a solid surface (the button).
4. After reading about Raleigh’s work, Pockels knew the scientific community was interested in the type of experimental evidence she had collected. However, the traditional avenues of sharing scientific discoveries (presenting a paper at a university or publishing results in a science journal) were not open to her. Writing the letter ultimately enabled her to communicate her results with the larger scientific community.
5. A monolayer film is a sheet of a liquid or solid substance that is only one molecule thick.
6. The Pockels point is the minimum area occupied by a particular monolayer film.
7. Monolayer films can be spread over a pool or pond as a non-toxic method of insect control. They are also used in the delivery of medicine across cell membranes and in certain types of fire extinguishers.

8. Perhaps she was motivated by a strong innate curiosity about the natural world; encouragement from her brother also probably played a role.

Extra information: Have students use an Internet search engine to find Agnes Pockel's letter to Lord Raleigh so that they can read her description of her apparatus. A project for Unit 3 includes building this device for measuring surface tension.

Unit 3

Archimedes

1. Density: a property that describes the relationship between a material’s mass and volume. Buoyancy: A measure of the upward force a fluid exerts on an object.
2. Sample answer: I, Archimedes, have a wide variety of skills to offer. First, I am an inventor of problem-solving devices, including a device for transporting water upward. I have also worked as a crime scene investigator for the king, uncovering fraud through scientific testing of materials. Furthermore, I am a writer with several treatises already published. I also have advanced skills in mathematics and can even estimate for you the number of grains of sand needed to fill the entire universe.
3. In the treatise entitled “The Sand Reckoner”, Archimedes devised a system of exponents that allowed him to represent large numbers on paper—up to $8 \times 10^{63}$ in modern scientific notation. This was large enough, he said, to count the grains of sand that would be needed to fill the universe. His assessment of the universe’s size was an underestimate, but he was the first to think of the universe being so large.
4. A helium balloon floats in air because the air it displaces weighs more than the filled balloon. A balloon filled with air from someone’s lungs sinks because the combined weight of the latex balloon and the air inside is greater than the weight of the air it displaces.
5. Inventions attributed to Archimedes include war machines (such as a lever used to turn enemy boats upside down), the Archimedes screw, compound pulley systems, and a planetarium. There is some debate about whether he invented a water organ and a system of mirrors and/or lenses to focus intense, burning light on enemy ships. Students can use the Internet or library to find more information and diagrams of the inventions.

Ernest Rutherford

1. Alpha particle: a particle that has two protons and two neutrons (also known as a helium nucleus). Beta particle: An electron emitted by an atom when a neutron splits into a proton and an electron.
2. For one atom to turn into another kind of atom, the number of protons in the nucleus must change. This can happen when an alpha particle is ejected (two protons are lost then) or when a neutron splits into a proton and an electron (in that case the number of protons increases by one).
3. Diagram:

   ![Alpha decay](image)
   ![Beta decay](image)

Chein-Shiung Wu

1. Weak nuclear force: One of the fundamental forces in the atom that governs certain processes of radioactive decay. It is weaker than both the electric force and the strong nuclear force. If you leave a solitary neutron outside the nucleus, the weak force eventually causes it to break into a proton and an electron. The weak force does not play an important role in a stable atom, but comes into action in certain cases when atoms break apart.
1. Both Rutherford and Bohr described atoms as having a tiny dense core (the nucleus) surrounded by electrons in orbit. Bohr described the nature of the electrons’ orbits in much greater detail.

2. Niels Bohr described atoms as existing in specific orbital pathways, and explained how atoms emit light.

3. In the Bohr’s model of the atom, the electrons are in different energy levels. Bohr’s model of the atom at right:

4. An electron absorbs energy as it jumps from an inner orbit to an outer one. When the electron falls back to the inner orbit, it releases the absorbed energy in the form of visible light.

5. Answers will vary. You may wish to ask students to research world events from the end of World War II to Bohr’s death in 1962. Students should look for events that may have raised concerns in Bohr’s mind about the potential use/misuse of nuclear weapons. They might also choose to research Bohr’s own comments on the subject.

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**Beta decay:** a radioactive transformation in which a neutron splits into a proton and an electron. The electron is emitted as a beta particle and the proton stays in the nucleus, increasing the atomic number by one.

**Isotope:** Forms of the same element that have different numbers of neutrons and different mass numbers.

2. When Enrico Fermi was having difficulty with a fission experiment, he turned to Wu for assistance. She recognized the cause of the problem: a rare gas she had studied in graduate school. Because she was familiar with the behavior of the gas she was able to help Fermi get on with his work.

3. The law of conservation of parity stated that in nuclear reactions, there should be no favoring of left or right. In beta decay, for example, electrons should be ejected to the left and to the right in equal numbers.

4. Cobalt-60 has 27 protons and 33 neutrons. There is only one stable isotope of cobalt, cobalt-59.

5. Wu cooled cobalt-60 to less than one degree above absolute zero, then placed the material in a strong magnetic field so that all the cobalt nuclei lined up and spun along the same axis. As the radioactive cobalt broke down and gave off electrons, Wu observed that far more electrons flew off in the direction opposite the spin of the nuclei. She proved that the law of conservation of parity does not hold true in all cases.

6. Margaret Burbidge, professor of astronomy, UCLA-awarded the National Medal of Science in the physical sciences in 1983. Citation: “For leadership in observational astronomy. Her spectroscopic investigations have provided crucial information about the chemical composition of stars and the nature of quasi-stellar objects.”

7. Answers may vary. Some interesting questions to research include:

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**Rosalyn Sussman Yalow**

1. There are some striking similarities in the lives of Rosalyn Yalow and Marie Curie. As young women, both were outstanding math and science students. Even though Yalow was 54 years younger than Marie Curie, both faced limited higher education opportunities because they were women. Undaunted, each earned a doctorate degree in physics. Both Yalow and Curie's research focused on radioactive materials. Curie's work was at the forefront of discovery of how radiation works, while Yalow's work was to develop a new application of radiation. Both women were particularly interested in the medical uses of radiation. Each was committed to using their scientific discoveries to promote humanitarian causes. Both women won Nobel Prizes for their work (Marie Curie won two!).

2. RIA is a technique that uses radioactive molecules to measure tiny amounts of biological substances (like hormones) or certain drugs in blood or other body fluids.

3. Using RIA, they showed that adult diabetics did not always lack insulin in their blood, and that, therefore, something must be blocking their insulin’s normal action. They also studied the body’s immune system response to insulin injected into the bloodstream.

4. The issue of patents in medical research remains a hotly debated issue in our society. Proponents of patents, especially for new drugs, claim that because very few new drugs make it through the extensive safety and effectiveness trials required for FDA approval, research costs are very high. Patents, they claim, are the only means of recouping these research costs. On the other side of the issue, critics say that the profit motive drives research into certain types of medicines—tending to be drugs for chronic illnesses, so that patients will take the drugs for a long time. Research into drugs (like new antibiotics) that are generally taken only for a short period of time tends to be less of a priority. You may wish to have students research the pros and cons of the patent system and write a position paper or hold a class discussion or debate on the topic.

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**Niels Bohr**

1. Both Rutherford and Bohr described atoms as having a tiny dense core (the nucleus) surrounded by electrons in orbit. Bohr described the nature of the electrons’ orbits in much greater detail.

2. Niels Bohr described atoms as existing in specific orbital pathways, and explained how atoms emit light.

3. In the Bohr’s model of the atom, the electrons are in different energy levels. Bohr’s model of the atom at right:

4. An electron absorbs energy as it jumps from an inner orbit to an outer one. When the electron falls back to the inner orbit, it releases the absorbed energy in the form of visible light.

5. Answers will vary. You may wish to ask students to research world events from the end of World War II to Bohr’s death in 1962. Students should look for events that may have raised concerns in Bohr’s mind about the potential use/misuse of nuclear weapons. They might also choose to research Bohr’s own comments on the subject.
**Lise Meitner**

1. Ludwig Boltzmann was a pioneer of statistical mechanics. He used probability to describe how properties of atoms (like mass, charge, and structure) determine visible properties of matter (like viscosity and thermal conductivity).
2. They discovered protactinium. Its atomic number is 91 and atomic mass is 231.03588. It has 20 isotopes. All are radioactive.
3. The graphic at right illustrates fission (n = a neutron):
4. Some topics students may research and describe include nuclear power plants, nuclear weapons, nuclear-powered submarines or aircraft carriers.

\[ n + U^{235} \rightarrow Mo^{99} + Sn^{135} + 2n + \text{energy} \]

**Marie and Pierre Curie**

1. Sample answer: Marie (or Marya, as she was called) had a strong desire to learn and had completed all of the schooling available to young women in Poland. She was part of an illegal “underground university” that helped young women prepare for higher education. Perhaps her own thirst for knowledge fueled her empathy for the peasant children, who were also denied the right to an education.
2. Marie Curie proposed that uranium rays were an intrinsic part of uranium atoms, which encouraged physicists to explore the possibility that atoms might have an internal structure.
3. Marie and Pierre worked with uranium ores, separating them into individual chemicals. They discovered two substances that increased the conductivity of the air. They named the new substances polonium and radium.
4. Answers include nuclear physics, nuclear medicine, and radioactive dating.
5. Marie Curie thought carefully about how to balance her scientific career and the needs of her children. When the children were young, Pierre’s father lived with the family and took care of the children while their parents were working. Marie spent a great deal of time finding schools that best fit the individual needs of her children and at one point set up an alternative school where she and several friends took turns tutoring their children. When her daughters were in their teens, Marie included them in her professional activities when possible. Irene, for example, helped her mother set up mobile X-ray units for wounded soldiers during the war.

**Albert Einstein**

1. Students can use their textbook glossary, a standard English dictionary, or an Internet search engine to find the definitions. *radiation*: the flow of energy through space; alpha and beta radiation (from radioactive decay) are forms of radiation based on moving particles. *quantum mechanics*: the branch of physics that deals with the world at the atomic scale. *theory of special relativity*: a theory that describes what happens to matter, energy, time, and space at speeds close to the speed of light. *theory of general relativity*: describes gravity by stating that the presence of mass changes the shape of space-time—objects in orbit move in a straight line through curved space. *inertia*: the resistance of a body to change in its state of motion. *gravity* (acceleration due to): an acceleration of an object due to gravitational field strength; on Earth, it equals 9.8 m/sec\(^2\). *photoelectric effect*: effect observed when light incident to certain metal surfaces causes electrons to be emitted.
2. Young Albert Einstein, according to his family, was quiet and thoughtful. His sister described the concentration and perseverance with which he built elaborate card houses. He was a slow talker who paused to think carefully about what he would say. He loved classical music and enjoyed playing the violin. He did not enjoy his early schooling very much.
3. Einstein’s first paper formed the basis for quantum mechanics. The second paper unified pieces of special relativity into a unified theory. The third paper provided physical evidence for atoms.
4. Brownian motion was first observed by British botanist Robert Brown in 1827. He observed through a microscope that pollen grains suspended in water appeared to move erratically. He thought maybe it was because they were alive, but then found that ground glass and other non-living materials exhibited the same motion. He published his results in 1828. Eighty years later Einstein explained that the erratic motion was due to water molecules bumping into the small particles. Brownian motion can be demonstrated by suspending pollen grains (scraped from the anther of a lily flower, available year-round from a florist shop), graphite scraped from a #2 pencil, or talcum powder in water. Place several drops of the suspension in a cavity microscope slide and observe under a microscope.
5. A solar eclipse
6. Scientists tested Einstein’s theory of relativity by photographing a solar eclipse on November 8, 1919 from locations in Brazil and the African island of Principe. If Einstein's theory were correct, light from a cluster of stars called the Hyades behind the dimmed sun should be bent into the gravitational dimple created by the sun, making the stars appear slightly out of alignment. The photographs confirmed
Einstein's predictions. While some scientists debated the accuracy of this method and doubted Einstein's theory, conclusive evidence was provided by the European Space Agency's Hipparcos satellite, which in the years between 1989 and 1993 charted the positions of the stars with great precision and confirmed Einstein's prediction that gravity bends light.

7. Einstein wrote a letter to President Franklin about the importance of developing an atomic bomb before Germany did.

8. Einstein was concerned about nuclear proliferation and the destructive possibilities of nuclear weapons.

9. Sample answer: A unified field theory is an equation which would show that the fundamental forces in nature are all manifestations of a single basic force.

10. Answers will vary. Encourage students to back up their stated choice with scientific or historical evidence.

Unit 5

George Westinghouse

1. Westinghouse first developed his talents as an inventor in his father's agricultural machine shop.

2. Westinghouse enabled trains to travel more safely at higher speeds in two ways: He invented an air brake which allowed the engineer to stop all the cars at once, and he developed signaling and switching systems which reduced the likelihood of collisions.

3. Westinghouse promoted alternating current because it could be transmitted over longer distances.

4. Westinghouse demonstrated the potential of alternating current by lighting the streets of Philadelphia and then the entire Chicago World's Fair using this technology.

5. Direct current occurs when charge flows in one direction. Batteries provide direct current. Alternating current, in contrast, switches directions. Household circuits in the United States run on alternating current that reverses direction 60 times each second. The diagrams below compare direct and alternating current.

6. Westinghouse used hydroelectric generators at Niagara Falls to provide electricity to the city of Buffalo.

7. Westinghouse’s Manhattan elevated trains were electrical powered using alternating current.

8. Answers may vary. Some of Westinghouse’s other inventions include: Apparatus for safe transmission of natural gas, the transformer, a machine that placed derailed train cars back on the tracks, and a compressed air spring.

Benjamin Franklin

1. Franklin learned through reading, writing, discussing, and experimenting.

2. Franklin’s hypothesis was that lightning is an example of a large-scale discharge of static electricity.

3. Franklin’s reported results were that the loose threads of the hemp stood up and that touching the key resulted in a static electric shock. He concluded that the results were consistent with other demonstrations of static electricity; therefore, lightning was a large-scale example of the same phenomenon.

4. If the kite had been struck by lightning, the amount of charge coming down the hemp string would most likely have electrocuted Franklin.

5. The diagram shows electrons moving from the glass rod to the silk so that the silk becomes negatively charged and the glass becomes positively charged.
6. A lightning rod is a metal rod attached to the roof of a building. A thick cable stretches from the rod to a metal stake buried in the ground. When lightning strikes the rod, it follows the path of least resistance—from the rod, through the cable, into the ground, where the charge can safely dissipate.

Unit 6

Michael Faraday

1. Faraday took careful notes during lectures given by Davy, then bound his notes and sent them to Davy along with a request for a job. Faraday had little formal training in science, so this was a means of proving his capabilities.

2. Benzene is used in cleaning solvents, herbicides, insecticides, and varnishes. Note: Benzene is a known carcinogen and highly flammable. Safety precaution must be taken whenever it is used.

3. Electromagnetic induction is the use of a moving magnet to create an electric current.

4. Sample answer: When light is polarized (vibrating in one plane), a strong magnetic field can change the orientation of that plane.

5. Faraday instituted the Friday Evening Discourses and the Christmas Lectures for Children, which gave non-scientists the opportunity to learn about the scientific community and about recent advances in science.

6. The electric motor, invented by Faraday, is used in all sorts of household appliances including electric fans, hair dryers, food processors, and vacuum cleaners. Electromagnetic induction is used by local power plants to generate the electricity that is used every day.

7. Faraday had a reputation as an engaging speaker who used exciting demonstrations to catch his audience’s interest. He had a knack for communicating scientific knowledge in terms that non-scientists understood. It also would be interesting to see who else might be in attendance at the lecture!

8. Iron filings are available from many science supply catalogs. Place some iron filings on a piece of clear plastic (such as an overhead transparency). Place the plastic over a magnet to observe the field lines.

Stephen Hawking

1. As a child and teenager, Hawking had a vivid imagination. He was more interested in how his models worked than how they looked, and he was able to keep track of complicated scenarios in his mind as he invented various games. These hobbies may have helped him to develop the thinking skills necessary to become a theoretical physicist.

2. Note: Answers may vary with advances in research.

   Treatment for Lou Gehrig's disease focuses on helping the patient maintain independence for as long as possible through physical, occupational, and speech therapy. There is one drug, riluzole, that has been shown to increase the life span of an individual by about two months, but it does not improve quality of life. Researchers found that a dietary supplement called creatine, when combined with an antibiotic, minocyclene, delayed the onset of the disease in mice and increased life span by 25 percent. Unfortunately, those results have not been duplicated in humans in early trials. However, researchers are still working to find other treatments.

3. Cygnus X-1 is a binary star system. The visible star has something orbiting around it. Scientists think this “something” may be a black hole.

4. Big Crunch: The theory that the expansion of the universe will slow down until it reaches a maximum size. Then an inward collapse would begin. Like a video of the Big Bang and the expansion run backward, the universe would get denser and hotter until it ended in an infinitely hot and dense Big Crunch. This might perhaps provide the seed for another Big Bang.

   Hawking radiation: In the 1970's Hawking worked to fuse the ideas of quantum mechanics with those of general relativity. He realized through this process is that black holes are not actually completely black—in other words, some things can escape a black hole. Hawking showed that black holes emit radiation. This radiation is now known as Hawking radiation.

   As this radiation carries energy away from the black hole, the black hole shrinks. Eventually, Hawking explained, the black hole will disappear in a final explosion.

   Wormholes: Theoretical space-time “tubes” that act as shortcuts connecting distance space-time regions. If you traveled through a wormhole, you could travel between the two regions faster than a beam of light that went the “long way” through normal space-time.

   String theory: The string theory proposes that electrons, quarks, photons, and other elementary particles are not tiny “specks” of stuff but rather tiny strings that vibrate and contort in all sorts of miniscule curled up dimensions. This idea is another proposal which helps link quantum mechanics and general relativity.

5. Answers may vary. Students may wish to search Hawking’s web site, www.hawking.org.uk for answers to their questions. If the answers aren’t found, they might wish to email Professor Hawking through this site.
Unit 7

Thomas Edison

1. Edison's education included one-on-one tutoring from his mother, reading lots of books, and performing experiments in laboratories that he set up.
2. Edison learned that in order to sell an invention, not only does it have to be a technical success, it also has to be something that people want to buy.
3. Edison's research facility at Menlo Park had workshops, laboratories, offices, and a library. Edison hired a team of assistants with various specialties to work there.
4. The tin foil phonograph and a practical, safe, and affordable incandescent light were developed at Menlo Park.
5. Edison's invention process was to brainstorm as many ideas as possible, try everything that seems even remotely workable, record everything, and use failed experiments to redirect the project.
6. Edison was not easily discouraged by failure. Instead, he saw failed projects as providing useful information to narrow down the possibilities of what does work.
7. Students can find information about Edison's tin foil phonograph using the Internet. Here's a summary of how it worked:
   Edison set up a membrane that vibrated when exposed to sound waves. The membrane (called a diaphragm) had an embossing needle attached. When someone spoke, the diaphragm would vibrate and the embossing needle would make indentations on tin foil wrapped around a metal cylinder. The cylinder was turned by a hand-crank at around 60 revolutions per minute. There was a second diaphragm-and-needle apparatus for playback. When the needle followed the “tracks” made in the tin foil, it made the diaphragm vibrate which reproduced the recorded sounds.

Unit 8

Galileo Galilei

1. “On Motion” described how a pendulum’s long and short swings take the same amount of time.
2. Galileo's many inventions include the thermometer, water pump, military compass, microscope, telescope, and pendulum clock. Information and illustrations of the inventions can be found using the Internet or library.
3. Galileo observed the motion of Jupiter’s moons and realized that despite what Ptolemy said, heavenly bodies do not revolve exclusively around Earth. He also realized that his observation of the phases of Venus showed that Venus was revolving around the sun, not around Earth. Galileo therefore concluded that Copernicus’ assertion that the sun, not Earth, was at the center must be correct.
4. Answers will vary. Students might suggest that Galileo use a less abrasive approach to convince people that the Copernican view is correct.
5. Galileo's telescope is the most likely student response, because it so profoundly changed our understanding of the solar system. However, students may choose another invention as long as they provide valid reasons for their decision.

Arthur Walker

1. You may wish to have students compare and contrast their definitions with those of a student who used a different source. Discuss with the class the value of using a variety of sources and the importance of crediting these sources.
2. Walker didn’t allow prejudice to dissuade him from pursuit of his goals. As a result he made important contributions to science and society. He also spent time and energy helping other members of minority groups achieve their own goals.
3. A spectrometer separates light into spectral lines. Each element has its own unique pattern of lines, so scientists use the patterns to identify the ions in the corona. Temperature can be determined by the colors seen in the corona. For example, red indicates cooler areas, while bluish light indicates a very hot area.
4. Magazines and journals that may have one of Walker’s photographs can be found at public and university libraries. You might suggest that students contact a reference librarian for assistance.
5. The committee found that the accident was caused by a failure in a seal of the right solid rocket booster. They also made nine specific recommendations of changes to be made to the space shuttle program prior to another flight. These steps included:
   a. Redesign the solid rocket boosters.
   b. Upgrade the space shuttle landing system
   c. Create a crew escape system that would allow astronauts to parachute to safety in certain situations.
   d. Improve quality control in both NASA and contractor manufacturing.
   e. Reorganize the space shuttle program to place astronauts in key decision-making roles.
   f. Revoke any waivers to current safety standards, especially those related to launches in poor weather conditions.
   g. Open the review of a mission's technical issues to independent government agencies.
   h. Set up an extensive open review system to evaluate issues related to each particular mission.
   i. Provide a means of anonymous, reprisal-free reporting of space shuttle safety concerns by any NASA employee or contractor.