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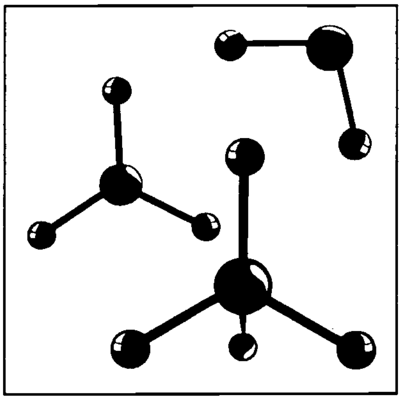
IDENTIFIERS	*Periodic Table

ABSTRACT

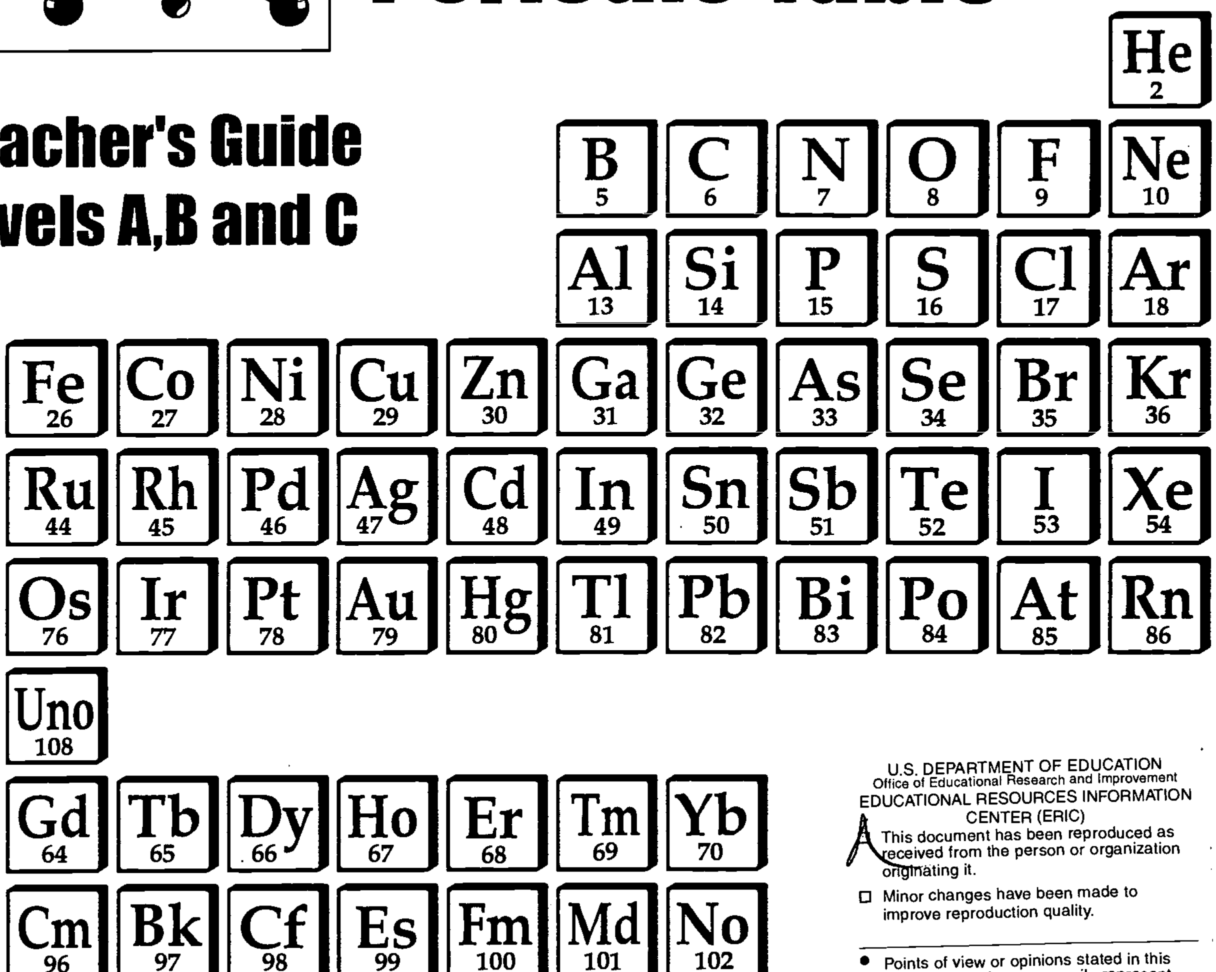
This is a two-part curriculum package for the teaching of chemistry and the periodic table. The first part, the Teacher's Guide, contains information necessary for using the equipment in a typical classroom including learning goals, vocabulary, math skills, and sample data for each activity. The second part of the package consists of photocopy masters for a set of student activity guides, a cut-and-paste quiz builder, and scoring rubrics for assessment of those activities. The photocopy masters are designed for copy and use in the classroom. Most of the experiments have two skill levels to accommodate students from a wide range of grades and abilities. Level A activities are intended to introduce the periodic table and enough key concepts for students to be able to read useful information off of it. The concept of valence is introduced but not explained. Using charts of the valences of the elements, students will make simple molecules and then learn how to balance chemical equations. Level B activities differ from Level A in the introduction of electron shells and the explanation of valence. The Activity Guides are written to provide a framework for encouraging students to observe and learn science process skills as well as content. (PVD)

Cambridge
CPO
Physics Outlet



Chemistry and the Periodic Table

Teacher's Guide
Levels A,B and C



PRELIMINARY LIMITED EDITION

The CPO Curriculum Package

This curriculum package has two parts. The first part is the **Teacher's Guide**, which includes information necessary for using the equipment in a typical classroom. The second part of the package consists of a photocopy masters for a set of **Student Activity Guides**, a cut and paste **Quiz Builder**, and **Scoring Rubrics** for assessment of the Activities. These photocopy masters are designed to be copied and used in the classroom.

Most of the experiments have three skill levels to accommodate students from a wide range of grades and abilities.

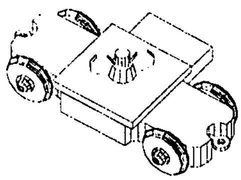
Teacher's Guides

- An elementary review of key concepts to be used in the experiment
- Experimental techniques, measuring tips, and equipment maintenance
- Learning goals for each level
- Vocabulary for each level
- Math skills checklists for each level
- In-depth reference, with a review of mathematical techniques and derivations
- Detailed discussion of answers and lab results for each Activity Guide
- Detailed discussion of Assessment questions and derivations of answers

Photocopy Masters

- Classroom ready Activity Guide worksheets
- Self guiding illustrated set up and procedure for hands-on activities
- Includes writing space, discussion questions, graph paper, and data tables
- Activity Guides can be collected for portfolio/performance assessment
- Customizable cut and paste Quiz Builder
- Scoring Rubrics for weighted assessment of each Activity

Level A
Suggested Curriculum Sequence



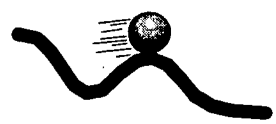
Motion
Speed
Acceleration

1

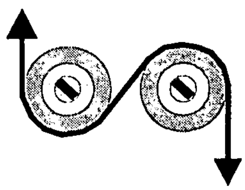
CAR AND RAMP

2

Energy
Speed
Graphing



ROLLERCOASTER



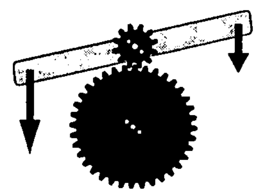
Simple Machines
Force
Work
Energy

3

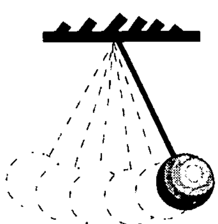
ROPES AND PULLEYS

4

Simple Machines
Angles
Rotation
Work



GEARS AND LEVERS

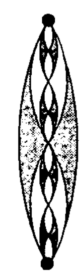


5

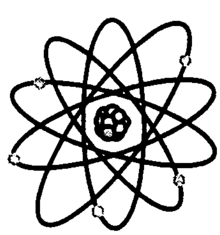
Harmonic Motion
Time, Frequency, and Period

PENDULUM

6 Sound and Music



SOUND AND WAVES



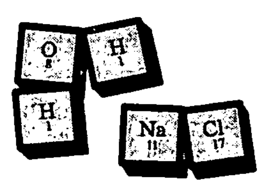
Atomic Structure
Electrons, Protons,
and Neutrons

7

ATOMIC BUILDING GAME

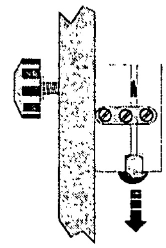
8

The Elements
Chemical Equations



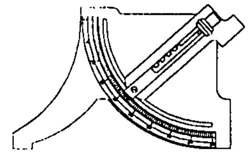
PERIODIC PUZZLE

Level B
Suggested Curriculum Sequence



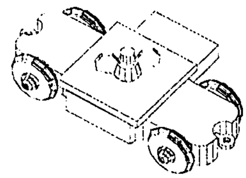
GRAVITY DROP

① Motion in a Line
Speed and Acceleration
Graphing



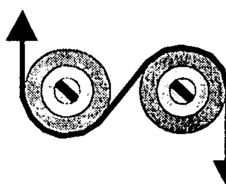
MARBLE LAUNCHER

② Vectors and Trigonometry
Motion in a Plane



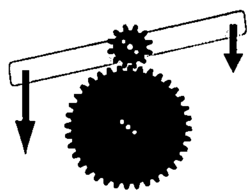
CAR AND RAMP

③ Force and Newton's Laws
Uniform Acceleration
Multiple Variables



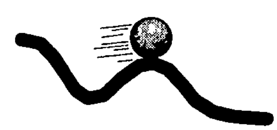
ROPES AND PULLEYS

④ Simple Machines
Work and Energy



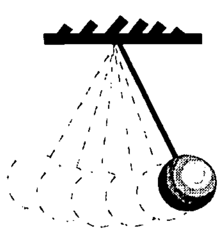
GEARS AND LEVERS

⑤ Circular Motion
Rotating Machines
Angles, Degrees, and Radians
Torque



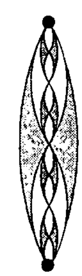
ROLLERCOASTER

⑥ Conservation of Energy



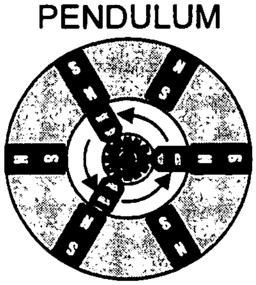
PENDULUM

⑦ Harmonic Motion
Time, Frequency, and Period



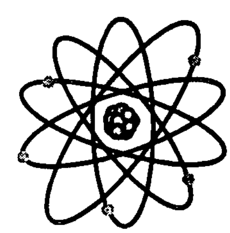
SOUND AND WAVES

⑧ Sound and Music
Frequency and Wavelength



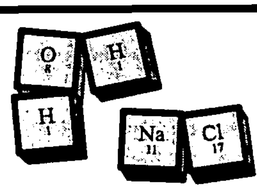
ELECTRIC MOTOR

⑨ Electricity and Magnetism



ATOM BUILDING GAME

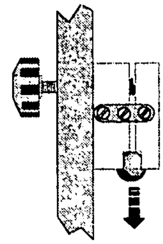
⑩ Atomic Structure,
Bonding and Valence,
Atoms, Ions, and Isotopes



PERIODIC PUZZLE

⑪ The Elements
Chemical Equations

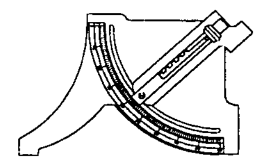
Level C
Suggested Curriculum Sequence



GRAVITY DROP

1

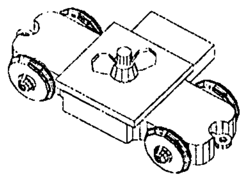
The Acceleration of Gravity
Uniform Accelerated Motion in One Dimension



MARBLE LAUNCHER

2

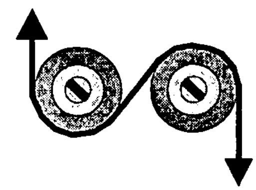
Vectors and Trigonometry
Accelerated Motion in a Plane



CAR AND RAMP

3

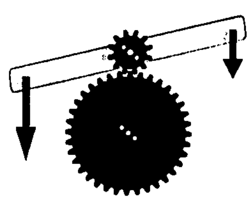
Force and Newton's Laws
Friction
The Physics of the Inclined Plane



ROPES AND PULLEYS

4

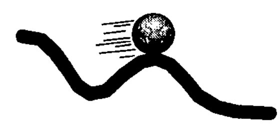
Simple Machines
Work and Energy



GEARS AND LEVERS

5

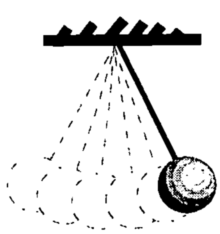
Circular Motion
Rotating Machines
Angles, Degrees, and Radians
Torque



ROLLERCOASTER

6

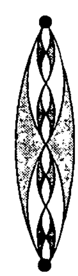
Kinetic and Potential Energy
Conservation of Energy
Rotation



PENDULUM

7

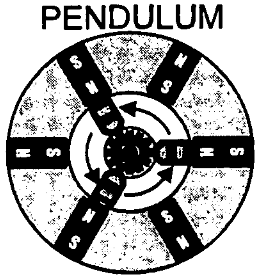
Harmonic Motion
Time, Frequency, and Period



SOUND AND WAVES

8

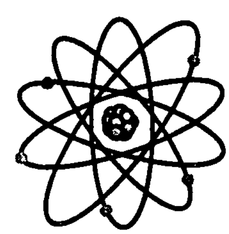
Harmonic Motion
Resonance
Frequency and Wavelength
Interference



ELECTRIC MOTOR

9

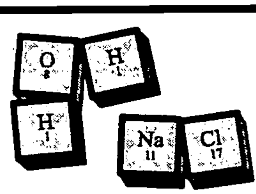
Simple Electric Circuits
Magnetism
Work and Energy



ATOM BUILDING GAME

10

Valence and Bonding
Atoms, Ions, and Isotopes
Atomic Spectra and Lasers
Radioactive Decay



PERIODIC PUZZLE

11

Valence
Chemical Equations

Organization of the Teacher's Guide

The **Reference** chapter provides a deeper level of background, especially the mathematical tools used in the activities.

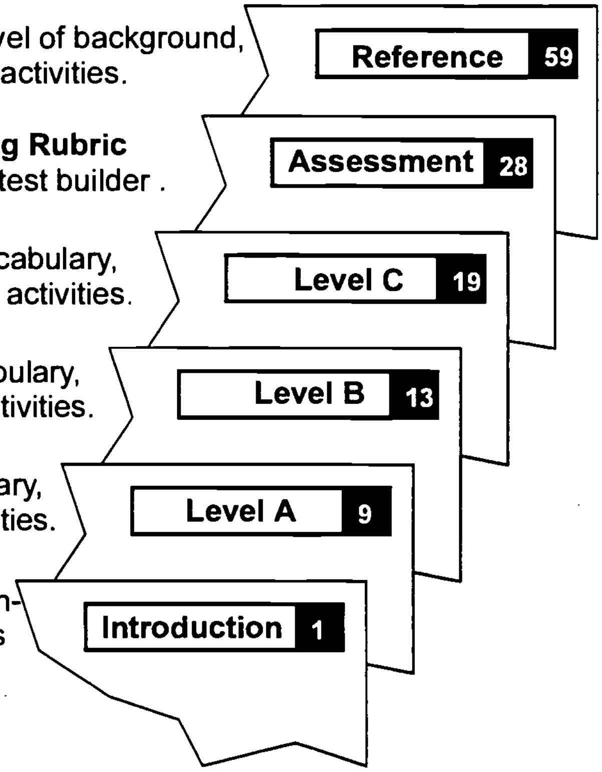
The **Assessment Package,** together with the **Scoring Rubric** and **Quiz Builder Masters,** provides a customizable test builder .

The **Level C** chapter presents Learning Goals, Vocabulary, Math Skills, answers, and sample data for Level C activities.

The **Level B** chapter presents Learning Goals, Vocabulary, Math Skills, answers, and sample data for Level B activities.

The **Level A** chapter presents Learning Goals, Vocabulary, Math Skills, answers, and sample data for Level A activities.

The **Introduction** chapter gives a review of the key concepts used in the experiment, and detailed descriptions of the set up, use, and maintenance of the equipment.



Organization of the Photocopy Masters

Photocopy Masters of **Activity Guides, Scoring Rubrics**, and **Quiz Builders** are included at the end of the Teacher's Guide. The sections are identified by the legend in the page footer. Activity guides are further identified by the square icon in the upper right corner.

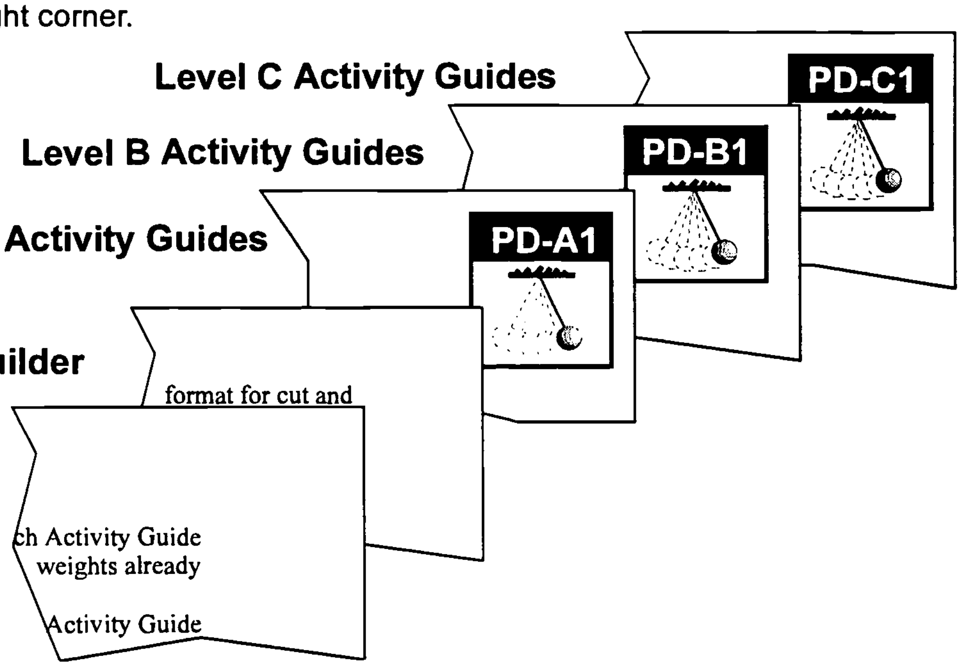
Level C Activity Guides

Level B Activity Guides

Level A Activity Guides

Quiz Builder

Scoring Rubrics



Student Activity Guides

The **Activity Guides** are comparable to classroom lab procedures and are meant to provide a structure for guiding the students' exploration through a particular experiment. Activity Guides are provided at up to **three skill levels** which differ in both language and content. The table below provides an overview of the three levels and the approximate grade range for which each is intended. Please note that the grade ranges are only approximate. Which level you use is dependent on the skill set and motivation of your students.

Level A **Introductory level for late elementary or middle school** ***(Grades 5-9)***	• Learn to be comfortable with numbers and measurements, and analytical thinking • Practice using simple mathematical tools, such as multiplication, division, and ratios without formal mathematical language (i.e. no equations) • Explore key concepts such as speed, force, and work • Develop qualitative understanding of concepts through observation of patterns in measurements
Level B **Advanced middle school, introductory high school level** ***(Grades 8-12)***	• Use measurements to discover quantitative rules of nature • Extend mathematical tools to introductory algebra, simple geometry, functions such as square roots, discussion of errors, and more complex graphing skills • Develop inquiry based scientific method, including quantitative testing of theory against measurement
Level C **High school physics, basic (non-calculus) college physics.** ***(Grades 10-College)***	• Emphasis on rigorous deduction of physical laws through experimental and theoretical analysis • Emphasis on problem solving and extending concepts learned to complex experimental situations • Mathematical tools include trigonometry, algebra, geometry, and ideas from calculus (although no calculus)

Using the Three Levels

The three level curriculum can be effectively used in many different ways. Science and math learning can be **vertically integrated** with common basic equipment. The same student may see the Periodic Puzzle in middle school at Level A, and again in high school at Level B or C. As the student's skills grow, the same familiar equipment can be used to reach deeper comprehension. This process is akin to a child using a crayon to learn to draw and an adult artist using the same crayon in a much more sophisticated manner.

Multiple level learning works between grades, but also within a single grade/classroom. The graduated skill levels encourage quicker learners to move on to more advanced exploration. Slower learners can succeed at basic levels, with each group working at a challenging but comfortable pace. With today's heterogeneous school population the ability for **groups** to **progress independently** is crucial to providing an exciting and fulfilling learning environment.

The Level A activities are complete in that they cover the chosen topics with the Level. The Activities were designed to meet national and state frameworks for math and science for the later elementary and middle school grades. *Students may need calculators.*

Level B was designed for the advanced middle school class or introductory high school course. Level C is appropriate for high school physics or elementary college work. **The B and C Levels are not independent, but together form a consistent progression from basic observation to complex analysis.** In many cases the Level C activity assumes that Level B has been completed by the student. Students with high aptitude in math and science may progress from Level B to Level C within the same class without repeating the same material twice.

The Activity Guides are written to provide a framework for encouraging students to observe and learn process skills as well as content. We expect (and hope) that your classroom activities will go beyond our programmed Guides. The Activity Guides should be considered a foundation on which your students will erect a house of understanding. The house will be shaped differently for each student. Some will be grandly constructed with much detail, and others will be simple. In all cases, however, the student's exploration should not be stopped at the foundation. If you develop a novel way to use the materials, please let us know; we can then share your discovery with other teachers.

Using the Periodic Puzzle Activities

The heart of the Chemistry Curriculum package is the set of **Activity Guides**. The photocopy masters of these activities are at the end of this package, and should be copied and distributed (one per student) to accompany the hands-on activity. Chapters 2, 3, and 4 of this package comprise the **Teachers Guides** for the level A, B, and C activities. The Teacher's Guide presents the learning goals, vocabulary, math skills, and sample data for each activity, as well as some sample answers (and errors) for the activity questions. The content of each activity is summarized below:

LEVEL A

Level A consists of three activities and two games. The activities are intended to introduce the Periodic Table and enough key concepts for the students to be able to read useful information off of it. The concept of valence is introduced, but not explained. Using charts of the valences of the elements, the students will make simple molecules, then learn how to balance chemical equations.

Activity A1: The Periodic Table

In this activity, the students will build the Periodic Table from the Periodic Puzzle blocks. The purpose is to familiarize them with: the elements, the shape of the Periodic Table, the sequence of atomic numbers, and the idea that the Periodic Table reminds us of chemical similarities. Several key concepts, such as elements, compounds, atoms, and molecules are introduced.

Activity A2: The Families of Elements

The second activity starts by defining additional properties of elements: mass and valence. For this purpose, protons and neutrons are briefly introduced (full lessons on the structure of the atom can be found in the Atom Building Game activities). We now have enough knowledge to read the Periodic Table, so now we try using what we know to make simple molecules. We use the valence of elements to figure out how to combine them together, and work through water (**H_2O**). A few other simple (and hopefully familiar) molecular compounds are introduced

Activity A3: Chemical Reactions

This activity is a superb hands-on experiment in chemistry (without getting wet). Chemical reactions are introduced, and the Periodic Puzzle blocks are used to show that reactions **rearrange** the atoms in the reactants to make the products; the atoms aren't changed, and atoms can't be taken away or added. This is a powerful demonstration of a concept that is traditionally difficult for some students. The combination of algebraic, problem solving, and chemistry skills that must be used to solve chemical equations are easily visualized by manipulating the blocks.

GAMES

There are two games in the Periodic Puzzle curriculum. These are great activities for reinforcing the lessons learned in the traditional activities. The rules of the games are contrived to build the students' intuition while they have fun. These games can be played by Levels A, B, and C students, but should be played after completing the appropriate activities.

Activity G1: Element Bingo

This is a simple game, similar to traditional bingo. The students will gain familiarity with the element names and symbols while having fun. Element Bingo can be played by the entire class with only one set of Periodic Puzzle blocks.

Activity G2: Molecular Crossword

This is a more challenging game; it requires and reinforces knowledge of valence and molecular bonding, and rewards students for grasping the concepts of Groups of similar elements in the Periodic Table. The students take turns adding to a crossword pattern of molecules. They must form complete molecules that satisfy the valence properties of the atoms to score. Most of the blocks in the Periodic Puzzle set are arranged with elements from one Group on the different faces of each block -- the students should quickly realize that if they can make a familiar compound with blocks they have available, like salt (**NaCl**), then they can make a higher-scoring compound from the same two blocks by using different faces of the same blocks (i.e. **CsI**).

LEVEL B

Level B consists of five activities and two games. The activities are intended to introduce the Periodic Table and enough key concepts for the students to be able to read useful information off of it.

Level B differs from Level A mostly in the introduction of electron shells and the explanation of valence. In Level A, valence is introduced as a tool, but only read off of charts. In Level B, electron shells are introduced, and the Periodic Table is more minutely examined as we look at the details of the electronic structure of the atom. We also include a "tour" of the Periodic Table, to introduce the common Groups (or columns) of elements. The first and last activities of Level B are essentially the same as the first and last of Level A (build the Periodic Table, and balance chemical equations). The depth of understanding between them comprises most of the difference.

Activity B1: The Periodic Table

In this activity, the students will build the Periodic Table from the Periodic Puzzle blocks. This activity is essentially the same as Activity A1.

Activity B2: Valence and the Families of Elements

We start by introducing additional concepts of atomic structure (protons, neutrons, electrons), and define atomic mass, isotopes, and valence. We then look at the rules for how atoms are built, concentrating on the electron shells. We see that each row of the Periodic Table represents another filled shell. We finish by applying what we learned about valence to build an atom from hydrogen and oxygen (to make water), and by exploring a few other common molecules.

Activity B3: A Tour of the Periodic Table

We now explore the *columns* of the Periodic Table. Each column has elements that share similar chemical properties. We explore some of those properties, and how elements from different columns mix and match to make molecules. Most of this chapter builds "cultural understanding" of the family of elements. We cover only the more common elements in this activity, and leave the more difficult ones for the next activity.

Activity B4: Orbital Names and the Transition Elements

The chemical properties of the transition elements cannot be understood using our simple model of valence. We must look into the order that electrons fill the shells. For this, we define the different types of electron shells (*s, p, d, and f*) and revisit the rules for building atoms. This forms a consistent picture with the simpler model we used through the last activity, but has enough depth to explain the chemical properties of the transition elements. We then continue our tour of the Periodic Table to cover all the weird elements (transition elements, Lanthanides, Actinides, man-made elements, etc.).

Activity B4 is more difficult than the others in Level B. It may be skipped without problems, since Activity B5 does not require any knowledge from B4.

Activity B5: Chemical Reactions

In this activity, the students manipulate the Periodic Puzzle blocks to balance chemical reactions. This Activity is essentially the same as Activity A3. It is a good way for students to visualize what is traditionally a difficult topic, and should not be skipped (even if some previous Activities are).

Contents

Chapter 1 Introduction

Section 1.1: The Development of Chemistry

Chemistry as a modern science arose from many strands of inquiry. Healers and practitioners of early medicine, Alchemists seeking to turn lead into gold, and metallurgists looking for better materials all were major contributors. Elements are the simplest substances and atoms are the smallest unit of an element. Compounds are mixtures of elements bonded together in specific ratios of elements, and molecules are the smallest unit of a compound.

From Aristotle to Alchemy

People have always been curious about what the world is made from. Some substances seem to last forever, unaltered by fire, water, or exposure to air. Other substances change, such as wood burning into ashes. The material world displays a huge variety of different materials: wood, gold, flesh, rocks, water, salt, etc. The list is endless. To make things even more confusing many materials either came from, or could be turned into other materials. Plants grow from soil and water. Wood burns into ashes, smoke, and water. Animals grow from food and water. If one material could be transformed into another the early philosophers reasoned (correctly) that the materials we knew were themselves made up of simpler materials. The simple materials which were the building blocks of the world were called **elements.**

By definition an element is a pure substance. Elements have the defining property that they cannot be broken down into simpler substances. Elements are pure and fundamental. Other materials can be made from combinations of elements, but the elements themselves are the most basic building blocks. This definition of an element is still correct today as it was when written down by Aristotle (384-322 BC), more than two thousand years ago.

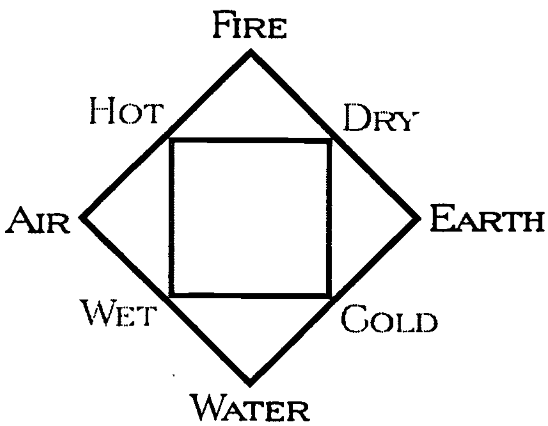


Figure 1.1: The first attempt break materials down into fundamental elements included only four elements: Air, Fire, Earth, and Water. The four elements also gave rise to four properties: Hot, Dry, Wet, and Cold. According to Greek philosophy all materials were different mixtures of the four elements.

The first conception of the elements included only four: Air, Earth, Fire, and Water (figure 1.1). These were the elements of the Greeks. This simple list seemed to explain what was observed. Wood when burned was known to give off fire, smoke, water, and ashes. The smoke was a mixture of fire and air, the ashes were earth. Thus, wood could be shown to be made up of these four simple elements. Each different substance known to the ancient peoples could similarly be understood in terms of this model. The difference between wood and stone would be explained by the proportion of the different elements contained. Stone had more earth than water, air, or fire. The composition the observed variety of materials was a matter of relative proportion of the four basic ingredients in the recipe.

Over the centuries separating the Greek philosophers from the scientific thinkers of the enlightenment the science of chemistry evolved along many paths. As was typical of the early growth of knowledge, inquiry and discovery proceeded in fits and starts among thousands of artisans and practitioners in little shops and laboratories scattered across Europe, China, Japan, and Arabia. These early experimentalists communicated with each other only rarely, and if fortunate, passed on their knowledge to their children. Once in a great while something was written down and to become a treasured and sought after volume by all who came after.

One strand of development was tied to medicine and the mysterious effects of potions, herbs, and salves. The knowledge of, and proper preparation of medicines was a highly valued art and the principal occupation of "magicians" and court philosophers.

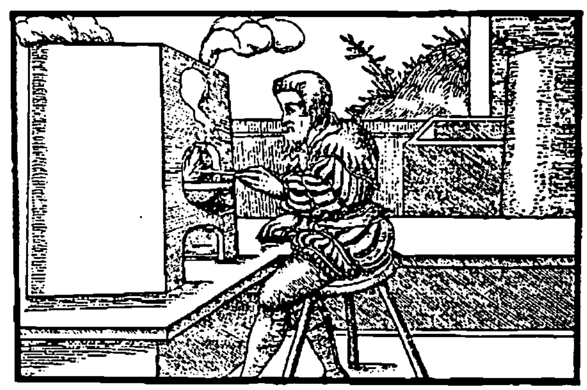


Figure 1.2: Medieval alchemists seeking the formula for turning lead into gold were among the early contributors to the body of art and knowledge that would later become the science of chemistry.

A second thread of inquiry was the transmutation of the elements, and specifically the turning of lesser metals into gold. It was reasoned that if all metals were composed of the four elements then it should be possible to take lead (for example) and add or subtract something to get the correct mixture for gold. It did not help matters that most people of the time could not distinguish between what looked like gold (such as "fools gold" or iron pyrite) and what was truly gold, the pure elemental metal. The pursuit of the

Philosopher's Stone[1] was the primary focus of the so called "alchemists" and their quest generated a huge body of experimental knowledge and skills during the middle ages.

Finally, a third thread in the development of chemistry was the invention and production of practical materials, such as bronze, iron, and steel. The arts of the metallurgist were of prime importance in the technological advances that ushered in the enlightenment bringing civilization. out of the dark ages and into what would become the industrial revolution.

The birth of modern quantitative chemistry is often associated with Antoine Lavoisier (1743-1794) who correctly identified oxygen and the process of combustion. Lavoisier introduced carefully controlled weighing and was able to provide chemistry with a solid quantitative foundation that could serve as a footing for those who followed.

[1] The Philosopher's Stone was the secret for making gold from other materials.

Elements, Molecules, Compounds, and Atoms

The search for the fundamental nature of matter was vigorously pursued through out the age of enlightenment, as it is still pursued today. We count over 108 elements today, quite an increase over the four postulated by Aristotle. Each element is a **pure substance**, something that is not made up of other, simpler substances. Hydrogen and Oxygen are two examples of elements. Neither can be broken down into simpler substances[2].

Most common materials are not pure elements, being composed of mixtures, or **compounds** of elements, for example, water (H_2O) is not an element since it is constructed of hydrogen and oxygen, which are elements.

If an element is the simplest substance, what is the simplest for of an element? The answer is the **atom**. An atom is the smallest particle that maintains the identity of the element the atom comes from. For example, suppose one divides a piece of iron into fine pieces. Those pieces are themselves divided, and the divided pieces divided again and again. Eventually one gets to a single particle of iron that is still identifiable as iron. This particle is a single atom of iron. It has 26 protons in its nucleus. If the single iron atom were divided again the pieces would no longer be iron but two different elements.

[2] From the perspective of the makeup and behavior of real materials the elements are the smallest chemically identifiable, stable constituent of matter. The elements themselves are built from protons, electrons, and neutrons but these particles do not normally exist outside of atoms.

Daltonş Atomic Theory

- Each element is composed of extremely small particles called atoms.
- All atoms of a given element are identical.
- Atoms of different elements have different properties, including mass and chemical reactivity.
- Atoms are not changed by chemical reactions, but merely rearranged into different compounds. Atoms are neither created or destroyed by chemical reactions.
- Compounds are formed when atoms of more than one element combine.
- A compound is defined by the number, type (element), and proportion of the constituent atoms.

Although the idea of the atom as the smallest particle of matter was proposed by Democritus, one of the Greek philosophers, it was not until John Dalton (1766-1844) that the modern atom was introduced. Dalton's atomic theory was the basis for explaining why compounds seemed to be composed of certain ratios of weights of the different constituents.

Just as an atom is the smallest unit of an element, a **molecule** is the smallest unit of a compound. For example, one molecule of water (H_2O) is the smallest unit of the compound water.

The idea that compounds are mixtures of pure substances called elements was the culmination of the search (from the chemist's perspective) that was started by Aristotle. The atomic theory provided a framework for the understanding of molecules as bonded groups of atoms. The concept of a molecule subsequently provided a basis for understanding the reactions between different substances, such as the burning of wood.

Chemical Formulas and Reactions

The language of chemical formulas and reactions describe how elements combine to make compounds and also how compounds combine with other compounds.

The **chemical formula** is a prescription for making one molecule of a given compound. Figure 1.3 shows the chemical formula for methane, which is a flammable gas where each molecule contains one carbon atom and four hydrogen atoms. The chemical formula for methane is CH_4 where the subscript *4* indicates that there are four hydrogen atoms.

Chemical name: *Methane*
Chemical Formula: CH_4

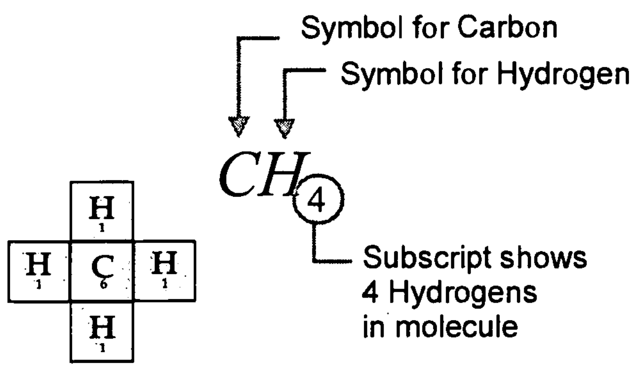
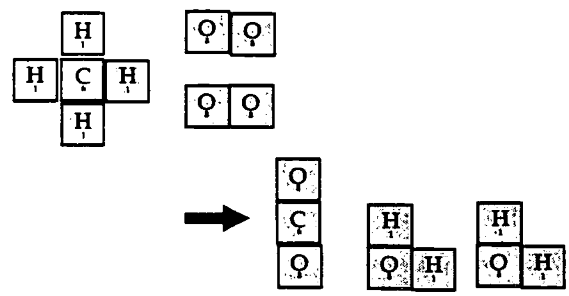


Figure 1.3: How to read a chemical formula. The letters are the symbols for the elements and the subscripts indicate how many atoms of each element are present in one molecule of the compound.

A more complicated example of a chemical formula would be the mineral spumodene, $LiAlSi_2O_6$. Each molecule of this mineral has contains one lithium atom, one aluminum atom, two silicon atoms, and six oxygen atoms.

Chemical **reactions** are what make the world interesting, and coincidentally what make life itself possible. Chemical reactions are processes in which compounds (or elements) are **reacted** to form different compounds. Figure 1.4 shows an example reaction for the combustion (burning) of methane in oxygen. In this reaction one molecule of methane and two molecules of oxygen combine to form one molecule of carbon dioxide and two molecules of water.



$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Figure 1.4: A chemical reaction between methane (CH_4) and oxygen (O_2) yields carbon dioxide (CO_2) and water (H_20).

Note that the type and number of the elements do not change during the reaction. There are four oxygen atoms, four hydrogen atoms, and one carbon atom at the start and the same four oxygen atoms, four hydrogen atoms, and one carbon atom at the end of the reaction. What is different is how the atoms are grouped into molecules. All chemical reactions have this same property.

Section 1.2: The Periodic Table

The Periodic Table organizes the elements in two important ways. The vertical columns contain groups of elements with similar chemical properties. The horizontal rows correspond to the filling of electron shells. Elements are classified according to their atomic number, which represents the number of protons in the nucleus.

The Behavior of the Elements and the Periodic Table

With the acceptance of Dalton's atomic theory of the elements the stage was set for the next great unifying discovery in chemistry, that of the periodic table. Early researchers, such as Laviosier, knew that certain elements were reactive and others were not. Some elements reacted with oxygen and some did not. Some substances that were at first considered to be elements turned out to be compounds. How many elements were there, and why were some elements similar in their behavior while others were different?

Group 1A	Group 2A	Group 3B	Group 4B	Group 5B
Li 1 Lithium	**Be** 2 Beryllium			
Na 11 Sodium	**Mg** 12 Magnesium			
K 19 Potassium	**Ca** 20 Calcium	**Sc** 21 Scandium	**Ti** 22 Titanium	**V** 23 Vanadium
Rb 37 Rubidium	**Sr** 38 Strontium	**Y** 39 Yttrium	**Zr** 40 Zirconium	**Nb** 41 Niobium

Figure 1.5: *A selection of the Periodic Table showing several different groups near the left side of the Table. Group 1A are the alkali metals, light and very reactive, all tending to form compounds with two oxygen atoms per metal atom. Group 2A are also light metals but these form compounds with one oxygen atom per metal atom.*

The single biggest clue towards unraveling the mystery of common chemical properties was discovered by Dmitri Mendeleev (1834-1907). A Russian chemist, Mendeleev devised a way to group elements which displayed common properties. For example, the light metals lithium, sodium, and potassium form compounds with two oxygen atoms per metal atom (LiO_2, NaO_2, KO_2) but one chlorine atom per metal atom (LiCL, NaCl, KCl). Mendeleev organized these groups into the first Periodic Table of the Elements. In the Periodic Table the vertical columns represent elements with common properties. By the previous example we find Lithium (Li), Sodium (Na) and Potassium (K) in the same group of the table. Some of the groups (figure 1.6) have been given special names which reflect their chemical or physical properties. The noble gasses are group 8A which includes Helium, Neon, Argon, Krypton, Xenon, and Radon. None of these elements reacts with anything and they all form no compounds, existing only as pure elements.

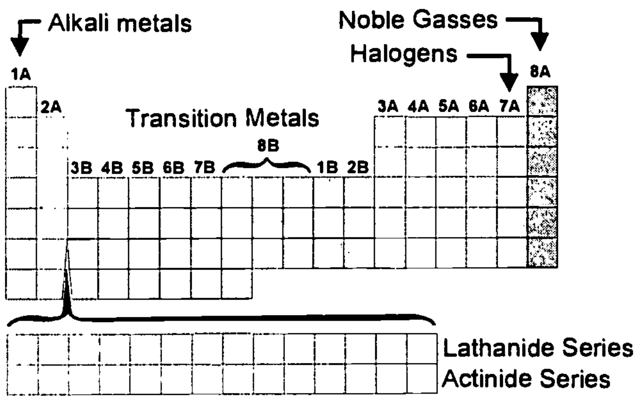


***Figure 1.6:** The Periodic Table groups elements by common chemical properties. All the elements in each group have similar properties. For example, all of the group 8A elements are gasses that do not react with anything (noble gasses).*

Section 1.3: Chemical Bonding and Compounds

Most of the materials we are familiar with are compounds, mixtures of the elements. Compounds are formed by chemical reactions. It is possible to determine how much of each element is needed from the chemical formula for a compound.

Chemical Bonding

The periodic table groups elements according to how they react with other elements to form compounds. Before we talk about which elements combine with which, it is useful to talk about just what happens when elements bond together. Bonding involves interactions between the electrons that live outside the nucleus (figure 1.7).

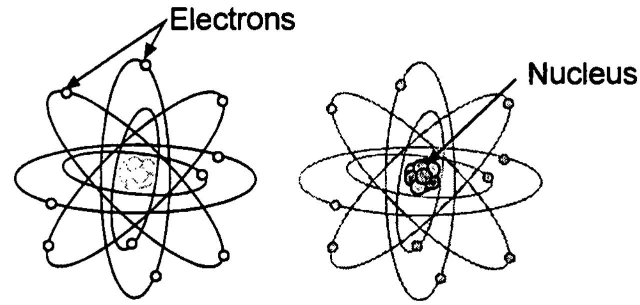


***Figure 1.7:** Electrons live outside the nucleus and have negative charge while the nucleus has positive charge. Chemical bonding involves only the electrons.*

Atoms like to be electrically neutral, which means that the numbers of electrons (-) and protons (+) are exactly balanced. Atoms also like to have their electrons in particular groupings that we call **electron shells.** At first pass the whole idea of electron shells seems to make no sense. Don't worry about this, the fact that electron shells exist is not something anyone except a highly trained physicist actually understands. For now accept that the electrons in an atom exist in "shells" that each hold a limited number of electrons. Figure 1.8 shows a diagram of the first five shells.

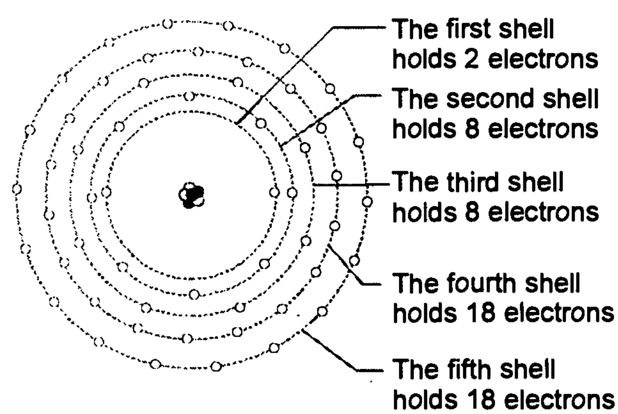


***Figure 1.8:** A diagram of the first five shells of the electron shell model of the atom. Electrons are attracted to the nucleus and fill the closer shells first.*

Atoms seem to be built along the following rules.

- Each shell can only hold a maximum number of electrons.
- Electrons are attracted to the nucleus and therefore always settle to the lowest unfilled shell.
- Atoms prefer to have either completely full or completely empty shells and this preference is what determines how elements bond together.
- The first shell holds two electrons
- The second and third shells hold eight electrons each.
- The fourth and fifth shells hold 18 electrons each.
- The sixth and seventh shells hold 32 electrons each.

It took many centuries of observation to deduce the theory of electron shells that explains the structure of the Periodic Table. Each row of the Table represents all the elements that fill up a particular shell. The seven rows of the modern Periodic Table correspond to the first seven electron shells (figure 1.9).

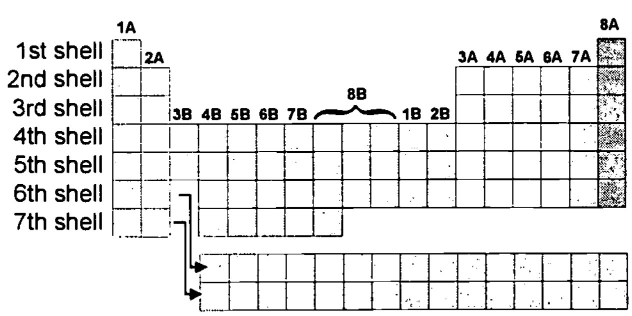


Figure 1.9: The seven rows of the Periodic Table correspond to the filling the first seven electron shells.

The shells are actually a little more complex than the diagram in figure 1.8. Electrons physically fall into groups of 2, 6, 10, and 14[3] which have been given the names ***s***, ***p***, ***d***, and ***f***. The electron shells are really the filling patterns for these electron groups called **orbitals**. Figure 1.10 shows how the electron shells are constructed from the orbitals. You may find different chemistry books will use terms such as **electron configuration**, or **orbital configuration** to describe how many electrons are in each shell and how the electrons are arranged in the orbitals within each shell. The key idea is the concept of shells and that atoms prefer to bond in such a way that by trading electrons with other atoms each atom gets to have full shells.

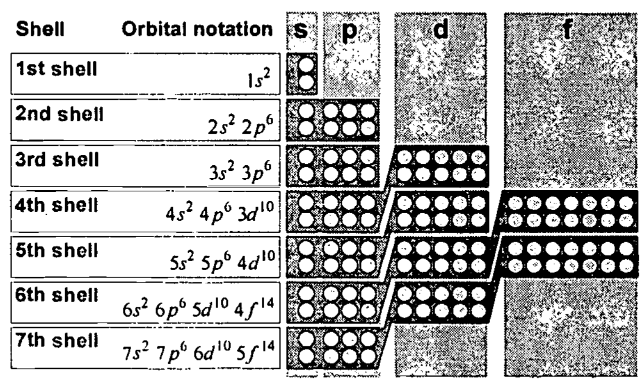


Figure 1.10: How the electron shells are arranged in standard spectroscopic notation in terms of the s, p, d, and f orbitals.

Electron Shells and Chemical Bonding

The theory of electron shells explained many things, but for our purposes the relation to chemical bonding is most relevant. This comes from the third rule, that **atoms prefer to have completely filled or completely empty shells.** Atoms form molecules by sharing electrons so

[3] Actually these are only the first four angular momentum groups for electrons, which are enough to accomodate all the 108 known elements.

that each atom in the molecule gets to have completely filled or completely empty shells.

An example will help the ideas settle. Suppose we put the elements sodium (Na) and chlorine (Cl) together. Sodium has 11 electrons, which by our rules fill up the first (2) and second (8) shells leaving one single electron in the third shell. Chlorine has 17 electrons. If two go in the first shell, and eight more in the second shell, there are seven left in the third shell. The third shell of chlorine is one electron short of being full. The third shell of sodium has only one lonely electron.

If the sodium atom could trade one electron to the chlorine atom both atoms would have only full shells. But, each atom would then be charged. The sodium would have a charge of +1 since it traded away one electron. The chlorine atom would have a charge of -1 since it gained one electron. The way to resolve trading electrons with the need to be electrically neutral is for both atoms to **bond** forming a **molecule**. The sodium chloride (NaCl) molecule is electrically neutral since it has 28 protons and 28 electrons.

> Bonds between atoms happen by sharing electrons so each of the atoms gains a filled shell electron configuration while the molecule as a whole stays electrically neutral.

Lets look at a more complex molecule, like water, H2O. Why are there two hydrogen atoms and only one oxygen atom in the water molecule?

Hydrogen has only one electron. To get a filled shell it must either gain one electron, filling the first shell. Or, hydrogen can lose its one electron giving it an empty shell. Oxygen has eight electrons, enough to fill the first shell (2) and fill six out of the eight slots in the second shell. If one oxygen atom trades an electron with each of two hydrogen atoms the molecule satisfies all the rules. The oxygen has 10 electrons, its 8 plus one each from the two hydrogens. Ten electrons perfectly fills the first and second shells. The hydrogen atoms each have zero electrons, giving each only empty shells, also favored states according to the rules. The water molecule has a total of ten protons and ten electrons, making it electrically neutral.

Valence

Understanding valence makes it easy to figure out chemical formulas. The concept of valence can be deduced directly from our discussion about how shells and bonding works. Lets go back to chlorine with its 17 electrons. Recall that the third shell has only seven out of its eight slots filled. Chlorine would like to get an extra electron. An extra electron would give a chlorine atom a charge of -1. We say **chlorine has a valence of -1 because it needs one extra electron to get a filled outer shell**. The valence is the charge that an atom would have if it added or subtracted electrons to get full or empty shells. As you might expect chlorine would rather gain one electron (valence -1) than lose 7 electrons (valence +7) even though losing seven would also give chlorine only full or empty shells.

The valences of the other elements can easily be determined in the same fashion. Nitrogen has seven electrons. Two go in the first shell, leaving five for the second shell. A full second shell needs eight electrons therefore nitrogen wants to make bonds that provide three electrons, for a valence of -3.

Lithium has three electrons. Two fill the first shell leaving one in the second shell. The easiest way for lithium to reach the preferred full or empty shell configuration is to lose one electron, giving a valence of +1. Lithium forms bonds with elements that need electrons.

Elements form molecules so that all the valences sum to zero. This is another way of stating that there have to be just the right number of electrons trades that all the atoms n a molecule have filed or empty shells.

It is easier to work out molecules in terms of valence than by counting electrons. For example, consider lithium and chlorine. Lithium has a valence of +1 and chlorine has a valence of -1. One lithium atom bonded with one chlorine atom gives a total valence for the molecule of +1-1=0. Lithium chloride has the formula LiCl because one lithium and one chlorine add up to zero net valence for the molecule.

Sometimes it takes more than one of each kind of atom to make the valences work out. Consider oxygen and lithium. Oxygen needs two more electrons to fill the second shell therefore has a valence of -2. Lithium wants to lose its single electron in the second shell and therefore has a valence of +1. A molecule made with lithium and oxygen would need two lithium atoms to balance valence. (+ 1 + 1 - 2 = 0) The chemical formula for lithium oxide is Li_2O.

Molecules form with the proportions of atoms that make the overall valence of the molecule sum to zero. Each atom in the molecule contributes its valence to the sum.

Multivalent Atoms

Some atoms, actually the majority of atoms, can form compounds with more than one valence. This is because the mixtures of electrons in a molecule can significantly change the orbital configurations. The shell model predicts one valence for each atom based on electron shells. This valence is usually the most common one.

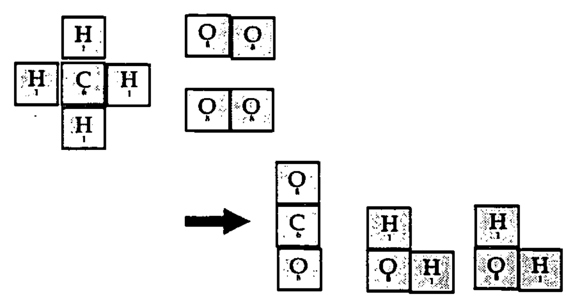
The transition metals (groups 1B - 8B) all have complicated valences because the d and f orbitals mix together in complex ways.

Carbon, a group 4B element has four of eight in the second shell. It can lose four electrons (valence -4) or gain four electrons (valance +4) to get to the filled shell configuration.

While the shell model provides a useful explanation for valence and chemical bonding, there are more complex things that happen with electrons that make other valences possible.

Chemical Reactions

Chemical reactions rearrange atoms into different compounds but do not change the atoms themselves. If a reaction starts with four hydrogen atoms, such as in methane, then the same four hydrogen atoms must appear in the products of the reaction (figure 1.11).



$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Figure 1.11: A typical chemical reaction between methane and oxygen (reactants) yields carbon dioxide and water (products).

The numbers in the reaction indicate how many of each kind of element or molecule are produced, or used by the reaction. The process of **balancing** chemical equations means figuring out how many of each kind of atom or molecule it takes so that the same number of elements appear in the reactants and products. For example, there can't be half an oxygen atom.

Section 1.4:
The Periodic Puzzle Cubes

The Periodic Puzzle has two kinds of cubes. One kind has elements from the same group on each face. All the elements on this type of cube have common chemical properties. The second type of cube has common elements, such as carbon, hydrogen, oxygen, and nitrogen. The second kind of cube provides enough extra elements to build complex molecules.

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Chapter 2
Level A Activities

Section 2.1: Learning Goals for Level A

The Periodic Puzzle Curriculum provides a basic introduction to chemistry. We introduce the key concepts:

- Elements are the simplest substances, and an atom is the smallest indivisible portion of an element,
- Compounds are substances made from multiple atoms, and a molecule is the smallest indivisible portion of a compound,
- The Periodic Table is a chart of the elements that reminds us of similarities of chemical properties,
- Chemical reactions neither create, destroy, nor transform elements; they only rearrange the atoms of the reactants to make the products

We use the Periodic Puzzle blocks as model atoms for these activities. In this way, we can do "experiments" building molecules and making chemicals react, while clearly visualizing what is happening and without using expensive or dangerous apparatus or chemicals. We will work through a basic introduction to chemistry that will give the students familiarity with the Periodic Table and what can be learned from it.

Apparatus:

- One Periodic Puzzle Set per group
- One Activity Guide per student

Key Vocabulary for Level A

- **Element:** The simplest substances, which cannot be reduced to other substances by chemical reactions.
- **Atom:** The smallest indivisible unit of an element.
- **Compound:** A more complex substance, made of combinations of elements.
- **Molecule:** The smallest indivisible unit of a compound.
- **Periodic Table:** A chart of the elements which reminds us of chemical similarities between the elements.
- **Protons:** One of the particles of which atoms are made of. The **atomic number** of an element tells us how many protons are in the atom.
- **Neutrons:** One of the particles of which atoms are made of. The **atomic mass** of an element tells us how many protons and neutrons are in the atom.
- **Isotope:** An element has a unique **atomic number**, or number of protons, but may have many values for the **atomic mass.** This means that the element may exist with different numbers of neutrons. These are different **isotopes** of the element.
- **Groups:** The Periodic Table shows the elements divided into different **Groups** by columns. These groups share chemical similarities.
- **Reactants:** The ingredients that go into a chemical reaction.
- **Products:** The results of a chemical reaction.

Section 2.2: The Periodic Table

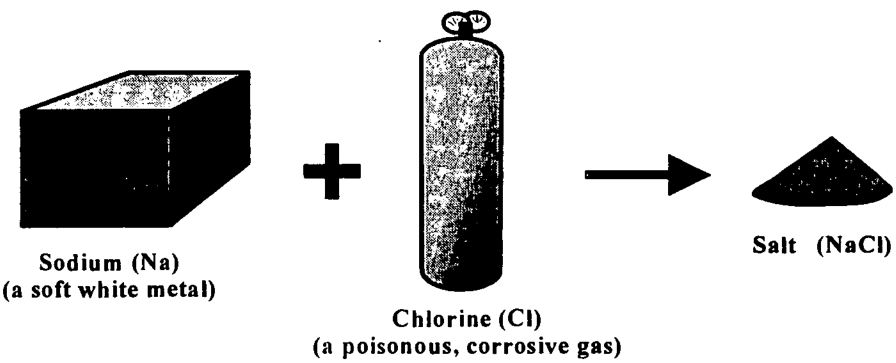
Activity Guide PT-A1

The first Activity Guide is intended to introduce the students to the Periodic Table. The key concepts learned include elements and compounds, and their composition from atoms and molecules. The odd shape of the Periodic Table, and the more common elements, must become familiar in order to explore them in more detail in the next lesson.

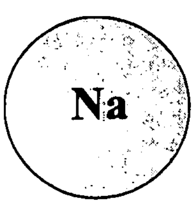
WHAT IS THE PERIODIC TABLE?

Everything in our world is made of atoms. There are many different types of atoms. Some are large and heavy, some are small and light. Some are very reactive, and combine fiercely with other atoms, often releasing heat. Some are inert, and never combine with other atoms at all.

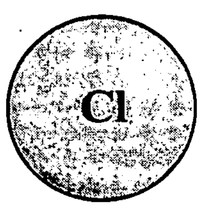
Chemistry is the study of atoms and how they combine together. The different types of atoms are called elements.



Elements are the simplest substances, and atoms are the smallest unit of an element. In the chemical reaction at the right, sodium and chlorine are both elements.



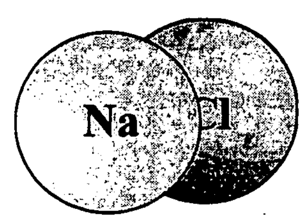
One sodium atom



One chlorine atom

The smallest piece of sodium that can be found is an atom of sodium. Similarly, the smallest piece of chlorine that can be found is an atom of chlorine.

Compounds are mixtures of elements bonded together in specific ratios of elements, and **molecules** are the smallest units of compounds. In the reaction above, salt is a compound. The smallest piece of salt that can be made is a molecule of salt. One molecule of salt is made of one atom of sodium and one atom of chlorine.



One salt molecule

Early scientists were very confused about the differences between compounds and elements. They tried mixing, boiling, dissolving in acid, burning, and many other processes to transform one substance into another. Sometimes, very profound changes could be made by simple mixing: for example, mixing sodium and chlorine together to make salt. Why not, these pioneers asked, make gold from lead? How about diamonds from glass?

We now know that **chemical reactions rearrange atoms, they don't change atoms from one element to another.** Thus, we can make salt from sodium and chlorine, because salt has both sodium and chlorine atoms in it. We can transform iron into rust without doing *anything*. Rust is made from iron (**Fe**) and oxygen (**O**), which is always present in the air. We can't make gold from lead, or diamonds from glass, because either reaction would require changing one element into another.

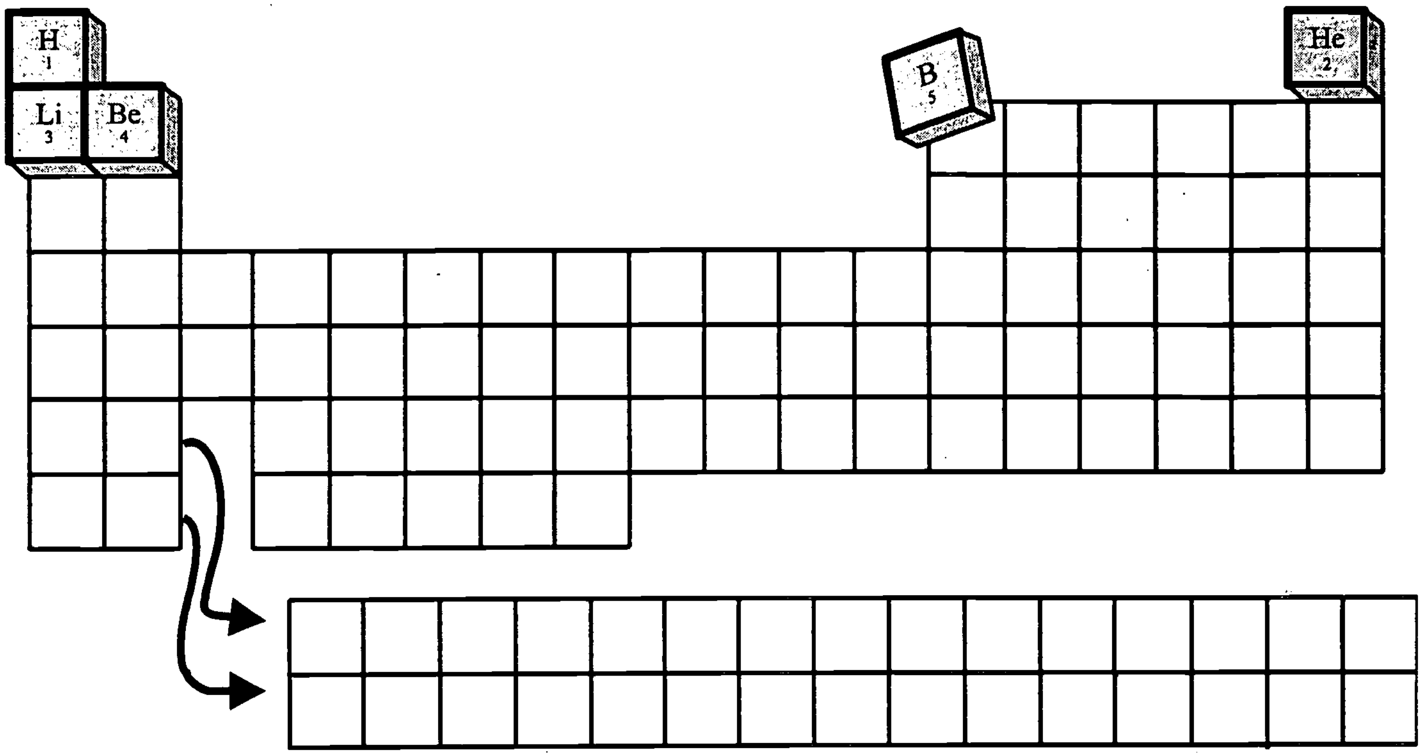
A1.1: Do astronauts need to worry about iron rusting on the moon? Why or why not?

no.....there is no oxygen to combine with iron to make rust

Element - a material made from only one type of atom

Compound - a material made from two or more types of atoms

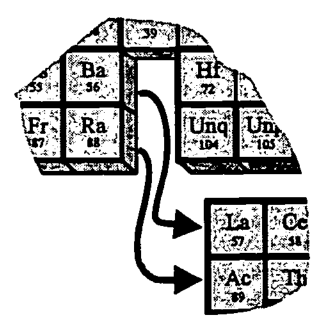
The chemical elements can be arranged in groups with similar properties. The **Periodic Table** is a chart of the elements, arranged to remind us of these similarities. The chart below shows the *shape* of the Periodic Table, and the first few elements in sequence from left to right. The elements are arranged in sequence using the **atomic numbers.**



A1.2: Using the chart on the previous page as an example, build the Periodic Table out of the Periodic Puzzle blocks. The numbers on the blocks are the atomic numbers.

The students should be assembling the Periodic Table blocks at this point. There is no answer required for **A1.2**, *but the students should not skip this activity. This is a good time to make sure that the students are building the Table correctly. Common mistakes include using the wrong number of columns, or missing a number. It is easy to check to see that the right hand column (the noble gases) are* ***He, Ne, Ar, Kr, Xe, Rn.***

There is a tricky part down near the bottom of the table. The table breaks off between elements 56 (**Ba**) and 72 (**Hf**), and fills in the first of two long rows at the bottom (we will learn why later). It does the same thing in the row below. Be sure to fill it in correctly in this area, like in the picture at right.



IMPORTANT: Be sure that you don't duplicate the two-page Periodic Table chart onto 2-sided paper for this activity. The students will need to tape both pieces of paper together, which will be impossible if they are duplicated back-to-back. Any activities that are on the backside of the Periodic Table will be difficult to complete and to collect and grade.

A1.3: After you have built your table, tape together the chart on the next two pages, and fill in the symbols and atomic numbers for the elements. Use the chart below to get the names of the elements.

Symbols and Names for the elements

H	hydrogen	**He**	helium	**Li**	lithium	**Be**	beryllium
B	boron	**C**	carbon	**N**	nitrogen	**O**	oxygen

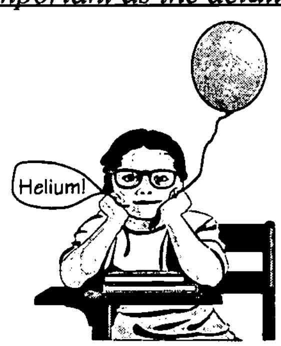
(remainder of table deleted.....it can be found in the activities)

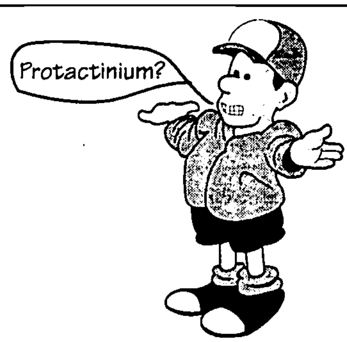
Once finished, this chart should be a resource for the students. Each student should complete a full (two page wide) chart with the atomic number, element symbol, and element name, and keep it for further use in other activities.

Assessment suggestion: It can be quite difficult to proofread an entire classroom full of Periodic Tables. Instead, at the end of this activity, go over the chart orally with the entire class, and let everybody proofread their own.

A1.4: Do some of the elements sound familiar? Pick two, and say something about them.

this is open ended. many students will pick helium, oxygen, gold, iron, silver...
again, we are after familiarity with the elements, so thinking about the question
is as important as the details of the answer.





A1.5: Have you heard of the following elements? What do you know about them?

Oxygen: *major component of air, necessary for life and/or fire*

Silver: *precious metal, used in coins, electrical conductor*

Mercury: *metal that is liquid at room temperature, used in thermometers*

Silicon: *useful in electronics, major component of rocks and glass*

Iron: *industrial metal, used for making steel*

Neon: *noble gas, used in electrical discharge lamps*

Uranium: *radioactive material, useful for nuclear power plants or bombs*

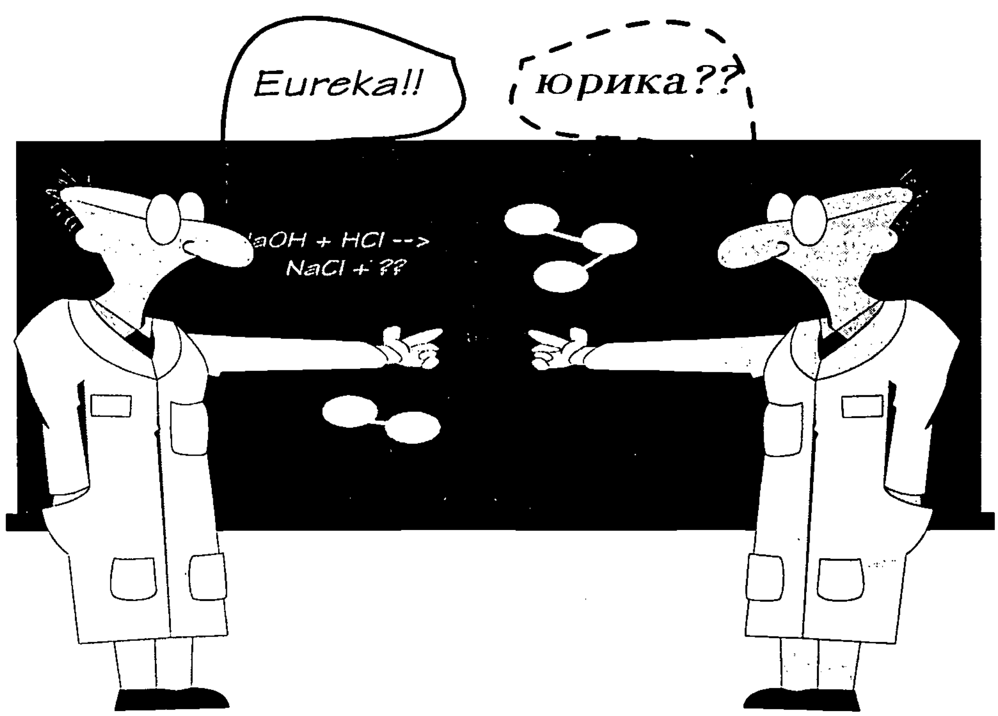
Tungsten: *hard metal, high melting point, used for light bulb filaments*

Iodine: *useful in solution for killing germs on wounds*

Krypton: ***not kryptonite,** nothing to do with superman.....a noble gas like neon*

Some of the element symbols don't seem to make sense. A typical example is the abbreviation for tungsten: is the letter **W.** Actually, tungsten was named by German scientists, and the German name for tungsten is "wolfram", so the abbreviation *does* makes sense after all.

Most of the abbrevia-tions that aren't obvious are for similar reasons -- the elements were studied and named by scientists from around the world.



Some elements don't have names yet! Elements 104 through 108 don't occur in nature, but have been made in the laboratory. There are still discussions going on worldwide over what to name them. Many people want to name them after famous scientists who have contributed to their discovery (just like element 99 Einsteinium (in honor of Albert Einstein) or element 100 Fermium (in honor of Enrico Fermi)). This is a problem if there are more scientists than elements! What do you think you need to do to get an element named after you?

A1.6: Some of the materials below are elements, and some are not. Circle the elements.

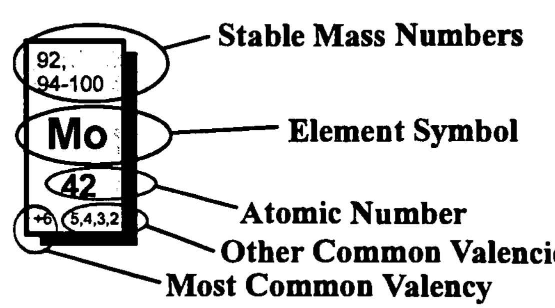
air	gas	oxygen	nitrogen	argon
iron	steel	copper	brass	aluminum
tin	nickel	bronze	chromium	lead
gold	silver	sapphire	ruby	platinum
chlorine	quinine	strychnine	iodine	bromine

Section 2.3: The Families of Elements

Activity Guide PT-A2

The second Activity Guide defines a few key terms (atomic number, atomic mass, valence), and adds to the Periodic Table these numbers for the more common elements (i.e. all elements up to xenon). In Level A activities, we do not explain the "why" of valence, but merely state the rules and introduce the concepts of patterns within the Periodic Table.

In the last lesson, we learned that the elements were numbered in sequence with the **atomic number.** The atomic number is the number that is used to order the elements in the Periodic Table. There are several other numbers which are used to identify atoms.



The next page shows a chart of the Periodic Table, with some of these other numbers added. These numbers tell us what is in the atom, and how the atom wants to combine with other atoms.

Take a look at the key to the chart at the right. The symbol for the element and the atomic number are the same as we used last lesson. These are printed on the blocks as well.

The **atomic number** is unique to each element. There is only one element with atomic number 42, and that is Molybdenum (**Mo**). The atomic number tells us how many **protons** are in the atom. Protons are one of the three types of particles that atoms are made of.

A2.1: How many protons are in an oxygen atom?

the atomic number is eight, so there are eight protons

The **atomic mass** or stable mass number is the number or numbers at the top. The atomic mass is the total number of protons and **neutrons** in the atom. If there is more than one number here, than there are several **isotopes**, or atoms of different mass, that exist. For example, molybdenum has stable mass numbers of 92, 94, 95, 96, 97, 98, 99, 100. Since molybdenum must always have 42 protons, these isotopes have 50, 52, 53, 54, 55, 56, 57, and 58 neutrons, respectively.

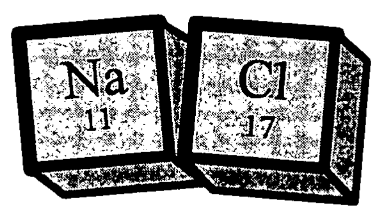
A2.2: How many neutrons are in the oxygen isotope that has a mass number of 16?

the mass number is the number of protons and neutrons, so there are eight neutrons.

(The table which appears on the following page of the Activity Guide does not appear here).

The **valence** is the number of electrons that the atom has to contribute when forming compounds. Atoms join together to form molecules in such a way as to share extra electrons. Sodium has a valence of +1, since it has one electron to lend out. Chlorine has a valence of -1, since it has one missing electron which it wants to borrow.

Salt has one sodium and one chlorine, since they cancel out their valencies together. Make a salt molecule out of one sodium atom and one chlorine atom with the Periodic Puzzle blocks.



A2.3: Hydrogen has a valence of +1. Oxygen has a valence of -2. How many hydrogen atoms does it take to make a molecule with one oxygen atom? Make a molecule of hydrogen and oxygen out of the periodic puzzle blocks.

it takes two hydrogen atoms. the students should make a molecule of 2 H and 1 O blocks

A2.4: We write a molecule of hydrogen and oxygen as **H_2O.** Have you heard of this? What is it?

water

The chart often has several numbers for the valence of an atom, since the atom may combine differently with different atoms. The most common valence is given first, and other common ones afterwards.

A2.5: Find all of the elements with a valence of 0. (These are marked "none"). What are their symbols? Are they gathered together in any way on the Periodic Table?

He, Ne, Ar, Kr, Xe. They are all in the right hand column

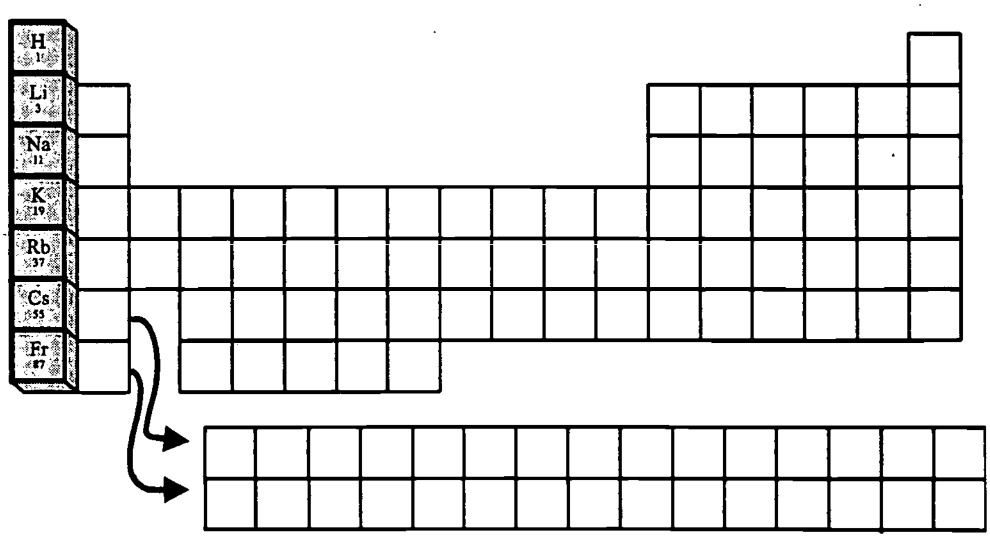
A2.6: Find all of the elements with a valence of +2. Are they arranged together as well? Where?

Be, Mg, Ca, Sr. They are all in the second column

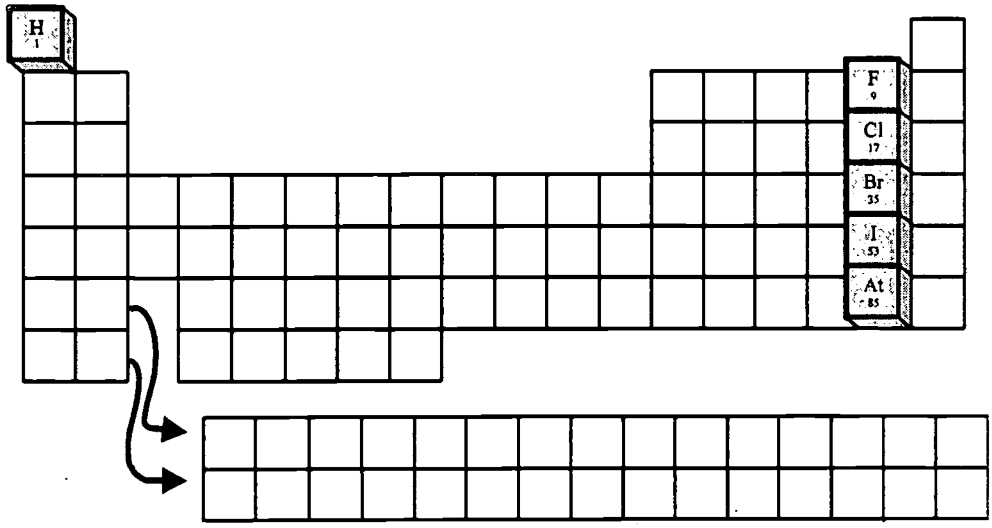
(also Mn, Co, Ni, Cu, Zn, Cd in the transition metals, but this is less important.)

THE PERIODIC TABLE IS PERIODIC

The Periodic Table is arranged to remind us of the similar valences of the elements. You noticed that all of the 0 valence elements were in one column, and most of the +2 valence elements are in another. These columns are called **Groups.** The group numbers usually give the most common valence of the elements, although there are plenty of exceptions.



When we think of the elements as belonging to groups, it is easier to remember how they will interact. For example, all the elements which commonly have a valence of +1 are in the first column. These are called the Group 1A elements. They have many similarities besides the same valence: except for hydrogen, they all are soft metals, react very quickly with water to form strong bases, and form salts with the Group 7A elements using one atom from Group 1A and one from Group 7A. We call the Group 1A elements (again, except for hydrogen) the alkali metals.



Similarly, the elements which commonly have a valence of -1 are in the next to last column. These are called the Group 7A elements. They also have many similarities: they are pungent and corrosive and react quickly with water to form strong acids, and form salts with Group 1A elements as we just mentioned.

We include hydrogen in the elements of -1 valence, since it often does *both*.

Let's look at some more simple molecules.

A2.7: Ammonia is made up of nitrogen (**N**) and hydrogen (**H**). Nitrogen has a valence of -3, and hydrogen has a valence of +1. Make an ammonia molecule out of blocks. What is the symbol for ammonia?

_______ NH_3 _______

A2.8: Carbon dioxide is made up of carbon (**C**) and oxygen (**O**). Carbon has a valence of +4. What is the valence for oxygen? Make a carbon dioxide molecule out of blocks. What is the symbol for carbon dioxide?

_______ CO_2 _______

A2.9: Methane, or natural gas, is what you might cook with or heat your house with. It is made of carbon (**C**) and hydrogen (**H**). The most common valence of hydrogen is +1. What is the most common valence of carbon?

_______ *+4* _______

A2.10: Can we make a methane molecule using the most common valences for carbon and hydrogen?

_______ *no, they both have positive valence* _______

A2.11: Try using a valence of -4 for carbon. Now make a methane molecule with the blocks, and give the formula.

_______ CH_4 _______

A2.12: Salt is a compound using one atom from Group 1A and one atom from Group 7A. Make three more compounds from Group 1A and Group 7A elements. How many of each block did you need? Write the chemical formula for them here.

many possibilities here: LiF, LiCl, LiBr, LiI, NaF, NaCl, NaBr, NaI, KF, KCl, KBr, KI, RbF, RbCl, RbBr, RbI

all of these need only one of each block.

Section 2.4: Chemical Reactions

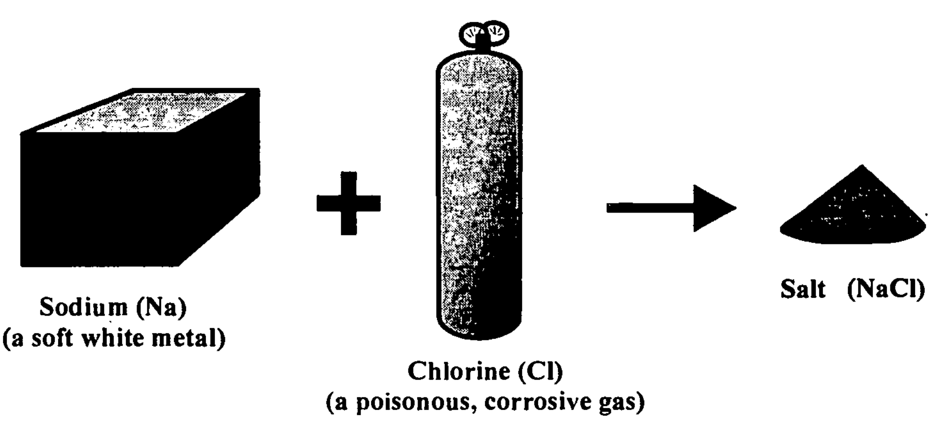
Activity Guide PT-A3

*This activity brings together key concepts from **PT-A1** and **PT-A2**, and explores how chemical reactions occur. We use what we know of valency and molecules to learn how to balance the reactants and products in chemical reactions. This can be an especially difficult lesson for some students. Skills in algebra, problem solving, as well as the fundamentals of chemistry are required. The Periodic Puzzle blocks are a particularly good way for students to visualize these concepts.*

Now that we know all about the elements and how they combine to make molecules, let's look at the way that these combinations take place.

A chemical reaction is what happens when we mix together two or more chemicals which rearrange themselves to make new chemicals.

Let's look at the first reaction that we learned, combining sodium and chlorine to make salt. The **reactants** are the ingredients that we mix together to start the reaction.



A3.1: What are the reactants in the reaction above?

the reactants are sodium and chlorine

The **products** of a reaction are the end results of the reaction, or the stuff that we make.

A3.2: What are the products in the reaction above?

the product is salt

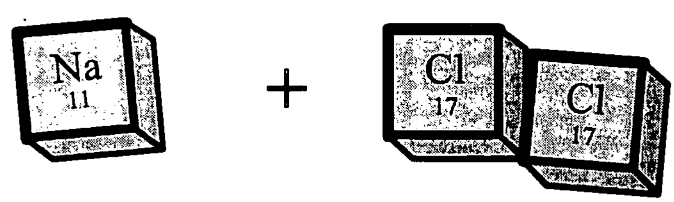
We write chemical reactions much like we write mathematical equations. We *might* write the above reaction

$$\mathbf{Na + Cl \rightarrow NaCl} \qquad \textit{(almost right)}$$

to show that we started with sodium (**Na**) and chlorine (**Cl**), and ended up with salt (**NaCl**). The only problem is that chlorine is not available in the atomic state. Pure chlorine forms a two-atom molecule with itself. These are called **diatomic** molecules. The formula for diatomic chlorine is $\mathbf{Cl_2}$. We then must write the left side of the chemical equation like this:

$$\mathbf{Na + Cl_2 \rightarrow .....}$$

A3.3: Take three blocks to form the reactants above: one sodium, and two chlorines joined together to make a molecule. Rearrange them to make salt. Is there any problem?



yes!

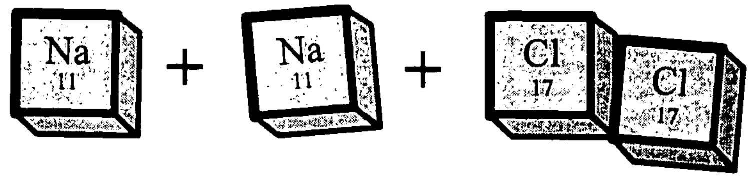
the sodium and chlorine atoms don't balance - there is an extra chlorine left over

Chemical reactions must always balance. The rule for chemical reactions is that you have to use all the atoms that you start with, and you can't add any more or have any leftovers at the end.

Since chlorine comes in molecules with two atoms, we need to have two sodium atoms to match. The proper way to write this reaction is like this

$$\mathbf{2Na + Cl_2 \rightarrow NaCl} \qquad \textit{(correct)}$$

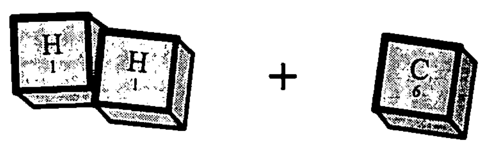
A3.4: Add another sodium block to the three blocks you already have. Now let the chemicals react! Does this balance?



_______*yes, the elements balance out*_______

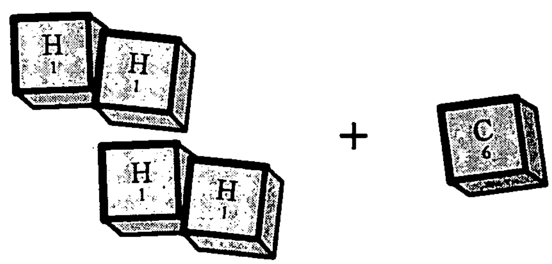
A3.5: Let's try another reaction. Combine hydrogen gas (which is also diatomic, $\mathbf{H_2}$) with carbon (**C**) to make methane ($\mathbf{CH_4}$). First get some hydrogen blocks and carbon blocks, and then try setting up the reactants. Remember that you must be able to rearrange all the reactant atoms to get complete products. Which of these reactant combinations works?

$\mathbf{H_2 + C \rightarrow .....}$



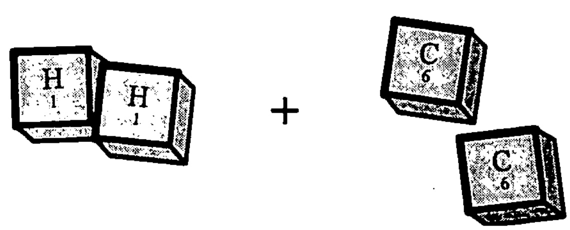
or...

This one works $\mathbf{2H_2 + C \rightarrow .....}$



or...

$\mathbf{H_2 + 2C \rightarrow .....}$



Write down the equation for making methane from hydrogen gas and carbon.

__________$2H_2 + C \dashrightarrow CH_4$__________

A3.6: Let's balance some more chemical equations. The following equations have the proper reactants and products.

First assemble the reactants out of blocks, then rearrange them to make reactants.

Figure out the right number of each reactant and product to make the chemical equation balance. Fill in the numbers in the boxes below, just as in the first two examples.

burn hydrogen to make water	$\boxed{2}\ H_2 + \boxed{1}\ O_2 \longrightarrow \boxed{2}\ H_2O$
make salt out of sodium and chlorine	$\boxed{2}\ Na + \boxed{1}\ Cl_2 \longrightarrow \boxed{2}\ NaCl$
make carbon dioxide	$\boxed{1}\ O_2 + \boxed{1}\ C \longrightarrow \boxed{1}\ CO_2$
let iron rust	$\boxed{4}\ Fe + \boxed{3}\ O_2 \longrightarrow \boxed{2}\ Fe_2O_3$
burn methane	$\boxed{1}\ CH_4 + \boxed{2}\ O_2 \longrightarrow \boxed{1}\ CO_2 + \boxed{2}\ H_2O$
neutralize acid and base	$\boxed{1}\ HCl + \boxed{1}\ NaOH \longrightarrow \boxed{1}\ NaCl + \boxed{1}\ H_2O$
burn octane (gasoline)	$\boxed{2}\ C_8H_{18} + \boxed{25}\ O_2 \longrightarrow \boxed{16}\ CO_2 + \boxed{18}\ H_2O$

The last reaction, burning octane, will take more blocks than the Periodic Puzzle set has available, and is not an easy problem. Be careful suggesting that the students combine blocks from multiple sets to accomplish this, as it may not be easy to get the proper distribution of blocks back into the boxes at the end of the lesson. Instead, encourage the students to look for the patterns they can use to solve the puzzle.

You may want to "burn octane" on the chalkboard as a class exercise if the students seem to have trouble at this point. The logic may go something like this:

1) Start with one octane molecule in the reactants.

2) One octane molecule makes 8 carbon atoms available, and 18 hydrogen atoms available. The only other reactant is oxygen, which has neither carbon nor hydrogen atoms, so we know exactly how many carbon and hydrogen atoms are available for the products.

1 x 18 = 18 hydrogen atoms available

$\boxed{1}\,C_8H_{18}$

1 x 8 = 8 carbon atoms available

3) Since there are eight carbon atoms in the reactants, there must be eight carbon atoms in the products. The only product with carbon is CO_2*, which has only one carbon atom. There must then be eight* CO_2 *molecules in the products.*

4) Since there are 18 hydrogen atoms in the reactants, there must be eighteen hydrogen atoms in the products. The only product with hydrogen is water, which has two hydrogen atoms per molecule. There must then be nine H_2O *molecules in the products.*

5) We can now count the oxygen atoms that we require in the products. Eight CO_2 *molecules need 16 oxygen atoms. Nine* H_2O *molecules need nine oxygen atoms. We need to supply 9+16 or 25 oxygen atoms. The products supply oxygen as* O_2 *molecules. This means that we need 12.5 oxygen molecules to balance the equation.*

6) We aren't allowed to have leftovers or fractional atoms in a chemical equation, so let's double all the quantities to get whole numbers. We will start with 2 octanes and 25 oxygens in the reactants, and end up with 16 carbon dioxide and 18 water molecules.

Section 2.5: Element Bingo

Activity Guide PT-G1

This activity is the first of two games in this curriculum. These are the real heart of the activities, and provide a great chance to have fun while reinforcing the lessons of the Periodic Table.

These games can be played by Level A, Level B, or Level C students. The appropriate activities should be completed first.

This game, Element Bingo, helps students learn the element names and associate the names and symbols. The game only requires one Periodic Puzzle for the entire class. It can be played after Activity A1 or B1 are completed.

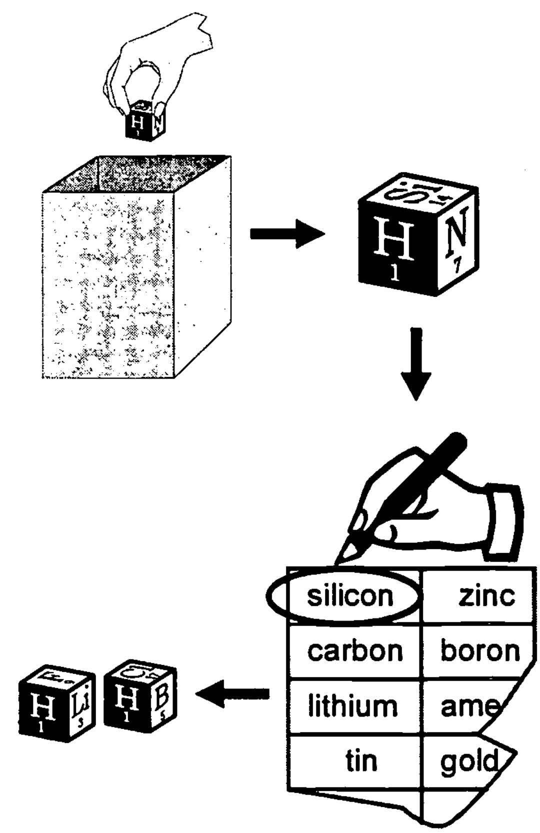
Element bingo is very similar to the popular bingo game played with numbers. One Periodic Puzzle is required per class or per playing group. The game can easily accomodate a whole class and we recommend it as a class exercise.

The rules are simple. Each student gets one Activity Guide PT-G1 (these are numbered cards 1 through 32). **Each student should have a different numbered card.** It is important that no two students be given the same number Activity Guide or they would have identical cards to play.

Each student should also have a copy of the reference chart that gives all the element names and corresponding symbols.

The teacher, or a selected student takes turns drawing a cube out of a bucket and rolling the cube on the desk or floor. The figure shows the steps. Do not mix cubes from two different Periodic Puzzles!

- Start with all the cubes in a box or bag.
- Draw one at a time and roll it on the desk or floor.
- Students circle the element that comes up on the top face.
- Blocks are saves to the side to check winning cards.



Students circle the element represented by the symbol that comes face-up on the cube when it lands. If the group is large the symbol should be written on the board so everyone can see.

The cube just played is taken to the side and left with the same face showing so that winning cards can be checked against the elements that were called.

Three ways to win

Horizontal line

silicon	iron	xenon	uranium	gallium
oxygen	carbon	argon	sulfur	nickel
tin	indium	lead	bromine	barium
cesium	fluorine	lithium	iodine	erbium
cerium	copper	osmium	cobalt	silver

Vertical line

silicon	iron	xenon	uranium	gallium
oxygen	carbon	argon	sulfur	nickel
tin	indium	lead	bromine	barium
cesium	fluorine	lithium	iodine	erbium
cerium	copper	osmium	cobalt	silver

Diagonal line

silicon	iron	xenon	uranium	gallium
oxygen	carbon	argon	sulfur	nickel
tin	indium	lead	bromine	barium
cesium	fluorine	lithium	iodine	erbium
cerium	copper	osmium	cobalt	silver

The first player to circle five elements in a line wins. The line can be vertical, horizontal, or diagonal).

Each Game Card page has two element bingo cards. This allows two games to be played without photocopying a second set of sheets.

Section 2.6: Molecular Crossword

Activity Guide PT-G2

This activity is the second of two games in this curriculum. These are the real heart of the activities, and provide a great chance to have fun while reinforcing the lessons of the Periodic Table.

These games can be played by Level A, Level B, or Level C students. The appropriate activities should be completed first.

*This game, Molecular Crossword, helps students learn how elements bond to form compounds, and reinforces the rules for valence. The game requires one Periodic Puzzle for each group of two to six players. It can be played after Activity **A2** or **B3** are completed.*

The game is played like a crossword with the exception that molecules are built instead of words. Players score by adding up the atomic numbers. Since the cubes can be rotated, there are many possibilities to increase score by using the higher atomic numbered elements with similar chemical properties. The noble gas cubes are of special significance since they do not form any bonds. Accumulating noble gas cubes cuts down on scoring ability.

Rules:

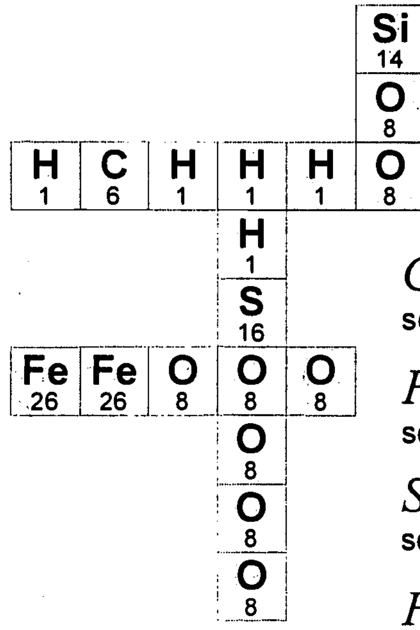
- This is a game for two to six players.
- The objective is to get the highest score.
- Each player starts with ten cubes.
- The player with the highest atomic numbered element goes first and play continues with the player to the right.
- Each player tries to build a new molecule by adding off the molecules already on the board. All combinations horizontal and vertical must satisfy the rules for proper formation of molecules.
- The score is calculated by adding up the atomic numbers of all the elements in the molecule.
- Cubes may be rotated to use any element on any face.
- Any molecule may be challenged by any player before the next turn begins. The player who placed the challenged molecule must prove that it satisfies the valence rules. If the rules are violated the molecule must be removed, the score is not added to the offending player's score, and the player forfeits the turn.

Players score for every molecule that their play creates. Playing into a corner or side-by-side may make more than one molecule. If all the molecules are built according to the valence rules, then all count towards the score. If any one molecule conflicts with the valence rules then the turn is forfeit and the offending player must remove all the cubes just played.

After making a play each player draws enough cubes to maintain a stack of ten by choosing random cubes from a bag or box.

A player may trade one or more cubes for ones in the bag in place of a turn.

The figure at the right shows a successful game after four moves.



CH_3OH
score: 18 points

Fe_2O_3
score: 76 points

SiO_2
score: 30 points

H_2SO_4
score: 50 points

End Games

There are several choices of ways to end the game. The group should agree on one before starting.

Option 1: The game ends when all the cubes have been used up and one player runs out of cubes.

Option 2: The game ends when one player (the winner) reaches a set score. Choose 500, 750, or 1000 points.

Valence Rules:

A valid molecule is one for which the total valence is zero. The total valence is obtained by summing the valances of the constituent elements. The following example shows a correct molecule where all the valences are permissible and the total of valences sums to zero for the entire molecule.

The periodic table should be consulted for possible valances. The chart can be used to work out or prove molecules.

Chapter 3
Level B Activities

Section 3.1: Learning Goals for Level B

The Periodic Puzzle Curriculum provides a basic introduction to chemistry. We introduce the key concepts:

- Elements are the simplest substances, and an atom is the smallest indivisible portion of an element,
- Compounds are substances made from multiple atoms, and a molecule is the smallest indivisible portion of a compound,
- The Periodic Table is a chart of the elements that reminds us of similarities of chemical properties,
- Atoms are made of protons and neutrons in the nucleus, and electrons in layers or shells.

- The arrangement of electrons in the layers determines chemical properties.
- Chemical reactions neither create, destroy, nor transform elements; they only rearrange the atoms of the reactants to make the products

We use the Periodic Puzzle blocks as model atoms for these activities. In this way, we can do "experiments" building molecules and making chemicals react, while clearly visualizing what is happening and without using expensive or dangerous apparatus or chemicals. We will work through a basic introduction to chemistry that will give the students familiarity with the Periodic Table and what can be learned from it.

Apparatus:

- One Periodic Puzzle Set per group
- One Activity Guide per student

Key Vocabulary for Level A

- **Element:** The simplest substances, which cannot be reduced to other substances by chemical reactions.
- **Atom:** The smallest indivisible unit of an element.
- **Compound:** A more complex substance, made of combinations of elements.
- **Molecule:** The smallest indivisible unit of a compound.
- **Periodic Table:** A chart of the elements which reminds us of chemical similarities between the elements.
- **Protons:** One of the particles of which atoms are made of. The **atomic number** of an element tells us how many protons are in the atom.
- **Neutrons:** One of the particles of which atoms are made of. The **atomic mass** of an element tells us how many protons and neutrons are in the atom.
- **Isotope:** An element has a unique **atomic number**, or number of protons, but may have many values for the **atomic mass.** This means that the element may exist with different numbers of neutrons. These are different **isotopes** of the element.
- **Groups:** The Periodic Table shows the elements divided into different **Groups** by columns. These groups share chemical similarities.
- **Reactants:** The ingredients that go into a chemical reaction.
- **Products:** The results of a chemical reaction.

Section 3.2: The Periodic Table
Activity Guide PT-B1

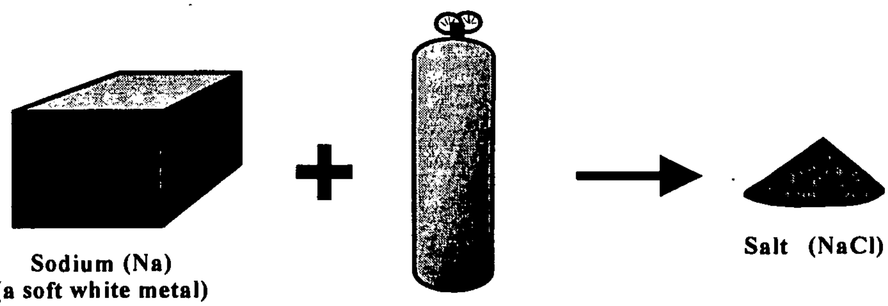
The first Activity Guide is intended to introduce the students to the Periodic Table. The key concepts learned include elements and compounds, and their composition from atoms and molecules. The odd shape of the Periodic Table, and the more common elements, must become familiar in order to explore them in more detail in the next lesson. This activity is essentially similar to Activity A1.

WHAT IS THE PERIODIC TABLE?

Everything in our world is made of atoms. There are many different types of atoms. Some are large and heavy, some are small and light. Some are very reactive, and combine fiercely with other atoms, often releasing heat. Some are inert, and never combine with other atoms at all.

Chemistry is the study of atoms and how they combine together. The different types of atoms are called elements.

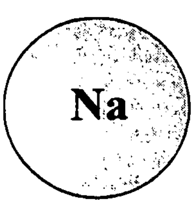
Elements are the simplest substances, and atoms are the smallest unit of an element. In the chemical reaction at the right, sodium and chlorine are both elements.



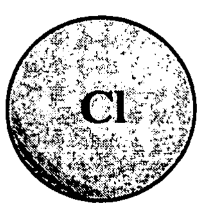
Sodium (Na)
(a soft white metal)

Chlorine (Cl)
(a poisonous, corrosive gas)

Salt (NaCl)



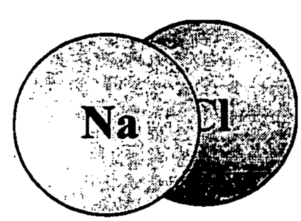
One sodium atom



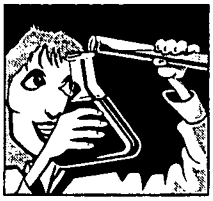
One chlorine atom

The smallest piece of sodium that can be found is an atom of sodium. Similarly, the smallest piece of chlorine that can be found is an atom of chlorine.

Compounds are mixtures of elements bonded together in specific ratios of elements, and **molecules** are the smallest units of compounds. In the reaction above, salt is a compound. The smallest piece of salt that can be made is a molecule of salt. One molecule of salt is made of one atom of sodium and one atom of chlorine.



One salt molecule



Early scientists were very confused about the differences between compounds and elements. They tried mixing, boiling, dissolving in acid, burning, and many other processes to transform one substance into another. Sometimes, very profound changes could be made by simple mixing: for example, mixing sodium and chlorine together to make salt. Why not, these pioneers asked, make gold from lead? How about diamonds from glass?

We now know that **chemical reactions rearrange atoms, they don't change atoms from one element to another.** Thus, we can make salt from sodium and chlorine, because salt has both sodium and chlorine atoms in it. We can transform iron into rust without doing *anything*. Rust is made from iron (**Fe**) and oxygen (**O**), which is always present in the air. We can't make gold from lead, or diamonds from glass, because either reaction would require changing one element into another.

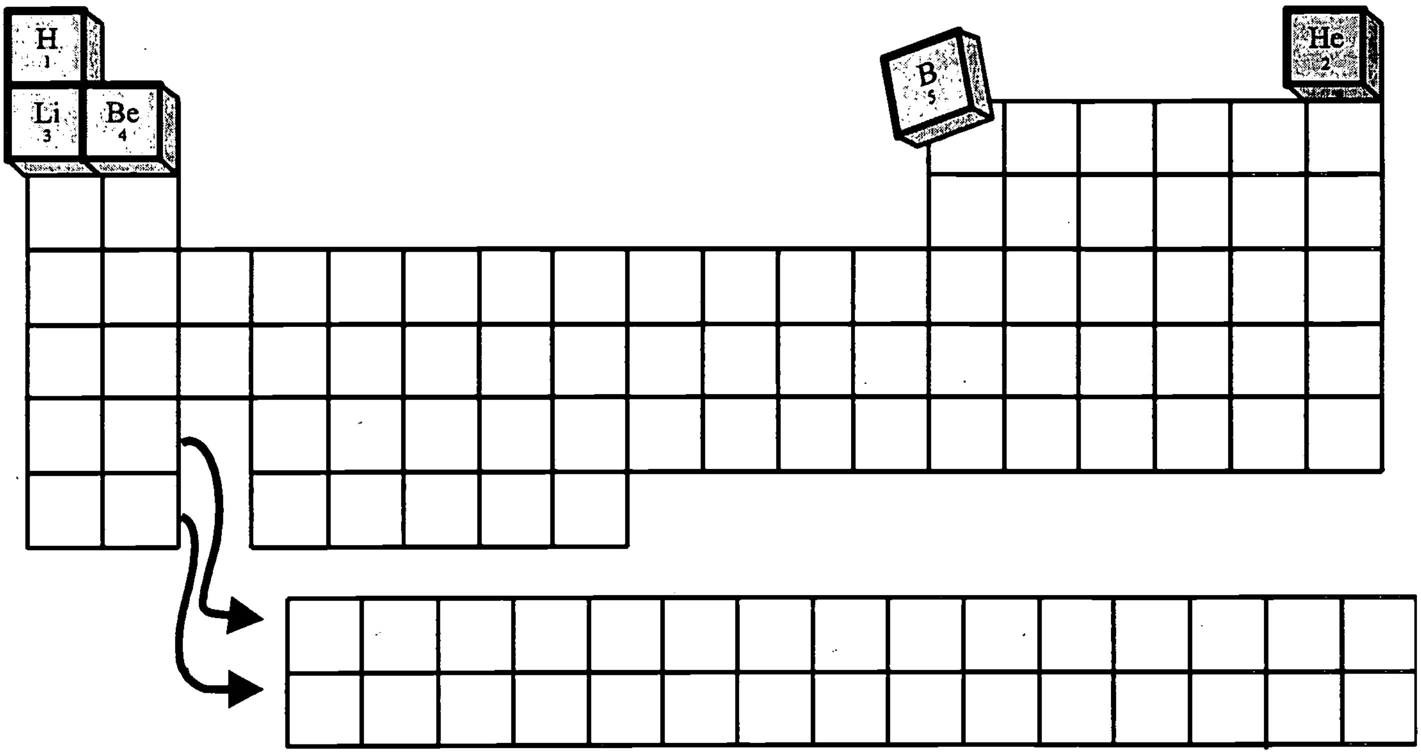
B1.1: Do astronauts need to worry about iron rusting on the moon? Why or why not?

no.....there is no oxygen to combine with iron to make rust

Element - a material made from only one type of atom

Compound - a material made from two or more types of atoms

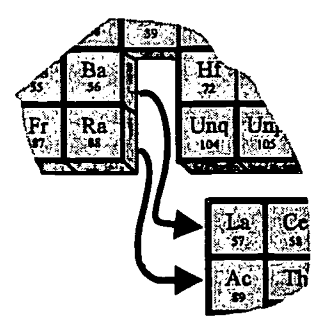
The chemical elements can be arranged in groups with similar properties. The **Periodic Table** is a chart of the elements, arranged to remind us of these similarities. The chart below shows the *shape* of the Periodic Table, and the first few elements in sequence from left to right. The elements are arranged in sequence using the **atomic numbers.**



B1.2: Using the chart on the previous page as an example, build the Periodic Table out of the Periodic Puzzle blocks. The numbers on the blocks are the atomic numbers.

The students should be assembling the Periodic Table blocks at this point. There is no answer required for **B1.2,** *but the students should not skip this activity. This is a good time to make sure that the students are building the Table correctly. Common mistakes include using the wrong number of columns, or missing a number. It is easy to check to see that the right hand column (the noble gases) are* ***He, Ne, Ar, Kr, Xe, Rn.***

There is a tricky part down near the bottom of the table. The table breaks off between elements 56 (**Ba**) and 72 (**Hf**), and fills in the first of two long rows at the bottom (we will learn why later). It does the same thing in the row below. Be sure to fill it in correctly in this area, like in the picture at right.



IMPORTANT: Be sure that you don't duplicate the two-page Periodic Table chart onto 2-sided paper for this activity. The students will need to tape both pieces of paper together, which will be impossible if they are duplicated back-to-back. Any activities that are on the backside of the Periodic Table will be difficult to complete and to collect and grade.

B1.3: After you have built your table, tape together the chart on the next two pages, and fill in the symbols and atomic numbers for the elements. Use the chart below to get the names of the elements.

Symbols and Names for the elements

H	hydrogen	**He**	helium	**Li**	lithium	**Be**	beryllium
B	boron	**C**	carbon	**N**	nitrogen	**O**	oxygen

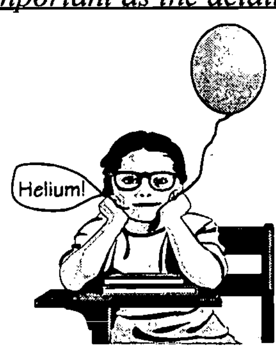
(remainder of table deleted.....it can be found in the activities)

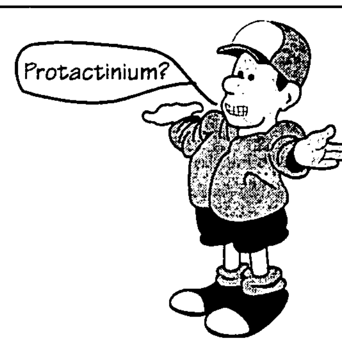
Once finished, this chart should be a resource for the students. Each student should complete a full (two page wide) chart with the atomic number, element symbol, and element name, and keep it for further use in other activities.

Assessment suggestion: It can be quite difficult to proofread an entire classroom full of Periodic Tables. Instead, at the end of this activity, go over the chart orally with the entire class, and let everybody proofread their own.

B1.4: Do some of the elements sound familiar? Pick two, and say something about them.

this is open ended. many students will pick helium, oxygen, gold, iron, silver... again, we are after familiarity with the elements, so thinking about the question is as important as the details of the answer.





B1.5: Have you heard of the following elements? What do you know about them?

Oxygen: *major component of air, necessary for life and/or fire*

Silver: *precious metal, used in coins, electrical conductor*

Mercury: *metal that is liquid at room temperature, used in thermometers*

Silicon: *useful in electronics, major component of rocks and glass*

Iron: *industrial metal, used for making steel*

Neon: *noble gas, used in electrical discharge lamps*

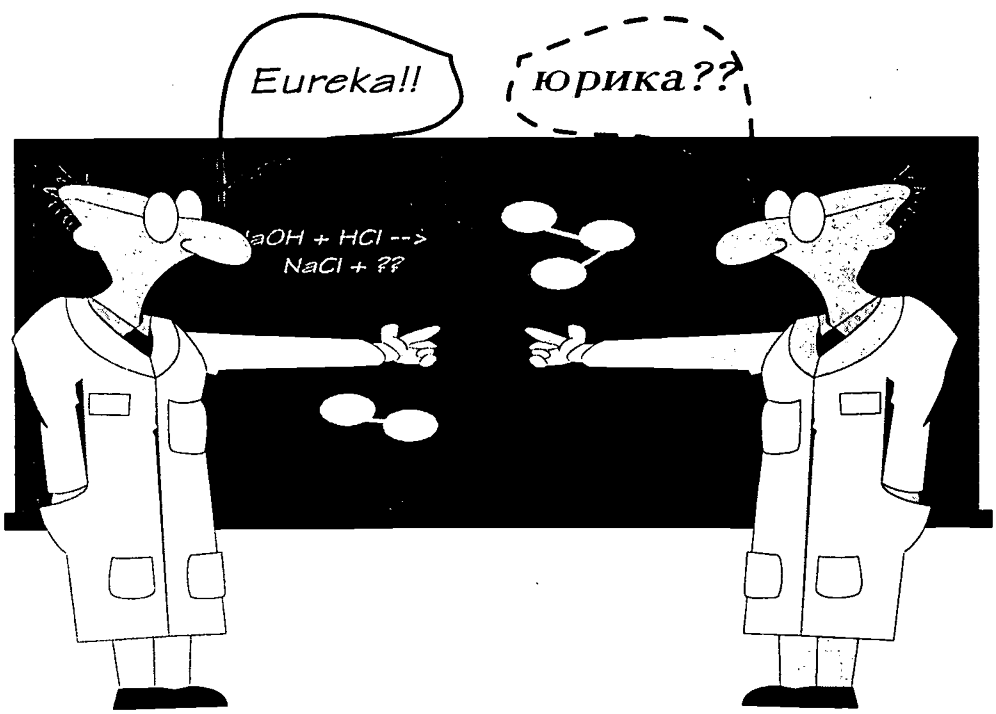
Uranium: *radioactive material, useful for nuclear power plants or bombs*

Tungsten: *hard metal, high melting point, used for light bulb filaments*

Iodine: *useful in solution for killing germs on wounds*

Krypton: ***not kryptonite,** nothing to do with superman.....a noble gas like neon*

Some of the element symbols don't seem to make sense. A typical example is the abbreviation for tungsten: is the letter **W.** Actually, tungsten was named by German scientists, and the German name for tungsten is "wolfram", so the abbreviation *does* makes sense after all.



Most of the abbreviations that aren't obvious are for similar reasons -- the elements were studied and named by scientists from around the world.

Some elements don't have names yet! Elements 104 through 108 don't occur in nature, but have been made in the laboratory. There are still discussions going on worldwide over what to name them. Many people want to name them after famous scientists who have contributed to their discovery (just like element 99 Einsteinium (in honor of Albert Einstein) or element 100 Fermium (in honor of Enrico Fermi)). This is a problem if there are more scientists than elements! What do you think you need to do to get an element named after you?

B1.6: Some of the materials below are elements, and some are not. Circle the elements.

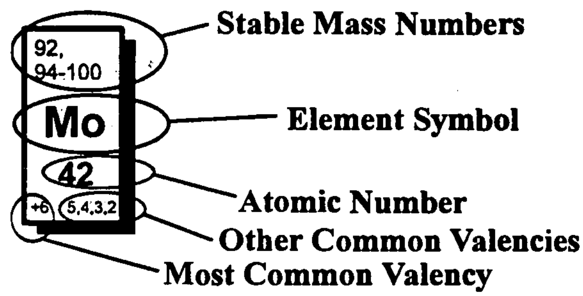
air	gas	oxygen	nitrogen	argon
iron	steel	copper	brass	aluminum
tin	nickel	bronze	chromium	lead
gold	silver	sapphire	ruby	platinum
chlorine	quinine	strychnine	iodine	bromine

Section 3.3: Valence and the Families of Elements

Activity Guide PT-B2

The second Activity Guide defines a few key terms (atomic number, atomic mass, valence), and adds to the Periodic Table these numbers for the more common elements (i.e. all elements up to xenon). In Level B activities, we explain the "why" of valence rather than just state the rules (as in Level A). This activity and the subsequent two will complete this understanding, after which we rejoin the concepts we learned in Level A to balance chemical equations.

In the last lesson, we learned that the elements were numbered in sequence with the **atomic number.** The atomic number is the number that is used to order the elements in the Periodic Table. There are several other numbers which are used to identify atoms.



The next page shows a chart of the Periodic Table, with some of these other numbers added. These numbers tell us what is in the atom, and how the atom wants to combine with other atoms.

Take a look at the key to the chart at the right. The symbol for the element and the atomic number are the same as we used last lesson. These are printed on the blocks as well.

The **atomic number** is unique to each element. There is only one element with atomic number 42, and that is Molybdenum (**Mo**). The atomic number tells us how many **protons** are in the atom. Protons are one of the three types of particles that atoms are made of.

B2.1: How many protons are in an oxygen atom?

the atomic number is eight, so there are eight protons

The **atomic mass** or stable mass number is the number or numbers at the top. The atomic mass is the total number of protons and **neutrons** in the atom. If there is more than one number here, than there are several **isotopes**, or atoms of different mass, that exist. For example, molybdenum has stable mass numbers of 92, 94, 95, 96, 97, 98, 99, 100. Since molybdenum must always have 42 protons, these isotopes have 50, 52, 53, 54, 55, 56, 57, and 58 neutrons, respectively.

B2.2: How many neutrons are in the oxygen isotope that has a mass number of 16?

the mass number is the number of protons and neutrons, so there are eight neutrons.

(The table which appears on the following page of the Activity Guide does not appear here).

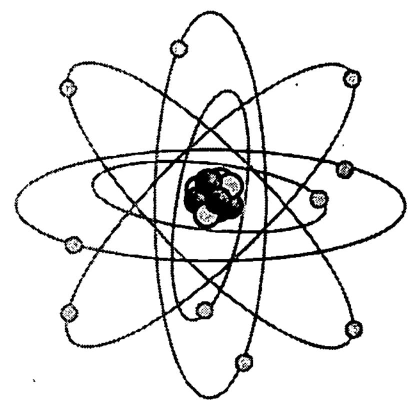
The **valence** is the number of electrons that the atom has to contribute when forming compounds. Atoms join together to form molecules in such a way as to share extra electrons. Sodium has a valence of +1, since it has one electron to lend out. Chlorine has a valence of -1, since it has one missing electron which it wants to borrow.

Salt.has one sodium and one chlorine, since they cancel out their valencies together. Make a salt molecule out of one sodium atom and one chlorine atom with the Periodic Puzzle blocks.

WHERE DO THESE NUMBERS COME FROM?

Let's look at the rules for building atoms.

Rule #1

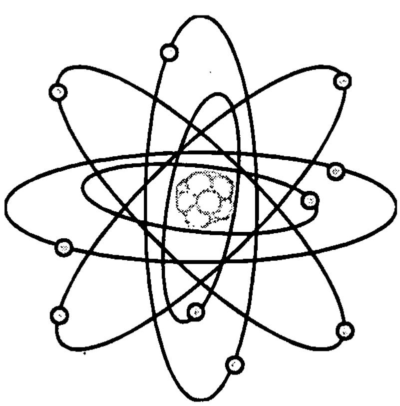


The atom has a small nucleus, which contains protons and neutrons. The protons have a positive electrical charge, and the neutrons are not charged at all.

The atomic number is the number of protons in the nucleus.

B2.3: How many protons are there in Hydrogen? ____*one*_______

B2.4: What is the charge of the Oxygen nucleus? ____*+8*_______



Rule #2

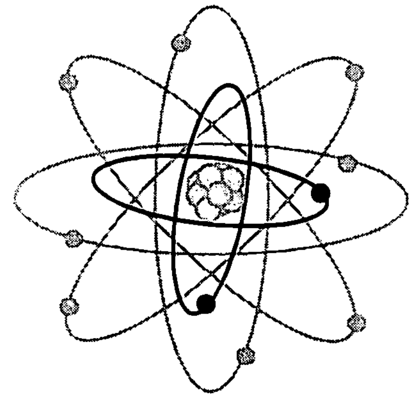
Electrons orbit the nucleus at a large distance. Electrons have a negative charge (exactly the opposite charge from the protons). Atoms want to be neutral -- they want the same number of electrons and protons so that the electrical charge cancels out.

B2.5: How many electrons orbit a neutral Helium atom? ___*two*___

B2.6: How many electrons orbit a neutral Uranium atom? __*92*___

Rule #3

The electrons orbit the nucleus in shells, and only a limited number of electrons will fit in each shell. The first shell only holds two electrons.

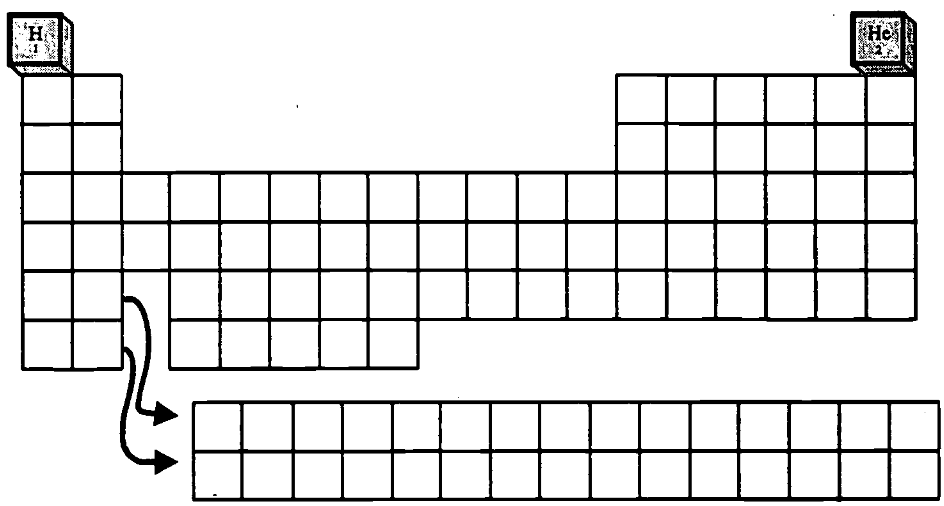


B2.7: Which two elements have all their electrons in the first shell?

hydrogen and helium

The connection between the pictures of the atoms (with a fixed number of electrons in a shell) and the pictures of the Periodic Table (with the same number of elements in a row) should be clear to the students. It is a good idea to ask students to verbalize this connection when circulating during this part of the hands-on activities.

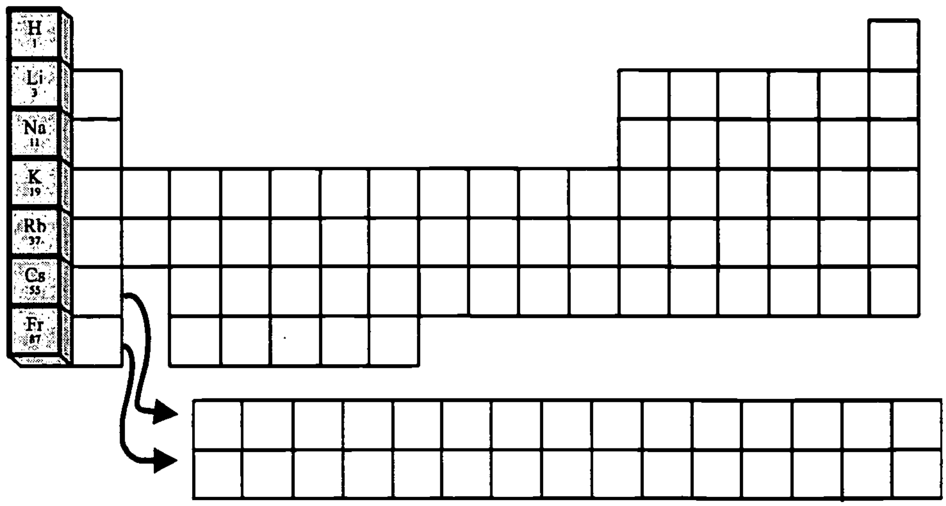
LET'S START REBUILDING THE PERIODIC TABLE, ROW BY ROW.



Rule #3 said that only the first two elements could fit their electrons in the first shell. Build the first row of the table using these two elements. You now have a complete shell. The last element in this shell is both neutral, and has a full shell. There is very little it needs from any other atom -- and indeed, it will not form any compounds with any other elements.

LET'S TAKE A TOUR OF THE COLUMNS OF THE PERIOD TABLE.

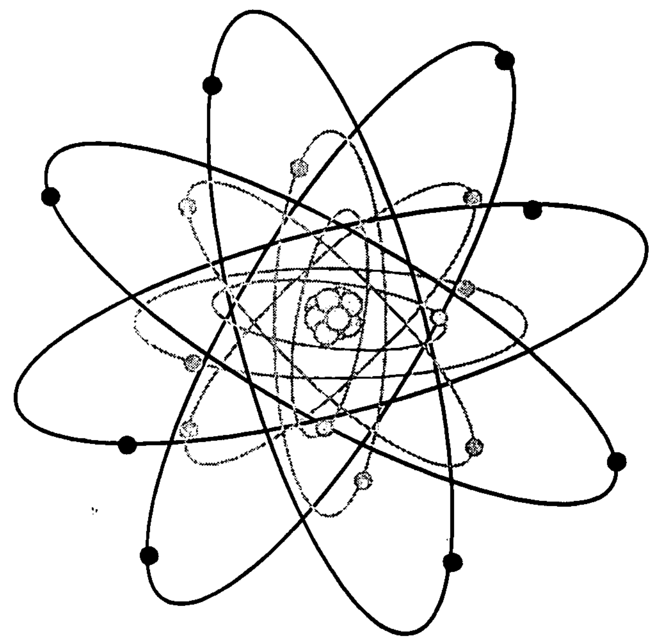
Start with the first column. These elements all have only one electron starting to fill a shell. Because of this, they very easily lend this extra electron out to make compounds with elements that need electrons.



These elements, called the **GROUP 1A** elements, are *very* reactive. They are only rarely found in the pure form in nature, because they want to combine with other elements so readily.

Except for hydrogen, the Group 1A elements are all soft metals in the pure form. They are so reactive, however, that they quickly combine with air to make oxides. Cesium can even burst into flame when exposed to air.

The Group 1A elements all have a valence of +1.



Rule #5

The third electron shell holds only eight more electrons.

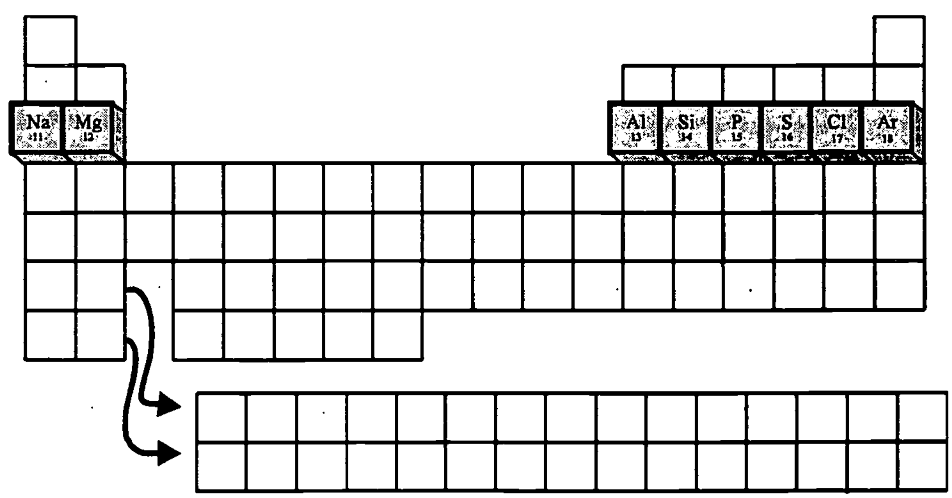
B2.10: Which neutral element has one electron in the third shell?

sodium

B2.11: Which neutral element has all eight electrons in the third shell?

argon

Add the third row to your table. Once again, the last element in this row has a complete shell, and is unwilling to react with other elements.



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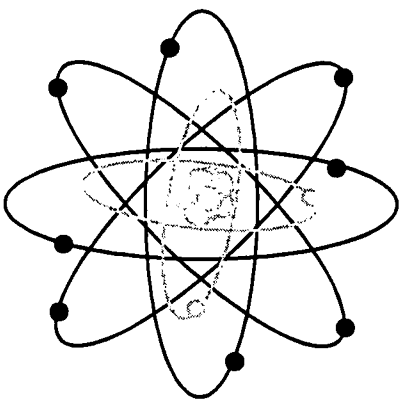


Rule #4

The second electron shell holds only eight more electrons.

B2.8: Which neutral element has one electron in the second shell?

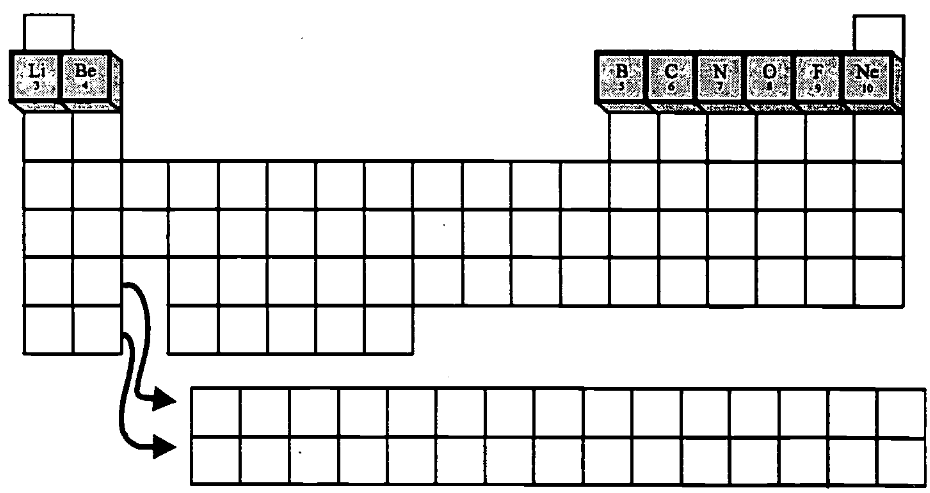
______*lithium*______________________________________

B2.9: Which neutral element has all eight electrons in the second shell?

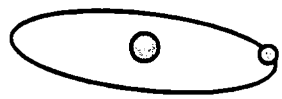
_______*neon*______________________________________

Add on the second row of the Periodic Table, using Rule #4.

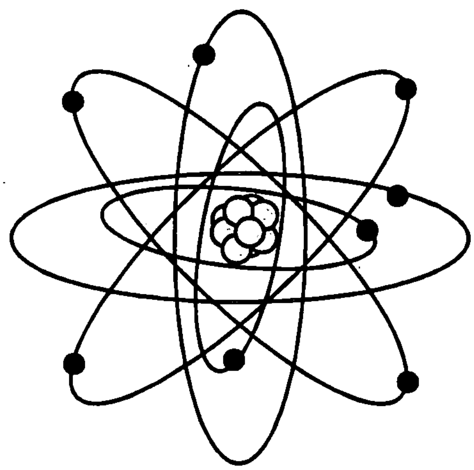
There are eight more elements in this row. The shell is again complete with the last element in this row. This is another element that will not react to make compounds.



Atoms will try to combine with one another and share electrons so that they can be neutral *and* have complete shells. Because of this, the atoms with one extra electron in the outer shell will behave differently than atoms with two extra electrons in the outer shell. We call this property **valency.** The valence of an atom is the number of electrons in the outer shell.



Let's look at an example. **Hydrogen** has only one electron, but the first shell has room for two. Hydrogen has an extra electron floating around that it would like to share, leaving the first shell empty. Since it has an extra electron to share, we say that hydrogen has a valency of +1.



Oxygen, on the other hand, had a total of eight electrons -- two in the first shell, and six in the second shell. Since the second shell has room for eight electrons, there are two "holes" in the shell waiting to be filled. If oxygen can find some way to share two electrons to fill this shell, then it will have a full second shell. Since there are two holes in the outer shell to share, we say that oxygen has a valence of -2.

What happens when we bring oxygen and hydrogen together? Hydrogen could lend its extra electrons to oxygen, but then neither element would be neutral. Instead, one oxygen atom and two hydrogen atoms will bond together to form a **molecule**. The material made from a lot of these molecules is called a **compound.** Each molecule will have one oxygen and two hydrogens stuck together and sharing electrons. This way, all the shells can be full, and all the atoms can be neutral.

When we form a molecule like this, we write it using the abbreviations for the elements. Earlier, we learned that we could make salt by combining sodium (**Na**) with chlorine (**Cl**). Although sodium is a soft metal and chlorine is a poisonous gas, salt is a common chemical that we sprinkle on our food! We write the formula for salt as **NaCl.** Similarly, when we combine one oxygen and two hydrogen atoms, we make a molecule that we write as $\mathbf{H_2O}$. The subscript "2" shows that there are two hydrogen atoms in the molecule.

B2.14: Have you ever heard of $\mathbf{H_2O}$? What is it?

water

B2.15: Find blocks from the Periodic Table for hydrogen, oxygen, sodium, and chlorine. Combine the blocks on the desk to make salt and $\mathbf{H_2O}$ molecules.

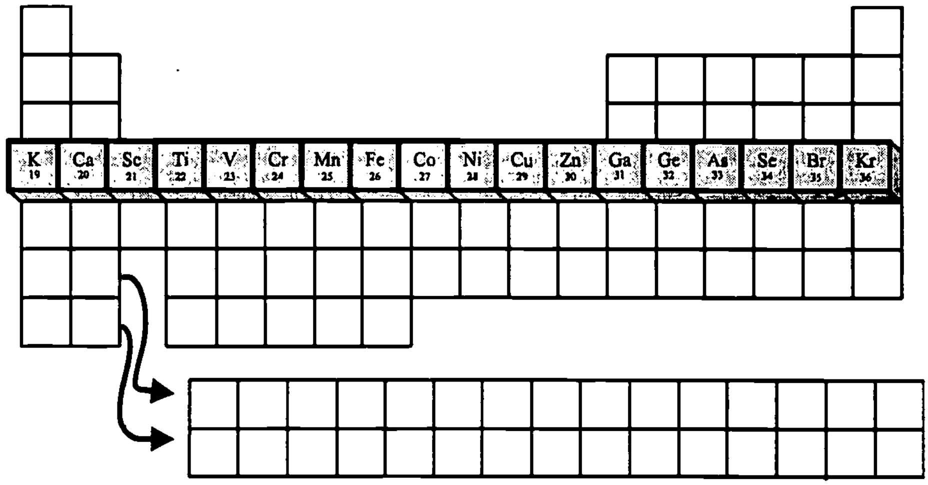
Rule #6

The fourth shell can hold eighteen more electrons.

Add the fourth row to the Periodic Table. (We won't try to draw these electron shells...)

B2.12: Which element has a complete shell in the fourth row?

___*krypton*___________________



Rule #7
The fifth shell can hold another eighteen more electrons.

Add the fifth row to the Periodic Table.

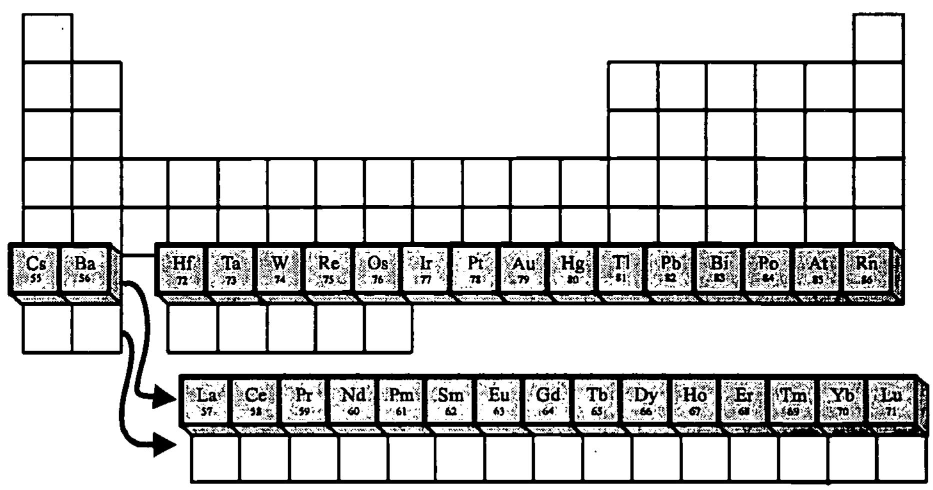
Rule #8

The sixth shell can hold thirty-two more electrons.

Add the sixth row. Be careful to include the Lanthanide series when you add the sixth row.

B2.13: Which element completes the sixth shell?

______*radon*_______________



Rule #9
The seventh shell can hold another thirty-two more electrons.

Finish building the Periodic Table by adding the seventh row (don't forget the Actinide series).

Section 3.4: A Tour of the Periodic Table

Activity Guide PT-B3

We now survey the Groups, or columns of the Periodic Table. Along the way, we will learn a great deal of "culture" about the elements. The particulars about the elements are much easier to remember if we remember the similarities within groups of elements. This is the structure we will use to explore the Periodic Table. This lesson only covers the more familiar elements; Activity B4 continues on with the remainder of the Periodic Table (and can be skipped without harm).

In the last two lessons, we learned that the Periodic Table groups elements in ways to remind us of the chemical similarities of the elements. We learned that these similarities are due to the way that electrons fill the shells around the atom.

We learned that the each **row** of the Periodic Table contains the atoms that have the same partially filled outer shell. The first row has all the atoms that have electrons in the first shell (**H, He**). The second row has all the atoms that have electrons in the second shell (**Li, Be, B, C, N, O, F, Ne**). And so on.

The columns of the Periodic Table tell us which atoms share the **same number of electrons, or the same number of missing electrons** in the outermost shell. The columns thus tell us which elements behave most similarly.

There are many other common compounds that we can write the chemical formulas for.

B2.16: Ammonia is made up of nitrogen (**N**) and hydrogen (**H**). Nitrogen has a valence of -3, and hydrogen has a valence of +1. Make an ammonia molecule out of blocks. What is the symbol for ammonia?

NH_3

B2.17: Carbon dioxide is made up of carbon (**C**) and oxygen (**O**). Carbon has a valence of +4. What is the valence for oxygen? Make a carbon dioxide molecule out of blocks. What is the symbol for carbon dioxide?

CO_2

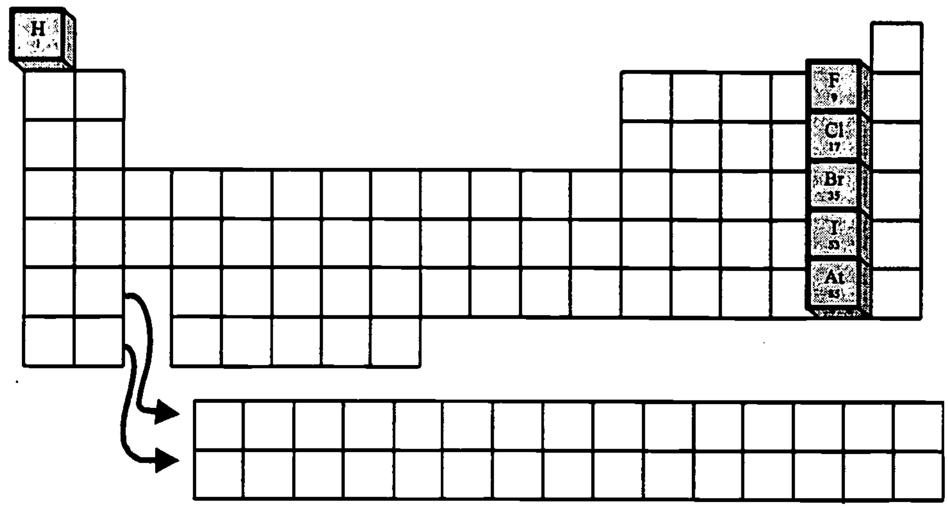
B2.18: Rust is what you get when you let iron (**Fe**) with a valence of +3 combine with oxygen (**O**) with a valence of -2. Make rust out of blocks, and write down the symbol for rust.

Fe_2O_3

B2.19: Methane, or natural gas, is what you might cook with or heat your house with. It is made of carbon (**C**) and hydrogen (**H**). We already learned that hydrogen has a valence of +1 and carbon has a valence of +4. Carbon actually has four electrons in the second shell, which has room for eight. That means that it can either lend its four electrons out to empty the second shell (for a valence of +4) or borrow four more electrons to complete the second shell (for a valence of -4). In methane, it borrows four electrons, and has a valence of -4. Make methane out of blocks, and write down the symbol for methane.

CH_4

The next to last column is all the elements that have a shell completely filled except for one electron. These are the **GROUP 7A** elements. They are just as reactive as the Group 1A elements, for exactly the opposite reason. They are so willing to share an electron that any other atom is willing to lend, that they will combine very readily to form compounds. The Group 7A elements are corrosive and pungent.



Note that we include hydrogen in this group as well! Hydrogen has only one electron in a shell big enough for two. It will happily share electrons in such a way as to lend its electron out (and empty its shell), or take another electron (and complete its shell).

These elements all have a valence of -1.

B3.1: We learned earlier that we could combine sodium with chlorine to make salt, **NaCl**. We now see why salt has only one sodium and one chlorine; sodium has a valence of +1 and chlorine has a valence of -1. Write down the chemical formulas for ten other compounds that can be formed by combining Group 1A elements with Group 7A elements, and make them out of the Periodic Puzzle blocks.

many are possible: LiF, LiCl, LiBr, LiI, LiAt, NaF, NaCl, NaBr, NaI, NaAt,

KF, KCl, KBr, KI, KAt, RbF, RbCl, RbBr, RbI, RbAt,

CsF, CsCl, CsBr, CsI, CsAt, FrF, FrCl, FrBr, FrI, FrAt

B3.2: Hydrogen is a special case. When we combine hydrogen (from Group 1A) with one of the Group 7A elements, we form an especially corrosive combination. **HCl** is the chemical symbol for hydrochloric acid. Write down the chemical symbols for three other acids that use hydrogen and Group 7A elements, and make them out of the Periodic Puzzle blocks. Try to guess their names.

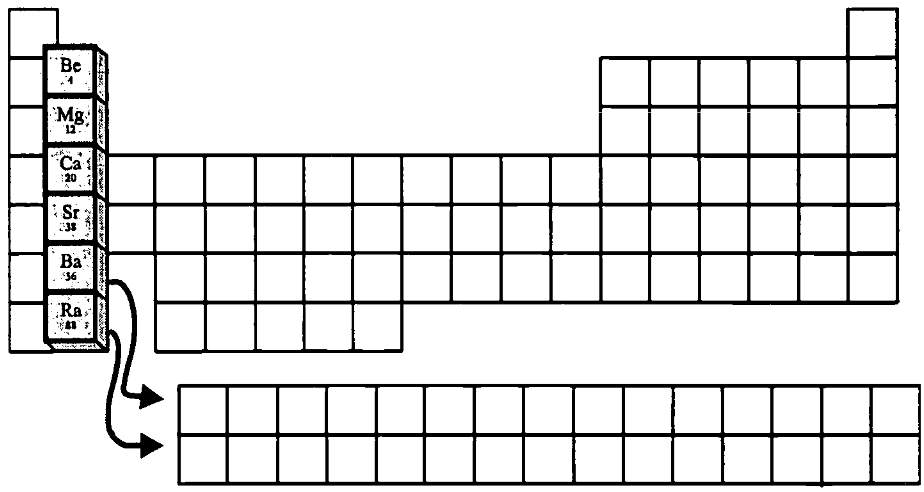
HF is hydrofluoric acid (extremely corrosive and toxic, will eat through glass!)

HBr is hydrobromic acid HI and HAt are less common

(it is not crucial that they can guess the names right, but they should try!)

The second column of the Periodic Table contains those elements that have two electrons in the outermost shell. They are reactive, but not as reactive as the Group 1A elements.

Although most of these are rarely found in their pure form, magnesium is occasionally useful as a structural metal, because it is so light (it is the first practical metal in the Periodic Table). Ultra-lightweight bicycles might have magnesium frames, or frames made out of an **alloy**, or mixture, of magnesium and other metals.



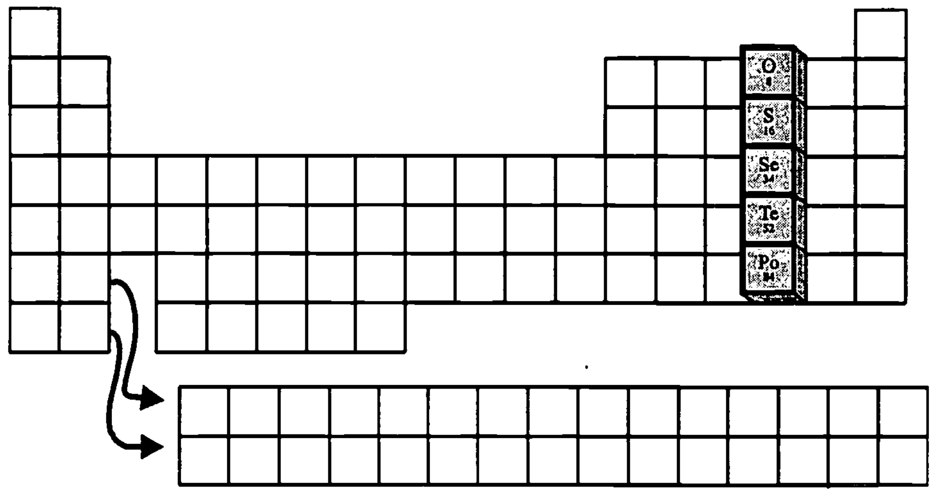
These are called the Group 2A elements, and they all have a valence of +2.

B3.3: Magnesium fluoride is a clear, hard glassy material. It is often used as a hard anti-reflective coating on optical surfaces, such as binocular or camera lenses. The chemical symbol for magnesium fluoride is $\mathbf{MgF_2}$. Make magnesium fluoride out of the Periodic Puzzle blocks. Write down the chemical symbols for four more compounds made from Group 2A elements and Group 7A elements, and make them from the blocks.

many possibilities: **BeF_2, $BeCl_2$, $BeBr_2$, BeI_2, $BeAt_2$, or $MgCl_2$, $MgBr_2$, etc.**

CaF_2, $CaCl_2$, etc. SrF_2, $SrCl_2$, etc.

The Group 6A elements are those which have two missing electrons from the outermost shell. They usually have a valence of -2 (or +6). They are not as strongly reactive as the Group 1A, 2A, or 7A elements. Oxygen is found in its pure form in air (although it forms a molecule with itself, O_2). Sulfur can be found in nature in its pure form; a yellow powdery substance.



B3.4: Calcium oxide is a hard white material. Eggshells are largely calcium oxide, and there is a great deal of it in bones, as well. What is the formula for calcium oxide? Make it out of blocks.

CaO

B3.5: Make four more compounds out of Group 2A and Group 6A elements out of blocks, and give their symbols here.

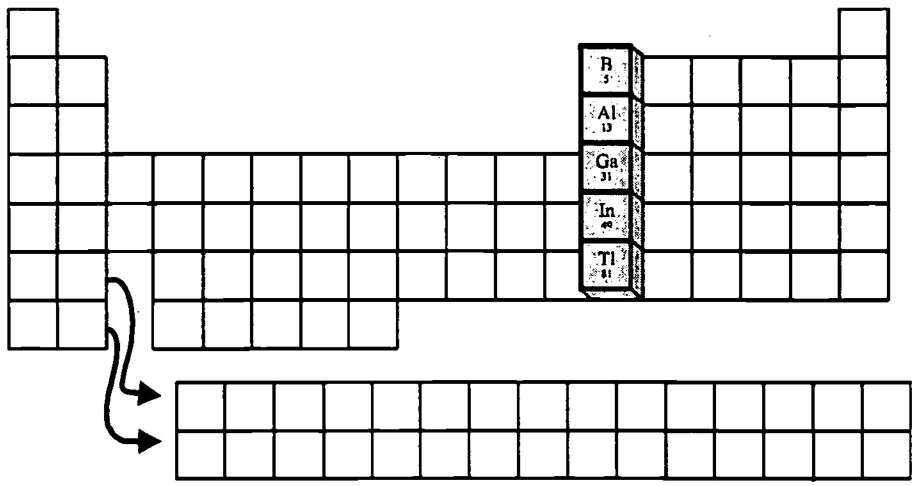
again, many possibilities: **BeO, BeS... MgO, MgS... CaO, CaS... SrO, SrS...** *etc.*

B3.6: Make four compounds out of Group 1A and Group 6A elements out of blocks, and give their symbols here.

again, many possibilities: **Li_2O, Li_2S..... Na_2O, Na_2S.... K_2O, K_2S...** *etc.*

The Group 3A elements are those which have three electrons in the outermost shell. They usually have a valence of +3.

The Group 3A elements are mildly reactive. Pure aluminum, for example, is stable enough to use as a common structural material.



B3.7: Make four compounds out of Group 3A and Group 7A elements out of blocks, and give their symbols here.

many possibilities: **BF_3, BCl_3....** **AlF_3, $AlCl_3$....** **GaF_3,** *etc.*

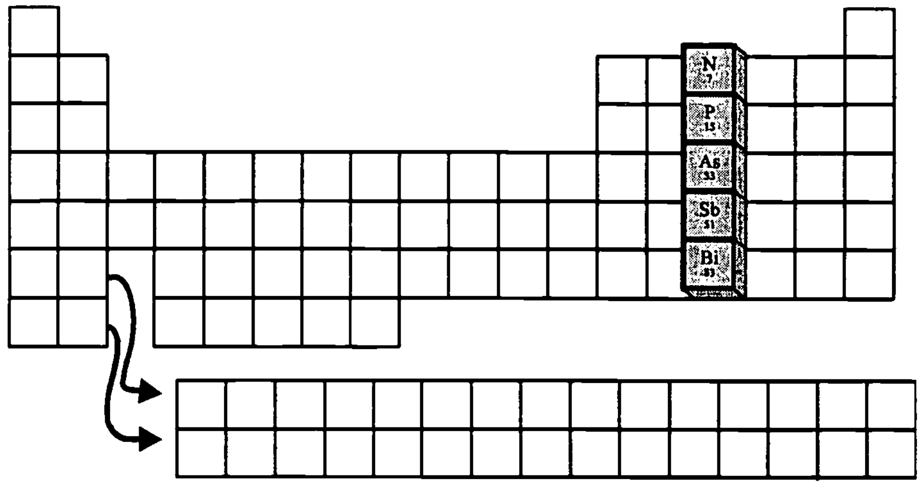
B3.8: Do the same with Group 3A and Group 6A elements.

many possibilities, but these are tougher:

B_2O_3, B_2S_3..... **Al_2O_3, Al_2S_3,** *etc.*

The Group 5A elements are those which have three missing electrons in the outermost shell. They usually have a valence of -3 (or +5).

The Group 5A elements are mildly reactive. They can exist in nature in their pure form: nitrogen makes up nearly 80% of the air that we breathe (although it is in a molecule with itself, N_2).



The group 5A elements often form much more complex molecules that have a mixture of elements from several groups. Nitrogen and phosphorous, for example, are very important in organic molecules -- molecules that make up living organisms. Some nitrogen compounds are also very efficient at storing large amounts of chemical energy. Most explosives use nitrogen compounds as a key to store a great deal of energy and release it quickly when ignited.

B3.9: Group 5A elements have recently started becoming important in electronics. Some new semiconductors, called 3-5 semiconductors (usually written in roman numerals, III-V), make use of interesting electronic properties of compounds made with Group 3A elements. List six compounds made from Group 3A and Group 5A, and make them out of the puzzle blocks.

lots of possibilities: **BN, BP.... AlN, AlP, AlAs..... GaN, GaP, GaAs....** *etc.*

(the ones of late electronic interest are **GaN, GaP, GaAs, InP, InAs, InSb***)*

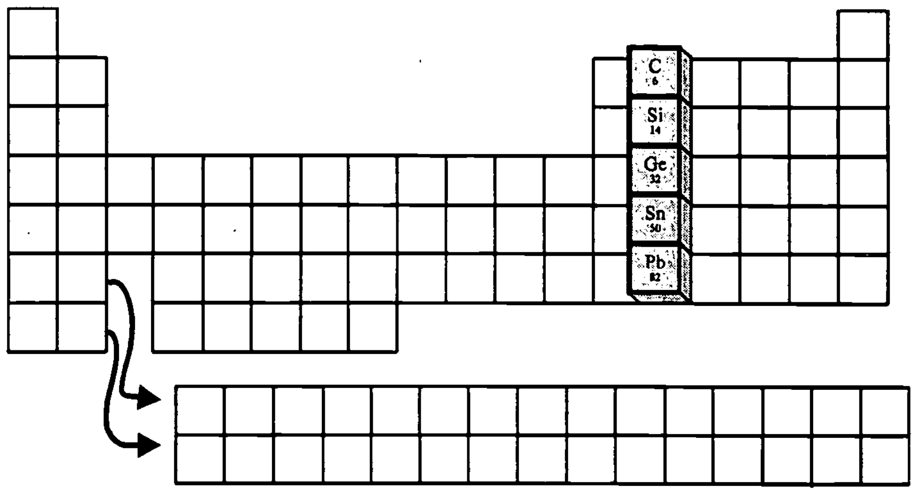
B3.10: Make four compounds out of Group 1A elements and Group 5A elements. List them here and make them out of the puzzle blocks.

many possibilities: **Li_3N, Li_3P..... Na_3N, Na_3P..... K_3N, K_3P...** *etc.*

B3.11: Make four compounds out of Group 2A elements and Group 5A elements. List them here and make them out of the puzzle blocks.

lots of possibilities, but more difficult to figure out:

Be_3N_2, Be_3P_2.... Mg_3N_2, Mg_3P_2.... Ca_3N_2, Ca_3P_2....*etc.*



The Group 4A elements are those which have four electrons in the outermost shell (at least for the first couple rows). We will later see that the larger shells fill up in a more complex and layered way, which still leaves four electrons in the outermost part of the shell for **Ge, Sn, and Pb.** They all have a valence of +4

Since these elements also have four missing electrons from the outermost shell, they should also have a valence of -4, but in fact only carbon ever does.

These elements form the most complex molecules of all. They are not particularly reactive, but can combine in many ways with elements from multiple groups of the Periodic Table.

Carbon is the essential element that all living organisms are based on. There is an entire subject within chemistry, called organic chemistry, which is really just the study of carbon compounds. In nature, carbon can be found in two different pure forms. Most of the time, it is graphite - a dark powder. Under extremes of pressure and temperature, however, carbon can form diamond, which is the hardest substance known to man.

We have also all heard of silicon, which is the material that nearly all semiconductors are made from. Silicon, and also Germanium, has very useful and complex electronic properties when combined with very very small amounts of impurity elements. Computer chips are made from tiny pieces of silicon, with patterns of impurities microscopically printed to make an electric circuit.

B3.12: Make four compounds from Group 4A and Group 6A elements with the blocks, and give their chemical symbols here. Did you think of carbon dioxide?

lots of possibilities: CO_2, CS_2, CSe_2,.... SiO_2, SiS_2, $SiSe_2$,.... *etc.*

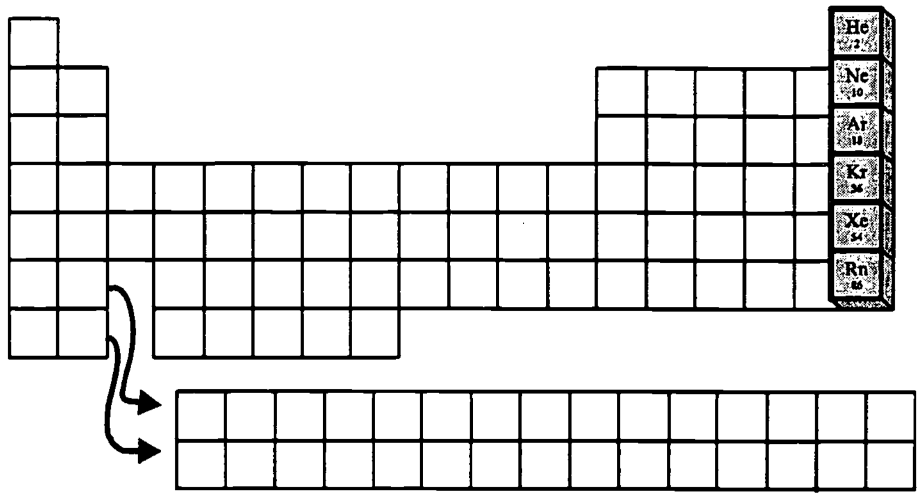
(if the opportunity arises, point out that SiO_2 *is the bulk of rock, sand, and glass).*

B3.13: Carbon tetrachloride is made of carbon and chlorine. Make this and three other compounds from Group 4A and Group 7A elements with the blocks, and give their symbols here.

lots of possibilities: CCl_4, CF_4, CBr_4,.. SiF_4, $SiCl_4$, $SiBr_4$, ... *etc.*

The Group 8A elements are the ones with completely filled outermost shells. They have a valence of 0, since they neither want have extra nor missing electrons to share.

These elements don't form compounds at all. They are found in nature in their pure, gaseous, form only. Early scientists called the Group 8A elements the **noble gases,** since they behaved like royalty and refused to combine with any of the other elements.



B3.14: Have you heard of helium? Where have you used it?

in balloons! helium is less dense than air, so it floats nicely

B3.15: There is a significant amount of argon in the air that we breathe (almost 1%). Do you think our bodies do anything with the argon in the air? Why or why not?

argon is inert - it does not react with anything. our bodies use food, air, and water in chemical reactions. argon has no effect on our bodies at all.

B3.16: Have we left out any elements? Which ones?

we haven't talked about the "ones in the middle" yet.

Section 3.5: Orbital Names and the Transition Elements

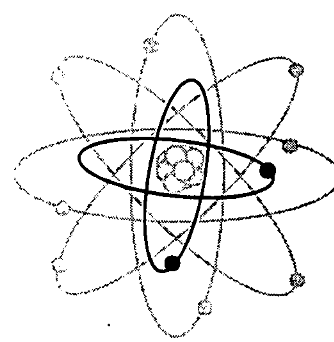
Activity Guide PT-B4

We now finish our survey of the Groups, or columns of the Periodic Table. What remains are the transition elements: the elements in the middle of the Periodic Table. These are harder to understand, because the chemical properties are determined by more subtle ordering of the electrons within shells. This makes this material a bit harder to digest for most students. It may be included or skipped without compromising further lessons.

We have learned that electrons fill orbit the atom in shells, and that the chemical behavior of the atom depends on how many electrons are left in the outermost, partially filled shell.

This chemical behavior becomes a bit more complicated further down in the Periodic Table, because the shells have additional layers, and the electrons fill the layers in a peculiar order. Let's look at some of our rules from Activity **B2**.

The first shell only holds two electrons. The first shell is the simplest, and has no layers to worry about. We call a shell that holds only two electrons an **s-shell.** The first shell consists of only the first s-shell, and is called the *1s* shell.

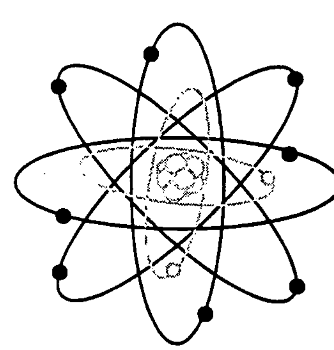


1s shell

B4.1: List the elements that fill up the *1s* shell.

hydrogen and helium

The second shell holds only eight more electrons. The second shell actually has two layers. The first layer to fill up is another s-shell, the *2s* layer, which holds two electrons. The next layer holds the remaining six electrons. Shells which hold six electrons are called **p-shells.** This is called the *2p* layer.



2s and 2p shells

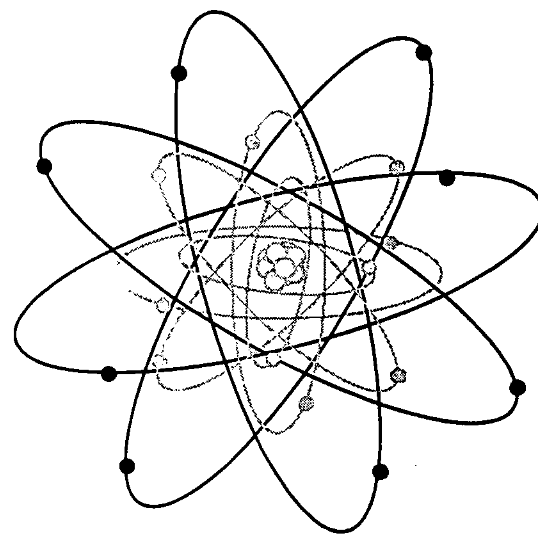
B4.2: List the elements that fill up the *2s* shell.

lithium and beryllium

B4.3: List the elements that fill up the *2p* shell.

boron, carbon, nitrogen, oxygen, fluorine, and neon

The third shell holds another eight more electrons. The third shell is just like the second, and is composed of two electrons in the *3s* layer and six electrons in the *3p* layer.



3s and 3p shells

B4.4: List the elements that fill up the *3s* shell.

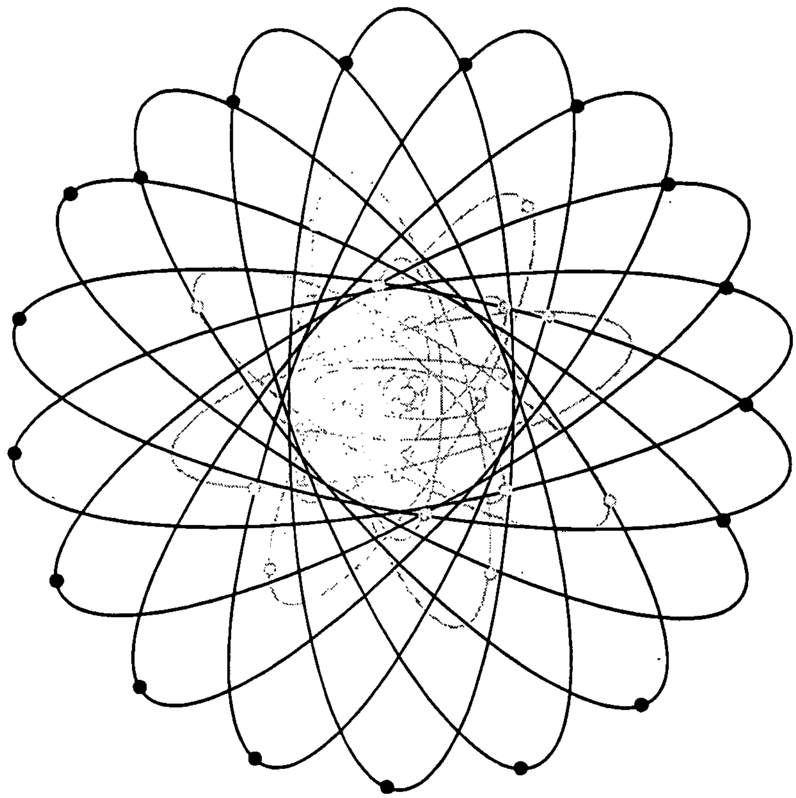
sodium and magnesium

B4.5: List the elements that fill up the *3p* shell.

aluminum, silicon, phosphorus, sulfur, chlorine, and argon

The fourth shell can hold only eighteen more electrons. This shell has eight electrons, just like the last couple layers; two in the *4s* layer and six in the *4p* layer. In addition, this shell has ten electrons in what is called a **d-shell**. This is numbered *3d* (not *4d*) for mathematical reasons that we don't want to know.

The fifth shell can hold another eighteen more electrons. This shell is the same as the previous one. There are two electrons in the *5s* layer, six in the *5p* layer, and ten in the *4d* layer.



4s, 4p, and 3d shells

B4.6: List the elements that fill up the *4s* shell.

potassium and calcium

B4.7: List the elements that fill up the *3d* shell.

Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn

B4.8: List the elements that fill up the *4p* shell.

Ga, Ge, As, Se, Br, and Kr

The sixth shell can hold thirty-two more electrons. (No, we won't try to draw this!) This shell has the first eighteen as we would expect them by now: two in the *6s*, six in the *6p*, and ten in the *5d*. In addition, there are another fourteen electrons in what is called an **f-shell.** This is numbered *4f.*

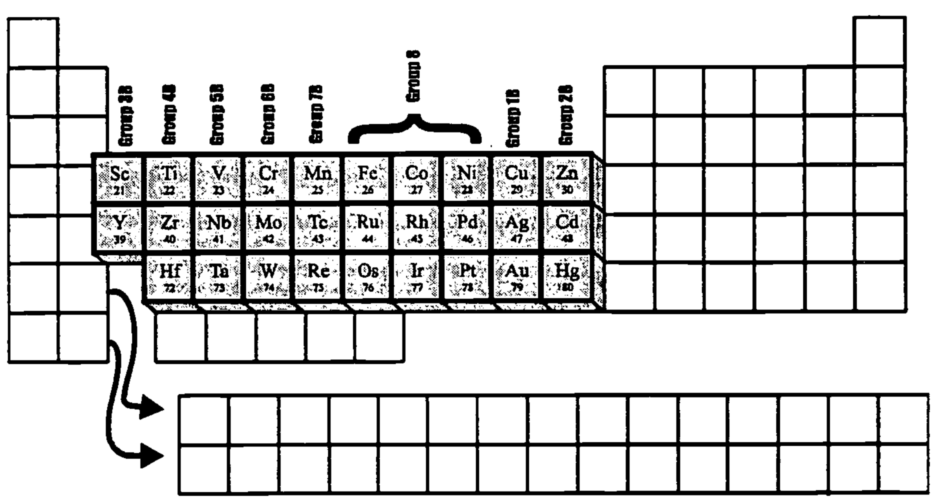
The seventh shell can hold another thirty-two electrons. This is the same as the previous one. Two electrons are in the *7s*, six in the *7p*, ten in the *6d*, and fourteen in the *5f.*

WHY DO WE CARE?

The order in which the electrons fill up the shells gets pretty tricky as we move down the Periodic Table. The layers will sometimes fill partially, leaving an atom with **several partially filled shells.** This means that the valence might be appropriate to lend out all the electrons in one of the partially filled shells, another, or all of them. Similarly, the partially filled shells may want to share additional electrons, enough to fill some or all of them. The elements lower down the Periodic Table thus have many possible values for the valencies. We will look at the most common ones.

THE TRANSITION ELEMENTS

The elements at the right are called the transition elements. They are the ones with partially filled **d-shells.** The valence can usually be understood by thinking of the extra electrons in the d-shell.



Within these elements, there are several Groups. As the d-shell fills up, the valence will change accordingly.

The Group 3B elements usually have a valence of +3. The Group 4B elements usually have a valence of +4. Similarly for the Group 5B, 6B, and 7B elements, which have valences of +5, +6, and +7.

The Group 8 elements are much harder to understand. They make compounds that will give them enough electrons to half-fill the d-shell, plus or minus a little. They all have valencies of +2, +3, or +4; most of them some or all of these valencies.

The Group 1B and 2B elements actually borrow electrons from the s-shell outside of the d-shell (which fills up first) to completely fill the d-shell. The valence of these is then due to the number of electrons in the outlying s-shell. Because of this, the 1B elements have a valence of +1 (and sometimes +2 or +3). Similarly, the 2B elements have a valence of +2.

B4.9: Iron is in the Group 8 portion of the transition elements. It has a preferred valence of +3. When oxygen combines with iron, you get rust (iron oxide). What is the formula for rust? Make it out of blocks.

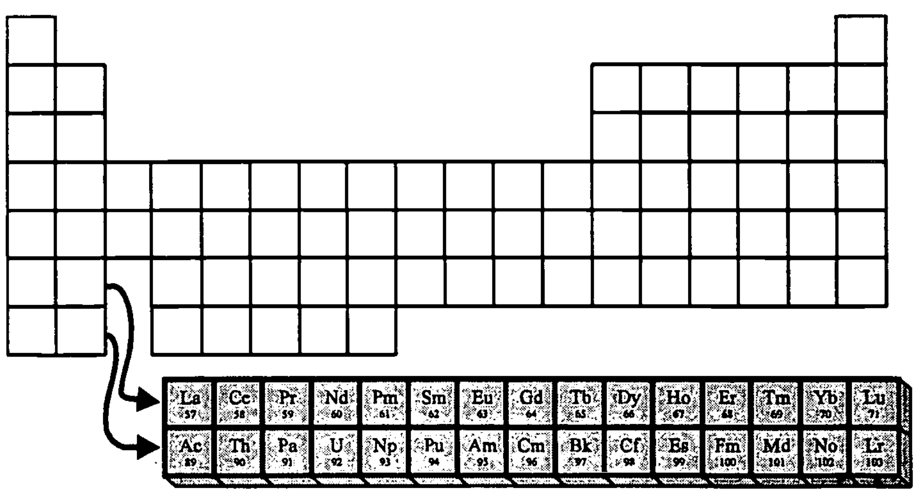
Fe_2O_3

B4.10: Silver is in the Group 1B portion of the transition elements. It has a valence of +1. When you combine silver with chlorine, you get a compound that is very sensitive to light. This is the stuff that is spread out on the film in your camera to capture images when you take pictures. What is the formula for silver chloride? Make it out of blocks.

AgCl

DEEPER AND DEEPER

The Lanthanides and Actinides are the two rows of elements that are usually left hanging below the bottom of the Periodic Table. These are the elements that have partially filled f-shells. The f-shells fill up below the outlying s-shells, and play little role in the chemistry of these elements. Since the entire series squeezes in under the Group 3B elements, they nearly all behave similarly to Group 3B, and have valences of +3.



B4.11: Uranium is in the Actinide group. Most of the uranium found in nature is non-radioactive, but a very small fraction is radioactive. When scientists want to isolate the radioactive part from the non-radioactive part of uranium, they can't use the chemical properties of uranium to do this. Why not?

(tough question) the different isotopes of uranium have the same electron structure.

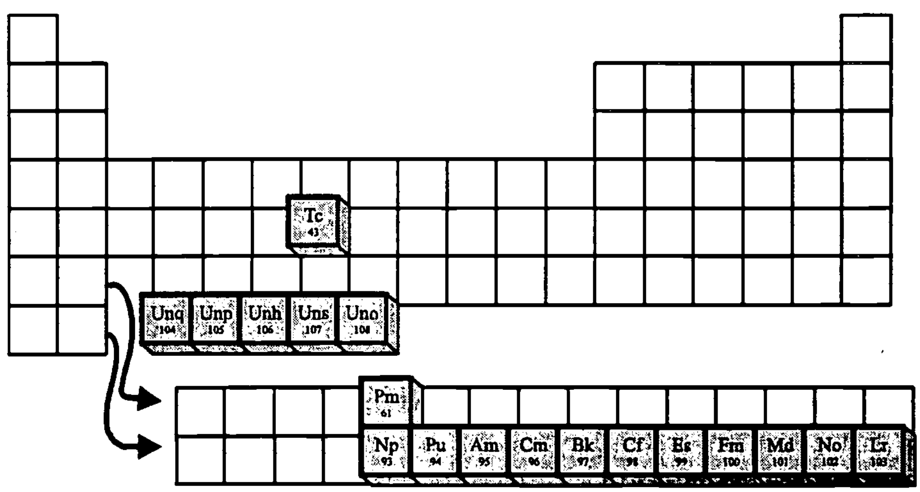
so they react the same - you can't separate them (you must use the mass differences).

B4.12: Scientists separate radioactive from non-radioactive uranium by making use of the slight difference in mass. They can "sift" gaseous compounds of uranium much like you would sift sand. The gaseous compound that they usually use is called uranium hexafluoride, which is made of uranium and fluorine. The valence for uranium is usually +6 (although it can be +5, +4, or +3). What is the formula for uranium hexafluoride. Make some (with blocks, not real uranium).

UF_6

WEIRD ELEMENTS

There are some elements that aren't found in nature. Some elements are **radioactive,** which means that the nucleus is unstable and decays into something else eventually. For some elements, there are several isotopes (atoms with the same number of protons but different numbers of neutrons) that are radioactive and some that aren't. Usually, the non-radioactive isotopes are far more common in nature.



Some elements have only radioactive isotopes. Some of these are found in nature only briefly; they are created during the decay of one element, and quickly decay into something else. Some of them are not found in nature at all. The ones shown at the right have only been observed by making them in the laboratory using nuclear (not chemical) reactions.

B4.13: Why can't these be made with chemical reactions?

chemical reactions can mix up and recombine atoms, but they can't change one type of atom (one element) into another. if the atoms don't already exist, chemistry can't make them.

Section 3.6: Chemical Reactions

Activity Guide PT-B5

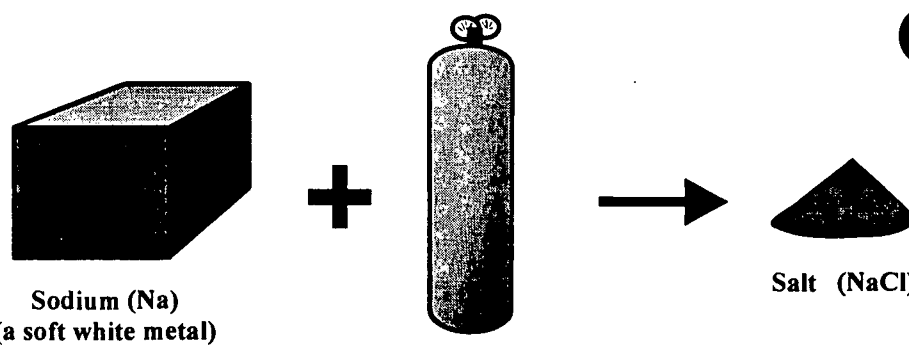
*This activity brings together key concepts from **PT-B1** through **PT-B4**, and explores how chemical reactions occur. We use what we know of valency and molecules to learn how to balance the reactants and products in chemical reactions. This can be an especially difficult lesson for some students. Skills in algebra, problem solving, as well as the fundamentals of chemistry are required. The Periodic Puzzle blocks are a particularly good way for students to visualize these concepts.*

This lesson is essentially identical to PT-A3.

Now that we know all about the elements and how they combine to make molecules, let's look at the way that these combinations take place.

A chemical reaction is what happens when we mix together two or more chemicals which rearrange themselves to make new chemicals.

Let's look at the first reaction that we learned, combining sodium and chlorine to make salt. The **reactants** are the ingredients that we mix together to start the reaction.



B5.1: What are the reactants in the reaction above?

the reactants are sodium and chlorine

The **products** of a reaction are the end results of the reaction, or the stuff that we make.

B5.2: What are the products in the reaction above?

the product is salt

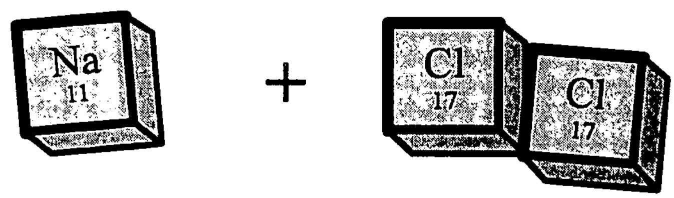
We write chemical reactions much like we write mathematical equations. We *might* write the above reaction

$$\mathbf{Na + Cl \rightarrow NaCl} \qquad \textit{(almost right)}$$

to show that we started with sodium (**Na**) and chlorine (**Cl**), and ended up with salt (**NaCl**). The only problem is that chlorine is not available in the atomic state. Pure chlorine forms a two-atom molecule with itself. These are called **diatomic** molecules. The formula for diatomic chlorine is $\mathbf{Cl_2}$. We then must write the left side of the chemical equation like this:

$$\mathbf{Na + Cl_2 \rightarrow .....}$$

B5.3: Take three blocks to form the reactants above: one sodium, and two chlorines joined together to make a molecule. Rearrange them to make salt. Is there any problem?



______ *yes!* ______________________

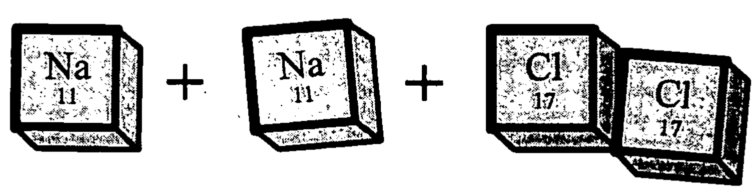
______ *the sodium and chlorine atoms don't balance - there is an extra chlorine left over* __________

Chemical reactions must always balance. The rule for chemical reactions is that you have to use all the atoms that you start with, and you can't add any more or have any leftovers at the end.

Since chlorine comes in molecules with two atoms, we need to have two sodium atoms to match. The proper way to write this reaction is like this

$$\mathbf{2Na + Cl_2 \rightarrow NaCl} \qquad \textit{(correct)}$$

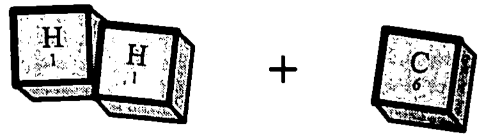
B5.4: Add another sodium block to the three blocks you already have. Now let the chemicals react! Does this balance?



______ *yes, the elements balance out*

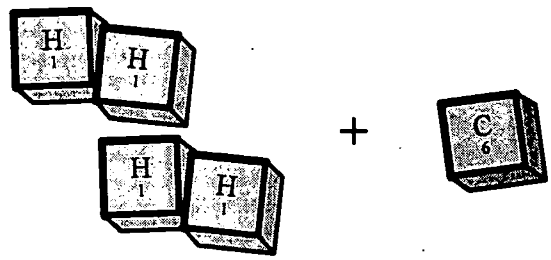
B5.5: Let's try another reaction. Combine hydrogen gas (which is also diatomic, $\mathbf{H_2}$) with carbon (**C**) to make methane ($\mathbf{CH_4}$). First get some hydrogen blocks and carbon blocks, and then try setting up the reactants. Remember that you must be able to rearrange all the reactant atoms to get complete products. Which of these reactant combinations works?

$\mathbf{H_2 + C \rightarrow .....}$



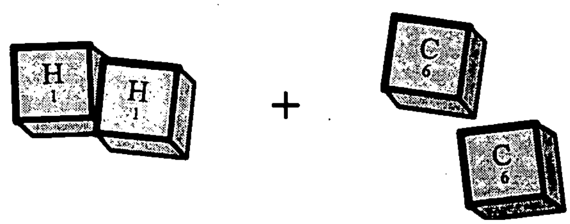
or...

This one works $\mathbf{2H_2 + C \rightarrow .....}$



or...

$\mathbf{H_2 + 2C \rightarrow .....}$



Write down the equation for making methane from hydrogen gas and carbon.

$2H_2 + C \dashrightarrow CH_4$

B5.6: Let's balance some more chemical equations. The following equations have the proper reactants and products.

First assemble the reactants out of blocks, then rearrange them to make reactants.

Figure out the right number of each reactant and product to make the chemical equation balance. Fill in the numbers in the boxes below, just as in the first two examples.

burn hydrogen to make water	$\boxed{2}\ H_2 + \boxed{1}\ O_2 \longrightarrow \boxed{2}\ H_2O$
make salt out of sodium and chlorine	$\boxed{2}\ Na + \boxed{1}\ Cl_2 \longrightarrow \boxed{2}\ NaCl$
make carbon dioxide	$\boxed{1}\ O_2 + \boxed{1}\ C \longrightarrow \boxed{1}\ CO_2$
let iron rust	$\boxed{4}\ Fe + \boxed{3}\ O_2 \longrightarrow \boxed{2}\ Fe_2O_3$
burn methane	$\boxed{1}\ CH_4 + \boxed{2}\ O_2 \longrightarrow \boxed{1}\ CO_2 + \boxed{2}\ H_2O$
neutralize acid and base	$\boxed{1}\ HCl + \boxed{1}\ NaOH \longrightarrow \boxed{1}\ NaCl + \boxed{1}\ H_2O$
burn octane (gasoline)	$\boxed{2}\ C_8H_{18} + \boxed{25}\ O_2 \longrightarrow \boxed{16}\ CO_2 + \boxed{18}\ H_2O$

The last reaction, burning octane, will take more blocks than the Periodic Puzzle set has available, and is not an easy problem. Be careful suggesting that the students combine blocks from multiple sets to accomplish this, as it may not be easy to get the proper distribution of blocks back into the boxes at the end of the lesson. Instead, encourage the students to look for the patterns they can use to solve the puzzle.

You may want to "burn octane" on the chalkboard as a class exercise if the students seem to have trouble at this point. The logic may go something like this:

1) Start with one octane molecule in the reactants.

2) One octane molecule makes 8 carbon atoms available, and 18 hydrogen atoms available. The only other reactant is oxygen, which has neither carbon nor hydrogen atoms, so we know exactly how many carbon and hydrogen atoms are available for the products.

1 x 18 = 18 hydrogen atoms available

$\boxed{1}\ C_8H_{18}$

1 x 8 = 8 carbon atoms available

3) Since there are eight carbon atoms in the reactants, there must be eight carbon atoms in the products. The only product with carbon is CO_2*, which has only one carbon atom. There must then be eight* CO_2 *molecules in the products.*

4) Since there are 18 hydrogen atoms in the reactants, there must be eighteen hydrogen atoms in the products. The only product with hydrogen is water, which has two hydrogen atoms per molecule. There must then be nine H_2O *molecules in the products.*

5) We can now count the oxygen atoms that we require in the products. Eight CO_2 *molecules need 16 oxygen atoms. Nine* H_2O *molecules need nine oxygen atoms. We need to supply 9+16 or 25 oxygen atoms. The products supply oxygen as* O_2 *molecules. This means that we need 12.5 oxygen molecules to balance the equation.*

6) We aren't allowed to have leftovers or fractional atoms in a chemical equation, so let's double all the quantities to get whole numbers. We will start with 2 octanes and 25 oxygens in the reactants, and end up with 16 carbon dioxide and 18 water molecules.

Section 3.7: Element Bingo

Activity Guide PT-G1

This activity is the first of two games in this curriculum. These are the real heart of the activities, and provide a great chance to have fun while reinforcing the lessons of the Periodic Table.

The Activity Guide for this game is merely a set of Bingo cards. These

rules, and two charts for reference. Both games are played similarly at Levels A, B, and C. The rules don't change between the levels, but the understanding that the students should have going into the games will be deeper at each succeeding level. Since the rules of atomic structure are built into the structure of the game, as the students' understanding deepens, the lessons that will be reinforced by playing the game deepens as well.

The students should have worked through Activities A1 and A2 before playing this game.

Section 3.8: Molecular Crossword

Activity Guide PT-G2

This activity is the second of two games in this curriculum. These are the real heart of the activities, and provide a great chance to have fun while reinforcing the lessons of Atomic Structure.

The Activity Guide for this game is merely a set of rule. Both games are played similarly at Levels A, B, and C. The rules don't change between the levels, but the understanding that the students should have going into the games will be deeper at each succeeding level. Since the rules of atomic structure are built into the structure of the game, as the students' understanding deepens, the lessons that will be reinforced by playing the game deepens as well.

*The students should have worked through Activities **A1** and **A2** before playing this game.*

Chapter 4
Level C Activities

The Level B activities are suitable for both Level B and Level C students. There are no activities that are exclusively Level C as of this revision.

If this curriculum is being used to supplement a high school or college chemistry course, then additional experiments might be interleaved to make further connections to those lessons.

Some of these suggested supplements are:

- Ionic vs. covalent compounds
- Solutions, and ions in solution
- The chemistry of water; acids and bases
- Introductory organic compounds

Future revisions of this curriculum may incorporate some or all of these topics -- call CPO at 1-800-932-LABS for updated revision information.

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Chapter 5 Assessment

The Assessment Package for Chemistry and the Periodic Table is not complete as of this revision. Contact Cambridge Physics Outlet at 1-800-932-LABS for the latest revision information.

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Chapter 6
Reference

The Reference Section is not complete as of this revision. A good introduction to the key concepts taught throughout the Chemistry and the Periodic Table Curriculum is contained in Chapter 1. Contact Cambridge Physics Outlet at 1-800-932-LABS for the latest revision information.

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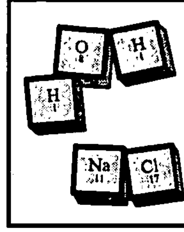
Name:

THE PERIODIC TABLE

PT-A1

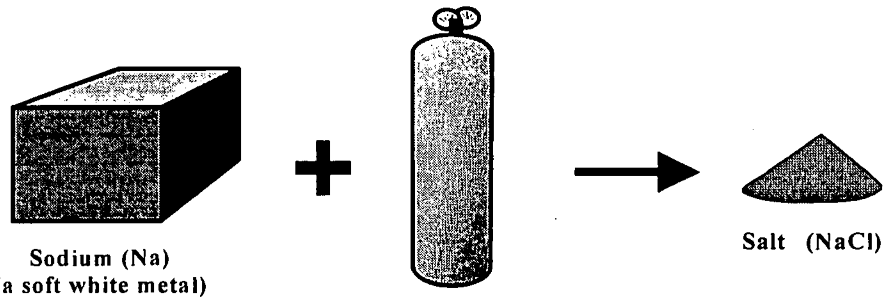


WHAT IS THE PERIODIC TABLE?

Everything in our world is made of atoms. There are many different types of atoms. Some are large and heavy, some are small and light. Some are very reactive, and combine fiercely with other atoms, often releasing heat. Some are inert, and never combine with other atoms at all.

Chemistry is the study of atoms and how they combine together. The different types of atoms are called elements.

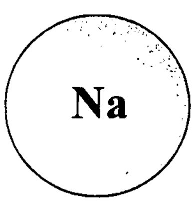
Elements are the simplest substances, and atoms are the smallest unit of an element. In the chemical reaction at the right, sodium and chlorine are both elements.



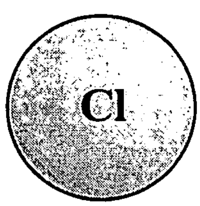
Sodium (Na)
(a soft white metal)

Chlorine (Cl)
(a poisonous, corrosive gas)

Salt (NaCl)



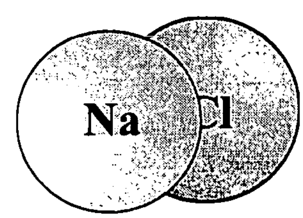
One sodium atom



One chlorine atom

The smallest piece of sodium that can be found is an atom of sodium. Similarly, the smallest piece of chlorine that can be found is an atom of chlorine.

Compounds are mixtures of elements bonded together in specific ratios of elements, and **molecules** are the smallest units of compounds. In the reaction above, salt is a compound. The smallest piece of salt that can be made is a molecule of salt. One molecule of salt is made of one atom of sodium and one atom of chlorine.



One salt molecule

Early scientists were very confused about the differences between compounds and elements. They tried mixing, boiling, dissolving in acid, burning, and many other processes to transform one substance into another. Sometimes, very profound changes could be made by simple mixing: for example, mixing sodium and chlorine together to make salt. Why not, these pioneers asked, make gold from lead? How about diamonds from glass?

We now know that **chemical reactions rearrange atoms, they don't change atoms from one element to another.** Thus, we can make salt from sodium and chlorine, because salt has both sodium and chlorine atoms in it. We can transform iron into rust without doing *anything*. Rust is made from iron (**Fe**) and oxygen (**O**), which is always present in the air. We can't make gold from lead, or diamonds from glass, because either reaction would require changing one element into another.

A1.1: Do astronauts need to worry about iron rusting on the moon? Why or why not?

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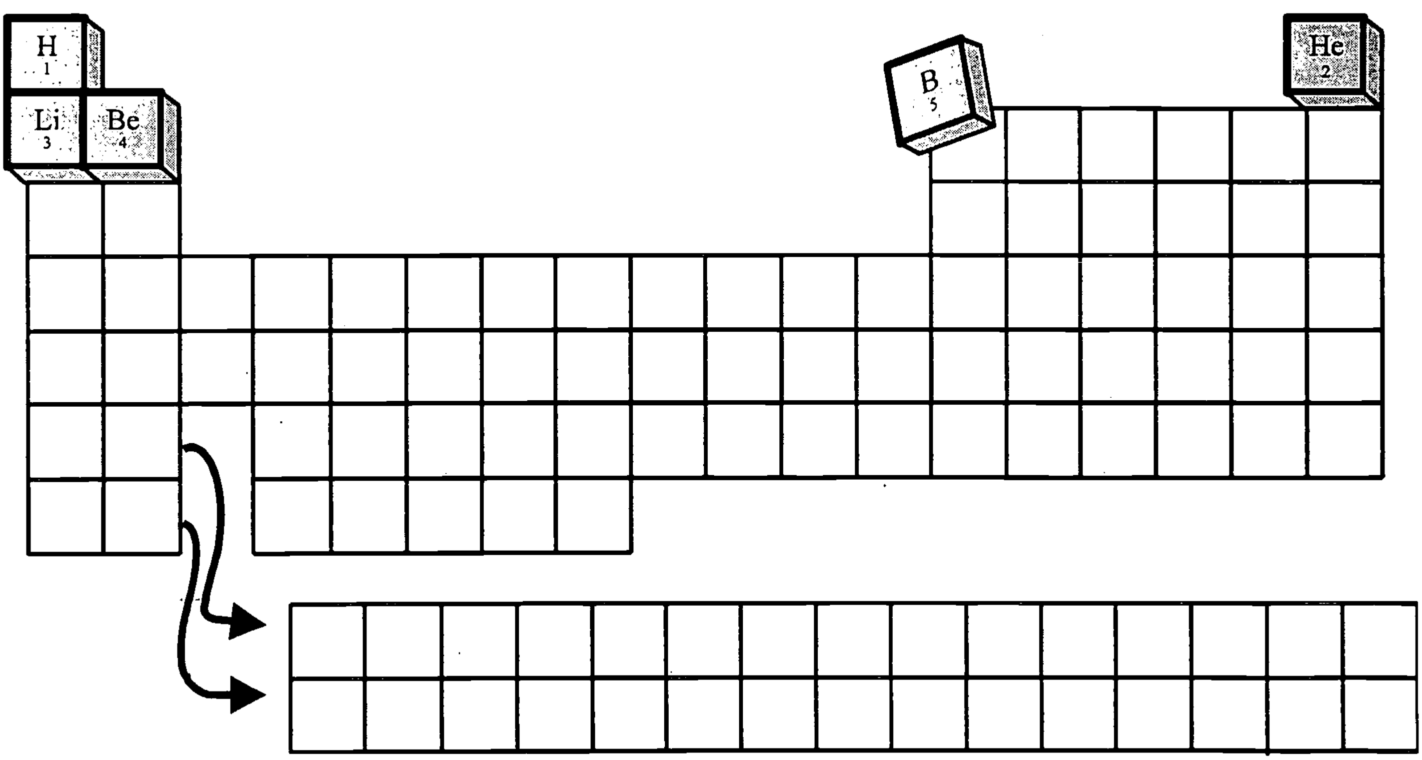
Element - a substance made from only one type of atom

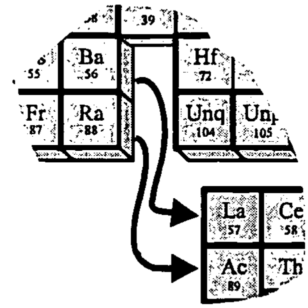
Compound - a substance made from two or more types of atoms

The chemical elements can be arranged in groups with similar properties. The **Periodic Table** is a chart of the elements, arranged to remind us of these similarities. The chart below shows the *shape* of the Periodic Table, and the first few elements in sequence from left to right. The elements are arranged in sequence using the **atomic numbers.**



A1.2: Using the chart on the previous page as an example, build the Periodic Table out of the Periodic Puzzle blocks. The numbers on the blocks are the atomic numbers.

There is a tricky part down near the bottom of the table. The table breaks off between elements 56 (**Ba**) and 72 (**Hf**), and fills in the first of two long rows at the bottom (we will learn why later). It does the same thing in the row below. Be sure to fill it in correctly in this area, like in the picture at right.



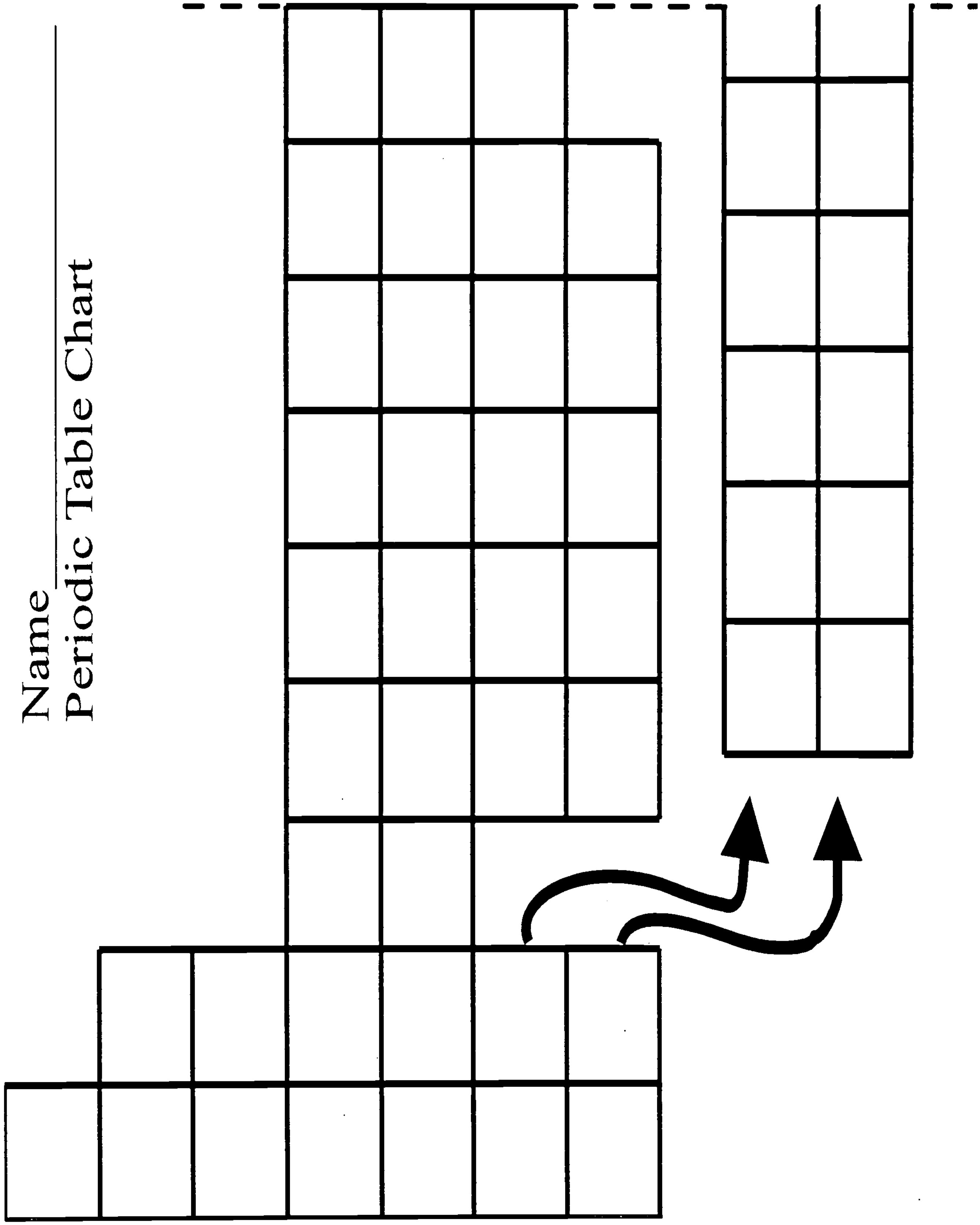
A1.3: After you have built your table, tape together the chart on the next two pages, and fill in the symbols and atomic numbers for the elements. Use the chart below to get the names of the elements.

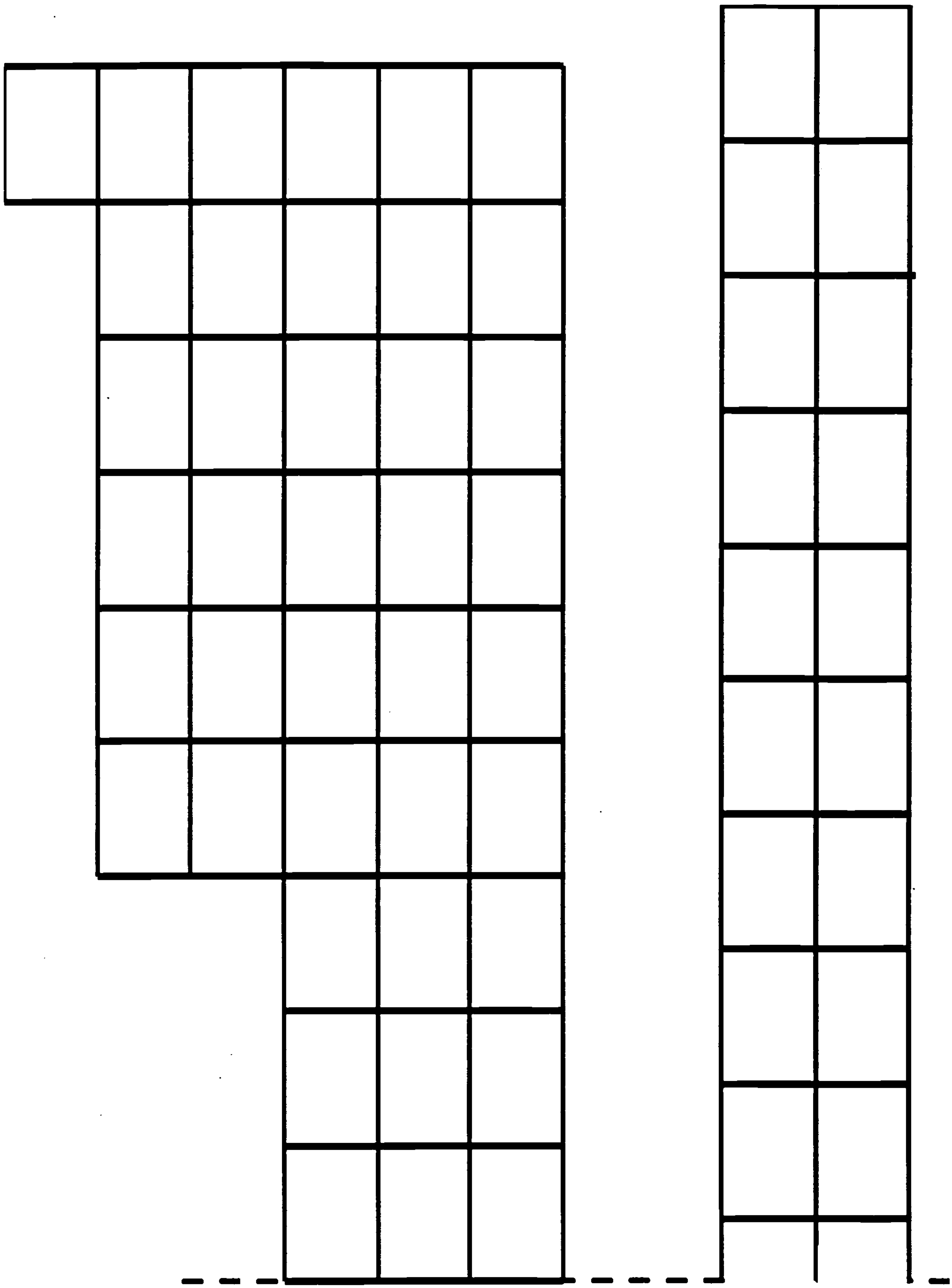
Symbols and Names for the elements

H	hydrogen	**He**	helium	**Li**	lithium	**Be**	beryllium
B	boron	**C**	carbon	**N**	nitrogen	**O**	oxygen
F	fluorine	**Ne**	neon	**Na**	sodium	**Mg**	magnesium
Al	aluminum	**Si**	silicon	**P**	phosphorus	**S**	sulfur
Cl	chlorine	**Ar**	argon	**K**	potassium	**Ca**	calcium
Sc	scandium	**Ti**	titanium	**V**	vanadium	**Cr**	chromium
Mn	manganese	**Fe**	iron	**Co**	cobalt	**Ni**	nickel
Cu	copper	**Zn**	zinc	**Ga**	gallium	**Ge**	germanium
As	arsenic	**Se**	selenium	**Br**	bromine	**Kr**	krypton
Rb	rubidium	**Sr**	strontium	**Y**	yttrium	**Zr**	zirconium
Nb	niobium	**Mo**	molybdenum	**Tc**	technetium	**Ru**	ruthenium
Rh	rhodium	**Pd**	palladium	**Ag**	silver	**Cd**	cadmium
In	indium	**Sn**	tin	**Sb**	antimony	**Te**	tellurium
I	iodine	**Xe**	xenon	**Cs**	cesium	**Ba**	barium
La	lanthanum	**Ce**	cerium	**Pr**	praseodymium	**Nd**	neodymium
Pm	promethium	**Sm**	samarium	**Eu**	europium	**Gd**	gadolinium
Tb	terbium	**Dy**	dysprosium	**Ho**	holmium	**Er**	erbium
Tm	thulium	**Yb**	ytterbium	**Lu**	lutetium	**Hf**	hafnium
Ta	tantalum	**W**	tungsten	**Re**	rhenium	**Os**	osmium
Ir	iridium	**Pt**	platinum	**Au**	gold	**Hg**	mercury
Tl	thallium	**Pb**	lead	**Bi**	bismuth	**Po**	polonium
At	astatine	**Rn**	radon	**Fr**	francium	**Ra**	radium
Ac	actinium	**Th**	thorium	**Pa**	protactinium	**U**	uranium
Np	neptunium	**Pu**	plutonium	**Am**	americium	**Cm**	curium
Bk	berkelium	**Cf**	californium	**Es**	einsteinium	**Fm**	fermium
Md	mendelevium	**No**	nobelium	**Lr**	lawrencium	**Unq**	(not named)
Unp	(not named)	**Unh**	(not named)	**Uns**	(not named)	**Uno**	(not named)

Name____________

Periodic Table Chart





A1.4: Do some of the elements sound familiar? Pick two, and say something about them.

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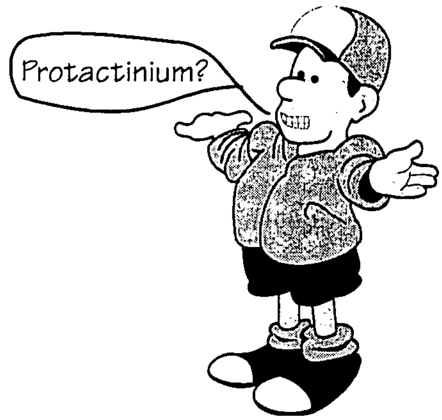


A1.5: Have you heard of the following elements? What do you know about them?

Oxygen: ____

Silver: ____

Mercury: ____

Silicon: ____

Iron: ____

Neon: ____

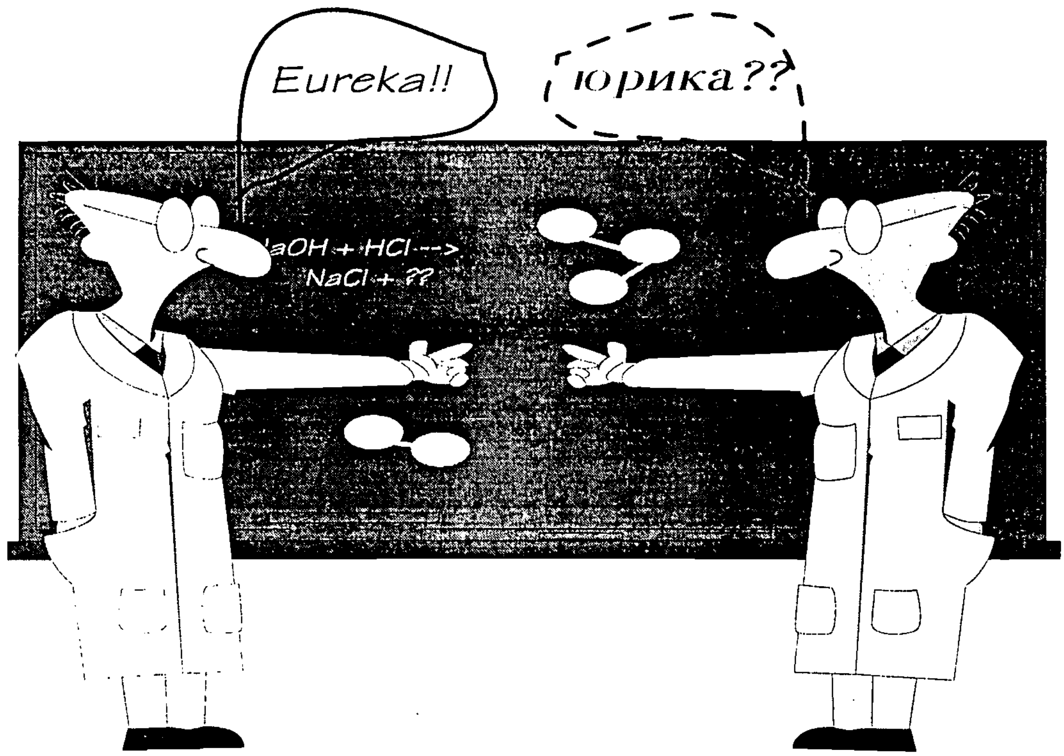
Uranium: ____

Tungsten: ____

Iodine: ____

Krypton: ____

Some of the element symbols don't seem to make sense. A typical example is the abbreviation for tungsten: the letter **W**. Actually, tungsten was named by German scientists, and the German name for tungsten is "wolfram", so the abbreviation *does* makes sense after all.



Most of the abbreviations that aren't obvious are for similar reasons -- the elements were studied and named by scientists from around the world.

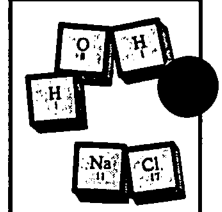
Some elements don't have names yet! Elements 104 through 108 don't occur in nature, but have been made in the laboratory. There are still discussions going on worldwide over what to name them. Many people want to name them after famous scientists who have contributed to their discovery (just like element 99 Einsteinium (in honor of Albert Einstein) or element 100 Fermium (in honor of Enrico Fermi)). This is a problem if there are more scientists than elements! What do you think you need to do to get an element named after you?

A1.6: Some of the materials below are elements, and some are not. Circle the elements.

air	**gas**	**oxygen**	**nitrogen**	**argon**
iron	**steel**	**copper**	**brass**	**aluminum**
tin	**nickel**	**bronze**	**chromium**	**lead**
gold	**silver**	**sapphire**	**ruby**	**platinum**
chlorine	**quinine**	**strychnine**	**iodine**	**bromine**

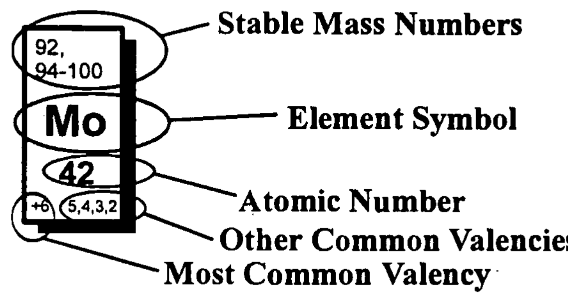
Name:

PT-A2



THE FAMILIES OF ELEMENTS

In the last lesson, we learned that the elements were numbered in sequence with the **atomic number.** The atomic number is the number that is used to order the elements in the Periodic Table. There are several other numbers which are used to identify atoms.



The next page shows a chart of the Periodic Table, with some of these other numbers added. These numbers tell us what is in the atom, and how the atom wants to combine with other atoms.

Take a look at the key to the chart at the right. The symbol for the element and the atomic number are the same as we used last lesson. These are printed on the blocks as well.

The **atomic number** is unique to each element. There is only one element with atomic number 42, and that is Molybdenum (**Mo**). The atomic number tells us how many **protons** are in the atom. Protons are one of the three types of particles that atoms are made of.

A2.1: How many protons are in an oxygen atom?

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The **atomic mass** or stable mass number is the number or numbers at the top. The atomic mass is the total number of protons and **neutrons** in the atom. If there is more than one number here, than there are several **isotopes**, or atoms of different mass, that exist. For example, molybdenum has stable mass numbers of 92, 94, 95, 96, 97, 98, 99, 100. Since molybdenum must always have 42 protons, these isotopes have 50, 52, 53, 54, 55, 56, 57, and 58 neutrons, respectively.

A2.2: How many neutrons are in the oxygen isotope that has a mass number of 16?

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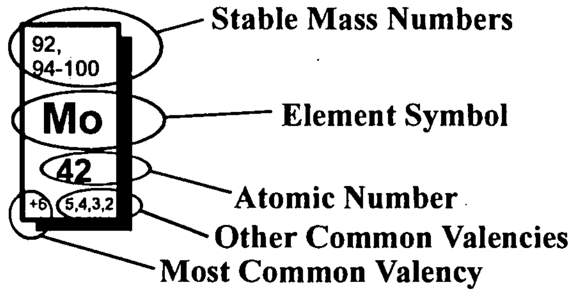
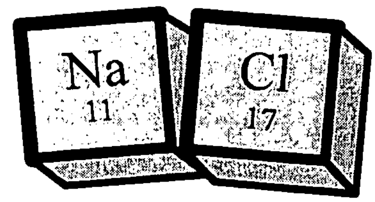
Partial Periodic Table (up to Xenon)



GROUP 1A	GROUP 2A	GROUP 3B	GROUP 4B	GROUP 5B	GROUP 6B	GROUP 7B	GROUP 8	GROUP 8	GROUP 8	GROUP 1B	GROUP 2B	GROUP 3A	GROUP 4A	GROUP 5A	GROUP 6A	GROUP 7A	GROUP 8A
1,2 H 1 +1 -1																	3,4 He 2 (none)
6,7 Li 3 +1	9 Be 4 +2											10,11 B 5 +3	12,13 C 6 +4 -4,+2	14,15 N 7 -3 +2,3,4,5	16-18 O 8 -2	19 F 9 -1	20-22 Ne 10 (none)
23 Na 11 +1	24-26 Mg 12 +2											27 Al 13 +3	28-30 Si 14 +4	31 P 15 +5 +3,-3,+4	32-34, 36 S 16 +6 -2,+2,+4	35,37 Cl 17 -1 +1,3,5,7	36,38, 40 Ar 18 (none)
39,41 K 19 +1	40,42- 44,46, 48 Ca 20 +2	45 Sc 21 +3	46-50 Ti 22 +4 3	51 V 23 +5 4,3,2	50, 52-54 Cr 24 +3 6,2	55 Mn 25 +2 7,6,4,3	54,56- 58 Fe 26 +3 2	59 Co 27 +2 3	58,60- 62,64 Ni 28 +2 3	63,65 Cu 29 +2 1	64,66- 68,70 Zn 30 +2	69,71 Ga 31 +3	70,72- 74,76 Ge 32 +4	75 As 33 -3 +5,-3	74,76- 78,80, 82 Se 34 +4 -2,+6	79,81 Br 35 -1 +1,+5	78,80, 82-84, 86 Kr 36 (none)
85 Rb 37 +1	84, 86-88 Sr 38 +2	89 Y 39 +3	90-92, 94,96 Zr 40 +4	93 Nb 41 +5 3	92, 94-100 Mo 42 +6 5,4,3,2	none Tc 43 +7	96,98- 103,104 Ru 44 +3 2,4,6,8	103 Rh 45 +3 2,4	102,104- 106,108, 110 Pd 46 +2 4	107,109 Ag 47 +1	106,108, 110-112, 114,116 Cd 48 +2	113 In 49 +3	112,114- 120,122, 124 Sn 50 +4 +2	121 Sb 51 -3 +5,+3	120,122, 124-126, 128,130 Te 52 +4 -2,+6	127 I 53 -1 +1,5,7	124,126, 128-132, 134,136 Xe 54 (none)

The **valence** is the number of electrons that the atom has to contribute when forming compounds. Atoms join together to form molecules in such a way as to share extra electrons. Sodium has a valence of +1 since it has one electron to lend out. Chlorine has a valence of -1, since it has one missing electron which it wants to borrow.



Salt has one sodium and one chlorine, since they cancel out their valencies together. Make a salt molecule out of one sodium atom and one chlorine atom with the Periodic Puzzle blocks.

A2.3: Hydrogen has a valence of +1. Oxygen has a valence of -2. How many hydrogen atoms does it take to make a molecule with one oxygen atom? Make a molecule of hydrogen and oxygen out of the periodic puzzle blocks.

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A2.4: We write a molecule of hydrogen and oxygen as **H_2O.** Have you heard of this? What is it?

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The chart often has several numbers for the valence of an atom, since the atom may combine differently with different atoms. The most common valence is given first, and other common ones afterwards.

A2.5: Find all of the elements with a valence of 0. (These are marked "none"). What are their symbols? Are they gathered together in any way on the Periodic Table?

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____

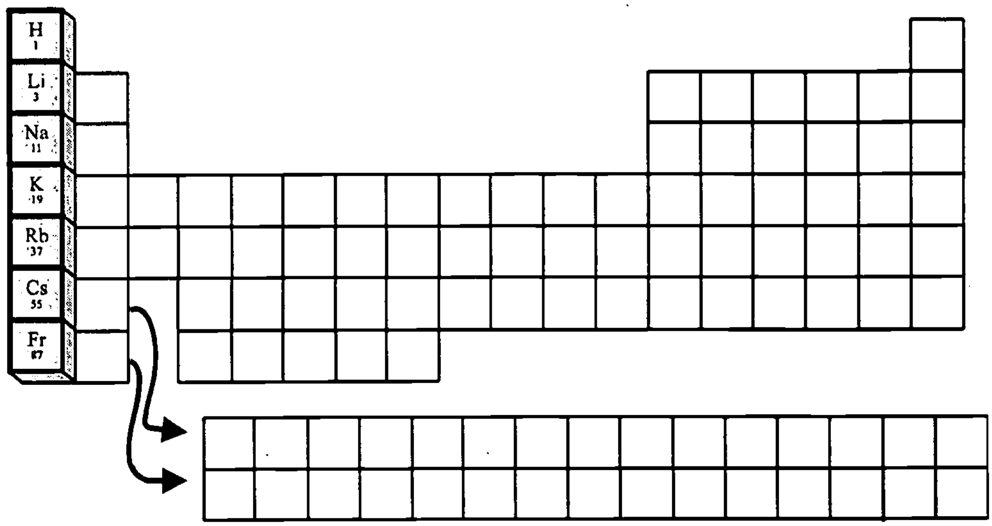
A2.6: Find all of the elements with a valence of +2. Are they arranged together as well? Where?

____

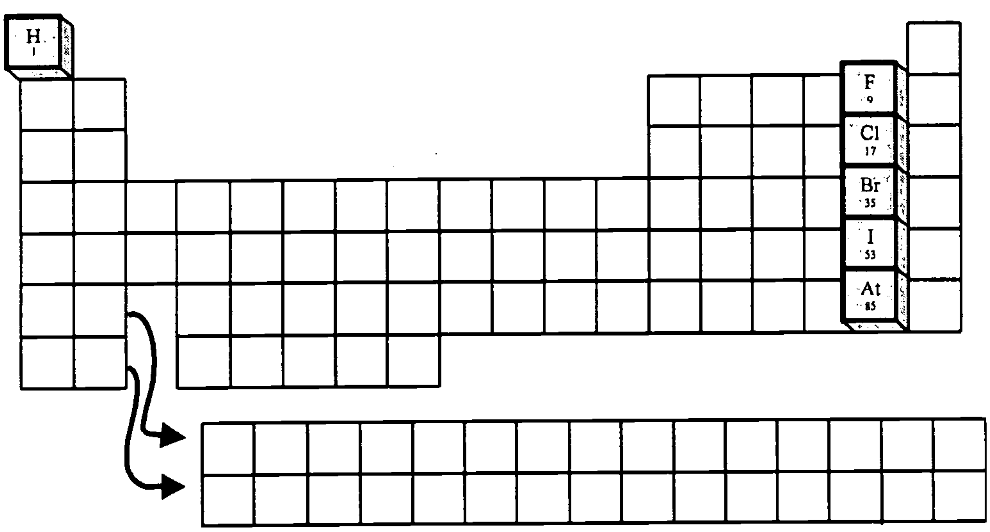
____

THE PERIODIC TABLE IS PERIODIC

The Periodic Table is arranged to remind us of the similar valences of the elements. You noticed that all of the 0 valence elements were in one column, and most of the +2 valence elements are in another. These columns are called **Groups.** The group numbers usually give the most common valence of the elements, although there are plenty of exceptions.



When we think of the elements as belonging to groups, it is easier to remember how they will interact. For example, all the elements which commonly have a valence of +1 are in the first column. These are called the Group 1A elements. They have many similarities besides the same valence: except for hydrogen, they all are soft metals, react very quickly with water to form strong bases, and form salts with the Group 7A elements using one atom from Group 1A and one from Group 7A. We call the Group 1A elements (again, except for hydrogen) the alkali metals.



Similarly, the elements which commonly have a valence of -1 are in the next to last column. These are called the Group 7A elements. They also have many similarities: they are pungent and corrosive and react quickly with water to form strong acids, and form salts with Group 1A elements as we just mentioned.

We include hydrogen in the elements of -1 valence, since it often does *both*.

Let's look at some more simple molecules.

A2.7: Ammonia is made up of nitrogen (**N**) and hydrogen (**H**). Nitrogen has a valence of -3, and hydrogen has a valence of +1. Make an ammonia molecule out of blocks. What is the symbol for ammonia?

____

A2.8: Carbon dioxide is made up of carbon (**C**) and oxygen (**O**). Carbon has a valence of +4. What is the valence for oxygen? Make a carbon dioxide molecule out of blocks. What is the symbol for carbon dioxide?

____

A2.9: Methane, or natural gas, is what you might cook with or heat your house with. It is made of carbon (**C**) and hydrogen (**H**). The most common valence of hydrogen is +1. What is the most common valence of carbon?

____

A2.10: Can we make a methane molecule using the most common valences for carbon and hydrogen?

____

A2.11: Try using a valence of -4 for carbon. Now make a methane molecule with the blocks, and give the formula.

____

A2.12: Salt is a compound using one atom from Group 1A and one atom from Group 7A. Make three more compounds from Group 1A and Group 7A elements. How many of each block did you need? Write the chemical formula for them here.

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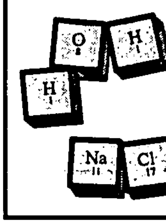
Name:

CHEMICAL REACTIONS

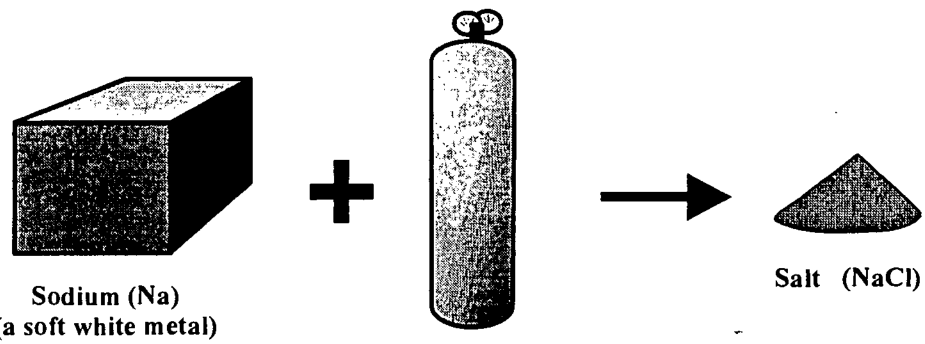
PT-A3



Now that we know all about the elements and how they combine to make molecules, let's look at the way that these combinations take place.

A chemical reaction is what happens when we mix together two or more chemicals which rearrange themselves to make new chemicals.

Let's look at the first reaction that we learned, combining sodium and chlorine to make salt. The **reactants** are the ingredients that we mix together to start the reaction.



Sodium (Na)
(a soft white metal)

Chlorine (Cl)
(a poisonous, corrosive gas)

Salt (NaCl)

A3.1: What are the reactants in the reaction above?

The **products** of a reaction are the end result of the reaction, or the stuff that we make.

A3.2: What are the products in the reaction above?

We write chemical reactions much like we write mathematical equations. We *might* write the above reaction

$$\mathbf{Na + Cl \rightarrow NaCl} \qquad \textit{(almost right)}$$

to show that we started with sodium (**Na**) and chlorine (**Cl**), and ended up with salt (**NaCl**). The only problem is that chlorine is not available in the atomic state. Pure chlorine forms a two-atom molecule with itself. These are called **diatomic** molecules. The formula for diatomic chlorine is $\mathbf{Cl_2}$. We then must write the left side of the chemical equation like this:

$$\mathbf{Na + Cl_2 \rightarrow .....}$$

A3.3: Take three blocks to form the reactants above: one sodium and two chlorines joined together to make a molecule. Rearrange them to make salt. Is there any problem?

____

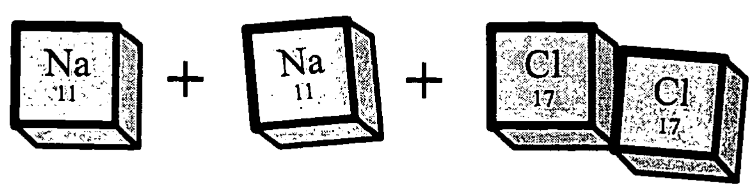
____

Chemical reactions must always balance. The rule for chemical reactions is that you have to use all the atoms that you start with, and you can't add any more or have any leftovers at the end.

Since chlorine comes in molecules with two atoms, we need to have two sodium atoms to match. The proper way to write this reaction is like this

$$\mathbf{2Na + Cl_2 \rightarrow NaCl} \qquad \textit{(correct)}$$

A3.4: Add another sodium block to the three blocks you already have. Now let the chemicals react! Does this balance?



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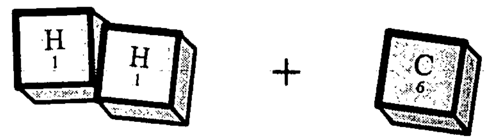
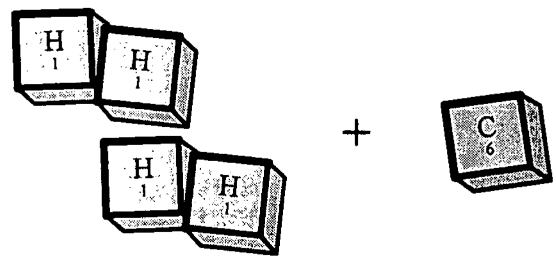
A3.5: Let's try another reaction. Combine hydrogen gas (which is also diatomic, $\mathbf{H_2}$) with carbon (**C**) to make methane ($\mathbf{CH_4}$). First get some hydrogen blocks and carbon blocks, and then try setting up the reactants. Remember that you must be able to rearrange all the reactant atoms to get complete products. Which of these reactant combinations works?

$\mathbf{H_2 + C \rightarrow .....}$



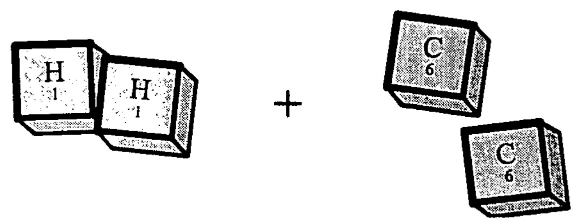
or...

$\mathbf{2H_2 + C \rightarrow .....}$

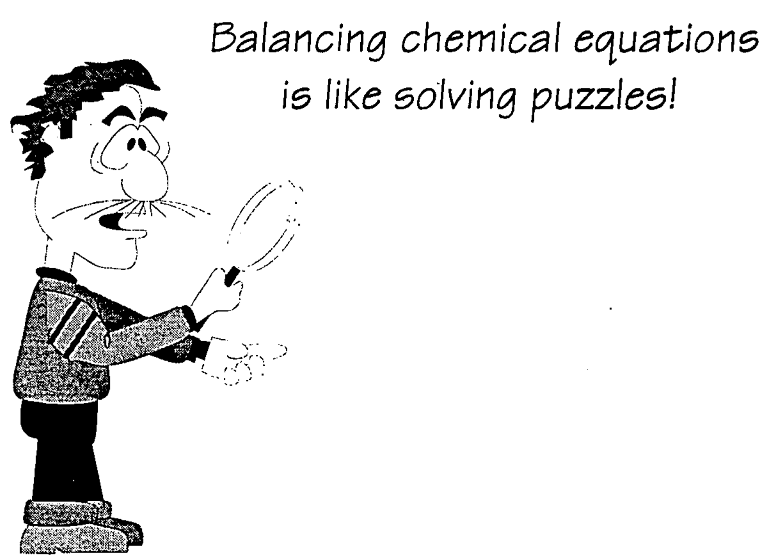


or...

$\mathbf{H_2 + 2C \rightarrow .....}$



Write down the equation for making methane from hydrogen gas and carbon.



A3.6: Let's balance some more chemical equations. The following equations have the proper reactants and products.

First assemble the reactants out of blocks, then rearrange them to make reactants.

Figure out the right number of each reactant and product to make the chemical equation balance. Fill in the numbers in the boxes below, just as in the first two examples.

burn hydrogen to make water	$\boxed{2}\ H_2 + \boxed{1}\ O_2 \longrightarrow \boxed{2}\ H_2O$
make salt out of sodium and chlorine	$\boxed{2}\ Na + \boxed{1}\ Cl_2 \longrightarrow \boxed{2}\ NaCl$
make carbon dioxide	$\square\ O_2 + \square\ C \longrightarrow \square\ CO_2$
let iron rust	$\square\ Fe + \square\ O_2 \longrightarrow \square\ Fe_2O_3$
burn methane	$\square\ CH_4 + \square\ O_2 \longrightarrow \square\ CO_2 + \square\ H_2O$
neutralize acid and base	$\square\ HCl + \square\ NaOH \longrightarrow \square\ NaCl + \square\ H_2O$
burn octane (gasoline)	$\square\ C_8H_{18} + \square\ O_2 \longrightarrow \square\ CO_2 + \square\ H_2O$

Name: ______________________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 1

Game Number 1

fluorine	oxygen	cerium	hydrogen	chlorine
magnesium	lithium	aluminum	carbon	boron
helium	thulium	antimony	scandium	lithium
manganese	aluminum	scandium	chromium	fluorine
bismuth	carbon	potassium	lanthanum	cobalt

Game Number 2

neon	hafnium	sodium	phosphorus	sulfur
rhodium	polonium	molybdenum	chromium	calcium
silicon	terbium	bromine	silicon	nitrogen
oxygen	helium	platinum	beryllium	cerium
mercury	magnesium	silver	magnesium	titanium

Name: ______________________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 2 **Game Number 1**

krypton	silver	sulfur	lithium	ruthenium
titanium	praseodymium	palladium	silicon	fluorine
argon	carbon	lithium	europium	bismuth
polonium	hydrogen	beryllium	neon	silver
osmium	yttrium	calcium	phosphorus	niobium

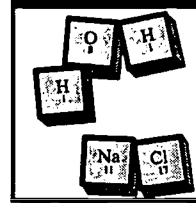
Game Number 2

potassium	aluminum	platinum	scandium	krypton
strontium	aluminum	phosphorus	fluorine	scandium
silicon	sodium	lithium	krypton	oxygen
technetium	chlorine	lanthanum	sulfur	antimony
sodium	zirconium	fluorine	gold	neon

Name: ____________________

ELEMENT BINGO

PT-G1



Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 3

Game Number 1

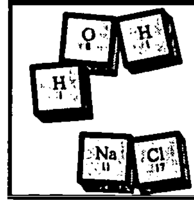
lithium	osmium	osmium	cadmium	carbon
cesium	beryllium	aluminum	lithium	helium
antimony	boron	neon	hydrogen	dysprosium
praseodymium	rubidium	scandium	zinc	cadmium
nickel	fluorine	silicon	niobium	tungsten

Game Number 2

hydrogen	beryllium	vanadium	hydrogen	rhodium
sodium	carbon	potassium	barium	beryllium
tungsten	chlorine	argon	oxygen	argon
lithium	bismuth	zirconium	boron	silver
neon	erbium	cobalt	gold	fluorine

Name: ____________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 4

Game Number 1

carbon	potassium	chlorine	polonium	oxygen
aluminum	holmium	neon	sodium	aluminum
phosphorus	calcium	aluminum	bromine	iron
neon	oxygen	beryllium	scandium	sulfur
hydrogen	chlorine	argon	xenon	selenium

Game Number 2

radon	argon	zirconium	hydrogen	tin
titanium	thallium	dysprosium	mercury	silver
oxygen	helium	gallium	nitrogen	vanadium
zinc	carbon	iodine	selenium	lead
technetium	molybdenum	nitrogen	samarium	lutetium

Name: ______________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 5

Game Number 1

carbon	cesium	vanadium	tin	indium
radon	silicon	thorium	uranium	americium
niobium	tungsten	nitrogen	barium	francium
promethium	phosphorus	selenium	copper	fluorine
strontium	iodine	mercury	gadolinium	rhenium

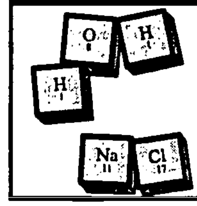
Game Number 2

argon	carbon	oxygen	indium	thallium
iridium	gold	silver	platinum	technetium
tantalum	actinium	cerium	samarium	cobalt
iron	lead	sulfur	oxygen	xenon
astatine	tellurium	bismuth	terbium	plutonium

Name: ______________________________

ELEMENT BINGO

PT-G1



Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 6

Game Number 1

zinc	neon	hydrogen	polonium	antimony
tin	erbium	nobelium	terbium	cerium
actinium	strontium	cobalt	zinc	astatine
aluminum	manganese	neptunium	tantalum	yttrium
scandium	calcium	francium	ruthenium	iron

Game Number 2

vanadium	terbium	einsteinium	thulium	thallium
gallium	iodine	nitrogen	xenon	chlorine
sodium	cobalt	iron	osmium	rhenium
barium	potassium	uranium	thorium	magnesium
strontium	lead	polonium	fermium	silicon

Name: ______________________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 7

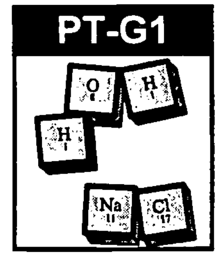
Game Number 1

sodium	hydrogen	tin	gold	iridium
actinium	mercury	scandium	hafnium	curium
lanthanum	tantalum	iron	cesium	beryllium
cadmium	silver	copper	silicon	bismuth
carbon	oxygen	americium	lawrencium	radium

Game Number 2

calcium	oxygen	vanadium	iron	gallium
arsenic	potassium	uranium	lead	nobelium
xenon	tungsten	scandium	thorium	mercury
bismuth	astatine	germanium	indium	rhodium
nitrogen	carbon	cobalt	cesium	chlorine

Name:



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 8 **Game Number 1**

fluorine	neon	rubidium	calcium	actinium
rhenium	californium	terbium	tungsten	silver
bismuth	gold	technetium	nickel	copper
molybdenum	calcium	hydrogen	oxygen	nitrogen
titanium	carbon	cesium	cadmium	thulium

Game Number 2

xenon	lithium	lead	ruthenium	germanium
silicon	plutonium	nickel	protactinium	niobium
scandium	lead	silver	gold	hydrogen
nitrogen	oxygen	zirconium	samarium	tantalum
cobalt	holmium	mendelevium	iridium	platinum

Name: ______________________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 9

Game Number 1

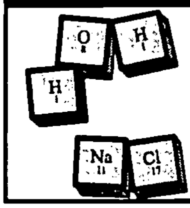
zinc	carbon	chromium	iron	vanadium
lead	uranium	europium	fermium	yttrium
tungsten	radon	nitrogen	hydrogen	boron
calcium	bismuth	astatine	bromine	rubidium
radium	iodine	scandium	nickel	oxygen

Game Number 2

helium	argon	krypton	xenon	radon
tungsten	tantalum	rhenium	osmium	iridium
palladium	rhodium	ruthenium	technetium	molybdenum
hydrogen	lithium	sodium	potassium	rubidium
radium	francium	cesium	uranium	neptunium

Name:

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 10 **Game Number 1**

lanthanum	hafnium	tantalum	tungsten	oxygen
hydrogen	boron	aluminum	gallium	indium
thorium	protactinium	nitrogen	carbon	silicon
lead	mercury	iron	copper	iodine
calcium	scandium	titanium	vanadium	chromium

Game Number 2

oxygen	sulfur	selenium	tellurium	polonium
nickel	copper	zinc	gallium	germanium
hydrogen	nitrogen	titanium	zirconium	hafnium
promethium	cerium	berkelium	iron	platinum
silver	erbium	nobelium	bromine	carbon

Name: ____________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 11

Game Number 1

fluorine	chlorine	bromine	iodine	astatine
silicon	carbon	germanium	tin	lead
molybdenum	tungsten	tantalum	osmium	iridium
terbium	erbium	gadolinium	berkelium	sulfur
oxygen	nitrogen	palladium	silver	cadmium

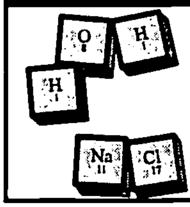
Game Number 2

beryllium	magnesium	calcium	strontium	barium
hydrogen	helium	lithium	boron	carbon
nitrogen	bismuth	iridium	ruthenium	technetium
yttrium	samarium	iron	chromium	radon
cerium	fermium	thulium	arsenic	oxygen

Name: ______________________

ELEMENT BINGO

PT-G1



Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 12

Game Number 1

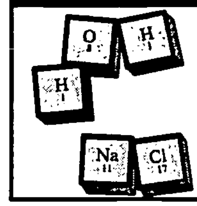
iron	carbon	molybdenum	vanadium	tin
aluminum	copper	silver	platinum	nitrogen
tungsten	nickel	copper	titanium	magnesium
zinc	gold	lead	chromium	iridium
indium	palladium	iridium	niobium	hydrogen

Game Number 2

chlorine	neon	xenon	oxygen	nitrogen
hydrogen	radon	bromine	mercury	fluorine
lithium	sodium	beryllium	boron	argon
helium	cesium	francium	silicon	carbon
phosphorus	sulfur	selenium	astatine	arsenic

Name: ______________________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 13

Game Number 1

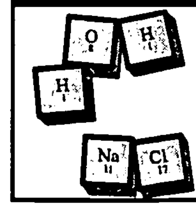
oxygen	hafnium	neodymium	rhenium	platinum
tantalum	rubidium	potassium	phosphorus	calcium
nitrogen	hydrogen	silicon	carbon	polonium
samarium	thorium	uranium	barium	magnesium
zinc	fluorine	xenon	thulium	mercury

Game Number 2

cobalt	iron	hydrogen	tungsten	iridium
actinium	lanthanum	potassium	carbon	oxygen
nitrogen	polonium	silver	palladium	niobium
titanium	gadolinium	fermium	lead	chromium
yttrium	mercury	radon	titanium	antimony

Name: ______________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 14

Game Number 1

plutonium	uranium	thorium	lead	oxygen
carbon	silicon	gallium	germanium	iodine
astatine	nitrogen	hydrogen	niobium	calcium
lithium	chromium	tungsten	gadolinium	fluorine
iridium	osmium	titanium	nickel	radium

Game Number 2

radon	neon	fluorine	nitrogen	hydrogen
lithium	sodium	calcium	potassium	rubidium
cesium	francium	cerium	samarium	terbium
tungsten	platinum	cobalt	iron	zinc
xenon	tantalum	tin	tellurium	polonium

Name: ______________________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 15 **Game Number 1**

phosphorus	palladium	plutonium	platinum	promethium
carbon	chromium	calcium	cesium	californium
nitrogen	nickel	niobium	neptunium	nobelium
sulfur	sodium	selenium	strontium	samarium
barium	bromine	boron	beryllium	berkelium

Game Number 2

arsenic	bromine	calcium	dysprosium	erbium
fluorine	germanium	holmium	iridium	krypton
lithium	molybdenum	nitrogen	oxygen	phosphorus
ruthenium	strontium	uranium	vanadium	xenon
yttrium	zinc	hydrogen	sulfur	silicon

Name:

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 16 **Game Number 1**

oxygen	sulfur	selenium	tellurium	polonium
boron	aluminum	gallium	indium	thallium
beryllium	magnesium	calcium	strontium	barium
hydrogen	lithium	sodium	potassium	rubidium
cerium	neodymium	promethium	carbon	nitrogen

Game Number 2

rhodium	manganese	vanadium	titanium	iron
lead	oxygen	hydrogen	platinum	silver
aluminum	chromium	magnesium	nickel	tin
indium	antimony	osmium	tungsten	tantalum
copper	scandium	nitrogen	carbon	gold

Name: ______________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 17

Game Number 1

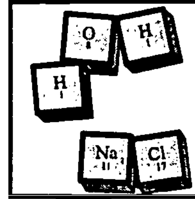
hydrogen	helium	lithium	beryllium	boron
carbon	nitrogen	neon	oxygen	sodium
zirconium	niobium	molybdenum	technetium	ruthenium
rhodium	palladium	silver	cadmium	indium
tin	antimony	tellurium	iodine	xenon

Game Number 2

lutetium	thulium	nitrogen	manganese	carbon
tantalum	titanium	yttrium	actinium	lithium
sodium	copper	zinc	tin	dysprosium
radium	xenon	phosphorus	lead	gold
californium	calcium	rhodium	hydrogen	nitrogen

Name: ______________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 18

Game Number 1

sulfur	arsenic	chromium	oxygen	fluorine
sodium	gold	manganese	fermium	ruthenium
lithium	sulfur	phosphorus	nitrogen	carbon
argon	platinum	thorium	protactinium	indium
radon	radium	tantalum	vanadium	nickel

Game Number 2

nickel	nitrogen	nobelium	niobium	neptunium
oxygen	osmium	radium	radon	ruthenium
tantalum	technetium	tellurium	thallium	titanium
thorium	copper	cobalt	calcium	cesium
californium	cerium	cadmium	chlorine	carbon

Name:

ELEMENT BINGO

PT-G1

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 19 **Game Number 1**

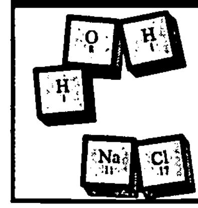
vanadium	carbon	arsenic	astatine	aluminum
americium	argon	actinium	beryllium	boron
bromine	barium	berkelium	chromium	calcium
cesium	cerium	copper	chlorine	californium
dysprosium	erbium	einsteinium	europium	fluorine

Game Number 2

hydrogen	holmium	hafnium	helium	iodine
iridium	indium	krypton	zinc	xenon
tantalum	barium	francium	calcium	rubidium
cadmium	silicon	sulfur	ytterbium	uranium
neon	nitrogen	carbon	osmium	oxygen

Name: ______________________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 20 **Game Number 1**

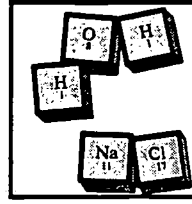
iodine	carbon	arsenic	thallium	thorium
nitrogen	zinc	astatine	chromium	sulfur
titanium	fluorine	americium	uranium	lead
scandium	mercury	actinium	hydrogen	nickel
radon	bromine	argon	copper	zirconium

Game Number 2

fluorine	nitrogen	hafnium	uranium	zinc
lead	sulfur	tin	calcium	chromium
dysprosium	americium	gold	strontium	xenon
argon	iridium	beryllium	copper	carbon
hydrogen	thorium	lawrencium	germanium	tin

Name:

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 21

Game Number 1

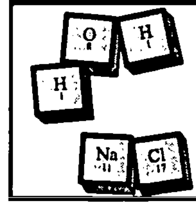
copper	chlorine	sodium	iodine	carbon
nitrogen	titanium	oxygen	tantalum	argon
cadmium	xenon	iridium	tungsten	neptunium
cerium	cesium	calcium	bismuth	silicon
molybdenum	vanadium	iron	gold	hydrogen

Game Number 2

gallium	arsenic	titanium	silicon	carbon
chlorine	sodium	antimony	tin	lead
uranium	sulfur	francium	dysprosium	erbium
ytterbium	boron	niobium	oxygen	hydrogen
xenon	aluminum	nickel	rhodium	nitrogen

Name: ______________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 22 **Game Number 1**

cobalt	nickel	oxygen	phosphorus	potassium
nitrogen	tellurium	beryllium	calcium	erbium
copper	iron	scandium	tungsten	nobelium
zinc	silicon	oxygen	strontium	radium
radon	selenium	aluminum	samarium	cerium

Game Number 2

carbon	actinium	fluorine	neon	zinc
tin	lead	oxygen	ytterbium	boron
nickel	copper	uranium	hydrogen	plutonium
radon	radium	mercury	osmium	americium
polonium	krypton	vanadium	niobium	nitrogen

Name: ______________________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 23

Game Number 1

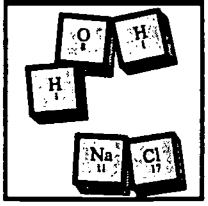
vanadium	californium	cesium	oxygen	nobelium
hafnium	holmium	tantalum	tungsten	mercury
silicon	sulfur	barium	rubidium	calcium
thulium	antimony	nitrogen	hydrogen	neon
molybdenum	manganese	iridium	tungsten	copper

Game Number 2

xenon	carbon	yttrium	lanthanum	actinium
cobalt	copper	aluminum	silver	lead
gold	hydrogen	oxygen	nickel	nitrogen
potassium	mercury	rhenium	tungsten	uranium
plutonium	thorium	strontium	iodine	gold

Name: ____________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 24 **Game Number 1**

osmium	nobelium	oxygen	selenium	boron
carbon	zinc	hydrogen	vanadium	lead
thorium	dysprosium	mercury	silicon	ruthenium
radon	astatine	sulfur	europium	gadolinium
hydrogen	nitrogen	palladium	gold	iridium

Game Number 2

gold	astatine	argon	xenon	zinc
copper	calcium	lithium	bromine	silver
nitrogen	carbon	lead	iridium	uranium
promethium	barium	terbium	manganese	plutonium
tin	chlorine	niobium	titanium	hydrogen

Name: ______________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 25

Game Number 1

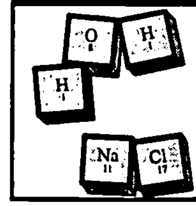
silicon	oxygen	chromium	germanium	carbon
vanadium	boron	nitrogen	selenium	uranium
palladium	tantalum	calcium	hydrogen	gold
osmium	radon	argon	lead	neptunium
tungsten	tantalum	nickel	iron	hydrogen

Game Number 2

boron	erbium	astatine	carbon	nickel
tungsten	uranium	silver	manganese	tantalum
europium	samarium	lanthanum	rhenium	antimony
tin	helium	oxygen	vanadium	silver
cobalt	calcium	cesium	thorium	hydrogen

Name: ______________________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 26 **Game Number 1**

argon	krypton	hydrogen	helium	lead
uranium	calcium	tin	antimony	strontium
ytterbium	silver	bromine	nitrogen	lithium
holmium	tungsten	carbon	zirconium	palladium
rubidium	neodymium	iridium	oxygen	beryllium

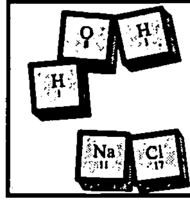
Game Number 2

neon	tin	bismuth	antimony	polonium
thallium	silicon	carbon	nickel	uranium
terbium	actinium	scandium	cesium	hydrogen
oxygen	rhenium	technetium	chromium	iron
gallium	tellurium	argon	lithium	nitrogen

Name: ______________________

ELEMENT BINGO

PT-G1



Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 27 **Game Number 1**

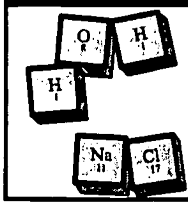
iron	helium	cesium	cobalt	nickel
tin	niobium	ytterbium	fermium	cadmium
lead	nitrogen	oxygen	copper	carbon
ruthenium	vanadium	francium	lutetium	neon
chlorine	boron	silicon	mercury	platinum

Game Number 2

titanium	carbon	nickel	nitrogen	phosphorus
uranium	lead	actinium	americium	arsenic
cadmium	zinc	zirconium	tin	antimony
sulfur	lithium	gadolinium	tungsten	terbium
scandium	cerium	cesium	hydrogen	oxygen

Name:

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 28 **Game Number 1**

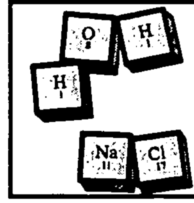
samarium	cobalt	iron	oxygen	sulfur
silicon	tantalum	argon	copper	aluminum
ytterbium	zinc	mercury	indium	antimony
lead	polonium	thulium	neptunium	argon
neon	rhenium	platinum	nitrogen	carbon

Game Number 2

nobelium	einsteinium	palladium	silver	aluminum
oxygen	fluorine	chromium	vanadium	iron
hydrogen	sulfur	cesium	rubidium	radon
neptunium	thorium	mercury	cadmium	carbon
nitrogen	copper	chlorine	phosphorus	zinc

Name: ______________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 29

Game Number 1

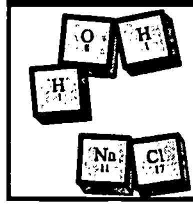
sulfur	dysprosium	oxygen	silver	bromine
fluorine	tungsten	tantalum	iron	promethium
cadmium	rhodium	lithium	hydrogen	bismuth
germanium	palladium	americium	silver	lanthanum
cesium	vanadium	hydrogen	holmium	carbon

Game Number 2

potassium	chlorine	neon	argon	fluorine
actinium	radium	radon	krypton	tantalum
boron	nitrogen	zinc	oxygen	phosphorus
manganese	molybdenum	silicon	germanium	cerium
uranium	scandium	cobalt	carbon	helium

Name: ______________________

PT-G1



ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 30 **Game Number 1**

zirconium	oxygen	helium	argon	sulfur
iodine	cesium	tungsten	rhenium	copper
chlorine	holmium	hydrogen	zinc	carbon
thallium	arsenic	iron	lanthanum	cobalt
tellurium	samarium	radium	beryllium	bismuth

Game Number 2

niobium	bismuth	oxygen	zinc	tin
lead	sulfur	phosphorus	gold	palladium
iridium	francium	americium	lead	mercury
rubidium	polonium	radon	radium	rhenium
tungsten	lithium	uranium	nitrogen	carbon

Name: ____________________

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 31 **Game Number 1**

chromium	ytterbium	cesium	ruthenium	oxygen
zinc	carbon	nickel	tantalum	technetium
phosphorus	bismuth	bromine	plutonium	iridium
nitrogen	hydrogen	helium	argon	copper
iron	gadolinium	osmium	mercury	vanadium

Game Number 2

oxygen	fluorine	francium	californium	mercury
lead	cesium	carbon	zinc	tantalum
zirconium	rhenium	yttrium	rubidium	arsenic
selenium	xenon	berkelium	nitrogen	chlorine
vanadium	silicon	hafnium	krypton	tin

Name:

PT-G1

ELEMENT BINGO

Circle the Elements as they are called. Any straight line of five across, five down or five diagonal wins.

Card Number 32 **Game Number 1**

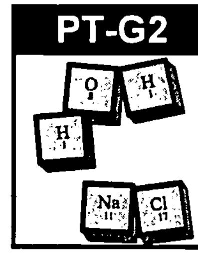
hydrogen	helium	argon	lead	polonium
copper	magnesium	manganese	tantalum	carbon
chlorine	chromium	arsenic	plutonium	thallium
scandium	bismuth	curium	samarium	mercury
palladium	tungsten	gold	xenon	oxygen

Game Number 2

radon	radium	chromium	fluorine	bismuth
boron	phosphorus	iron	oxygen	nickel
bromine	rhenium	calcium	nobelium	astatine
actinium	nitrogen	protactinium	magnesium	mercury
cerium	cesium	niobium	tellurium	aluminum

Name:

Molecular Crossword



Rules:

This is a game for two to six players.

The objective is to get the highest score.

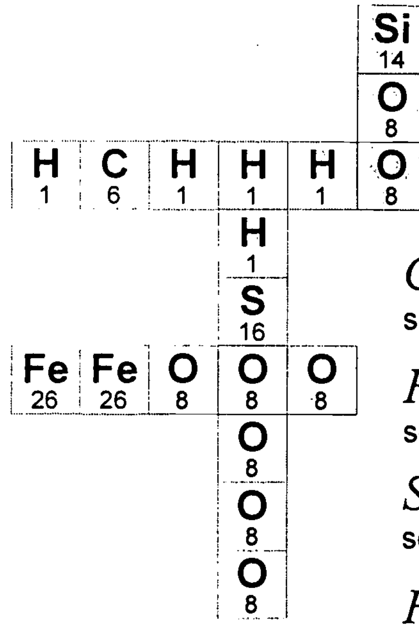
Each player starts with ten cubes.

The player with the highest atomic numbered element goes first and play continues with the player to the right.

Each player tries to build a new molecule by adding off the molecules already on the board. All combinations horizontal and vertical must satisfy the rules for proper formation of molecules.

The score is calculated by adding up the atomic numbers of all the elements in the molecule.

Cubes may be rotated to use any element on any face.



CH_3OH
score: 18 points

Fe_2O_3
score: 76 points

SiO_2
score: 30 points

H_2SO_4
score: 50 points

Any molecule may be challenged by any player before the next turn begins. The player who placed the challenged molecule must prove that it satisfies the valence rules. If the rules are violated the molecule must be removed, the score is not added to the offending player's score, and the player forfeits the turn.

Players score for every molecule that their play creates. Playing into a corner or side-by-side may make more than one molecule. If all the molecules are built according to the valence rules, then all count towards the score. If any one molecule conflicts with the valence rules then the turn is forfeit and the offending player must remove all the cubes just played.

After making a play each player draws enough cubes to maintain a stack of ten by choosing random cubes from a bag or box.

A player may trade one or more cubes for ones in the bag in place of a turn.

End Games

There are several choices of ways to end the game. The group should agree on one before starting.

Option 1: The game ends when all the cubes have been used up and one player runs out of cubes.

Option 2: The game ends when one player (the winner) reaches a set score. Choose 500, 750, or 1000 points.

Valence Rules:

A valid molecule is one for which the total valence is zero. The total valence is obtained by summing the valances of the constituent elements. The following example shows a correct molecule where all the valences are permissible and the total of valences sums to zero for the entire molecule.

The periodic table should be consulted for possible valances. The chart can be used to work out or prove molecules.

Molecule												Total
CH_3OH (methanol, for example)	Element	C	H	H	H	H	O					
	Valence	+4	-1	-1	-1	+1	-2					0
	Element											
	Valence											
	Element											
	Valence											
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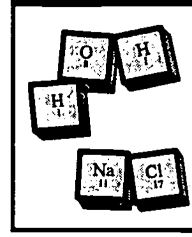
Name:



PT-B1

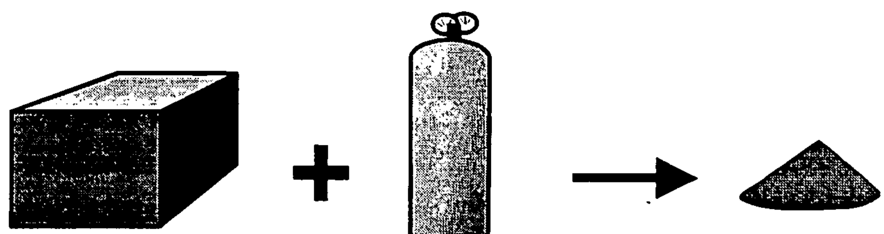
The Periodic Table

WHAT IS THE PERIODIC TABLE?

Everything in our world is made of atoms. There are many different types of atoms. Some are large and heavy, some are small and light. Some are very reactive, and combine fiercely with other atoms, often releasing heat. Some are inert, and never combine with other atoms at all.

Chemistry is the study of atoms and how they combine together. The different types of atoms are called elements.

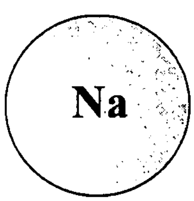
Elements are the simplest substances, and atoms are the smallest unit of an element. In the chemical reaction at the right, sodium and chlorine are both elements.



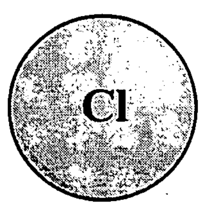
Sodium (Na)
(a soft white metal)

Chlorine (Cl)
(a poisonous, corrosive gas)

Salt (NaCl)



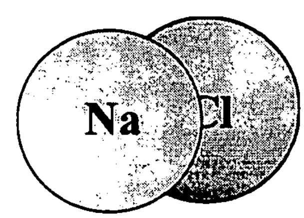
One sodium atom



One chlorine atom

The smallest piece of sodium that can be found is an atom of sodium. Similarly, the smallest piece of chlorine that can be found is an atom of chlorine.

Compounds are mixtures of elements bonded together in specific ratios of elements, and **molecules** are the smallest units of compounds. In the reaction above, salt is a compound. The smallest piece of salt that can be made is a molecule of salt. One molecule of salt is made of one atom of sodium and one atom of chlorine.



One salt molecule

Early scientists were very confused about the differences between compounds and elements. They tried mixing, boiling, dissolving in acid, burning, and many other processes to transform one substance into another. Sometimes, very profound changes could be made by simple mixing: for example, mixing sodium and chlorine together to make salt. Why not, these pioneers asked, make gold from lead? How about diamonds from glass?

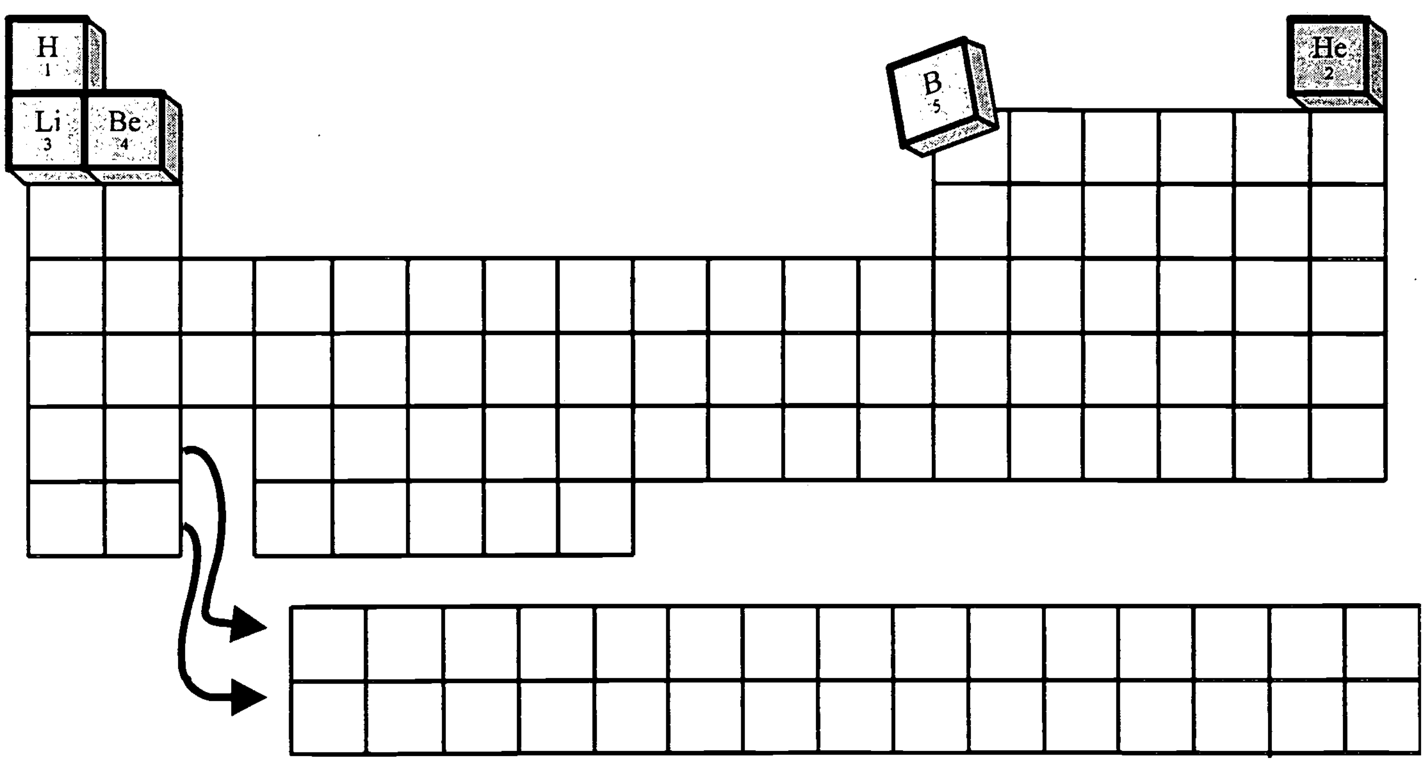
We now know that **chemical reactions rearrange atoms, they don't change atoms from one element to another.** Thus, we can make salt from sodium and chlorine, because salt has both sodium and chlorine atoms in it. We can transform iron into rust without doing *anything*. Rust is made from iron (**Fe**) and oxygen (**O**), which is always present in the air. We can't make gold from lead, or diamonds from glass, because either reaction would require changing one element into another.

B1.1: Do astronauts need to worry about iron rusting on the moon? Why or why not?

Element - a material made from only one type of atom

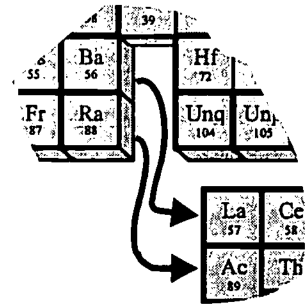
Compound - a material made from two or more types of atoms

The chemical elements can be arranged in groups with similar properties. The **Periodic Table** is a chart of the elements, arranged to remind us of these similarities. The chart below shows the *shape* of the Periodic Table, and the first few elements in sequence from left to right. The elements are arranged in sequence using the **atomic numbers.**



B1.2: Using the chart on the previous page as an example, build the Periodic Table out of the Periodic Puzzle blocks. The numbers on the blocks are the atomic numbers.

There is a tricky part down near the bottom of the table. The table breaks off between elements 56 (**Ba**) and 72 (**Hf**), and fills in the first of two long rows at the bottom (we will learn why later). It does the same thing in the row below. Be sure to fill it in correctly in this area, like in the picture at right.



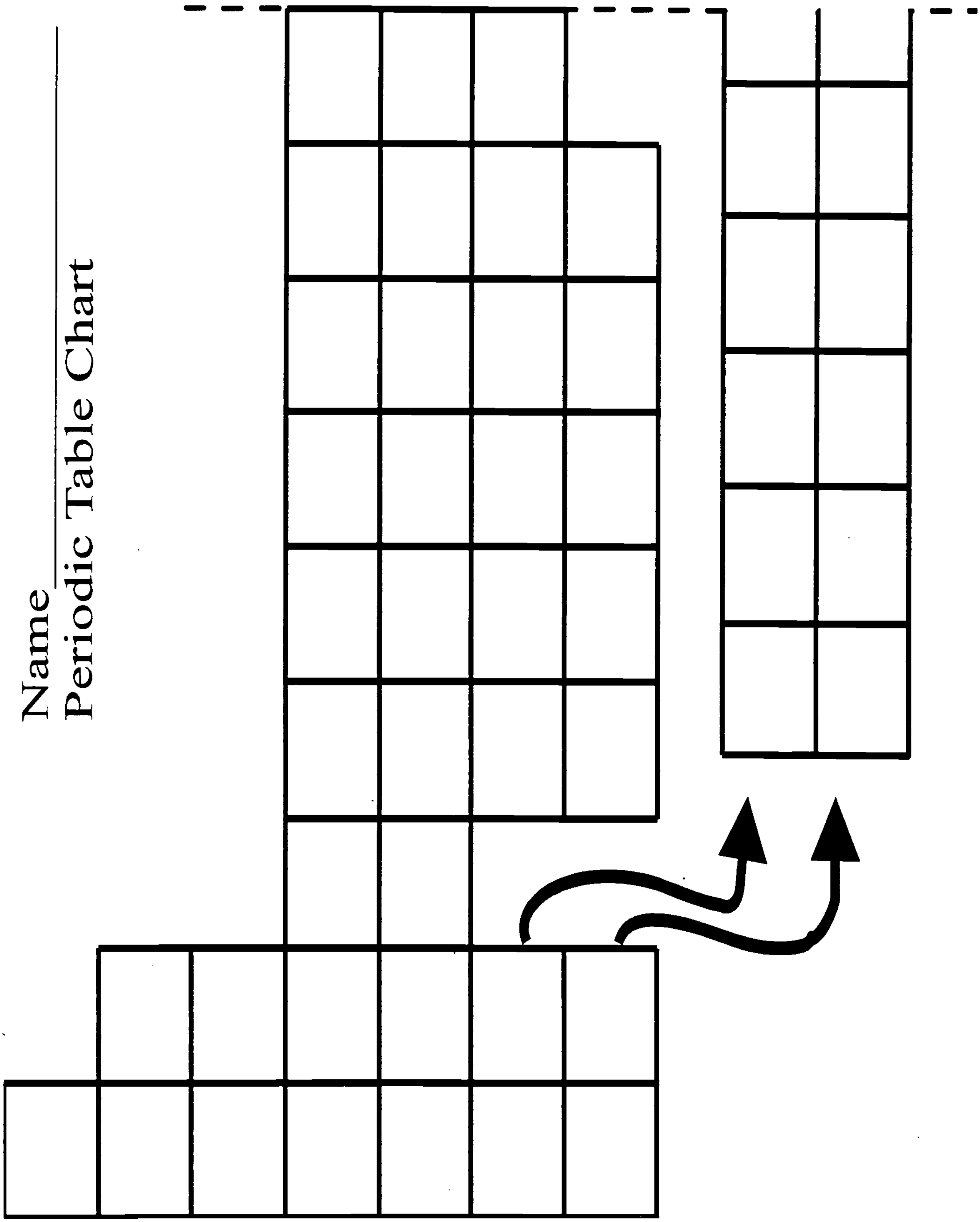
B1.3: After you have built your table, tape together the chart on the next two pages, and fill in the symbols and atomic numbers for the elements. Use the chart below to get the names of the elements.

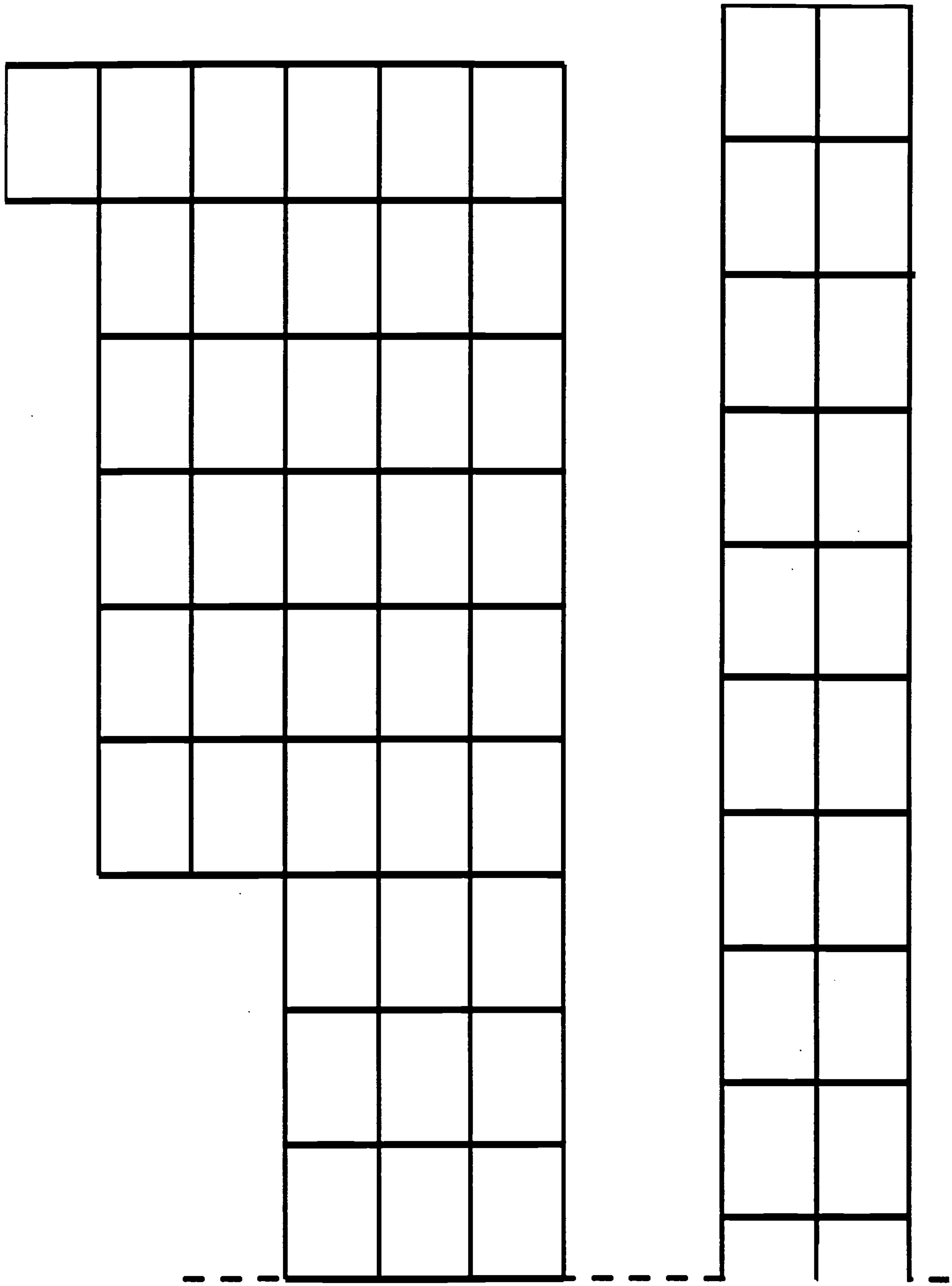
Symbols and Names for the elements

H	hydrogen	**He**	helium	**Li**	lithium	**Be**	beryllium
B	boron	**C**	carbon	**N**	nitrogen	**O**	oxygen
F	fluorine	**Ne**	neon	**Na**	sodium	**Mg**	magnesium
Al	aluminum	**Si**	silicon	**P**	phosphorus	**S**	sulfur
Cl	chlorine	**Ar**	argon	**K**	potassium	**Ca**	calcium
Sc	scandium	**Ti**	titanium	**V**	vanadium	**Cr**	chromium
Mn	manganese	**Fe**	iron	**Co**	cobalt	**Ni**	nickel
Cu	copper	**Zn**	zinc	**Ga**	gallium	**Ge**	germanium
As	arsenic	**Se**	selenium	**Br**	bromine	**Kr**	krypton
Rb	rubidium	**Sr**	strontium	**Y**	yttrium	**Zr**	zirconium
Nb	niobium	**Mo**	molybdenum	**Tc**	technetium	**Ru**	ruthenium
Rh	rhodium	**Pd**	palladium	**Ag**	silver	**Cd**	cadmium
In	indium	**Sn**	tin	**Sb**	antimony	**Te**	tellurium
I	iodine	**Xe**	xenon	**Cs**	cesium	**Ba**	barium
La	lanthanum	**Ce**	cerium	**Pr**	praseodymium	**Nd**	neodymium
Pm	promethium	**Sm**	samarium	**Eu**	europium	**Gd**	gadolinium
Tb	terbium	**Dy**	dysprosium	**Ho**	holmium	**Er**	erbium
Tm	thulium	**Yb**	ytterbium	**Lu**	lutetium	**Hf**	hafnium
Ta	tantalum	**W**	tungsten	**Re**	rhenium	**Os**	osmium
Ir	iridium	**Pt**	platinum	**Au**	gold	**Hg**	mercury
Tl	thallium	**Pb**	lead	**Bi**	bismuth	**Po**	polonium
At	astatine	**Rn**	radon	**Fr**	francium	**Ra**	radium
Ac	actinium	**Th**	thorium	**Pa**	protactinium	**U**	uranium
Np	neptunium	**Pu**	plutonium	**Am**	americium	**Cm**	curium
Bk	berkelium	**Cf**	californium	**Es**	einsteinium	**Fm**	fermium
Md	mendelevium	**No**	nobelium	**Lr**	lawrencium	**Unq**	(not named)
Unp	(not named)	**Unh**	(not named)	**Uns**	(not named)	**Uno**	(not named)

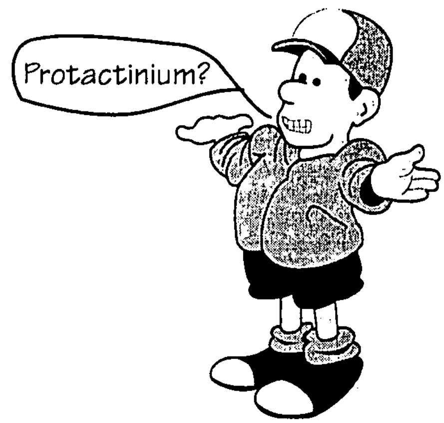
Name

Periodic Table Chart





B1.4: Do some of the elements sound familiar? Pick two, and say something about them.



B1.5: Have you heard of the following elements? What do you know about them?

Oxygen: ______

Silver: ______

Mercury: ______

Silicon: ______

Iron: ______

Neon: ______

Uranium: ______

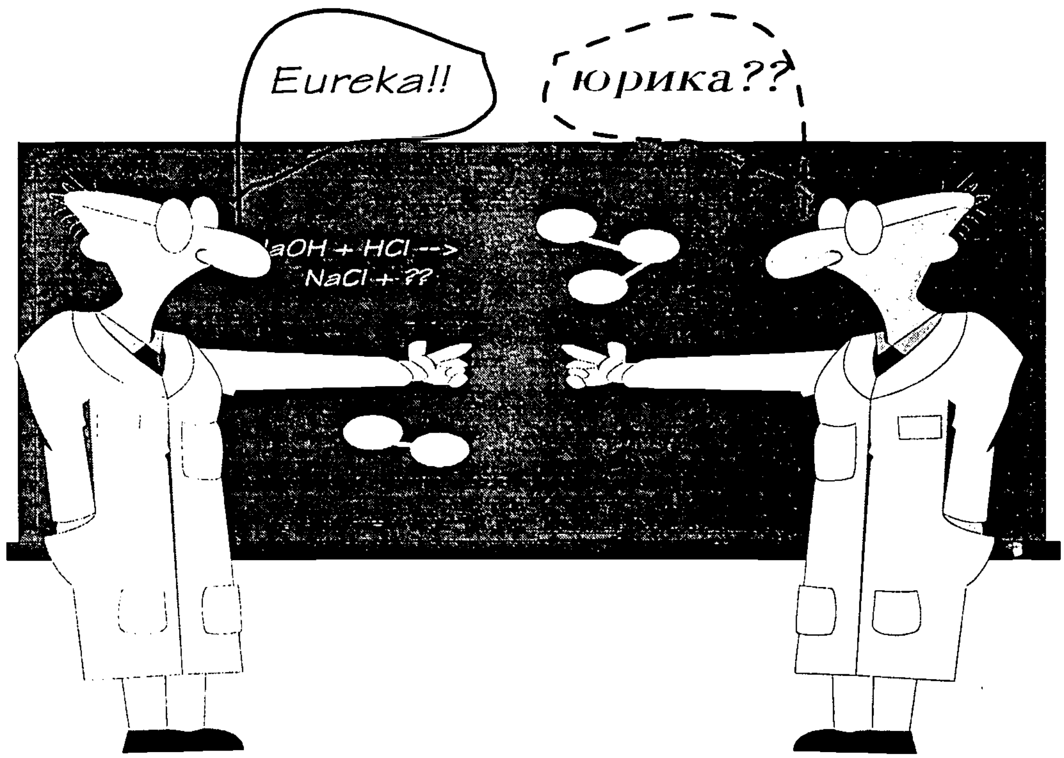
Tungsten: ______

Iodine: ______

Krypton: ______

Some of the element symbols don't seem to make sense. A typical example is the abbreviation for tungsten: the letter **W.** Actually, tungsten was named by German scientists, and the German name for tungsten is "wolfram", so the abbreviation *does* makes sense after all.

Most of the abbreviations that aren't obvious are for similar reasons -- the elements were studied and named by scientists from around the world.



Some elements don't have names yet! Elements 104 through 108 don't occur in nature, but have been made in the laboratory. There are still discussions going on worldwide over what to name them. Many people want to name them after famous scientists who have contributed to their discovery (just like element 99 Einsteinium (in honor of Albert Einstein) or element 100 Fermium (in honor of Enrico Fermi)). This is a problem if there are more scientists than elements! What do you think you need to do to get an element named after you?

B1.6: Some of the materials below are elements, and some are not. Circle the elements.

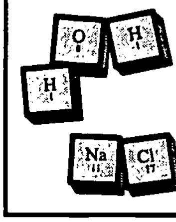
air	**gas**	**oxygen**	**nitrogen**	**argon**
iron	**steel**	**copper**	**brass**	**aluminum**
tin	**nickel**	**bronze**	**chromium**	**lead**
gold	**silver**	**sapphire**	**ruby**	**platinum**
chlorine	**quinine**	**strychnine**	**iodine**	**bromine**

Name:

Valence

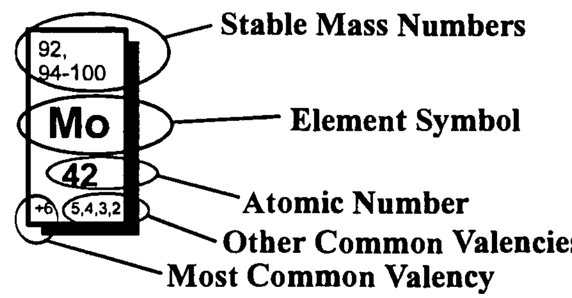
and the Families of Elements

PT-B2



In the last lesson, we learned that the elements were numbered in sequence with the **atomic number.** The atomic number is the number that is used to order the elements in the Periodic Table. There are several other numbers which are used to identify atoms.

The next page shows a chart of the Periodic Table, with some of these other numbers added. These numbers tell us what is in the atom, and how the atom wants to combine with other atoms.



Take a look at the key to the chart at the right. The symbol for the element and the atomic number are the same as we used last lesson. These are printed on the blocks as well.

The **atomic number** is unique to each element. There is only one element with atomic number 42, and that is Molybdenum (**Mo**). The atomic number tells us how many **protons** are in the atom. Protons are one of the three types of particles that atoms are made of.

B2.1: How many protons are in an oxygen atom?

The **atomic mass** or stable mass number is the number or numbers at the top. The atomic mass is the total number of protons and **neutrons** in the atom. If there is more than one number here, than there are several **isotopes**, or atoms of different mass, that exist. For example, molybdenum has stable mass numbers of 92, 94, 95, 96, 97, 98, 99, 100. Since molybdenum must always have 42 protons, these isotopes have 50, 52, 53, 54, 55, 56, 57, and 58 neutrons, respectively.

B2.2: How many neutrons are in the oxygen isotope that has a mass number of 16?

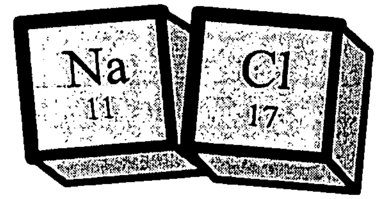
Partial Periodic Table (up to Xenon)

Key (Mo)	
92, 94-100	Stable Mass Numbers
Mo	Element Symbol
42	Atomic Number
5,4,3,2	Other Common Valencies
+6	Most Common Valency

GROUP 1A	GROUP 2A	GROUP 3B	GROUP 4B	GROUP 5B	GROUP 6B	GROUP 7B	GROUP 8			GROUP 1B	GROUP 2B	GROUP 3A	GROUP 4A	GROUP 5A	GROUP 6A	GROUP 7A	GROUP 8A
1,2 **H** 1 +1 -1																	3,4 **He** 2 (none)
6,7 **Li** 3 +1	9 **Be** 4 +2											10,11 **B** 5 +3	12,13 **C** 6 +4 -4,+2	14,15 **N** 7 -3 +2,3,4,5	16-18 **O** 8 -2	19 **F** 9 -1	20-22 **Ne** 10 (none)
23 **Na** 11 +1	24-26 **Mg** 12 +2											27 **Al** 13 +3	28-30 **Si** 14 +4	31 **P** 15 +5 +3,-3,+4	32-34, 36 **S** 16 +6 -2,+2,+4	35,37 **Cl** 17 -1 +1,3,5,7	36,38, 40 **Ar** 18 (none)
39,41 **K** 19 +1	40,42-44,46, 48 **Ca** 20 +2	45 **Sc** 21 +3	46-50 **Ti** 22 +4 3	51 **V** 23 +5 4,3,2	50, 52-54 **Cr** 24 +3 6,2	55 **Mn** 25 +2 7,6,4,3	54,56-58 **Fe** 26 +3 2	59 **Co** 27 +2 3	58,60-62,64 **Ni** 28 +2 3	63,65 **Cu** 29 +2 1	64,66-68,70 **Zn** 30 +2	69,71 **Ga** 31 +3	70,72-74,76 **Ge** 32 +4	75 **As** 33 -3 +5,-3	74,76-78,80, 82 **Se** 34 +4 -2,+6	79,81 **Br** 35 -1 +1,+5	78,80, 82-84, 86 **Kr** 36 (none)
85 **Rb** 37 +1	84, 86-88 **Sr** 38 +2	89 **Y** 39 +3	90-92, 94,96 **Zr** 40 +4	93 **Nb** 41 +5 3	92, 94-100 **Mo** 42 +6 5,4,3,2	none **Tc** 43 +7	96,98-103,104 **Ru** 44 +3 2,4,6,8	103 **Rh** 45 +3 2,4	102,104-106,108, 110 **Pd** 46 +2 4	107,109 **Ag** 47 +1	106,108, 110-112, 114,116 **Cd** 48 +2	113 **In** 49 +3	112,114-120,122, 124 **Sn** 50 +4 +2	121 **Sb** 51 -3 +5,+3	120,122, 124-126, 128,130 **Te** 52 +4 -2,+6	127 **I** 53 -1 +1,5,7	124,126, 128-132, 134,136 **Xe** 54 (none)

The **valence** is the number of electrons that the atom has to contribute when forming compounds. Atoms join together to form molecules in such a way as to share extra electrons. Sodium has a valence of +1, since it has one electron to lend out. Chlorine has a valence of -1, since it has one missing electron which it wants to borrow.

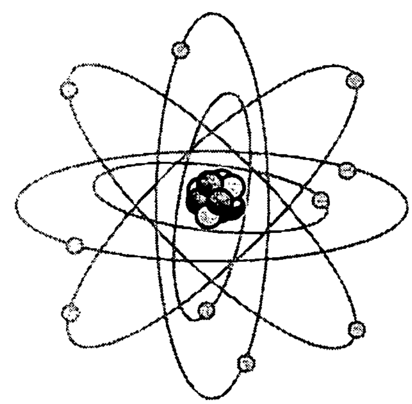
Salt has one sodium and one chlorine, since they cancel out their valencies together. Make a salt molecule out of one sodium atom and one chlorine atom with the Periodic Puzzle blocks.



WHERE DO THESE NUMBERS COME FROM?

Let's look at the rules for building atoms.

Rule #1

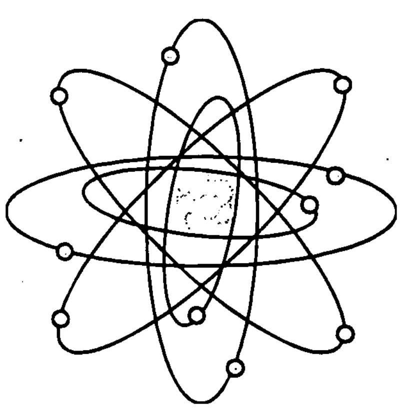


The atom has a small nucleus, which contains protons and neutrons. The protons have a positive electrical charge, and the neutrons are not charged at all.

The atomic number is the number of protons in the nucleus.

B2.3: How many protons are there in Hydrogen? ______________

B2.4: What is the charge of the Oxygen nucleus? ______________



Rule #2

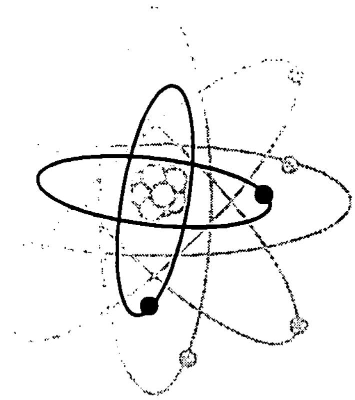
Electrons orbit the nucleus at a large distance. Electrons have a negative charge (exactly the opposite charge from the protons). Atoms want to be neutral -- they want the same number of electrons and protons so that the electrical charge cancels out.

B2.5: How many electrons orbit a neutral Helium atom? _________

B2.6: How many electrons orbit a neutral Uranium atom? ________

Rule #3

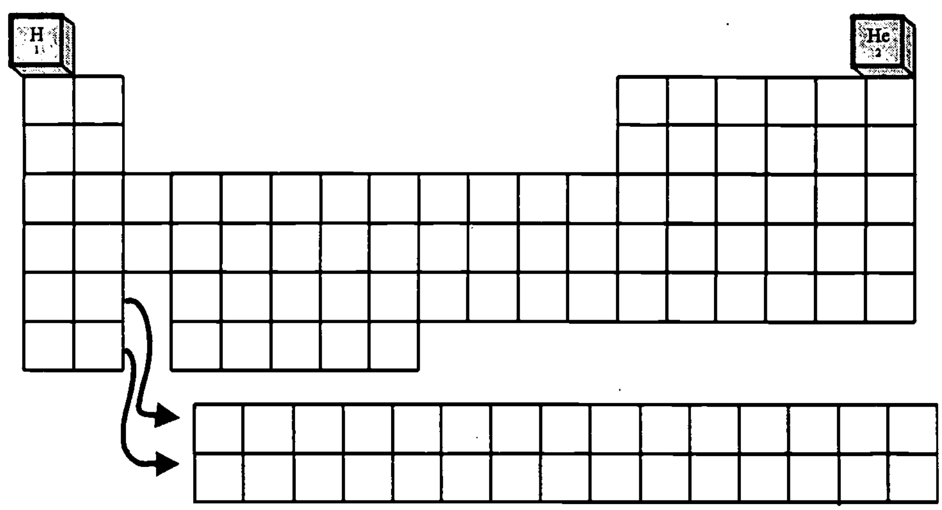
The electrons orbit the nucleus in shells, and only a limited number of electrons will fit in each shell. The first shell only holds two electrons.



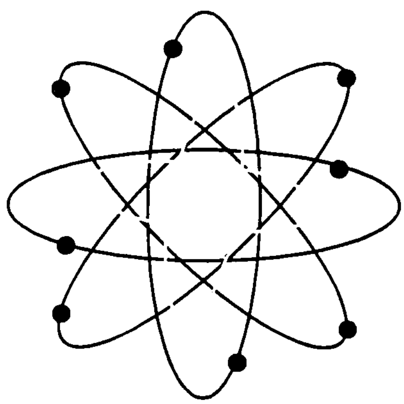
B2.7: Which two elements have all their electrons in the first shell?

____

LET'S START REBUILDING THE PERIODIC TABLE, ROW BY ROW.



Rule #3 said that only the first two elements could fit their electrons in the first shell. Build the first row of the table using these two elements. You now have a complete shell. The last element in this shell is both neutral, and has a full shell. There is very little it needs from any other atom -- and indeed, it will not form any compounds with any other elements.



Rule #4

The second electron shell holds only eight more electrons.

B2.8: Which neutral element has one electron in the second shell?

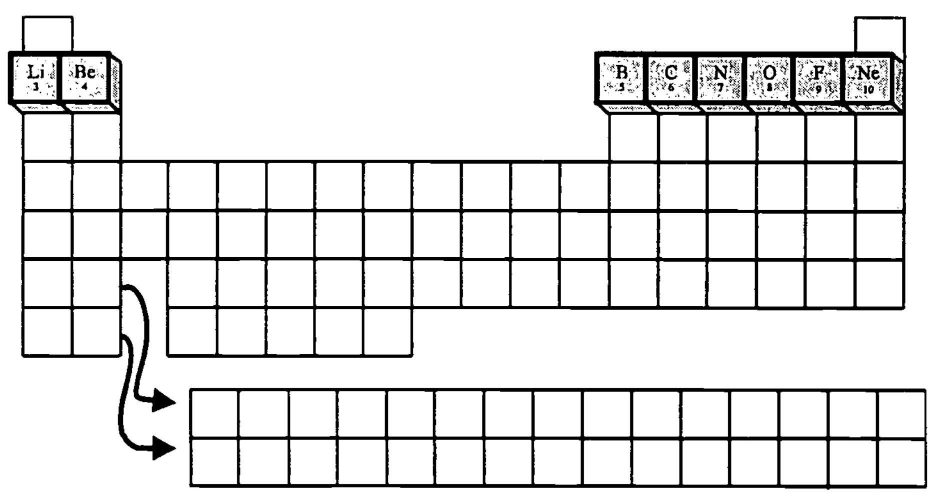
____

B2.9: Which neutral element has all eight electrons in the second shell?

____

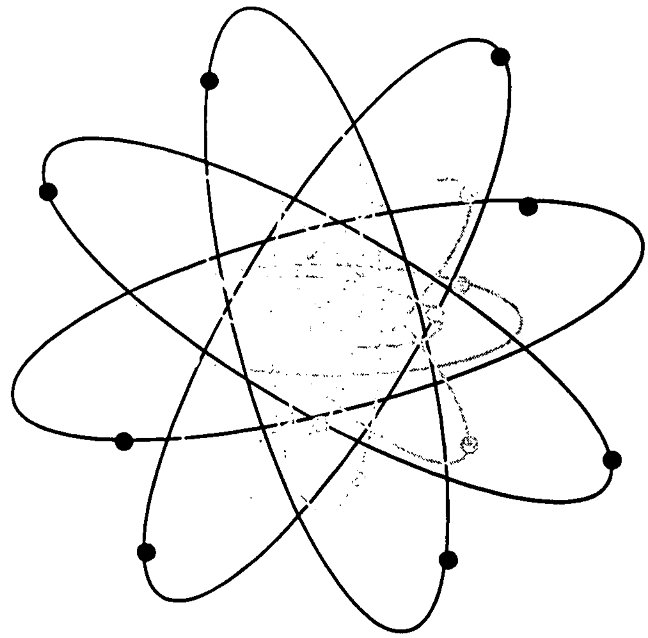
Add on the second row of the Periodic Table, using Rule #4.

There are eight more elements in this row. The shell is again complete with the last element in this row. This is another element that will not react to make compounds.



Rule #5

The third electron shell holds only eight more electrons.



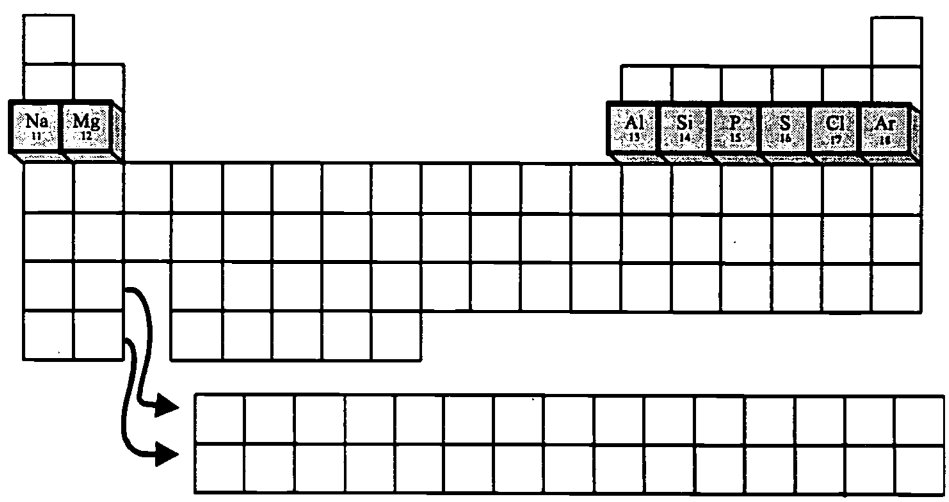
B2.10: Which neutral element has one electron in the third shell?

____

B2.11: Which neutral element has all eight electrons in the third shell?

____

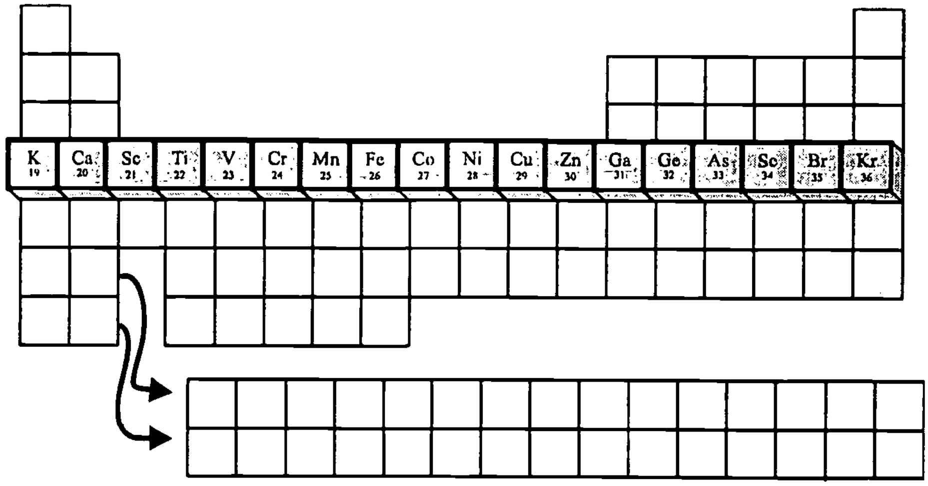
Add the third row to your table. Once again, the last element in this row has a complete shell, and is unwilling to react with other elements.



Rule #6

The fourth shell can hold eighteen more electrons.

Add the fourth row to the Periodic Table. (We won't try to draw these electron shells...)



B2.12: Which element has a complete shell in the fourth row?

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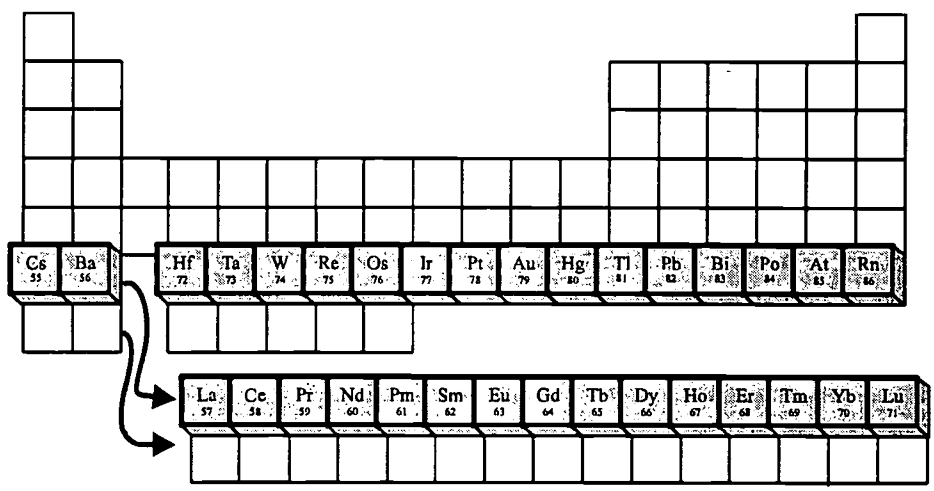
Rule #7
The fifth shell can hold another eighteen more electrons.

Add the fifth row to the Periodic Table.

Rule #8

The sixth shell can hold thirty-two more electrons.

Add the sixth row. Be careful to include the Lanthanide series when you add the sixth row.



B2.13: Which element completes the sixth shell?

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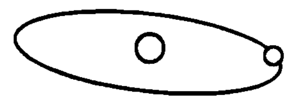
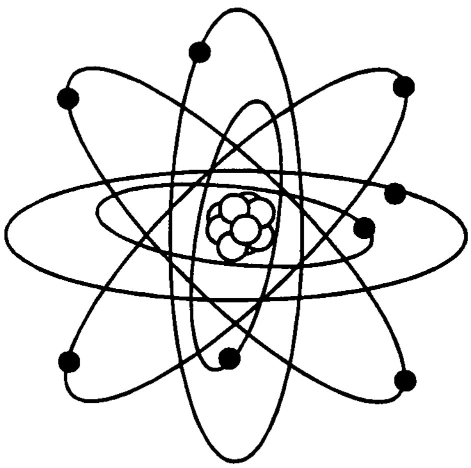
Rule #9
The seventh shell can hold another thirty-two more electrons.

Finish building the Periodic Table by adding the seventh row (don't forget the Actinide series).

Atoms will try to combine with one another and share electrons so that they can be neutral *and* have complete shells. Because of this, the atoms with one extra electron in the outer shell will behave differently than atoms with two extra electrons in the outer shell. We call this property **valency.** The valence of an atom is the number of electrons in the outer shell.



Let's look at an example. **Hydrogen** has only one electron, but the first shell has room for two. Hydrogen has an extra electron floating around that it would like to share, leaving the first shell empty. Since it has an extra electron to share, we say that hydrogen has a valency of +1.



Oxygen, on the other hand, had a total of eight electrons -- two in the first shell, and six in the second shell. Since the second shell has room for eight electrons, there are two "holes" in the shell waiting to be filled. If oxygen can find some way to share two electrons to fill this shell, then it will have a full second shell. Since there are two holes in the outer shell to share, we say that oxygen has a valence of -2.

What happens when we bring oxygen and hydrogen together? Hydrogen could lend its extra electrons to oxygen, but then neither element would be neutral. Instead, one oxygen atom and two hydrogen atoms will bond together to form a **molecule**. The material made from a lot of these molecules is called a **compound.** Each molecule will have one oxygen and two hydrogens stuck together and sharing electrons. This way, all the shells can be full, and all the atoms can be neutral.

When we form a molecule like this, we write it using the abbreviations for the elements. Earlier, we learned that we could make salt by combining sodium (**Na**) with chlorine (**Cl**). Although sodium is a soft metal and chlorine is a poisonous gas, salt is a common chemical that we sprinkle on our food! We write the formula for salt as **NaCl.** Similarly, when we combine one oxygen and two hydrogen atoms, we make a molecule that we write as **H_2O.** The subscript "2" shows that there are two hydrogen atoms in the molecule.

B2.14: Have you ever heard of **H_2O?** What is it?

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B2.15: Find blocks from the Periodic Table for hydrogen, oxygen, sodium, and chlorine. Combine the blocks on the desk to make salt and **H_2O** molecules.

There are many other common compounds that we can write the chemical formulas for.

B2.16: Ammonia is made up of nitrogen (**N**) and hydrogen (**H**). Nitrogen has a valence of -3, and hydrogen has a valence of +1. Make an ammonia molecule out of blocks. What is the symbol for ammonia?

B2.17: Carbon dioxide is made up of carbon (**C**) and oxygen (**O**). Carbon has a valence of +4. What is the valence for oxygen? Make a carbon dioxide molecule out of blocks. What is the symbol for carbon dioxide?

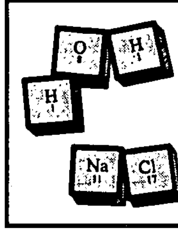
B2.18: Rust is what you get when you let iron (**Fe**) with a valence of +3 combine with oxygen (**O**) with a valence of -2. Make rust out of blocks, and write down the symbol for rust.

B2.19: Methane, or natural gas, is what you might cook with or heat your house with. It is made of carbon (**C**) and hydrogen (**H**). We already learned that hydrogen has a valence of +1 and carbon has a valence of +4. Carbon actually has four electrons in the second shell, which has room for eight. That means that it can either lend its four electrons out to empty the second shell (for a valence of +4) or borrow four more electrons to complete the second shell (for a valence of -4). In methane, it borrows four electrons, and has a valence of -4. Make methane out of blocks, and write down the symbol for methane.

Name: ____________________

A Tour of the Periodic Table

PT-B3

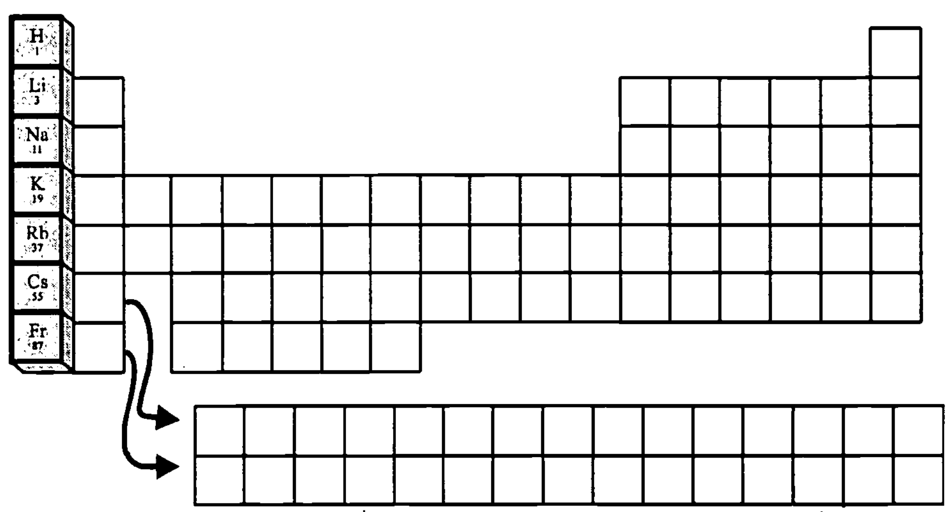


In the last two lessons, we learned that the Periodic Table groups elements in ways to remind us of the chemical similarities of the elements. We learned that these similarities are due to the way that electrons fill the shells around the atom.

We learned that the each **row** of the Periodic Table contains the atoms that have the same partially filled outer shell. The first row has all the atoms that have electrons in the first shell (**H, He**). The second row has all the atoms that have electrons in the second shell (**Li, Be, B, C, N, O, F, Ne**). And so on.

The columns of the Periodic Table tell us which atoms share the **same number of electrons, or the same number of missing electrons** in the outermost shell. The columns thus tell us which elements behave most similarly.

LET'S TAKE A TOUR OF THE COLUMNS OF THE PERIOD TABLE.



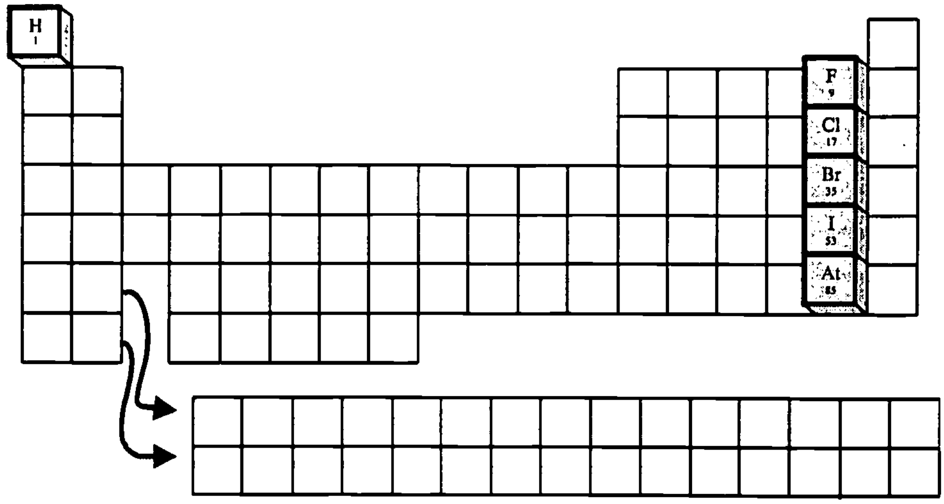
Start with the first column. These elements all have only one electron starting to fill a shell. Because of this, they very easily lend this extra electron out to make compounds with elements that need electrons.

These elements, called the **GROUP 1A** elements, are *very* reactive. They are only rarely found in the pure form in nature, because they want to combine with other elements so readily.

Except for hydrogen, the Group 1A elements are all soft metals in the pure form. They are so reactive, however, that they quickly combine with air to make oxides. Cesium can even burst into flame when exposed to air.

The Group 1A elements all have a valence of +1.

The next to last column is all the elements that have a shell completely filled except for one electron. These are the **GROUP 7A** elements. They are just as reactive as the Group 1A elements, for exactly the opposite reason. They are so willing to share an electron that any other atom is willing to lend, that they will combine very readily to form compounds. The Group 7A elements are corrosive and pungent.



Note that we include hydrogen in this group as well! Hydrogen has only one electron in a shell big enough for two. It will happily share electrons in such a way as to lend its electron out (and empty its shell), or take another electron (and complete its shell).

These elements all have a valence of -1.

B3.1: We learned earlier that we could combine sodium with chlorine to make salt, **NaCl**. We now see why salt has only one sodium and one chlorine; sodium has a valence of +1 and chlorine has a valence of -1. Write down the chemical formulas for ten other compounds that can be formed by combining Group 1A elements with Group 7A elements, and make them out of the Periodic Puzzle blocks.

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B3.2: Hydrogen is a special case. When we combine hydrogen (from Group 1A) with one of the Group 7A elements, we form an especially corrosive combination. **HCl** is the chemical symbol for hydrochloric acid. Write down the chemical symbols for three other acids that use hydrogen and Group 7A elements, and make them out of the Periodic Puzzle blocks. Try to guess their names.

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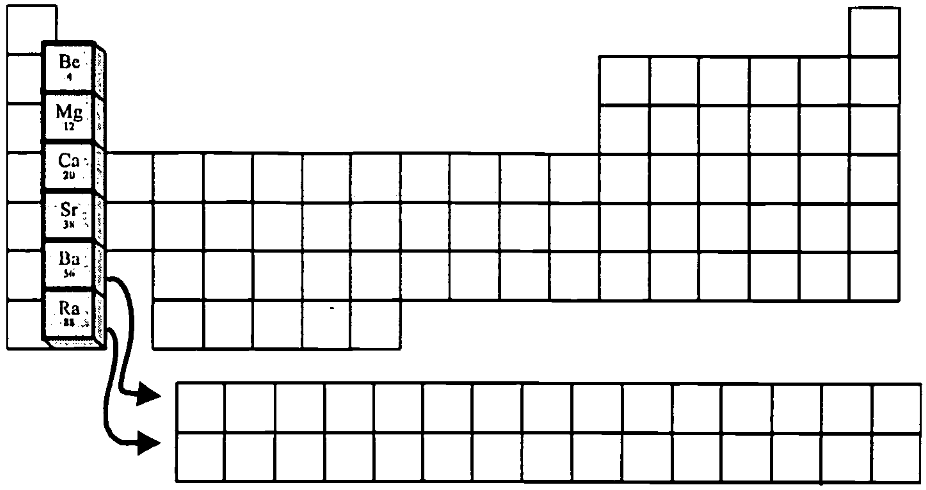
The second column of the Periodic Table contains those elements that have two electrons in the outermost shell. They are reactive, but not as reactive as the Group 1A elements.



Although most of these are rarely found in their pure form, magnesium is occasionally useful as a structural metal, because it is so light (it is the first practical metal in the Periodic Table). Ultra-lightweight bicycles might have magnesium frames, or frames made out of an **alloy**, or mixture, of magnesium and other metals.

These are called the Group 2A elements, and they all have a valence of +2.

B3.3: Magnesium fluoride is a clear, hard glassy material. It is often used as a hard anti-reflective coating on optical surfaces, such as binocular or camera lenses. The chemical symbol for magnesium fluoride is $\mathbf{MgF_2}$. Make magnesium fluoride out of the Periodic Puzzle blocks. Write down the chemical symbols for four more compounds made from Group 2A elements and Group 7A elements, and make them from the blocks.

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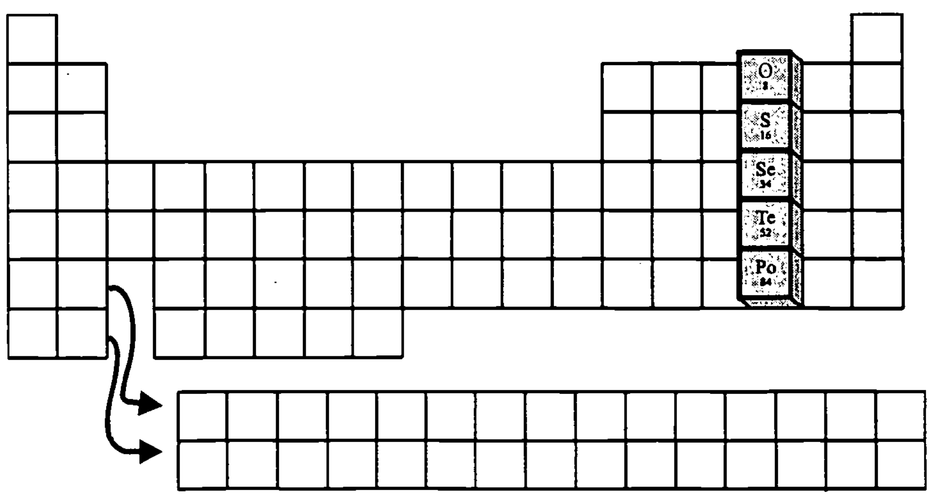
The Group 6A elements are those which have two missing electrons from the outermost shell. They usually have a valence of -2 (or +6). They are not as strongly reactive as the Group 1A, 2A, or 7A elements. Oxygen is found in its pure form in air (although it forms a molecule with itself, $\mathbf{O_2}$). Sulfur can be found in nature in its pure form; a yellow powdery substance.



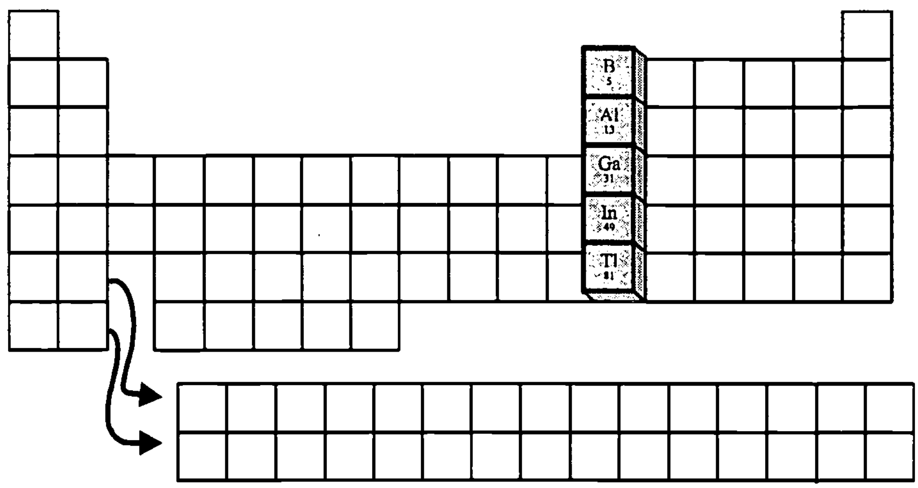
B3.4: Calcium oxide is a hard white material. Eggshells are largely calcium oxide, and there is a great deal of it in bones, as well. What is the formula for calcium oxide? Make it out of blocks.

B3.5: Make four more compounds out of Group 2A and Group 6A elements out of blocks, and give their symbols here.

B3.6: Make four compounds out of Group 1A and Group 6A elements out of blocks, and give their symbols here.

The Group 3A elements are those which have three electrons in the outermost shell. They usually have a valence of +3.

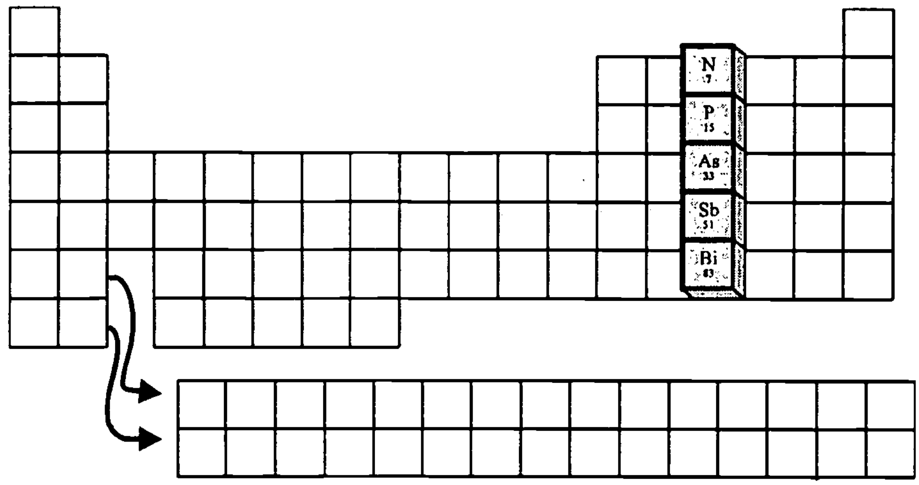
The Group 3A elements are mildly reactive. Pure aluminum, for example, is stable enough to use as a common structural material.



B3.7: Make four compounds out of Group 3A and Group 7A elements out of blocks, and give their symbols here.

B3.8: Do the same with Group 3A and Group 6A elements.

The Group 5A elements are those which have three missing electrons in the outermost shell. They usually have a valence of -3 (or +5).



The Group 5A elements are mildly reactive. They can exist in nature in their pure form: nitrogen makes up nearly 80% of the air that we breathe (although it is in a molecule with itself, N_2).

The group 5A elements often form much more complex molecules that have a mixture of elements from several groups. Nitrogen and phosphorous, for example, are very important in organic molecules -- molecules that make up living organisms. Some nitrogen compounds are also very efficient at storing large amounts of chemical energy. Most explosives use nitrogen compounds as a key to store a great deal of energy and release it quickly when ignited.

B3.9: Group 5A elements have recently started becoming important in electronics. Some new semiconductors, called 3-5 semiconductors (usually written in roman numerals, III-V), make use of interesting electronic properties of compounds made with Group 3A elements. List six compounds made from Group 3A and Group 5A, and make them out of the puzzle blocks.

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B3.10: Make four compounds out of Group 1A elements and Group 5A elements. List them here and make them out of the puzzle blocks.

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B3.11: Make four compounds out of Group 2A elements and Group 5A elements. List them here and make them out of the puzzle blocks.

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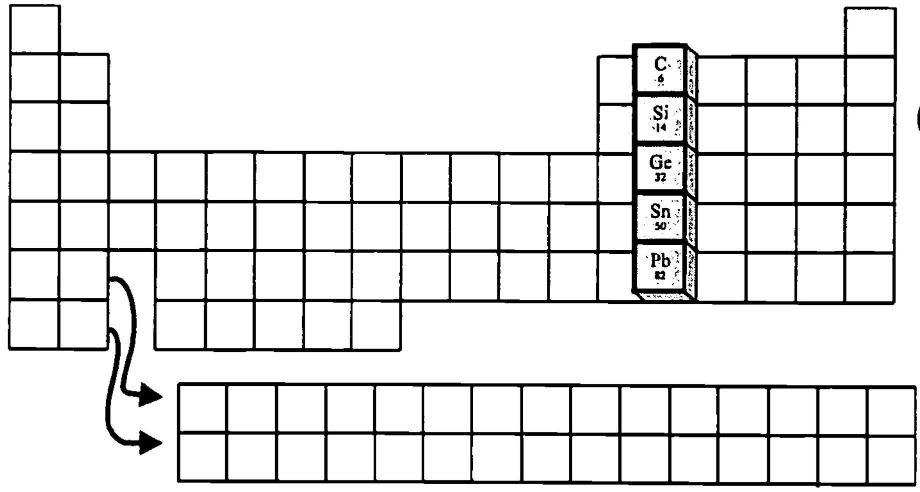
The Group 4A elements are those which have four electrons in the outermost shell (at least for the first couple rows). We will later see that the larger shells fill up in a more complex and layered way, which still leaves four electrons in the outermost part of the shell for **Ge, Sn, and Pb.** They all have a valence of +4



Since these elements also have four missing electrons from the outermost shell, they should also have a valence of -4, but in fact only carbon ever does.

These elements form the most complex molecules of all. They are not particularly reactive, but can combine in many ways with elements from multiple groups of the Periodic Table.

Carbon is the essential element that all living organisms are based on. There is an entire subject within chemistry, called organic chemistry, which is really just the study of carbon compounds. In nature, carbon can be found in two different pure forms. Most of the time, it is graphite - a dark powder. Under extremes of pressure and temperature, however, carbon can form diamond, which is the hardest substance known to man.

We have also all heard of silicon, which is the material that nearly all semiconductors are made from. Silicon, and also Germanium, has very useful and complex electronic properties when combined with very very small amounts of impurity elements. Computer chips are made from tiny pieces of silicon, with patterns of impurities microscopically printed to make an electric circuit.

B3.12: Make four compounds from Group 4A and Group 6A elements with the blocks, and give their chemical symbols here. Did you think of carbon dioxide?

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B3.13: Carbon tetrachloride is made of carbon and chlorine. Make this and three other compounds from Group 4A and Group 7A elements with the blocks, and give their symbols here.

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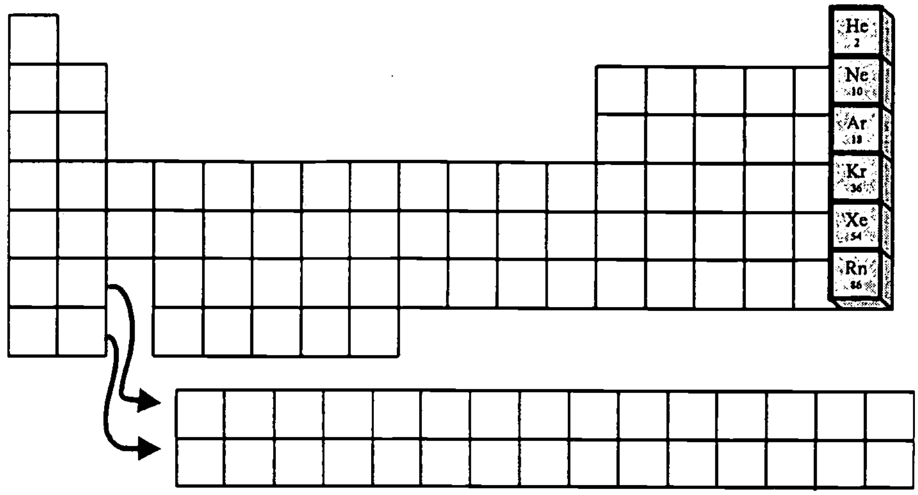
The Group 8A elements are the ones with completely filled outermost shells. They have a valence of 0, since they neither want have extra nor missing electrons to share.

These elements don't form compounds at all. They are found in nature in their pure, gaseous, form only. Early scientists called the Group 8A elements the **noble gases,** since they behaved like royalty and refused to combine with any of the other elements.



B3.14: Have you heard of helium? Where have you used it?

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B3.15: There is a significant amount of argon in the air that we breathe (almost 1%). Do you think our bodies do anything with the argon in the air? Why or why not?

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B3.16: Have we left out any elements? Which ones?

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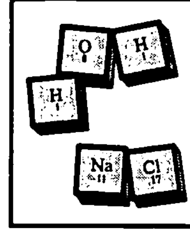
Name:

Orbital Names and the Transition Elements

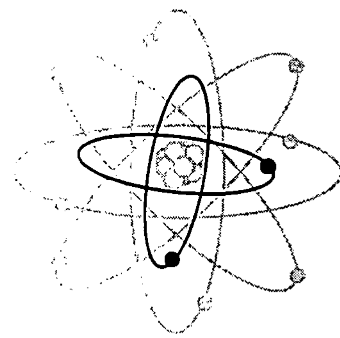
PT-B4



We have learned that electrons fill orbit the atom in shells, and that the chemical behavior of the atom depends on how many electrons are left in the outermost, partially filled shell.

This chemical behavior becomes a bit more complicated further down in the Periodic Table, because the shells have additional layers, and the electrons fill the layers in a peculiar order. Let's look at some of our rules from Activity **B2**.

The first shell only holds two electrons. The first shell is the simplest, and has no layers to worry about. We call a shell that holds only two electrons an **s-shell.** The first shell consists of only the first s-shell, and is called the *1s* shell.



1s shell

B4.1: List the elements that fill up the *1s* shell.

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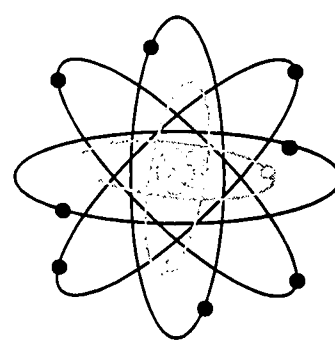
The second shell holds only eight more electrons. The second shell actually has two layers. The first layer to fill up is another s-shell, the *2s* layer, which holds two electrons. The next layer holds the remaining six electrons. Shells which hold six electrons are called **p-shells.** This is called the *2p* layer.

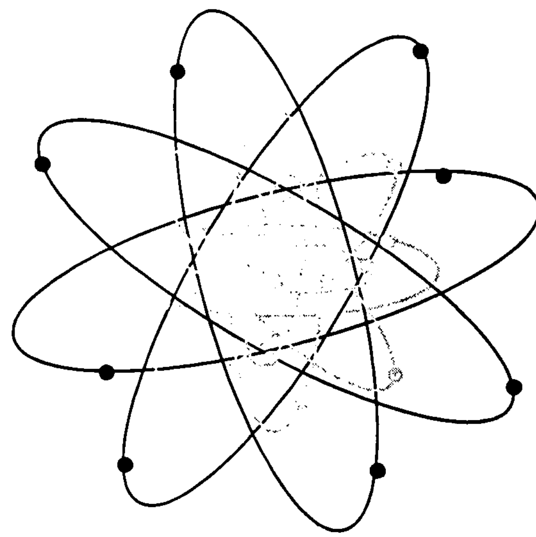


2s and 2p shells

B4.2: List the elements that fill up the *2s* shell.

B4.3: List the elements that fill up the *2p* shell.

The third shell holds another eight more electrons. The third shell is just like the second, and is composed of two electrons in the *3s* layer and six electrons in the *3p* layer.



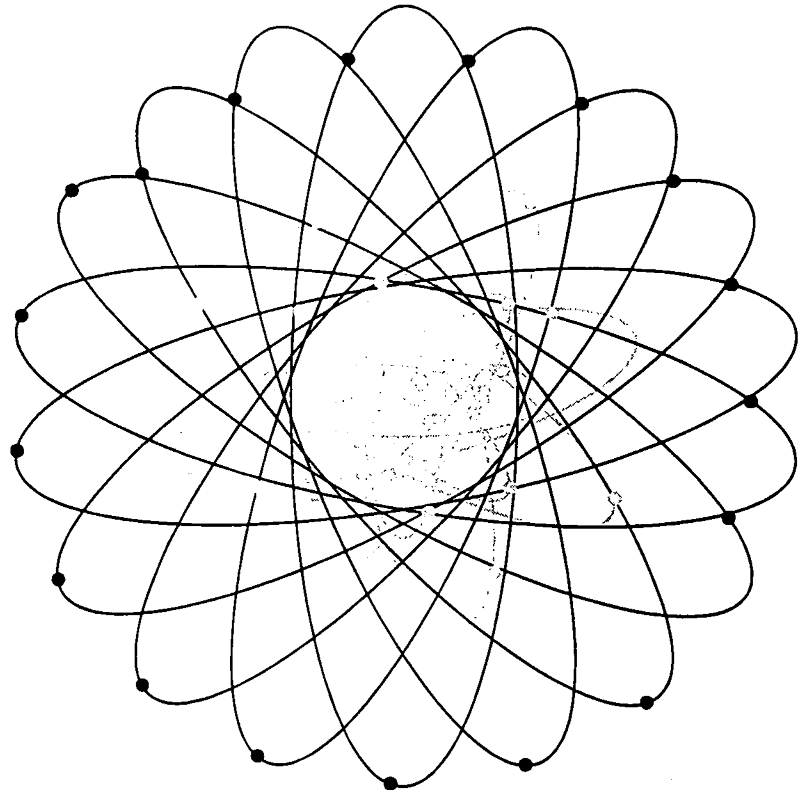
3s and 3p shells

B4.4: List the elements that fill up the *3s* shell.

B4.5: List the elements that fill up the *3p* shell.

The fourth shell can hold only eighteen more electrons. This shell has eight electrons, just like the last couple layers; two in the *4s* layer and six in the *4p* layer. In addition, this shell has ten electrons in what is called a **d-shell**. This is numbered *3d* (not *4d*) for mathematical reasons that we don't want to know.

The fifth shell can hold another eighteen more electrons. This shell is the same as the previous one. There are two electrons in the *5s* layer, six in the *5p* layer, and ten in the *4d* layer.



4s, 4p, and 3d shells

B4.6: List the elements that fill up the *4s* shell.

B4.7: List the elements that fill up the *3d* shell.

B4.8: List the elements that fill up the *4p* shell.

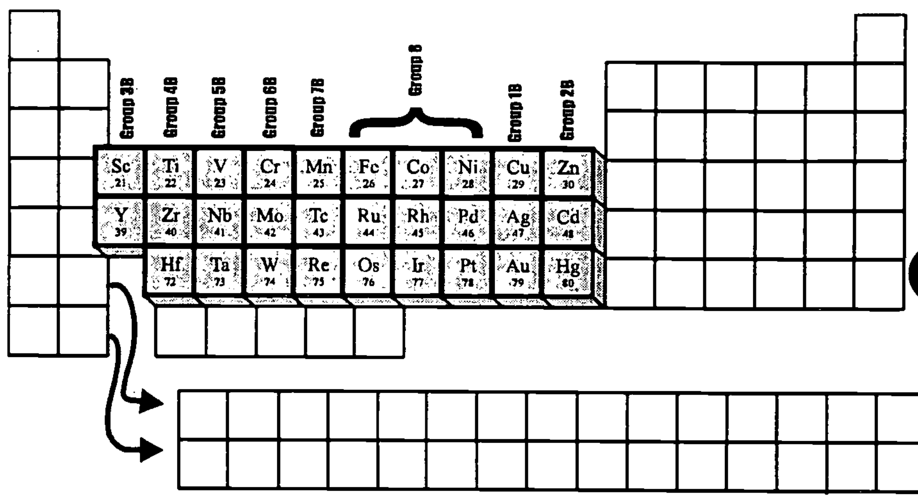
The sixth shell can hold thirty-two more electrons. (No, we won't try to draw this!) This shell has the first eighteen as we would expect them by now: two in the *6s*, six in the *6p*, and ten in the *5d*. In addition, there are another fourteen electrons in what is called an **f-shell.** This is numbered *4f*.

The seventh shell can hold another thirty-two electrons. This is the same as the previous one. Two electrons are in the *7s*, six in the *7p*, ten in the *6d*, and fourteen in the *5f*.

WHY DO WE CARE?

The order in which the electrons fill up the shells gets pretty tricky as we move down the Periodic Table. The layers will sometimes fill partially, leaving an atom with **several partially filled shells.** This means that the valence might be appropriate to lend out all the electrons in one of the partially filled shells, another, or all of them. Similarly, the partially filled shells may want to share additional electrons, enough to fill some or all of them. The elements lower down the Periodic Table thus have many possible values for the valencies. We will look at the most common ones.

THE TRANSITION ELEMENTS



The elements at the right are called the transition elements. They are the ones with partially filled **d-shells.** The valence can usually be understood by thinking of the extra electrons in the d-shell.

Within these elements, there are several Groups. As the d-shell fills up, the valence will change accordingly.

The Group 3B elements usually have a valence of +3. The Group 4B elements usually have a valence of +4. Similarly for the Group 5B, 6B, and 7B elements, which have valences of +5, +6, and +7.

The Group 8 elements are much harder to understand. They make compounds that will give them enough electrons to half-fill the d-shell, plus or minus a little. They all have valencies of +2, +3, or +4; most of them some or all of these valencies.

The Group 1B and 2B elements actually borrow electrons from the s-shell outside of the d-shell (which fills up first) to completely fill the d-shell. The valence of these is then due to the number of electrons in the outlying s-shell. Because of this, the 1B elements have a valence of +1 (and sometimes +2 or +3). Similarly, the 2B elements have a valence of +2.

B4.9: Iron is in the Group 8 portion of the transition elements. It has a preferred valence of +3. When oxygen combines with iron, you get rust (iron oxide). What is the formula for rust? Make it out of blocks.

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B4.10: Silver is in the Group 1B portion of the transition elements. It has a valence of +1. When you combine silver with chlorine, you get a compound that is very sensitive to light. This is the stuff that is spread out on the film in your camera to capture images when you take pictures. What is the formula for silver chloride? Make it out of blocks.

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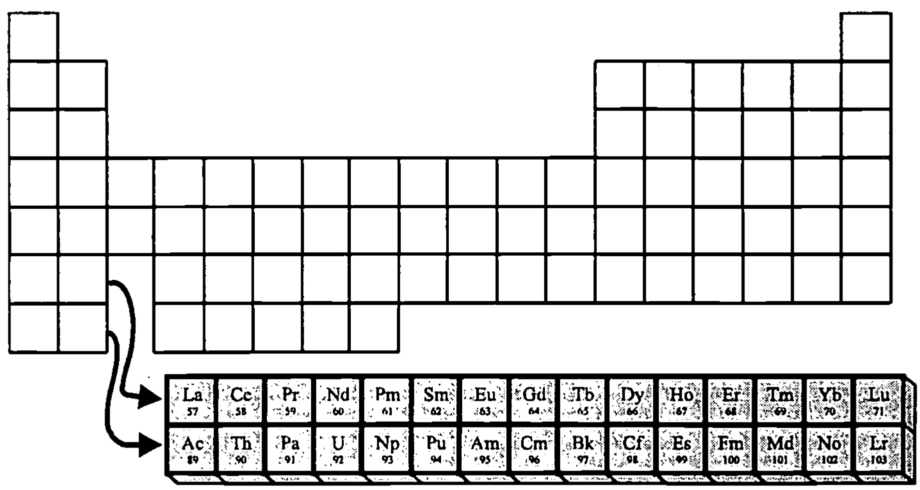
DEEPER AND DEEPER

The Lanthanides and Actinides are the two rows of elements that are usually left hanging below the bottom of the Periodic Table. These are the elements that have partially filled f-shells. The f-shells fill up below the outlying s-shells, and play little role in the chemistry of these elements. Since the entire series squeezes in under the Group 3B elements, they nearly all behave similarly to Group 3B, and have valences of +3.



B4.11: Uranium is in the Actinide group. Most of the uranium found in nature is non-radioactive, but a very small fraction is radioactive. When scientists want to isolate the radioactive part from the non-radioactive part of uranium, they can't use the chemical properties of uranium to do this. Why not?

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B4.12: Scientists separate radioactive from non-radioactive uranium by making use of the slight difference in mass. They can "sift" gaseous compounds of uranium much like you would sift sand. The gaseous compound that they usually use is called uranium hexafluoride, which is made of uranium and fluorine. The valence for uranium is usually +6 (although it can be +5, +4, or +3). What is the formula for uranium hexafluoride. Make some (with blocks, not real uranium).

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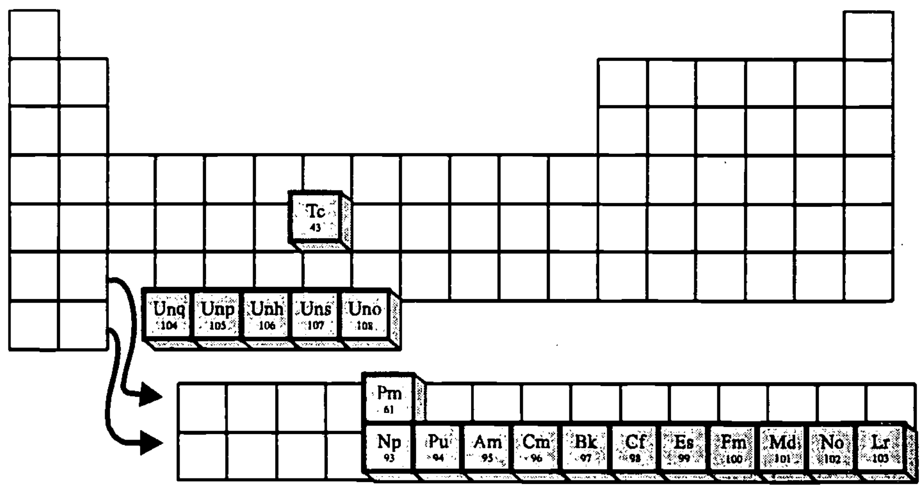
WEIRD ELEMENTS



There are some elements that aren't found in nature. Some elements are **radioactive,** which means that the nucleus is unstable and decays into something else eventually. For some elements, there are several isotopes (atoms with the same number of protons but different numbers of neutrons) that are radioactive and some that aren't. Usually, the non-radioactive isotopes are far more common in nature.

Some elements have only radioactive isotopes. Some of these are found in nature only briefly; they are created during the decay of one element, and quickly decay into something else. Some of them are not found in nature at all. The ones shown at the right have only been observed by making them in the laboratory using nuclear (not chemical) reactions.

B4.13: Why can't these be made with chemical reactions?

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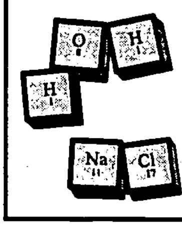
Name: ____________________

PT-B5

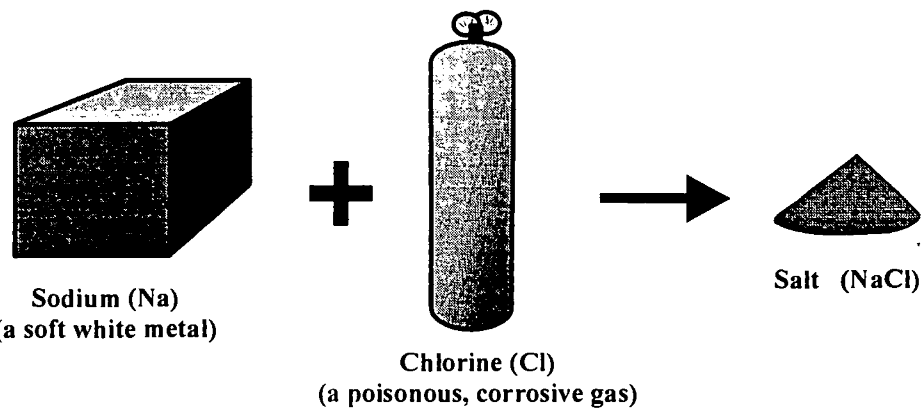


Chemical Reactions

Now that we know all about the elements and how they combine to make molecules, let's look at the way that these combinations take place.

A chemical reaction is what happens when we mix together two or more chemicals which rearrange themselves to make new chemicals.

Let's look at the first reaction that we learned, combining sodium and chlorine to make salt. The **reactants** are the ingredients that we mix together to start the reaction.



B5.1: What are the reactants in the reaction above?

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The **products** of a reaction are the end results of the reaction, or the stuff that we make.

B5.2: What are the products in the reaction above?

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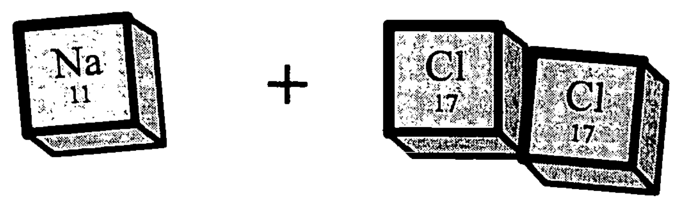
We write chemical reactions much like we write mathematical equations. We *might* write the above reaction

$$\mathbf{Na + Cl \rightarrow NaCl} \qquad \textit{(almost right)}$$

to show that we started with sodium (**Na**) and chlorine (**Cl**), and ended up with salt (**NaCl**). The only problem is that chlorine is not available in the atomic state. Pure chlorine forms a two-atom molecule with itself. These are called **diatomic** molecules. The formula for diatomic chlorine is $\mathbf{Cl_2}$. We then must write the left side of the chemical equation like this:

$$\mathbf{Na + Cl_2 \rightarrow .....}$$

B5.3: Take three blocks to form the reactants above: one sodium, and two chlorines joined together to make a molecule. Rearrange them to make salt. Is there any problem?



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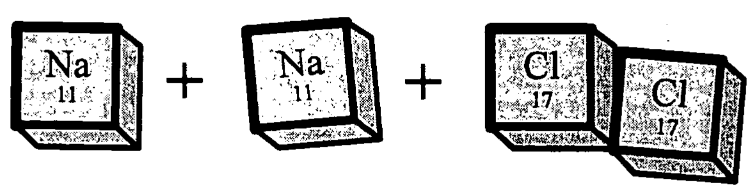
Chemical reactions must always balance. The rule for chemical reactions is that you have to use all the atoms that you start with, and you can't add any more or have any leftovers at the end.

Since chlorine comes in molecules with two atoms, we need to have two sodium atoms to match. The proper way to write this reaction is like this

$$\mathbf{2Na + Cl_2 \rightarrow NaCl} \qquad \textit{(correct)}$$

B5.4: Add another sodium block to the three blocks you already have. Now let the chemicals react! Does this balance?



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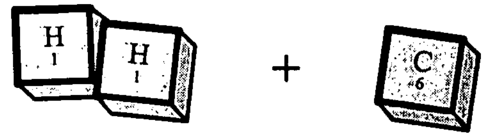
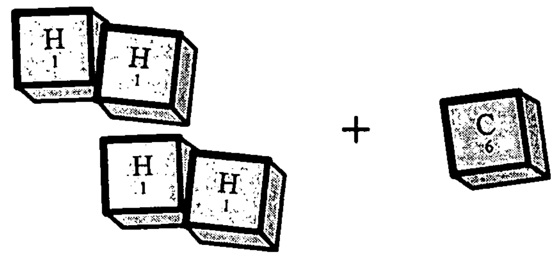
B5.5: Let's try another reaction. Combine hydrogen gas (which is also diatomic, $\mathbf{H_2}$) with carbon (**C**) to make methane ($\mathbf{CH_4}$). First get some hydrogen blocks and carbon blocks, and then try setting up the reactants. Remember that you must be able to rearrange all the reactant atoms to get complete products. Which of these reactant combinations works?

$\mathbf{H_2 + C \rightarrow .....}$



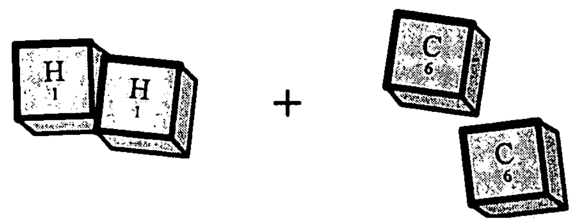
or...

$\mathbf{2H_2 + C \rightarrow .....}$

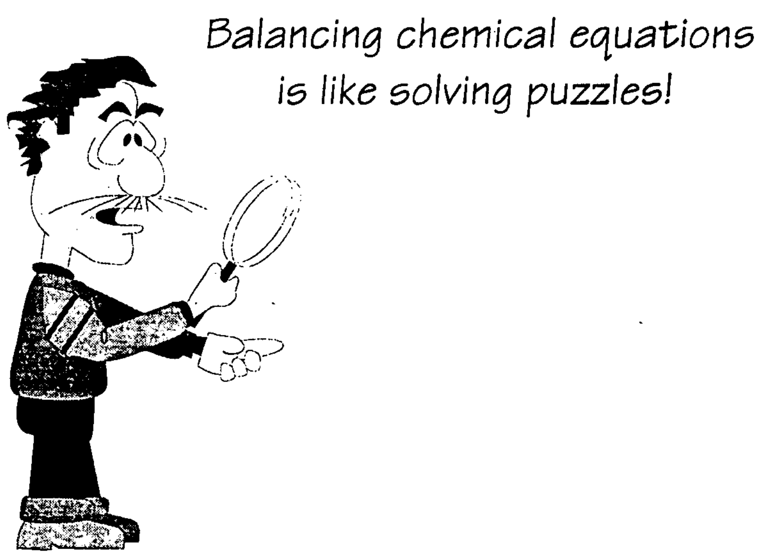


or...

$\mathbf{H_2 + 2C \rightarrow .....}$



Write down the equation for making methane from hydrogen gas and carbon.



B5.6: Let's balance some more chemical equations. The following equations have the proper reactants and products.

First assemble the reactants out of blocks, then rearrange them to make reactants.

Figure out the right number of each reactant and product to make the chemical equation balance. Fill in the numbers in the boxes below, just as in the first two examples.

burn hydrogen to make water	$\boxed{2}\,H_2 + \boxed{1}\,O_2 \longrightarrow \boxed{2}\,H_2O$
make salt out of sodium and chlorine	$\boxed{2}\,Na + \boxed{1}\,Cl_2 \longrightarrow \boxed{2}\,NaCl$
make carbon dioxide	$\boxed{}\,O_2 + \boxed{}\,C \longrightarrow \boxed{}\,CO_2$
let iron rust	$\boxed{}\,Fe + \boxed{}\,O_2 \longrightarrow \boxed{}\,Fe_2O_3$
burn methane	$\boxed{}\,CH_4 + \boxed{}\,O_2 \longrightarrow \boxed{}\,CO_2 + \boxed{}\,H_2O$
neutralize acid and base	$\boxed{}\,HCl + \boxed{}\,NaOH \longrightarrow \boxed{}\,NaCl + \boxed{}\,H_2O$
burn octane (gasoline)	$\boxed{}\,C_8H_{18} + \boxed{}\,O_2 \longrightarrow \boxed{}\,CO_2 + \boxed{}\,H_2O$

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