(I) Multiple Choices.　Please choose the one alternative that best answers the question. (56%, 2% of each)

(1) One nanogram doesn't seem like a very large number.　How many magnesium atoms are there in 1.00 ng of magnesium?

(A) 4.11×10^{12} atoms　　　　(B) 2.48×10^{13} atoms　　　　(C) 6.83×11^{15} atoms

(D) 6.02×10^{14} atoms　　　　(E) 1.46×10^{14} atoms

(2) The Hall process for the production of aluminum involves the reaction of aluminum oxide with elemental carbon to give aluminum metal and carbon monoxide.　If the yield of this reaction is 82% and aluminum ore is 71% by mass aluminum oxide, what mass of aluminum ore must be mined in order to produce 1.0×10^3 kg of aluminum metal by the Hall process?

(A) 1.8×10^3 kg　　　　(B) 2.2×10^3 kg　　　　(C) 1.1×10^3 kg

(D) 1.6×10^3 kg　　　　(E) 3.3×10^3 kg

(3) Which of the following compounds is a weak electrolyte?

(A) HCl　　　(B) CH_3COOH　　　(C) $C_6H_{12}O_6$　　　(D) O_2　　　(E) NaCl

(4) When 20.0 mL of a 0.25 M $(NH_4)_2S$ solution is added to 150.0 mL of a solution of $Cu(NO_3)_2$, a CuS precipitate forms.　The precipitate is then filtered from the solution, dried, and weighed.　If the recovered CuS is found to have a mass of 0.3491 g, what was the concentration of copper ions in the original $Cu(NO_3)_2$ solution?

(A) 3.65×10^{-3} M　　　　(B) 1.22×10^{-2} M　　　　(C) 3.33×10^{-2} M

(D) 4.87×10^{-2} M　　　　(E) 2.43×10^{-2} M

(5) Air contains 78% N_2, 21% O_2, and 1% Ar by volume.　What is the density of air at 1,000 torr and $-10\ ^\circ C$?

(A) 1.3 g/L　　　(B) 2.6 g/L　　　(C) 3.5 g/L　　　(D) 1.8 g/L　　　(E) 0.56g /L

(6) Which statement is false?

(A) The average kinetic energies of molecules from samples of different "ideal" gases are the same at the same temperature.

(B) The molecules of an ideal gas are relatively far apart.

(C) All molecules of an ideal gas have the same kinetic energy at constant temperature.

(D) Molecules of a gas undergo many collisions with each other and the container walls.

(E) Molecules of greater mass have a lower average speed than those of less mass at the same temperature.

(7) A 100.0 mL sample of 0.2 M aqueous hydrochloric acid is added to 100.0 mL of 0.2 M aqueous ammonia in a calorimeter whose heat capacity (excluding any water) is 480 J/K. The following reaction occurs when the two solutions are mixed.

$$HCl_{(aq)} + NH_{3(aq)} \rightarrow NH_4Cl_{(aq)}$$
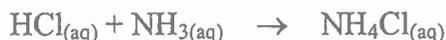
The temperature increase is 2.34°C. Calculate ΔH per mole of HCl and NH_3 reacted.

(A) 154 kJ/mol　(B) 1.96 kJ/mol　(C) 485 kJ/mol　(D) −1.96 kJ/mol　(E) −154 kJ/mol

(8) The atomic radius of sodium is 186 pm and of chlorine is 100 pm. The ionic radius for Na^+ is 102 pm and for Cl^- is 181 pm. In going from Na to Cl in Period 3, why does the atomic radius decrease while the ionic radius increases?

(A) The inner electrons in the sodium cation shield its valence electrons more effectively than the inner electrons in the chloride anion do.

(B) The inner electrons shield the valence electrons more effectively in the chlorine atom than in the chloride anion.

(C) The outermost electrons in chloride experience a smaller effective nuclear charge than those in the sodium cation do.

(D) The outermost electrons in chloride experience a larger effective nuclear charge than those in the sodium cation do.

(E) Monatomic ions are bigger than the atoms from which they are formed.

(9) Examine the phase diagram for the substance Bogusium (Bo) and select the correct statement.
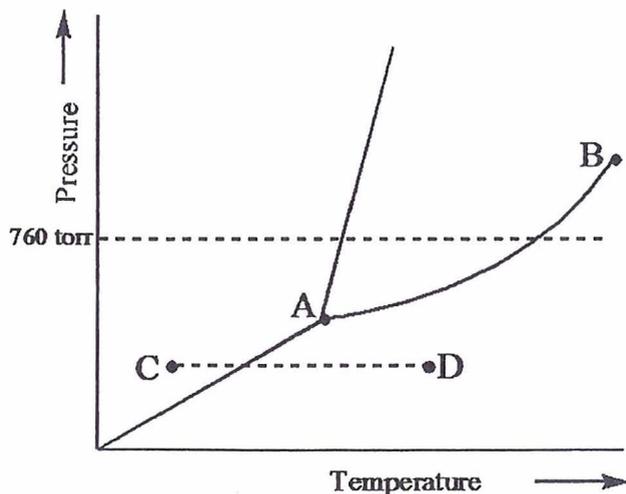
(A)　$Bo_{(s)}$ has a lower density than $Bo_{(l)}$.

(B)　The triple point for Bo is at a higher temperature than the melting point for Bo.

(C)　Bo changes from a solid to a liquid as one follows the line from C to D.

(D)　Bo changes from a liquid to a gas as one follows the line from C to D.

(E)　Point B represents the critical temperature and pressure for Bo.

(10) Ozone (O_3) in the atmosphere can be reacted with nitric oxide (NO) to produce oxygen gas and nitrogen dioxide.　What is the enthalpy change when 8.50L of ozone at a pressure of 1.00 atm and 25°C reacts with 12.0 L of nitric oxide at the same initial pressure and temperature? [$\Delta H°_f(NO) = 90.4$ kJ/mol; $\Delta H°_f(NO_2) = 33.85$ kJ/mol; $\Delta H°_f(O_3) = 142.2$ kJ/mol]

(A) –69.2 kJ　　　(B) –19.7 kJ　　　(C) –1690 kJ　　　(D) –97.6 kJ　　　(E) –167 kJ

(11) Green light has a wavelength of 520 nm. Calculate the energy of one photon of green light.

(A) 3.4×10^{-40} J　　(B) 3.4×10^{-30} J　　(C) 3.8×10^{-29} J　　(D) 3.4×10^{-27} J　　(E) 3.8×10^{-19} J

(12) The longest wavelength of light that causes electrons to be ejected from the surface of a copper plate is 243 nm.　What is the maximum velocity of the electrons ejected when light of wavelength 200 nm shines on a copper plate?

(A) 1.48×10^6 m/s　　　　(B) 6.22×10^5 m/s　　　　(C) 4.67×10^4 m/s

(D) 1.97×10^4 m/s　　　　(E) 1.34×10^6 m/s

(13) Which one of the following sets of quantum numbers is not possible?

	n	l	m_l	m_s
(A)	4	3	-2	+1/2
(B)	3	2	-3	-1/2
(C)	3	0	0	+1/2
(D)	4	1	1	-1/2
(E)	2	0	0	+1/2

(14) Consider the species Cl_2^+, Cl_2, and Cl_2^-.　Which of these species will be paramagnetic?

(A) Only Cl_2　　　　(B) Cl_2^+ and Cl_2　　　　(C) Cl_2 and Cl_2^-

(D) Cl_2^+ and Cl_2^-　　　　(E) All three are paramagnetic

(15) Potassium bromide, KBr, crystallizes like NaCl in a face-centered lattice. The ionic radii of K^+ and Br^- ions are 133 pm and 195 pm, respectively. Assuming that all Br^- ions are positioned in the face and corners of the unit cell, while the K^+ ions are positioned along the edge alternating between anions, calculate the length of a unit cell edge.

(A) 230 pm   (B) 328 pm   (C) 523 pm   (D) 656 pm   (E) 780 pm

(16) The thermal decomposition of acetaldehyde, $CH_3CHO \rightarrow CH_4 + CO$, is a second-order reaction. The following data were obtained at 518°C.

Time (s)	Pressure CH_3CHO (mm-Hg)
0	364
42	330
105	290
720	132

Based on the data given, what is the half-life for the disappearance of acetaldehyde?

(A) 1.5×10^5 s   (B) 410 s   (C) 5.4×10^7 s   (D) 520 s   (E) 305 s

(17) Which of the following is a true statement about chemical equilibria in general?

(A) At equilibrium the total concentration of products equals the total concentration of reactants.

(B) Equilibrium is the result of the cessation of all chemical change.

(C) There is only one set of equilibrium concentrations that equals the K_c value.

(D) At equilibrium, the rate constant of the forward reaction is equal to the rate constant for the reverse reaction.

(E) At equilibrium, the rate of the forward reaction is equal to as the rate of the reverse reaction.

(18) Arrange the acids HF, HCl, H_2SO_4 and HNO_3 in order of increasing acid strength.

(A) $HF < HCl < HNO_3 < H_2SO_4$ (B) $HCl < HF < H_2SO_4 < HNO_3$

(C) $HCl < HNO_3 < H_2SO_4 < HF$ (D) $HF < HNO_3 < H_2SO_4 < HCl$

(E) $HF < H_2SO_4 < HCl < HNO_3$

(19) Arrange the following substances in the order of increasing entropy at 25°C.

$$HF_{(g)}, \quad NaF_{(s)}, \quad SiF_{4(g)}, \quad SiH_{4(g)}, \quad Al_{(s)}$$

(A) $SiF_{4(g)} < SiH_{4(g)} < NaF_{(s)} < HF_{(g)} < Al_{(s)}$

(B) $HF_{(g)} < Al_{(s)} < NaF_{(s)} < SiF_{4(g)} < SiH_{4(g)}$

(C) $Al_{(s)} < NaF_{(s)} < HF_{(g)} < SiH_{4(g)} < SiF_{4(g)}$

(D) $Al_{(s)} < HF_{(g)} < NaF_{(s)} < SiF_{4(g)} < SiH_{4(g)}$

(E) $NaF_{(s)} < Al_{(s)} < HF_{(g)} < SiF_{4(g)} < SiH_{4(g)}$

(20) Sodium carbonate can be made by heating sodium bicarbonate:

$$2NaHCO_{3(s)} \rightarrow Na_2CO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$$

Given that $\Delta H° = 128.9$ kJ/mol and $\Delta G° = 33.1$ kJ/mol at 25°C, above what minimum temperature will the reaction become spontaneous under standard state conditions?

(A) 104 K   (B) 295 K   (C) 321 K   (D) 401 K   (E) 525 K

(21) For the reaction $H_{2(g)} + S_{(s)} \rightarrow H_2S_{(g)}$, $\Delta H° = -20.2$ kJ/mol and $\Delta S° = +43.1$ J/K-mol.   Which of the following statements is true?

(A) The reaction is only spontaneous at low temperatures.

(B) The reaction is spontaneous at all temperatures.

(C) $\Delta G°$ becomes less favorable as temperature increases.

(D) The reaction is spontaneous only at high temperatures.

(E) The reaction is at equilibrium at 25°C under standard conditions.

(22) The substance of $AlCl_3$ is considered as

(A) a strong Brönsted acid   (B) a weak Brönsted acid   (C) a strong Lewis acid

(D) a weak Lewis acid   (E) a neutral compound

(23) The half-reaction that occurs at the cathode during electrolysis of an aqueous sodium iodide solution is:

(A) $Na^+ + e^- \rightarrow Na$ (B) $Na \rightarrow Na^+ + e^-$ (C) $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

(D) $I_2 + 2e^- \rightarrow 2I^-$ (E) $2I^- \rightarrow I_2 + 2e^-$

(24) In the complex ion $[Co(en)_2Br_2]^+$, the oxidation number of Co is

(A) +1   (B) +2   (C) +3   (D) -2   (E) -1

(25) Consider the following structures (1 and 2 are octahedral; 3 and 4 are square planar).
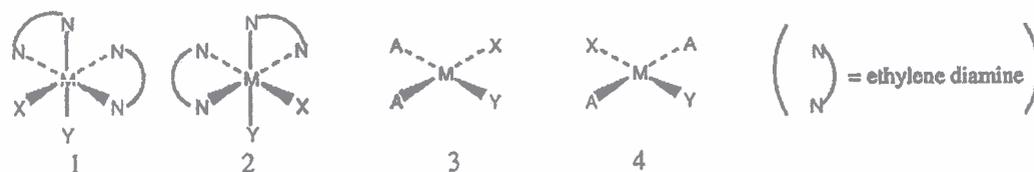
Which one of the following statements about the above structures is correct?

(A) 1 and 2 are superimposable.　　　　(B) 1 and 2 are geometric isomers.

(C) 3 and 4 are structural isomers.　　　(D) 3 and 4 are optical isomers.

(E) 3 and 4 are geometric isomers.

(26) Which one of the following statements about fission and fusion is false?

(A) Fission occurs among the heaviest isotopes, whereas fusion occurs more readily for light isotopes.

(B) For a fission reaction the mass defect (Δm) is negative, whereas for fusion Δm is positive.

(C) In order for fusion reactions to occur, temperatures must be in the millions of degrees.

(D) The fission of Pu-239 atoms produces a great number of isotopes of a large number of elements.

(E) Neutron-induced fission processes can occur at room temperature, rather than at millions of degrees.

(27) How many ^{14}C atoms are in a charcoal sample that has a decay rate of 3,500 disintegrations per min? (For ^{14}C, $t_{1/2}$ = 5,730 yr.)

(A) 2.9×10^7 atoms　　　　(B) 8.0×10^7 atoms　　　　(C) 1.4×10^{14} atoms

(D) 1.5×10^{13} atoms　　　　(E) 6.02×10^{20} atoms

(28) One can safely assume that the 3s- and 3p-orbitals will form molecular orbitals similar to those formed when 2s- and 2p-orbitals interact. According to molecular orbital theory, what will be the bond order for the Cl_2^+ ion?

(A) 0.5　　　　(B) 1.0　　　　(C) 1.5　　　　(D) 2.0　　　　(E) 3.0

(II) (a) Explain how the crystal field theory can use the magnitude of the splitting energy (Δ) to provide an explanation of the color and magnetic properties of octahedral complexes. (3%)

(b) In promoting an electron from the t_{2g} set of orbitals to the e_g set, an octahedral complex absorbs a photon with a wavelength λ of 523 nm. Calculate the value of Δ in the complex, in kJ/mol. (3%)

(III) Scuba diving is an exhilarating sport and is also a safe activity for trained individuals who are in good health.　A typical dive might be 10 to 20 meters, but dives to 30 meters are not uncommon.

(a) What would happen if a diver rose to the surface from a depth of 15 meters rather quickly without breathing?　Please use the change in pressure to explain this phenomenon. (3%)

(b) Usually the divers will equip with scuba tank to ensure that the air pressure they breathe equals the water pressure at all time and inert gas is usually used to dilute oxygen gas for meeting this purpose.　Of various inert gases used, helium (He) gas is the often used gas rather nitrogen (N_2) to dilute oxygen gas in scuba tank.　Please use Dalton's law and gas solubility to explain why inert gas is needed to dilute oxygen gas in scuba tank and why helium is better than nitrogen? (3%)

(IV) Ozone is the most important atmospheric gas to protect human beings against UV radiation. Given that the quantity of ozone in the stratosphere at 26 km is equivalent to a 3.0-mm-thick layer of ozone on Earth at STP.

(a) Calculate the number of ozone molecules in the stratosphere and their mass by assuming the radius of Earth is 6370 km. (3%)

(b) In the mid-1980s, evidence began to accumulate that an "Antarctic ozone holes" developed in late winter.　Now it is clear that the polar ozone hole is mainly caused by the massive use of chlorinated compounds such as Freon (chlorofluorocarbons, CFCs).　Taking Freon-12 as an example, explain how CFCs deplete the ozone molecules in the stratosphere? (3%)

(c) If ozone is generated according to the process $3O_{2(g)} \rightarrow 2O_{3(g)}$, please calculate the wavelength the oxygen molecules can absorb to convert to ozone.　How many ozone molecules can be produced in the stratosphere at 26 km when oxygen molecules absorb the wavelength? (4%)

Species	ΔH_f^0 (kJ/mol)	ΔG_f^0 (kJ/mol)	ΔS_f^0 (J/mol-K)
$O_{2(g)}$	0	0	205.0
$O_{(g)}$	249.2	231.7	160.95
$O_{3(g)}$	142.2	163.0	238.82

(V)　A quantitative measurement of how efficiently spheres pack into unit cells is called packing efficiency, which is the percentage of the cell space occupied by the spheres.　Please calculate the packing efficiencies of a simple cubic cell, a body-centered cubic cell, and a face-centered cubic cell. (8%)

(VI) Acetylene (C_2H_2) has a tendency to lose two protons and form the carbide ion (C_2^{2-}), which is present in a number of ionic compounds, such as CaC_2 and MgC_2.　Please describe the bonding scheme in the C_2^{2-} ion in terms of molecular orbital theory.　Also compare the bond order C_2^{2-} with that in C_2. (8%)

(VII) An acidified solution was electrolyzed using copper electrodes.　A constant current of 1.18 A caused the anode to lose 0.584 g after 25 min.

(a) What is the gas produced at the cathode and what is its volume at STP? (3%)

(b) Calculate the experimental Avogadro's number.　**Compare your result with** the generally accepted value of Avogadro's number. (3%)

Note: The atomic masses of elements are as follows:

H = 1.0	He = 4.0	C = 12.0	N = 14.0	O = 16.0	F = 19.0
Na = 23.0	Mg = 24.3	Al = 27.0	S = 32.1	Cl = 35.5	K = 39.1
Mn = 54.9	Cu = 63.5	Br = 79.9	I = 126.9		