

## Visual Effects and Models of Human Vision

Observation of different colors by humans is not as simple as correlation of a specific wavelength of visible light with a particular sensation of color. The human brain plays a large role in our visual perceptions and these perceptions are the result of a number of factors other than the wavelength of light stimulating the visual system. We see colors as a result of electromagnetic radiation of specific wavelengths interacting with light-sensitive **cone cells** in the retina of our eyes. Many operations of the eyes and brain work automatically and almost instantly in providing us with color vision. Certain visual effects we have unconsciously learned not to "see". But many of these color-vision effects which we normally do not notice can be easily demonstrated. A number of these visual effects have stimulated scientists to study and develop models for human color vision. Four of these visual effects include:

- **Successive Contrast (Afterimage)**
- **Simultaneous Contrast of Hue**
- **Simultaneous Contrast of Value**
- **Spatial Effects of Color**

### Successive Contrast

Afterimage or successive contrast is an optical illusion that is experienced whenever a bright color leaves its impression on the eye. The afterimage appears to be in the complementary color to the actual color observed. So for example if you stare at a red-orange color for a period of time and then look at a white screen or paper you will see the afterimage hue of blue-green. The longer you stare at a color the stronger the afterimage will appear. The complete understanding of this phenomenon is yet to be discovered, however, it is believed that when the eye perceives a color, it seems at the same time to require the complement of that color, generating it spontaneously as an illusion. The physiology of the human eye apparently makes it strive to experience a balance of light, black, white and all of the additive primary hues for a combined total of neutral grayness.

### Simultaneous Contrast of Hue

When a grey line is placed on a background color the grey line appears to take on a slight tint of the complementary color to the background. For example a grey line with a blue background would appear to have a slight yellow tint while the same grey line with a yellow background would appear to take on a slight blue tint.

### Simultaneous Contrast of Value

Value is the term describing the whiteness or brightness and darkness or blackness of color. If a neutral grey line is placed on a white background and compared with the same grey line placed on a black background, the value of each grey line is affected by the background value. The grey line will appear to be darker when viewed on a brighter background and lighter when viewed against a darker background.

### Spatial Effects of Color

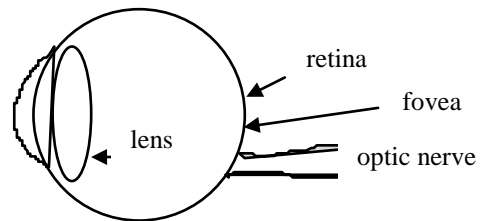
When the background color is either highly contrasting to or highly similar to a colored object it can affect the perceived depth or distance of that object from the viewer. Painters take advantage of this visual perception to create a sense of depth and perspective in their paintings.

For example, on a black background yellow will appear to advance while purple will appear to recede from the viewer. If the background color is changed to white, then the purple will stand out and the yellow appears more vivid. This effect can be utilized to make colors appear to "pop out" if complementary colors are placed in close proximity.

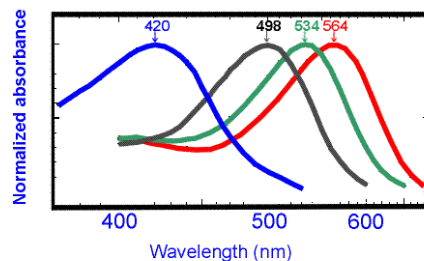
## Vision Theories

Humans have been curious about how they are able to see since early times. Empedocles, Plato, and Aristotle all proposed theories on human vision as far back as 400-300 B.C. These included the idea that vision resulted from particles given off by objects interacting with the eye, that the eyes emitted some kind of ray which would interact with objects and then bounce back to the eye, or that some transparent stuff between the object and eyes made it possible to see things. In 100 A.D., Galen thought rays from the eyes made the air carry tiny images of the objects to the eyes where the little images were analyzed by a "visual spirit" between the eyes and the brain. It was only after scientific experimentation on light and vision which was carried out between 1600 and 1800 by Sir Isaac Newton and Johann Wolfgang von Goethe that the mystery of human vision began to be unraveled.

The first substantial theory of vision was developed in the 1850s by Thomas Young and Hermann von Helmholtz. The **Young-Helmholtz theory**, better known as the **trichromatic theory**, stated that the eye contains three types of color-sensitive cells (**cone cells**) which respond to the three primary colors of light — red, blue, and green. Furthermore, color sensation result of the stimulation of these cones by to produces electrical impulses that travel to brain and are interpreted as color. Other sensitive cells within the eye, called **rod cells**, respond only to the intensity of the light and color producing sensations of lightness and darkness. Both of these cells, rods and cones, are located in the layer of cells at the back of the eyeball called the **retina**. There are many more rod cells than cone cells (about 150 million rods to 7 million cones), and the cone cells are concentrated in a spot on the retina called the **fovea centralis** (central pit). Each cone cell has its own nerve fiber running through the optic nerve directly to the visual center in the back of the brain called the **visual cortex**. The fovea is the area of our sharpest vision and it is the center of our color vision. At night, however, our color vision does not work well because cones need light to work. It is the rods that account for our night vision.



The basic hypothesis of the trichromatic theory has been supported by research that has actually isolated three different types of cone cells in retina (George Wald, 1964) and three different color-vision pigments (*Biochemistry*, 30, 11367.1991) within these cone cells. These pigments have absorption maxima of 420nm (blue), 534nm (green), 564nm (red). See the figure to the right. However, some of the interesting visual effects and anomalies



After Bowmaker & Dartnall, 1980

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vision have not been well explained by the trichromatic theory. For example the trichromatic theory does not explain color blindness or the phenomenon of afterimages.

The most common form of **color blindness**, occurring in 2% of men and less than 1% of women is so called “red-green color blindness”. In this condition people have difficulty distinguishing red and green seeing them only as a yellowish gray color. An even smaller percentage of people suffer from “blue-yellow color blindness” where these two colors are difficult to distinguish. Both types of color deficiencies are referred to as *dichromatic vision* because the eyes only respond to two colors instead of three. A third type of color blindness occurs when there is no color perception at all and people see only shades of gray. Monochromism or achromism is an extremely rare form of color blindness occurring in less than 0.1 percent of the population. The fact that color blindness affects two colors at a time, either red-green or yellow-blue, indicates that the trichromatic theory is not a complete explanation of color vision.

Afterimage is the visual sensation that persists after a visual stimulus is removed. Afterimages appear always as complementary color pairs. For example staring at red produces a green afterimage, staring at blue produces a yellow afterimage, and staring at white produces a black afterimage. This too contradicts the trichromatic theory that says there are three separate color sensitive cells and vision pathways in the eye.

Another theory attempting to explain some of these contradictory phenomena is the **opponent-process theory** put forth in 1874 by Ewald Hering a German physiologist. In this theory Hering proposed two response mechanisms involving pairs of opposing colors — a red-green response, and a blue-yellow response. A third response to level of lightness or brightness is also included. This theory is better able to explain dichromatic vision in which people confuse reds and greens and only see yellows, blues, and shades of gray. Each of these light receptors can respond in two ways — positively stimulated (excited) and negatively stimulated (inhibited) — leading to the perception of one color when the receptor is excited and another color when the receptor is inhibited. This theory would explain why we never see bluish yellow or reddish green but we often see bluish green and reddish yellow. Afterimages can also be explained in this manner: if we stare at the color red, the red-green receptor is stimulated and the red dominates. When we look away, the red stimulus is turned off and the green receptor dominates producing the complementary color afterimage.

As with most theoretical debates, neither theory alone is sufficient to adequately explain human vision. Today the best theory incorporates both the trichromatic theory and the opponent-process theory into a **composite theory** of human vision. According to this theory, vision is a two-stage process in which the three different cone cells with their three color-sensitive pigments, take in visual information according to the trichromatic theory. Then the second stage of vision occurs at the level of the thalamus within the brain. At this point the responses are governed by the opponent-process theory where certain neurons in the thalamus are turned on (excited) by red (or blue) and turned off (inhibited) by green (or yellow). The neurons in the thalamus then relay the response to the visual cortex and we experience color.

### Important Chapter Terms

Moiré effect	Retina	spatial effects of color
Four-color process	Fovea	Trichromatic theory
successive contrast	Cone cells	Opponent-process theory
afterimage	Rod cells	Composite theory
simultaneous contrast	Dichromatic vision	Achromism (monochromism)

## Glasses and Crystals

### History of Glass and Glassmaking

Long before humans learned how to manufacture glass from raw materials, people fashioned tools and weapons from naturally occurring glasses. Several types of natural glasses were used including tektites, obsidian, and pumice. Tektites are small oval-shaped pieces of glass believed to be from meteors. Obsidian, or cooled lava, is a glassy volcanic rock. And pumice is a foamed glass formed when gases are released from lava as it cools. Among the first glass artifacts were knives and arrowheads of flaked obsidian dating from Paleolithic times. Among the oldest pieces of synthetically manufactured glass known is a bead found in Egypt dating back to about 3500 BC. Most historians indicate that the birthplace of man-made glass was in Egypt or Mesopotamia prior to 3000 BC. It has been speculated that glassmaking was accidentally discovered while cooking in a sandy, alkaline environment. More likely glassmaking came about as an offshoot of metalworking. Silicate impurities in metal ores would have separated during refining and formed an intriguing glassy slag. Another likely scenario may have been from experimentation with ceramic glazes that were developing during approximately the same time period.

The Egyptians became excellent workers of glass and produced colored glass sticks as raw materials for glass objects such as glass vessels, glass eyes, beads, mirrors, and ornaments. The art of glassmaking died out in about 1200 BC and did not reemerge until about the 7th century BC. During the 4th to 2nd century BC new technical and artistic developments allowed for the making of gold-sandwich bowls in which a layer of gold leaf was trapped between two layers of glass. Other developments of this Hellenistic period included the manufacture of mosaic glass rods and cameo glass, a two-layer glass that could be carved.

It was the Romans who took the Egyptian's knowledge of glass working and raised it to a new level of excellence. When the technique of glass blowing was invented in the first century AD, glass quickly became an object of common use throughout the Roman Empire because it was inexpensive and easy to produce. Techniques perfected by the Roman glass workers were soon spread throughout Europe and everything from blown glass vessels to cast glass windowpanes were produced. The Romans also became expert in coloring glass and modifying the reflective nature of the glass surface. Glass making centers arose in Italy and glass was exported as far away as Britain. By the fourth century, different glass-making centers throughout the East and the West were developing their own particular regional styles. As a result of barbarian invasions after the 5th century, glassmaking experienced somewhat of a decline and it became a less centralized activity. This gave rise to more widely distributed yet smaller glass centers throughout Europe.

During the Medieval Period, glassmaking was dominated by the demand for colored window glass for churches and cathedrals. The earliest surviving painted glass dates from the 10th century in Germany but it is suspected that painted windows date back to even earlier times. In the late 13th century a strong glass industry emerged in Venice. Techniques for making stemmed glasses and vessels, mosaic glass used to produce *millefiori* glass, and ornately decorated glass objects were fiercely protected by laws which prohibited glass makers from practicing their skills outside of Venice. Eventually, during the 16th century, the Italian knowledge of glass working did spread throughout Europe influencing glassmaking in Vienna, Sweden, England, and Bohemia. By the late 16th century Bohemian glass began to develop a new style which involved the cutting and engraving of glass. This was the beginning of the famous German "crystal" industry. The Germans also introduced less expensive methods for producing colored glass by coating the outside of a clear glass vessel with a layer of colored glass.

Glassmaking was introduced to North America in 1608 at Jamestown. Most of the early glass produced there was sent back to England. A number of other glass factories were founded including one begun by Baron Stiegel in 1763 in Manheim, Pennsylvania. Over the years since the American Revolution a number of glass manufacturers grew up and died out. Many came to influence modern day glassmaking in the United States and they include Owens-Illinois Glass Company, Wheaton Glass Company, Kimble Glass Company, Tiffany glass, and the Steuben Glassworks in Corning, New York.

Today glass is one of the most common substances in home and industry, and, at the same time, one of the most intriguing. Its hardness is evident in windowpanes and jars; its brittleness is unfortunately seen with table glass and light bulbs. Yet, **glass is not a solid!** It has little internal crystalline structure and therefore we call it **amorphous**. Usually it is described as a super cooled liquid. Like other liquids, the

viscosity (ability to flow) of glass decreases with temperature. Upon heating, it flows, and can either be molded or blown.

### What Is Glass?

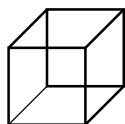
Chemically, we can describe glass as an inorganic product of melting that has cooled to a rigid state without crystallizing. It is rich in silicon and oxygen, coming from its basic component silicon dioxide ( $\text{SiO}_2$ ) or sand, but it also contains other metal ions such as Fe, Na, K, Ca, Mg, B, and Al. Glass does not have a sharp melting point but rather melts over a range of temperatures in which it first softens and then flows as the bonds holding the glass structure together gradually break. The temperature at which the glass first begins to soften is called the **glass transition temperature ( $T_g$ )**. Below this temperature the glass is hard and brittle, above this temperature the glass is soft and flows.

Crystals on the other hand are true solids. There are several categories of crystals some of which we are already familiar with. They are:

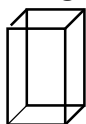
1. **Ionic Inorganics** — These compounds are held together by strong electrostatic forces giving them very high melting points. Many are water soluble due to their ionic character. Examples include  $\text{NaCl}$ ,  $\text{CaCO}_3$  and many other naturally occurring minerals.
2. **Metallic Crystals** — All metals in their solid state exist with the nuclei of their atoms arranged in a crystalline array surrounded by a “sea of valence electrons”. This structure contributes to the characteristic bulk properties we associate with metals such as electrical and thermal conduction, and luster. Examples include Fe, Al, Cu, Ni, Cr, and Ag.
3. **Molecular Crystals** — Certain covalent molecules such as  $\text{I}_2$ ,  $\text{ICl}$ , and  $\text{S}_8$  form soft, low melting, water insoluble crystals.
4. **Network Solids** — Some elements and compounds are covalently bonded to form one large network of indefinite size. These substances typically have high melting points and are quite insoluble in water or other common solvents. Examples include diamond (C), graphite (C), and quartz ( $\text{SiO}_2$ ).

In all these compounds or elements the atoms are arranged in definite and repetitive three-dimensional patterns. As a result of this regular atomic arrangement in which the particles are held in rigid, fixed positions which do not change, crystals show definite external geometrical shapes, bounded by plane faces. Crystals come in many different shapes and sizes however, crystals may be grouped into seven basic categories with characteristic angles and shapes.

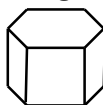
**Cubic (Isometric)**



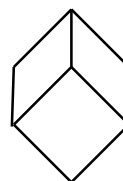
**Tetragonal**



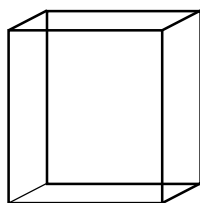
**Hexagonal**



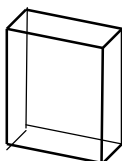
**Rhombohedral**



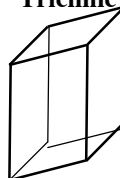
**Orthorhombic**



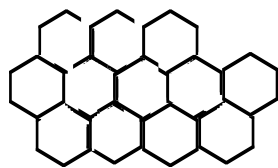
**Monoclinic**



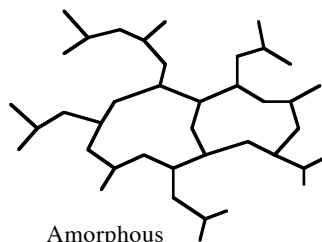
**Triclinic**



In contrast to crystals, amorphous solids have an intermediate state between the crystalline and liquid states. They contain no long-range order because the particles (atoms, molecules) are not in rigidly fixed positions within the substance. In addition to glass, rubber and most plastics are classified as amorphous solids. Complicating the situation is the fact that within plastics regions of microcrystalline structure can exist or be induced.



Crystalline



Amorphous

### Structure and Composition of Glasses

Glasses are composed of a number of different kinds of oxides. There are four types: (1) **network, glass-forming or acidic oxides**, (2) **fluxing, network-modifying or basic oxides**, (3) **refractory or neutral oxides**, and (4) **opacifying oxides**. The table below lists these oxides and gives their general chemical formula, examples of each type, and the function they fulfill in the manufacture of the glass.

Oxide Type	General Formula	Examples	Function
Glass-forming (Acidic)	$RO_2, R_2O_3$	$SiO_2, B_2O_3$	Major glass structure component
Fluxing (Basic)	$RO$ or $R_2O$	$CaO, MgO, BaO, SrO, ZnO, PbO, Na_2O, K_2O, Li_2O$	Lower the melting point of glass-forming oxides
Refractory (Neutral)	$R_2O_3$	$Al_2O_3, B_2O_3$	Inhibit flow, control viscosity, retard crystallization
Opacifying	$RO_2$	$TiO_2, SnO_2, ZrO_2$	To make glass opaque

A variety of glasses can be manufactured by varying the types and amounts of these four oxide groups. The glass-forming oxides are essentially inorganic, polar covalent compounds while the fluxing, refractory and opacifying oxides are simple inorganic, binary, ionic compounds.

Pure **quartz glass** is composed chiefly of silica,  $SiO_2$ . It contains an irregular array of silicon atoms covalently bonded to four oxygen atoms in a tetrahedral configuration. It has excellent chemical durability, can withstand sudden temperature changes, and is transparent to many wavelengths of light including ultraviolet radiation. For this reason it is used in the optical systems and sample holders (cuvettes) of ultraviolet spectrophotometers. Due to

the extremely high melting point (1723°C) and high viscosity of molten silica, this glass is difficult to work and shape making it an expensive glass which is only used in limited applications.

A relatively new application of pure silica glass is in the manufacture of **optical fibers**. These glass fibers are becoming increasingly important to the field of telecommunications and require extremely pure  $SiO_2$  glass. Optical fibers are composed of a core of pure silica surrounded by a coating of silica doped with chemicals that lower the refractive index of the glass. Light introduced

into the central core of the fiber is transmitted through it over long distances by a series of internal reflections off the boundary between the core and the coating.

The glass most commonly encountered in windowpanes, mirrors, and light bulbs is **soda-lime glass**. This glass is composed of silica ( $SiO_2$ ) with the addition of oxides of sodium ( $Na_2O$ ) and calcium ( $CaO$ ) as fluxing agents. The role of fluxing oxides is to break the regular crystalline structure of the  $SiO_2$  network lowering the glass melting point from 1723°C to a more workable 1300°C. Although soda-lime glass is fairly resistant to atmospheric corrosion it can be attacked and weakened or dissolved by strong acids ( $H^+$ ) and bases ( $OH^-$ ). Another disadvantage of soda-lime glass is its high **coefficient of thermal expansion**. Because of this, soda-lime glass cracks easily when heated and rapidly cooled. When working with soda-lime glass it must be carefully **annealed** to relieve the internal stresses that result from the initial rapid cooling and hardening of the glass. To anneal glass it is reheated after forming in a special oven to the annealing temperature (depends on the glass composition). Then the glass is allowed to slowly cool at a

controlled rate to room temperature. Stress is relieved because the glass can still flow somewhat during the annealing process.

#### Prince Rupert's Tears

If soda-lime glass is melted and the molten glass is dropped into cold water, the rapid cooling of the surface of the glass "freezes" the outside and contracts the molten center so much that a small hollow bubble containing a vacuum appears in the center of the teardrop-shaped glass. Tremendous internal stresses exist within the drop with the surface layer of glass being highly compressed and the internal regions under great tension. The compressed glass is so strong that hitting the glass drop with a hammer will not break the glass. However, a small scratch near the thin tail section will cause the entire bead to shatter into powdered glass as the stress is quickly released.



To produce a glass that is more thermally resistant, oxides of boron ( $B_2O_3$ ) are added to the mixture of  $Na_2O$  and  $SiO_2$ . Boron lowers the thermal expansion of the resulting **borosilicate glass** by as much as 50% over soda-lime glass. This makes borosilicate glass highly resistant to cracking under conditions of rapidly changing temperatures. Pyrex® or Kimax® glass is used for ovenproof baking dishes and scientific glassware such as beakers, flasks, test tubes, and other items. Use of boron as a fluxing oxide also lowers the melting point and the viscosity as well. Borosilicate glass is a highly durable and chemically resistant glass.

The term **lead crystal** describes a type of glass that has been cut and polished to resemble natural crystal faces. It is actually not a crystalline material, just an amorphous silica-based glass. Lead oxide ( $PbO$ ) is added to silica as a fluxing agent making the glass easy to melt and work. In addition the lead imparts a number of unique properties to the glass. Lead glass has a higher refractive index than other types of glass making it particularly good at refracting and reflecting light from its cut and polished surfaces. Because of the presence of heavy lead atoms, this glass also is able to deflect various types of high-energy radiation and consequently it is used in applications like TV and computer screens and radiation windows. However, lead flux in glass can pose a health hazard because the toxic lead ions can be leached from the glass when it is exposed to acidic conditions.

#### Coloring of Glass

When we look through a windowpane we probably consider the glass to be colorless and transparent. This is true for thin layers of soda lime glass. However, if we were to look through a very thick layer of the same glass we would notice that it was not colorless. In fact it would have a yellow-green color that gets darker the thicker the glass becomes. The color comes from the presence of impurities of iron oxides in the glass. If during the manufacturing process, other transition metal compounds are added to the melted glass, various colored glasses can be produced. For example addition of selenium and zinc oxide to glass will result in transparent red glass suitable for red stoplights. Deep blue glass, sometimes called **cobalt glass**, results from the addition of small amounts of cobalt chloride ( $CoCl_2$ ) to the glass. Color can also be imparted to glass by suspending submicroscopic particles of metals in glass. Gold and copper ruby glasses owe their bright red color to the presence of a colloidal suspension of these metals in the glass. In general, copper compounds are used to color glass blue and blue-green, manganese produces pinks, and iron compounds impart yellow, green or brown coloration (think beer bottles). Opaque or opalescent glasses can be made by the addition of opacifiers. In small quantities they make the glass appear to have a pearl-like sheen and in larger amounts they make the glass totally opaque. Antimony, tin, and titanium oxides are typically used for this purpose.

#### Other Forms of Glass

Thin layers of colored glass can be applied to the surface of metals in the process known as **enameling**. Layers of colored glass melted onto the surface of pottery and ceramics are called **glazes**. Both of these processes rely upon knowledge of glass composition and the colors associated with transition metal compounds. Enamels and glazes are quite similar in that both are mixtures of colored metal oxides mixed with **glass frit**. Glass frit is prepared by mixing the raw materials of glass (silica and fluxing agents), melting them to form the glass, and then cooling the glass and grinding it to a powder (frit). The

melting temperature needed for the glaze or enamel should be lower than that of the substrate onto which the glaze or enamel is placed (metal or ceramic) and this can be controlled by the flux composition of the glass frit. True “stained glass” is actually the process of painting on glass with glazes that are then fired to fuse them onto the surface layer of glass.

### Deterioration of Glass

Although glass seems to be quite a non-reactive substance, it is susceptible to various forms of attack. Depending upon the composition of the glass, it may be affected to a greater or lesser degree by such things as water, acids, alkalis, complexing agents, sunlight, and “acid rain”. Even constant exposure to high humidity (water vapor) can be damaging to glass. Microorganisms such as mosses, lichens, fungi, and bacteria have also produced deterioration of glass surfaces most likely as a result of secretion of acidic waste products during their growth. Deterioration of glass is exhibited through the presence of chemical crust formation and pitting of the glass surface. Conservation of glass artifacts requires a thorough knowledge of the chemical composition and physical and chemical properties of a wide variety of glass types from ancient to modern.

### REFERENCES

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2. *Glass and Glassmaking*, Gerald J. Fine, **J. Chem. Ed.**, **68**, 765 (1991).
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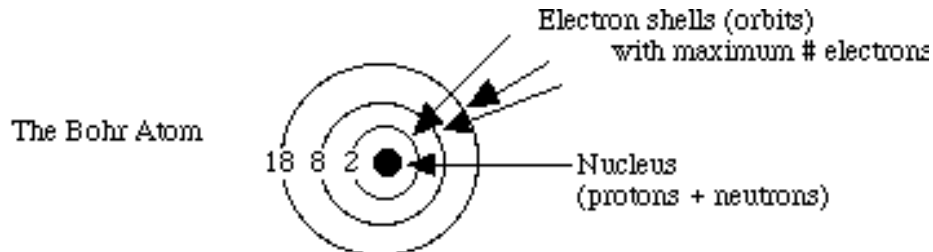
### Important Chapter Terms

- crystalline
- amorphous
- glass transition temperature ( $T_g$ )
- annealing
- network-forming oxide
- fluxing oxide
- opacifying oxide
- quartz glass
- soda-lime glass
- leaded crystal
- cobalt glass
- enamel
- silica
- borosilicate glass
- glaze

## Work with a periodic table

1. Label the first two vertical columns at the top with numbers 1A and 2A. And label the last 6 columns with numbers 3A through 8A. Label the middle 10 columns with the letter "B" at the top of each.
2. Label the areas of the periodic table corresponding to the following categories of elements:
  - Alkali metals
  - Alkaline earth metals
  - Halogens
  - Nobel gases
  - Transition metals
  - Hydrogen
  - Metalloids
  - Non-metallic elements

3. Draw a Bohr diagram structure for three of the first 18 elements in the periodic table.



4. Give the name and symbol of a representative element from the following groups:
  - a. Halogens
  - b. Alkaline Earth Metals
  - c. Transition Metals
  - d. Main Group Elements
  - e. Alkali Metals
  - f. Nobel Gases
  - g. Metalloids
5. Give the atomic number, mass number, number of protons, neutrons, and electrons, in each of the elements you listed for question 3.
6. Examine the Bohr Diagrams of the first 18 elements and answer the following questions.
  - a. What is the pattern by which elements are placed within the same period?
  - b. What is the pattern by which elements are placed within the same family or group?

- c. Draw the Lewis dot (electron dot) structures for the three elements in the periodic table you selected in question 3.

### Concepts for Matter

- pure substances
- homogeneous
- groups or families
- transition metals
- alkaline earth metals
- atomic number (Z)
- electron shells
- nucleus
- orbitals
- compounds
- periods
- subshells
- mixtures
- heterogeneous
- metals
- main group elements
- halogens
- atomic mass (A)
- proton
- amu
- isotopes
- metalloids
- symbol
- elements
- periodic table
- nonmetals
- inner transition metals
- Nobel gases
- free or native state
- electron
- neutron quantum theory
- neutral atoms
- alkali metals
- Bohr Theory

### Concepts for Metals and Alloys

- free or native state
- ferrous metals
- alloy
- ores
- chemical formula
- anion
- refining
- ductile
- nonferrous metals
- valence electrons
- metallic bonds
- chemical equation
- cation
- rust or corrosion
- diatomic molecule
- bronze
- sterling silver
- malleable
- base metals
- valence shell
- ionic bonds
- reactants
- oxidation
- binary compound
- core electrons
- steel
- Karat gold
- coefficient of expansion
- precious or noble metals
- electron dot structure
- electrostatic attraction
- products
- reduction
- octet rule
- metallurgy
- alumina

### Naming Binary compounds

Chemical formulas give lots of information about a particular substance. By reading a formula, one can tell what elements are present and the number of atoms (or ions) of each element that are present. A formula unit is the smallest neutral particle formed by the bonding of two or more ions or atoms. Some examples of chemical formulas are:



Some simple rules apply to interpreting and understanding chemical formulas.

1. The formula contains the symbols of all elements in a compound.
2. Each symbol represents one atom of an element. If only one atom of the element is present no number subscript is associated with the symbol.
3. **Subscripts** are used to indicate more than one atom or ion of an element in a molecule or formula unit.
4. Formulas **do not** show how atoms or ions are arranged or connected to each other in a molecule.

If you want to be able to write the correct chemical formula or name for a simple binary compound you must also learn some simple rules. The rules depend upon whether you are dealing with ionic compounds or covalent

compounds. So the first thing you must do is determine if the compound is ionic or covalent. To do that you look at the names or symbols of elements present in the compound.

Simple binary **ionic compounds** contain a **metallic element** and a **nonmetallic** element.

Simple binary **covalent compounds** contain two **nonmetallic elements**.

Identify the following compounds as ionic or covalent (I or C).

Cr <sub>2</sub> O <sub>3</sub>		Iron (II) oxide	
Fe <sub>2</sub> O <sub>3</sub>		Potassium chloride	
CdS		Hydrogen fluoride	
CdSe		Mercury (II) sulfide	
CoO		Potassium sulfide	
ZnO		Carbon disulfide	
TiO <sub>2</sub>		Calcium oxide	
Al <sub>2</sub> O <sub>3</sub>		Carbon tetrachloride	
PbO		Silicon dioxide	
HCl		Tin (IV) oxide	

### A. Naming Simple Binary Compounds

Binary compounds are composed of only two different elements. These may be **inorganic, ionic compounds** (metallic and nonmetallic elements present) or they may be **covalent inorganic or organic compounds** (only nonmetallic elements present).

If you see a chemical formula that contains only two different elements, you can name it by following these steps.

1. Examine the formula for a compound and decide if the compound is ionic (metallic element present) or covalent (only nonmetal elements present).
2. If it is an ionic compound composed of only 2 elements, the first element in formula (the metal) is given its elemental name. For the second element (the nonmetal), change the ending of the elements name to **-ide**. Do not include any numbers or number prefixes in the name.

For example:     NaCl                 Sodium chloride  
                         CaCl<sub>2</sub>                 Calcium chloride

3. If the compound is covalent, the first element or elements are given the elemental name and the ending of second or last element's name is changed to **-ide**. If numerical subscripts are present in the formula, then use prefixes in front of the elements' names to indicate how many atoms of each element are present (eg. di-, tri-, tetra, penta- etc.)

For example:     HCl                 Hydrogen chloride  
                         H<sub>2</sub>S                 Dihydrogen sulfide  
                         CCl<sub>4</sub>                 Carbon tetrachloride

Practice writing the correct names of the following binary compounds. Each formula is correct and represents a unique chemical compound with unique chemical properties.

1. NaCl

2. CuO

3. Cu<sub>2</sub>O

4. Ag<sub>2</sub>S

5. PbS (galena)

6. FeS<sub>2</sub> (pyrite or fool's gold)

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7. ZnS (sphalerite)

8. CuCl

9. CuCl<sub>2</sub>

10. As<sub>2</sub>S<sub>3</sub> (orpiment)

11. H<sub>2</sub>O

12. NH<sub>3</sub>

### B. Writing Correct Formulas for Binary Ionic Compounds

The chemical formulas of binary ionic compounds contain positively charged ions (**cations**) and negatively charged ions (**anions**). The cations in simple binary compounds come from metal elements in Groups 1A, 2A, and 3A, from the transition metals, and from the metallic elements in Groups 4A and 5A. The anions come from the nonmetallic elements in Groups 4A, 5A, 6A and 7A and Hydrogen. When the cations and anions combine, there must be the correct number of each ion so that the **overall charge on the molecule is equal to zero**.

It is very easy to determine the correct charge for cations and anions in groups 1-7A. The following table summarizes these charges and they apply to each element in the group.

Group 1A	Group 2A	Group 3A	Group 4A	Group 5A	Group 6A	Group 7A
+1	+2	+3	NA	-3	-2	-1

The story is a bit different with the transition metals. These metals can form cations with several possible charges. The most common ones used in this course are listed in the following table with their charges.

#### Common Ions for Transition Metals with Multiple Possible Charges

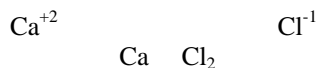
	+1	+2	+3	+4		+1	+2	+3	+4
Titanium				x	Zinc		x		
Chromium		x			Silver	x			
<b>Iron</b>		x	x		Cadmium		x		
Cobalt		x			<b>Tin</b>		x		x
Nickel		x			<b>Mercury</b>	x	x		
<b>Copper</b>	x	x							

To create the correct chemical formula for a simple binary ionic compound you must do the following:

- Put the symbols for the two elements next to each other with the metallic element first.
- Determine the correct charge for each ion by looking at the periodic table or the table of transition metal ionic charges.
- Place number subscripts after each element's symbol to indicate how many of each ion is needed to make sure the overall positive and negative charges add up to zero. If only one ion for an element is needed, you do not put a number subscript after the symbol.



- You may have noticed that a simple way to do this is to use the absolute value of the charge on one ion as the numerical subscript for the other ion. This is called the "cross-over" technique and is a shortcut to writing correct binary ionic formulas.



### C. Writing Formulas for Binary Covalent Compounds

These compounds contain only nonmetallic elements. The elements do not form ions but rather combine by sharing electrons between the atoms. They combine based upon the number of bonds which each element can form with another element. This is called the element's **covalency**. The table below summarizes the nonmetal elements' covalency or bonding ability.

Group 4A	Group 5A	Group 6A	Group 7A and Hydrogen
forms 4 bonds	forms 3 bonds	forms 2 bonds	forms 1 bond

Because the name of the binary covalent compound usually contain numerical prefixes before the element name, it is rather easy to determine the correct molecular formulas for these compounds.

The following binary compounds find use in artists' materials. Practice writing the names of the following compounds.

1.  $\text{Cr}_2\text{O}_3$  \_\_\_\_\_
2.  $\text{Fe}_2\text{O}_3$  (hematite, Venetian Red) \_\_\_\_\_
3. CdS (cadmium yellow) \_\_\_\_\_
4. CdSe (cadmium red) \_\_\_\_\_
5. CoO \_\_\_\_\_
6. ZnO \_\_\_\_\_
7.  $\text{TiO}_2$  (China White) \_\_\_\_\_
8.  $\text{Al}_2\text{O}_3$  (alumina) \_\_\_\_\_
9. PbO (litharge) \_\_\_\_\_
10. HCl (muriatic acid) \_\_\_\_\_

Write the formulas for the following compounds.

1. Iron (II) oxide \_\_\_\_\_
2. Potassium chloride \_\_\_\_\_
3. Hydrogen fluoride \_\_\_\_\_
4. Mercury (II) sulfide (cinnabar, vermilion) \_\_\_\_\_
5. Potassium sulfide (liver of sulfur) \_\_\_\_\_
6. Carbon disulfide \_\_\_\_\_
7. Calcium oxide (quicklime) \_\_\_\_\_
8. Carbon tetrachloride \_\_\_\_\_
9. Silicon dioxide (silica, quartz) \_\_\_\_\_

10. Tin (IV) oxide

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Practice writing the correct names of the following binary compounds.

1. NaCl

2. CuO

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3. Cu<sub>2</sub>O

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4. Ag<sub>2</sub>S

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5. PbS (galena)

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6. FeS

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7. ZnS (sphalerite)

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8. CuCl

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9. CuCl<sub>2</sub>

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10. As<sub>2</sub>S<sub>3</sub> (orpiment)

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11. H<sub>2</sub>O

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