

It's in the Cards

Discovering the Periodic Law

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 great discovery, it is worthwhile to go back in time and look at how it was achieved. What did Mendeleev know and when did he know it?

Concepts

- Periodic law
- Atomic mass
- Periodic table
- Ionization energy

Background

In the years 1868–1870, Dmitri Mendeleev, a professor of chemistry at the University of St. Petersburg in Russia, was intent on writing a new textbook of chemistry, called *Principles of Chemistry*. More than 60 individual elements were known, and a great many facts had been discovered about their properties and compounds. Mendeleev knew the atomic masses of the elements, their densities, boiling points, melting points, the formulas of their compounds with hydrogen, oxygen, and chlorine, and many other isolated facts. 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 is translated from Mendeleev's first published report of the periodic law:

"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 systematically 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 important 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*.

Experiment 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.

Pre-Lab Questions

The element cards list all of the following properties for each element. Use your textbook to write a clear definition of each property. Give the typical units for each numerical property, if appropriate.

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

Materials

Special deck of 31 element cards

Procedure

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

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	Ionic Charge

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

3. Working in a collaborative manner, 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 following questions:
 - What are the similarities and differences among the elements?
 - Are there any 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 courage 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 Data Sheet, 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 (in any direction). On the Data Sheet, complete the card for the missing element by entering its predicted properties alongside the name of each property.

Do these
on
page
#4

Name: _____

Class/Lab Period: _____

It's in the Cards Data Sheet

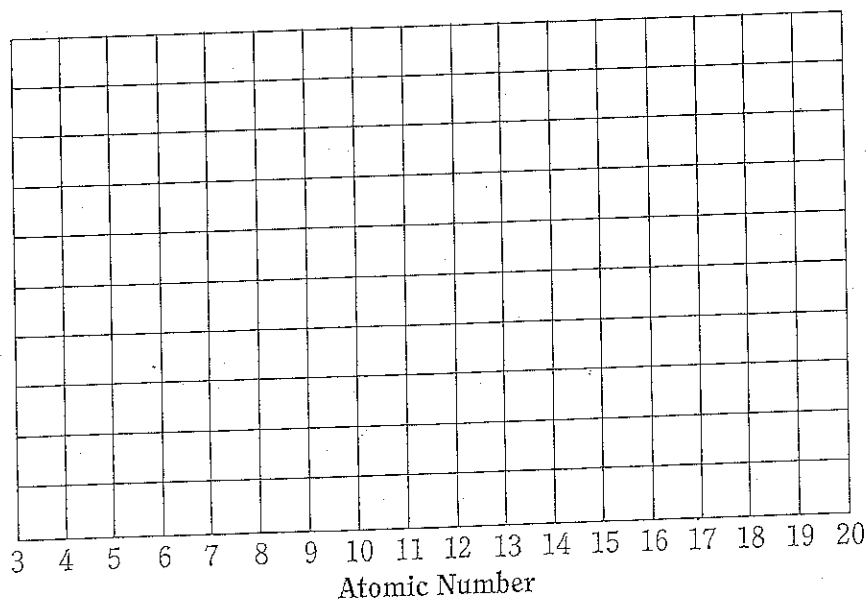
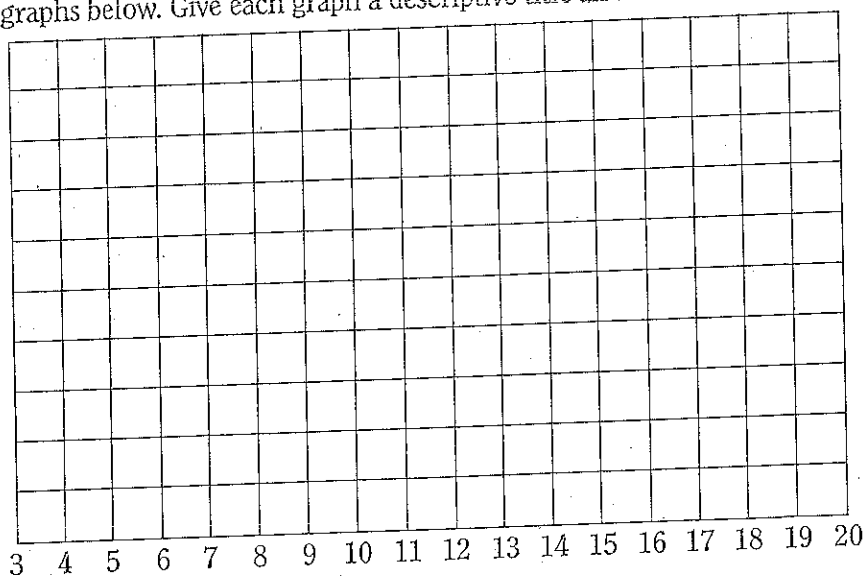
Table of the Elements (

Properties of the Missing Element : Your Predictions (#7)

Ionization energy =	Atomic radius =
Atomic mass =	Formula of its oxide =
Formula of its chloride =	Melting point =
Density =	Formula of its hydride =
Electronegativity =	Ionic Charge =

Post-Lab Questions (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 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 of the elements on the handout with its *atomic number* and *chemical symbol*.
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.



* Cut these cards out

3	520	0.16	899	0.11	801	.083	1086	.077
—	6.9	X ₂ O	9.0	XO	10.8	X ₂ O ₃	12.0	XO ₂
5	XCl	453.7	XCl ₂	1560	XCl ₃	2300	XCl ₄	4100
—	0.53	XH	1.85	XH ₂	2.34	XH ₃	2.62	XH ₄
0	0.98	+1	1.57	+2	2.04	+3	2.55	NA
7	496	0.19	738	0.16	578	0.14	786	0.11
—	23.0	X ₂ O	24.3	XO	27.0	X ₂ O ₃	28.1	XO ₂
1	XCl	371.0	XCl ₂	922	XCl ₃	933.3	XCl ₄	1685
—	0.97	XH	1.74	XH ₂	2.7	XH ₃	2.33	XH ₄
>	0.93	+1	1.31	+2	1.61	+3	1.90	NA
9	419	0.24	590	0.20	579	0.14	762	0.12
—	39.1	X ₂ O	40.1	XO	69.7	X ₂ O ₃	72.6	XO ₂
8	XCl	336.4	XCl ₂	1112	XCl ₃	302.9	XCl ₄	1210
—	0.86	XH	1.55	XH ₂	5.91	XH ₃	5.3	XH ₄
0	0.82	+1	1.00	+2	1.81	+3	2.01	NA
1	403	0.25	549	0.22	558	0.17	709	0.16
3	85.5	X ₂ O	87.6	XO	114.8	X ₂ O ₃	118.7	XO ₂
4	XCl	312.0	XCl ₂	1041	XCl ₃	429.8	XCl ₄	505.1
—	1.53	XH	2.6	XH ₂	7.31	XH ₃	7.30	XH ₄
0	0.80	+1	0.95	+2	1.78	+3	1.96	NA

1402 .070 14.0 X_2O_5 XCl_3 63.14 1.25 XH_3 3.04 -3	1314 .066 16.0 XO XCl_2 50.35 1.4 XH_2 3.44 -2	1681 .062 19.0 X_2O XCl 53.48 1.7 XH 3.98 -1	2081 0.13 20.2 — — 24.55 0.901 — — 0
1012 0.11 31.0 X_2O_5 XCl_3 317.3 1.8 XH_3 2.19 -3	1000 0.10 32.1 XO_2 XCl_2 388.4 2.07 XH_2 2.58 -2	1251 0.10 35.5 X_2O XCl 172.2 3.17 XH 3.16 -1	1521 0.17 39.9 — — 83.81 1.78 — — 0
947 0.12 74.9 X_2O_5 XCl_3 1081 5.72 XH_3 2.18 -3	"Missing Element"	1140 0.12 79.9 X_2O XCl 265.9 3.1 XH 2.96 -1	1351 0.19 83.8 — — 115.8 3.74 — — 0
834 0.14 121.8 X_2O_5 XCl_3 904 6.68 XH_3 2.05 -3	869 0.14 127.6 XO_2 XCl_2 722.7 6.24 XH_2 2.10 -2	1008 0.14 126.9 X_2O XCl 386.7 4.92 XH 2.66 -1	1170 0.21 131.3 XO_3 — 161.4 5.89 — — 0