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It's in the Cards

A Periodic Table Activity

Introduction

Dmitri Mendeleev's discovery of the Periodic Law ranks as one of the greatest achievements in the history of science. It has survived the test of time and stands to this day as the single most important tool to understand the chemistry of the elements. As we try to understand the essence of this discovery, it is worthwhile to go back in time and look at how it was achieved.

Concepts

- Periodic law
- Periodic table

Background

In the years 1868–1870, Dmitri Mendeleev, a professor of chemistry at the University of St. Petersburg in Russia, was writing a new textbook called *Principles of Chemistry*. More than 60 individual elements were known, along with a great many facts about their properties and compounds. Mendeleev knew the atomic masses of the elements, their densities, boiling points, and melting points, as well as the formulas of their compounds with hydrogen, oxygen, and chlorine. What was missing was a way to organize these facts, a way to understand how individual facts related to each other—in short, a way to classify the elements. The following quote from Mendeleev reveals his thoughts at the time:

"I wished to establish some sort of system of elements in which their distribution is not guided by chance . . . but by some sort of definite and exact principle."

Mendeleev decided to arrange the elements according to their atomic mass. He wrote out the exact atomic masses (as they were known at the time) in the margin of a list of the elements, then wrote out separate cards for each of the elements, with their atomic mass and other chemical and physical properties. Using these cards, Mendeleev played "chemical solitaire" for several hours, finally copying to a sheet of paper the arrangement he had worked out with the cards. With slight modification, this became Mendeleev's first *Periodic Table of the Elements*.

Activity Overview

The purpose of this activity is to re-create Mendeleev's discovery of the classification of the elements and the periodic law using a special deck of element cards. The real properties of the elements, but not their names or symbols, are written on these cards. As the cards are arranged and rearranged based on logical trends in some of these properties, the nature of the periodic law should reveal itself.

Review Questions

Define each property and give its typical units, if appropriate.

- Ionization energy
- Atomic mass
- Atomic radius
- Density
- Melting point
- Electronegativity

Materials

Special deck of 31 element cards

Procedure

1. Form a group with three other students. Obtain a deck of element cards and spread the cards out on the table.
2. Each card lists the properties of a single element (X), as shown at the right:

   *Density values are in units of g/cm^3 for solids and liquids, g/L for gases.

   †Dashed lines for a property indicate that no data is available. Some elements, for example, may not form a compound with hydrogen.

Ionization energy	**Atomic radius**
Atomic mass	**Formula of its -oxide X_bO_c**
Formula of its -chloride XCl_a	**Melting point**
Density*	**Formula of its† -hydride XH_d**
Electronegativity	

3. Working together, discuss the possibilities for arrangement of the element cards with all members of the group, and look for a logical arrangement of the cards. Consider the similarities and differences among the elements as well as possible numerical or logical trends in their properties.
4. It is NOT within the rules of this game of chemical solitaire to look up information in a textbook or to use a modern periodic table as a guide!

Mendeleev's greatest insight in creating the periodic table was in recognizing there were some gaps when the elements were arranged in logical order. He had the ingenuity not only to leave blanks in his table for the missing elements, but also to predict their properties.

5. One of the element cards is also missing in your deck of cards. Decide where the missing element belongs in the arrangement of the elements and rearrange the cards if necessary to accommodate the missing element.
6. On the worksheet, fill in the Table of the Elements to illustrate a logical arrangement of the element cards. To do this, write down only the atomic mass of each element, as shown on its card. Leave a blank space for the missing element. *Note:* The table is 8 × 8 and contains 32 more squares than are needed—plenty of room to arrange the elements many different ways!
7. Predict the properties of the missing element by averaging the properties of its nearest neighbors. On the worksheet, complete the card for the missing element by entering its predicted properties alongside the name of each property.
8. Answer Questions 1–9 on the "It's in the Cards" Worksheet.

Name: ______________________________

"It's in the Cards" Worksheet

Table of the Elements

Properties of the Missing Element

Ionization energy	**Atomic radius**
Atomic mass	**Formula of its oxide**
Formula of its chloride	**Melting point**
Density	**Formula of its hydride**
Electro-negativity	

Name: ______________________________

"It's in the Cards" Worksheet

(Use a separate sheet of paper to answer the following questions.)

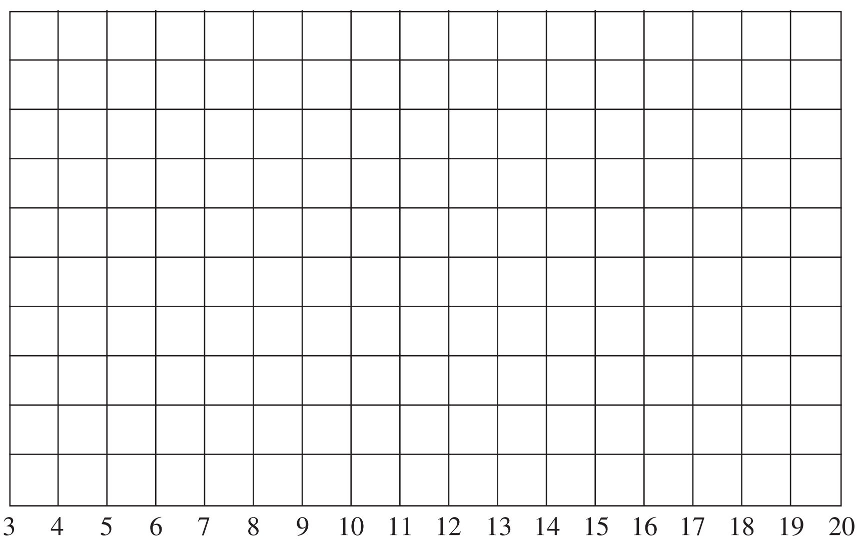
1. Mendeleev's Periodic Law can be stated: *"The physical and chemical properties of elements are periodic functions of their atomic masses"*. Looking at your arrangement of the element cards, describe in your own words what the term "periodic function" means.

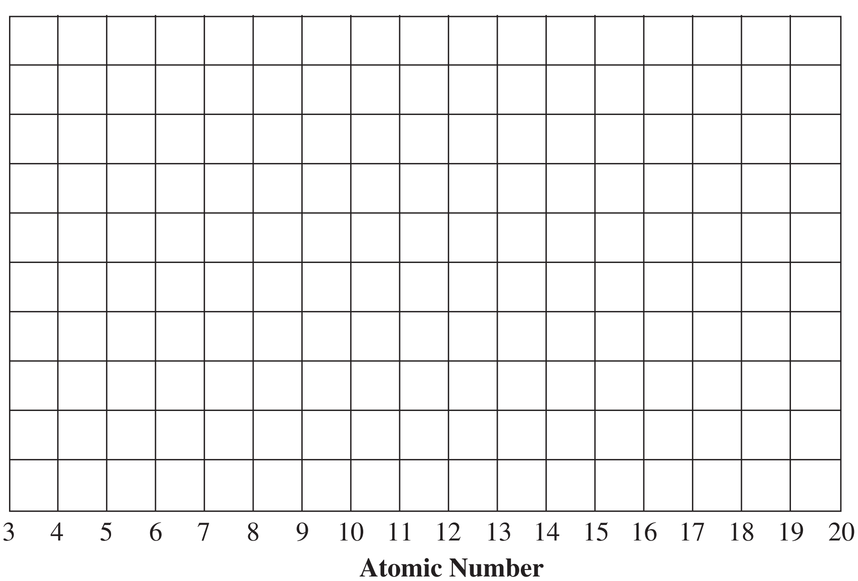
2. Some of the properties listed on each card are periodic properties, others are not. Name one property that is periodic and one that is not.

3. The elements in the modern periodic table are arranged in order of increasing atomic number (instead of increasing atomic mass). Why didn't Mendeleev use atomic number to arrange the elements?

4. From your instructor, obtain a handout showing one possible arrangement of the element cards. Identify each element on the handout with its *atomic number* and *chemical symbol*. Use your textbook to obtain this information.

5. Using the possible arrangement of the element cards obtained from your instructor, pick two of the *numerical properties* of the elements that are periodic and plot their values on the graphs below. Give each graph a descriptive title and label the axes.

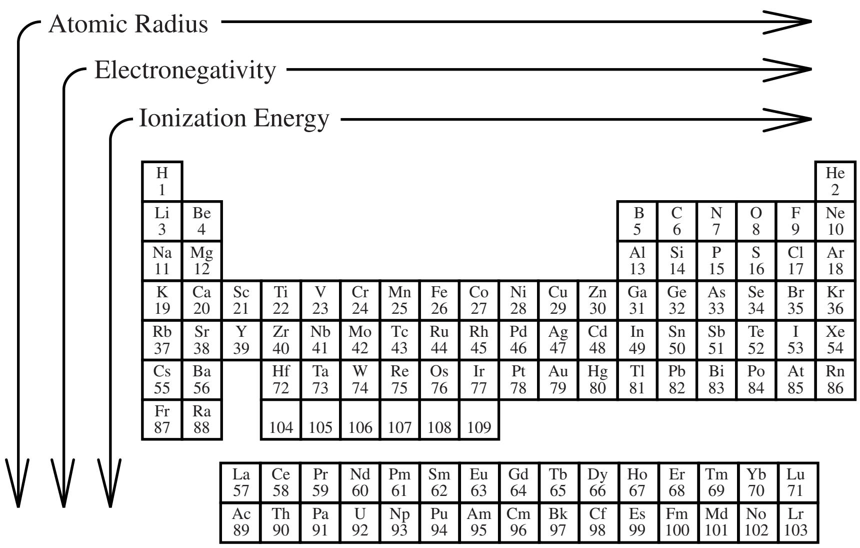




Name: ______________________________

"It's in the Cards" Worksheet

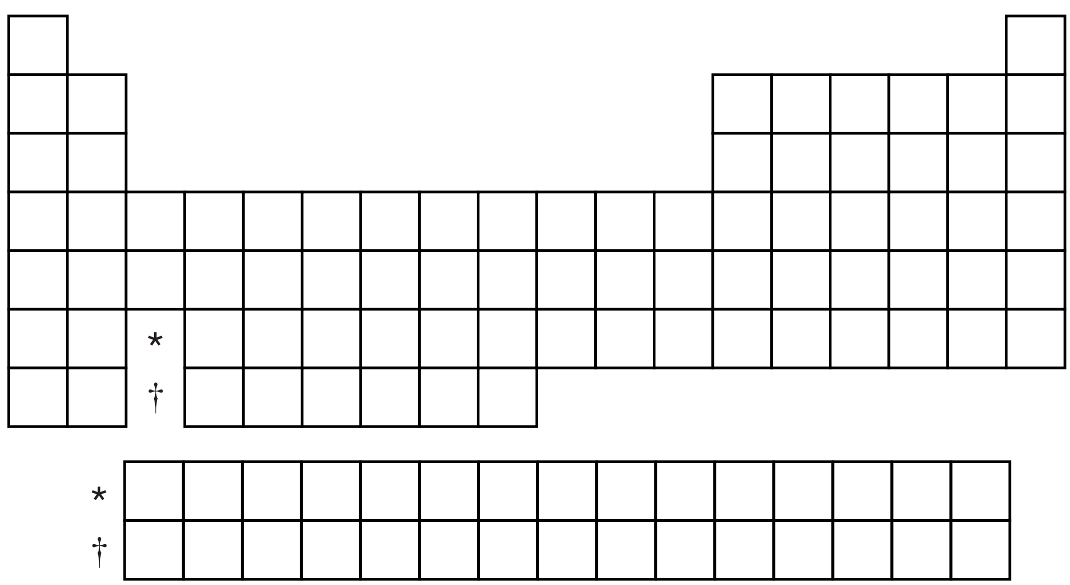
6. There are certain trends in the properties of the elements, both within a column (from top to bottom) and across a row (from left to right) in the periodic table. On the arrow for each property, write the word *increases* or *decreases* to describe how that property changes.



H 1																	He 2
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Cs 55	Ba 56		Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
Fr 87	Ra 88		104	105	106	107	108	109									

La 57	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
Ac 89	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103

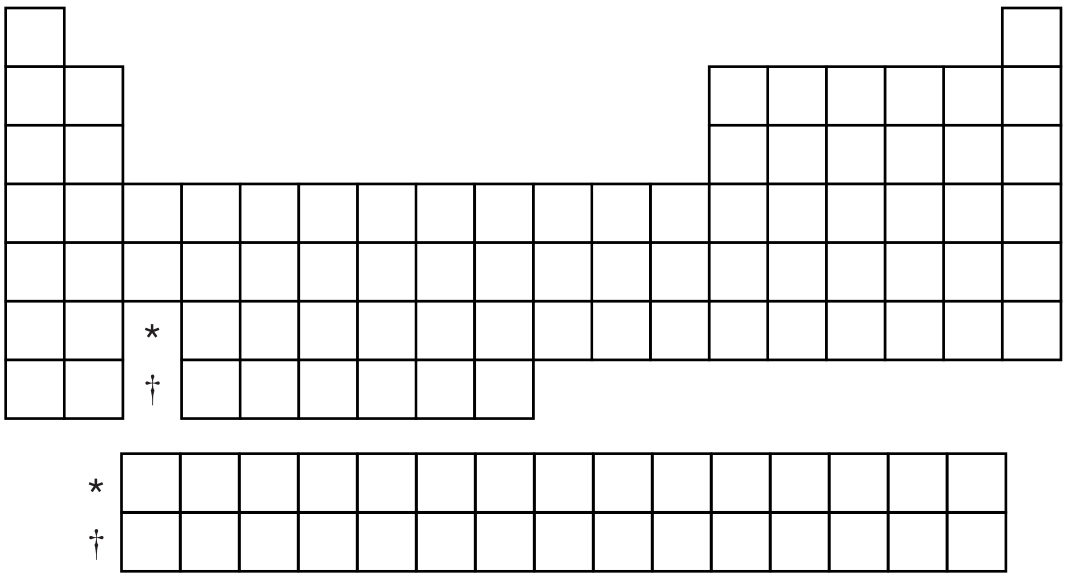
7. On the outline of the periodic table shown below, locate the following: *metals, nonmetals,* and *metalloids* (or *semimetals*). Use your textbook to define these terms, if necessary.



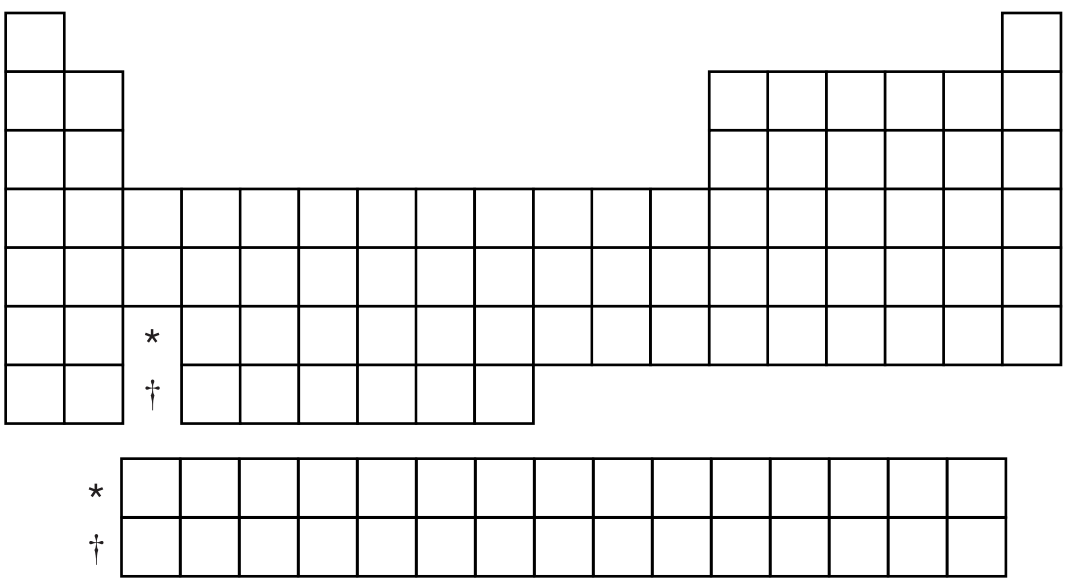
Name: ______________________________

"It's in the Cards" Worksheet

8. On the outline of the periodic table shown below, locate the following: *groups or families of elements, periods or series of elements, noble gases, alkali metals, alkaline earth metals,* and *halogens*. Use your textbook to define these terms, if necessary.



9. On the outline of the Periodic Table shown below, locate the following: *transition elements, inner transition elements, representative elements*. Use your textbook to define these terms, if necessary.



Teacher's Notes

It's in the Cards

Materials Included in Kit (for a class of 24 students working in groups)

Element card decks, 6 sets

Tips

- *Element Card Arrangement Handout:* Make enough copies of this handout (see page 13) on regular paper to give each student an individual copy. After students have completed their own element arrangement on the worksheet, they will work from this handout to complete the questions and graphs on the "It's in the Cards" Worksheet.
- Although this is a "dry-lab" activity, it is best to schedule enough time for it in class so that students can complete Steps 1–6 in the *Procedure* section. This will ensure that students really do treat the lab as a discovery activity. Do not give students the Element Card Arrangement Handout until they have completed the *Table of the Elements* on the Data Sheet.
- Keeping in mind the spirit of discovery, remind students that there is no single correct answer for the arrangement of the elements. Remember that in Mendeleev's first published table of the elements (1869), elements were listed in order of increasing atomic mass in columns, so that similar elements (e.g., Cl, Br, I) were found in horizontal rows rather than vertical columns. The vertical arrangement of similar elements into element groups appeared two years later, in 1871.
- Although Dmitri Mendeleev is often given top billing in textbook discussions of the development of the periodic table, Lothar Meyer in Germany is credited with independent discovery of the periodic law. In an 1870 paper, Meyer printed a graph of atomic volume versus atomic weight that revealed the characteristic repeating pattern in the properties of elements. In the same paper, Meyer also displayed an arrangement of the elements into a table of rows and columns on the basis of increasing atomic weight. Meyer did not, however, predict the existence of missing or undiscovered elements.

Answers to Review Questions

1. **Ionization energy** — energy needed to remove one of the electrons from an atom (specifically, from an isolated atom in the gas phase). The energy needed to remove successive electrons is called the first ionization energy, second ionization energy, etc. Units are kilojoules per mole (kJ/mole).
2. **Atomic radius** — for a neutral atom, the distance from the center of an atom's nucleus to its outermost electron. Since the electron cloud that surrounds the nucleus does not have an exact boundary, the atomic radius of an atom is not a precise number. The atomic radius is usually estimated as one-half the distance between two atoms in a form of the element—for example, one-half the distance between chlorine atoms in the diatomic chlorine molecule. Units are nanometers ($1\ \text{nm} = 1 \times 10^{-9}\ \text{m}$).
3. **Density** — the ratio of mass to unit volume for the standard form of the element. Units are grams per cubic centimeter (g/cm^3) for a solid or liquid and grams per liter (g/L) for a gas. Density depends on temperature.
4. **Electronegativity** — assigned numerical value for an element that reflects the ability of an atom to attract electron density in a covalent bond. Electronegativity is not an amount of energy, nor can it be directly measured. There are no units for electronegativity; it is assigned on a relative scale from 0.5 to 4.0.
5. **Atomic mass** — also called the average atomic mass; the average mass of an element's atoms. Since the mass of an individual atom is too small to be directly measured, atomic mass is defined relative to that of a reference atom, an arbitrary standard. Thus, the mass of the carbon-12 isotope is defined as exactly equal to 12 atomic mass units. The atomic mass of a particular atom is very nearly, but not exactly, equal to its mass number (number of protons and neutrons). The average atomic mass of an element is computed as a weighted average of the masses of the isotopes that make up the element and their fractional (natural) abundance. The units of atomic mass are atomic mass units (amu).
6. **Melting point** — temperature at which the solid form of an element is in equilibrium with the liquid phase at atmospheric pressure. Usually given in units of kelvin (K).

Teacher's Notes *continued*

Sample Data

"Vertical" Table of the Elements

6.9	*9.0*	*10.8*	*12.0*	*14.0*	*16.0*	*19.0*	*20.2*
23.0	*24.3*	*27.0*	*28.1*	*31.0*	*32.1*	*35.5*	*39.9*
39.1	*40.1*	*69.7*	*72.6*	*74.9*	Missing Element	*79.9*	*83.8*
85.5	*87.6*	*114.8*	*118.7*	*121.8*	*127.6*	*126.9*	*131.3*

"Horizontal" Table of the Elements

6.9	*23.0*	*39.1*	*85.5*				
9.0	*24.3*	*40.1*	*87.6*				
10.8	*27.0*	*69.7*	*114.8*				
12.0	*28.1*	*72.6*	*118.7*				
14.0	*31.0*	*74.9*	*121.8*				
16.0	*32.1*	Missing Element	*127.6*				
19.0	*35.5*	*79.9*	*126.9*				
20.2	*39.9*	*83.8*	*131.3*				

Properties of the Missing Element

Ionization energy *950*	**Atomic radius** *0.12*
Atomic mass *77.4*	**Formula of its oxide** XO_2
Formula of its chloride XCl_2	**Melting point** *600*
Density *4.4*	**Formula of its hydride** XH_2
Electro-negativity *2.6*	

These are the predicted, not actual, properties. Student predictions will, of course, vary.

Answers to "It's in the Cards" Worksheet *(Student answers will vary.)*

1. Mendeleev's Periodic Law can be stated: *"The physical and chemical properties of elements are periodic functions of their atomic masses."* Looking at your arrangement of the element cards, describe in your own words what the term "periodic function" means.

   "Periodic function" means that the properties of the elements repeat in a regular manner (are periodic) and that the cycle for the repeating pattern depends on (is a function of) the atomic masses of the elements.

2. Some of the properties listed on each card are periodic properties, others are not. Name one property that is periodic and one that is not.

   Ionization energy, electronegativity, and atomic radius reveal distinct periodic trends when the elements are arranged in order of increasing atomic mass. Density and melting point show trends, but they are not as obvious. Atomic mass is not a periodic property.

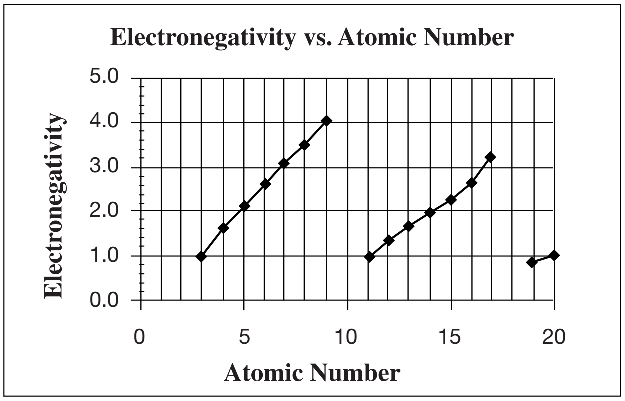
3. The elements in the modern periodic table are arranged in order of increasing atomic number (instead of increasing atomic mass). Why didn't Mendeleev use atomic number to arrange the elements?

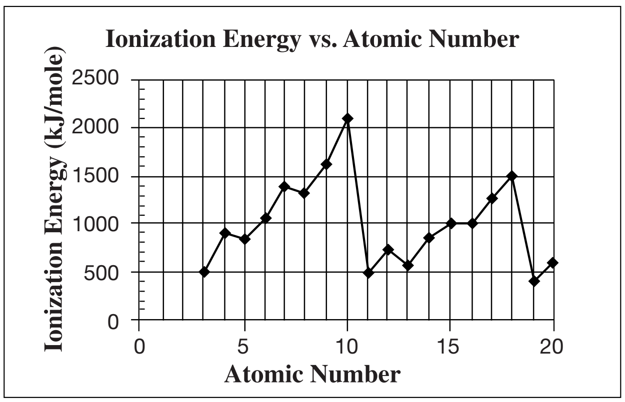
   The concept of atomic number did not exist at the time of Mendeleev. ***Note to teachers:*** *In 1913, the English chemist Henry Moseley, working in Ernest Rutherford's laboratory on the properties of the nucleus, hypothesized that every element had a different amount of positive charge, and that the amount of positive charge occurred in whole-number increments. Moseley introduced the concept of atomic number to account for the positive charge of the nucleus.*

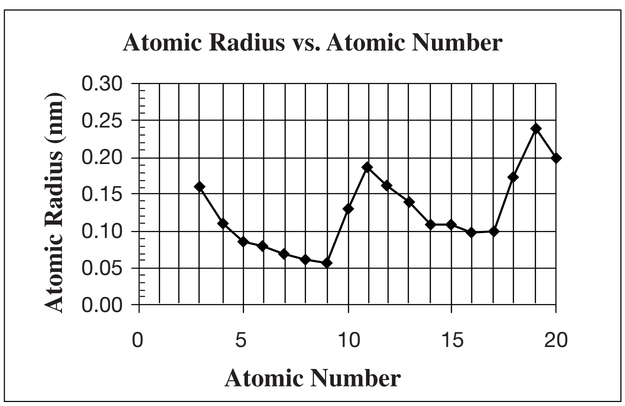
4. From your instructor, obtain a handout showing one possible arrangement of the element cards. Identify each elements on the handout with its *atomic number* and *chemical symbol*. Use your textbook to obtain this information.

   The elements are listed in order from left to right on page 13, in rows according to their periodic number. The transition metals are not included. The atomic numbers of the elements listed are 3–20; 31–38; and 49–54.

5. Using the possible arrangement of the element cards obtained from your instructor, pick two of the numerical properties of the elements that are periodic and plot their values on the graphs below. Give each graph a descriptive title and label the axes.







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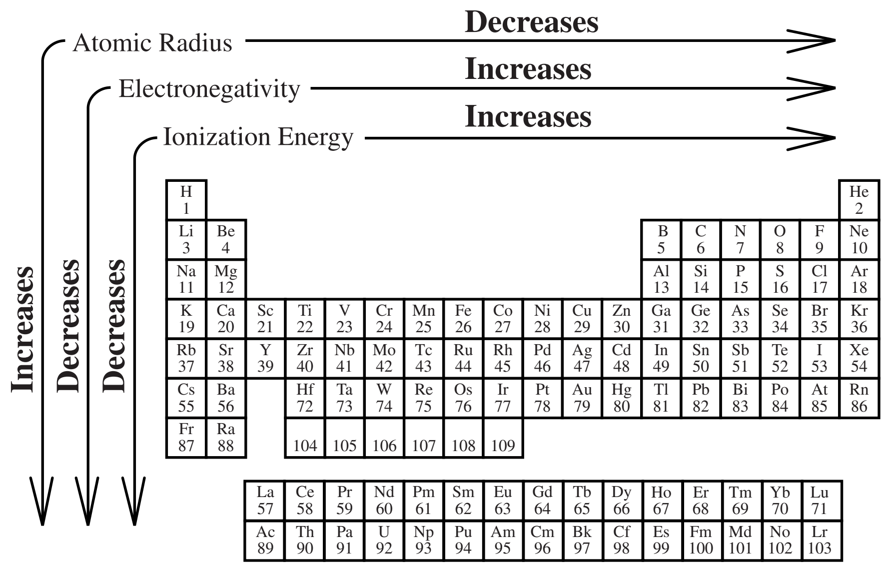
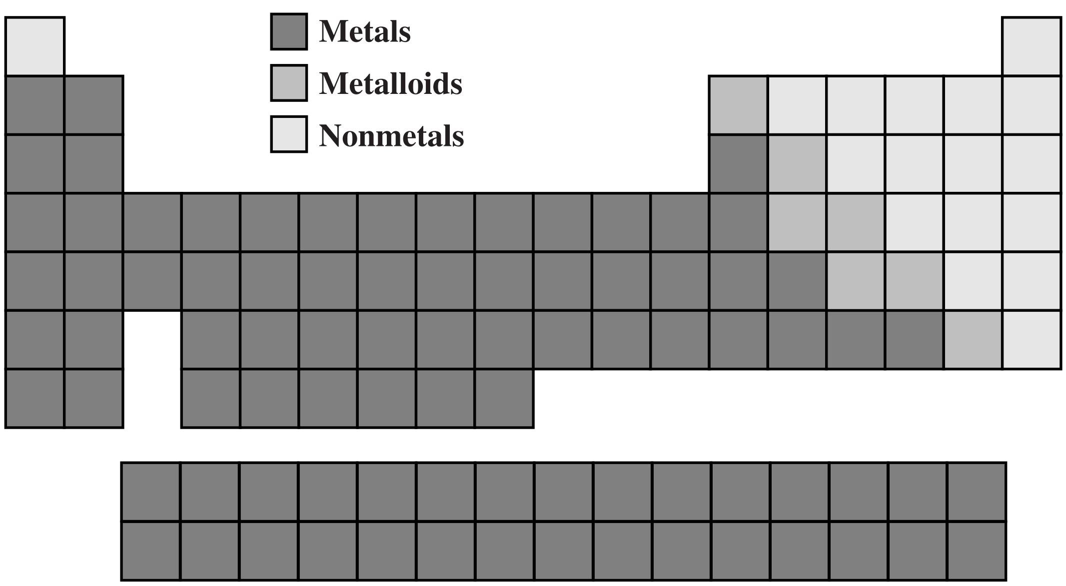
6. There are certain trends in the properties of the elements, both within a column (from top to bottom) and across a row (from left to right) in the periodic table. On the arrow for each property, write the word *increases* or *decreases* to describe how that property changes.

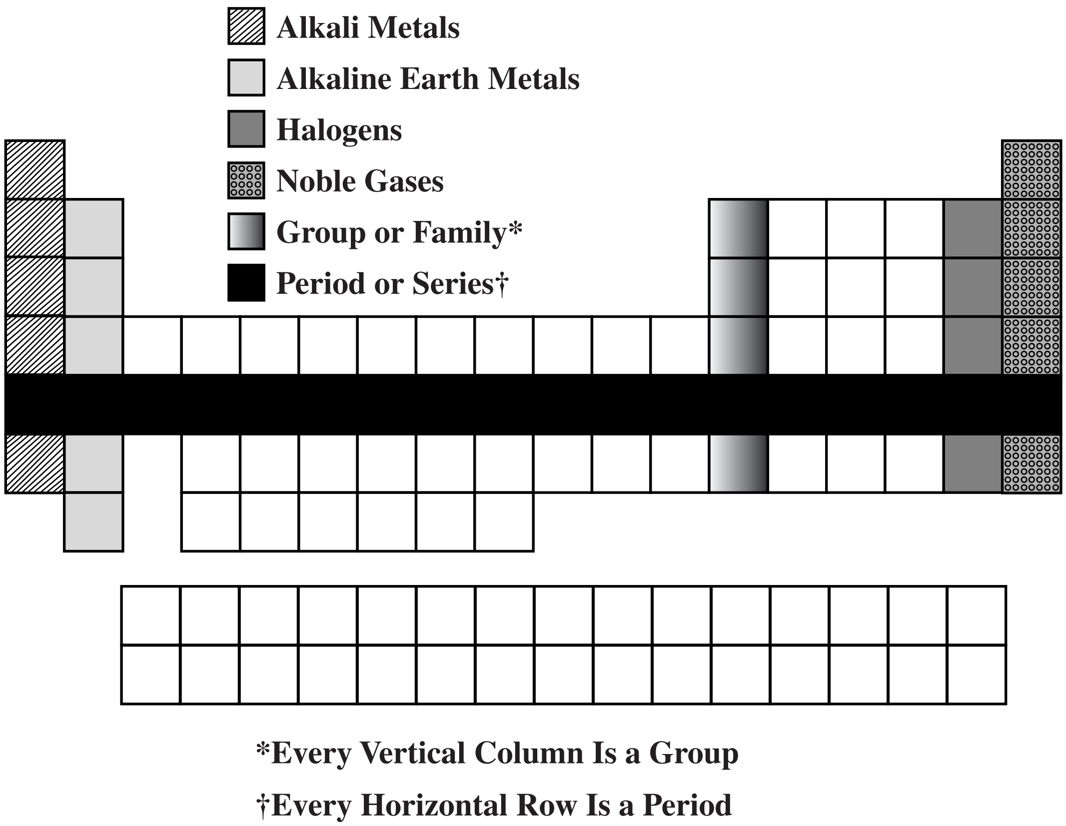


7. On the outline of the periodic table shown below, locate the following: *metals, nonmetals,* and *metalloids* (or semimetals).

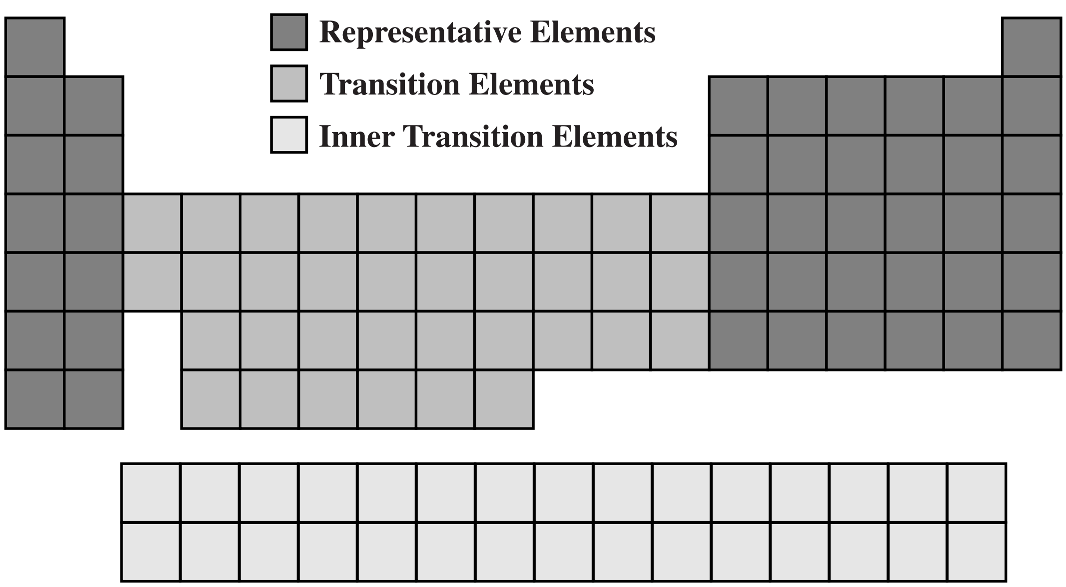


Teacher's Notes *continued*

8. On the outline of the periodic table shown below, locate the following: *groups* or *families* of elements, *periods* or *series* of elements, *noble gases, alkali metals, alkaline earth metals,* and *halogens*.



9. On the outline of the Periodic Table shown below, locate the following: *transition elements, inner transition elements, representative elements*.



Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter
Content Standard G: History and Nature of Science
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter
Content Standard G: History and Nature of Science

It's in the Cards—Student Activity Kit is available from Flinn Scientific, Inc.

Catalog No.	Description
AP6289	It's in the Cards—Student Activity Kit

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Element Card Arrangement Handout

520	0.16	899	0.11	801	.083	1086	.077	1402	.070	1314	.066	1681	.062	2081	0.13
6.9	X_2O	9.0	XO	10.8	X_2O_3	12.0	XO_2	14.0	X_2O_5	16.0	XO	19.0	X_2O	20.2	—
XCl	453.7	XCl_2	1560	XCl_3	2300	XCl_4	4100	XCl_3	63.14	XCl_2	50.35	XCl	53.48	—	24.55
0.53	XH	1.85	XH_2	2.46	XH_3	2.27	XH_4	1.25	XH_3	1.4	XH_2	1.7	XH	0.901	—
0.98		1.57		2.04		2.55		3.04		3.44		3.98		—	
496	0.19	738	0.16	578	0.14	786	0.11	1012	0.11	1000	0.10	1251	0.10	1521	0.17
23.0	X_2O	24.3	XO	27.0	X_2O_3	28.1	XO_2	31.0	X_2O_5	32.1	XO_2	35.5	X_2O	39.9	—
XCl	371.0	XCl_2	922	XCl_3	933.3	XCl_4	1685	XCl_3	317.3	XCl_2	388.4	XCl	172.2	—	83.81
0.97	XH	1.74	XH_2	2.7	XH_3	2.33	XH_4	1.8	XH_3	2.07	XH_2	3.17	XH	1.78	—
0.93		1.31		1.61		1.90		2.19		2.58		3.16		—	
419	0.24	590	0.20	579	0.14	762	0.12	947	0.12			1140	0.12	1351	0.19
39.1	X_2O	40.1	XO	69.7	X_2O_3	72.6	XO_2	74.9	X_2O_5			79.9	X_2O	83.8	—
XCl	336.4	XCl_2	1112	XCl_3	302.9	XCl_4	1210	XCl_3	1081	"Missing		XCl	265.9	—	115.8
0.86	XH	1.55	XH_2	5.91	XH_3	5.3	XH_4	5.72	XH_3	Element"		3.1	XH	3.74	—
0.82		1.00		1.81		2.01		2.18				2.96		—	
403	0.25	549	0.22	558	0.17	709	0.16	834	0.14	869	0.14	1008	0.14	1170	0.21
85.5	X_2O	87.6	XO	114.8	X_2O_3	118.7	XO_2	121.8	X_2O_5	127.6	XO_2	126.9	X_2O	131.3	XO_3
XCl	312.0	XCl_2	1041	XCl_3	429.8	XCl_4	505.1	XCl_3	904	XCl_2	722.7	XCl	386.7	—	161.4
1.53	XH	2.6	XH_2	7.31	XH_3	7.30	XH_4	6.68	XH_3	6.24	XH_2	4.66	XH	5.89	—
0.80		0.95		1.78		1.96		2.05		2.10		2.66		—	

Key

Ionization Energy	Atomic Radius
Atomic Mass	X_bO_c
XCl_a	Melting Point
Density†	XH_d
Electro-negativity	

†Density values are in units of g/cm^3 for solids and liquids and g/L for gases.