3. Dmitri Mendeleev: Chemistry's Improbable Savior

Joseph Priestley (identified on screen) blows out a splint, which then bursts back into flame when put in a vessel.

VO

Previously on *The Mystery of Matter …*

Priestley stoops down and looks in wonder at the burning split.

BIOGRAPHER STEVEN JOHNSON, partly in VO

He realizes that something fundamentally different has happened. This air is some kind of super air.

JOSEPH PRIESTLEY

How could I explain this?

As his wife watches, Antoine Lavoisier (identified on screen) lowers a bell jar over a candle. It too burns brightly.

ANTOINE LAVOISIER, partly in VO

This subject is destined to bring about a revolution in physics and chemistry.

Lavoisier and Marie Anne are delighted when a piece of wood throws out sparks in this new gas.

HISTORIAN ALAN ROCKE VO

The discovery of oxygen really served as a starting gun for a worldwide race for new elements.

Humphry Davy (identified on screen) experiments with his first voltaic pile.

NARR: Davy had found a powerful new tool for the discovery of elements: the battery.

Davy watches the bubbles generated by electricity in water.

HUMPHRY DAVY VO

Nothing promotes the advancement of knowledge so much as a new instrument.

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

Episode Title: Unruly Elements

CHAPTER 1: Chemistry's Unruly Garden

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure and Properties of Matter:

- An element is composed of a single type of atom.
- A substance composed of a single kind of atom is called an "element." The atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.

G: History and Nature of Science

Historical Perspectives

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

Alignment with the Next Generation Science Standards

Science and Engineering Practices

1. Asking Questions and Defining Problems

- Ask questions to clarify and refine a model, an explanation, or an engineering problem.

3. Planning and Carrying Out Investigations

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

Fade up to reveal a single flame. A wire loop held in the flame burns bright yellow. A wide shot reveals the host holding the loop in the flame.

HOST

One of the oldest tricks in the chemist's toolbox is called the flame test.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

He now puts a different substance into the flame. It burns red.

HOST

More than a thousand years ago, Arab alchemists discovered that every substance gave off a telltale color as it burned.

Notes from the Field:

My kids appreciate seeing scientists that come from different backgrounds and that they are not all wealthy and privileged.

He now puts in a series of elements that all burn shades of green.

HOST

But as the number of elements grew, this test became less and less useful, because some elements gave off such similar colors it was hard to tell them apart.

Host motions to photo of Bunsen and Kirchhoff

HOST

One day in 1859, a German chemist named Robert Bunsen described this problem to his good friend, physicist Gustav Kirchhoff.

STOP AND THINK 1: Up to this time, scientists had identified elements by determining the properties of elemental substances. Because the properties of elements differ from the properties of compounds that contain those elements, scientists had used a variety of methods, including the battery, to decompose compounds into elemental substances. How did the spectroscope change the way scientists looked for elements?

Possible Student Answers: Spectra are emitted by elements no matter how they are combined with other elements. Finding elements became much easier using this method; compounds no longer had to be decomposed first.

He motions to parts of spectroscope, then moves an element into the flame of the Bunsen burner.

HOST

A few days later, Kirchhoff came to Bunsen's laboratory with an instrument made from two telescopes, a wooden box and a prism. They used Bunsen's latest invention – the Bunsen burner – to heat their samples. Light from the burning element passed down the barrel of this telescope to the prism, which split the light into a spectrum of colors.

CONCEPT IN BRIEF: element

Host now leans down to look into the eyepiece.

EXAMPLE OF SCIENCE PRACTICE: planning and carrying out investigations

HOST

What they saw when they looked into the eyepiece was a revelation.

We cut to his point of view, revealing what he sees.

HISTORIAN ALAN ROCKE, partly in VO

You see a whole collection of sharp bright lines at very particular wavelengths, and that map of lines is distinctive for every element.

Animation reveals spectra of four distinct elements

PHYSICIST DAVID KAISER, partly in VO

It's almost like each element has its own barcode. It's a unique way of saying: this is that element and not some other.

Closeups of the spectroscope and host peering into it

CONCEPT IN BRIEF: importance of scientific tools

NARR: Like Humphry Davy's battery, the "spectroscope" kicked off a whole new round in the discovery of elements …

Composite image of Bunsen and Kirchhoff and the spectra of cesium and rubidium

CONCEPT IN BRIEF: spectroscopy

NARR: … starting with *cesium* and *rubidium*, discovered by Bunsen and Kirchhoff themselves

Composite image of the discoverers of thallium and indium and the spectra of those elements

CONCEPT IN DEPTH: Scientific knowledge evolves by using new evidence to build on earlier knowledge

NARR: … quickly followed by *thallium* and *indium*, discovered by other chemists who seized on their new tool.

Image: Astronomer looks into spectroscope attached to a telescope.

NARR: Astronomers, too, embraced the new technology, turning the spectroscope to the heavens.

Image of the solar eclipse and the spectrum of helium

PHYSICIST JIM GATES, partly in VO

In fact, there's one element that we found by first looking at the sun. We didn't even know it was here on earth. It was helium.

Animation showing unruly garden of elements

CONCEPT IN BRIEF: element

PHYSICIST DAVID KAISER, partly in VO

By the middle of the 19th century, there had been an explosion in the numbers of new elements that had been found. And this was exciting, but it also led to a kind of muddle that seemed to have no order, no reason behind it.

HISTORIAN ALAN ROCKE VO

Chemistry looked like an unruly garden, a jungle of bewildering details.

HISTORIAN LAWRENCE PRINCIPE, partly in VO

Human beings like to make things simple. And part of the whole, scientific enterprise is to bring order out of what appears to be chaos, to bring simplicity out of complexity.

NARR: But the ever-rising number of elements – now up to 63 – promised chemists just the opposite of simplicity: more and more variety, with no end in sight.

HISTORIAN ALAN ROCKE

How many elements were there? Was this going to continue forever?

CHAPTER 2: Improbable Savior

Alignment with the NRC's National Science Education Standards
B: Physical Science
Structure and Properties of Matter:

- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the "atomic number"), repeating patterns of physical and chemical properties identify families of elements with similar properties.

G: History and Nature of Science
Science as a Human Endeavor

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

Footage of Mendeleev working in his study

NARR: The man who would finally bring order to the elements was a young Russian chemistry professor named Dmitri Mendeleev. He didn't set out to be a savior. He was simply trying to organize the textbook he was writing. But as he grappled with this challenge over one weekend in 1869, Mendeleev would make a discovery for the ages:

Animation of the Periodic Table. We fly through the gap in the middle to discover a photo of Mendeleev.

NARR: The Periodic Table of the Elements. Today it hangs in every chemistry classroom in the world – one of the most familiar images in all of science. But behind the table is a fascinating untold story. Who *was* this man, and how did he do it?

Image of St. Pete U and footage of Mendeleev moving into his new office as housekeeper lays out the rules.

NARR: Mendeleev had recently been named a professor at the University of St. Petersburg, the leading institution in Russia's capital. But getting there had been a long, improbable journey from humble beginnings.

Cut to map showing Tobolsk in relation to Moscow, St. Petersburg and the rest of Siberia

Notes from the Field:
A lot of students have already heard some about the Periodic Table. When starting this section, I like to see what previous knowledge they're coming with.

BIOGRAPHER MICHAEL GORDIN, partly in VO

Mendeleev was born in Tobolsk, Siberia, which is basically smack in the middle of Russia, if you look at it on a map. It's very much the boonies of Imperial Russia.

Painting of Mendeleev's father

NARR: His father, the headmaster of the local high school, went blind during the year of Dmitri's birth, leaving Mendeleev's mother to support and raise about a dozen children.

Painting of Maria Mendeleeva

NARR: Maria Mendeleeva sensed something special in her youngest child.

Glimpse of sleigh in snow, then dissolve to graphic map showing the long trip from Siberia to Moscow and St. Petersburg. Photo of sleigh on snowy St. Petersburg street.

NARR: So in 1849, she set out with her 15-year-old son on a 1500-mile trip by horse-drawn sleigh in search of a school that would accept him. Like most students from the provinces, Dmitri was turned away in Moscow. But in St. Petersburg he landed a spot in the teacher training school his father had attended. Exhausted by the journey, Maria died a few months later.

Mendeleev places picture of mother on shelf.

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

DMITRI MENDELEEV, partly in VO

She took me out of Siberia and sacrificed what remained of her money … her life … so that I could get an education. From her I learned that it is through work – not words – that we must seek divine *and* scientific truth.

CHAPTER 3: Atomic Weight

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure and Properties of Matter:

- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the "atomic number"), repeating patterns of physical and chemical properties identify families of elements with similar properties.

Structure of Atoms:

- Matter is made of minute particles called "atoms," and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge.
- G: History and Nature of Science

Science as a Human Endeavor

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

Nature of Scientific Knowledge

- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available.
- Historical Perspectives
- Usually, changes in science occur as small modifications in extant knowledge.

Alignment with the Next Generation Science Standards

Science and Engineering Practices

5. Using Mathematics and Computational Thinking

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

8. Obtaining, Evaluating, and Communicating Information

- Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.

Photo of young Mendeleev in a group of other students.

NARR: Scientific truth was elusive for any young chemistry student in the mid-1800s.

Photo of chemistry students in lab

NARR: There were deep divisions in the field over even the most basic concepts – particularly the atomic weights of the elements.

CONCEPT IN BRIEF: atomic weight

Animation of atoms of different elements

NARR: Most chemists believed each element had its own unique kind of atom, and ever since the early 1800s they'd been working to determine how much an atom of each element weighed.

STOP AND THINK 2: Why do different elements have different values of atomic mass (previously called atomic weight)?

Possible Student Answers: Students may know that atoms are made up of protons, electrons, and neutrons, and that the number of protons and neutrons determines the atomic mass. Some students may know that atomic weight is an average of the weights of the different isotopes of an element.

HISTORIAN ALAN ROCKE, partly in VO

That's how one distinguished on element from another. So it was crucial to understand what were the correct atomic weights for each of the elements.

EXAMPLE OF SCIENCE PRACTICE: using mathematics and computational thinking

In the animation, hydrogen is assigned a weight of 1. But then differing weights for the other elements appear in columns to the right. Among them are the weights Gordin mentions for carbon.

NARR: Everyone agreed that hydrogen, the lightest element, should be assigned a weight of 1, and that heavier elements should have proportionally higher weights. But that's where the agreement ended.

BIOGRAPHER MICHAEL GORDIN, partly in VO

Did carbon weigh six or did it weigh 12? Did it weigh four? That depended on who you talked to and when you talked to them. By the late 1850s people were incredibly confused.

Notes from the Field:

Since my students are already familiar with the Periodic Table and the concept of atomic weight, I use this opportunity to make a comparison to the current Periodic Table and how C_{14} is used as 1.

HISTORIAN ALAN ROCKE

This was an unsupportable situation. Something had to be done.

EVERYDAY APPLICATION 1: A device called a "mass spectrometer" is used today to measure the mass of atoms. A mass spectrometer can analyze the atomic composition of any material. When a sample is inserted into the mass spectrometer, its atoms are ionized, which means that they acquire an electrical charge. The ionized atoms are then sent through a magnetic field. The ionized atoms are deflected (turned to one side or the other) by the magnetic field. Atoms with more mass are deflected less, and the amount of the deflection is used to calculate the mass of the atoms. Because the atomic masses are now known, the mass spectrometer can identify the kinds and ratios of the atoms in the material. A common use of a mass spectrometer is to detect leaks in containers or hoses of industrial products which need to stay sealed. This technique is used to test food packaging, aerosol cans, fire extinguishers, tire valves, the parts of refrigeration and air conditioning systems, and compressed gas bottles.

Map of Germany highlighting Karlsruhe

NARR: Hoping to sort out the mess, chemists organized their first-ever international meeting, held in Karlsruhe, Germany, in 1860.

Image of young Mendeleev

BIOGRAPHER MICHAEL GORDIN, partly in VO

Mendeleev, being a young, enterprising student, goes to this meeting, and he hears a very important speech by an Italian chemist, Stanislao Cannizzaro.

Cannizzaro photo and animation of new weights

NARR: Cannizzaro laid out a persuasive case for a new, uniform system of atomic weights.

DMITRI MENDELEEV

I still remember the powerful impression Cannizzaro made. He seemed to advocate truth itself!

Karlsruhe image

BIOGRAPHER MICHAEL GORDIN, partly in VO

After Karlsruhe, something astonishing starts to happen. Within a few years of the congress you start seeing lots of different attempts to organize the elements that are all based on these new, post-Karlsruhe weights.

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

Notes from the Field:
This was a really critical step in the process of identifying the elements, so I stop here to discuss it with my students.

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

STOP AND THINK 3: The Karlsruhe Congress brought together scientists who had been struggling to determine atomic weights. How might the exchange of ideas at this congress help create new scientific knowledge?

Possible Student Answers: Students' answers to this question might explain that scientists could share ideas, hypotheses, experimental methods, data, and conclusions about atomic weights at the congress, which could help create new scientific knowledge by giving scientists new information and perspectives. Students' might also explain that scientists can build relationships with each other that can result in a future exchange of new information and perspectives on topics of mutual interest.

EVERYDAY APPLICATION 2: Conferences or congresses provide a venue for people to learn from each other and discuss their work and ideas. There are conferences about almost any topic, including those in academia, industry, and recreation. Conferences facilitate the exchange of information about research, methods, and products. They also facilitate the building of personal networks. Over 200 million people attend conferences in the United States each year.

Animation of the barber pole

NARR: A French geologist arranged the known elements in a spiral along the outside of a cylinder, like the stripes on a barber pole, and found that elements with similar properties tended to fall into columns.

Animation of the Law of Octaves

NARR: An English chemist arranged the elements by atomic weight in rows of seven, and found that their properties repeated like musical notes one octave apart.

Animation of the five men who sensed an order among the elements; they pop up in their respective countries on a map.

NARR: By the end of the 1860s, five different European scientists had detected glimmers of a hidden order among the elements. But no one could quite put the puzzle together.

Notes from the Field:

My students need to be reminded of why this work was needed and important. Understanding the context makes a big difference to them.

CHAPTER 4: Textbook

Alignment with the NRC's National Science Education Standards
B: Physical Science
Structure and Properties of Matter:

- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties.

G: History and Nature of Science
Science as a Human Endeavor

- Individuals and teams have contributed and will continue to contribute to the scientific enterprise. Doing science or engineering can be as simple as an individual conducting field studies or as complex as hundreds of people working on a major scientific question or technological problem. Pursuing science as a career or as a hobby can be both fascinating and intellectually rewarding.
- Scientists are influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society but rather science is a part of society.

Historical Perspectives

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.
- The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge.

Alignment with the Next Generation Science Standards
Science and Engineering Practices
2. Developing and Using Models

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

Mendeleev continues moving into his office.

CONCEPT IN BRIEF: Influence of society and culture on science.

NARR: That's where things stood when Mendeleev finally landed a professorship at the University of St. Petersburg. One of the duties of his new post was to teach introductory chemistry.

BIOGRAPHER MICHAEL GORDIN, partly in VO

He has to teach this class, hundreds of students, and he has to give them a textbook. There are no up-to-date, Russian language, college-level textbooks available.

Mendeleev writes in his study.

NARR: So Mendeleev set out to write his own: *Principles of Chemistry*, in two volumes.

Image of Volume 1

NARR: He completed the first volume in 1868 …

Re-enactment: In his study, Mendeleev hands a package to his housekeeper.

NARR: … and on Friday, February 14, 1869, he sent the first two chapters of Volume 2 off to his publisher.

DMITRI MENDELEEV (to housekeeper)

Marina!

NARR: He was in a hurry to finish it, because he was struggling to make ends meet.

Photo of Mendeleev and his wife

BIOGRAPHER MICHAEL GORDIN, partly in VO

He hasn't yet gotten any royalties from the textbook, because it hasn't been written yet. He's got to keep his family fed and clothed. He has, at this point, two children and a wife. So he was always looking for more funds.

Montage of short Mendeleev scenes – packing his trunk, rubbing his eyes, playing cards.

NARR: To make a little extra money, Mendeleev planned to take a short break on Monday to do some consulting for a cheese-makers cooperative. But he had something on his mind: His publisher was expecting the next chapter of his textbook in two weeks, and he still hadn't settled on a way to organize the rest of his book.

> Notes from the Field:
> A lot of kids think that science takes place in a vacuum, completely independent from the culture and society. This is a good example to show them that they actually influence each other.

EXAMPLE OF SCIENCE PRACTICE: developing and using models

Images of Vol. 1 contents, hydrogen and oxygen highlighted

NARR: Mendeleev had spent most of the first volume covering a few common elements like hydrogen and oxygen in great detail.

BIOGRAPHER MICHAEL GORDIN, partly in VO
You learn a huge amount of chemistry, but it's slow. Volume 1 contains just eight elements out of the 63 that were then known.

List of the remaining 55 elements he needs to deal with appears behind Scerri.

AUTHOR ERIC SCERRI, partly in VO
When it came to writing the second volume of his textbook, Mendeleev realized that he had better find an organizing principle fairly quickly, because he had to cover the remaining 55 elements.

DMITRI MENDELEEV
Since I'd set out to write a book called *Principles of Chemistry,* I felt I had to establish a system for classifying the elements – a system based not on chance, or guesswork, but on some sort of … *principle.*

Despondent Mendeleev refuses tea.

NARR: The problem gnawed at him all weekend.

BIOGRAPHER MICHAEL GORDIN, partly in VO
He's trying to come up with a way of packing more elements in the same amount of space. He couldn't ramble the way he did in Volume 1, however useful that was.

CHAPTER 5: Chemical Families

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure and Properties of Matter:

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

G: History and Nature of Science

Science as a Human Endeavor

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Historical Perspectives

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Alignment with the Next Generation Science Standards

Science and Engineering Practices

4. Analyzing and Interpreting Data

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

5. Using Mathematics and Computational Thinking

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

Disciplinary Core Ideas

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

Crosscutting Concepts

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

Mendeleev works at his desk.

NARR: Mendeleev had already hit on the idea of focusing on whole families of elements, rather than treating one at a time.

CONCEPT IN BRIEF: scientific knowledge evolves by building on earlier knowledge and new evidence

Animation: Meet the Halogens

NARR: Chemists had long known that certain elements resemble each other in much the way family members do.

CHEMIST GREG PETSKO
You can often tell people are related because they have the same sort of face.

BIOGRAPHER MICHAEL GORDIN, partly in VO
They have the same nose. They have the same color eyes. There's something in common.

Animation: Three halogens bond with oxygen in the same way

BIOGRAPHER MICHAEL GORDIN VO
And that's something very similar in these chemical families. They tend to react similarly to the same kinds of substances.

STOP AND THINK 4: Chemical reactivity is one property of substances. What other properties could Mendeleev examine to determine families of elements?

Possible Student Answers: Other properties that may be useful to examine are state, color, luster, melting point and/or boiling point, and ability to conduct heat.

Vol 1 Table of Contents – the halogens

NARR: Mendeleev had ended Volume 1 with two chapters on a well-known family, the halogens: chlorine, fluorine, bromine and iodine.

Vol 2 Table of Contents highlighting the alkali metals

NARR: He began Volume 2 in the same way, with chapters on sodium, potassium and lithium, a family called the alkali metals.

Mendeleev continues to work in his study.

BIOGRAPHER MICHAEL GORDIN VO

He realized that a family of elements is a good way of organizing so you can do more with less space.

Mendeleev looks up and ponders.

NARR: The problem was, there was no obvious family to turn to next. For insight into what other elements might be grouped together, Mendeleev looked more closely at the two families he already had.

Animation of floating families

BIOGRAPHER MICHAEL GORDIN, partly in VO

And in that process he figures out something rather extraordinary about the elements.

CONCEPT IN DETAIL: atomic weight

CU of Mendeleev writing. He writes the symbols for Li and Na on a piece of paper and notes the difference in their weights. Then he writes the symbols F and Cl on a separate piece of paper and notes the difference in their weights. He puts one piece alongside the other. The differences are almost the same: 16 and 16.5.

BIOGRAPHER MICHAEL GORDIN, partly in VO

He looks at the atomic weights of sodium and lithium and looks at the difference between them. And then he does the same thing for fluorine to chlorine, and notices that those two differences are very close to each other.

Mendeleev stops to think, then grabs a piece of paper and starts writing. Pan along calligrapher's writing shows that for each pair of elements, the difference between the top row and the bottom is between 15 and 17.

NARR: Was this just a coincidence – or a clue? Excited, Mendeleev wrote down the lightest elements and their atomic weights. After seven elements, he broke off and started a new row, keeping elements with similar chemical properties in the same column. The numerical pattern continued to hold.

CONCEPT IN DETAIL: element

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

DMITRI MENDELEEV, partly in VO

The eye is immediately struck by a pattern – a regular change in the atomic weights of the elements within the horizontal rows and the vertical columns.

Animation. Focusing on three families, we show how the difference in weight within a family – 16 – is the same in all three families.

Notes from the Field:

I made sure to point out to my students that if you compare rows 2 and 3, the difference in mass between elements in the same column is about the same no matter which column you look at, about 16 amu. I then had my students relate the difference in mass to the electron shell. The difference in mass is equal to the addition of 8 neutrons and 8 protons, and the filled electron shell has 8 electrons.

BIOGRAPHER MICHAEL GORDIN, partly in VO

He notices that there's a regularity in the differences. That is, the changes that happen within a family happen regularly across families. And that's the fundamental insight that gets him thinking about how to organize all the other elements.

Reprise image of two rows of elements and their differences. Footage of Mendeleev at work.

AUTHOR ERIC SCERRI, partly in VO

Mendeleev had begun the weekend trying to solve the problem of what to do next in his textbook. But having reached this aha moment, he dropped everything else, and he poured all his energy into revealing an absolutely fundamental principle of nature.

CONCEPT IN BRIEF: Periodic Table

EXAMPLE OF SCIENCE PRACTICE: using mathematics and computational thinking

CHAPTER 6: Jigsaw Puzzle

Alignment with the NRC's National Science Education Standards

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Alignment with the Next Generation Science Standards
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- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

Crosscutting Concepts

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

Mendeleev is in the throes, scrawling letters and numbers on a piece of paper, then scratching them out.

BIOGRAPHER MICHAEL GORDIN, partly in VO

When he was taken by an idea, he was really taken by it. He starts putting together this system, and he's trying to figure out the hard spots, the things that don't quite make sense. Maybe I can scratch out this element here and put this element in its place. Should I change the atomic weights? Do I have to rethink their properties? And the problems of it, the intellectual puzzle, just grabs him.

Mendeleev plays solitaire.

EXAMPLE OF SCIENCE PRACTICE: developing and using models

NARR: The challenge Mendeleev faced was similar to one of his favorite diversions, the card game called Patience, in which the object is to arrange playing cards by both suit and number.

BIOGRAPHER MICHAEL GORDIN, partly in VO
That process of keeping several different variables in mind is kind of analogous to how Mendeleev was thinking. He started using *both* the regular, increasing order of atomic weights *and* the relationships of chemical properties with each other to build two dimensions.

Calligrapher leaves a blank.

NARR: Mendeleev didn't just lay out the known elements in order of rising atomic weight.

BIOGRAPHER MICHAEL GORDIN, partly in VO
When it looks like the next element doesn't have the properties it is supposed to have, he scooches it over and leaves a blank spot.

AUTHOR ERIC SCERRI
And has the audacity, has the daring to suggest that there might one day exist such an element that would fill that space.

Image of the fragment known as D2a/D2b. Mendeleev writes.

NARR: The few scraps of paper left from Mendeleev's struggle that weekend reveal that he sometimes arranged the chemical families in rows instead of columns.

Draft of table morphs into puzzle animation. The alkali metals, arranged horizontally, move to a different position in the lower table. The rest of the puzzle pieces take their positions, and the puzzle morphs back into his draft of the table.

NARR: Unhappy with this early attempt at a table, he moved the alkali metals to a new position in the next draft below… but kept them together.

AUTHOR ERIC SCERRI, partly in VO
Mendeleev is not moving elements individually. But he is moving them as a block. It is as if it's a composite piece of a jigsaw puzzle that he's moving all together.

STOP AND THINK 5: Mendeleev made a table that organizes two features of elements: atomic weight and chemical similarity (or properties). In the modern version of the Periodic Table, which element feature is organized into rows and which element feature is organized into columns?

Possible Student Answers: Students should note that atomic weight is organized into rows and properties are organized into columns.

CHAPTER 7: The First Periodic Table

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure and Properties of Matter:

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

G: History and Nature of Science

Nature of Scientific Knowledge

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

Alignment with the Next Generation Science Standards

Science and Engineering Practices

2. Developing and Using Models

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

8. Obtaining, Evaluating, and Communicating Information

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

Disciplinary Core Ideas

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

Crosscutting Concepts

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

Sleigh pulls up in front of Mendeleev's building.

NARR: On Monday morning, a driver arrived to take Mendeleev to the train station for his trip to the cheese cooperative.

Mendeleev dips a sugar cube into his tea.

NARR: He was well into his task but still struggling to make all the pieces fit.

Mendeleev lifts his cup, turns over the paper and begins to write.

NARR: We know this because one of the surviving fragments is a letter, delivered that morning, concerning arrangements for his trip to the cheese cooperative.

The back of the letter

AUTHOR ERIC SCERRI VO

And on the back of the letter, which still bears the stain of a cup, Mendeleev has sketched a few symbols and has carried out some very simple calculations. He is looking at differences in atomic weights.

NARR: So he was still working on the problem, even after wrestling with it all weekend.

Housekeeper enters to tell him driver is waiting. He shoos her away. Outside in the snow, the horse whinnies.

Notes from the Field:

This is a great point to make with students. Mendeleev didn't suddenly "discover" the Periodic Table but, rather, he worked very diligently on the idea.

CU of an original Mendeleev document – a draft of the table littered with calculations, transpositions and cross-outs. Cut back occasionally to Mendeleev working on the table, puzzling, crossing out.

NARR: The drafts of Mendeleev's table show plainly the struggle he went through.

CHEMIST ROALD HOFFMANN, partly in VO

At the bottom of the page he lists the elements to be classified. As he fits them into the table on that page, he crosses out the elements. It's just what you and I would do. We can see the effort in that page. He's making mistakes. He's correcting them. It is full of crossings out. There are things that don't quite fit. This is a human being trying to understand this world.

Mendeleev paces. Outside, the driver is growing impatient, pacing to keep warm. Finally, he seizes the reins and drives off with a tinkling of sleigh bells.

NARR: Hour after hour, Mendeleev worked on the table, missing one train after another. Finally, he dismissed the coachman. The cheese-makers would have to wait.

We find Mendeleev lying on the sofa. When the housekeeper shows in a visitor, he jumps up, shakes hands and explains what's troubling him.

NARR: That afternoon, a visitor found him distraught, unable to capture the order he knew was there, just out of reach.

MENDELEEV TO HIS VISITOR (in Russian with subtitles)

I'm trying to finish my work. It's all formed in my head, but I just can't express it.

Mendeleev looks up something in a reference book.

NARR: Later that day, Mendeleev came to a choice that would crystallize his thinking. The elements involved were iodine and tellurium.

Notes from the Field:

My kids were struck by the fact that to be a successful scientist you don't have to be a genius. I tell them it helps to be knowledgeable about some basic facts, have a good general understanding of the area being explored, and demonstrate common sense.

Mendeleev writes, then stops to think. As he looks up, we cut to an animation of the elements he's thinking about – iodine and tellurium – and their respective families.

BIOGRAPHER MICHAEL GORDIN, partly in VO
Iodine's a little lighter than tellurium so it should come first. But Mendeleev looks at that and says, "Well, if I put iodine first, it's in the wrong family. It is actually a halogen, which is the next row down."

CHEMIST GREGORY PETSKO, partly in VO
If he stuck to that weight rule, it would put an element outside of the family it obviously belonged in.

Iodine and tellurium switch places in the animation.

BIOGRAPHER MICHAEL GORDIN
So he decides tellurium, the heavier element, should go first.

Mendeleev writes Te=128?, then J=127. Continued animation showing the family resemblances Mendeleev has decided are more important

BIOGRAPHER MICHAEL GORDIN, partly in VO
It always bothered him the iodine was lighter than tellurium but came after. That breaks the order of atomic weights, but it preserves the family resemblances, which are more important than just the increase of atomic weights.

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

EXAMPLE OF SCIENCE PRACTICE: developing and using models

Notes from the Field:
I ask my students to consider, "Why did Mendeleev decide that chemical properties trump atomic weight?"

STOP AND THINK 6: Mendeleev had proposed that there is an underlying principle that relates atomic weight with properties. However, he regarded properties as the most important feature in regards to organizing the elements into a table. When he had a conflict about where to put an element, he used properties to determine the placement. Why do you think that he regarded properties as the most important element feature?

Possible Student Answers: Students' might explain that Mendeleev regarded properties as the most important feature because they take into account a variety of measurements about an element; that although Mendeleev established the relationship between atomic weight and properties, the nature of this relationship was not yet clear; and that Mendeleev was taking into account the uncertainty of establishing atomic weight.

Mendeleev writes quickly.

NARR: With that principle established, Mendeleev hurried toward the end.

BIOGRAPHER MICHAEL GORDIN VO
And the more he worked on it, the better it looked.

Mendeleev copies over his completed table, then puts his pen down, satisfied.

NARR: Finally, that evening, Mendeleev completed his table.

The driver arrives again with his sleigh. We see Mendeleev inspecting his work. He looks pleased.

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

NARR: Before leaving the next day, he ordered 200 copies printed and sent to leading European chemists.

Mendeleev blows on the paper to dry the ink and places the table in a folder.

AUTHOR ERIC SCERRI, partly in VO
By the time he left for the cheese factory, Mendeleev knew that he was onto something extremely important. I think he realized that day that he had cracked it.

Mendeleev's handwritten fair copy is reset in type, rotated 90 degrees and flipped over. Finally, the alkali metals are moved to the opposite side of the table. When boxes are place around the elements, it closely resembles the familiar Periodic Table of the Elements.

CONCEPT IN DETAIL: Periodic Table

NARR: With a few modifications, soon made by Mendeleev himself, his 1869 draft is easily recognized as the Periodic Table of the Elements – incomplete but unmistakable.

CHAPTER 8: Law of Nature

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure and Properties of Matter:

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

G: History and Nature of Science

Nature of Scientific Knowledge

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

Alignment with the Next Generation Science Standards

Science and Engineering Practices

1. Asking Questions and Defining Problems

- Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships.

2. Developing and Using Models

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

6. Constructing Explanations and Designing Solutions

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

Disciplinary Core Ideas

- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

Crosscutting Concepts

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

Zoom to empty spaces with question marks and proposed weights of the missing elements

NARR: In his published table, Mendeleev left blanks for some of the elements he thought were missing.

HISTORIAN ALAN ROCKE VO
Not only did he leave a blank space, but he suggested an approximate atomic weight for that future element.

EXAMPLE OF SCIENCE PRACTICE: constructing explanations and designing solutions

CONCEPT IN BRIEF: periodic law

BIOGRAPHER MICHAEL GORDIN, partly in VO
And the fact that Mendeleev, on that first weekend, is already thinking this way, that's a sign that he believed that there's something deeper going on here.

> **Notes from the Field:**
>
> I have my students, who are already very familiar with the Periodic Table, make comparisons between Mendeleev's table and the current Periodic Table, especially paying attention to how elements are ordered by atomic weight vs. atomic number now.

In the graphic of Mendeleev's table, the columns are highlighted one by one.

NARR: Mendeleev believed his table was more than a convenient way to arrange the elements. He was convinced he had discovered a Law of Nature: that the properties of the elements are determined by their atomic weights and vary in a regular, periodic way, across the table.

CHEMIST GREG PETSKO, partly in VO
It's periodic because the properties of the elements repeat in a regular fashion. When you wrap around from one row to the next and come back to where you were, the elements that are in the same column have similar properties.

EXAMPLE OF SCIENCE PRACTICE: developing and using models

AUTHOR OLIVER SACKS
He had an almost mystical feeling that this was there in nature and not so much a human invention as a discovery.

The camera pauses on the empty spot with question marks.

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

NARR: Given the remarkable regularity of his table, Mendeleev couldn't believe nature would have just left some spaces empty.

DMITRI MENDELEEV
Laws of nature do not permit exceptions.

AUTHOR ERIC SCERRI

There must be an element, which we have not yet discovered. Go look for that element.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

AUTHOR OLIVER SACKS

And he was bold enough to not only to say an element is missing but to predict.

DMITRI MENDELEEV

The periodic law allows us not only to predict what new elements will be found but also to determine *in advance* their chemical and physical properties.

CONCEPT IN DETAIL: periodic law

CHAPTER 9: Predictions

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure and Properties of Matter:

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

G: History and Nature of Science

Nature of Scientific Knowledge

- Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world.
- Scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public.
- Because all scientific ideas depend on experimental and observational confirmation, all scientific knowledge is, in principle, subject to change as new evidence becomes available. … In situations where information is still fragmentary, it is normal for scientific ideas to be incomplete, but this is also where the opportunity for making advances may be greatest.

Historical Perspectives

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, their daily work, and their efforts to advance scientific knowledge in their area of study.
- The historical perspective of scientific explanations demonstrates how scientific knowledge changes by evolving over time, almost always building on earlier knowledge.

2. Developing and Using Models

- Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships.

Alignment with the Next Generation Science Standards

Science and Engineering Practices

1. Asking Questions and Defining Problems

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

8. Obtaining, Evaluating, and Communicating Information

- Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source.
- Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.

Disciplinary Core Ideas

- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

Crosscutting Concepts

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

Image of Mendeleev's 1871 journal article in Annalen

NARR: In 1871, Mendeleev published an article making predictions about three of the missing elements, based on the properties of their neighbors in the table.

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

Graphic showing the specificity of Mendeleev's predictions

BIOGRAPHER MICHAEL GORDIN, partly in VO

Chemists really weren't used to making predictions of any kind, let alone ones to this degree of specificity. They are remarkably precise and quite daring for Mendeleev to print them.

EXAMPLE OF SCIENCE PRACTICE: developing and using models

Photos of Boisbaudran and a sample of gallium

NARR: Four years later, a French chemist found a new metal so soft it melted in his hand. He called it gallium.

EXAMPLE OF SCIENCE PRACTICE: asking questions and defining problems

Zoom to blank below aluminum in the PTE

NARR: It seemed to be a good fit for the empty spot below aluminum, but the density didn't match Mendeleev's prediction. He wrote the Frenchman, suggesting that he check his data.

Graphic contrasts Mendeleev's prediction with the measured density.

AUTHOR ERIC SCERRI, partly in VO

So you can just imagine this Frenchman, who actually has the element in his hands, hearing from this Siberian, who has never seen the element, daring to say to him that he's made a mistake**.**

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

Graphic: Gallium takes its place in the Periodic Table, replacing the question mark just below aluminum.

NARR: But sure enough, when the French scientist rechecked his measurements, Mendeleev was correct.

CONCEPT IN DETAIL: periodic law

AUTHOR ERIC SCERRI, partly in VO

So not only had Mendeleev predicted the element, but he knew the properties of the element better than the discoverer of the element knew them.

BIOGRAPHER MICHAEL GORDIN

Within 15 years all three of the detailed predictions are discovered. And that catapults Mendeleev to chemical superstardom.

DMITRI MENDELEEV
I never thought I would live to see my ideas verified. [He pauses and smiles.] I was wrong.

STOP AND THINK 7: Mendeleev was able to successfully predict the existence of unknown elements by using his periodic law. How did this strengthen the acceptance of his theory?

Possible Student Answers: Students' answers to this question might explain that the successful predictions support Mendeleev's conclusion that atomic weight is correlated to properties as explained in his periodic law.

CHAPTER 10: The Noble Gases

Alignment with the NRC's National Science Education Standards

B: Physical Science

Structure and Properties of Matter:

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

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

Historical Perspectives

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

Alignment with the Next Generation Science Standards

Science and Engineering Practices

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

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

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

7. Engaging in Argument from Evidence
   - Make and defend a claim based on evidence about the natural world that reflects scientific knowledge.

8. Obtaining, Evaluating, and Communicating Information
   - Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.

Disciplinary Core Ideas

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

Crosscutting Concepts

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

Photo of William Ramsay and Lord Rayleigh

NARR: But in 1894, two British scientists made a discovery that threatened to bring Mendeleev's carefully crafted edifice crashing down. They found a new gas they called argon that didn't seem to fit into the table.

Letter from Ramsay to Rayleigh

HISTORIAN ALAN ROCKE, partly in VO

When Lord Rayleigh and William Ramsay discovered argon, it looked like a problem – a very serious challenge to the Periodic Table itself.

Photo of angry Mendeleev. Then animation of argon unable to bond with other elements, finding no place in the table.

BIOGRAPHER MICHAEL GORDIN, partly in VO

Mendeleev's first reaction to almost anything that was contradictory to the system was to be hostile to it and suspicious. And Mendeleev therefore decides it's not an element. There are lots of reasons to think that. First, it doesn't react with anything.

EXAMPLE OF SCIENCE PRACTICE: engaging in argument from evidence

CHEMIST GREG PETSKO, partly in VO

Chemists couldn't get it to do anything. It was inert. It behaved like no other gas that anybody had ever encountered.

BIOGRAPHER MICHAEL GORDIN VO

And secondly, it has no place on the table. So how can it exist?

Photo of Ramsay, then animated helium wanders across the table in search of a spot.

NARR: Matters got worse when Ramsay announced he'd also isolated helium – 30 years after it was first detected in the sun. It was definitely an element, and it too had no place in the table.

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

Animation showing colored tubes of the three new gases

HISTORIAN ALAN ROCKE, partly in VO

And then just three years after that William Ramsay's research group discovered three new rare gases, krypton, xenon and neon.

BIOGRAPHER MICHAEL GORDIN, partly in VO

They display the same kind of properties. They are all inert gases. And they display the same increase of atomic weights as the other natural families do.

EXAMPLE OF SCIENCE PRACTICE: analyzing and interpreting data

Atoms of four gases emerge from behind argon and move to the right side of the table.

CONCEPT IN DETAIL: periodic law

HISTORIAN ALAN ROCKE, partly in VO

And that changed the situation dramatically. What began as a single anomaly, a single puzzle, now looked like a group of elements.

CONCEPT IN DETAIL: scientific knowledge evolves by building on earlier knowledge and new evidence

DMITRI MENDELEEV, partly in VO

Now we can see that helium, neon, argon, krypton and xenon are as closely united as any other group.

EXAMPLE OF SCIENCE PRACTICE: constructing

The noble gases take their place in the table.

explanations and designing solutions

BIOGRAPHER MICHAEL GORDIN
And so Mendeleev makes the single, biggest revision to the system he ever did. He puts in a new column. And that is the family of noble gases.

EXAMPLE OF SCIENCE PRACTICE: developing and using models

DMITRI MENDELEEV
My periodic system is in no way injured by these discoveries. In fact, they confirm and strengthen it.

Animation: the unruly garden is finally brought to order as the Periodic Table emerges from the weeds.

AUTHOR ERIC SCERRI, partly in VO
It turned out to be a vindication of the periodic system, and, if anything, made it even more profound a discovery.

Notes from the Field:

When we're working on atomic theory, we talk about how Mendeleev advanced the understanding of atoms.

NARR: Mendeleev's table had finally brought order to chemistry's unruly garden.

HISTORIAN ALAN ROCKE, partly in VO
After Mendeleev one could see that each element had a place. It was a grand design that worked.

STOP AND THINK 8: How did Mendeleev add to scientists' understanding of the elements?

Possible Student Answers: Students' answers to this question might include that by establishing a relationship between atomic weight and properties, Mendeleev raised the idea that there were unknown features about each kind of atom that both defined an atom's weight and determined an element's properties. Furthermore, these unknown features would be similar enough in a group of elements so that those elements would have very similar properties. Students' answers to this question might also include that Mendeleev promoted the idea that each kind of atom was both unique and unchanging.

Pan of the table

CONCEPT IN BRIEF: matter

BIOGRAPHER MICHAEL GORDIN, partly in VO
Chemistry wasn't just one thing after another – random substances we've dug up from the earth. They are interlinked in a complicated and rich way.

DMITRI MENDELEEV, partly in VO

We are at the dawn of a new era in chemical science – approaching a new understanding of the still mysterious nature of the elements.

STOP AND THINK 9: How are elements organized in the modern periodic table? What trends among elements are shown by this organization?

Possible Student Answers: If students have recently studied the periodic table, they may be able to explain that the modern periodic table is organized by atomic structure. The elements are listed in order of increasing atomic number, which is the number of protons in the atomic nucleus. The rows represent electron shells (or electron energy levels). The most important trend is that the arrangements of electrons in the outermost shell correspond to properties. The groups identified by Mendeleev are the alkali metals, the alkaline earth metals, the halogens, and the noble gases. Other sections of the periodic table that include elements with similar properties are the transition metals, the nonmetals, the rare earth metals, and the lanthanides. Hydrogen is typically grouped by itself due to its unique properties. Another trend is that metals are on the left side of the table and nonmetals are on the right side of the table, with the exception of hydrogen.

ACTIVITY IDEAS

Comparing the Properties of Elements

Prepare sealed samples of elements, such as pure metals, sulfur, carbon, nitrogen, and hydrogen, and have students examine them in the classroom. Discuss what properties can be seen by observation and what additional properties could be tested for each element. Have students create a table of properties of the elements they are observing. Students can first record the properties that they can see and then they can record selected properties obtained from resource materials, including melting point and density. Review how properties vary according to where the elements are in the periodic table.

Path to the Periodic Table

Reference: http://www.chemheritage.org/discover/online-resources/chemistry-in-history/activities/path-to-the-periodic-table.aspx

Have students recreate the process of making the first periodic table using element cards provided on the website of this Chemical Heritage Foundation activity. Students will be working with the same elements that were known to Mendeleev.

Representing the Elements

Have student groups figure out a creative way to represent the order of elements using a different criterion than chemical groups. Suggestions for this activity include a representation of elements according to their percentage on Earth, their percentage in the human body, their relative dollar value, the year they were discovered, or some other variable chosen by the student group.

TEACHER NOTES

IN-DEPTH INVESTIGATION: ORGANIZING THE ELEMENTS

Notes from the Field:

My students were really engaged in this activity, so much so that they didn't get to finish by the end of the class period. It may be helpful to do this investigation in a double period or two class periods.

Context

Mendeleev did not have all the information that we now have about elements. Therefore, he grouped elements by their properties.

Overview

Students read a short review of Mendeleev's work on creating the periodic table, and then they identify the first 20 elements in the periodic table using only descriptions of their appearance, their densities, their melting points, their reaction products, and especially the number of bonds in those products.

Next Generation Science Standards Alignment

Science and Engineering Practices

2. Developing and Using Models
    - Use a model based on evidence to illustrate the relationships between components of a system.
5. Using Mathematics and Computational Thinking
    - Use mathematical representations of phenomena to support explanations.
6. Constructing Explanations and Designing Solutions
    - Apply scientific reasoning, theory, and models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion.

Disciplinary Core Ideas

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

Crosscutting Concepts

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

Understanding Goals

Students should understand:

- The periodic table groups elements that have similar physical and chemical properties.
- Elements on the periodic table are arranged into several kinds of series: main-group elements, which include the alkali metals, the alkali earth metals, the halogens, and the noble gases; and into regions, which include hydrogen, transition metals, poor metals, nonmetals, rare earths, and lanthanides.
- It is possible to predict properties of an element, given the physical and chemical properties of another element in the same group on the periodic table.

Student Materials

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

Activity Facilitation

- Review the organization of the elements in the periodic table and the periodic law before students work on this activity.
- You may want to print out the element cards found in the activity on card stock.
- Circulate around to students as they work on the activity.
- Make students complete step 2 in the activity procedure before going on to step 3.
- The key to the identification of the elements on the element cards is shown in Table 1.

Table 1: Which Element?

Card Number	Element Name/Symbol
1	*Argon/Ar*
2	*Boron/B*
3	*Aluminum/Al*
4	*Magnesium/Mg*
5	*Beryllium/Be*
6	*Carbon/C*
7	*Sulfur/S*
8	*Potassium/K*
9	*Fluorine/F*
10	*Phosphorus/P*
11	*Helium/He*
12	*Lithium/Li*
13	*Silicon/Si*

14	*Nitrogen/N*
15	*Sodium/Na*
16	*Neon/Ne*
17	*Calcium/Ca*

Notes from the Field:

My more advanced students quickly realized that they could sort elements by melting point. It helped if I reminded them to also focus on reactivity. To make this activity more difficult, you might want to remove the densities and melting points from the element cards before printing them out.

Activity Rubric

Criteria	**Not evident**	**Limited**	**Developing**	**Competent**	**Accomplished**
Describe properties used to sort elements, and for each property, describe how elements in a group were similar	No properties described	Only one property was described	More than one property was described, but the description of how elements were similar in terms of each property was mostly incomplete	More than one property was described, and for all groups the description of how elements were similar in terms of each property was mostly complete	More than one property was described, and for all groups the description of how elements were similar in terms of each property was fully complete
How should hydrogen be grouped?	No explanation	Explanation referred to only one property	Explanation referred to more than one property, but reasoning in explanation was not convincing	Explanation referred to more than one property, and reasoning in explanation was somewhat convincing	Explanation referred to more than one property, and reasoning in explanation was completely convincing
Which properties change across a row, and how do they change?	No properties listed	Only one property was listed	More than one property was listed, but the description of the changes across the period were mostly incorrect	More than one property was listed, and the description of the changes across the period were mostly correct	More than one property was listed, and the description of the changes across the period were fully correct
How was Mendeleev able to use the properties of elements in a column to predict the existence of undiscovered elements?	No explanation	Explanation did not explicitly or implicitly refer to the periodic law	Explanation explicitly or implicitly referred to the periodic law, but the explanation of how to use the periodic law to predict undiscovered elements was mostly incomplete	Explanation explicitly or implicitly referred to the periodic law, and the explanation of how to use the periodic law to predict undiscovered elements was mostly complete	Explanation explicitly or implicitly referred to the periodic law, and the explanation of how to use the periodic law to predict undiscovered elements was fully complete

IN-DEPTH INVESTIGATION: ORGANIZING THE ELEMENTS

READING: Mendeleev Made the Periodic Table with Limited Information

Dmitri Mendeleev: Chemistry's Improbable Savior shows how Mendeleev tried to find an underlying principle that explained the repetition of certain properties among the elements. However, he often had limited information about each element.

Chemists during Mendeleev's time studied the physical and chemical properties of each element that they isolated, which included characterization as a metal or nonmetal, density, melting point, and reactivity with other elements to produce compounds. Of particular interest was the number of bonds an element could form with another highly reactive element, such as oxygen. Chemists also attempted to determine atomic weight, which was difficult in some cases. (Note: Atoms are now measured in units of mass.)

Like many other chemists, Mendeleev believed that there was some pattern among the properties of elements. Working on his textbook encouraged him to try to find that pattern. The program describes Mendeleev's discovery:

> *"Excited, Mendeleev wrote down the lightest elements and their atomic weights. After seven elements, he broke off and started a new row, keeping elements with similar chemical properties in the same column. The numerical pattern continued to hold."*

Mendeleev's discovery is called the periodic law. The groups with similar chemical properties identified by Mendeleev are the alkali metals, the alkaline earth metals, the halogens, and the noble gases. These same groups are also in the modern Periodic Table.

ACTIVITY: Which Element?

Mendeleev had to try to find a pattern of elements while working with limited information. In this activity, you will try to identify 17 unknown elements using limited information. How fast can you identify the elements correctly?

Materials

- sheet of element cards that contain descriptions of 3 known elements and 17 unknown elements (provided below)
- scissors
- access to the Internet
- access to chemistry textbooks and resource books
- copy of periodic table

Procedure

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

1. Use the scissors to cut out the element cards. Having the cards cut up will make it easier to sort the elements by their properties.
2. Working with your group, sort the elements into piles of elements that have similar properties as best as you can. Consider appearance, state, whether the element is metal or nonmetal, and the similarity of reaction products with oxygen, hydrogen, and chlorine. Note that the elements in a pile might not be the same in all these categories.

3. Now use your resource materials to try to identify the unknown elements. Some strategies you can try are to look up the properties of each pile that are found among elements 1 through 20, and to look up the densities and melting points of elements 1 through 20. Be sure to check that the units of both quantities are the same on the cards and in the resource material. Note that melting point values might vary slightly depending on which source that you use.
4. Identify the unknown elements and fill out Table 1: Which Element?, shown below.

Table 1: *Which Element?*

Card Number	Element Name/Symbol
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	

5. Share your conclusions with the whole class.

Questions

1. Which properties were used to sort the elements in each group you identified? For each property used, how were the elements in each group similar? Refer to the information in the cards and from your research in your answer.
2. Should hydrogen be grouped with the other elements in the first column? Justify your answer using properties of the elements.
3. Arrange the element cards as they are arranged on the Periodic Table. How do the elements change as you go across the periodic table from left to right? List as many changes as you can think of.
4. How was Mendeleev able to use the properties of elements in a column to predict the existence of undiscovered elements?

Element Cards for In-depth Investigation: Organizing the Elements

NOTE: The following information is shown on each card: color and physical state, density, melting point, and reaction products with hydrogen, chlorine, and oxygen. The letter "X" represents the unknown element. Metals are identified.

1 colorless gas density 0.0018 g/cm^3 melting point -189°C unreactive	2 brown or black solid density 2.35 g/cm^3 melting point 2075°C reacts with: O_2 to form X_2O_3 H_2 to form X_2H_6 Cl_2 to form XCl_3	3 silver-gray solid metal density 2.699 g/cm^3 melting point 660°C reacts with: O_2 to form X_2O_3 H_2 to form XH_3 Cl_2 to form XCl_3	4 silver-white solid metal density 1.738 g/cm^3 melting point 650°C reacts with: O_2 to form XO H_2 to form XH_2 Cl_2 to form XCl_2
O colorless gas density 0.0014 g/cm^3 melting point -218°C reacts with: H_2 to form H_2O Cl_2 to form OCl_2	5 steel-gray solid metal density 1.848 g/cm^3 melting point 1280°C reacts with: O_2 to form XO H_2 to form XH_2 Cl_2 to form XCl_2	H colorless gas density 0.0001 g/cm^3 melting point -259°C reacts with: O_2 to form H_2O Cl_2 to form HCl	6 soft black solid density 2.266 g/cm^3 melting point 3500°C reacts with: O_2 to form XO_2 H_2 to form XH_4 Cl_2 to form XCl_4
7 lemon-yellow solid density 2.069 g/cm^3 melting point 115°C reacts with: O_2 to form XO_2 H_2 to form H_2X Cl_2 to form XCl_2	Cl green-yellow gas density 0.0032 g/cm^3 melting point -101°C reacts with: O_2 to form Cl_2O H_2 to form HCl	8 soft silver solid metal density 0.856 g/cm^3 melting point 64°C reacts with: O_2 to form X_2O H_2 to form XH Cl_2 to form XCl	9 pale-yellow gas density 0.0017 g/cm^3 melting point -220°C reacts with: O_2 to form OX_2 H_2 to form XH Cl_2 to form XCl

10	11	12	13
white solid density 1.823 g/cm^3 melting point 44°C reacts with: O_2 to form X_2O H_2 to form XH_3 Cl_2 to form XCl_3	colorless gas density 0.0002 g/cm^3 melting point -272°C unreactive	soft silver solid metal density 0.534 g/cm^3 melting point 181°C reacts with: O_2 to form X_2O H_2 to form XH Cl_2 to form XCl	lustrous gray solid density 2.336 g/cm^3 melting point 1410°C reacts with: O_2 to form XO_2 H_2 to form XH_4 Cl_2 to form XCl_4
14	**15**	**16**	**17**
colorless gas density 0.0012 g/cm^3 melting point -210°C reacts with: O_2 to form X_2O H_2 to form XH_3 Cl_2 to form XCl_3	silver-white solid metal density 0.968 /cm^3 melting point 98°C reacts with: O_2 to form X_2O H_2 to form XH Cl_2 to form XCl	colorless gas density 0.0009 g/cm^3 melting point -249°C unreactive	silver-white solid metal density 1.55 g/cm^3 melting point 842°C reacts with: O_2 to form XO H_2 to form XH_2 Cl_2 to form XCl_2

TEACHER NOTES

IN-DEPTH INVESTIGATION: PREDICTING REACTION PRODUCTS

Context

Mendeleev's Periodic Table provided a powerful model of the trends in properties of elements, including reactivity. Scientists who were trying to determine the structure of the atom developed models that provided an explanation for the trends in the properties of elements.

Overview

Students read about successive theories on the arrangement of electrons in atoms and learn how bonding is related to the attainment of full energy levels. Students use this information to model electron arrangements in elements and to predict reaction products.

Next Generation Science Standards Alignment

2. Developing and Using Models
    - Use a model based on evidence to illustrate the relationships between components of a system.
5. Using Mathematics and Computational Thinking
    - Use mathematical representations of phenomena to support explanations.

6. Constructing Explanations and Designing Solutions

- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.

Disciplinary Core Ideas

- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

Crosscutting Concepts

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

Performance Expectations

- Chemical Reactions HS-PS1-2: Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

Understanding Goals

Students should understand:

- Atoms are made up of three kinds of subatomic particles: electrons, protons, and neutrons.
- Electric charge is associated with subatomic particles. Protons have positive electric charge and electrons have negative electric charge.
- Each element has one more proton than the previous element in the Periodic Table; the atomic number is the number of protons and the number of electrons found in a neutral atom of that element.
- The structure of an atom is composed of a dense nucleus consisting of protons and neutrons and layers that contain specified number of electrons. The electrons move around within the layers, which take up most of the space of the atom. The layers are called energy levels or shells.
- Each electron energy level corresponds to a row in the Periodic Table and can contain as many electrons as there are elements in that row. Therefore, energy level 2 corresponds to the second row in the Periodic Table and can hold up to 8 electrons.
- Both within and between atoms, there is an electric attractive force between the negative electrons and the positive nucleus.
- The electrons in an atom's outermost energy level, called valence electrons, determine the physical and chemical properties of an element.

- Elements that have similar physical and chemical properties have a similar configuration of valence electrons.
- In most cases, the chemical bond that forms between atoms will result in full energy levels for each atom. Atoms with filled energy levels are very stable.
- The configuration of valence electrons in atoms determines if they lose, gain, or share electrons when bonding.

Student Materials

You will find on the following page a reading and an activity.

Activity Facilitation

- There are different methods for keeping tack of valence electrons. In this activity, have students work out their own method.
- Circulate around to students as they work on the activity.

Activity Rubric

Criteria	Not evident	Limited	Developing	Competent	Accomplished
Determine the chemical formulas of sodium chloride and methane	No chemical formulas	Chemical formulas and number of valence electrons mostly incorrect	Chemical formulas and number of valence electrons somewhat correct	Chemical formulas and number of valence electrons mostly correct	Chemical formulas and number of valence electrons completely correct
Explain why sodium and chlorine are both very reactive elements	No explanation	Explanation did not refer to stability of filled energy levels	Explanation referred to stability of filled energy levels, but reasoning in explanation was not convincing	Explanation referred to stability of filled energy levels, and reasoning in explanation was somewhat convincing	Explanation referred to stability of filled energy levels, and reasoning in explanation was completely convincing
Explain how arrangement of electrons in atoms is correlated with the organization of elements by properties in the Periodic Table.	No explanation	Explanation did not refer to one or more of the following: filled energy levels, properties, and valence electrons	Explanation referred to filled energy levels, properties, and valence electrons, but the explanation was not clear.	Explanation referred to filled energy levels, properties, and valence electrons, and the explanation was somewhat clear.	Explanation referred to filled energy levels, properties, and valence electrons, and the explanation was completely clear.

IN-DEPTH INVESTIGATION: PREDICTING REACTION PRODUCTS

READING: Atomic Structure And Reactivity

Electron Arrangements in the Atom

When Dmitri Mendeleev created the Periodic Table, his found his organizing principle when he examined the reactivity of elements. He noticed that certain elements reacted with another element, such as oxygen, in the same ratios. He organized elements with similar reactivity into groups called families. The groups were incorporated into the Periodic Table.

Mendeleev's Periodic Table inspired significant new work by scientists. Some scientists searched for an explanation for the reactivity patterns among elements, which they believed was related to patterns in the structure of the atom. For example, J. J. Thomson, who discovered the electron, proposed that electrons were arranged in concentric rings. Elements with similar properties have similar configurations of electrons.

Niels Bohr updated Thomson's model and proposed that electrons are found in concentric shells that encircle the positive nucleus. Bohr's atomic model took into account different kinds of experimental evidence. Each shell corresponded to a row in the Periodic Table and could contain as many electrons as there are elements in that row. To explain reactivity patterns, Bohr explained that elements with similar properties have similar configurations of electrons in its shell.

Bohr's atomic model also provided an explanation for why noble gases lack reactivity. Positioned at the end of a row in the Periodic Table, the noble gases have filled outer shells of electrons, a very stable configuration. In contrast, other elements are reactive because they do not have a filled outer shell of electrons, and they form bonds that result in filled outer shells.

In the current atomic model, the electrons in the layers do not occupy a specific physical space. Therefore, the layer that contains the electrons is now often called an energy level rather than a shell. As in the Bohr model, elements with similar properties have similar configurations of electrons.

Chemical reactions involve atoms' outermost electrons, which are called valence electrons. The number of valence electrons is equal to an element's position in its row, counting from the left. Table 2 shows the outermost energy level and number of valence electrons for the first 18 elements.

Table 2: *Valence Electrons for Elements 1–18*

Element/ Symbol	Outermost Energy Level	# of Valence Electrons	Element/ Symbol	Outermost Energy Level	# of Valence Electrons
Hydrogen/H	1	1	Neon/Ne	2	8 (Filled)
Helium/He	1	2 (Filled)	Sodium/Na	3	1
Lithium/Li	2	1	Magnesium/Mg	3	2
Beryllium/Be	2	2	Aluminum/Al	3	3
Boron/B	2	3	Silicon/Si	3	4
Carbon/C	2	4	Phosphorus/P	3	5
Nitrogen/N	2	5	Sulfur/S	3	6
Oxygen/O	2	6	Chlorine/Cl	3	7
Fluorine/F	2	7	Argon/Ar	3	8 (Filled)

Chemical Bonds

In most cases, the chemical bond that forms between atoms during a reaction will result in filled energy levels for each atom. Atoms with filled energy levels are very stable. To achieve a filled energy level, valence electrons are transferred or shared between atoms. This process occurs along a continuum from complete transfer to fully equal sharing.

Since filled energy levels have the most stable configuration, it is possible to predict reaction products of elements. For example, let's examine what occurs when carbon is burned and reacts with the oxygen in the air. Table 2 shows that an oxygen atom needs two more electrons to have a filled energy level and a carbon atom needs four more electrons to have a filled energy level.

If the oxygen shares two electrons and the carbon share two electrons, each atom gains two electrons. After sharing, the energy level of the oxygen is now eight, which is filled. However, the carbon has only gained two valence electrons and still needs two more for a filled energy level. Therefore, the carbon bonds to a second oxygen atom to gain the additional two electrons. The chemical formula of the reaction product is CO_2 (carbon dioxide). A representation of CO_2 that shows the bonds follows:

O=C=O

In this representation, each pair of shared of electrons is a bond, and a line between two atoms shows each bond. Note that the number of valence electrons each element needs to have a filled energy level is equal to the number of bonds if forms. Oxygen needed two valence electrons, and it formed two bonds. Carbon needed four valence electrons, and it formed four bonds. Atoms that bond by sharing electrons usually form small identical groups of atoms called molecules.

Elements can transfer electrons as well as share them. When an element on the left side of the Periodic Table reacts with an element on the right side, the first element's valence electrons are transferred to the second element. Atoms that bond by transferring transfer electrons form a crystal, which is a solid substance that has a regular pattern of ions, atoms, or molecules.

ACTIVITY: What are the reaction products?

Apply the ideas presented in this reading by completing the following tasks.

1. In the reaction between sodium and chlorine, bonds form due to transferring of electrons. Determine the ratio of elements in the reaction product of sodium and chlorine and write its chemical formula. Also explain how each element achieves a filled energy level.
2. Explain why sodium and chlorine are both very reactive elements. Refer to the idea of the stability of filled energy levels.
3. In the reaction between carbon and hydrogen, bonds form due to sharing of electrons. Determine the ratio of elements in the reaction product of carbon and hydrogen and write its chemical formula. Also explain how each element achieves a filled energy level.
4. Explain how the arrangement of electrons in atoms is correlated with the organization of elements by properties in the Periodic Table.

WEB RESOURCES

The Periodic Table Live!

http://www.chemeddl.org/resources/ptl/index.php

This site features an interactive Periodic Table that allows users to link to extensive information about each element. Of particular interest are Quicktime videos of reactions, which are found in the media section for each element. The website is a product of the American Chemical Society's Chemical Education Digital Library.

The History of the Periodic Table

http://www.rsc.org/Education/Teachers/Resources/periodictable/

This site describes the search for elements. The website contains numerous activities that ask students to examine an interactive Periodic Table that shows the discovery of the elements over time. The website was developed with support from the Royal Society of Chemistry.

A Visual Interpretation of the Table of Elements

http://www.rsc.org/chemsoc/visualelements/pages/history_ii.html

Highlights of this diverse site are a history of the development of the Periodic Table and artistic interpretations of the elements contained in Quicktime videos. The website was developed with support from the Royal Society of Chemistry.

Graphing the Periodic Table

http://www.teachersdomain.org/resource/lsps07.sci.phys.matter.graphperiodic/

In this interactive activity from the American Chemical Society, students can explore patterns in the Periodic Table. They are able to see how the electron configurations and properties of the elements vary according to their place in the table, and investigate the patterns by plotting and comparing the elements by molar mass, atomic radius, ionic radius, melting point, boiling point, electronegativity, and ionization energies.

Periodic Table of the Elements

http://www.pbslearningmedia.org/resource/phy03.sci.phys.matter.ptable

This interactive Periodic Table, developed for Teachers' Domain, helps unlock some of the information the table contains, making clear the relationships among some elements and illustrating the electron configurations responsible for each element's chemical properties.

The Periodic Table of the Elements

http://www.teachersdomain.org/resource/phy03.sci.phys.matter.lp_pertable/

In this activity, students learn about the origin of the modern Periodic Table of elements and explore an interactive version that teaches them how to extract information from it.

Repeating Patterns: The Shape of the Periodic Table

http://www.teachersdomain.org/resource/phy03.sci.phys.matter.lp_patterns/

This lesson explains why the elements exhibit periodicity, why the Periodic Table of elements is shaped the way it is, and how we are able to predict the characteristics of elements yet to be discovered or created. Students create electron configuration diagrams that describe the arrangement of electrons around the nucleus.