Ohio Science

Chemistry Content Elaborations: Grades 9-12

Adopted 2018

Chemistry

Structure And Properties Of Matter

1. Atomic structure `C.PM.1`
    1. Students understand that physical science includes properties and locations of protons, neutrons and electrons, atomic number, mass number, cations and anions, isotopes and the strong nuclear force which holds the nucleus together. `C.PM.1.1`
    2. Students understand that atomic models are constructed to explain experimental evidence and make predictions. `C.PM.1.2`
    3. Students understand that the changes in the atomic model over time exemplify how scientific knowledge changes as new evidence emerges and how technological advancements like electricity extend the boundaries of scientific knowledge. `C.PM.1.3`
    4. Students understand that Thompson's study of electrical discharges in cathode-ray tubes led to the discovery of the electron and the development of the plum pudding model of the atom. `C.PM.1.4`
    5. Students understand that Rutherford's experiment, in which he bombarded gold foil with α-particles, led to the discovery that most of the atom consists of empty space with a relatively small, positively charged nucleus. `C.PM.1.5`
    6. Students understand that Bohr used data from atomic spectra to propose a planetary model of the atom in which electrons orbit the nucleus, like planets around the sun. `C.PM.1.6`
    7. Students understand that Schrödinger used the idea that electrons travel in waves to develop a model in which electrons travel randomly in regions of space called orbitals (quantum mechanical model). `C.PM.1.7`
    8. Students understand that based on the quantum mechanical model, it is not possible to predict exactly where electrons are located but there is a region of space surrounding the nucleus in which there is a high probability of finding an electron (electron cloud or orbital). `C.PM.1.8`
    9. Students understand that data from atomic spectra (emission and absorption) gives evidence that electrons can only exist at certain discrete energy levels and not at energies between these levels. `C.PM.1.9`
    10. Students understand that atoms are usually in the ground state where the electrons occupy orbitals with the lowest available energy. However, the atom can become excited when the electrons absorb a photon with the precise amount of energy (indicated by the frequency of the photon) to move to an orbital with higher energy. `C.PM.1.10`
    11. Students understand that any photon without this precise amount of energy will be ignored by the electron. `C.PM.1.11`
    12. Students understand that the atom exists in the excited state for a very short amount of time. `C.PM.1.12`
    13. Students understand that when an electron drops back down to the lower energy level, it emits a photon that has energy equal to the energy difference

between the levels. C.PM.1.13

14. Students understand that the amount of energy is indicated by the frequency of the light that is given off and can be measured. C.PM.1.14
15. Students understand that each element has a unique emission and absorption spectrum due to its unique electron configuration and specific electron energy jumps that are possible for that element. C.PM.1.15
16. Students understand that being aware of the quantum mechanical model as the currently accepted model for the atom is important for science literacy as it explains and predicts subatomic interactions, but details should be reserved for more advanced study. C.PM.1.16
17. Students understand that electron energy levels consist of sublevels (s, p, d and f), each with a characteristic number and shape of orbitals. C.PM.1.17
18. Students understand that orbital diagrams and electron configuration can be constructed to show the location of the electrons in an atom using established rules. C.PM.1.18
19. Students understand that valence electrons are responsible for most of the chemical properties of elements. C.PM.1.19
20. Students understand that in this course, electron configuration (extended and noble gas notation) and orbital diagrams can be shown for any element in the first three periods. C.PM.1.20
21. Students understand that although the quantum mechanical model of the atom explains the most experimental evidence, other models can still be helpful. C.PM.1.21
22. Students understand that thinking of atoms as indivisible spheres is useful in explaining many physical properties of substances, such as the state (solid, liquid or gas) of a substance at room temperature. C.PM.1.22
23. Students understand that Bohr's planetary model is useful to explain and predict periodic trends in the properties of elements. C.PM.1.23

2. Periodic table C.PM.2
    1. Students understand that in the physical science course, the concept that elements are placed in order of increasing atomic number in the periodic table such that elements with similar properties are placed in the same column is introduced. C.PM.2.1
    2. Students understand that how the periodic table is divided into groups, families, periods, metals, nonmetals and metalloids is also included and will be revisited here. C.PM.2.2
    3. Students understand that in this course, with more information about the electron configuration of elements, similarities in the configuration of the valence electrons for a particular group can be observed. C.PM.2.3
    4. Students understand that the electron configuration of an atom can be determined from the position on the periodic table. C.PM.2.4

5. Students understand that the repeating pattern in the electron configuration for elements on the periodic table explains many of the trends in the properties observed. C.PM.2.5
6. Students understand that atomic theory is used to describe and explain trends in properties across periods or down columns including atomic radii, ionic radii, first ionization energies, electronegativities and whether the element is a solid or gas at room temperature. C.PM.2.6
7. Students understand that additional ionization energies, electron affinities and periodic properties of the transition elements, and the lanthanide and actinide series are reserved for more advanced study. C.PM.2.7

3. Chemical bonding C.PM.3
   1. Students understand that content in the physical science course included recognizing that atoms with unpaired electrons tend to form ionic and covalent bonds with other atoms, forming molecules, ionic lattices or network covalent structures. C.PM.3.1
   2. Students understand that in this course, electron configuration, electronegativity values and energy considerations will be applied to bonding and the properties of materials with different types of bonding. C.PM.3.2
   3. Students understand that atoms of many elements are more stable when they are bonded to other atoms. In such cases, as atoms bond, energy is released to the surroundings, resulting in a system with lower energy. C.PM.3.3
   4. Students understand that an atom's electron configuration, particularly the valence electrons, determines how an atom interacts with other atoms. C.PM.3.4
   5. Students understand that molecules, ionic lattices and network covalent structures have different, yet predictable, properties that depend on the identity of the elements and the types of bonds formed. C.PM.3.5
   6. Students understand that differences in electronegativity values can be used to predict where a bond fits on the continuum between ionic and covalent bonds. C.PM.3.6
   7. Students understand that the polarity of a bond depends on the electronegativity difference and the distance between the atoms (bond length). C.PM.3.7
   8. Students understand that polar covalent bonds are introduced as an intermediary between ionic and pure covalent bonds. C.PM.3.8
   9. Students understand that the concept of metallic bonding is also introduced to explain many of the properties of metals (e.g., conductivity). C.PM.3.9
   10. Students understand that since most compounds contain multiple bonds, a substance may contain more than one type of bond. C.PM.3.10
   11. Students understand that carbon atoms can bond together and with other atoms, especially hydrogen, oxygen, nitrogen and sulfur, to form chains, rings and branching networks that are present in a variety of important compounds, including synthetic polymers, fossil fuels and the large molecules essential to life. C.PM.3.11

12. Students understand that detailed study of the structure of molecules responsible for life is reserved for more advanced courses. C.PM.3.12

4. Representing compounds C.PM.4
    1. Students understand that using the periodic table, formulas of ionic compounds containing specific elements can be predicted. C.PM.4.1
        a. Students understand that this can include ionic compounds made up of elements from groups 1, 2, 17, hydrogen, oxygen and polyatomic ions (given the formula and charge of the polyatomic ion). C.PM.4.1.A
    2. Students understand that given the formula, a compound can be named using conventional systems that include Greek prefixes and Roman numerals where appropriate. C.PM.4.2
    3. Students understand that given the name of an ionic or covalent substance, formulas can be written. C.PM.4.3
    4. Students understand that many different models can be used to represent compounds including chemical formulas, Lewis structures, and ball and stick models. C.PM.4.4
    5. Students understand that these models can be used to visualize atoms and molecules and to predict the properties of substances. C.PM.4.5
    6. Students understand that each type of representation provides unique information about the compound. C.PM.4.6
    7. Students understand that different representations are better suited for particular substances. C.PM.4.7
    8. Students understand that Lewis structures can be drawn to represent covalent compounds using a simple set of rules and can be combined with valence shell electron pair repulsion (VSEPR) theory to predict the three-dimensional electron pair and molecular geometry of compounds. C.PM.4.8
    9. Students understand that Lewis structures and molecular geometries will only be constructed for the following combination of elements: hydrogen, carbon, nitrogen, oxygen, phosphorus, sulfur and the halogens. C.PM.4.9
    10. Students understand that organic nomenclature is reserved for more advanced courses. C.PM.4.10
5. Quantifying matter C.PM.5
    1. Students understand that in earlier grades, properties of materials were quantified with measurements that were always associated with some error. C.PM.5.1
    2. Students understand that in this course, scientific protocols for quantifying the properties of matter accurately and precisely are studied. C.PM.5.2
    3. Students understand that using the International System of Units (SI), significant digits or figures, scientific notation, error analysis and dimensional analysis are vital to scientific communication. C.PM.5.3
    4. Students understand that there are three domains of magnitude in size and time: the macroscopic (human) domain, the cosmic domain and the submicroscopic

(atomic and subatomic) domain. C.PM.5.4

5. Students understand that measurements in the cosmic domain and submicroscopic domains require complex instruments and/or procedures. C.PM.5.5
6. Students understand that matter can be quantified in a way that macroscopic properties such as mass can reflect the number of particles present. C.PM.5.6
7. Students understand that elemental samples are a mixture of several isotopes with different masses. C.PM.5.7
8. Students understand that the atomic mass of an element is calculated given the mass and relative abundance of each isotope of the element as it exists in nature. C.PM.5.8
9. Students understand that because the mass of an atom is very small, the mole is used to translate between the atomic and macroscopic levels. C.PM.5.9
10. Students understand that a mole is equal to the number of atoms in exactly 12 grams of the isotope carbon-12. C.PM.5.10
11. Students understand that the mass of one mole of a substance is equal to its molar mass in grams. C.PM.5.11
12. Students understand that the molar mass for a substance can be used in conjunction with Avogadro's number and the density of a substance to convert between mass, moles, volume and number of particles of a sample. C.PM.5.12

6. Intermolecular forces of attraction C.PM.6
   1. Students understand that in middle school, solids, liquids and gases were explored in relation to the spacing of the particles, motion of the particles and strength of attraction between the particles that make up the substance. C.PM.6.1
   2. Students understand that the intermolecular forces of attraction between particles that determine whether a substance is a solid, liquid or gas at room temperature are addressed in greater detail in this course. C.PM.6.2
   3. Students understand that intermolecular attractions are generally weak when compared to intramolecular bonds, but span a wide range of strengths. C.PM.6.3
   4. Students understand that the composition of a substance and the shape and polarity of a molecule are particularly important in determining the type and strength of bonding and intermolecular interactions. C.PM.6.4
   5. Students understand that types of intermolecular attractions include London dispersion forces (present between all molecules), dipole-dipole forces (present between polar molecules) and hydrogen bonding (a special case of dipole-dipole where hydrogen is bonded to a highly electronegative atom such as fluorine, oxygen or nitrogen), each with its own characteristic relative strength. C.PM.6.5
   6. Students understand that the configuration of atoms in a molecule determines the strength of the forces (bonds or intermolecular forces) between the particles and therefore the physical properties (e.g., melting point, boiling point, solubility, vapor pressure) of a material. C.PM.6.6

7. Students understand that for a given substance, the average kinetic energy (temperature) needed for a change of state to occur depends upon the strength of the intermolecular forces between the particles. C.PM.6.7
8. Students understand that therefore, the melting point and boiling point depend upon the amount of energy that is needed to overcome the attractions between the particles. C.PM.6.8
9. Students understand that substances that have strong intermolecular forces or are made up of three-dimensional networks of ionic or covalent bonds, tend to be solids at room temperature and have high melting and boiling points. C.PM.6.9
10. Students understand that nonpolar organic molecules are held together by weak London dispersion forces. However, substances with longer chains provide more opportunities for these attractions and tend to have higher melting and boiling points. C.PM.6.10
11. Students understand that increased branching of organic molecules results in lower melting and boiling points due to interference with the intermolecular attractions. C.PM.6.11
12. Students understand that substances will have a greater solubility when dissolving in a solvent with similar intermolecular forces. C.PM.6.12
13. Students understand that if the substances have different intermolecular forces, they are more likely to interact with themselves than the other substance and remain separated from each other. C.PM.6.13
14. Students understand that water is a polar molecule and it is often used as a solvent since most ionic and polar covalent substances will dissolve in it. C.PM.6.14
15. Students understand that in order for an ionic substance to dissolve in water, the attractive forces between the ions must be overcome by the dipole-dipole interactions with the water. C.PM.6.15
16. Students understand that dissolving of a solute in water is an example of a process that is difficult to classify as a chemical or physical change and it is not appropriate to have students classify it one way or another. C.PM.6.16
17. Students understand that evaporation occurs when the particles with enough kinetic energy to overcome the attractive forces separate from the rest of the sample to become a gas. C.PM.6.17
18. Students understand that the pressure of these particles is called vapor pressure. Vapor pressure increases with temperature. C.PM.6.18
19. Students understand that particles with larger intermolecular forces have lower vapor pressures at a given temperature since the particles require more energy to overcome the attractive forces between them. C.PM.6.19
20. Students understand that molecular substances often evaporate more due to the weak attractions between the particles and can often be detected by their odor. C.PM.6.20

21. Students understand that ionic or network covalent substances have stronger forces and are not as likely to volatilize. C.PM.6.21
22. Students understand that these substances often have little, if any, odor. C.PM.6.22
23. Students understand that liquids boil when their vapor pressure is equal to atmospheric pressure. C.PM.6.23
24. Students understand that in solid water, there is a network of hydrogen bonds between the particles that gives it an open structure. C.PM.6.24
25. Students understand that this is why water expands as it freezes and why solid water has a lower density than liquid water. C.PM.6.25
26. Students understand that this has important implications for life (e.g., ice floating on water acts as an insulator in bodies of water to keep the temperature of the rest of the water above freezing). C.PM.6.26

Interactions Of Matter

1. Chemical reactions C.IM.1
   1. Students understand that in the Physical Science course, coefficients were used to balance simple equations. C.IM.1.1
      a. Students also understand that other representations, including Lewis structures and three-dimensional models, were also used and manipulated to demonstrate the conservation of matter in chemical reactions. C.IM.1.1.A
   2. Students understand that in this course, more complex reactions will be studied, classified and represented with balanced chemical equations and three-dimensional models. C.IM.1.2
   3. Students understand that classifying reactions into types can be a helpful organizational tool for recognizing patterns of what may happen when two substances are mixed. C.IM.1.3
   4. Students understand that teachers should be aware that the common reaction classifications that are often used in high school chemistry courses may lead to misconceptions because they are not based on the actual chemistry, but on surface features that can be similar from one system to another (e.g., exchanging partners), even though the underlying chemistry is not the same. C.IM.1.4
      a. Students also understand that these classifications may be useful in making predictions about what happens when two substances are mixed. C.IM.1.4.A
   5. Students understand that some general types of chemical reactions are oxidation/reduction, synthesis, decomposition, single replacement, double replacement (including precipitation reactions and some acid-base neutralizations) and combustion reactions. C.IM.1.5
   6. Students understand that some reactions can fit into more than one category. For example, a single replacement reaction can also be classified as an oxidation/reduction reaction. C.IM.1.6
   7. Students understand that identification of reactions involving oxidation and reduction as well as indicating what substance is being oxidized and what is being reduced are appropriate in this course. However, balancing complex oxidation/reduction reactions is reserved for more advanced study. C.IM.1.7
   8. Students understand that organic molecules release energy when undergoing combustion reactions and are used to meet the energy needs of society (e.g., oil, gasoline, natural gas) and to provide the energy needs of biological organisms (e.g., cellular respiration). C.IM.1.8
   9. Students understand that when a reaction between two ionic compounds in aqueous solution results in the formation of a precipitate or molecular compound, the reaction often occurs because the new ionic or covalent bonds are stronger than the original ion-dipole interactions of the ions in solution. C.IM.1.9
   10. Students understand that laboratory experiences (3-D or virtual) with different types of chemical reactions should be provided. C.IM.1.10

11. Students understand that reactions occur when reacting particles collide in an appropriate orientation and with sufficient energy. C.IM.1.11
12. Students understand that the rate of a chemical reaction is the change in the amount of the reactants or products in a specific period of time. C.IM.1.12
13. Students understand that increasing the probability or effectiveness of the collisions between the particles increases the rate of the reaction. Therefore, changing the concentration of the reactants, changing the temperature or the pressure of gaseous reactants, or using a catalyst, can change the reaction rate. C.IM.1.13
14. Students understand that the collision theory can be applied to dissolving solids in a liquid solvent and can be used to explain why reactions are more likely to occur between reactants in the aqueous or gaseous state than between solids. C.IM.1.14
15. Students understand that the rate at which a substance dissolves should not be confused with the amount of solute that can dissolve in a given amount of solvent (solubility). C.IM.1.15
16. Students understand that mathematical treatment of reaction rates is reserved for more advanced study. C.IM.1.16
17. Students understand that computer simulations can help visualize reactions from the perspective of the kinetic-molecular theory. C.IM.1.17
18. Students understand that for chemical systems, potential energy is in the form of chemical energy and kinetic energy is in the form of thermal energy. C.IM.1.18
19. Students understand that the total amount of chemical energy and/or thermal energy in a system is impossible to measure. However, the energy change of a system can be calculated from measurements (mass and change in temperature) from calorimetry experiments in the laboratory. Conservation of energy is an important component of calorimetry equations. C.IM.1.19
20. Students understand that thermal energy is the energy of a system due to the movement of its particles. C.IM.1.20
21. Students understand that the thermal energy of an object depends upon the amount of matter present (mass), temperature and chemical composition. C.IM.1.21
22. Students understand that some materials require little energy to change their temperature and other materials require a great deal to change their temperature by the same amount. C.IM.1.22
23. Students understand that specific heat is a measure of how much energy is needed to change the temperature of a specific mass of material a specific amount. C.IM.1.23
24. Students understand that specific heat values can be used to calculate the thermal energy change, the temperature (initial, final or change in) or mass of a material in calorimetry. C.IM.1.24

25. Students understand that water has a particularly high specific heat capacity, which is important in regulating Earth's temperature. C.IM.1.25
26. Students understand that as studied in middle school, chemical energy is the potential energy associated with chemical systems. C.IM.1.26
27. Students understand that chemical reactions involve valence electrons forming bonds to yield more stable products with lower energies. C.IM.1.27
28. Students understand that energy is required to break interactions and bonds between the reactant atoms and energy is released when an interaction or bond is formed between the atoms in the products. C.IM.1.28
29. Students understand that molecules with weak bonds (e.g., ATP) are less stable and tend to react to produce more stable products, releasing energy in the process. C.IM.1.29
30. Students understand that generally, energy is transferred out of the system (exothermic) when the products have stronger bonds than the reactants and is transferred into the system (endothermic) when the reactants have stronger bonds than the products. C.IM.1.30
31. Students understand that predictions of the energy requirements (endothermic or exothermic) of a reaction can be made given a table of bond energies. C.IM.1.31
32. Students understand that graphic representations can be drawn and interpreted to represent the energy changes during a reaction. C.IM.1.32
33. Students understand that the role of energy in determining the spontaneity of chemical reactions is dealt with conceptually in this course. C.IM.1.33
34. Students understand that entropy and its influence on the spontaneity of reactions are reserved for more advanced study. C.IM.1.34
35. Students understand that all reactions are reversible to a degree and many reactions do not proceed completely toward products but appear to stop progressing before the reactants are all used up. At this point, the amounts of the reactants and the products appear to be constant and the reaction can be said to have reached dynamic equilibrium. C.IM.1.35
36. Students understand that dynamic equilibrium means the rate of the reverse reaction is equal to the rate of the forward reaction so there is no apparent change in the reaction. C.IM.1.36
37. Students understand that if a chemical system at equilibrium is disturbed by a change in the conditions of the system (e.g., increase or decrease in the temperature, pressure on gaseous equilibrium systems, concentration of a reactant or product), then the equilibrium system will respond by shifting to a new equilibrium state, reducing the effect of the change (Le Chatelier's Principle). C.IM.1.37
38. Students understand that if products are removed as they are formed during a reaction, then the equilibrium position of the system is forced to shift to favor the products. In this way, an otherwise unfavorable reaction can be made to occur. C.IM.1.38

39. Students understand that mathematical treatment of equilibrium reactions is reserved for advanced study. C.IM.1.39

40. Students understand that computer simulations can help visualize the progression of a reaction to dynamic equilibrium and the continuation of both the forward and reverse reactions after equilibrium has been attained. C.IM.1.40

41. Students understand that properties of acids and bases and the ranges of the pH scale were introduced in Physical Science. C.IM.1.41

42. Students understand that in this course, the structural features of molecules are explored to further understand acids and bases. C.IM.1.42

43. Students understand that acids often result when hydrogen is covalently bonded to an electronegative element and is easily dissociated from the rest of the molecule to bind with water to form a hydronium ion (H3O+). C.IM.1.43

44. Students understand that the acidity of an aqueous solution can be expressed as pH, where pH can be calculated from the concentration of the hydronium ion. C.IM.1.44

45. Students understand that bases are likely to dissociate in water to form a hydroxide ion. C.IM.1.45

46. Students understand that acids can react with bases to form a salt and water. Such neutralization reactions can be studied quantitatively by performing titration experiments. C.IM.1.46

2. Gas laws C.IM.2

   1. Students understand that the kinetic-molecular theory can be used to explain the properties of gases (pressure, temperature and volume) through the motion and interactions of its particles. C.IM.2.1

   2. Students understand that problems can also be solved involving the changes in temperature, pressure, volume and amount of a gas. C.IM.2.2

   3. Students understand that when two of these four are kept constant, the relationship between the other two can be quantified, described and explained using the kinetic-molecular theory. C.IM.2.3

   4. Students understand that real-world phenomena (e.g., why tire pressure increases in hot weather, why a hot air balloon rises) can be explained using this theory. C.IM.2.4

   5. Students understand that when solving gas problems, the Kelvin temperature scale must be used since only in this scale is the temperature directly proportional to the average kinetic energy. C.IM.2.5

   6. Students understand that the Kelvin temperature is based on a scale that has its minimum temperature at absolute zero, a temperature at which all motion theoretically stops. C.IM.2.6

   7. Students understand that since equal volumes of gases at the same temperature and pressure contain an equal number of particles (Avogadro's law), problems can be solved for an unchanging gaseous system using the ideal gas law (PV =

nRT) where R is the ideal gas constant (e.g., represented in multiple formats, 8.31 joules/(mole·K). C.IM.2.7

8. Students understand that the focus in this course is solving problems using the gas laws and understanding their applications, rather than memorizing the specific names and formulas. C.IM.2.8
9. Students understand that deviations from ideal gaseous behavior are reserved for more advanced study. C.IM.2.9
10. Students understand that relationships between the volume, temperature and pressure can be explored in the laboratory or through computer simulations or virtual experiments. C.IM.2.10

3. Stoichiometry C.IM.3
   1. Students understand that a stoichiometric calculation involves the conversion from the amount of one substance in a chemical reaction to the amount of another substance. C.IM.3.1
   2. Students understand that the coefficients of the balanced equation indicate the ratios of the substances involved in the reaction in terms of both particles and moles. C.IM.3.2
   3. Students understand that once the number of moles of a substance is known, amounts can be changed to mass, volume of a gas, volume of solutions and/or number of particles. C.IM.3.3
   4. Students understand that molarity is a measure of the concentration of a solution that can be used in stoichiometric calculations. C.IM.3.4
   5. Students understand that when performing a reaction in the lab, the experimental yield can be compared to the theoretical yield to calculate percent yield. C.IM.3.5
   6. Students understand that the concept of limiting reagents is treated conceptually. C.IM.3.6
   7. Students understand that mathematical applications can be utilized, but it is important to address the symbolic representations as well. C.IM.3.7
   8. Students understand that molality and normality are concepts reserved for more advanced study. C.IM.3.8