

***Principles of Alchemy (Chemistry)***  
**by Dr Jamie Love from Merlin Science**  
[www.synapse.co.uk/alchemy](http://www.synapse.co.uk/alchemy)  
**Syllabus and correlation/alignment with Standards**

Here you will find

1. a simple syllabus of the course
2. details of how the course correlates or aligns with US National Science Education Standards
3. where to find topics, using the California Learning Resource Network (CLRN) as an example

**Syllabus for *Principles of Alchemy (Chemistry)***

AIR (Atoms)

Atoms and atomic structure. Mass and Daltons. Isotopes, radioactivity and half-life. Nuclear chemistry and nuclear synthesis. Electron shells and orbitals (s and p orbitals; d and f orbitals are covered in EARTH). The Bohr atom. Quantum mechanics.

WATER (Molecules)

Molecular formulas and molecular mass. Lewis structures. Strong bonds - ionic, covalent and metal. Weak "bonds" - polar(ized), hydrogen and van Der Waals. Hydrophobic and hydrophilic forces. The states of matter. Solutions, condensation, evaporation and distillation. Molecular shapes - electrostatics, molecular orbitals, hybrid orbitals and VSEPR theory. Allotropes. Crystals. Amorphous and devitrified structures. Gels.

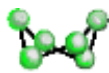
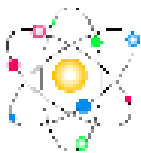
EARTH (Elements)

The Periodic Table - its trends, uses and concepts (including atomic size, ionization energies, electron affinity and electronegativity). A "tour" highlights the traits, similarities and differences among the common elements. More shells and orbitals.

FIRE (Chemical Reactions)

Breaking and making bonds. Exothermic and endothermic. Combination, decomposition and replacement reactions. Standard conditions. Energy diagrams and reaction paths. Catalysts. Valency. Oxidation and reduction. Balancing equations. Rates and equilibria. Entropy and enthalpy. Thermodynamics, Hess's Law, Le Chatelier's principle and Gibbs energy. Dissociation and ionization in water. Enthalpy of formation. "Special reactions" like combustion, electrolysis, photosynthesis, and respiration.

Many other topics are covered in less detail. For example, the graduate will gain an understanding of the fundamentals of pH but not to the depths required for calculating it (because that requires logarithms). Another example is Gibbs energy - the student will learn how changes in Gibbs energy determine the direction of a reaction but s/he will not see the (complete) Gibbs energy equation. As needed and where relevant, the student will learn a wee bit of Biology, Physics and Geology too!



## US National Science Education Standards for *Principles of Alchemy (Chemistry)*

As a result of activities in grades 9-12, all students should develop ...

### Science as Inquiry - CONTENT STANDARD A:

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry



### Physical Science - CONTENT STANDARD B:

#### STRUCTURE OF ATOMS

- Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.
- The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.
- The nuclear forces that hold the nucleus of an atom together, at nuclear distances, are usually stronger than the electric forces that would make it fly apart. Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions. Fusion is the joining of two nuclei at extremely high temperature and pressure, and is the process responsible for the energy of the sun and other stars.
- Radioactive isotopes are unstable and undergo spontaneous nuclear reactions, emitting particles and/or wavelike radiation. The decay of any one nucleus cannot be predicted, but a large group of identical nuclei decay at a predictable rate. This predictability can be used to estimate the age of materials that contain radioactive isotopes.

#### STRUCTURE AND PROPERTIES OF MATTER

- Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element.
- An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.
- Bonds between atoms are created when electrons are paired up by being transferred or shared. A substance composed of a single kind of atom is called an element. The atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.
- The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them.

- Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart.
- Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.

## CHEMICAL REACTIONS

- Chemical reactions occur all around us, for example in health care, cooking, cosmetics, and automobiles. Complex chemical reactions involving carbon-based molecules take place constantly in every cell in our bodies.
- Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.
- A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions.
- Chemical reaction rates depend on how often the reacting atoms and molecules encounter one another, on the temperature, and on the properties--including shape--of the reacting species.
- Catalysts, such as metal surfaces, accelerate chemical reactions. Chemical reactions in living systems are catalyzed by protein molecules called enzymes.

## CONSERVATION OF ENERGY AND INCREASE IN DISORDER

- The total energy of the universe is constant. Energy can be transferred by collisions in chemical and nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be destroyed. As these transfers occur, the matter involved becomes steadily less ordered.
- Heat consists of random motion and the vibrations of atoms, molecules, and ions. The higher the temperature, the greater the atomic or molecular motion.
- Everything tends to become less organized and less orderly over time.

The two missing sections of Physical Science -CONTENT STANDARD B (INTERACTIONS OF ENERGY AND MATTER and MOTIONS AND FORCES) are only briefly mentioned in “Principles of Alchemy (Chemistry)” because they are covered in detail in “Principles of Astronomy”.

## California Learning Resource Network listing for *Principles of Alchemy (Chemistry)*

Standards that all students are expected to achieve in the course of their studies are unmarked. Standards that all students should have the opportunity to learn are marked with an asterisk (\*).

### Introduces and Provides for Systematic Development for Grade 9

Strand: Physical Sciences

#### Substrand: **Heat and Thermodynamics**

3c Students know the internal energy of an object includes the energy of random motion of the object's atoms and molecules, often referred to as thermal energy. The greater the temperature of the object, the greater the energy of motion of the atoms and molecules that make up the object. *alchemy/wat1d2.htm#states*

3d Students know that most processes tend to decrease the order of a system over time and that energy levels are eventually distributed uniformly. *alchemy/fir1d2.htm#entropy*

3e Students know that entropy is a quantity that measures the order or disorder of a system and that this quantity is larger for a more disordered system. *alchemy/fir1d2.htm#entropy*

3f \*Students know the statement "Entropy tends to increase" is a law of statistical probability that governs all closed systems (second law of thermodynamics). *alchemy/fir1d2.htm#entropy*

Strand: Chemistry

#### Substrand: **Atomic and Molecular Structure**

1a Students know how to relate the position of an element in the periodic table to its atomic number and atomic mass. *alchemy/ear1d.htm#introtable*

1b Students know how to use the periodic table to identify metals, semimetals, nonmetals, and halogens. *alchemy/ear1d2.htm#alkali*

1c Students know how to use the periodic table to identify alkali metals, alkaline earth metals and transition metals, trends in ionization energy, electronegativity, and the relative sizes of ions and atoms. *alchemy/ear1d.htm*

1d Students know how to use the periodic table to determine the number of electrons available for bonding. *alchemy/ear1d.htm*

1e Students know the nucleus of the atom is much smaller than the atom yet contains most of its mass. *alchemy/air1d.htm#dalton*

1f \*Students know how to use the periodic table to identify the lanthanide, actinide, and transactinide elements and know that the transuranium elements were synthesized and identified in laboratory experiments through the use of nuclear accelerators. *alchemy/ear1d2.htm#transition*

1g \*Students know how to relate the position of an element in the periodic table to its quantum electron configuration and to its reactivity with other elements in the table. *alchemy/air1d.htm#electronshells* *alchemy/ear1d.htm#atomsizes*



### Substrand: **Chemical Bonds**

2a Students know atoms combine to form molecules by sharing electrons to form covalent or metallic bonds or by exchanging electrons to form ionic bonds.

*alchemy/wat1d.htm#lewishell*

2b Students know chemical bonds between atoms in molecules such as  $H_2$ ,  $CH_4$ ,  $NH_3$ ,  $H_2CCH_2$ ,  $N_2$ ,  $Cl_2$ , and many large biological molecules are covalent.

*alchemy/wat1d.htm#lewishell*

2c Students know salt crystals, such as  $NaCl$ , are repeating patterns of positive and negative ions held together by electrostatic attraction. *alchemy/wat1d2.htm#simple*

2d Students know the atoms and molecules in liquids move in a random pattern relative to one another because the intermolecular forces are too weak to hold the atoms or molecules in a solid form. *alchemy/wat1d2.htm#weakbonds*

2e Students know how to draw Lewis dot structures. *alchemy/wat1d.htm#lewis*

2f \*Students know how to predict the shape of simple molecules and their polarity from Lewis dot structures. *alchemy/wat1d2.htm#molestrc*

2g \*Students know how electronegativity and ionization energy relate to bond formation. *alchemy/ear1d.htm#eleneg* *alchemy/ear1d.htm#ionization*

2h \*Students know how to identify solids and liquids held together by Van der Waals forces or hydrogen bonding and relate these forces to volatility and boiling/melting point temperatures. *alchemy/wat1d2.htm#weakbonds*

### Substrand: **Conservation of Matter and Stoichiometry**

3a Students know how to describe chemical reactions by writing balanced equations.

*alchemy/fir1d.htm#balance*

3g \*Students know how to identify reactions that involve oxidation and reduction and how to balance oxidation-reduction reactions. *alchemy/fir1d.htm#redox*

### Substrand: **Acids and Bases**

5a Students know the observable properties of acids, bases, and salt solutions.

*alchemy/fir1x.htm#ph*

5b Students know acids are hydrogen-ion-donating and bases are hydrogen-ion-accepting substances. *alchemy/fir1qa.htm#a27*

5c Students know strong acids and bases fully dissociate and weak acids and bases partially dissociate. *alchemy/wat1d.htm#elbonds*

### Substrand: **Solutions**

6b Students know how to describe the dissolving process at the molecular level by using the concept of random molecular motion. *alchemy/wat1d2.htm#weakbonds*

### Substrand: **Chemical Thermodynamics**

7b Students know chemical processes can either release (exothermic) or absorb (endothermic) thermal energy. *alchemy/fir1d.htm#reactions*

7c Students know energy is released when a material condenses or freezes and is absorbed when a material evaporates or melts. *alchemy/fir1d2.htm#gibbs*

7e \*Students know how to apply Hess's law to calculate enthalpy change in a reaction. *alchemy/fir1d2.htm#enthalpy*



7f \*Students know how to use the Gibbs free energy equation to determine whether a reaction would be spontaneous. [alchemy/fir1d2.htm#gibbs](#)

**Substrand: Reaction Rates**

8a Students know the rate of reaction is the decrease in concentration of reactants or the increase in concentration of products with time. [alchemy/fir1d2.htm#rates](#)

8b Students know how reaction rates depend on such factors as concentration, temperature, and pressure. [alchemy/fir1d2.htm#rates](#)

8c Students know the role a catalyst plays in increasing the reaction rate. [alchemy/fir1d2.htm#rates](#)

8d \*Students know the definition and role of activation energy in a chemical reaction. [alchemy/fir1d2.htm#rates](#)

**Substrand: Chemical Equilibrium**

9a Students know how to use Le Chatelier's principle to predict the effect of changes in concentration, temperature, and pressure. [alchemy/fir1d2.htm#equilb](#)

9b Students know equilibrium is established when forward and reverse reaction rates are equal. [alchemy/fir1d2.htm#equilb](#)

**Substrand: Nuclear Processes**

11a Students know protons and neutrons in the nucleus are held together by nuclear forces that overcome the electromagnetic repulsion between the protons. [alchemy/air1d.htm](#)

11c Students know some naturally occurring isotopes of elements are radioactive, as are isotopes formed in nuclear reactions. [alchemy/air1d.htm#isotopes](#) and [alchemy/air1d.htm#radiation](#)

11d Students know the three most common forms of radioactive decay (alpha, beta, and gamma) and know how the nucleus changes in each type of decay. [alchemy/air1d.htm#radiation](#)

11e Students know alpha, beta, and gamma radiation produce different amounts and kinds of damage in matter and have different penetrations. [alchemy/air1d.htm#radiation](#)

11f \*Students know how to calculate the amount of a radioactive substance remaining after an integral number of half lives have passed. [alchemy/air1d.htm#radiation](#)



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