(Closed Book, 180 minutes, 350 points)

Version A

Name:________________________ **TA:**________

SID:__________________________ **Section:**_____

Please read this first: Write your name and that of your TA on all 16 pages; On the **Scantron™**, bubble in Form A.

Test-taking Strategy

This test consists of two parts: multiple choice (**answers to be circled and entered on the Scantron™ sheet**) and short answer. In order to maximize your score on the exam:

- Do the questions you know how to do first.
- Then, go back and spend more time on the questions you find more challenging.
- Budget your time carefully -- don't spend too much time on one problem.
- Show all work for which you want credit and don't forget to include units.

Page	Score
MC	
11	
12	
13	
14	
15	
Total	

Potentially Useful Information

$E = h\nu$

$\lambda\nu = c$

$\lambda_{deBroglie} = h / p = h / mv$

$E_{kin}(e^-) = h\nu - \Phi = h\nu - h\nu_0$

$$E_n = -\frac{Z^2}{n^2} R_\infty$$

$PV = nRT$

$$E_{kin} = \frac{3}{2} RT$$

$$v_{rms} = \sqrt{\frac{3RT}{M}}$$

$\Delta E = q + w$

$w = - P_{ext}\Delta V$

$$\Delta E = \frac{3}{2} nR\Delta T$$

$\Delta G° = \Delta H° - T\Delta S°$

$\Delta H° = \Sigma\, \Delta H°_f\,(\text{products}) - \Sigma\, \Delta H°_f\,(\text{reactants})$

$\Delta S° = \Sigma\, S°\,(\text{products}) - \Sigma\, S°\,(\text{reactants})$

$\Delta G° = \Sigma\, \Delta G°_f\,(\text{products}) - \Sigma\, \Delta G°_f\,(\text{reactants})$

$S = k_B \ln W$

for $aA + bB \rightleftarrows cC + dD$

$$Q = \frac{[C]^c[D]^d}{[A]^a[B]^b} \quad \text{At equilibrium, } Q = K$$

$\Delta G° = - RT\ln K$

$$\ln K = -\frac{\Delta H°}{R}\frac{1}{T} + \frac{\Delta S°}{R}$$

$\Delta G° = - nF\Delta \epsilon°$

$pX = - \log X$

$$pH = pK_a + \log\frac{[A^-]}{[HA]}$$

$R = 0.08206\ (\text{atm·L}) / (\text{mol·K})$
$\quad = 8.314\ \text{J/(mol·K)}$

$k_B = 1.381 \times 10^{-23}$ J / K

$h = 6.626 \times 10^{-34}$ J s

$c = 3.0 \times 10^8\ \text{m·s}^{-1}$

$R_\infty = 2.18 \times 10^{-18}$ J

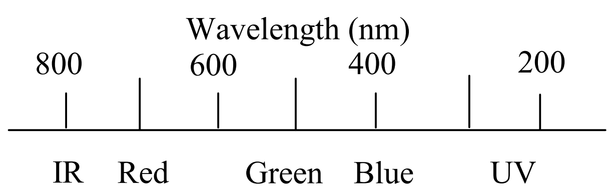
F = 96,485 C / mol

1 V = 1 J / C

1 nm = 10^{-9} m

1 kJ = 1000 J

Color and Wavelength of Light



Average Bond Enthalpies

Bond	Enthalpy (kJ / mol)
C – C	348
C = C	612
C ≡ C	838
C – H	413
H – H	436

Part I Multiple Choice (5 pts each, 225 pts total) Bubble in the correct answer on your Scantron™ form AND circle your answer on the exam. There is only one correct answer for each question, so you should circle and fill in one and only one answer for each question. There is no penalty for an incorrect response.

1) Consider the formation of hydrogen peroxide from the elements in their standard states:

$H_2 + O_2 \rightarrow H_2O_2$

How does the oxidation number of oxygen change in the above reaction?

A) $-2 \rightarrow -2$ B) $-1 \rightarrow 0$ C) $0 \rightarrow 0$ $\boxed{\text{D) } 0 \rightarrow -1}$ E) $0 \rightarrow -2$

2) Which of the following samples of gas has the highest root mean square speed?

A) H_2 at 200 K
B) He at 200 K
C) Ar at 200 K
D) Ar at 400 K
E) CO_2 at 500 K

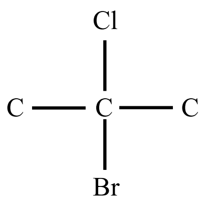
3) Which of the following reactions exhibits the greatest change in entropy?

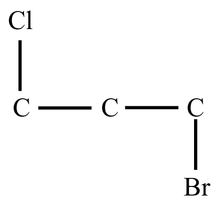
A) $CaO\ (s) + CO_2\ (g) \rightarrow CaCO_3\ (s)$
B) $N_2\ (g) + 3\ H_2\ (g) \rightarrow 2\ NH_3\ (g)$
C) $C\ (s) + H_2O\ (g) \rightarrow H_2\ (g) + CO\ (g)$
D) $CO\ (g) + H_2O\ (g) \rightarrow CO_2\ (g) + H_2\ (g)$
E) $2\ NO\ (g) + O_2\ (g) \rightarrow 2\ NO_2\ (g)$

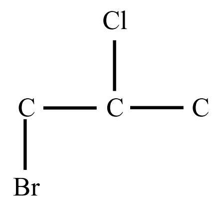
4) The empirical formula of a hydrocarbon gas is CH_2. If 2.10 g of gas occupies 1.12 L at 1.00 atm and 273 K, what is the molecular formula of the hydrocarbon gas?

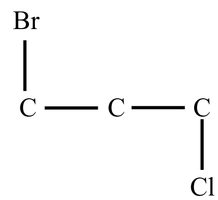
A) CH B) CH_2 C) C_2H_4 $\boxed{\text{D) } C_3H_6}$ E) C_4H_8

5) Which of the following structural isomers of chlorobromopropane (C_3H_6BrCl) is chiral (note the H atoms are omitted for clarity)?

A) 

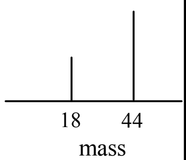
B) 

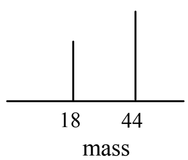
C) 

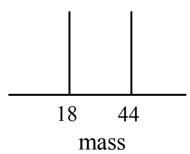
D) 

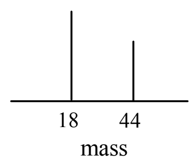
E) none of these

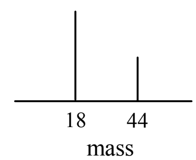
6) Which of the following is the mass spectrum of the combustion products of trimethylbenzene (C_9H_{12})?

A) 

B) 

C) 

D) 

E) 

7) What is the hybridization of the carbon atoms in ethylene, C_2H_4?

A) sp B) $\boxed{\text{sp}^2}$ C) sp^3 D) s^2p E) s^2p^4

8) Use the table of average bond enthalpies to estimate ΔH° (in kJ /mol) for the following reaction:

$$C_2H_4 + H_2 \rightarrow C_2H_6$$

A) -290 B) $\boxed{-126}$ C) 0 D) 126 E) 290

9) Which of the following molecules has a nonzero dipole moment?

A) CH_3^+ B) BF_3 C) $AlBr_3$ D) $\boxed{PCl_3}$ E) CO_2

10) A gas expands isothermally against a vacuum ($P_{ext} = 0$), which of the following is NOT true?

A) $q = 0$ B) $w = 0$ C) $\Delta E = 0$ D) $\Delta H = 0$ $\boxed{\text{E) } \Delta S = 0}$

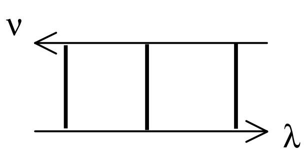
11) Which of the following is always conserved during a chemical reaction?

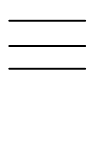
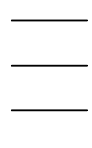
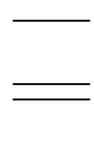
A) entropy B) molecules C) moles $\boxed{\text{D) mass}}$ E) none of these

12) A flask is filled with 16.0 g of methane (CH_4) and 16.0 g of oxygen which combust to form carbon dioxide and water. Which is the limiting reagent?

A) CH_4 $\boxed{\text{B) } O_2}$ C) CO_2 D) H_2O E) none of these

13) To which energy level diagram does the following emission spectrum correspond?



A)  B)  C)  D)  E) 

14) Light of 121 nm wavelength is emitted in the n =2 → 1 transition in H. What transition in He^+ will emit the same wavelength of light?

A) 2 → 1 B) 2 → 2 C) 4 → 1 $\boxed{\text{D) } 4 \rightarrow 2}$ E) 4 → 3

15) Which of the following has the lowest ionization energy?

A)H(1s) B) He(1s4p) C) He(1s3d) D) Li($1s^2 3p$) $\boxed{\text{E) Li}(1s^2 5s)}$

16) Which atom or ion can have the electronic configuration $[He]2s^2 2p^5 3s^1$?

A) F^+ B) F $\boxed{\text{C) }Na^+}$ D) Na E) Mg^+

17) Which of the following is required in the least amount to dissolve 10 mg of aluminum hydroxide {$Al(OH)_3$, $Ksp = 1.9 \times 10^{-33}$} ?

A) 8 M NaOH B) 1 M NaOH $\boxed{\text{C) 5 M acetic acid}}$ D) 1 M acetic acid E) H_2O

18) Which of the following molecules has a molecular geometry most similar to SF_4^{2-}?

A) CCl_4 B) NH_4^+ C) BF_4^- D) SI_4 $\boxed{\text{E) }XeF_4}$

19) The K_a for chloroacetic acid ($CH_2ClCOOH$) is 5.65×10^{-3}. If the equilibrium concentrations of $[CH_2ClCOOH] = 8.88 \times 10^{-2}$ M and $[CH_2ClCOO^-] = 2.24 \times 10^{-2}$ M, what is the corresponding $[H_3O^+]$ (in M)?

$$CH_2ClCOOH\ (aq) + H_2O\ (l) \leftrightarrow CH_2ClCOO^-\ (aq) + H_3O^+\ (aq)$$

A) 5.65×10^{-3} B) 8.88×10^{-2} $\boxed{\text{C) }2.24 \times 10^{-2}}$ D) 5.01×10^{-4} E) 6.36×10^{-2}

20) Formic acid is a weak acid with $pK_a = 3.75$. How many mL of 0.10 M NaOH solution should be added to 100.0 mL of 0.10 M formic acid solution to make a buffer solution with pH = 3.27?

A) 0.0 $\boxed{\text{B) 25.0}}$ C) 50.0 D) 75.0 E) 100.0

21) The ionization energy of a certain one-electron species in its ground state is 3.28×10^4 kJ / mol. How many protons are contained in its nucleus?

A) 1 B) 2 C) 3 D) 4 $\boxed{\text{E) 5}}$

22) Consider the conversion of ozone to oxygen:

$$2\ O_3 \rightarrow 3\ O_2 \quad \Delta H° = -286 \text{ kJ / mol}$$

Which of the following is true about the bond enthalpies (E)?

$\boxed{\text{A) } E_{O=O} > 2\ E_{O\text{-}O}}$
B) $E_{O=O} = 2\ E_{O\text{-}O}$
C) $E_{O=O} < 2\ E_{O\text{-}O}$
D) $E_{O=O} < E_{O\text{-}O}$
E) $E_{O=O} = E_{O\text{-}O}$

23) Which of the following atoms or ions has the smallest radius?

A) Mg $\boxed{\text{B) } Na^+}$ C) Ne D) F^- E) O^{2-}

24) When a system has reached equilibrium, which of the following is true for the rates of the forward and reverse reactions?

A) Forward = 0
B) Reverse = 0
C) Forward < Reverse
$\boxed{\text{D) Forward = Reverse}}$
E) Forward > Reverse

25) Why is the ionization energy for Na^+ larger than the ionization energy for Ne?

A) Neon is a noble gas.
B) Neon has a smaller radius that Na^+.
C) Neon has fewer protons.
D) The outer electrons in sodium are in a higher energy level.
E) Sodium is more metallic.

26) Consider the following reaction at equilibrium:

$$2\ NH_3\ (g) \rightarrow N_2\ (g) + 3\ H_2\ (g) \qquad \Delta H^\circ = +92.4\ kJ$$

Removing some N_2 (g) from the system at equilibrium will __________.

A) increase the partial pressure of NH_3 (g) at equilibrium
B) decrease the partial pressure of H_2 (g) at equilibrium
C) increase the value of the equilibrium constant
D) cause the reaction to shift to the right
E) increase the reaction temperature

27) Of the following, ΔG_f° is not zero for __________.

A) O_2 (liquid)
B) C(graphite)
C) N_2(gas)
D) F_2(gas)
E) Cl_2(gas)

28) What is the pH of a 0.10 M HCl solution?

A) 0.00 B) 1.00 C) 1.89 D) 3.75 E) 10.00

29) What is the change in the internal energy, ΔE (in J) of a system that absorbs 4000 J of heat and that does 2000 J of work on the surroundings?

A) 6000
B) 4000
C) 2000
D) -2000
E) -4000

30) At lower temperatures

A) Chemical reactions are more favorable.
B) Chemical reactions are less favorable.
C) Equilibrium constants are smaller.
D) Equilibrium constants are larger.
E) Chemical reactions are sometimes more favorable.

31) We have seen many times in lecture that heat is given off in the combustion of hydrogen gas. Which of the following is responsible for the heat?

A) Breaking H-H and O-O bonds.
B) Breaking O-H bonds.
C) Forming H-H bonds and O-O bonds.
D) Forming O-H bonds.
E) Vaporization of the water formed.

32) For the reaction :

$$A(l) + D(g) \rightarrow X(g) + Z(s)$$

having ΔG° = -500 kJ / mol at 25˚C, the equilibrium mixture __________.

A) will consist almost exclusively of A and D.
B) will consist almost exclusively of X and Z.
C) will consist almost exclusively of A and Z.
D) will consist of significant amounts of A, D, X, and Z.
E) has a composition predictable only if one knows T and ΔH°.

33) A beam of yellow light does not eject electrons from a certain metal. What change to the beam should be made in an attempt to eject electrons?

A) Increase the wavelength.
B) Increase the intensity.
C) Increase the frequency.
D) Change the color to red.
E) None of the above will work

34) A 0.10 mole sample of He (g) is added to a 1.00 L flask containing Ar gas at 1.00 atm at 273 K. What is the partial pressure of He?

A) 0.10 atm B) 1.24 atm C) 1.00 atm $\boxed{\text{D) 2.24 atm}}$ E) 3.24 atm

35) A 0.10 mole sample of He (g) is added to a 1.00 L flask containing Ar gas at 1.00 atm at 273 K. What is the total pressure in the flask?

A) 0.10 atm B) 1.24 atm C) 1.00 atm D) 2.24 atm $\boxed{\text{E) 3.24 atm}}$

Use the following table to answer questions 36-38.

Reaction	Standard Reduction Potential (Volts)
Ag^{+1} (aq) + e^- $\rightarrow$ Ag (s)	+0.80
Cu^{+2} (aq) + 2 e^- $\rightarrow$ Cu (s)	+0.34
Ni^{+2} (aq) + 2 e^- $\rightarrow$ Ni (s)	-0.23
Fe^{+2} (aq) + 2 e^- $\rightarrow$ Fe (s)	-0.41
Zn^{+2} (aq) + 2 e^- $\rightarrow$ Zn (s)	-0.76

36) What will be produced when an iron rod is placed in a solution of $AgNO_3$ solution?

A) H_2 (g) B) Ag (s) C) Fe^{+2} D) $AgNO_3$ (s) $\boxed{\text{E) B and C}}$

37) What is the potential (in volts) for the cell described below?

Cu | $CuSO_4$ (1.0 M) || $AgNO_3$ (1.0 M) | Ag

A) 0.16 B) 0.34 $\boxed{\text{C) 0.46}}$ D) 0.80 E) 1.14

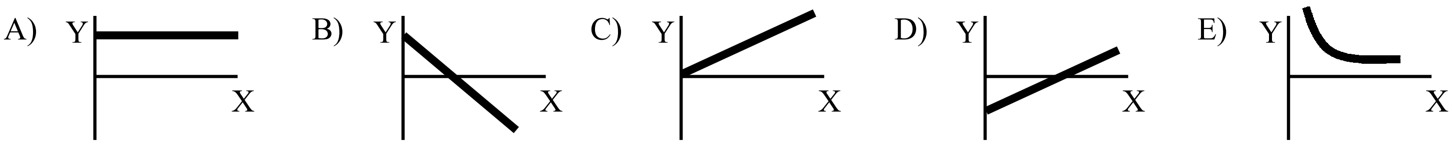
38) What is the ΔG° (in kJ) for the cell described below?

Zn | $ZnSO_4$ (1.0 M) || H_2SO_4 (1.0 M) | H_2 | Pt

$\boxed{\text{A) -147}}$ B) -78 C) 0 D) 78 E) 147

Name:____________________ TA:______________________

For Questions 39-45, which sketch best depicts the dependence of Y vs X for the following:



39) P vs V for an ideal gas.

A) A B) B C) C D) D $\boxed{\text{E) E}}$

40) $\Delta G°$ vs T for the reaction $Cl_2 \rightarrow 2\ Cl$.

A) A $\boxed{\text{B) B}}$ C) C D) D E) E

41) ln K vs 1/T for dissolution of borax $Na_2[B_4O_5(OH)_4]\bullet 8H_2O$ (the reaction is endothermic).

A) A $\boxed{\text{B) B}}$ C) C D) D E) E

42) Kinetic Energy vs T for 1 mole of an ideal gas.

A) A B) B $\boxed{\text{C) C}}$ D) D E) E

43) Absorbance vs. concentration for a dilute solution of sunscreen.

A) A B) B $\boxed{\text{C) C}}$ D) D E) E

44) ΔЄº vs number of moles of magnesium for the reduction of magnesium metal.

$\boxed{\text{A) A}}$ B) B C) C D) D E) E

45) Photon energy versus wavelength of light.

A) A B) B C) C D) D $\boxed{\text{E) E}}$

Part 2: Short Answer Problems (125 pts total)
Instructions: Enter answers in the boxes where provided. Show all work for which you wish to receive credit. Where explanations are required, only the first fifteen words will be considered for your grade.

1.) (85 pts) Nitrous acid (HNO_2) has a $pK_a = 3.34$.

$$HNO_2\,(aq) + H_2O\,(l) \rightleftarrows NO_2^-\,(aq) + H_3O^+\,(aq)$$

a) (15 pts) Calculate $\Delta G°$ (in kJ / mol) for the reaction of nitrous acid with water at 25 °C.

$pK_a = -\log K_a$

$10^{-3.34} = K_a$

$K_a = 4.57 \times 10^{-4}$

$\Delta G° = -RT\ln K$

$$= -8.314\frac{J}{mol \bullet K} \bullet 298K \ln(4.57\times10^{-4})$$

$= 19.1$ kJ / mol

$\Delta G°$:
19.1 kJ / mol

b) (10 pts) Classify HNO_2 as an acid or base by circling an option below. Provide an explanation.

strong acid   strong base   weak acid   weak base   none of these

Explanation:
Proton donor, $\Delta G° > 0$, equilibrium lies to the left

c) (10 pts) Which of the following pH ranges corresponds to the region where a solution containing HNO_2 is an effective buffer. Circle your answer and provide an explanation.

$\boxed{4.34 – 2.34}$ 5.34 – 1.34 5.34 – 7.34

Explanation:

Buffer region is around $pK_a \pm 1$ pH unit

d) (25 pts) A solution 100 mL 0.1 M HNO_2 is titrated to the equivalence point with 0.1 M NaOH.

i) What is the total volume of the solution(in mL)?

0.1 L (0.1 M HNO_2) = 0.01 moles HNO_2
0.1 moles NaOH = 0.1M NaOH X L
X = 0.1 L
V_{tot} = 0.2 L = 200 mL

V:
200 mL

ii) What is the pH of the solution?
at the equivalence point 0.01 moles $NaNO_2$ have been formed
$[NaNO_2]$ = 0.01 moles / 0.2 L = 0.05 M Kb = Kw / Ka = $1 \times 10^{-14} / 4.57 \times 10^{-4} = 2.18 \times 10^{-11}$

$NaNO_2^-$ (aq) + H_2O (l) $\rightleftarrows$ HNO_2 (aq) + OH^- (aq)

pH:
8.0

$$K_b = \frac{[HNO_2][OH^-]}{NaNO_2^-} = \frac{x^2}{0.05 - x} = 2.18 \times 10^{-11}$$ if x << 0.05 x = 1.04×10^{-6} = $[OH^-]$

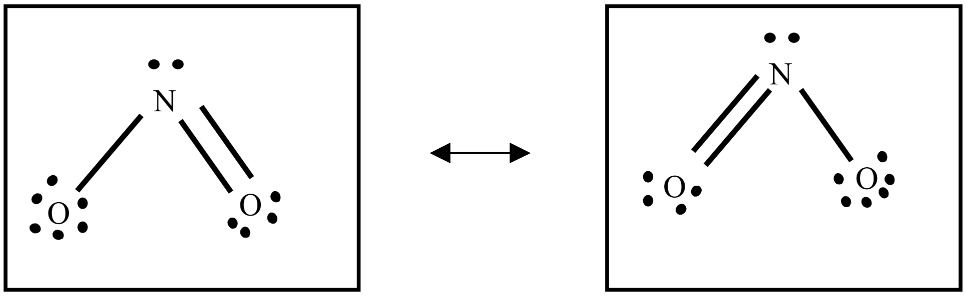
pOH = -log (1.04×10^{-6}) = 5.98 pH = 14 – pOH = 8.0

iii) For the titration of HNO_2, the pH at the equivalence point is **not** 7. Explain.

Explanation:

HNO_2 is a weak acid, the titration generates a conjugate base → pH > 7

e) (25 pts) Draw a pair of valid resonance lewis dot structures for the NO_2^- ion.



i) Which of the following best describes the bond angle in NO_2^-. Circle your answer.

= 180° = 120° >120° $\boxed{<120°}$

the repulsion from the lone pair of electrons will create a bond angle less than the ideal 120

ii) What is the nitrogen/oxygen bond order NO_2^-?

$$Bond\ order = \frac{total\ \#\ of\ \ N/O\ bonds}{total\ \#\ of\ \ resonance\ structures}$$

Bond order:
1.5

iii) Does NO_2^- have a dipole moment? Circle your answer.

Yes No

unequal distribution of electrons about the central atom make NO_2^- polar

2.) (40 pts) Consider the dissociation of molecular chlorine (Cl_2) to atomic chlorine (Cl):

$$Cl_2 \rightarrow 2\ Cl$$

a) (15 pts) The bond enthalpy of the Cl-Cl bond is 242 kJ / mol. What is the maximum wavelength (λ, in nm) of light required to break the bond?

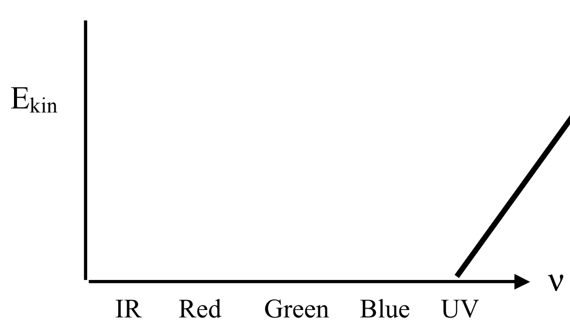
For 1 mole of bonds:
$E = h\nu(6.02 \times 10^{23}) = 242$ kJ / mol

For a single photon to break a single bond:

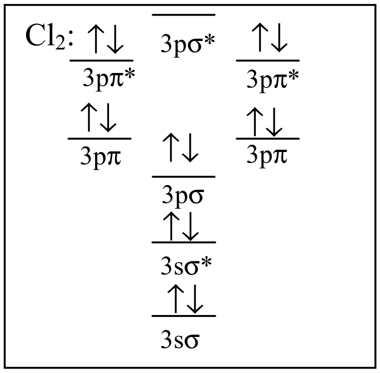
$$E = \frac{242000 \frac{J}{mol}}{6.02 \times 10^{23} \frac{bonds}{mole}} = 4.01 \times 10^{-19}\ \mathrm{J} = \mathrm{h}\nu = h\frac{c}{\lambda}$$

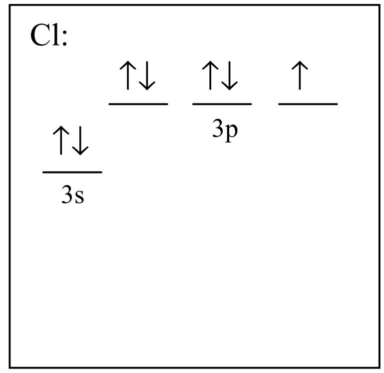
$\lambda = 495\ nm$

b) (10 pts) The minimum frequency of light required to ionize a Cl atom corresponds to the UV region in the electromagnetic spectrum. On the axes provided, sketch a plot of the kinetic energy of electrons ionized from a Cl atom as a function of light frequency.



c) (8 pts) Using ↑ and ↓, fill in the corresponding electronic orbital diagrams for Cl_2 and Cl.





d) (7 pts) What is the change in paramagnetism for the Cl_2 dissociation reaction. Circle your answer.

$\boxed{\text{Increases}}$ Decreases Stays the same