

The Path to the Periodic Table: Building the Periodic Table

Teacher Activity

Procedural Notes

To prepare for the activity, print out the three sets of element cards at the end of this document. Since the students will be working in groups of three or four, you will need as many sets of cards as there are groups. There are three parts to this activity, and three different sets of cards. Each group will make use of all three sets of cards.

Part 1

Give each group the set of cards designated for Part 1. Ask the groups to look carefully at the properties listed for each element, and ask them to arrange the cards in a two-dimensional grid of some sort, in any way that makes sense to them. Stress to students that you aren't giving them all the elements but just some of the elements that had been discovered at the time Mendeleev and Meyer were working on their tables.

When students have finished, have them answer the post-lab questions as groups. Ask the groups to share with the class their answers to the questions. Questions 4 and 5 will deserve special attention. Question 4 asks whether any elements deviated from a general trend in atomic masses in the arrangements they have created. Specifically, they may have placed tellurium before iodine, even though tellurium has a higher atomic mass. Explain to the students that Mendeleev made the same switch. Also explain that today we know that elements have the properties they do because of their atomic numbers, not their atomic masses. Since protons had not yet been discovered in Mendeleev's time, he had no way of knowing this. He thought instead that the masses of iodine and tellurium had been measured incorrectly and that eventually better measurements would show iodine to be heavier than tellurium. In fact, Mendeleev died still believing this would happen some day.

Part 2

Question 5 is the segue into Part 2. This question asks students about holes or gaps in their arrangements. Specifically, some groups may have gaps in the families containing aluminum and silicon. Some students may correctly guess that these gaps represent elements that had not yet been discovered in 1870. Tell the students that Mendeleev predicted that elements would soon be discovered to fill these gaps. It is worth noting that some scientists were skeptical of these predictions. Since there was no evidence from the laboratory at that time of such elements actually existing, some scientists didn't give much weight to Mendeleev's predictions. You might want to read to your class a quote by Friedrich Beilstein, a colleague of Mendeleev (who didn't like him very much):

“Mendeleev. .. has prophesied the existence of all sorts of new elements and believes that he needs only to conceive of them in order to have them immediately in the bag.... He is in general an odd chap.”

Far from painting Beilstein as a villain in this story, you should stress the important role that healthy skepticism plays in science and that predictions without evidence to bear them out aren't worth much.

However, such evidence came in 1875. The French chemist Paul-Emile Lecoq de Boisbaudran discovered a new element he named gallium. Later, in 1886 a German chemist named Clemens Winkler discovered an element he called germanium. After telling students these facts, pass out to each group the Part 2 card set, which contains gallium and germanium. Ask the groups to try to fit them into their tables. They should find that gallium fits well in the family of boron and aluminum, while germanium fits into the family of carbon and silicon. You should point out that the discovery of these elements brought a lot of attention to the periodic table and

persuaded many skeptics to accept it.

Part 3

Part 3 of the activity involves elements that Mendeleev did not predict. In the 1890s, many years after Meyer and Mendeleev first published their periodic tables, five new gases were isolated, largely through the work of Scottish chemist Sir William Ramsay. Pass out the card set for Part 3, which includes helium, neon, argon, krypton, and xenon. Ask the groups to try to fit these into their periodic tables. They should conclude that these elements constitute a new family of their own. In Extension Question #4, students are asked why Mendeleev hadn't predicted the existence of these elements. It is important for students to realize that Mendeleev predicted the existence of gallium and germanium because the other members of their families gave them away. Since none of the noble gases had been isolated before the 1890s, there were no clues that they should exist.

Additional Notes

In this activity some historical liberties have been taken. Obviously, modern atomic masses are used, which have been refined since the days of Mendeleev and Meyer. In addition, for the sake of clarity and simplicity the student activity does not include transition elements. In fact, these elements were very difficult to fit into a periodic table. Mendeleev tried to shoehorn them into the main groups of the periodic table. Since he died before the discovery of quantum mechanics, he could not have known that the transition metals are characterized by having their outermost electrons in d-orbitals and therefore belong in a separate place, the d-block of the modern periodic table. For this reason this activity ignores the story of scandium, another element that Mendeleev predicted based on a gap in his table, and which was later discovered.

A bigger historical liberty might be the cards themselves. It has long been the stuff of legend that Mendeleev used cards like the ones the student groups use in this activity to construct his first periodic tables. However, historians seriously doubt he did so. The reasons for their skepticism is that while Mendeleev saved many pieces of paper containing his notes and scribbles from his early work on the periodic table, no cards have ever been found. Given Mendeleev's concern with posterity, it seems unlikely that he would have thrown away his cards had he actually used them. Furthermore, the earliest accounts of the card story are found several decades after the first periodic tables were published. There are no known accounts of cards that date from the actual time of the birth of the periodic table.

This activity is designed with a historical perspective, and the information on the cards is the kind that Mendeleev and Meyer would have had at their disposal. Furthermore, the information on the cards has been kept simple so that the activity may be carried out early in the semester. Depending on when in the semester you carry out this activity, you may choose to add more information to the cards. For example, if you cover ions before you carry out this activity, you may choose to add the charge that each atom of each element acquires when it becomes an ion. Or you might carry out the activity early in the semester but refer back to it in a spiraling manner when new subjects are introduced that involve elemental properties for which there is a periodic dependence, such as ionic charge.

Student Skills Required

Students should have an understanding of elements and compounds, as well as of atoms and molecules. They should especially understand the atomic-level definition of an element as a substance made of only one kind of atom. It is also important that students have an understanding of atomic masses and atomic numbers. Students should also have a basic understanding of formulas of compounds.

Student Misconceptions

- 1. Mendeleev discovered gallium and germanium.** Gallium was discovered by Paul-Emile Lecoq de Boisbaudran, and germanium by Clemens Winkler. Mendeleev himself never discovered any elements. His brief attempt to find the element we now call germanium in the early 1870s lasted only a few months, after which Mendeleev gave up and never did any wet chemistry research the rest of his life. It was this sort of thing that provoked the disapproving comments of people like Beilstein.
- 2. Meyer and Mendeleev developed the periodic table together.** Meyer and Mendeleev worked separately and were unaware of each other's efforts. In fact, there was a priority dispute between them that was not settled until the 1880s.
- 3. The periodic table is hard because you have to memorize it.** Some misguided educators have wrought much needless hardship on students by requiring them to memorize the periodic table. Such exercises completely miss the point of the table. Both Meyer and Mendeleev created their tables so that students would not have to memorize as much seemingly disconnected information. Real knowledge of the periodic table does not consist of memorizing its arrangement but rather of being able to look at the table and obtain useful information from its arrangement. Letting students know early that they will not be asked to memorize the periodic table can remove a large and intimidating psychological barrier to true learning of the table's power and utility.
- 4. Mendeleev and Meyer weren't very smart because they didn't predict the existence of the noble gases and because they couldn't figure out where the transition elements belong.** It is the nature of science that our picture of the world changes as new evidence becomes available. If the evidence required to conclude that noble gases exist is not available, then even the smartest scientist in the world cannot be expected to predict their existence.
- 5. Beilstein wasn't very smart because he doubted Mendeleev's predictions.** Skepticism is an important part of science. Any claim or prediction must be supported by evidence before it can be accepted. Until gallium was actually discovered, Mendeleev didn't have any evidence to support his predictions, and he was rightly and fairly the target of healthy scientific skepticism.

Answers to Pre-Lab Questions

1. What is an element? How many different kinds of atom is any element made of?
An element is a substance made of only one kind of atom.
2. What is the atomic mass of an element?
The atomic mass is the mass of an atom of a particular element. It is the total number of protons and neutrons in the nucleus of an atom of a particular element, averaged over all the isotopes of the element. (Note: students may not have studied isotopes yet, and may not be ready to grapple with the distinction between atomic mass and mass number. At this point it is sufficient that they simply understand atomic mass as resulting from the number of protons and neutrons in the nucleus.)
3. What is the atomic number of an element?
The atomic number is the number of protons in the nucleus of an atom of a given element.
4. How many atoms of each element are present in molecules of the following compounds?
 - ***HCl 1 hydrogen, 1 chlorine***
 - ***H₂O 2 hydrogens, 1 oxygen***
 - ***CH₄ 1 carbon, 4 carbons***

- **NH₃ 1 nitrogen, 3 hydrogens**

Answers to Post-Lab Questions

1. How many groups or families of elements are in your table?
There are seven families in the table. (Note: this answer assumes that the students answer the questions immediately after doing Part 1 of the activity, before Part 3 in which the noble gas cards are distributed. The noble gases, of course, constitute an eighth group.)
2. What criteria did you use to choose which group or family an element belongs to?
Note: Student answers will vary, but they may include the criteria below. Our group arranged the elements according to atomic mass, the compounds formed, and the properties of the element listed under "Description."
3. Is there a trend in atomic mass going across your table? Is there a trend in atomic mass going from top to bottom?
There is an increasing trend in atomic mass.
4. Are there any exceptions to these trends? If so, which elements break the trend? Why did you arrange these elements the way you did?
Iodine and tellurium break the trend in atomic masses, but the other properties of iodine make it fit better with fluorine, chlorine, and bromine, while the properties of tellurium make it fit better with oxygen, sulfur, and selenium.
5. Are there any holes or gaps in your arrangement? Where are they? What do you think these gaps might mean?
There are gaps in the family of boron and aluminum and in the family of carbon and silicon. These gaps might indicate that there were elements not yet discovered in Meyer's and Mendeleev's time.

Assessment

The extension questions are the true assessment of a student's understanding of this experiment. You may expand on the extension questions by having the students answer the following questions.

1. Find the elements cesium (Cs), thallium (Tl), radium (Ra), and radon (Rn) on the periodic table. Which groups are each of these elements in? What would you expect the formulas to be for compounds of each of these elements with chlorine?

Cs	the same group or family as lithium	CsCl
Tl	the same group or family as boron	TlCl ₃
Ra	the same group or family as beryllium	RaCl ₂
Rn	the same group or family as helium	a compound with Cl would not form

2. Suppose four new elements A, D, E, and G are discovered. Each new element forms a compound with oxygen. The formulas for the new compounds are AO, D₂O₃, E₂O, and GO₂. What groups or families do you think each of these elements would belong to?

A	the same group or family as beryllium
D	the same group or family as boron
E	the same group or family as lithium
G	the same group or family as carbon

Answers to Extension Questions

1. After you prepared your periodic tables, your teacher gave you additional sets of cards to fit into your tables. How did your table change each time you added new elements to your table?
Gallium was placed in the family of boron and aluminum, germanium was placed in the family with carbon and silicon, and the noble gases were arranged into a new family.
2. How is your table similar to a modern periodic table? How is yours different?
Student answers may vary here. Our table didn't include transition elements like the modern table, our table stops at xenon, and our table is organized by atomic mass rather than atomic number.
3. How do we explain today the fact that tellurium comes before iodine in the periodic table, even though tellurium has a higher atomic mass than iodine?
While tellurium has a higher atomic mass than iodine, iodine has the higher atomic number. Atomic number, not atomic mass, is the true organizing principle of the periodic table.
4. Mendeleev predicted the existence of gallium and germanium because of the holes in his periodic table. Why do you think Mendeleev did not predict the existence of the noble gases?
The existence of aluminum and silicon tipped off Mendeleev that gallium and germanium should exist. Since Mendeleev did not know about any member of the noble gas family, he didn't have a tip-off that others might exist as well.
5. Look at a modern periodic table. Suppose two new elements were discovered with the atomic numbers 120 and 121. Where in the periodic table do you think we would place these new elements?
Element 120 would go beneath francium, while element 121 would go beneath radium.
6. Suppose a new element X is discovered. It forms a compound with chlorine, and the formula of this compound is XCl_4 . What group or family do you think this element would belong to?
The new element would belong in the same group or family as carbon, silicon, and germanium.
7. Find the element barium (Ba) on a modern periodic table. What group or family is barium in? What do you think the formula of a compound of barium and chlorine would be?
Barium is in the same group or family as beryllium, magnesium, calcium, and strontium. The formula of a compound of barium and chlorine should be BaCl_2 .

Additional Teacher Resources

- Dmitry Mendeleev Museum & Archives—official museum site in St. Petersburg with information for visitors.
<http://www.spbu.ru/Structure/Culture/Museums/Mendeleev/enmuseum.html>
- Dmitriy Mendeleev Online—comprehensive listing of Mendeleev resources online, from Moscow State University.
<http://www.chem.msu.su/eng/misc/mendeleev/welcome.html>
- “About a New Metal, Gallium”—1875 paper by Paul-Emile Lecoq de Boisbaudran describing the first discovery of an element that Mendeleev had predicted, reprinted by the ChemTeam at Diamond Bar High School.
<http://dbhs.wvusd.k12.ca.us/webdocs/Chem-History/Disc-of-Gallium.html>
- “About Ytterbine, the New Earth of Marniac”—1879 paper by Lars Fredrick Nilson describing the second discovery of an element that Mendeleev had predicted, reprinted by the ChemTeam at Diamond Bar High School.
<http://dbhs.wvusd.k12.ca.us/webdocs/Chem-History/Disc-of-Scandium.html>

- “Germanium, Ge, a New Nonmetallic Element” —1886 paper by Clemens Winkler describing the third discovery of an element that Mendeleev had predicted, reprinted by the ChemTeam at Diamond Bar High School.
<http://dbhs.wvusd.k12.ca.us/webdocs/Chem-History/Disc-of-Germanium.html>

References

Gordin, Michael D. *A Well-Ordered Thing: Dmitrii Mendeleev and the Shadow of the Periodic Table* (New York: Basic Books, 2004).

Scerri, Eric R. *The Periodic Table: Its Story and Its Significance* (Oxford/New York: Oxford University Press, 2007).