EXPERIMENT 11

Periodicity of Chemical Properties

Objective

The astute student can predict chemical behavior for the elements based on their position in the periodic table. In this experiment the student will explore the chemistry of selected elements and discern periodic trends based on graphical analysis of periodic trends.

Introduction

The World Wide Web has many sites which demonstrate the properties of the chemical elements. The following sites are interesting, but there are many others as well. Try them out...

- http://www.webelements.com/ This site has a periodic table and you can click on any element to learn about it. Notice especially here the crystal structures in the right margin. They may be useful.
- http://www.chemeddl.org/resources/ptl This site has a periodic table and you can click on any element to learn about it. It includes information of price of elements. It is an electronic version of the Periodic Table Alive software.
- http://chemcollective.org/applets/pertable.php This site shows the electron configurations of all the elements including the orbital diagrams.
- http://chemicalelements.com/ This site has periodic table with clickable elements to show properties. You can also customize the chart to add different kinds of data under the symbol on the chart. This could be useful for determining trends.
- http://www.chemicool.com/Chemicool/ Another site with elemental data appearing when you click on the element on the periodic table.

Procedure

Graphical Analysis

Investigate one of the following and write a discussion:

1. Graph atomic number versus density;
2. Graph atomic number versus number of isotopes (Is there a relationship between odd and even numbers of protons and neutrons?);
3. Graph atomic number versus atomic radius;
4. Graph atomic number versus boiling point;
5. Graph atomic number versus melting point;
6. Graph atomic number versus heat of vaporization;
7. Graph atomic number versus heat of fusion;
8. Graph atomic number versus hardness;
9. Graph atomic number versus velocity of sound.
10. Graph atomic number versus electronegativity and look for trends in groups 1, 3, 6, and 7;
11. Graph atomic number versus atomic radius for groups 2, 3, 7, and 8 and for periods 2, 3, and 4;
12. Graph second ionization energy for groups 1, 2, 7, and 8 and for periods 2, 3, and 4.

Element Biography

Write a biography of an element of your choosing.

Discussion

For the relationship you investigated write a short report of your findings including the following:

1. Name of the trend you examined.
2. Definition - A short definition of the property you've studied.
3. Summary - The summary should be a brief description of the trend or grouping you observed. Describe the general trend, not every small "glitch" in the trend. A table summarizing your data would be useful here.
4. Graph - The pictorial representation of the trend you examined.
5. Discussion - In this section, you should discuss why the trends you observed behave in the manner illustrated by the programs. For example, if a certain property appears to decrease in value going across a period, you should explain why (in an atomic sense) the value is decreasing. A one or two paragraph discussion per relationship is sufficient.
6. References - You may use any book or journal article as a reference to help write your discussion. However, make sure you give proper credit for this reference at the end of your report. A basic sample report is shown below; the one you write should be more comprehensive.

Sample Report

1. Boiling point for groups 6, 7, and 8.
2. Definition

   The boiling point of a liquid under a given pressure is the temperature at which its vapor pressure is just equal to the applied pressure. The normal boiling point is the temperature at which the vapor pressure of the liquid is equal to exactly one atmosphere of pressure (1).

   A group is a vertical column on the periodic table, which contains elements that have similar chemical properties (2).

3. Summary

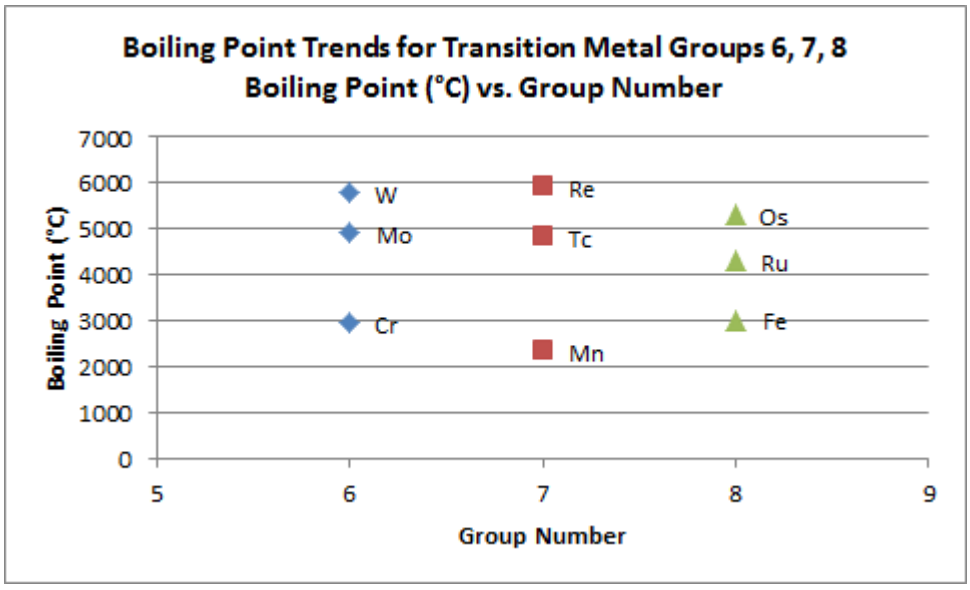
   The boiling points of the elements increase as you go down groups 6, 7 and 8. There is not a regular trend for boiling point across a period.

TABLE 11.1

Element	Group Number	Boiling Point (°C)	Element	Group Number	Boiling Point (°C)	Element	Group Number	Boiling Point (°C)
Cr	6	2963	Mn	7	2333	Fe	8	3023
Mo	6	4923	Tc	7	4840	Ru	8	4823
W	6	5773	Re	7	5923	Os	8	5298
Sg	6	?	Bh	7	?	Hs	8	?

4. Graph

FIGURE 11.1



5. Discussion

   The boiling points of the elements increase as you go down groups 6, 7 and 8. There is not a smooth trend for boiling point across a period. The boiling point depends on two factors: the molar mass of the particles and the cohesive forces holding the atoms or molecules together

making them more difficult to separate into individual gas particles; Going down a group both become greater. Each factor will be discussed separately.

As we go down a group, the size of the atom increases because shells of electrons are added. As the nuclear charge decreases the positive charge felt by the electrons decreases so that electrons are not held as closely to the nucleus increasing the size of the atom. In multi-electron systems there is also a repulsion between electrons, which also slightly increases the atomic size. The boiling point does not follow a trend across a period for transition metals because when electrons are added across a row the d electrons are added to the inner shell (n-1) and do not change the size of the atoms greatly (3).

Cohesive interactions between atoms and molecules (intermolecular forces) increase with increasing size and increasing number of electrons. As you go down a column there are more electrons, causing an increase in the cohesive interactions. Melting involves a change of state from the liquid state to the gaseous state. There are two types of energy involved in changing state: potential energy and kinetic energy. When a substance is in one phase adding energy to the system changes the potential energy, but not the average kinetic energy of the particles. During the change from a liquid to a gas, the temperature remains constant, but the potential energy of the particles in increasing (4). The larger the particle the more cohesive interactions are present, thus, it takes more energy to pull atoms or molecules away from the liquid to the gas phase, which results in a higher boiling point. Across a period the change in cohesive interactions does not change as much resulting in an uneven trend.

6. References

(1) Whitten, Kenneth W., Gailey, Kenneth D., and Davis, Raymond E. General Chemistry 3rd ed. Philadelphia: Saunders College Publishing, 1988, p. 308.

(2) Gilbert, Thomas, Kirss, Rein V., Foster, Natalie, Davies, Geoffrey Chemistry: The Science in Context 2nd ed. New York: W. W. Norton & Company, Inc., 2009, p. A-33.

(3) Gilbert, Thomas, Kirss, Rein V., Foster, Natalie, Davies, Geoffrey Chemistry: The Science in Context 2nd ed. New York: W. W. Norton & Company, Inc., 2009, p. 338-339.

(4) Dahm, Donald J., Nelson, Eric A., Calculations in Chemistry: An Introduction, 1st ed. New York: W. W Norton & Company, Inc. 2013, p. 361.

Post Lab Questions

Answer the questions below:

1. Which elements are
   a. Orange

   b. Yellow

   c. Liquids

2. When were the elements discovered? Using a periodic table color elements discovered between BC and 1600 AD green, elements discovered between 1601 and 1900 blue, and elements discovered between 1901 and the present red.

FIGURE 11.2

IA												IIIA	IVA	VA	VIA	VIIA	NOBLE GASES
1 H 1.008	IIA															1 H 1.008	2 He 4.002
3 Li 6.941	4 Be 9.012					Transition Metals						5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 23.00	12 Mg 24.30	IIIB	IVB	VB	VIB	VIIB		VIIIB		IB	IIB	13 Al 27.00	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.70	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (99)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.0	89 Ac 227.0	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (268)	110 Ds (271)	111 Rg (272)	112 ?? (???)	113 ?? (??)	114 ?? (??)	115 ?? (???)	116 ?? (???)		118 ?? (???)

Lanthanide series	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (147)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
Actinide series	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

3. Which element derives its name from the German word Kobald meaning goblin?

4. Which element is a commonly found element which forms a green gas in its elemental state? This gas is extremely toxic and can be fatal at concentrations of less than 1000 ppm.

5. This element forms an interesting allotrope called Buckminster fullerene. Which element is Buckminster fullerene composed of and how did this allotrope get its name?

6. Many gemstones are composed of aluminum compounds. When this element is present in trace amounts in beryl or beryllium aluminum silicate it forms emeralds. When this element is present in corundum or aluminum oxide it forms rubies. What is this element?

7. Which element is a solid at room temperature, but will melt when held in your hand (37 °C)? This element was named after a chicken because it was discovered by Paul-Emile Lecoq. And has highest spread between MP and BP!

8. This element was named from the Greek word “iris” meaning rainbow because of the colorful compounds it tends to form.

9. What element forms the most dense elemental liquid known?

10. What primary elements are added to iron to make stainless steel?

11. What element is dephloginisticated air missing?

12. How was plutonium first synthesized?

13. What radioactive gas sometimes accumulates in houses built in regions with lots of uranium in the ground? How does the color of this gas change as it is cooled below its freezing point?

14. What element common to computers is found at the beach?

15. What element has the highest melting point and the lowest vapor pressure of all metals?

16. What element has the highest electrical and thermal conductivity of all metals? Would this element be good for making cooking pots? Why or why not? Would this metal be good for making electrical connectors? Why or why not?

17. What is an allotrope? Identify the major allotropes of carbon and phosphorus.

18. Zirconium and hafnium occur together in nature. It is ever so difficult to obtain the pure elements.

a. Why do you think this is so?

b. If you had two ingots of equal size, one Hf and the other Zr, how could you determine which is which?

19. A mystery element is expensive because it is not readily available on the surface of the earth. It has a high density and can be scratched by glass and iron. It can be melted in a chromium or vanadium crucible. It forms the chloride MCl_3. Predict the identify of the mystery element and state your reasons for making this conclusion.

20. Copper is used for electrical wiring. If copper became scarce, what element would make the best substitute? Explain your reasoning.

21. Answer the questions below using a plot of ionization energy versus atomic number.

a. Define ionization energy.

b. Explain why the ionization energy increases from Al to Ar.

c. Explain why there is a decrease in ionization energy from Mg to Al.

d. Explain why the ionization energy of S slightly lower than P when we would expect it to be higher based on the general trend.

e. Explain why there is a decrease in ionization energy form Zn to Ga.

22. Answer the questions below using plots of electron affinity for groups IA, IIIA, and VIIA.

a. Define electron affinity.

b. Explain why the electron affinities for groups IIA and VIIIA are ~0 kJ/mol.

c. Explain why the electron affinities for group VIIA is so high compared to the other groups.

d. Explain why the electron affinity for F is less than for Cl.