

1. A The second law of thermodynamics states any process within an isolated system always increases the entropy of the system. [76,10]
2. C Acid-base reactions are a specific type of double replacement reaction. When an acid and base react, a salt and water are produced. [58,4]
3. C The first manned hydrogen-fueled balloon flight took place on December 1, 1783. The balloon had two passengers—Jacques Charles and Nicolas-Louis Robert. [34,1]
4. A Dalton published *A New System of Chemical Philosophy* in 1808, in which he outlined what is now considered the first modern atomic theory. [9,2]
5. C The five basic types of reactions are synthesis, decomposition, double replacement, single replacement, and combustion. Acid-base reactions are a specific type of double-replacement reaction. [53,2]
6. D While the arrangement might cause trends in other chemical properties as well, the elements within the periodic table is strictly arranged according to increasing atomic number. There is a difference of 1 proton between each element, starting from hydrogen with an atomic number of 1. [13,2]
7. B State functions are properties of a system that are determined by where the system is, not how it arrived there—only the initial and final stages are important. Some examples of state functions are enthalpy, entropy, Gibbs Free Energy, and pressure. Heat only transfers energy in or out of a system, and therefore it depends on the pathway a system takes. [76,1]
8. A Joseph Black discovered carbon dioxide when he heated calcium carbonate and observed the gas it produced, and he referred to the new gas as “fixed air”. [46,1]
9. B Dalton’s law of multiple proportions states that if two elements combine to form more than one compound, their masses will combine in whole-number ratios. This idea was built off Proust’s law of definite proportions, which states that a substance is always composed of the same proportion of each element. [9,2]
10. B There are two main types of solutions: aqueous solutions, where the solvent is water, and organic solutions, where the solvent is a nonpolar substance such as octane. [46,3]
11. C Metallic bonds exist when metal atoms are bonded in such a way that the electrons are freed, and can move freely between the atoms. These moving electrons make up electricity, making metals good conductors of electricity. [16,6]
12. C Through his experiments, British chemist Henry Cavendish noted that the reaction of a metal with acid released a substance that was distinct from other gases, and described its properties. At the time, this substance was known as “phlogiston”, but was later officially named by Antoine Lavoisier. [20,2]
13. D Metals are good conductors of electricity, because the closeness of their atomic structure allows their electrons to move freely. Insulators are poor conductors of electricity. [43,4]
14. D When the ΔG value of a reaction is negative, the reaction proceeds spontaneously at all temperatures. The change in enthalpy is negative, and the change in entropy is positive. [77,Figure 76]
15. B The cell voltage is equal to the difference between the reduction potential of the reduction reaction and the reduction potential of the oxidation reaction within a redox reaction. When this number is positive, it is a naturally occurring reaction, or a spontaneous reaction. [66,6]
16. E When Dalton proposed his conclusions on atomic behavior, he theorized that matter was composed of indivisible particles. However, this aspect of his theory was later proven wrong, as we now know that atoms can be broken down into subatomic particles. [9,3]
17. C The chemical formula for mercuric oxide is HgO . It is also known as quicksilver. [39,1]
18. A All matter can be represented by wave equations but also exhibits particle properties simultaneously. Quantum physics is the field of science that deals with such issues. [12,3]
19. D Mass spectrometers are used by chemists to determine the relative masses of single atoms. These devices are also used at airports, to check that passengers are not carrying compounds that could be indicative of explosives. [7,5]
20. C An atom in its standard form has an equal number of protons or electrons. However, when an atom gains or loses an electron, it becomes an ion. A positively charged ion is a cation, and a negatively charged ion is an anion. [7,Figure 1]
21. A Atomic radii increase down a group, because of the added electron shell for each row added. This increases the distance of the outermost electrons from the nucleus, causing them to be less affected by the attractive pull of the nucleus. [14,5]
22. D Charles’s law states that there is a direct relationship between a gas’s volume and temperature, when its pressure is held constant. [32,5]

23. E Phlogiston theory is the idea that phlogiston is released as materials burned, and it was a popular theory before the discovery of oxygen. However, one of its biggest faults was that it couldn't answer why air is required for combustion. [56,4]
24. A Solubility refers to the amount of solute that will dissolve in a certain amount of solvent. [46,4]
25. A Acids are reactants that have an excess of H⁺ ions, and donate H⁺ ions in a reaction. [57,7]
26. D NaCl, or sodium chloride, is the chemical formula for table salt. Within a single salt molecule, a sodium cation and a chlorine anion are bonded, with the sodium atom giving an electron to the chlorine atom. [15,7]
27. D The Scientific Revolution was characterized by the transition from supernatural explanations for natural processes to ones that were rooted in experimentation. The process of using the scientific method and concrete reasoning to deduce conclusions is called empiricism. The Scientific Revolution occurred in the sixteenth and seventeenth centuries. [6,2]
28. C When electronegative atoms pull electrons towards them within molecules, partial charges are created on either side of the molecule. Van der Waals forces are created by the attraction between partial negative charges on one molecule's end and partial positive charges on another molecule's end. Highly polar molecules exhibit strong van der Waals forces. [17,2]
29. B Copper is above silver on the activity series of metals, which indicates that it is more reactive. Therefore, if silver metal is placed in a copper solution, no reaction will occur. [54,6]
30. C The latent heat involved in melting a solid or freezing a liquid is called the heat of fusion. [75,3]
31. C The photoelectric effect is where a photon transfers its energy to an electron, and this electron is then emitted from a metal surface. The photoelectric effect demonstrates the particle properties of light. [12,4]
32. B Jacques Charles was interested in hot air balloons and began studying the properties of gases. Over time, his goal became to use hydrogen as a means of fueling balloon flight. [33,5]
33. B Chemists have established that it takes 4.18 joules of heat to raise the temperature of 1 gram of water by 1° C. [76,4]
34. D Enthalpy is the measure of heat released or absorbed during a chemical reaction. Enthalpy is proportional to the amount of chemical present, in moles. [76,2]
35. C Nonpolar solvents are generally compounds that only contain carbon and hydrogen. [48,3]
36. A Hess's Law states that the heat absorbed or released in a chemical reaction is the same whether the process takes place in one or in several steps. Essentially, this restates the law of conservation of energy. [76,5]
37. D At 97° C and 1 atm, water will be in its liquid state according to the given phase diagram. [44,Figure 53]
38. D In the Davisson-Germer experiment, electrons scattered at preferred angles from a nickel crystal. This experiment showed the wave properties of electrons. [12,4]
39. D As electrons move around their orbitals, the charges present in a molecule can also change. When electrons are unevenly distributed throughout a nonpolar molecule, the temporary charges on either end are called induced dipoles. These London dispersion forces are created by a nearby polar molecule disturbing an adjacent nonpolar molecule. London dispersion forces are the only intermolecular forces that can occur in nonpolar molecules. [18,2]
40. D Electronegativity is a measure of one atom's attraction to electrons of an adjacent atom to which it is bonded. For example, within a water molecule, the electrons attached to the hydrogen atoms are pulled towards the oxygen atom due to its higher electronegativity. This is what causes water molecules to become polar, with a partial positive charge on the hydrogen end and a partial negative end on the oxygen end due to the extra electrons present there. [15,4]
41. A Chlorofluorocarbons were used as refrigerator cooling liquids for years, but they caused environmental damage by destroying Earth's ozone layer. As a result, ammonia is used instead now. [40,5]
42. D When atoms are held together in a constant ratio by strong bonds, they are together called a single molecule. Glucose has a chemical formula of C₆H₁₂O₆, which simplifies to a ratio of 1:2:1. [15,Figure 13]
43. A The ratio that atoms combine in is always measured in grams. In the case of HF, 1 gram of hydrogen always combines with 19 grams of fluorine. Since fluorine has a mass number of 19 and hydrogen has a mass number of 1, this is equal to 1 atom of hydrogen combining with 1 atom of fluorine. [7,4]
44. E When temperatures are increased, more energy is added to the molecules within a substance. As a result, they collide with each other more often, increasing reaction rates simultaneously. [73,3]
45. B While Antoine Lavoisier made many advancements in the field of chemistry, it was Johann Baptista van Helmont that refuted the notion of alchemy and element transmutation. [57,3]
46. E James Watt, the inventor of the steam engine, utilized the concept of latent heat in his invention. [75,3]

47. B Endothermic processes are reactions that have a net absorption of heat. [74,6]
48. C The metal single replacement reaction, when the numbers of atoms are balanced, will be $\text{Cu} + 2\text{AgNO}_3 \rightarrow \text{Cu}(\text{NO}_3)_2 + 2\text{Ag}$. [54,4]
49. D Before chemistry was fully developed, it shared many characteristics with alchemy, which involved supernatural explanations for natural phenomena. Alchemy was of popular interest in the Middle Ages before the Scientific Revolution. [6,4]
50. A The temperature that represents the lowest one possible, and an absence of all molecular motion, is called “absolute zero”. This term refers to 0 K, or -273°C . [33,1]

Science Comprehensive Exam 02

1. B When an organic hydrocarbon like methane reacts with oxygen through combustion, the products of the reaction are water and carbon dioxide. This can be symbolized by the chemical equation $\text{CH}_4 + \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{CO}_2$. When both sides of the equations are balanced, the equation becomes $\text{CH}_4 + 2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{CO}_2$, showing that two water molecules are produced through this reaction. [54,7]
2. E In the Davisson-Germer experiment, electrons scattered at preferred angles from a nickel crystal. This experiment showed the wave properties of electrons. [12,4]
3. A When an electron absorbs a photon, it is excited and raises to a higher energy level. [11,8]
4. E Through his experiments, British chemist Henry Cavendish noted that the reaction of a metal with acid released a substance that was distinct from other gases, and described its properties. At the time, this substance was known as "phlogiston", but was later officially named by Antoine Lavoisier. [20,2]
5. B Michael Faraday determined that it took one mole of electrons to convert one mole of silver ion, Ag^+ , to silver metal. In his honor, the electric charge on one mole of electrons was named the Faraday. One Faraday has 96,500 coulombs of charge. [68,1]
6. D The atomic mass of carbon is 12, and the atomic mass of oxygen is 16. Thus, the two oxygen atoms have a mass of 32. The mass ratio of carbon to oxygen of 12:32 can be simplified down to 3:8. [70,4]
7. E Cobalt-60 does not occur naturally, but is made in nuclear reactors. As a result, it is highly radioactive. [11,4]
8. E Solids are the most orderly state of matter, then liquids and then gases. Most metals are solid at room temperature, with mercury as an exception due to its weak intermolecular forces. [76,11]
9. B The aerospace industry uses gold plating on certain components of rockets and space shuttles to protect them from solar radiation in outer space. Almost 41 kilograms of gold were used to plate components of the space shuttle *Columbia*. [67,3]
10. D The Brønsted-Lowry model expands on Arrhenius's work by defining acids as H^+ donators, and bases as H^+ acceptors in a reaction. When ammonia is added to water, the water donates an H^+ to ammonia, making ammonia a base. [59,6]
11. D A metal single replacement reaction usually takes the form of $\text{M} + \text{BC} \rightarrow \text{MC} + \text{B}$. In this reaction, the copper replaces the silver to bond with the nitrate molecule. [54,4]
12. B Dalton found that gases could only combine in specific proportions. This finding drew on Antoine Lavoisier's law of conservation of mass, and Joseph Louis Proust's law of definite proportions. [9,2]
13. A The process of measuring changes in enthalpy is called calorimetry. For example, to measure the heat of an acid-base reaction, the change in temperature of the reacting mixture is measured. [76,4]
14. C German Swedish chemist Carl Wilhelm Scheele is one of three scientists credited with discovering oxygen. In the early 1770s, Scheele discovered through his experiments in heating oxides that oxygen was odorless and tasteless. [38,8]
15. B The Scientific Revolution was characterized by the transition from supernatural explanations for natural processes to ones that were rooted in experimentation. The process of using the scientific method and concrete reasoning to deduce conclusions is called empiricism. [6,2]
16. A The ratio that atoms combine in is always measured in grams. In the case of NaCl , 23 grams of sodium will always combine with 25 grams of chlorine. Since sodium has a mass number of 23 and chlorine has a mass number of 25, this is equivalent to 1 atom of sodium combining with 1 atom of chlorine. [7,4]
17. D When 1 mole of carbon is converted to 1 mole of carbon dioxide, the heat given off is equal to 393.5 kJ. This is called the "heat of reaction". [76,3]
18. A An isotope differs from the standard form of an atom in its number of neutrons. Therefore, its atomic number will stay the same, so it is still the same type of element, but the isotope will have a different atomic mass. [9,3]
19. D Mass spectrometers separate and measure atoms and compounds using magnetic fields. Moving charged ions are affected differently by magnetic fields, allowing them to be separated within a mass analyzer. [7,5]
20. A Electronegativity is a measure of one atom's attraction to electrons of an adjacent atom to which it is bonded. For example, within a water molecule, the electrons attached to the hydrogen atoms are pulled towards the oxygen atom due to its higher electronegativity. This is what causes water molecules to become polar, with a partial positive charge on the hydrogen end and a partial negative end on the oxygen end due to the extra electrons present there. [15,4]
21. D Robert Boyle suggested an inverse relationship between the pressure and volume of a gas. Based on these findings, Jacques Charles came up with the idea that hydrogen could be used to fuel balloon flight. [33,8]

22. C The first manned hydrogen-fueled balloon flight took place on December 1, 1783. The balloon had two passengers—Jacques Charles and Nicolas-Louis Robert. [34,1]
23. C Dalton published *A New System of Chemical Philosophy* in 1808, which presented his major conclusions on atomic behavior. These ideas were the groundwork for all future discoveries in the field of chemistry. [9,2]
24. D Johann Baptista was a Belgian physician who believed that if he could better understand chemistry, he would better understand the causes of disease. [56,3]
25. B Alchemists were focused on trying to transform less valued substances into more valuable ones—a process known as transmutation. Alchemists also pioneered the chemical processes of distillation, percolation, and extraction with their findings. [56,2]
26. A Hydrogen bonds form between water molecules when the hydrogen atom on one water molecule forms a weak bond with the oxygen atom of another water molecule. These bonds must break for water molecules to move, which is why water must be strongly heated to melt or boil. [19,1]
27. B At any given temperature, the state of matter of the substance is determined by the strength of the intermolecular forces that inhibit molecular motion. Heat is added to a substance in order to break these bonds and let the molecules move freely, showing that the temperature of a substance is a direct measure of its molecular motion. [21,3]
28. A Water is amphoteric and can therefore act as an acid or a base depending on the situation. Depending on what the other substance in a reaction is, water can either accept or donate electrons. [57,9]
29. C The symbol used to denote the state function of enthalpy is H . [77,1]
30. E Joseph Black first observed that snow melts slowly even after air temperature goes above the freezing point, and then started researching the reason behind why. Through his research, he became the first to describe latent heat. [75,3]
31. B When an element can exist as a solid in many different forms, each of these forms are called allotropes of the element. For example, pure carbon can be found in eight forms, or allotropes, two of which are diamond and graphite. [42,3]
32. E Within a Lewis structure, electron pairs that are not involved in bonding are known as non-bonding electron pairs, or “lone pairs”. [23,2]
33. A The internal structure of the atom determines the element's chemical behavior. This includes anything from the atom's electronegativity levels, to its number of valence electrons, to its number of neutrons. [7,3]
34. E Johannes van der Waals developed an equation to predict the behavior of non-ideal gases. This equation uses two parameters, a and b as correction values for the volume of the molecules and the molecular attraction respectively. These parameters are known as van der Waals constants. [40,4]
35. C When more than one element is present in a metallic substance, the metal is called an alloy. For example, brass is composed of copper and zinc. [16,6]
36. A Even though the process of electroplating was discovered in the early 1800s, it only became widely used by the 1840s. The process was used in the aerospace industry in rocket and space shuttle designs, and in cars to enhance the appearance. [67,2]
37. A Proust's main contribution to chemistry was the law of definite proportions. Dalton built off this law to support his atomic theory, which states that atoms combine in fixed proportions to form compounds. [70,5]
38. E When lithium metal is added to water, the lithium displaces hydrogen ions (H^+) in the water, and hydrogen gas results. [54,5]
39. D The idea that matter is comprised of small, indivisible particles is called atomism. Atomism was originally proposed by the Greek philosopher Leucippus in the fifth century. [8,3]
40. E Metallic bonds exist when metal atoms are bonded in such a way that the electrons are freed, and can move freely between the atoms. These moving electrons make up electricity, making metals good conductors of electricity. [16,6]
41. C Chrome plating is a common example of electroplating and is used to create shiny parts on appliances and automobiles. [64,4]
42. E All matter can be represented by wave equations but also exhibits particle properties simultaneously. Quantum physics is the field of science that deals with such issues. [12,3]
43. C The idea that there were four elements that made up nature—earth, air, fire, and water—was an Aristotelian view. Most scientists still subscribed to this view prior to the Scientific Revolution. [6,4]
44. A Combustion reactions occur when a reactant combines with oxygen gas. If the reactant is an organic hydrocarbon, then the combustion products will be water and carbon dioxide. [54,7]

45. E Sodium is an alkali metal in group 1 of the periodic table, and therefore has 1 valence electron in its outermost shell. In order to get a full octet, a sodium atom needs 7 more electrons. [62,3]
46. A In the early sixteenth century, alchemist Paracelsus experimented with dissolving metals in acids, and accidentally produced a flammable gas. This gas would later be recognized as hydrogen. [20,1]
47. E Acid rain is responsible for lowering soil pH in some regions of the world. As a result, farmers must add external substances to their soils to control soil pH and enable plant growth. [60,5]
48. C The critical point on a phase diagram is the point beyond which the line between liquid and gas blurs. In this phase, matter exists as a supercritical fluid, with the properties of both a liquid and a gas. [44,6]
49. C Many acids are substances whose formulas start with atoms of hydrogen, such as HCl or HBr. [58,4]
50. E Toxic substances are easier to dispose of than solutions are, so precipitation is often used to remove dissolved toxic substances from contaminated water, and then the precipitates are disposed of. [62,1]

Science Comprehensive Exam 03

1. E Molecules can develop induced dipoles due to the motion of the electron orbitals on atoms within a molecule. Even though these are temporary dipoles, they are still a source of attractive intermolecular forces. These forces are called London dispersion forces, and are the only type of intermolecular force between nonpolar molecules. [18,2]
2. E Many acids can be recognized as substances whose formulas start with hydrogen atoms. [58,4]
3. B Phase diagrams show how a substance exists as a solid, liquid or gas at any given point of pressure and temperature, and how they transform between states. [32,3]
4. C In the 1780s, Italian scientist Luigi Galvani found that when he dissected frogs hung on metal hooks, the frogs would twitch if touched with another piece of metal. Galvani proposed that this resulted from electricity originating within the frog's body, which he termed "animal electricity." [66,11]
5. A The field of alchemy focused around the use of transmutation to transform different elements, and alchemists also pioneered the chemical processes of distillation, percolation, and extraction. [56,2]
6. C The equation for a gas molecule's "root mean square" speed, or average speed, is $u = \sqrt{\frac{3kT}{m}}$. [38,2]
7. C Partial charges are indicated within a molecule by adding a δ sign ($\delta+$ or $\delta-$). [17,3]
8. E Deuterium, an isotope of hydrogen, exists naturally and exists in a ratio of one atom of deuterium to 6500 atoms of hydrogen. [10,5]
9. D As each element is added to the periodic table, one proton is added to the nucleus, increasing the atomic number by one. An increase in one proton corresponds with an increase in the atom's atomic number by one. [13,4]
10. B The basic form of a synthesis reaction is $A + B \rightarrow C$. An example of this is $2\text{Na} + \text{Cl}_2 \rightarrow 2\text{NaCl}$. [53,2]
11. C The four hydrogen bases that make up the structure of DNA molecules are adenine, thymine, guanine, and cytosine. Adenine is the base that bonds with thymine. [19,Figure 18]
12. C No rules concerning oxidation numbers have to do with halogens. [62,7]
13. C When copper wire is added to silver nitrate, what occurs is a metal single replacement reaction. This reaction is symbolized by the chemical equation $\text{Cu(s)} + 2\text{AgNO}_3\text{(aq)} \rightarrow \text{Cu(NO}_3)_2\text{(aq)} + 2\text{Ag(s)}$. [54,4]
14. A Antoine Lavoisier disproved phlogiston theory by heating mercury calx. He observed that the total mass remained the same throughout the reaction, which countered the notion that phlogiston was released. [56,3]
15. E While molecules change direction when they bounce off the container walls, they don't lose kinetic energy or momentum. As a result, these collisions are elastic. [35,5]
16. D Natural diamond is formed from graphite, at high temperatures and pressures underground. Scientists have learned how to replicate this process artificially, and now artificial diamonds are made from graphite. [42,5]
17. C The hydrogen bonds that form within water molecules help create water's rigid atomic structure. When water freezes, these bonds form a much more open structure, causing water to expand when it freezes. This also means that ice has a lower density than liquid water, and therefore ice will float on water. [19,1]
18. D Single replacement reactions can be predicted based on the activity series of metals. If a metal is above another on the activity series, then it can displace the latter from its source during a single replacement reaction. Iron (Fe) is the only given metal that is above hydrogen on the activity series, and therefore is the only one that could replace hydrogen in a reaction. [55,Figure 63]
19. D The most well-known use for Carbon-14 is for carbon dating, a process which allows archaeologists to determine when a living system died by determining the amount of Carbon-14 left. [11,2]
20. C In 1774, Joseph Priestley heated a sample of mercuric oxide (HgO) and observed the release of oxygen as the substance decomposed. [39,1]
21. A If the reactant is an organic hydrocarbon, then the complete combustion products will be water and carbon dioxide. This is shown in the given reaction with the combustion of methane. [54,7]
22. E The mass of a carbon atom is equal to 12 mass units. Helium, with a mass of 4, is $1/3$ the mass of carbon. [10,3]
23. E Carbon has three isotopes that are found in nature—C-12, which has six neutrons in its nucleus, C-13, which has seven neutrons, and C-14 which has eight neutrons. Atoms are unstable and decay over time and are therefore classified as radioactive atoms. [10,2]
24. D The pH scale measures the acid concentration of a substance using a logarithmic scale, and the equation $\text{pH} = -\log[\text{H}_3\text{O}^+]$. [58,10]

25. C All substances are considered ensembles of rapidly moving particles by chemists. This is true at every temperature except absolute zero, where all molecular motion stops. [32,2]
26. D is a radioactive isotope of cobalt. The penetration power of its radiation is greater than that from X-rays, and so its radiation is used to examine steel components and welds for possible flaws. [11,4]
27. B The four main types of solids are ionic lattice solids, covalent network solids, molecular solids, and metallic solids. [42,2]
28. D When two bonded atoms are identical, electrons are symmetrically distributed between the two nuclei. Because there is no charge separation due to the symmetry, the bond is nonpolar. [17,2]
29. C The trend in values of Pauling electronegativity is to increase from left to right, and decrease from top to bottom. This makes fluorine the most electronegative atom in the periodic table. [15,Figure 12]
30. C The Brønsted-Lowry acid-base theory defines a base as any H⁺ acceptor in a reaction. [57,3]
31. A Almost 41 kilograms of gold were used in the construction of the space shuttle *Columbia*. [67,3]
32. E Boyle's law and Charles's law are represented by the relationships PV = C and V/T = D respectively. When these are combined algebraically, the relationship PV/T = CD results, with CD being equal to a new arbitrary constant. [33,2]
33. B Michael Faraday determined that it took one mole of electrons to convert one mole of silver ion, Ag⁺, to silver metal. Therefore, the electric charge on one mole of electrons was named the Faraday in his honor. [68,2]
34. D In the modern periodic table, the elements are arranged in order of increasing atomic number. Within the table, vertical columns are arranged by increasing valence electrons, and horizontal rows are arranged by increasing electron shells. [13,3]
35. C When lithium metal is added to water, the lithium displaces the hydrogen ions in the water. As a result, elemental hydrogen gas results. [54,5]
36. B The most common example of electroplating is chrome plating, which is used to create shiny parts on appliances and automobiles. [64,6]
37. E Intramolecular forces are defined as those that occur mostly between two atoms in such close association that a chemical bond is formed. These bonds are classified as ionic, covalent, metallic, or hydrogen bonds. [16,3]
38. A Kinetic-molecular theory makes four assumptions about ideal gases and their molecules. The volume of gas molecules themselves is negligibly small, and the molecules are moving in all directions at different speeds. In addition, no intermolecular forces exist between molecules, and gas pressure results from the collisions of molecules with the walls of their container. [35,5]
39. D Phlogiston theory proposed that as materials burned, they released an undetectable substance called phlogiston. As a result, the theory couldn't answer why air is required for combustion. [56,4]
40. D Carbon-14 forms in the upper atmosphere as a result of cosmic rays hitting nitrogen atoms. It mixes with atmospheric carbon dioxide and then becomes part of the biosphere, entering the bodies of all living systems. [11,1]
41. E The field of alchemy involved mystical or supernatural explanations for natural phenomena, and was prominent prior to the Scientific Revolution of the sixteenth and seventeenth centuries. [6,4]
42. B The wave properties of electrons were shown in the classic Davisson-Germer experiment, where electrons scattered at preferred angles from a nickel crystal. [12,4]
43. E Oxidation-reduction reactions, or "redox" reactions, involve a transfer of electrons from one molecule to another. The oxidation part of a reaction frees up electrons from one reactant and uses them in the reduction of the other reactant. [62,3]
44. E Atomic radius, a measure of atomic size, is a quantity that decreases from left to right across a period in the periodic table. As one proton and one electron are added to an atom, there is one more proton to attract the electrons. If the added electrons are approximately the same distance away from the nucleus, and are in the same electron shell, then the increased attraction will shrink the radius or size of the atom. [14,1]
45. A Combustion reactions are reactions of a reactant with oxygen gas. [54,7]
46. A The same type of atom with a different mass number is called an isotope of the element. [10,2]
47. C The first hydrogen-powered balloon was launched on August 27, 1783, by Jacques Charles and the Robert brothers. The flight lasted about 45 minutes. [33,2]
48. D Robert Boyle was the first to suggest an inverse relationship between the pressure and volume of a gas. [33,1]
49. A Carl Wilhelm Scheele was the first scientist to produce oxygen by heating various oxides. As a result, he referred to the gas as "fire-air". [38,11]

50. C Water is a polar molecule due to the difference in electronegativity values between the hydrogen and oxygen molecules. The oxygen side has a partial negative charge because it attracts electrons with its higher electronegativity, and the hydrogen side has a partial positive charge due to the absence of electrons.

[17,Figure 16]

Science Comprehensive Exam 04

1. B Joseph Priestley is credited with isolating eight gases, notably one of which is oxygen. [39,1]
2. B Transmutation was a focus of alchemy for long before the advent of chemistry. These efforts were mostly fruitless, because the transformation of less valued substances into more valued ones cannot occur naturally. The research of alchemists did make up the bulk of early chemistry, however. [56,2]
3. A Scottish chemist Joseph Black conducted experiments in 1754 which he heated calcium carbonate and observed the release of carbon dioxide. [46,1]
4. C The mass of a carbon atom was first established, as 12 atomic mass units. The mass of every other element was established in relation to the ratio of their mass to carbon's. [10,3]
5. D The possible voltage is equal to the reduction potential of the reduction reaction minus the reduction potential of the oxidation reaction. This is symbolized by the equation $E^\circ_{\text{red}} - E^\circ_{\text{ox}}$. [66,4]
6. C Methane molecules have a tetrahedral shape, with the 4 hydrogen atoms arranged around the central carbon atom. [27,Figure 38]
7. D Strontium and magnesium are soluble. [47,4]
8. D Historians have used the term "Scientific Revolution" to refer to developments in science that occurred in the sixteenth and seventeenth centuries. [6,2]
9. C It takes less energy to pump water for reverse osmosis than it takes to heat water for distillation. [51,3]
10. E Increasing temperatures generally increases reaction rates. Heat is measured as the total kinetic energy of the molecules in an object, while temperature is the average kinetic energy of these same molecules. [73,3]
11. E When impurities are added to metals, the smooth layers are disrupted at the atomic level. As a result, the substance becomes less malleable and ductile, and stronger and more useful for structural purposes. [43,4]
12. B Within the symbol format ${}^A_Z X$, X is the element symbol, Z is the atomic number, and A is the mass number. [10,2]
13. C Joseph Black was a Scottish chemist who invented latent heat. James Watt was a friend of Black's who utilized this concept when inventing the steam engine. [75,3]
14. A State functions are properties of a system that are only determined by where the system is, not how it arrived there. Heat is not a state function because it is not an intrinsic property of a system—it cannot be quantified like every other quantity listed. [76,1]
15. E During uranium fission within a nuclear reactor, the uranium is hit by a free neutron, and the energy of this collision triggers the breakup of the uranium. As more neutrons are released, they break up other uranium atoms, releasing a tremendous amount of energy. [29,2]
16. D The critical point of carbon dioxide can be found in a phase diagram at 73 atm and 31.1° C. [45,4]
17. E Colligative properties of solutions are properties that depend on the amounts of substances present. The rules to explain these behaviors were created by French chemist François Raoult. [49,4]
18. E The Nernst equation connects cell potentials to free energy changes for chemical reactions. The equation can be used for any set of concentrations of reactants and products at any temperature. [68,2]
19. B Nuclei larger than bismuth, which has an atomic number of 83, break down via alpha decay. [28,3]
20. E Oxidation states are calculated by stating with the number of valence electrons an atom has, and then determining whether the atom has lost or gained any. In Li^+ , the lithium atom had three electrons in its original state. However, after losing one, its oxidation state is +1. [25,5]
21. A As scientists realized that all matter has wave and particle properties, a new model to show these properties was created—the quantum mechanical model. In this model, electrons are not at fixed locations, and do not rotate in orbits. [12,2]
22. B The oxidation number of O is -2. [62,7]
23. C There are different types of orbitals, which are denoted using letters—the four types are s, p, d and f orbitals. [13,1]
24. E The process by which changes in enthalpy are measured is called calorimetry. [76,4]
25. B Joseph Louis Proust established that elements combine in defined ratios to form compounds. Therefore, this idea, the law of definite proportions, is referred to as Proust's law. [70,5]
26. E Empirical formulas provide the lowest mole ratio of atoms to each other within a formula. Therefore, acetylene, with the chemical formula C_2H_2 , has an empirical formula of CH. However, CH doesn't exist as a stable molecule, even though C_2H_2 does. [69,7]
27. B Concentration in molality units is the number of moles of solute dissolved in 1 kilogram of solvent. [49,3]
28. E Platinum, palladium, nickel, copper, silver, and rhodium are metals that are often used in chrome plating. The metal chosen depends on the qualities desired, and what is required of the final structure. [67,4]

29. A The notion that all substances are comprised of small, indivisible particles is called atomism. This idea was proposed by Greek philosopher Leucippus in the fifth century CE. [8,2]
30. A Atoms that are unstable and decay over time are classified as radioactive atoms. One such example is Carbon-14, which is used for carbon dating. [10,2]
31. E In 1919, Ernest Rutherford showed that the combining of nitrogen atoms with alpha particles created oxygen atoms. The balanced chemical equation for this reaction is ${}_2^4He + {}_7^{14}N \rightarrow {}_8^{17}O + {}_1^1H$. [29,1]
32. C K_a is the equilibrium constant for reactions involving acids, K_b is used for reactions involving bases, K_c for solutions and concentrations, and K_{sp} when the reaction involves forming a precipitate. [71,9]
33. A A critical point is the temperature and pressure where the distinction between a gas and a liquid no longer exists. Therefore, both states of matter exhibit the same properties. [44,1]
34. B Endothermic processes are reactions that have a net absorption of heat. [74,7]
35. B Chlorine-37 is an isotope of chlorine which has 25% natural abundance on Earth. This means that 25% of naturally occurring chlorine anywhere on Earth will be of this specific isotope. [11,6]
36. B Calcium carbonate precipitates on the roofs and floors of caves to form stalactites and stalagmites. [48,1]
37. B Each covalent bond shown in a Lewis structure signifies that a pair of electrons is being shared. A triple covalent bond signifies that three pairs of electrons are being shared, or six electrons total. [23,6]
38. E The most well-known environmental contaminant is mercury, which enters the environment as metallic mercury emitted into the atmosphere from fossil fuel power plants, and enters lakes and soils as waste. [61,1]
39. D VSEPR models, or Valence Shell Electron Pair Repulsion models, predict the geometric shapes of molecules in three dimensions. [26,1]
40. D Dalton presented his research on the behavior of gases to the Manchester Literary and Philosophical Society, beginning in 1800. [8,3]
41. E The Aristotelian view proposed that there were four elements—earth, air, fire and water. This was the idea that many scientists subscribed to prior to the Scientific Revolution. [6,4]
42. E The sign of the Gibbs Free Energy (ΔG) determines a reaction's spontaneity. If ΔH (change in enthalpy) is positive and ΔS (change in entropy) is negative, then the reaction is nonspontaneous. [77,2]
43. D The chemical formula for a molecule of bleach is NaOCl. [48,7]
44. C Polar molecules exhibit strong van der Waals forces, making these molecules harder to separate. Such molecules have higher melting points and boiling points than molecules with lower polarity. Nonpolar molecules have the lowest melting and boiling points. [27,7]
45. D Antoine Lavoisier is often called the “father of modern chemistry” for his many contributions, including the system for naming chemical compounds, the discovery of oxygen, and many more. [57,3]
46. A When alpha decay occurs, the parent nucleus loses two neutrons and two protons. This combination of two protons and two neutrons is called an alpha particle, and is equivalent to a helium nucleus. [28,3]
47. A When an acid and base react, a salt and water are produced. Besides water, the other product of the reaction of HBr and KOH is KBr. [58,6]
48. A Electrons are excited to higher energy levels when they absorb a quantum of light energy, or a photon. [11,8]
49. D The molar mass of H = 1 g/mol, because 1 proton + 0 neutrons = 1. The molar mass of O = 16 g/mol, because 8 protons + 8 neutrons = 16. When adding 16 + 2 (for the two hydrogen atoms), this equals 18 g/mol for the total molar mass of water. [69,8]
50. E Sound waves can travel easily through the atomic lattice structure of metals, which makes them “sonorous”, or causes them to ring when struck. [43,4]

Science Comprehensive Exam 05

1. B The energies before and after a chemical reaction are shown on a potential energy diagram. [74,2]
2. E Ammonia is a weak base that does not ionize very much. It is produced as a conjugate base in the reaction of ammonium and chloride. [59,6]
3. B The Scientific Revolution was underway during the 1600s, during which scientific thought transitioned from being based in supernatural thought to being based in empiricism. [6,4]
4. E The process by which enthalpy changes are measures is called calorimetry. [76,4]
5. E The ideal gas law considers the relationships between pressure, volume and temperature concluded in Boyle's and Charles's law, and takes into account n , the number of moles of the gas as well as R , the universal gas constant. This leaves us with the final equation $PV = nRT$. [35,2]
6. E Paracelsus accidentally produced hydrogen when experimenting with dissolving metals in acids. [20,1]
7. B Molecules are polar if there is a measurable distance from the center of positive charge to the center of negative charge. These molecules have dipole moments, which means that if placed in an electric field, a rotational force will exist. [18,1]
8. E The backbone of a DNA molecule is made up of sugars and phosphates. [19,Figure 19]
9. A When a salt dissolves in water, its ions interact with water molecules through hydrolysis. [59,2]
10. B A phase diagram has temperature and pressure marked on its axes, and shows the relationship between these two quantities for a given substance. [32,3]
11. C Chlorofluorocarbons were used as refrigerator cooling liquids for years, but they caused environmental damage by destroying Earth's ozone layer. As a result, ammonia is used instead now. [40,5]
12. A Kinetic-molecular theory is a collection of theories that explain the laws that govern the behavior of gases. [32,2]
13. C The idea that there were four elements that made up nature—earth, air, fire, and water—was an Aristotelian view. Most scientists still subscribed to this view prior to the Scientific Revolution. [6,4]
14. A Hydrogen and fluorine always combine in a ratio of 1:19 to form the compound HF. [7,4]
15. A Boyle's law states that there is an inverse relationship between a gas's volume and pressure, when its temperature is held constant. [32,5]
16. B The photoelectric effect is where a photon transfers its energy to an electron, and this electron is then emitted from a metal surface. The photoelectric effect demonstrates the particle properties of light. [12,4]
17. E Scientists use Kelvin to measure temperature, as 0 K ("absolute zero") is defined as the starting point for all temperature measurements. [33,1]
18. A The greater the strength of the reducing agent and the lower the strength of the oxidizing agent, the lower the electrode potential of the reaction will be. [64,Figure 69]
19. D There are two main types of solutions: aqueous solutions, where the solvent is water, and organic solutions, where the solvent is a nonpolar substance such as octane. [46,3]
20. E Catalysts are substances that lower the required activation energy and speed up reactions. Specifically within the human body, they are called enzymes. [74,4]
21. A Many new pieces of technology were invented during the 18th century, including the steam engine, power looms, gas lighting, and the steamship. [1,1]
22. E Neutral substances have a pH of exactly 7.00. One example of such a substance is pure water. [58,3]
23. B Dalton found that gases could only combine in specific proportions. This finding drew on Antoine Lavoisier's law of conservation of mass, and Joseph Louis Proust's law of definite proportions. [9,2]
24. D Joseph Black discovered carbon dioxide when he heated calcium carbonate and observed the gas it produced, and he referred to the new gas as "fixed air". [46,1]
25. D American chemist J.W. Gibbs determined the relationship between enthalpy and entropy. [77,1]
26. D Dalton found that gases could only combine in specific proportions. This finding drew on Antoine Lavoisier's law of conservation of mass, and Joseph Louis Proust's law of definite proportions. [9,2]
27. A The chemical formula for mercuric oxide is HgO. [39,1]
28. A London dispersion forces are the only type of intermolecular forces between nonpolar molecules. [18,1]
29. D Synthesis reactions are also called combination reactions, and generally follow the format $A + B \rightarrow C$. [53,6]
30. C In 1919, Ernest Rutherford showed that the combining of nitrogen atoms with alpha particles created oxygen atoms. [29,1]
31. E In 1919, Ernest Rutherford showed that the combining of nitrogen atoms with alpha particles created oxygen atoms. [29,1]
32. E Brass is a metal alloy made from copper and zinc, and is a good conductor of electricity. [16,3]
33. A If a mixture looks as if it is a single substance, it is called a solution. [32,1]

34. B When copper reacts with a silver ion, the two half reactions are $\text{Ag}^+ + 1\text{e}^- \rightarrow \text{Ag}$ and $\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^-$. [64,3]
35. A The activity series of metals shows that copper is above silver, which indicates that it is more reactive. If silver metal were to be put in a copper solution, no reaction would occur. [54,6]
36. E Joseph Black discovered carbon dioxide, which was a major contribution to the field of thermochemistry. [75,1]
37. E Charles's law elaborates on the direct relationship between a gas's volume and temperature, and is quantified by the equation $V/T = D$, with D = an arbitrary constant. [32,5]
38. A The enthalpy of formation of CO is -110 kJ/mol. [76,9]
39. E Exothermic reactions have a net release of heat. Therefore, the products of a chemical reaction have less potential energy than the reactants, and are located lower on the potential energy diagram. [74,Figure 15]
40. A Catalysts are used to increase reaction rates by decreasing the activation energy. [74,5]
41. A As electrons move around their orbitals, the charges present in a molecule can also change. When electrons are unevenly distributed throughout a nonpolar molecule, the temporary charges on either end are called induced dipoles. These London dispersion forces are created by a nearby polar molecule disturbing an adjacent nonpolar molecule. London dispersion forces are the only intermolecular forces that can occur in nonpolar molecules. [18,2]
42. D The mass of a carbon atom was first established, as 12 atomic mass units. The mass of every other element was established in relation to the ratio of their mass to carbon's. [10,3]
43. C The ratio that atoms combine in is always measured in grams. In the case of water, 16 grams of oxygen will always combine with 2 grams of hydrogen. Since oxygen has a mass number of 16 and hydrogen has a mass number of 1, this is equivalent to 1 atom of oxygen combining with 2 atoms of hydrogen. [7,4]
44. A The branch of science that focuses on the quantities of heat released or absorbed is thermochemistry. [75,1]
45. A A hydrogen atom has zero neutrons—just one proton and one electron. [20,1]
46. D The equation to change from free energy to equilibrium constants is $\Delta G = -RT\ln K$. [77,5]
47. E Nonpolar solvents are generally compounds that only contain carbon and hydrogen. [48,3]
48. C Dalton published A New System of Chemical Philosophy in 1808, in which he outlined what is now considered the first modern atomic theory. [9,2]
49. C Carbonates, hydroxides, silicates and phosphates are all insoluble. [60,3]
50. B As scientists realized that all matter has wave and particle properties, a new model to show these properties was created—the quantum mechanical model. In this model, electrons are not at fixed locations, and do not rotate in orbits. [12,2]

1. C An isotope differs from the standard form of an atom in its number of neutrons. Therefore, its atomic number will stay the same, so it is still the same type of element, but the isotope will have a different atomic mass. [9,3]
2. D The word “lustrous” is used to describe the shine that is characteristic of metals. [43,4]
3. B All standard half-cell potentials are measured relative to the reduction of hydrogen gas, or the reaction $2\text{H}^+ + 2e^- \rightarrow \text{H}_2$. [66,2]
4. A Dalton’s law of multiple proportions states that if two elements combine to form more than one compound, their masses will combine in whole-number ratios. This idea was built off Proust’s law of definite proportions, which states that a substance is always composed of the same proportion of each element. [9,2]
5. D A positive ion is also called a cation. [83,17]
6. B The possible oxidation numbers for bromine are +5, +3, +1, and -1. [63,Figure 68]
7. E Elements within the periodic table are strictly arranged according to increasing atomic number. However, since every element on the periodic table is neutral and the numbers of electrons increase incrementally along with the numbers of protons, this also means that elements are arranged in order of increasing electrons. [13,2]
8. B The idea that matter is comprised of small, indivisible particles is called atomism. Atomism was originally proposed by the Greek philosopher Leucippus in the fifth century. Dalton also endorsed this idea. This idea was proven wrong with the discovery of subatomic particles such as protons, neutrons and electrons. [8,3]
9. E A single point, called the triple point, represents the only value of pressure and temperature on a phase diagram at which solid, liquid, and gas can exist in equilibrium. [44,6]
10. B The state function that tracks the relationship between enthalpy and entropy is Gibbs Free Energy, and is symbolized by ΔG . [77,1]
11. D A salt is formed through an acid-base reaction whenever the hydrogen ion in an acid is replaced by a metal ion. [58,4]
12. E Combustion reactions occur when a reactant combines with oxygen gas. If the reactant is an organic hydrocarbon, then the combustion products will be water and carbon dioxide. [54,7]
13. C Quantum physics is the field of science that deals with the wave-particle duality of matter. [12,3]
14. D The idea that there were four elements that made up nature—earth, air, fire, and water—was an Aristotelian view. Most scientists still subscribed to this view prior to the Scientific Revolution. [6,4]
15. D A neutrino is a subatomic particle that is very similar to an electron, but has no electrical charge. [28,Figure 40]
16. E Johannes van der Waals developed an equation to predict the behavior of non-ideal gases. This equation uses two parameters, a and b as correction values for the volume of the molecules and the molecular attraction respectively. These parameters are known as van der Waals constants. [40,4]
17. E Lavoisier heated mercury calx in his experiments involving combustion, which led him to discover oxygen. [56,5]
18. A Each covalent bond shown in a Lewis structure signifies that a pair of electrons is being shared. A double covalent bond signifies that two pairs of electrons are being shared, or four electrons total. [23,6]
19. D An isotope differs from the standard form of an atom in its number of neutrons. Therefore, its atomic number will stay the same, so it is still the same type of element, but the isotope will have a different atomic mass. [9,3]
20. A To convert a temperature from Kelvin to Celsius, simply subtract 273 from the original figure. [33,1]
21. D The aerospace industry uses gold plating on certain components of rockets and space shuttles to protect them from solar radiation in outer space. Almost 41 kilograms of gold was used to plate components of the space shuttle *Columbia*. [67,3]
22. E Gay-Lussac’s law states that there is a direct relationship between a gas’s pressure and temperature, when its volume is held constant. [32,5]
23. D Hydrogen and helium atoms only have the innermost electron shell, which can only hold 2 electrons instead of 8. [62,3]
24. C Joseph Black discovered carbon dioxide, which was a major contribution to the field of thermochemistry. [75,1]
25. E Along with Jacques Charles and Nicolas-Louis Robert, Anne-Jean Robert was responsible for assisting with the first hydrogen balloon flights. [34,1]
26. C The cell potential of a reaction is measured as the sum between the reduction potential of the reduction reaction and the reduction potential of the oxidation reaction. $-3.05 \text{ V} + -.77 \text{ V} = -3.82 \text{ V}$. [66,8]
27. A The direct relationship between a gas’s temperature and volume means that if a gas’s temperature is decreased enough, it will eventually take up zero volume. This occurs at -273° C . [32,6]
28. C At any given temperature, the state of matter of the substance is determined by the strength of the intermolecular forces that inhibit molecular motion. [21,3]

29. E In 1781, Henry Cavendish confirmed that water is produced from the burning of hydrogen. [20,2]
30. A Dalton published A New System of Chemical Philosophy in 1808, in which he outlined what is now considered the first modern atomic theory. [9,2]
31. E Any substance with a pH that ranges from 0 to 7 is considered acidic. [58,2]
32. C Paracelsus accidentally produced hydrogen when experimenting with dissolving metals in acids. [20,1]
33. A Even though the process of electroplating was discovered in the early 1800s, it only became widely used by the 1840s. [67,2]
34. A Elemental properties placed in the periodic table exhibit trends across and down the table that can be explained by the orbital structure of an element's atoms. These properties include atomic radius, ionization energy, electron affinity, and electronegativity. [30,9]
35. A Hess's law states that the heat evolved or absorbs in a chemical reaction, no matter how many steps the process takes steps in. [76,5]
36. E The galvanic electrochemical cell, invented in 1836, was the earliest reliable battery. [66,10]
37. C An alpha particle is equal to a helium nucleus, which contains 2 protons and 2 neutrons. [28,Figure 41]
38. C Mass spectrometers separate and measure atoms and compounds using magnetic fields. Moving charged ions are affected differently by magnetic fields, allowing them to be separated within a mass analyzer. [7,5]
39. D Processing photographs before the advent of digital photography involved the use of silver halide salts. [62,2]
40. B When ΔG is negative, E_{cell}° is positive and $K > 1$. The reaction favors the formation of products. [78,Figure 77]
41. C The measure of the acidity or basicity of an aqueous solution Is called pH. [57,10]
42. B Smog is a mixture of many different pollutants, while the other substances described have molecules that have dissolved completely. [32,1]
43. D When electronegative atoms pull electrons towards them within molecules, partial charges are created on either side of the molecule. Van der Waals forces are created by the attraction between partial negative charges on one molecule's end and partial positive charges on another molecule's end. Highly polar molecules exhibit strong van der Waals forces. [17,2]
44. A Antoine Lavoisier was called the “father of modern chemistry” for his numerous contributions to the field. [57,3]
45. C It takes 4.18 joules of heat to raise the temperature of 1 gram of water by 1 degree Celsius. [76,4]
46. E Joseph Black began researching heat in the 1750s. [75,1]
47. B An atom in its standard form has an equal number of protons or electrons. However, when an atom gains or loses an electron, it becomes an ion. A positively charged ion is a cation, and a negatively charged ion is an anion. [7,Figure 1]
48. E The Δ symbol is used by chemists to indicate a certain amount of change for any quantity. [76,1]
49. C An atom's ionization energy is the amount of energy needed to remove a mole of electrons from a mole of atoms. [15,4]
50. A The endpoint of a titration, when the reaction reaches equilibrium, is also called the titration's equivalence point. [58,8]

Science Comprehensive Exam 07

1. D Out of all the quantities related to the periodic table, the atomic radius of an atom is the one that increases down a group. As [14,5]
2. A The enthalpy for the formation of CO₂ is equal to the enthalpy of oxidation of CO to CO₂. [76,7]
3. C When water acts as a base and accepts a hydrogen ion, it forms a negative acetate ion. [57,8]
4. B The temperature that represents the lowest one possible, and an absence of all molecular motion, is called “absolute zero”. This term refers to 0 K, or -273° C. [33,1]
5. D Johannes van der Waals developed an equation to predict the behavior of non-ideal gases. This equation uses two parameters, a and b as correction values for the volume of the molecules and the molecular attraction respectively. These parameters are known as van der Waals constants. [40,4]
6. B Free energy has a direct relationship with equilibrium constants and electrode potentials. [77,3]
7. A When a reaction is endothermic, it absorbs heat. [74,7]
8. A Another word used to describe entropy is “chaos”. [76,10]
9. E Apart from hydrogen and helium, which only need 2, atoms need 8 electrons to fill their valence shell. [62,3]
10. C When acetic acid (HC₂H₃O₂) is added to water, vinegar is produced. [57,8]
11. A While many scientific advancements were made by van Helmont, it was actually Antoine Lavoisier that developed a scientific explanation for combustion. [56,3]
12. E Jacques Charles was interested in hot air balloons and began studying the properties of gases. Over time, his goal became to use hydrogen as a means of fueling balloon flight. [33,5]
13. C The sign of ΔG determines the spontaneity of a reaction. [77,2]
14. E Boyle’s law shows the inverse relationship between a gas’s pressure and temperature, which is quantified by the equation PV = C, with C = an arbitrary constant. [32,4]
15. E Entropy, by definition, is measure of the lack of order in a system. Entropy is also defined as a measure of “chaos”. [76,11]
16. E Each covalent bond shown in a Lewis structure signifies that a pair of electrons is being shared. A single covalent bond signifies that one pair of electrons is being shared, or two electrons total. [23,6]
17. A C₈H₁₀N₄O₂ is the chemical formula for a caffeine molecule. [15,Figure 13]
18. B For optimal plant growth, it is important for farmers to control the soil pH. [60,7]
19. D Oxygen has 6 electrons in its valence shell. To get a full octet, an oxygen atom needs 2 more electrons. [62,3]
20. C Ionization energy decreases down a group of the periodic table. This results from the extra distance between the nucleus and the outermost electrons, which causes a reduced attractive force. [15,1]
21. B Chrome plating is a common example of electroplating and is used to create shiny parts on appliances and automobiles. [64,4]
22. B Mass spectrometers are commonly used at airports during security checks, to make sure that passengers aren’t carrying compounds that are typically part of explosives. [7,5]
23. A The oxidation number of oxygen is -2. [62,7]
24. E Nitrogen gas (N₂) is an example of a molecule that is held together by triple covalent bonds. [15,Figure 13]
25. C The decomposition reaction used to produce oxygen gas back when it was first identified was the breakdown of mercury oxide into mercury and oxygen. [54,2]
26. E Paracelsus accidentally produced hydrogen when experimenting with dissolving metals in acids. [20,1]
27. D The branch of science that focuses on the quantities of heat released or absorbed is thermochemistry. [75,1]
28. C Despite having more than three hydrogen atoms, acetic acid (CH₃COOH) is a monoprotic acid because it disassociates to only release a single proton. [58,9]
29. A The “root mean square” speed of a molecule is quantified by the symbol u . [38,2]
30. E Democritus was the student of Leucippus, who originally proposed the idea of atomism. Building off of it, Democritus proposed that there are many different types of particles and that a substance’s properties are determined by the properties of its particles. [8,2]
31. D At equilibrium, the Gibbs Free Energy state function (ΔG) is equal to zero. [77,3]
32. D The critical point on a phase diagram is the point beyond which the line between liquid and gas blurs. In this phase, matter exists as a supercritical fluid, with the properties of both a liquid and a gas. [44,6]
33. D Any substance with a pH that ranges from 7 to 14 is considered basic. [58,2]
34. C Many scholars question the concept of a “Scientific Revolution”, simply because they can’t pinpoint one specific event that can be pointed to as a revolutionizing thought. Many historians also don’t see the “Scientific Revolution” as a time that was very different from the periods before or after it. [6,2]

35. D Endothermic reactions have a net absorption of heat. Therefore, the products of a chemical reaction have more potential energy than the reactants, and are located higher on the potential energy diagram. [74,Figure 15]
36. C When the electronegativity difference between two atoms is greater than 1.8, the atom with higher electronegativity will pull the electrons away from the other. This creates an ionic bond. [15,5]
37. C A carbon atom in its standard form, also known as Carbon-12, has 6 protons, 6 neutrons and 6 electrons. [14,Figure 10]
38. B The Pauling electronegativity value of Beryllium is 1.5. [15,Figure 12]
39. D The scanning of different masses by a mass spectrometer is accomplished by varying the magnetic field. [8,1]
40. D Free energy has a direct relationship with equilibrium constants and electrode potentials. [77,3]
41. D There are over 100 distinct elements within the periodic table, each with their own structure and mass. [7,2]
42. C Dalton's conclusions were published in *A New System of Chemical Philosophy*, one of which was the idea that atoms cannot be divided any further. However, this was proven false by the existence of subatomic particles such as protons, neutrons and electrons. [9,2]
43. B The first manned hydrogen-fueled balloon flight took place on December 1, 1783. The balloon had two passengers—Jacques Charles and Nicolas-Louis Robert. [34,1]
44. C Dalton proposed the law of partial pressures, which states that the total pressure of a mixture of gases is equal to the sum of pressures of each individual gas. [8,3]
45. A John Dalton, an English chemist, meteorologist and physicist was born in 1766. [8,2]
46. D Johannes van der Waals developed an equation to predict the behavior of non-ideal gases. This equation uses two parameters, a and b as correction values for the volume of the molecules and the molecular attraction respectively. These parameters are known as van der Waals constants. [40,4]
47. A Carbon-14 is a radioactive isotope, and is used to date materials. Carbon dating is done by measuring the amount of Carbon-14 left in organic material to determine when the material used to be alive. [11,2]
48. E At absolute zero temperature, which is 0 K, a molecular motion is considered to have stopped completely within a substance. [32,3]
49. C Metallic bonds occur when metal atoms are bonded in such a way that electrons can move freely between atoms. This phenomenon is called an “electron sea”, and these moving electrons make up electricity. [16,3]
50. E When uranium-238 undergoes alpha decay, the resulting product is thorium-234. [28,Figure 40]

Science Comprehensive Exam 08

1. A The difference in electronegativity between an Na atom and a F atom is $4.0 - 2 = 3.8$. [15,5]
2. A The volume and amount of gas is constant, so we can directly analyze the relationship between the pressure and temperature of a gas. When Boyle's and Charles's laws are combined, we see a direct relationship between pressure and temperature-- therefore, when the temperature is doubled, the pressure will. [33,3]
3. A Water is amphoteric, and can act as an acid or a base depending on the situation [57,9]
4. E The Aristotelian scientific view proposed the idea of four elements-- earth, air, fire and water. [6,4]
5. B Both momentum and kinetic energy are conserved in elastic collisions. [35,5]
6. C A decomposition reaction was used to make oxygen gas when it was first identified. Mercury oxide was broken down into mercury and oxygen through the reaction $2\text{HgO} \rightarrow 2\text{Hg} + \text{O}_2$. [54,1]
7. A When the K value of a reaction is positive, under standard-state conditions, the reaction will favor the formation of products. [78, Figure 77]
8. E Boyle's law states the inverse relationship between pressure and volume. [32,4]
9. B Hydrogen and helium atoms only have the innermost electron shell, which can only hold 2 electrons instead of 8. [62,3]
10. A Like the Bohr model, the quantum mechanical model limits an electron's energy to certain values. [12,Figure 7]
11. C Hess's law is most useful for calculating the enthalpy of chemical processes that have not been measured directly, by using data from related reactions. [76,5]
12. C Jacques Charles worked on hydrogen-powered balloon flights alongside the Roberts brothers; Benjamin Franklin was in the audience of the first one on August 27, 1783. [40,1]
13. D The measurement for 1 mole is based on the number of carbon atoms in 12.0 grams of Carbon-12. [36,8]
14. E Hydroxide ions (OH^-) are formed when bases break apart in water. [57,5]
15. E Luigi Galvani found that when he dissected frogs and hung them from metal hooks, the frogs would twitch if touched with another piece of metal. This observation led him to propose the phenomenon of "animal electricity". [66,11]
16. C Benjamin Franklin was in the crowd as Jacques Charles and the Roberts launched the first hydrogen-powered balloon on August 27, 1783. [33,5]
17. B Joseph-Louis Proust proposed the law of definite proportions in 1799. [9,1]
18. B In 1919, Ernest Rutherford created oxygen atoms by combining nitrogen atoms with alpha particles. [29,1]
19. A Empiricism refers to the trend of scientists developing conclusions based on experimental evidence. [6,4]
20. B John Dalton proposed the first modern atomic theory through *A New System of Chemical Philosophy* in the early 19th century. [8,2]
21. A A neutral substance has a pH of seven, and a H^+ concentration of 1.0×10^{-7} M. [58,2]
22. B The aerospace industry uses gold plating on certain components within rocket and space shuttle designs. [67,3]
23. D Joseph-Louis Gay-Lussac discovered in 1805 that when gases react with one another, the volumes of the reactants and products are always in whole-number ratios to each other. For example, it takes two volumes of hydrogen and one volume of oxygen to produce water. [37,1]
24. D John Dalton's interest in meteorology inspired him to research further into the behavior of gases. [8,3]
25. A Dalton was the first to observe that at constant pressure, different liquids expanded the same amount if they were subjected to the same increase in temperature. [8,3]
26. C Some common factors that are compared when considering methods of water purification include energy used, the pretreatment needed, the waste that must be discharged, and the frequency of required maintenance. [51,2]
27. D The rarest carbon isotope is Carbon-13, making up 1.109% of all natural carbon that can be found. [10,Figure 4]
28. B The steam engine was an invention of the Industrial Revolution era, which occurred during the 18th century. [6,1]
29. A C_2H_2 is the chemical formula for acetylene. [69,9]
30. A When atoms bond, their atomic orbitals combine. When these orbitals overlap, new molecular orbitals are formed, and either sigma or pi bonds are created. [23,8]
31. A The Faraday has 96,500 coulombs of charge. [68,1]
32. C Beta minus decay occurs when there are too many neutrons, in which case the nucleus converts neutrons to protons. [28,6]
33. D Antoine Lavoisier discovered oxygen in the 1770s through the heating of mercury calx, and he named the gas he discovered oxygène, or oxygen in French. [57,1]
34. D When a reaction is exothermic, heat is given to the surroundings. [76,9]

35. E Robert Boyle suggested an inverse relationship between the pressure and volume of a gas. Based on these findings, Jacques Charles came up with the idea that hydrogen could be used to fuel balloon flight. [33,8]
36. A Three key assumptions are made in kinetic-molecular theory. [40,1]
37. C A positive sign in an enthalpy change indicates an endothermic reaction, and that heat is absorbed from the surroundings. [76,9]
38. B When silver is taken out of waste solutions, it can take on many forms depending on what it is mixed with. When iron is added in the form of steel wool, silver can be precipitated as metallic silver. [61,2]
39. C The photoelectric effect is very common in photocells within digital cameras. [12,4]
40. D One atom of deuterium can be naturally found for every 6,500 atoms of hydrogen. [10,5]
41. D The equation to find Gibbs Free Energy is $\Delta G = \Delta H - T\Delta S$, where enthalpy is symbolized as ΔH and entropy as ΔS . [77,2]
42. C For atoms in polyatomic ions, the sum of their oxidation numbers must be equal to the charge on the ion. [62,7]
43. B Nonpolar solvents are compounds that only contain carbon and hydrogen. [48,3]
44. D Vertical columns within the periodic table are called "groups". [13,3]
45. B Group 1 elements, or alkali metals, have oxidation numbers of +1. [62,7]
46. A Many scientific societies were founded in the 17th century, which encouraged the sharing of knowledge and the publication of scientific papers. [7,1]
47. C The $[A]$ within equilibrium expressions indicates the concentration of substance A in moles per liter (molarity). [71,11]
48. D Democritus was a student of Leucippus, and expanded on his ideas of atomism. Democritus proposed that there are many different types of particles, and that a substance's properties are determined by the properties of its particles. [8,2]
49. C Some common examples of VSEPR shapes include hexagonal bipyramidal, octahedral, trigonal planar, tetrahedral, and trigonal bipyramidal. [26,Figure 33]
50. A Atomism is the idea that all substances are composed of very small indivisible particles. This idea was proposed by Greek philosopher Leucippus in the 5th century. [8,2]

Science Comprehensive Exam 09

1. B There is a direct relationship between the temperature of a gas and the motion of its molecules. If there are high levels of molecular motion, then that is an indication of high temperatures within a gas's container. [40,1]
2. A A negative sign in an enthalpy change indicates an exothermic reaction, and that heat is given off to the surroundings. [76,9]
3. E Colligative properties are properties of solutions that are dependent on the relative numbers of moles of solute and solvent. [49,3]
4. D The heat of vaporization is the latent heat associated with vaporizing a solid or liquid, or condensing a gas. [75,3]
5. E The measurement for 1 mole is based on the number of carbon atoms in 12.0 grams of Carbon-12. [36,8]
6. B Standard state conditions are measured at 273 K. [68,3]
7. A During uranium fission, the reaction is sparked when a uranium atom is hit by a free neutron. This energy causes the breakup of the uranium atom, releasing more neutrons that hit other uranium atoms, and so on. [29,2]
8. A No more than two electrons can exist in the same orbit. Each orbital contains different amounts of orbits, which is how s, p, d and f orbitals all hold different amounts of electrons. [12,1]
9. C Entropy is defined as the energy associated with disorder, and increases within the universe as natural processes occur. [76,10]
10. C An atom's mass number is equal to the sum of its number of protons and number of neutrons. [10,2]
11. D Every element listed except Li is below hydrogen on the activity series of metals. This means that none of those elements can displace H₂ from any source. However, since Li is so far above hydrogen on the activity series, this means that it can displace H₂ from any source. [55,Figure 63]
12. D Only materials that contain carbon can be carbon dated, which means that at one point the material must have been alive. [11,2]
13. E A hydrogen atom, with a mass of 1, is 1/12 the mass of a carbon atom. [10,3]
14. B Cobalt-60 is an isotope that doesn't occur naturally, but is made in nuclear reactors. [11,4]
15. C John Dalton was very interested in meteorology, which inspired him to research more into the behavior of gases. In addition, he maintained daily records of the weather for 57 years. [8,3]
16. D Heat is measured in joules, which are the SI unit for energy. [76,4]
17. D Carbon-14 naturally forms in the upper atmosphere as a result of cosmic rays hitting nitrogen atoms. [11,1]
18. E The first manned hydrogen-fueled balloon flight took place on December 1, 1783. The balloon had two passengers—Jacques Charles and Nicolas-Louis Robert. [34,1]
19. B Charles's law states the direct relationship between temperature and volume. This relationship is represented by the equation $V/T = D$. [32,4]
20. A While Antoine Lavoisier did make many contributions to the field of chemistry, the proposal of the law of partial pressures was not one of them. [57,3]
21. C John Dalton first proposed his conclusions on atomic behavior in the early 19th century. His ideas became known as the first modern atomic theory. [8,2]
22. B When the K value of a reaction is negative, under standard-state conditions, the reaction will favor the formation of reactants. The reverse reaction will occur naturally instead. [78,Figure 77]
23. B French physicist Jean Baptiste Perrin first used the term "Avogadro's number" when he estimated the figure in 1909. The number is named in honor of Avogadro to recognize his contributions. [36,8]
24. A The second hydrogen-powered balloon, launched on December 1, 1783, stayed airborne for just over 2 hours. [40,1]
25. C Gilbert N. Lewis was a chemist at the University of California, and developed a way to represent the valence electrons of an atom by creating Lewis structures. [22,4]
26. C Horizontal rows within the periodic table are called "periods". [13,3]
27. B Thermodynamics is the study of how energy and temperature relate to particle motion in the kinetic-molecular theory model. The main goal of thermodynamics is to explain whether or not a reaction will occur. [74,6]
28. A Basic substances have a pH above seven, and a H⁺ concentration below 1.0×10^{-7} M. [58,2]
29. C In many regions, the lowering of soil pH is due to acid rain. [60,7]
30. D Solids are the most ordered state of matter, then liquids, then solutions, and gases are the most disordered. [76,10]
31. E John Dalton first proposed his conclusions on atomic behavior in the early 19th century. His ideas became known as the first modern atomic theory. [8,2]

32. A According to Boyle's law, there is an inverse relationship between the volume and pressure of a gas. If a gas's pressure increases, its volume will decrease. [33,2]
33. A The Aristotelian scientific view proposed the idea of four elements-- earth, air, fire and water. [6,4]
34. C Joseph Black observed an interesting phenomenon that occurred when snow melted-- he saw that even after temperatures have risen above the freezing point, the snow will not immediately melt but rather will melt quite slowly. This observation was the basis for his research into latent heat. [75,1]
35. C Democritus was a student of Leucippus, and expanded on his ideas of atomism. Democritus proposed that there are many different types of particles, and that a substance's properties are determined by the properties of its particles. John Dalton expanded on these ideas in his publications that made up the first modern atomic theory. [8,2]
36. E Of carbon's 15 known isotopes, Carbon-12 and Carbon-13 are the only stable ones. [10,Figure 4]
37. A Gas lighting was invented during the 18th century, and played a major role in the Industrial Revolution. [6,1]
38. A Scientists didn't agree that elements mixed in fixed ratios until the late 1700s, when Joseph-Louis Proust proposed the law of definite proportions. [70,4]
39. C Jacques Charles studied the conclusions that Robert Boyle had made about the relationship between the pressure and volume of a gas. It was his research that prompted Charles with the idea that hydrogen could be used to fuel balloon flight. [33,4]
40. A A sigma bond forms when a region of high electron density holds two atoms together by their nuclei. [24,Figure 30]
41. B 1 Faraday has 96,500 coulombs of charge. Therefore, 3 Faradays would have $96,500 \times 3 = 289,500$ coulombs of charge. [68,1]
42. B After images are developed, they consist of silver metal on paper or plastic. Then, excess silver must be removed through a process called fixing. [62,2]
43. C Octane is a nonpolar solvent, and will therefore dissolve only other nonpolar compounds such as vegetable oil. [47,2]
44. D Isotopes are formed when the number of neutrons within an atom is changed. Occasionally, this can cause the atom to become unstable, in which case it is referred to as radioactive. [7,3]
45. B Hess's Law states that the heat released or absorbed in a chemical process is the same no matter how many steps the process takes place in. This essentially restates the law of conservation of energy (in the way that everything must "add up"). [76,5]
46. B A standard silver atom has 61 neutrons. The charge of the atom does not impact its number of neutrons. [62,3]
47. B Atomism is the idea that all substances are composed of very small indivisible particles. This idea was proposed by Greek philosopher Leucippus in the 5th century. [8,2]
48. B Transmutation was the process of transforming one element into another, such as lead into gold. Perfecting this process was the goal of most alchemists. [33,3]
49. B To convert from Celsius to Kelvin, simply add 273. As a result, 100° C is equal to 373 K. [33,1]
50. C Atomism is the idea that all substances are composed of very small indivisible particles. This idea was proposed by Greek philosopher Leucippus in the 5th century. [8,2]

Science Comprehensive Exam 10

1. E Nonpolar solvents are compounds that only contain carbon and hydrogen. [48,3]
2. B Hydrogen ions (H^+) are formed when acids break apart in water. [57,5]
3. C The amount of a gas can be expressed as a “mole fraction” by dividing the moles of gas A by the sum of the moles of all the gases present. [35,2]
4. B Democritus was a student of Leucippus, and expanded on his ideas of atomism. Democritus proposed that there are many different types of particles, and that a substance’s properties are determined by the properties of its particles. [8,2]
5. C James Watt invented the steam engine, which was the key invention that kickstarted the Industrial Revolution in Europe. [75,3]
6. B A concentration cell is one that has a cell voltage even though $E^\circ = 0$, due to unequal concentrations within the cell. [68,8]
7. E Acidic substances have a pH below seven, and a H^+ concentration above $1.0 \times 10^{-7} M$. [58,2]
8. A Raoult’s law states that the physical properties of a solution are determined by the relative number of moles of solute. [49,4]
9. E The goal of kinetic-molecular theory is to explain the motion of particles at any temperature. [32,2]
10. B Fixing is the process of removing excess silver from photographs once they are developed. [62,2]
11. D In the process of disproving Galvani’s theories, Volta built a voltaic pile that was the first battery to provide a continuous electric current. [67,3]
12. E The rate of collisions between gas molecules increases proportionally to the number of gas molecules added. [35,2]
13. D Beta minus decay occurs when there are too many neutrons, in which case the nucleus converts neutrons to protons. If there are too few neutrons present, then positron emission occurs. [28,6]
14. C Chemical reactions involving the formation of precipitates use the equilibrium constant K_{sp} . [71,9]
15. C An alpha particle contains 2 protons and 2 neutrons, which is the same composition as a helium nucleus. [28,4]
16. A The most abundant carbon isotope is Carbon-12, making up 98.89% of all natural carbon that can be found. [10,Figure 4]
17. D Robert Boyle suggested an inverse relationship between the pressure and volume of a gas. Based on these findings, Jacques Charles came up with the idea that hydrogen could be used to fuel balloon flight. [33,8]
18. B An atom’s number of protons is equal to its atomic number. If the number of protons in an atom changes, it is no longer an atom of the same element. [10,2]
19. E The photoelectric effect is where a photon transfers its energy to an electron, which is then emitted from a metal surface. [12,4]
20. A In their standard state, atoms have a neutral charge. However, atoms can lose or gain electrons to form positive or negative ions, respectively. [7,3]
21. E Precipitation reactions are a specialized type of double replacement reaction, where one of the products is a solid precipitate that forms within the solution. [59,10]
22. A Jacques Charles studied the conclusions that Robert Boyle had made about the relationship between the pressure and volume of a gas. It was his research that prompted Charles with the idea that hydrogen could be used to fuel balloon flight. [33,4]
23. B A helium atom, with a mass of 4, is $1/3$ the mass of a carbon atom. [10,3]
24. C Reverse osmosis was selected as the water purification method for the desalination operation in Carlsbad, California. [51,1]
25. D Alessandro Volta made many advancements in the field of electricity, inspired by Galvani’s research. Volta conducted experiments that helped create the world’s first continuous electric current as a result of his disagreement with Galvani’s conclusions. [67,1]
26. E Since both Boyle’s law and Charles’s law are set equal to constants C and D respectively, with $PV = C$ and $V/T = D$, the equations can be combined algebraically to equal $PV/T = CD$, a new constant. [33,2]
27. D Dalton’s law states that the total pressure of a mixture of gases is equal to the sum of the pressures of each individual gas. [8,3]
28. E Chemistry’s origins are in the field of alchemy, as alchemists developed processes such as distillation and extraction, and laid the foundations for the main principles of chemistry. Transmutation was a key focus of alchemy, but alchemy as a whole was much more influential towards the development of chemistry. [56,2]
29. D Johann Baptista van Helmont made many significant contributions to the field of chemistry through his research in an effort to understand the causes of disease. However, at first many leading physicians opposed his refutations of the notions of alchemy and element transmutation. [56,3]
30. D In 1919, Ernest Rutherford created oxygen atoms by combining nitrogen atoms with alpha particles. [29,1]
31. A Enthalpy is the measure of the heat that is absorbed or released during a chemical reaction. [76,2]

32. C Carbon-14 naturally forms in the upper atmosphere as a result of cosmic rays hitting nitrogen atoms. [11,1]
33. D The leftmost elements on the periodic table are Group 1 elements, or alkali metals. These elements have oxidation numbers of +1. [62,7]
34. A While many scientists had questioned the validity of phlogiston theory, it was Antoine Lavoisier that developed a scientific explanation for combustion that refuted phlogiston theory. [56,5]
35. D There are 18 vertical columns, or “groups”, in the periodic table. [13,3]
36. C The mass of a carbon atom was first established at 12 mass units. The mass of other atoms was then concluded in comparison to carbon atoms. [10,3]
37. B When atoms bond, their atomic orbitals combine. When these orbitals overlap, new molecular orbitals are formed. These new orbitals are referred to as “hybridized” orbitals. [23,7]
38. B VSEPR (Valence Shell Electron Pair Repulsion) models make predictions about the 3-D shape of molecules based on the bonds between atoms. [27,4]
39. C A node is the point within an orbital where an electron cannot be located. The more nodes there are within an orbital, the higher the energy level. [13,Figure 9]
40. A Catalysts are substances that are added to reactions to lower the required activation energy and speed up the reactions. [74,4]
41. C Carbonates, hydroxides, oxides and silicates are all insoluble. Generally, all sulfates are soluble (with some exceptions). [60,3]
42. D Oxygen gas was created using decomposition reactions when it was first discovered, as mercury oxide was broken down into mercury and oxygen gas. [54,1]
43. B Many scientific societies were founded in the 17th century, which encouraged the sharing of knowledge and the publication of scientific papers. This allowed other scientists to replicate experiments and review new theories and conclusions. [7,1]
44. E The law of conservation of mass was proposed by Antoine Lavoisier in 1789. [9,1]
45. E Deuterium is an isotope of hydrogen that contains 1 neutron. [10,5]
46. C The main purpose of the quantum mechanical model is to display the wave-particle duality of electrons. It does this by not placing electrons at exact distances or in fixed position from the nucleus, and by not placing them in rotating orbits. [12,2]
47. A In 1919, Ernest Rutherford created oxygen atoms by combining nitrogen atoms with alpha particles. [29,1]
48. E Avogadro’s law states that at a constant temperature and pressure, the volume of a gas is directly proportional to the number of moles of the gas. [36,5]
49. A The first hydrogen balloon flight was on August 27, 1783, and the second was on December 1, 1783. [34,1]
50. C Latent heat is the heat that is added or lost when a substance changes its state. The heat involved in the melting of a solid is specifically called the heat of fusion, but this still falls under the general phenomenon of latent heat. [75,3]