Multiple-Choice Section

In Section I, there are 60 multiple-choice questions. These questions represent the knowledge and skills students should know, understand, and be able to apply. Students will be given a periodic table and an equations and constants list to use during this section.

Information for Multiple-Choice Questions 1–60

Question 1

Essential Knowledge	1.A.3 The mole is the fundamental unit for counting numbers of particles on the macroscopic level and allows quantitative connections to be drawn between laboratory experiments, which occur at the macroscopic level, and chemical processes, which occur at the atomic level.
Science Practice	7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective	1.4 The student is able to connect the number of particles, moles, mass, and volume of substances to one another, both qualitatively and quantitatively.
(A)	This option is incorrect. The balanced chemical equation is $C_2H_2 + 5/2\ O_2 \rightarrow 2\ CO_2 + H_2O$, so combustion produces CO_2 and H_2O with a mole ratio of 2 to 1.
(B)	This option is incorrect. The balanced chemical equation is $C_2H_6 + 7/2\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$, so combustion produces CO_2 and H_2O with a mole ratio of 2 to 3.
(C)	**This option is correct. The balanced chemical equation is $C_4H_8 + 6\ O_2 \rightarrow 4\ CO_2 + 4\ H_2O$, so combustion produces CO_2 and H_2O with a mole ratio of 1 to 1, in agreement with the observed equimolar ratio.**
(D)	This option is incorrect. The balanced chemical equation is $C_6H_6 + 15/2\ O_2 \rightarrow 6\ CO_2 + 3\ H_2O$, so combustion produces CO_2 and H_2O with a mole ratio of 2 to 1.

Question 2

Essential Knowledge	2.B.3 Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
Science Practice	6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	2.16 The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces.
(A)	This option is incorrect. As discussed in option C, a high vapor pressure is an indication of weak intermolecular interaction, and this substance does not have the highest vapor pressure.
(B)	This option is incorrect. As discussed in option C, a high vapor pressure is an indication of weak intermolecular interaction, and this substance does not have the highest vapor pressure.
(C)	**This option is correct. Since the transition from liquid to vapor breaks the intermolecular interactions, a high vapor pressure indicates weak interactions between molecules. Based on the data, this substance has the highest vapor pressure and thus the weakest intermolecular interactions.**
(D)	This option is incorrect. As discussed in option C, a high vapor pressure is an indication of weak intermolecular interaction, and this substance does not have the highest vapor pressure.

Question 3

Essential Knowledge	2.B.2 Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force when very electronegative atoms (N, O, and F) are involved.
Science Practices	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	2.14 The student is able to apply Coulomb's Law qualitatively (including using representations) to describe the interactions of ions, and the attractions between ions and solvents to explain the factors that contribute to the solubility of ionic compounds.

(A)	**This option is correct. The interaction of ions with water is a Coulombic (specifically ion-dipole) interaction. Since all three ions have the same charge (+2), the strength of the interaction is related to distance, with shorter distances leading to the stronger interactions. The smaller ions therefore have stronger columbic attraction to water, as stated in this option.**
(B)	This option is incorrect. The trend in electronegativity across these ions has no bearing on the interaction between these ions and water. The electronegativity is useful for determining the ionic character and polarity of a bond, which is not of relevance to the interaction of these cations with water.
(C)	This option is incorrect. While Ba^{2+} is the largest ion and so the most polarizable, the interaction with water is dominated by ion-dipole interactions, and polarizability of the ion is not a relevant factor for such interactions.
(D)	This option is incorrect. The trend in electronegativity is not of relevance here, as discussed in option B.

Question 4

Essential Knowledge	1.C.1 Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	1.9 The student is able to predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model.

(A)	**This option is correct. Na has a single valence electron and a low first ionization energy and so can readily lose an electron and reduce other species.**
(B)	This option is incorrect. H^+ has no electrons to transfer to, and thereby reduce, another chemical species. (If the notation H^+ is interpreted as $H_3O^+(aq)$, this option is still incorrect since the hydronium ion is a much weaker reducing agent than Na.)
(C)	This option is incorrect. K^+ has the electronic configuration of Ar, giving it a much higher ionization energy than K. (Equivalently, the second ionization energy of K is much larger in magnitude than the first ionization energy.) The high ionization energy of K^+ makes it a poor choice for reducing other chemical species.
(D)	This option is incorrect. Cl^- has the electronic configuration of Ar, giving it a high ionization energy and making it a poor choice for reducing other chemical species.

Question 5

Essential Knowledge		2.B.2 Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force when very electronegative atoms (N, O, and F) are involved.
Science Practice		1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective		2.13 The student is able to describe the relationships between the structural features of polar molecules and the forces of attraction between the particles.
(A)	This option is incorrect. This interaction is a covalent bond within a water molecule, not a hydrogen bond between water molecules.	
(B)	This option is incorrect. This interaction is between oxygens on different water molecules, as opposed to a hydrogen bond.	
(C)	This option is incorrect. This interaction is between hydrogens on different water molecules, as opposed to a hydrogen bond.	
(D)	**This option is correct. This interaction correctly identifies a hydrogen bond as being between the hydrogen of one water molecule and the oxygen of an adjacent water molecule.**	

Question 6

Essential Knowledge		4.A.1 The rate of a reaction is influenced by the concentration or pressure of reactants, the phase of the reactants and products, and environmental factors such as temperature and solvent.
Science Practice		4.2 The student can design a plan for collecting data to answer a particular scientific question.
Learning Objective		4.1 The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., temperature, concentration, surface area) that may influence the rate of a reaction.
(A)	This option is incorrect. The rate of the reaction depends on the concentration of the ethanoic acid and the surface area of the solid $CaCO_3$. Decreasing the volume of ethanoic acid solution will not alter either of these factors and so has no effect on the rate of gas production.	
(B)	This option is incorrect. Decreasing the concentration of ethanoic acid solution will decrease the rate of the reaction and thus decrease the rate of gas production.	
(C)	This option is incorrect. Decreasing the temperature will decrease the rate of the reaction and thus decrease the rate of gas production.	
(D)	**This option is correct. Decreasing the particle size by grinding the $CaCO_3$ into a fine powder will increase the surface area of the $CaCO_3$ and increase the rate of the reaction and the rate of gas production.**	

Question 7

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	6.4 The student can, given a set of initial conditions (concentrations or partial pressures) and the equilibrium constant, K, use the tendency of Q to approach K to predict and justify the prediction as to whether the reaction will proceed toward products or reactants as equilibrium is approached.

(A)	This option is incorrect. As discussed in option B, $Q < K$ and the reaction will proceed in the forward direction, decreasing the amount of H_2 and I_2.
(B)	**This option is correct. Since the container is rigid and has a volume of 1.0 L, the original concentrations of the species are $[H_2] = [I_2] = [HI] = 2.0\ M$. The reaction quotient is therefore $Q = [HI]^2/([H_2][I_2]) = 1$. Since K is 50, $Q < K$ and the reaction proceeds in the forward direction, producing more HI, as stated in this option.**
(C)	This option is incorrect. As the reaction progresses in either direction, the number of moles of gas remains the same. (The reaction has two gas phase particles as both reactants and products.) The pressure will therefore not change as the reaction progresses.
(D)	This option is incorrect. The direction of the net reaction is determined by the relationship between Q and K, not the number of reactant and product molecules in the chemical equation. The system is not at equilibrium because $Q = 1$, which is not equal to 50, the given value of K.

Question 8

Essential Knowledge	5.A.1 Temperature is a measure of the average kinetic energy of atoms and molecules.
Science Practices	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	5.2 The student is able to relate temperature to the motions of particles, either via particulate representations, such as drawings of particles with arrows indicating velocities, and/or via representations of average kinetic energy and distribution of kinetic energies of the particles, such as plots of the Maxwell-Boltzmann distribution.

(A)	This option is incorrect. A decrease in temperature results in a decrease in the average speed of the molecules, as opposed to the increase shown here.
(B)	This option is incorrect. This is the distribution expected for a smaller number of particles at the same temperature as the original sample.
(C)	This option is incorrect. A decrease in temperature results in a decrease in the speed of the molecules, as opposed to the increase shown here.
(D)	**This option is correct. A decrease in temperature results in a decrease in the average speed of the molecules, as shown here.**

Question 9

Essential Knowledge	5.B.3 Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions.
Science Practice	2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	5.6 The student is able to use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to $P\Delta V$ work.

(A)	This option is incorrect. The amount of energy lost by the metal equals the amount of energy gained by the water.
(B)	**This option is correct. The amount of energy lost by the metal is equal to the amount of energy gained by the water.**
(C)	This option is incorrect. The observation that the change in temperature of the metal is larger than that of water indicates that the metal has a smaller heat capacity than water.
(D)	This option is incorrect. Energy is transferred from the metal to the water, with the total energy being conserved.

Question 10

Essential Knowledge	1.D.2 An early model of the atom stated that all atoms of an element are identical. Mass spectrometry data demonstrate evidence that contradicts this early model.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	1.14 The student is able to use data from mass spectrometry to identify the elements and the masses of individual atoms of a specific element.

(A)	This option is incorrect. The data are reported as mass number in amu, for which the charge on the ion is not relevant. (If the horizontal axis is interpreted as mass/charge, this option remains incorrect since the data provides evidence for an isotopic distribution of similarly charged species.)
(B)	This option is incorrect. The abundance in a particular sample does not necessarily reflect the abundance in the universe.
(C)	**This option is correct. The mass spectrum indicates the presence of multiple isotopes in the sample, providing evidence for Te. Furthermore, the graph shows no peak at 127, the mass number of the only stable isotope of I. This shows that there is no I in the sample, and the sample must be pure Te.**
(D)	This option is incorrect. The data provides evidence for an isotopic distribution, which is unrelated to the ionization energies of the elements.

Question 11

Essential Knowledge	3.B.2 In a neutralization reaction, protons are transferred from an acid to a base.
Science Practice	6.1 The student can justify claims with evidence.
Learning Objective	3.7 The student is able to identify compounds as Brønsted-Lowry acids, bases, and/or conjugate acid-base pairs, using proton-transfer reactions to justify the identification.

(A)	This option is incorrect. $H_2C_2O_4$ and $C_2O_4^{2-}$ is not a conjugate acid-base pair since conversion of $H_2C_2O_4$ to $C_2O_4^{2-}$ involves the loss of two hydrogen ions.
(B)	**This option is correct. Since $HC_2O_4^-$ loses one hydrogen ion to form $C_2O_4^{2-}$, these species are a conjugate acid-base pair.**
(C)	This option is incorrect. H_2O and $HC_2O_4^-$ are not related by loss or gain of a single hydrogen ion.
(D)	This option is incorrect. OH^- and H_3O^+ are not related by loss or gain of a single hydrogen ion.

Question 12

Essential Knowledge	5.E.2 Some physical or chemical processes involve both a decrease in the internal energy of the components ($\Delta H° < 0$) under consideration and an increase in the entropy of those components ($\Delta S° > 0$). These processes are necessarily "thermodynamically favored" ($\Delta G° < 0$).
Science Practice	2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	5.13 The student is able to predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both $\Delta H°$ and $\Delta S°$, and calculation or estimation of $\Delta G°$ when needed.

(A)	This option is incorrect. $\Delta G = \Delta H - T\Delta S$. At low temperature, ΔG is dominated by ΔH, and since $\Delta H < 0$, the reaction is favored. At high temperatures, ΔG is dominated by $-T\Delta S$, and since $\Delta S < 0$, the reaction is not favored.
(B)	**This option is correct. $\Delta G = \Delta H - T\Delta S$. At low temperature, ΔG is dominated by ΔH, and since $\Delta H > 0$, the reaction is not favored. At high temperatures, ΔG is dominated by $-T\Delta S$, and since $\Delta S > 0$, the reaction is favored.**
(C)	This option is incorrect. This reaction is favored at all temperatures, because it is driven by both enthalpy and entropy.
(D)	This option is incorrect. This reaction is not favored at any temperature, because it is not driven by either enthalpy or entropy.

Question 13

Essential Knowledge	1.E.1 Physical and chemical processes can be depicted symbolically; when this is done, the illustration must conserve all atoms of all types.
Science Practice	1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain.
Learning Objective	1.17 The student is able to express the law of conservation of mass quantitatively and qualitatively using symbolic representations and particulate drawings.

(A)	This option is incorrect. Both hydrogen and oxygen are diatomic molecules, unlike the monatomic gases depicted for the reactants. In addition, the number of atoms is not conserved.
(B)	This option is incorrect. Both hydrogen and oxygen are diatomic molecules, unlike the monatomic gases depicted for the reactants.
(C)	**This option is correct. The reactants are shown as diatomic molecules and the number of atoms is conserved (6 oxygen and 12 hydrogen atoms on both the reactant and product side).**
(D)	This option is incorrect. The number of atoms is not conserved (12 oxygen atoms on the reactant side but only 6 oxygen atoms on the product side).

Question 14

Essential Knowledge	6.C.2 The pH is an important characteristic of aqueous solutions that can be controlled with buffers. Comparing pH to pK_a allows one to determine the protonation state of a molecule with a labile proton.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.19 The student can relate the predominant form of a chemical species involving a labile proton (i.e., protonated/deprotonated form of a weak acid) to the pH of a solution and the pK_a associated with the labile proton.

(A)	**This option is correct. Point *R* is in the buffer region, where HA and A^- have the highest concentration of the four species listed as options. At the half-equivalence point, HA and A^- have equal concentrations and pH = pK_a. Point *R* is before the half-equivalence point, with a pH < pK_a, and so HA will have a higher concentration than A^-.**
(B)	This option is incorrect. As discussed for option A, since *R* is before the half-equivalence point, the concentration of A^- will be less than that of HA.
(C)	This option is incorrect. Since the pH at point *R* is about 3.5, the concentration of H_3O^+ is between 10^{-3} and 10^{-4}. Since the equivalence point is at 40 mL, the concentration of both HA and A^- are of the same order of magnitude as the titrant (0.1 *M* NaOH) and so are much larger than H_3O^+.
(D)	This option is incorrect. Since the pH is acidic, OH^- is present with very small concentration.

Question 15

Big Idea	3 Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Science Practice	7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective	3.1 Students can translate among macroscopic observations of change, chemical equations, and particle views.

(A)	This option is incorrect. Point *U* is substantially beyond the equivalence point and so OH^- is present in the solution with substantial concentration.
(B)	**This option is correct. Na^+, OH^-, and A^- ions are all present in large concentration. The ratio of species is also correct, since at point *U*, the concentrations of Na^+, A^-, and OH^- should be approximately 3:2:1.**
(C)	This option is incorrect. Since point *U* is substantially beyond the equivalence point, HA will be present in very small concentration. This is inconsistent with the two HA molecules shown in this option.
(D)	This option is incorrect. Since point *U* is substantially beyond the equivalence point, HA will be present in very small concentration. This is inconsistent with the four HA molecules shown in this option.

Question 16

Essential Knowledge	6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practice	5.1 The student can analyze data to identify patterns or relationships.
Learning Objective	6.13 The student can interpret titration data for monoprotic or polyprotic acids involving titration of a weak or strong acid by a strong base (or a weak or strong base by a strong acid) to determine the concentration of the titrant and the pK_a for a weak acid, or the pK_b for a weak base.

(A)	This option is incorrect. At the half-equivalence point, [HA] = $[A^-]$. Point *R* is before the half-equivalence point, and [HA] > $[A^-]$.
(B)	This option is incorrect. Point *S* is the half-equivalence point, at which [HA] = $[A^-]$.
(C)	**This option is correct. At the half-equivalence point, [HA] = $[A^-]$. Since point *T* is after the half-equivalence point but within the buffer region, [HA] and $[A^-]$ will both be present with large concentration with $[A^-]$ > [HA].**
(D)	This option is incorrect. Point *U* is well past the equivalence point, with a pH greater than 12. The concentration of HA will therefore be very small, and much less than half that of A^-.

Question 17

Essential Knowledge		1.E.2 Conservation of atoms makes it possible to compute the masses of substances involved in physical and chemical processes. Chemical processes result in the formation of new substances, and the amount of these depends on the number and the types and masses of elements in the reactants, as well as the efficiency of the transformation.
Science Practice		5.1 The student can analyze data to identify patterns or relationships.
Learning Objective		1.20 The student can design and/or interpret data from an experiment that uses titration to determine the concentration of an analyte in a solution.
(A)	This option is incorrect. The experimental error will be in a direction that increases the estimated concentration of the acid, as discussed in option B.	
(B)	**This option is correct. The relation $M_1V_1 = M_2V_2$ at the equivalence point (40.0 mL) gives a concentration of 0.0800 *M*. If the endpoint of the titration is measured past the actual endpoint, then the moles of base added to reach the endpoint is overestimated and this will lead to an overestimation of the number of moles of acid, and so a calculated concentration that is somewhat larger than the actual concentration.**	
(C)	This option is incorrect. An acid concentration of 0.125 *M* would place the equivalence point at 60.0 mL instead of the observed 40.0 mL.	
(D)	This option is incorrect. An acid concentration of 0.125 *M* would place the equivalence point at 60.0 mL instead of the observed 40.0 mL.	

Question 18

Essential Knowledge		5.A.1 Temperature is a measure of the average kinetic energy of atoms and molecules.
Science Practices		1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective		5.2 The student is able to relate temperature to the motions of particles, either via particulate representations, such as drawings of particles with arrows indicating velocities, and/or via representations of average kinetic energy and distribution of kinetic energies of the particles, such as plots of the Maxwell-Boltzmann distribution.
(A)	This option is incorrect. See option D.	
(B)	This option is incorrect. See option D.	
(C)	This option is incorrect. See option D.	
(D)	**This option is correct. The average kinetic energy is a function only of temperature, and each vessel has the same temperature.**	

Question 19

Essential Knowledge		2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.
Science Practice		2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective		2.6 The student can apply mathematical relationships or estimation to determine macroscopic variables for ideal gases.
(A)	This option is incorrect. See the explanation for option B.	
(B)	**This option is correct. Since all three containers are at the same temperature, the number of particles per unit volume is directly proportional to the pressure. The density is the mass per unit volume, so the density is proportional to the product of the pressure and the molar mass. This product is greatest for container B.**	
(C)	This option is incorrect. See the explanation for option B.	
(D)	This option is incorrect. See the explanation for option B.	

Question 20

Essential Knowledge		2.B.1 London dispersion forces are attractive forces present between all atoms and molecules. London dispersion forces are often the strongest net intermolecular force between large molecules.
Science Practice		6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective		2.11 The student is able to explain the trends in properties and/or predict properties of samples consisting of particles with no permanent dipole on the basis of London dispersion forces.
(A)	This option is incorrect. See the explanation for option C.	
(B)	This option is incorrect. See the explanation for option C.	
(C)	**This option is correct. Condensation will occur at the lowest pressure for the gas with the strongest intermolecular interactions. Since all of these gases are nonpolar, the interactions are dominated by London dispersion forces, which are largest for the most polarizable species. Since butane is the largest species, it is the most polarizable.**	
(D)	This option is incorrect. See the explanation for option C.	

Question 21

Essential Knowledge	1.A.2 Chemical analysis provides a method for determining the relative number of atoms in a substance, which can be used to identify the substance or determine its purity.
Science Practices	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.1 The student can justify claims with evidence.
Learning Objective	1.3 The student is able to select and apply mathematical relationships to mass data in order to justify a claim regarding the identity and/or estimated purity of a substance.

(A)	**This option is correct. An impurity that contains no carbon will decrease the mass percent of carbon relative to the pure substance. The mass percent of carbon in the sample is lower than that of pure glucose. So this option is consistent with the observation.**
(B)	This option is incorrect. Ribose has the same empirical formula as glucose (CH_2O) and so has the same mass percent of carbon as glucose. A ribose impurity would therefore have no effect on the measured mass percent of carbon and so cannot account for the low mass percent of carbon in the sample.
(C)	This option is incorrect. Since fructose is an isomer of glucose, it has the same mass percent of carbon as glucose. A fructose impurity would therefore have no effect on the measured mass percent of carbon and so cannot account for the low mass percent of carbon in the sample.
(D)	This option is incorrect. Sucrose has a higher mass percent of carbon than glucose. This can be seen by comparing the number of atoms in two glucose molecules, which is equivalent to $C_{12}H_{24}O_{12}$, to that in one sucrose molecule, $C_{12}H_{22}O_{11}$. Since sucrose has more carbon, relative to hydrogen and oxygen, a sucrose impurity would raise the mass percent of carbon in the sample. This is opposite to the experimentally observed effect.

Question 22

Essential Knowledge	6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practices	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.16 The student can identify a given solution as being the solution of a monoprotic weak acid or base (including salts in which one ion is a weak acid or base) and calculate the pH and concentration of all species in the solution and/or infer the relative strengths of the weak acids or bases from given equilibrium concentrations.

(A)	This option is incorrect. A weak base solution will have a basic pH. The pH range of 2-3 corresponds to an acidic solution.
(B)	This option is incorrect. A weak base solution will have a basic pH. The pH range of 5-6 corresponds to an acidic solution.
(C)	This option is incorrect. See option D for an estimation of the pH.
(D)	**This option is correct. The equilibrium expression for a weak base, B, is $K_b = \frac{[HB^+][OH^-]}{[B]}$. Here [B] = 0.01 *M*, K_b= 4 × 10^{-4} and [HB^+] = [OH^-]. Therefore [OH^-] = $\sqrt{K_b \times 0.01}$. This corresponds to $\sqrt{4 \times 10^{-6}}$ or 2 × 10^{-3}. The pOH is therefore somewhat less than 3, making the pH somewhat larger than 11. The pH therefore lies within the range of this option, pH = 11-12.**

Question 23

Essential Knowledge	2.C.4 The localized electron bonding model describes and predicts molecular geometry using Lewis diagrams and the VSEPR model.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	2.21 The student is able to use Lewis diagrams and VSEPR to predict the geometry of molecules, identify hybridization, and make predictions about polarity.

(A)	This option is incorrect. Although the molecular formulas are similar, the geometries are not similar and the differences in geometry lead to substantial differences in polarity.
(B)	This option is incorrect. Although C and S do have similar electronegativities, this implies only that the bond dipoles are similar in the two molecules. The differences in geometry cause the bond dipoles to cancel in CO_2 but not SO_2, leading to substantially different net dipoles for the molecules and substantial differences in polarity.
(C)	This option is incorrect. The lone pair on the sulfur is an important difference between these molecules. However, the most important effect of this lone pair is its influence on the molecular geometry, which causes SO_2 to be a bent molecule.
(D)	**This option is correct. Both the C-O and S-O bonds are polar, due to the different electronegativities of the bonded atoms. However, the CO_2 molecule is linear and so the bond dipoles cancel and the molecule has no net dipole. In SO_2, the molecule is bent and so the bond dipoles do not cancel and a net dipole is present. The polarity of the two substances differs because of the differences in geometry, which is a direct consequence of the number of electron domains around the central atom (2 in CO_2 and 3 in SO_2), as stated in this option.**

Question 24

Enduring Understanding		4.C Many reactions proceed via a series of elementary reactions.
Science Practice		6.5 The student can evaluate alternative scientific explanations.
Learning Objective		4.7 The student is able to evaluate alternative explanations, as expressed by reaction mechanisms, to determine which are consistent with data regarding the overall rate of a reaction, and data that can be used to infer the presence of a reaction intermediate.
(A)	This option is incorrect. A unimolecular reaction is one involving a single reactant molecule. The first step of this mechanism corresponds to a collision between two NO molecules, making it a bimolecular reaction.	
(B)	This option is incorrect. The fast and reversible character of the first step in the mechanism will establish an equilibrium. Increasing the concentration of NO will shift this equilibrium to the product side, increasing the concentration of the N_2O_2 intermediate. This increase in N_2O_2 will lead to an increase in the rate of the second step of the mechanism and so increase the overall rate of the reaction.	
(C)	This option is incorrect. The rate constant for this reaction depends on temperature. In particular, the slow character of the second step in the reaction mechanism implies a substantial activation energy.	
(D)	**This option is correct. The fast and reversible character of the first step in the mechanism will establish an equilibrium in which the concentration of the intermediate N_2O_2 is directly proportional to $[NO_2]^2$. The overall rate of the reaction is given by the second step, for which the rate is proportional to the product $[N_2O_2][O_2]$. Since $[N_2O_2]$ is directly proportional to $[NO_2]^2$ from step 1, substitution yields an overall reaction rate law of rate = $k\,[NO_2]^2[O_2]$, as stated in this option.**	

Question 25

Essential Knowledge		2.B.3 Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
Science Practice		6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective		2.16 The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces.
(A)	This option is incorrect. Both Br_2 and I_2 form molecular solids.	
(B)	This option is incorrect. The boiling point is established by the strength of the intermolecular forces. The covalent bonds remain intact on boiling and so their strength does not influence the boiling points.	
(C)	**This option is correct. Since both Br_2 and I_2 are nonpolar, London dispersion forces establish the boiling points. The larger electron cloud in I_2 gives it a greater polarizability and therefore stronger London dispersion forces. The higher boiling point of I_2 is therefore due to the greater polarizability of I_2, as stated in this option.**	
(D)	This option is incorrect. The bond polarity is related to the difference in electronegativity of the bonded atoms. Here, the bonds are between identical elements and so the bonds are nonpolar.	

Question 26

Essential Knowledge	2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.
Science Practices	1.3 The student can refine representations and models of natural or man-made phenomena and systems in the domain. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	2.5 The student is able to refine multiple representations of a sample of matter in the gas phase to accurately represent the effect of changes in macroscopic properties on the sample.

(A)	This option is incorrect. The correct pressure is 4.5 atm, as described below for option B.
(B)	**This option is correct. Since the volume of the three original containers are equal, the pressures are proportional to the number of atoms in the containers, which are in the ratio of 2:1:6. The pressure in the first container is given as 2 atm, therefore the pressures in the three containers are 2 atm, 1 atm, and 6 atm, respectively. If these were combined into a single container with a volume equal to that of the original vessels (1 liter), the total pressure would be the sum of these partial pressures, corresponding to 9 atm. The final container has a volume of 2 liters, which lowers the pressure by a factor of 2, to 4.5 atm.**
(C)	This option is incorrect. This option would be correct if the gases were combined in a 1-liter container, as opposed to the 2-liter container stated in the problem.
(D)	This option is incorrect. This option is obtained if one mistakenly assumes that doubling the size of the final container from 1 to 2 liters doubles the pressure as opposed to cutting it in half.

Question 27

Essential Knowledge		5.C.2 The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.
Science Practices		2.3 The student can estimate numerically quantities that describe natural phenomena. 7.1 The student can connect phenomena and models across spatial and temporal scales. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective		5.8 The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds.
(A)	This option is incorrect. Steps 1 and 2 break favorable intermolecular interactions and so are both endothermic.	
(B)	This option is incorrect. The final step establishes favorable intermolecular interactions between solute and solvent and so is exothermic.	
(C)	This option is incorrect. This option corresponds to the opposite of the correct response, as explained in option D below.	
(D)	**This option is correct. In steps 1 and 2, favorable intermolecular interactions are broken and this increases the enthalpy, corresponding to an endothermic process. In step 3, favorable intermolecular interactions are established, which decreases the enthalpy, corresponding to an exothermic process. (The sign of the enthalpy change for the overall process is established by the difference in magnitude between these enthalpy changes, and so the overall process can be either endothermic or exothermic.)**	

Question 28

Big Idea	3 Changes in matter involve the rearrangement and/or reorganization of atoms and/or the transfer of electrons.
Science Practices	1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. 7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective	3.1 Students can translate among macroscopic observations of change, chemical equations, and particle views.

(A)	This option is incorrect. The solution corresponds to AgCl solid with $NaNO_3$ in solution. Since excess NaCl was added, the drawing should show Na^+ and Cl^- in solution.
(B)	This option is incorrect. There should be Na^+ and NO_3^- ions in solution. In addition, since K_{sp} is small, the concentration of Ag^+ should be very low, and far below that of Na^+ and NO_3^-.
(C)	**This option is correct. The addition of excess NaCl will cause there to be additional Na^+ and Cl^- ions in the solution, along with NO_3^- ions remaining from the original $AgNO_3$ solution. Due to the low K_{sp}, almost all of the Ag^+ ions have precipitated from solution.**
(D)	This option is incorrect. Since K_{sp} is very small, the concentration of Ag^+ should be very low, and far below that of Na^+ and NO_3^-. In this drawing, Ag^+ has a concentration equal to that of Na^+ and NO_3^-.

Question 29

Essential Knowledge	2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.
Science Practices	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	2.4 The student is able to use KMT and concepts of intermolecular forces to make predictions about the macroscopic properties of gases, including both ideal and nonideal behaviors.

(A)	This option is incorrect. The principal effect on the pressure is a change in the number of particles in the vessel, not the strength of their interactions.
(B)	This option is incorrect. The principal effect on the pressure is a change in the number of particles in the vessel, not the strength of their interactions. In addition, an increase in intermolecular attractions would serve to decrease the pressure, unlike the observed increase in pressure.
(C)	**This option is correct. The number of particles in the vessel increases as the system reaches equilibrium. This increases the frequency of collisions with the walls and thus increases the pressure, as stated in this option.**
(D)	This option is incorrect. The speed of the particles influences pressure only via the temperature, and since the reaction is carried out at constant temperature, the only relevant variable regarding pressure is the number of particles in the container.

Question 30

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	6.3 The student can connect kinetics to equilibrium by using reasoning about equilibrium, such as Le Chatelier's principle, to infer the relative rates of the forward and reverse reactions.

(A)	This option is incorrect. Since the concentration of reactant species decreases as the reaction progresses, the rate of the forward reaction decreases.
(B)	This option is incorrect. Since the concentration of reactant species decreases as the reaction progresses, the rate of the forward reaction changes.
(C)	**This option is correct. As the reaction reaches equilibrium, the rate of the forward reaction decreases and the rate of the reverse reaction increases. Equilibrium is reached when the forward and reverse rates are equal. The statement in this option, that the forward rate decreases to a constant value, is therefore correct.**
(D)	This option is incorrect. The rate of the forward reaction decreases as the reaction progresses; however, equilibrium is established when the forward and reverse reaction rates are equal. The rate of the forward reaction therefore reaches a steady nonzero value, not zero as stated in this option.

Question 31

Essential Knowledge	3.A.2 Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note so that it does not seem to be simply an exercise done only by chemists.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	3.3 The student is able to use stoichiometric calculations to predict the results of performing a reaction in the laboratory and/or to analyze deviations from the expected results.

(A)	This option is incorrect. If the system is allowed to reach equilibrium, the pressure is 1.40 atm, as indicated in the stimulus to the question. This question specifically asks for the reaction going to completion.
(B)	**This option is correct. It demonstrates recognition of the stoichiometry of the provided reaction and application of mole ratios (1 mole of reactant decomposing to produce 2 moles of product) to determine the total pressure of the system, should it go to completion.**
(C)	This option is incorrect. This answer can be achieved by doubling the equilibrium pressure, which demonstrates confusion on what the equilibrium pressure represents in relation to the stoichiometry of the reaction.
(D)	This option is incorrect. This answer can be achieved by forgetting that the partial pressure of the reactant is equal to zero if the reaction goes to completion.

Question 32

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	6.5 The student can, given data (tabular, graphical, etc.) from which the state of a system at equilibrium can be obtained, calculate the equilibrium constant, K.

(A)	This option is incorrect. K_p is not greater than 1 based on the equilibrium pressure of the system provided in the stimulus.
(B)	**This option is correct. It demonstrates the ability to use an ICE chart or a K_p expression to determine the amount of change needed to reach equilibrium conditions: the pressure of the reactant drops by 0.40 atm and the products increase by 0.40 atm each, giving a total pressure of 1.40 atm.** $K_p = \frac{(0.40\text{ atm})^2}{(0.60\text{ atm})} < 1$
(C)	This option is incorrect. Each of the partial pressures of the products at equilibrium would have to be exactly equal to the square root of the equilibrium pressure of the reactant to achieve a K of 1.
(D)	This option is incorrect. Enough information is provided in the problem to calculate a value of K_p and compare its magnitude to 1.

Question 33

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	6.3 The student can connect kinetics to equilibrium by using reasoning about equilibrium, such as Le Chatelier's principle, to infer the relative rates of the forward and reverse reactions.

(A)	This option is incorrect. The rate of the reverse reaction would increase, but the rate would not be zero at equilibrium.
(B)	**This option is correct. It demonstrates recognition that the rate of the reverse reaction would rapidly increase upon the injection of more Cl_2 because a greater concentration of reactant (Cl_2 in this case) means an increase in the reaction rate. It also demonstrates understanding that as more Cl_2 is consumed and the system returns to equal forward and reverse reaction rates (i.e., equilibrium), the reverse rate will decrease and reach a new non-zero value that is higher than the original value.**
(C)	This option is incorrect. While increasing the concentration of Cl_2 will increase the reaction rate initially, it would not be possible for the reverse rate to be less than it was in the initial equilibrium, given the greater concentration of Cl_2.
(D)	This option is incorrect. Increasing the concentration of Cl_2 would increase the reaction rate, but it would not do so slowly if the time for injection and mixing is negligible, as the question states; as Cl_2 is consumed by the reverse reaction, the rate should drop some, not only increase.

Question 34

Essential Knowledge	5.B.3 Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions.
Science Practices	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	5.6 The student is able to use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to $P\Delta V$ work.

(A)	This option is incorrect. Reversing the exothermic process described in the stimulus reverses the direction of energy flow. Also, the stoichiometry of the reaction indicates that the energy value in the equation is for a half mole of Cl_2, not a full mole of Cl_2.
(B)	This option is incorrect. Reversing the exothermic process described in the stimulus reverses the direction of energy flow.
(C)	**This option is correct. It demonstrates understanding of the magnitude of the energy change based on the stoichiometry of the reaction and the correct direction of the energy transfer based on reversing the reaction.**
(D)	This option is incorrect. It correctly predicts the direction of the energy flow, but it does not correctly reflect the stoichiometry of the reaction.

Question 35

Essential Knowledge	3.A.2 Quantitative information can be derived from stoichiometric calculations that utilize the mole ratios from the balanced chemical equations. The role of stoichiometry in real-world applications is important to note so that it does not seem to be simply an exercise done only by chemists.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	3.4 The student is able to relate quantities (measured mass of substances, volumes of solutions, or volumes and pressures of gases) to identify stoichiometric relationships for a reaction, including situations involving limiting reactants and situations in which the reaction has not gone to completion.

(A)	This option is incorrect. Equal masses of K and Cl_2 do not have a 1:1/2 mole ratio, as required by the balanced chemical equation provided in the stimulus.
(B)	This option is incorrect. Since the molar mass of K is more than half that of Cl_2, there are fewer than twice the moles of K than Cl_2, so K cannot be the limiting reactant.
(C)	**This option is correct. It demonstrates correct calculation or recognition of the limiting reactant in the setup, based on moles of each reactant and the stoichiometry of the reaction and that the product of the reaction will also be present at the reaction conclusion.**
(D)	This option is incorrect. The reaction proceeds until one or both of the reactants have been completely consumed, so both reactants cannot remain in the reaction vessel upon reaction completion.

Question 36

Essential Knowledge	5.C.2 The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.
Science Practice	2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	5.8 The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds.

(A)	This option is incorrect. The formation of an ionic bond releases energy, but adding an electron to a gaseous halogen atom also releases energy.
(B)	**This option is correct. It demonstrates understanding of the exothermic processes listed in the stimulus that are a result of bond formation and Coulombic attractions: the electron affinity of Cl(*g*) and the ionic-bond formation between K^+(*g*) and Cl^-(*g*), both of which can be estimated to have a negative enthalpy value.**
(C)	This option is incorrect. Bond breaking always requires energy; it is not an exothermic process.
(D)	This option is incorrect. Both ionization of a K atom and breaking a Cl-Cl bond require the addition of energy and so are endothermic processes.

Question 37

Essential Knowledge	5.E.2 Some physical or chemical processes involve both a decrease in the internal energy of the components ($\Delta H° < 0$) under consideration and an increase in the entropy of those components ($\Delta S° > 0$). These processes are necessarily "thermodynamically favored" ($\Delta G° < 0$).
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	5.13 The student is able to predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both $\Delta H°$ and $\Delta S°$, and calculation or estimation of $\Delta G°$ when needed.

(A)	**This option is correct. It predicts correctly that the sign of the free energy change would be negative (thermodynamically favorable since it goes to completion) and driven by an enthalpy change, since the overall reaction listed in the stimulus is exothermic. The reaction is not driven by an entropy change because the entropy of the system decreases as reactants convert to products.**
(B)	This option is incorrect. The reaction is observed to go to completion (so is favorable), and the entropy of the system decreases; the entropy change does not drive the reaction.
(C)	This option is incorrect. The reaction is thermodynamically favorable, but the entropy change is not a factor driving the reaction toward the products.
(D)	This option is incorrect. The reaction is favorable and driven only by the enthalpy change.

Question 38

Essential Knowledge	5.C.2 The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.
Science Practice	7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective	5.8 The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds.

(A)	This option is incorrect. Two atoms (or two moles of atoms) of chlorine are each gaining one electron (or one mole of electrons), requiring a coefficient of 2 in front of the *y* term.
(B)	This option is incorrect. It does not account for two atoms of chlorine gaining electrons.
(C)	**This option is correct. It correctly tracks the ionization of diatomic chlorine, which requires both the endothermic breaking of the Cl-Cl covalent bond and the exothermic electron affinity of the separated chlorine atoms (of which there are two, yielding the coefficient on the *y* term). The negative sign is not required for the *y* term because the addition of an electron to a chlorine atom is exothermic, already implying a negative sign by convention.**
(D)	This option is incorrect. The question asks specifically about ionizing one mole of diatomic chlorine molecules, not one-half of a mole.

Question 39

Essential Knowledge	2.A.2 The gaseous state can be effectively modeled with a mathematical equation relating various macroscopic properties. A gas has neither a definite volume nor a definite shape; because the effects of attractive forces are minimal, we usually assume that the particles move independently.
Science Practices	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	2.4 The student is able to use KMT and concepts of intermolecular forces to make predictions about the macroscopic properties of gases, including both ideal and nonideal behaviors.

(A)	**This option is correct. It demonstrates understanding that gases with similar molar masses (HCl = 36 g/mol and CH_3NH_2 = 31 g/mol) at the same temperature will travel with similar average speeds, resulting in a solid being formed at roughly equal distances from each cotton ball.**
(B)	This option is incorrect. The molar mass of NH_3 is less than half of the molar mass of HCl, meaning NH_3 molecules will travel with greater average speed, and the solid will form closer to the cotton ball on the left.
(C)	This option is incorrect. The molar mass of HBr is more than double that of CH_3NH_3, which would result in a solid closer to the cotton ball on the left.
(D)	This option is incorrect. The molar mass of HBr is almost five times as large as that of NH_3, which would result in the least centered solid of any of the choices, residing far on the left side of the tube.

Question 40

Essential Knowledge	1.C.1 Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.
Science Practice	3.1 The student can pose scientific questions.
Learning Objective	1.11 The student can analyze data, based on periodicity and the properties of binary compounds, to identify patterns and generate hypotheses related to the molecular design of compounds for which data are not supplied.

(A)	**This option is correct. It recognizes that phosphorus atoms contain one additional valence electron over the silicon atoms that make up the bulk of the material, and that these additional mobile charges will increase the conductivity of the silicon material.**
(B)	This option is incorrect. While phosphorus does have additional protons, the particles in the nucleus are bound and are not able to move throughout the material like electrons can.
(C)	This option is incorrect. While germanium atoms do have more electrons than silicon atoms, the number of valence electrons is the same as in silicon, and it will not improve the conductivity of the material anywhere nearly as effectively as adding an impurity with a different valence electron count.
(D)	This option is incorrect. Germanium atoms have an additional electron shell, and they are therefore larger than silicon atoms, not smaller.

Question 41

Essential Knowledge		1.D.3 The interaction of electromagnetic waves or light with matter is a powerful means to probe the structure of atoms and molecules, and to measure their concentration.
Science Practice		4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question.
Learning Objective		1.15 The student can justify the selection of a particular type of spectroscopy to measure properties associated with vibrational or electronic motions of molecules.
(A)	This option is incorrect. Infrared light, not UV and visible, is matched to the vibrational states of chemical bonds in molecules.	
(B)	This option is incorrect. While electromagnetic radiation can be used to remove an electron from atoms and molecules, the energy of visible and UV light is insufficient to overcome both the bond energy and ionization energy.	
(C)	**This option is correct. It correctly justifies the observations about the molecules by recognizing that visible light and ultraviolet light can promote electrons to higher energy levels in atoms and molecules. Ultraviolet light is more energetic than visible light, so there must be some lower energy electronic transitions available in I_2 molecules that are not present in N_2 molecules; visible light would be a useful tool for differentiating I_2 from N_2 (which is exhibited by iodine vapor having a deep purple color and nitrogen gas being colorless).**	
(D)	This option is incorrect. Molecular mass is unrelated to UV and visible light spectroscopy; molecular mass would only be relevant if conducting a mass spectrometry experiment.	

Question 42

Essential Knowledge		2.D.2 Metallic solids are good conductors of heat and electricity, have a wide range of melting points, and are shiny, malleable, ductile, and readily alloyed.
Science Practice		7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective		2.25 The student is able to compare the properties of metal alloys with their constituent elements to determine if an alloy has formed, identify the type of alloy formed, and explain the differences in properties using particulate level reasoning.
(A)	This option is incorrect. The number of available oxidation states for these metals is not related to the hardness of the alloy.	
(B)	This option is incorrect. The melting points of the component metals are unrelated to the hardness of the alloy.	
(C)	**This option is correct. It reflects the data provided that the radii of Cu atoms is smaller than Ag atoms, which would prevent movement of Ag atoms in the alloy by creating points where Ag atoms could not slip past other atoms, making the overall alloy less deformable (i.e., less malleable).**	
(D)	This option is incorrect. London dispersion forces are not a significant factor in the nature of the metallic bond, and weaker interparticle forces would likely increase, not decrease, malleability.	

Question 43

Essential Knowledge	1.B.1 The atom is composed of negatively charged electrons, which can leave the atom, and a positively charged nucleus that is made of protons and neutrons. The attraction of the electrons to the nucleus is the basis of the structure of the atom. Coulomb's Law is qualitatively useful for understanding the structure of the atom.
Science Practice	6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	1.5 The student is able to explain the distribution of electrons in an atom or ion based upon data.

(A)	This option is incorrect. The presence or lack of electron-electron repulsions in the 2*p* sublevel would have no detectable effect on the amount of energy needed to remove a 1*s* electron from an atom.
(B)	This option is incorrect. The increased electron-electron repulsions in the oxygen atoms would have no detectable effect on the attraction of the 1*s* electrons to the nucleus of either atom, as both atoms have the same number of electrons (and hence the same degree of electron-electron repulsion) in the 1*s* sublevel.
(C)	This option is incorrect. Electron shielding involves inner electrons reducing the effective pull from the nucleus on outer electrons. Electrons in the 2*p* sublevel would have negligible, if any, shielding effect on the 1*s* electrons.
(D)	**This option is correct. It correctly explains the differences in the provided PES spectra for the energies required to remove electrons from the 1*s* sublevel, based on the increased Coulombic attraction to the nucleus due to a greater number of protons in the nucleus of the oxygen atom than in the nucleus of the nitrogen atom.**

Question 44

Essential Knowledge	2.B.3 Intermolecular forces play a key role in determining the properties of substances, including biological structures and interactions.
Science Practice	6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	2.16 The student is able to explain the properties (phase, vapor pressure, viscosity, etc.) of small and large molecular compounds in terms of the strengths and types of intermolecular forces.

(A)	This option is incorrect. Covalent bonds within molecules do not break when boiling occurs; boiling only involves molecules having enough energy to overcome interparticle attractions.
(B)	This option is incorrect. While the C-F bond is more polar than the C-H bond, the boiling point data indicate that the London dispersion forces between nonane molecules must be greater than the combined dipole-dipole attractions and London dispersion forces between molecules of 2,3,4-trifluoropentane.
(C)	**This option is correct. It correctly explains the higher boiling point of nonane due to the increased size and surface area of the electron cloud (yielding greater polarizability), which leads to more significant London dispersion forces between nonane molecules than between molecules of 2,3,4-trifluoropentane.**
(D)	This option is incorrect. Greater separation between molecules would have only slight effects on boiling point, and, if anything, the greater spacing between carbon chains in nonane would be consistent with a lower boiling point, not higher.

Question 45

Essential Knowledge	3.C.3 Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.
Science Practice	2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective	3.12 The student can make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faraday's laws.

(A)	This option is incorrect. Molar coefficients do not affect cell potential, so dividing by 3 does not yield the correct cell potential, even though reversing reaction Y and combining it with X yields a net reaction for Z that has molar coefficients 3 times greater than those in the equation given for Z.
(B)	**This option is correct. It predicts the standard cell potential for cell Z by reversing the net reaction for galvanic cell Y and adding it to the net reaction for cell X. Molar coefficients do not affect cell potential, so no further mathematical manipulations are necessary. (This is one method among several of reaching the correct answer.)**
(C)	This option is incorrect. Multiplying the cell potential by 3 does not yield the correct cell potential for Z, since molar coefficients do not affect cell potential.
(D)	This option is incorrect. The reaction in cell Y must be reversed, reversing the sign on the cell potential. Adding the net reaction from X and Y together does not yield the reaction given for Z without this reversal.

Question 46

Essential Knowledge	3.C.3 Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.
Science Practice	5.1 The student can analyze data to identify patterns or relationships.
Learning Objective	3.13 The student can analyze data regarding galvanic or electrolytic cells to identify properties of the underlying redox reactions.

(A)	This option is incorrect. Fe^{2+} ions are reduced only in cell Y, not cell Z.
(B)	This option is incorrect. Fe atoms are oxidized only in cell Z, not cell Y.
(C)	**This option is correct. It correctly tracks the oxidation numbers of the iron, based on the net reactions for each galvanic cell: Fe^{2+} ions are reduced to iron metal in galvanic cell Y, and Fe atoms are oxidized to Fe^{2+} ions in galvanic cell Z.**
(D)	This option is incorrect. Oxidation involves the loss of electrons, which does not happen to the Fe^{2+} ions in galvanic cell Y. Reduction involves the gain of electrons, which does not happen to the Fe atoms in the galvanic cell Z.

Question 47

Essential Knowledge	3.C.3 Electrochemistry shows the interconversion between chemical and electrical energy in galvanic and electrolytic cells.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	3.12 The student can make qualitative or quantitative predictions about galvanic or electrolytic reactions based on half-cell reactions and potentials and/or Faraday's laws.

(A)	This option is incorrect. Since Fe^{2+} ions are a reactant in cell Y and a product in cell Z, increasing the concentration of Fe^{2+} ions cannot increase the voltage in both cells.
(B)	This option is incorrect. Since Fe^{2+} ions are a reactant in cell Y and a product in cell Z, increasing the concentration of Fe^{2+} ions cannot decrease the voltage in both cells.
(C)	**This option is correct. It correctly predicts that increasing the Fe^{2+} ion concentration will increase the voltage for cell Y, where Fe^{2+} ions are reactants. Increasing the Fe^{2+} ion concentration will decrease the voltage for cell Z, where Fe^{2+} ions are products.**
(D)	This option is incorrect. It states the exact opposite of what would occur (see option C).

Question 48

Essential Knowledge	6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practices	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.16 The student can identify a given solution as being the solution of a monoprotic weak acid or base (including salts in which one ion is a weak acid or base), and calculate the pH and concentration of all species in the solution and/or infer the relative strengths of the weak acids or bases from given equilibrium concentrations.

(A)	**This option is correct. It correctly identifies that Acid 1 is a weak acid, and that it must have the lowest acid-dissociation constant since it has the highest pH (closest to neutral) at each of the provided concentrations.**
(B)	This option is incorrect. The pH values provided for this acid reflect the behavior of a strong acid using the relationship $pH = -\log[H_3O^+]$.
(C)	This option is incorrect. While the data on Acid 3 is consistent with a weak acid, the pH is lower than Acid 1 at all concentrations, indicating a greater degree of ionization than Acid 1.
(D)	This option is incorrect. While the data on Acid 4 is consistent with a weak acid, the pH is fairly close to Acid 2, indicating that it has a larger K_a value than Acid 1.

Question 49

Essential Knowledge		6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practice		1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective		6.12 The student can reason about the distinction between strong and weak acid solutions with similar values of pH, including the percent ionization of the acids, the concentrations needed to achieve the same pH, and the amount of base needed to reach the equivalence point in a titration.
(A)	This option is incorrect. The pH values provided for various concentrations of Acid 1 are not reflective of a strong acid.	
(B)	**This option is correct. It is based on recognition that HCl is a strong acid and reasoning that in every case the concentration of Acid 2 is equal to the H_3O^+ ion concentration, indicating 100 percent dissociation.**	
(C)	This option is incorrect. The pH values provided for various concentrations of Acid 3 are not reflective of a strong acid.	
(D)	This option is incorrect. The pH values provided for various concentrations of Acid 4 are not reflective of a strong acid.	

Question 50

Essential Knowledge		6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practice		6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective		6.17 The student can, given an arbitrary mixture of weak and strong acids and bases (including polyprotic systems), determine which species will react strongly with one another (i.e., with $K > 1$), and what species will be present in large concentrations at equilibrium.
(A)	This option is incorrect. The pH value provided for the 1.0 *M* solution of Acid 1 indicates that the $[OH^-]$ is many orders of magnitude less than any of the other substances in solution.	
(B)	This option is incorrect. The pH value provided for the 1.0 *M* solution of Acid 1 indicates that the $[H_3O^+]$ is more than one order of magnitude less than 1.0 *M*.	
(C)	**This option is correct. It correctly determines that Acid 1 is a weak acid, which has a small degree of ionization. In the 1.0 *M* solution, the protonated form of the acid will have the highest concentration.**	
(D)	This option is incorrect. The conjugate base for the acid would have an equal concentration to the $[H_3O^+]$, which is more than one order of magnitude less than 1.0 *M*.	

Question 51

Essential Knowledge	6.C.1 Chemical equilibrium reasoning can be used to describe the proton-transfer reactions of acid-base chemistry.
Science Practice	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	6.12 The student can reason about the distinction between strong and weak acid solutions with similar values of pH, including the percent ionization of the acids, the concentrations needed to achieve the same pH, and the amount of base needed to reach the equivalence point in a titration.

(A)	This option is incorrect. Initial acid concentration as opposed to pH determines the volume of base required.
(B)	This option is incorrect. Initial acid concentration as opposed to pH determines the volume of base required.
(C)	This option is incorrect. Initial acid concentration as opposed to pH determines the volume of base required.
(D)	**This option is correct. Since the concentrations of the acids are identical, the same volume of base is required to reach the equivalence point.**

Question 52

Essential Knowledge	6.C.2 The pH is an important characteristic of aqueous solutions that can be controlled with buffers. Comparing pH to pK_a allows one to determine the protonation state of a molecule with a labile proton.
Science Practice	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective	6.20 The student can identify a solution as being a buffer solution and explain the buffer mechanism in terms of the reactions that would occur on addition of acid or base.

(A)	This option is incorrect. The pH does not change much because the solution is a buffer.
(B)	This option is incorrect. The pH does not change much because the solution is a buffer.
(C)	**This option is correct. Acid 1 is a weak acid because the starting pH is higher than expected for complete dissociation. The added base converts half of the weak acid to its conjugate base, creating a buffer solution. If concentrated acid is added to the buffer solution, the acid reacts with the conjugate base, thereby keeping the pH roughly constant.**
(D)	This option is incorrect. The dominant species in solution are the weak acid and its conjugate base. There is very little OH^- ion in the buffer solution.

Question 53

Essential Knowledge		4.D.2 Important classes in catalysis include acid-base catalysis, surface catalysis, and enzyme catalysis.
Science Practice		6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective		4.9 The student is able to explain changes in reaction rates arising from the use of acid-base catalysts, surface catalysts, or enzyme catalysts, including selecting appropriate mechanisms with or without the catalyst present.
(A)	**This option is correct. Cl(*g*) is a catalyst for the reaction. The presence of Cl(*g*) decreases the activation energy and increases the rate.**	
(B)	This option is incorrect. Cl(*g*) does not decrease the rate as it promotes the decomposition of ozone.	
(C)	This option is incorrect. The equilibrium constant does not change with addition of a reactant, nor does the equilibrium constant have to do with overall reaction rate.	
(D)	This option is incorrect. The equilibrium constant does not change with addition of a reactant, nor does the equilibrium constant have to do with overall reaction rate.	

Question 54

Big Idea		2 Chemical and physical properties of materials can be explained by the structure and the arrangement of atoms, ions, or molecules and the forces between them.
Science Practice		7.1 The student can connect phenomena and models across spatial and temporal scales.
Learning Objective		2.1 Students can predict properties of substances based on their chemical formulas and provide explanations of their properties based on particle views.
(A)	**This option is correct. The Cl^- ion is larger than the F^- ion so the attractive interactions in NaCl are weaker than in NaF.**	
(B)	This option is incorrect. The bonding is weaker in NaCl and it is ionic, not covalent.	
(C)	This option is incorrect. The ions are spaced farther apart in NaCl compared with MgO, but this makes the bonding weaker and the boiling point for NaCl lower.	
(D)	This option is incorrect. The boiling point for NaCl is lower. Moreover, more energy is required to transfer two electrons from Mg to O than to transfer one electron from Na to Cl.	

Question 55

Essential Knowledge		6.C.2 The pH is an important characteristic of aqueous solutions that can be controlled with buffers. Comparing pH to pK_a allows one to determine the protonation state of a molecule with a labile proton.
Science Practice		2.3 The student can estimate numerically quantities that describe natural phenomena.
Learning Objective		6.18 The student can design a buffer solution with a target pH and buffer capacity by selecting an appropriate conjugate acid-base pair and estimating the concentrations needed to achieve the desired capacity.
(A)	This option is incorrect. This solution would not be a buffer solution.	
(B)	This option is incorrect. The pK_a of $HC_3H_5O_2$ is not close to 7.5.	
(C)	**This option is correct. The pK_a of HClO is close to 7.5.**	
(D)	This option is incorrect. The pK_a of C_6H_5OH is not close to 7.5.	

Question 56

Essential Knowledge		2.A.3 Solutions are homogenous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of the solutes and solvent.
Science Practice		1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective		2.9 The student is able to create or interpret representations that link the concept of molarity with particle views of solutions.
(A)	This option is incorrect. The solution in Z is the most dilute. The number of ions per volume is the smallest, contradicting that the concentrations of $Mg(NO_3)_2$ is 4.0 *M*.	
(B)	This option is incorrect. The metal ion concentrations are not equal in all three solutions.	
(C)	This option is incorrect. The relationship of concentrations in X and Y are correct, but the concentration of Mg^{2+} is not equal in Y and Z. The number of ions is equal, but the volume is twice as large in Z.	
(D)	**This option is correct. The concentration of Mg^{2+} in Y is half the concentration of Ag^+ in X. The concentration of Mg^{2+} in Z is half of what it is in Y because the volume doubled.**	

Question 57

Essential Knowledge		4.A.2 The rate law shows how the rate depends on reactant concentrations.
Science Practice		5.1 The student can analyze data to identify patterns or relationships.
Learning Objective		4.2 The student is able to analyze concentration versus time data to determine the rate law for a zeroth-, first-, or second-order reaction.
(A)	This option is incorrect. A plot of [A] versus *t* is not a straight line.	
(B)	**This option is correct. A plot of ln[A] versus *t* is a straight line.**	
(C)	This option is incorrect. A plot of 1/[A] versus *t* is not a straight line.	
(D)	This option is incorrect. The linearity of the plot of ln[A] versus *t* suggests the reaction order is 1, not 3.	

Question 58

Essential Knowledge		1.C.1 Many properties of atoms exhibit periodic trends that are reflective of the periodicity of electronic structure.
Science Practice		6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.
Learning Objective		1.9 The student is able to predict and/or justify trends in atomic properties based on location on the periodic table and/or the shell model.
(A)	This option is incorrect. The ionization energy of potassium is smaller than that of calcium.	
(B)	**This option is correct. Potassium is larger than calcium because it has a smaller effective nuclear charge. Because potassium is larger, less energy is required to remove an electron from it than is required to remove an electron from calcium.**	
(C)	This option is incorrect. The relative radii and ionization energies of potassium and calcium are both incorrect.	
(D)	This option is incorrect. The atomic radius of potassium is larger than that of calcium.	

Question 59

Essential Knowledge		2.B.2 Dipole forces result from the attraction among the positive ends and negative ends of polar molecules. Hydrogen bonding is a strong type of dipole-dipole force when very electronegative atoms (N, O, and F) are involved.
Science Practice		1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective		2.13 The student is able to describe the relationships between the structural features of polar molecules and the forces of attraction between the particles.
(A)	This option is incorrect. The accommodation of bond angles does not account for differences in bond lengths.	
(B)	**This option is correct. There is a shorter covalent bond between H and F within the molecules and longer hydrogen bond between the H in one molecule and the F in a second molecule.**	
(C)	This option is incorrect. Different isotopes do not cause significant differences in bond lengths.	
(D)	This option is incorrect. Repulsions between nonbonding pairs of electrons do not account for differences in bond lengths.	

Question 60

Essential Knowledge	6.A.3 When a system is at equilibrium, all macroscopic variables, such as concentrations, partial pressures, and temperature, do not change over time. Equilibrium results from an equality between the rates of the forward and reverse reactions, at which point $Q = K$.
Science Practice	2.2 The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	6.5 The student can, given data (tabular, graphical, etc.) from which the state of a system at equilibrium can be obtained, calculate the equilibrium constant, K.

(A)	This option is incorrect. See option B.
(B)	**This option is correct. Each molecule of $COCl_2$ that decomposes creates two moles of gas. When the number of moles of $COCl_2$ decreases such that the pressure is 0.8 atm, there is 0.2 mol of each of the product gas. The equilibrium constant $K = (0.2)(0.2)/(0.8) = 0.050$.**
(C)	This option is incorrect. See option B.
(D)	This option is incorrect. See option B. This assumes that K_p is equal to the original pressure in the flask.

Answers to Multiple-Choice Questions

1 – C	18 – D	35 – C	52 – C
2 – C	19 – B	36 – B	53 – A
3 – A	20 – C	37 – A	54 – A
4 – A	21 – A	38 – C	55 – C
5 – D	22 – D	39 – A	56 – D
6 – D	23 – D	40 – A	57 – B
7 – B	24 – D	41 – C	58 – B
8 – D	25 – C	42 – C	59 – B
9 – B	26 – B	43 – D	60 – B
10 – C	27 – D	44 – C	
11 – B	28 – C	45 – B	
12 – B	29 – C	46 – C	
13 – C	30 – C	47 – C	
14 – A	31 – B	48 – A	
15 – B	32 – B	49 – B	
16 – C	33 – B	50 – C	
17 – B	34 – C	51 – D	