Massachusetts Tests for Educator Licensure®

TEST INFORMATION BOOKLET

12 Chemistry

MA-SG-FLD012-04

Massachusetts Department of Education

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Test Overview Chart:
Chemistry (12)

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The Chemistry test is designed to assess the candidate's knowledge of the subject matter required for the Massachusetts Chemistry Teacher certificate. This subject matter knowledge is delineated in the Massachusetts Department of Education *Regulations for the Certification of Educational Personnel in Massachusetts* (April 1995), 603 C.M.R. 7.12, "Competencies for Specific Certificates," Section (10) (a) 2. "Competency I: Subject Matter Knowledge."

The Chemistry test assesses the candidate's proficiency and depth of understanding of the subject at the level required for a baccalaureate major, according to Massachusetts standards. Candidates are typically nearing completion of or have completed their undergraduate work when they take the test.

The multiple-choice items on the test cover the subareas as indicated in the chart above. The open-response items may relate to topics covered in any of the subareas and will typically require breadth of understanding of the chemistry field and the ability to relate concepts from different aspects of the field. Responses to the open-response items are expected to be appropriate and accurate in the application of subject knowledge, to provide high-quality and relevant supporting evidence, and to demonstrate a soundness of argument and understanding of the chemistry field.

PERIODIC TABLE OF THE ELEMENTS

1 **IA**	2 **IIA**	3 **IIIB**	4 **IVB**	5 **VB**	6 **VIB**	7 **VIIB**	8	9 **VIIIB**	10	11 **IB**	12 **IIB**	13 **IIIA**	14 **IVA**	15 **VA**	16 **VIA**	17 **VIIA**	18 **VIIIA**
1 **H** 1.01																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 23.0	12 **Mg** 24.3											13 **Al** 27.0	14 **Si** 28.1	15 **P** 31.0	16 **S** 32.1	17 **Cl** 35.5	18 **Ar** 39.9
19 **K** 39.1	20 **Ca** 40.1	21 **Sc** 45.0	22 **Ti** 47.9	23 **V** 50.9	24 **Cr** 52.0	25 **Mn** 54.9	26 **Fe** 55.8	27 **Co** 58.9	28 **Ni** 58.7	29 **Cu** 63.5	30 **Zn** 65.4	31 **Ga** 69.7	32 **Ge** 72.6	33 **As** 74.9	34 **Se** 79.0	35 **Br** 79.9	36 **Kr** 83.8
37 **Rb** 85.5	38 **Sr** 87.6	39 **Y** 88.9	40 **Zr** 91.2	41 **Nb** 92.9	42 **Mo** 95.9	43 **Tc** 98.9	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57–71	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (210)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.0	89–103	104 § (261)	105 § (260)	106 § (263)	107	108	109	110	111	112	113	114	115	116	117	118

Lanthanide Series	57 **La** 138.9	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (147)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
Actinide Series	89 **Ac** (227)	90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** 237.0	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (254)	100 **Fm** (257)	101 **Md** (258)	102 **No** (255)	103 **Lr** (257)

§ The International Union for Pure and Applied Chemistry has not adopted official names or symbols for these elements.

Sample Test Items: Chemistry (12)

All examinees taking the Chemistry test (Field 12) will be provided with a Texas Instruments TI 30X Solar Scientific calculator with functions that include the following: addition, subtraction, multiplication, division, square root, percent, sine, cosine, tangent, exponents, and logarithms. **You may NOT bring your own calculator to the test.**

1. The individual masses of two substances are recorded as 0.5621 g and 0.029 g. According to guidelines for using significant figures, which of the following properly reports the total mass of these two substances?

   A. 5.9×10^{-1}

   B. 5.91×10^{-1}

   C. 5.911×10^{-1}

   D. 6×10^{-1}

2. A major difference between the atomic model of Niels Bohr and the current quantum mechanical theory is that the current theory:

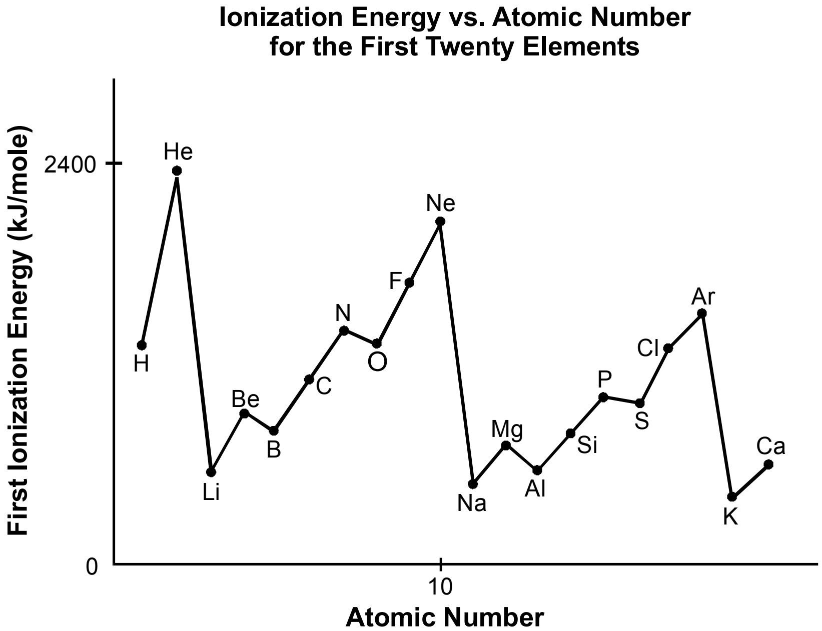
   A. allows for shell numbers that are not integers.

   B. treats the electron as a discrete particle.

   C. assumes the electrons move in discrete circular orbits.

   D. makes use of statistical probabilities.

3. **Use the diagram below to answer the question that follows.**



The graph of first ionization energy plotted against atomic number shows that ionization energy is a periodic function. First ionization energy generally increases from alkali metals to noble gases. Exceptions to this general trend can be seen in going from beryllium to boron and from magnesium to aluminum. These two deviations from the line can best be explained by considering each element's:

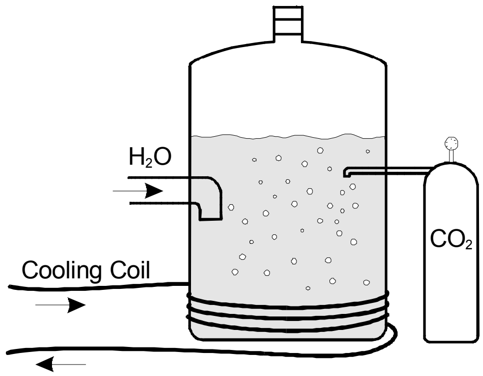
A. atomic radius.

B. electron configuration.

C. nuclear binding energy.

D. atomic mass.

Use the diagram below to answer the two questions that follow.



In the beverage industry, carbon dioxide is introduced into a pressure vessel containing flavored sugar water to give the characteristic fizz associated with soda. After the system has reached equilibrium, the carbonated water is sent through tubing to be bottled.

4. During the manufacturing process, which of the following conditions would shift the equilibrium to favor a reduced carbon dioxide concentration in the beverage?

   A. a leak in the pressure vessel

   B. a decrease in the temperature of the cooling coil

   C. an increase in the length of time the carbon dioxide is left in contact with the sugar water

   D. an increase in the level to which the vessel is filled with sugar water

5. To calculate the amount of energy required for the cooling coil to bring the contents of the vessel to the desired temperature, which of the following information is needed?

   I. desired temperature decrease

   II. specific heat of the sugar water

   III. mass of the sugar water

   IV. molecular weight of the sugar

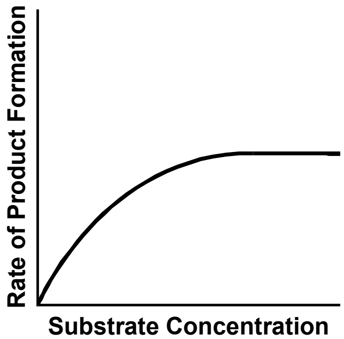
   A. I and IV only

   B. II and III only

   C. I, II, and III only

   D. I, III, and IV only

6. **Use the diagram below to answer the question that follows.**



The graph above shows the rate of product formation versus substrate concentration in an enzyme-catalyzed reaction. Which of the following best explains why the curve levels off?

A. All of the available enzyme sites are saturated, leaving no enzyme molecules available to bind with additional amounts of substrate.

B. As the product concentration increases, the equilibrium shifts so that substrate and product are being formed at equal rates.

C. As the reaction proceeds, the enzymes are used up and converted into other molecules that do not act as catalysts.

D. Once the substrate reaches a certain concentration, it inhibits the breakdown of the enzyme-substrate intermediates.

7. An oxide of element *X* can be made to decompose according to the following unbalanced reaction.

$X_2O_3 \longrightarrow X + O_2$

When 306 grams of X_2O_3 are dissociated, 4.50 moles of O_2 are produced. What is the approximate gram atomic mass of *X*?

A. 6.90

B. 10.8

C. 13.5

D. 27.0

8. **Use the reaction below to answer the question that follows.**

$K_2Cr_2O_7(aq)$	+	$14HI(aq)$	$\longrightarrow$	$2CrI_3(aq)$	+	$2KI(aq)$	+	$3I_2(s)$	+	$7H_2O(\ell)$
294.2 g/mol		127.9 g/mol		432.7 g/mol		166.0 g/mol		253.8 g/mol		18.0 g/mol

A solution that contains 98 g of $K_2Cr_2O_7$ is mixed with excess HI. What is the percent yield of the reaction if 130 g of CrI_3 are collected?

A. 48%

B. 45%

C. 42%

D. 40%

9. In the late eighteenth century, Antoine and Marie Lavoisier conducted a series of experiments involving combustion reactions. These experiments were significant primarily because they were the first to document that:

   A. atoms of different elements are present in fixed proportions in a given compound.

   B. combustion involves the splitting of molecules and the recombination of the atoms into different molecules.

   C. the total mass of the products of a reaction equals the total mass of the original substances.

   D. the elemental identities of individual atoms are not changed during a chemical reaction.

10. ^{32}P and ^{131}I are radioactive isotopes used to treat bone marrow and thyroid cancer. Their usefulness is in part due to their tendency to concentrate in specific organs. Which of the following characteristics is also necessary to make an isotope a good candidate for this form of radiotherapy?

    A. The isotope emits only alpha radiation.

    B. The isotope produces primarily heat energy rather than particle emissions.

    C. The isotope has a short half-life.

    D. The isotope's decay rate is constant.

11. **Use the information below to complete the exercise that follows.**

An automobile safety air bag inflates when a crash sensor sends an electrical signal to an igniter, which triggers an explosive chemical reaction that produces nitrogen gas. One reaction used in air bags is the decomposition of sodium azide (NaN_3) into solid sodium and nitrogen gas. Automobile safety engineers would like to know how many grams of sodium azide will be needed to inflate a 5.00×10^1 L bag to a pressure of 2.00 atm at a temperature of 25.0°C.

Using your knowledge of chemical equations, stoichiometry, and ideal gas laws, write an essay in which you analyze and solve this problem. You may assume the nitrogen gas behaves as an ideal gas. $R = 0.08205$ L atm K^{-1} mol^{-1}. In your essay:

- write a balanced chemical equation for the decomposition reaction;
- explain the role of the igniter in initiating the reaction; and
- determine the number of grams of sodium azide needed to inflate the bag under the conditions given above. Show your work.

Answer Key and Sample Responses: Chemistry (12)

Question Number	Correct Response	Test Objective*
1.	**B**	Understand principles and procedures of measurement used in chemistry.
2.	**D**	Understand the various models of atomic structure, the principles of quantum theory, and the properties and interactions of subatomic particles.
3.	**B**	Understand the organization of the periodic table.
4.	**A**	Understand the principles of chemical equilibrium.
5.	**C**	Understand the principles of thermodynamics and calorimetry.
6.	**A**	Understand factors that affect reaction rates and methods of measuring reaction rates.
7.	**D**	Understand the mole concept.
8.	**B**	Understand the quantitative relationships expressed in chemical equations.
9.	**C**	Understand the historical and contemporary contexts of the study of chemistry.
10.	**C**	Understand the applications of nuclear reactions.

*Each test objective is clarified and further described by a descriptive statement, which provides examples of the types of knowledge and skills covered by the test objective. The test objectives for the Chemistry test begin on page 44.

The sample response below reflects a weak knowledge and understanding of the subject matter.

When an automobile safety airbag inflates, a chemical reaction occurs that produces nitrogen gas from sodium azide (NaN_3). This reaction can be written as:

$$NaN_3 \rightarrow Na + N_3$$

When a car crashes, a sensor sets off the igniter. The igniter applies heat to the sodium azide. This causes the sodium azide to react and separate into solid sodium (Na) and nitrogen gas (N_3). The nitrogen gas expands and inflates the airbag. This reaction is very explosive, as you can tell since the nitrogen gas expands so quickly. The sodium solids just stay at the bottom of the airbag and do not pose any danger to the car's driver or passengers.

To figure out how much sodium azide you would need to inflate the airbag, you would need to know how much nitrogen gas would be needed. You can use the ideal gas laws to calculate the moles of nitrogen gas needed.

$$pv = RT$$

$$2.00 \times 5 = R(25)$$

$$R = \frac{10}{25}$$

$$R = 2.5 \text{ moles}$$

Therefore, you would need 2.5 moles of N_3 to inflate the airbag at the given temperature of 25.0°C. At another temperature, the reaction would be very different, and it might take more or less N_3 to fill the airbag. However, given the temperature the safety engineers were checking, this would be the correct response.

The sample response below reflects a strong knowledge and understanding of the subject matter.

The balanced equation for the decomposition of sodium azide to solid sodium and nitrogen gas is:

$$2NaN_3(s) \longrightarrow 2Na(s) + 3N_2(g)$$

In an automobile air bag, it's important that the substance responsible for inflating the air bag is stable under most ambient conditions, because it would be dangerous if the air bag inflated spontaneously while a person was driving normally. By using a reaction that has a high activation energy (that is, it requires an input of a large amount of energy to begin), spontaneous inflation is unlikely. When triggered by a crash sensor, the igniter supplies the sudden burst of energy needed for the activation energy to be reached and the decomposition reaction to be initiated. The energy supplied by the igniter increases the kinetic energy of the NaN_3 molecules, breaking the bonds in the molecules. Once these bonds are broken, the reaction can proceed rapidly, forming nitrogen gas.

To calculate the number of grams of sodium azide needed, the number of moles of N_2 that will inflate a 50.0 L air bag to a pressure of 2.00 atm at 25.0°C must first be calculated, since it's the N_2 gas that is responsible for inflating the air bag. The number of moles of N_2 needed can be calculated using the ideal gas equation in the following form.

$$n = \frac{PV}{RT}$$

where n is the number of moles of N_2, P is the pressure in the air bag, V is the volume of the air bag, R is the gas constant, and T is the temperature. The values can be plugged in and the equation solved as follows.

$$n = \frac{(2.00\ \text{atm})(50.0\ \text{L})}{(0.0821\ \text{L atm/K mol})(298\ \text{K})}$$

Note: 298 K = 273°C + 25.0°C

$$= \frac{100}{24.5}\ \text{mol}$$

$$= 4.08\ \text{mol}\ N_2$$

(continued on next page)

(continued from previous page)

So, 4.08 moles of N_2 are needed to inflate the bag under the conditions listed. From the balanced equation, we know the proportion of NaN_3 to N_2 is 2 to 3. Therefore, the number of moles of NaN_3 needed to produce 4.08 mol N_2 can be determined using the following equation.

$$\frac{x \text{ mol } NaN_3}{4.08 \text{ mol } N_2} = \frac{2 \text{ mol } NaN_3}{3 \text{ mol } N_2}$$

$$x = \frac{(2 \text{ mol } NaN_3)(4.08 \text{ mol } N_2)}{3 \text{ mol } N_2}$$

$$x = 2.72 \text{ mol } NaN_3$$

To calculate the number of grams of sodium azide in 2.72 moles of the substance, its molar mass must be calculated. From the periodic table, Na = 23.0 g and N = 14.0 g, so the molar mass of NaN_3 is:

$$23.0 \text{ g} + 3(14.0) = 65.0 \text{ g/mol}$$

Therefore, $(2.72 \text{ mol } NaN_3)(65.0 \text{ g/mol } NaN_3) = 177 \text{ g}$

So, theoretically, assuming 100% yield from the decomposition reaction, 177 g of NaN_3 will be needed to inflate a 50.0 L air bag to a pressure of 2.00 atm at 25°C.

SUBAREAS:

THE NATURE OF CHEMICAL INQUIRY
MATTER AND ATOMIC STRUCTURE
ENERGY, CHEMICAL BONDS, AND MOLECULAR STRUCTURE
CHEMICAL REACTIONS
QUANTITATIVE RELATIONSHIPS
INTERACTIONS OF CHEMISTRY, SOCIETY, AND THE ENVIRONMENT

THE NATURE OF CHEMICAL INQUIRY

0001 Understand the nature of scientific inquiry, scientific processes, and the role of observation and experimentation in science.

For example: processes by which new scientific knowledge and hypotheses are generated; experimental design and hypothesis testing; and the role of communication among scientists in promoting scientific progress.

0002 Understand the processes of gathering, organizing, reporting, and interpreting scientific data in the context of chemistry investigations.

For example: methods and procedures for collecting data for various purposes; appropriate and effective graphic representations (e.g., graph, table, diagram) for organizing and reporting experimental data; procedures and criteria for formally reporting experimental results and data to the scientific community; and relationships between factors (e.g., inverse, direct, linear) as indicated by experimental data.

0003 Understand principles and procedures of measurement used in chemistry.

For example: units of measurement, measuring devices, and methods of measurement for given situations; likely sources of error in given measurements in chemistry experiments; significant figures, scientific notation, and reporting data.

0004 Understand proper, safe, and legal use of equipment, materials, and chemicals used in chemistry investigations.

For example: the principles upon which given laboratory instruments are based (e.g., pH meters, gas chromatographs); proper methods for storing, identifying, and dispensing given chemicals and the legal guidelines for disposing chemicals; proper procedures for dealing with accidents and injuries in the chemistry laboratory; and proper procedures for safety in the laboratory (e.g., use of goggles, fire blankets, types of fire extinguishers).

MATTER AND ATOMIC STRUCTURE

0005 Understand the concept of matter, and analyze chemical and physical properties of and changes in matter.

For example: differentiating among elements, compounds, and mixtures; using the physical and chemical properties of an unknown substance in order to identify it; analyzing the methods by which chemical properties of matter are determined; and distinguishing between physical and chemical changes in matter.

0006 Understand the various models of atomic structure, the principles of quantum theory, and the properties and interactions of subatomic particles.

For example: major features of models of atomic structure (e.g., Bohr, Rutherford, Schrödinger); interactions among electrons, protons, and neutrons and their properties (e.g., mass, charge); relationships among electron energy levels, photons, and atomic spectra; and analyzing the electron configurations of atoms and ions.

0007 Understand the organization of the periodic table.

For example: the organization of the periodic table in terms of atomic number and properties of the elements; trends (e.g., ionization energies, covalent atomic radii) within periods and groups in the periodic table; predicting physical and chemical properties of given elements based on their positions in the periodic table; and using the periodic table to gain information (e.g., relative reactivity) about given elements.

0008 Understand the kinetic theory, the nature of phase changes, and the gas laws.

For example: arrangements and movements of particles in solids, liquids, and gases; basic principles of the kinetic theory (e.g., particles of matter are in continual motion, real versus ideal gas behavior); analyzing heating and cooling curves qualitatively and quantitatively; and setting up and solving problems involving gas law relationships.

0009 Apply the conventions of chemical notation and representations.

For example: the symbolic notation for given elements; applying the IUPAC rules of nomenclature to name given inorganic compounds from their formulas; recognizing and interpreting Lewis structures; and determining molecular geometry from Lewis structures.

0010 Understand the process of nuclear transformation.

For example: characteristics (e.g., mass, penetrating power) of the different types of emanations from the decay of radioactive elements; the processes of natural radioactivity and artificial transmutation; solving problems involving half-life of radioactive particles; and calculating nuclear mass defect and nuclear binding energy.

ENERGY, CHEMICAL BONDS, AND MOLECULAR STRUCTURE

0011 Understand the principles of thermodynamics and calorimetry.

For example: the three laws of thermodynamics and their applications to chemical systems; predicting the spontaneity of given reactions based on enthalpy changes, entropy changes, and temperatures of the systems; analyzing the results of calorimetry experiments; and distinguishing between heat and temperature.

0012 Understand energy relationships in chemical bonding and chemical reactions.

For example: energy changes due to the formation or breaking of chemical bonds; solving problems involving energy changes during chemical reactions (e.g., heat of combustion, heat of formation); and interpreting potential energy diagrams of chemical reactions.

0013 Understand the types of bonds between atoms (including ionic, covalent, and metallic bonds), the formation of these bonds, and properties of substances containing the different bonds.

For example: the characteristics of various types of bonds between atoms (e.g., bond strength, polarity); electron behavior in the formation of bonds between atoms; factors that affect bond strength (e.g., electronegativity, electron affinity); and predicting properties of a substance based on type of atomic bond.

0014 Understand types and characteristics of molecular interaction and properties of substances containing different types of interactive forces between molecules.

For example: predicting the kind of interaction between molecules of a given structure; the unique properties of water and its molecular structure and intermolecular forces; and relating the physical properties of substances to their intermolecular forces.

0015 Understand the nomenclature and structure of organic compounds.

For example: the IUPAC rules of nomenclature; the chemical composition and basic structure of organic compounds (e.g., saturated, unsaturated, and aromatic hydrocarbons; halogen, oxygen, and nitrogen derivatives); and distinguishing among structural, geometric, and optical isomers.

CHEMICAL REACTIONS

0016 Understand factors that affect reaction rates and methods of measuring reaction rates.

For example: collision theory and factors that influence reaction rates; relating experimental measurements to reaction rates and rate laws; relating reaction mechanisms to rate laws; determining order of reactions and rate constants; and solving first-order rate problems.

0017 Understand the principles of chemical equilibrium.

For example: the effects of concentration, pressure, temperature, and catalysts on chemical equilibrium; applying Le Chatelier's principle to chemical systems; solving problems involving equilibrium constants; and solving problems involving solubility product constants of slightly soluble salts.

0018 Understand the theories, principles, and applications of acid-base chemistry.

For example: analyzing acids and bases according to operational and conceptual definitions (Arrhenius, Brönsted-Lowry, Lewis); the principles and applications of acid-base titration; determining the hydronium ion concentration and the pH for various acid, base, and salt solutions; and the relative strengths of given acids based on periodic relationships.

0019 Understand redox reactions and electrochemistry.

For example: processes that occur during redox reactions; determining oxidation numbers and balancing redox equations; predicting whether given redox reactions will occur based on standard electrode potentials; and analyzing the components (e.g., anode, cathode) and operating principles of electrochemical and electrolytic cells.

0020 Understand the nature of organic reactions.

For example: analyzing the rates of reactions involving organic compounds based on bond types and strengths; and analyzing common types of reactions (i.e., combustion, addition, substitution, polymerization, oxidation, esterification).

QUANTITATIVE RELATIONSHIPS

0021 Understand the mole concept.

For example: relating the mole to Avogadro's number; relating the gram-atomic mass of an element to the mass of one mole of the element; and calculating the number of moles in a given mass or volume of a substance.

0022 Understand the relationship between the mole concept and chemical formulas.

For example: solving problems involving molecular and formula masses; solving percentage composition problems; and determining empirical and molecular formulas.

0023 Understand the quantitative relationships expressed in chemical equations.

For example: interpreting chemical notation; balancing equations; recognizing net ionic equations; and solving stoichiometric problems involving moles, mass, and volume (including limiting reactant and percent yield).

0024 Understand the properties of solutions and colloidal suspensions, and analyze factors that affect solubility.

For example: the colligative properties of solutions (i.e., freezing point depression, boiling point elevation, osmotic pressure, vapor pressure lowering); solving problems involving concentrations of solutions (e.g., molarity, molality, percent concentration); and factors (e.g., temperature, pressure, molecular structure) that affect solubility.

INTERACTIONS OF CHEMISTRY, SOCIETY, AND THE ENVIRONMENT

0025 Understand the historical and contemporary contexts of the study of chemistry.

For example: significant events, theories, experiments, and individuals in the history of chemistry; and the societal implications of developments in chemistry.

0026 Understand the chemistry of practical processes and applications of chemical theory to other scientific disciplines.

For example: industrial processes (e.g., processes by which petroleum is separated into fractions); chemical processes in the home (e.g., organic reactions involving leavening agents and fermentation); and the application of chemical theory to other disciplines (e.g., procedures by which nucleic acids are cleaved for genetic analysis).

0027 Understand the applications of nuclear reactions.

For example: the use of radioisotopes in the life sciences and in geological and archaeological dating; the role of the components of a nuclear reactor and the issue of waste disposal; and the risks and benefits of nuclear technology.

0028 Understand factors and processes related to the release of chemicals into the environment.

For example: the chemical processes that result from the release of chemicals into the atmosphere (e.g., acid rain, greenhouse effect, ozone depletion, photochemical smog); the chemical processes that result from the release of chemicals into aquatic and terrestrial environments (e.g., eutrophication, dissolved oxygen, groundwater contamination, toxic chemicals); and methods for preventing environmental damage resulting from the release of chemicals into the environment (e.g., recycling, sewage treatment plants, pollution control devices).

0029 Understand the interrelationships among chemistry, society, technology, and other disciplines.

For example: the impact of chemistry and technology on society; similarities and differences between science and technology (e.g., science as investigating the natural world, technology as solving human adaptation problems); the technological design process; ethical considerations related to science and technology; and the application of scientific and technological decision making at the community, state, national, and international level.