

Q1) 12 points (2 points each)

Arrange the following (Use “>” or “<” to show decreasing and increasing order, respectively. If two options have the same value, use “=” between them)

- a) **Decreasing** order of *wavelength* of a photon for the following transitions in a H atom (assume all given transitions are possible):

2s to 3p 3d to 2p 1s to 3p 2p to 1s 3d to 1s

2s to 3p = 3d to 2p > 2p to 1s > 1s to 3p = 3d to 1s

- b) **Increasing** *boiling point*:

Hexane; 2,3-dimethylbutane; 2-methylpropane; CH₃CH₂CH₂CH₂CH₂CH₂OH

2-methylpropane < 2,3-dimethylbutane < Hexane < CH₃CH₂CH₂CH₂CH₂CH₂OH

- c) **Decreasing** number *delocalized* electrons

Benzene O₃ CO₂ HCOO⁻

Benzene (6) > O₃ = HCOO⁻ (4 for both) > CO₂

Also accepted: Benzene (6) > O₃ = HCOO⁻ = CO₂ (4 for all)

- d) **Increasing** number of *unpaired* electrons

Mo²⁺ Zn²⁺ Fe³⁺ Zr²⁺

Zn²⁺ < Zr²⁺ < Mo²⁺ < Fe³⁺

- e) **Decreasing** *size*

Cs⁺ Sr²⁺ I⁻ Mg²⁺

I⁻ > Cs⁺ > Sr²⁺ > Mg²⁺

- f) **Increasing** number of *valence electrons*

F In Mn Ru

In < F = Mn < Ru

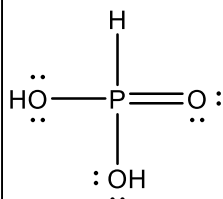
NO PARTIAL MARKS AWARDED FOR ABOVE

Q2) 9 points

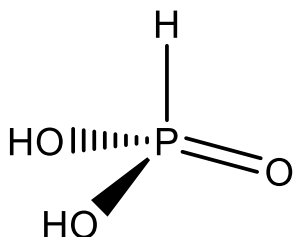
There are two possible ways to draw the Lewis structure of H_3PO_3 in both of which all of the atoms have zero formal charge, but each have different molecular geometry at the central atom (P).

- a) Draw both Lewis structures for H_3PO_3 (there are no O-O bonds). Indicate and draw (show solid wedge-dashed bonds) the molecular geometry around phosphorous atom for both the Lewis structures. **8 points**

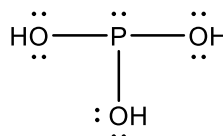
Structure 1:



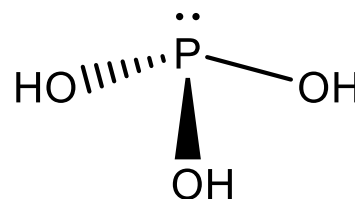
Molecular Geometry: Tetrahedral



Structure 2:



Molecular Geometry: Trigonal Pyramidal



- b) Are these Lewis structures resonance structures of each other? Why or why not? **1 points**

No, these are not resonance structures. There is rearrangement of atoms in the two structures above

Q3) 8 points

The **ionization energy (in kJ/mol)** for a given period 2 element are the following:

	IE₁	IE₂	IE₃	IE₄	IE₅	IE₆	IE₇	IE₈
X	1314	3388	5296	7467	10987	13320	71320	84070

a) What is element X? Briefly explain your reasoning. **3 points**

X is oxygen. Change from IE₆ to IE₇ is the largest change. Removal of the 7th electron must be removal of an electron from an ion with noble gas configuration (i.e there are 6 valence electron). X⁶⁺ is noble gas configuration: oxygen

b) Using the ionization energy values given above, calculate the **lowest frequency** (3 sig. figures) of a photon that can remove an electron from the ground state atom X? Show calculations. **5 points**

Lowest frequency = lowest energy = 1314 kJ/mol

Convert kJ/mol to J to get energy of one photon

$$= 1314 \text{ kJ/mol} * 1000 \text{ J/kJ} * 1 \text{ mol} / 6.023 \times 10^{23} = 2.18 \times 10^{-18} \text{ J}$$

$$E = h \nu$$

$$\nu = E/h = 2.18 \times 10^{-18} \text{ J} / 6.626 \times 10^{-34} \text{ J.s} = 3.29 \times 10^{15} \text{ s}^{-1}$$

Answer: $3.29 \times 10^{15} \text{ s}^{-1}$

Q4) 11 points

- a) A photon of wavelength 300 nm strikes an electron in a metal. The work function of the metal is 3.5×10^{-19} J. What is the velocity (ms^{-1} ; 2 significant figures) of the electron ejected, assuming it was initially at rest? Show calculations. **7 points**

$$E_{\text{photon}} = hc/\lambda = 6.626 \times 10^{-34} \text{ Js} * 2.998 * 10^8 \text{ ms}^{-1} / (300 * 10^{-9} \text{ m})$$

$$E_{\text{photon}} = 6.626 \times 10^{-19} \text{ J}$$

From photoelectric effect equation:

$$E_{\text{photon}} = \text{work function} + KE_{\text{electron}}$$

$$6.626 \times 10^{-19} = 3.5 \times 10^{-19} + KE$$

$$KE = 3.126 \times 10^{-19} \text{ J}$$

$$KE = \frac{1}{2} mv^2$$

$$v = (2KE / m)^{1/2}$$

$$v = 8.3 \times 10^5 \text{ ms}^{-1}$$

- b) Without doing any calculations, predict the change (increase, decrease, or no change) for the following, if the wavelength of the photon was changed to 200 nm. **4 points**

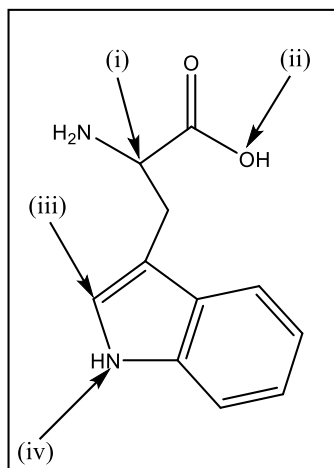
1. Work function of the metal: **No change**

2. Velocity of the electron: **Increase**

3. Number of electrons ejected: **No change**

4. Kinetic energy of the electron: **Increase**

Q5) 10 points



For the indicated atoms (denoted with an arrow), (i) to (iv), answer the following questions. Lone pairs are **not** indicated in the structure. All atoms have formal charge of 0.

a) **(2 points)** Describe the orbitals involved in all bonds formed by C(i). Designate sigma and pi bonds.

2 sp^3 - sp^3 sigma; sp^3 -s sigma; sp^3 - sp^2 sigma

b) **For (ii)**

1. **(1 point)** Indicate the molecular geometry at O:

Bent

2. **(1 point)** Circle the one value that best describes the C-O-H bond angle.

$>90^\circ$ to $<109.5^\circ$ 109.5° $>109.5^\circ$ to $<120^\circ$ 120° $>120^\circ$ to $<180^\circ$

c) **For (iii)**

1. **(1 points)** Indicate the hybridization at C(iii):

sp^2

2. **(3 points)** Consider x as the bond axis, how many p_x - p_x and p_y - p_y pi bonds does (iii) have?

p_x - p_x pi bonds =

0

p_y - p_y pi bonds =

0 or 1

d) **For (iv)**

1. **(1 point)** Indicate the molecular geometry at (iv):

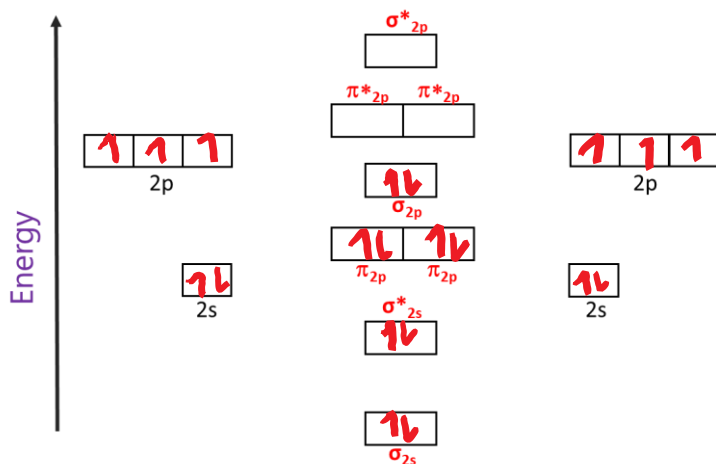
trigonal pyramidal

2. **(1 point)** Circle the one value that best describes the H-N-C bond angle.

$>90^\circ$ to $<109.5^\circ$ 109.5° $>109.5^\circ$ to $<120^\circ$ 120° $>120^\circ$ to $<180^\circ$

Q6) 10 points

- a) Draw the molecular orbital (MO) diagram for N_2 (valence orbitals only). Label all the atomic and molecular orbitals (No need to show contribution/dotted lines from atomic orbitals). What is the bond order for N_2 ? **6 points**



Bond order for $N_2 = 3$

- b) Based on MO diagrams only, predict which of the following has the higher ionization energy (IE) in each case, and why? **4 points**

1. Higher IE: N_2 or N_2^{2-}

N_2 has a higher IE than N_2^{2-} as electron being removed from a more stable orbital

2. Higher IE: C_2 or C_2^{2-}

C_2 has a higher IE than C_2^{2-} as electron being removed from a more stable orbital

Answer incomplete/incorrect if explained in terms of magnetism or bond order.

Q7) 11 points

a) Carbon can form bonds with itself as well as other elements. **5 points**

- i. In addition to the halogens, what 5 other atoms most *commonly* bond to carbon in organic compounds? (symbols or names are accepted)

H, O, N, P, S (part marks)

- ii. Which of those 5 atoms in part *i* are heteroatoms?

O, N, P, S –(also accepted) or all except H (no part marks)

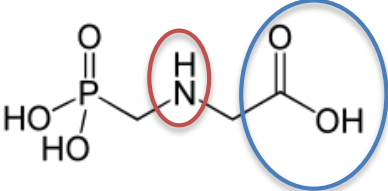
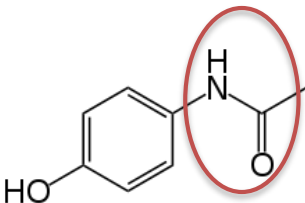
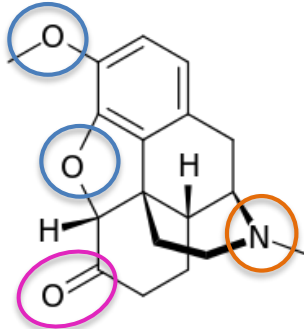
- iii. From the 5 atoms in part *i*, which elements are more electronegative than carbon?

O, N (no part marks)

- iv. From the 5 atoms in part *i*, which elements are less electronegative than carbon?

H, P (no part marks)

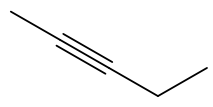
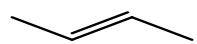
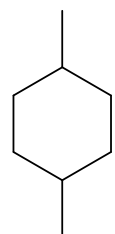
b) Circle and name the type of functional groups in each compound below. Specify if each is primary, secondary, or tertiary. **6 points**

 <p>Carboxylic acid Secondary amine</p> <p>glyphosate (an herbicide)</p>	 <p>Amide – also will accept amido (more specifically a substituted amide)</p> <p>acetaminophen (Tylenol)</p>	 <p>Ether Tertiary amine Ketone</p>
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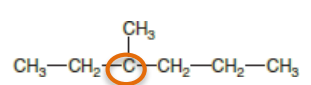
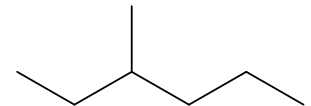
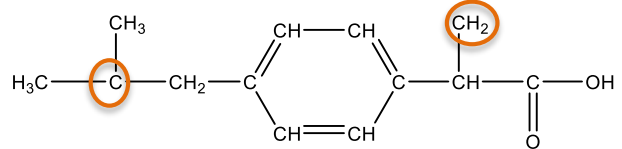
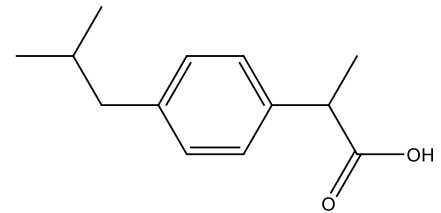
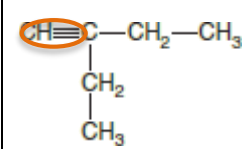
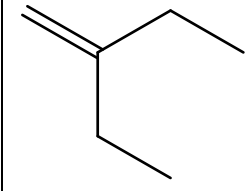
	hydrocodone
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Q8) 17 points

a) Draw the following structures in the space provided. **3 points**

2-pentyne 	<i>trans</i> -but-2-ene 	1,4-dimethylcyclohexane 
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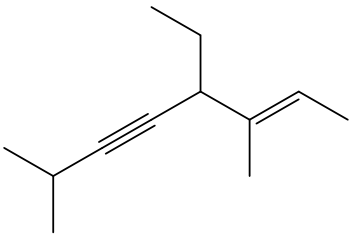
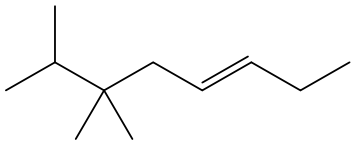
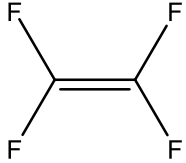
b) Circle any problems with the structures drawn below and draw the *corrected* structures as carbon skeletons. **6 points**

 	 	 
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Question 8 continued on next page

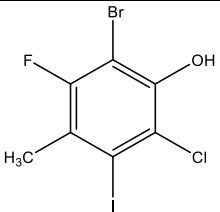
c) Provide the correct IUPAC names for the following structures. If necessary, specify *cis* vs *trans*.

6 points

 <p>trans-4-ethyl-3,7-dimethyloct-2-en-5-yne</p>	 <p><i>trans</i>-6,6,7-trimethyl-3-octene <i>trans</i>-6,6,7-trimethyloct-3-ene</p>	 <p>tetrafluoroethene</p>
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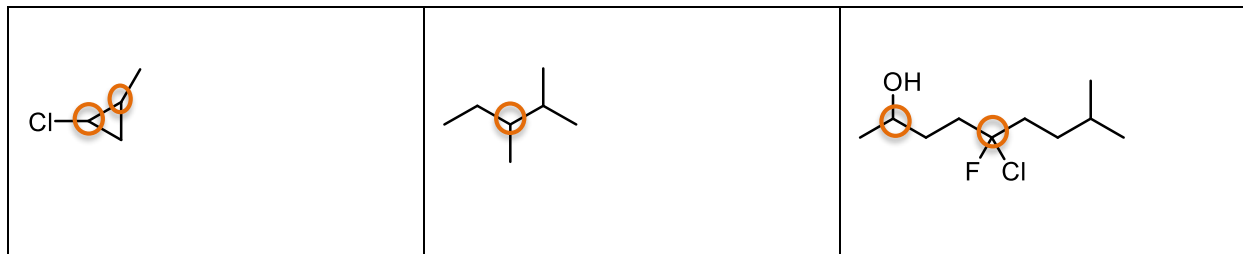
d) Taking the iodo as your reference, indicate the position of the other substituents as *ortho*, *meta*, *para*.

2 points

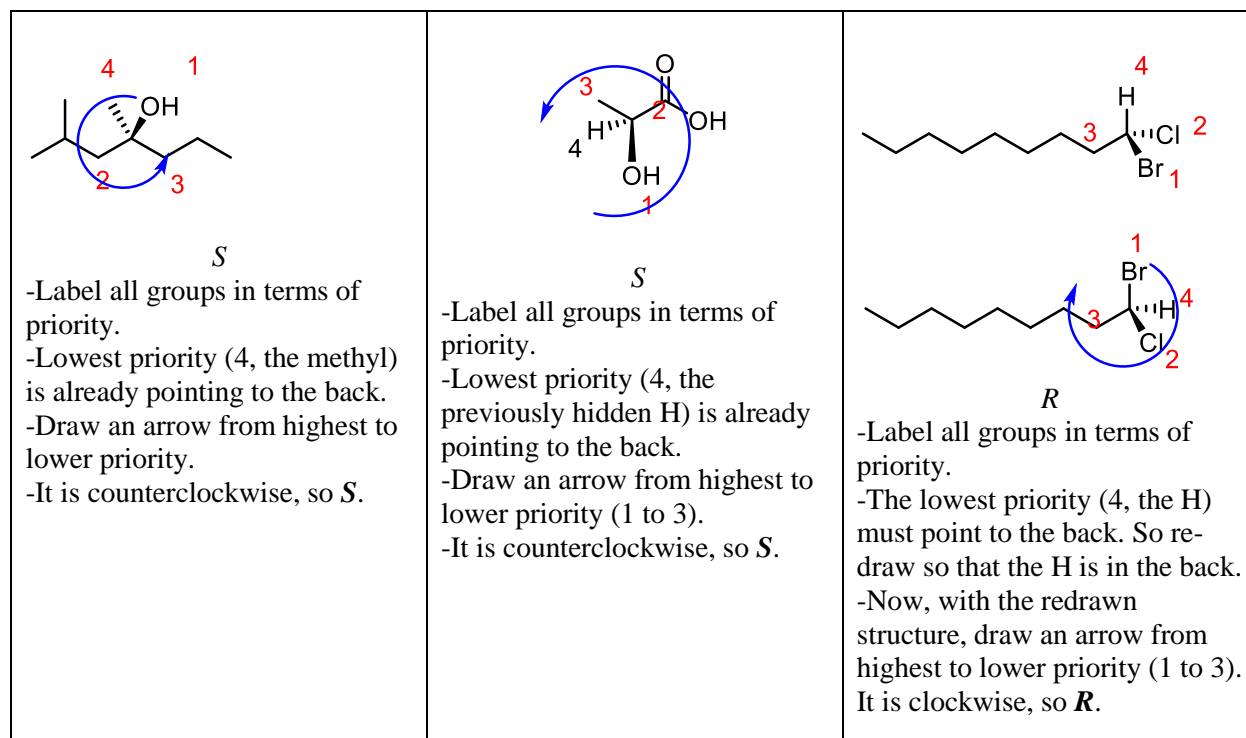
	Group	<i>ortho</i> , <i>meta</i> , <i>para</i>
	fluoro	meta
	bromo	para
	hydroxyl	meta
	methyl	ortho

Q9) 12 points

a) Circle all the chiral centres in the structures below. **3 points** (no part marks)



b) Give each molecule the appropriate stereochemical assignment (R vs S). Explain the steps you use to assign R vs S. **6 points**



c) Draw the Newman projection of the molecule below in the box provided, from the perspective indicated. **3 points**



Q10) 11 pointsa) What is the definition of a nucleophile? **1 point**

An “electron” rich species. (seeks a positive centre) (no part marks)

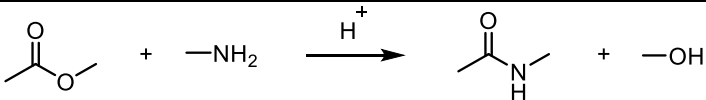
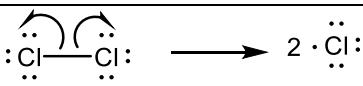
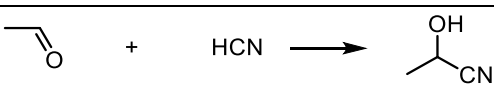
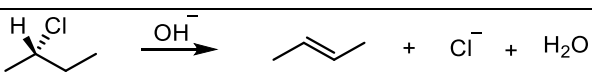
b) Circle the stronger nucleophile in each pair, and explain why it is a stronger nucleophile. **6 points**

Nucleophiles	Reason
H ₂ O vs <u>OH⁻</u>	Negatively charged nucleophile is stronger than its conjugate acid
<u>Br⁻</u> vs F ⁻	Br ⁻ is larger than F ⁻ , so electrons are more loosely held when comparing down a group. (also accepted: Br ⁻ is more polarizable)
<u>NH₂⁻</u> vs NH ₃	Negatively charged nucleophile is stronger than its conjugate acid
<u>CH₃⁻</u> vs NH ₂ ⁻	Carbon is less electronegative, more polarizable. (also accepted: basicity increase from right to left across the same row)

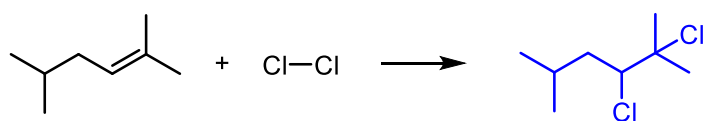
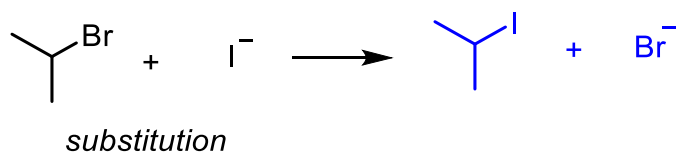
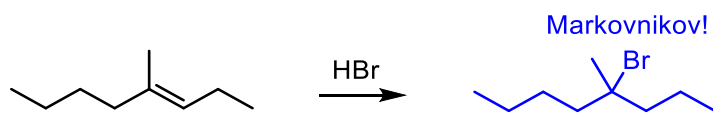
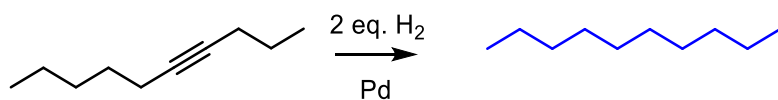
c) Label each reaction event below with either the bonding-breaking type or the specific reaction type.

Choose the type that **best** describes the reaction event drawn. **4 points** (no part marks)

Choices: substitution, addition, elimination, rearrangement, heterolytic cleavage, homolytic cleavage

Reaction scheme	Reaction type (one best choice)
	Substitution
	Homolytic cleavage
	Addition reaction
	Elimination

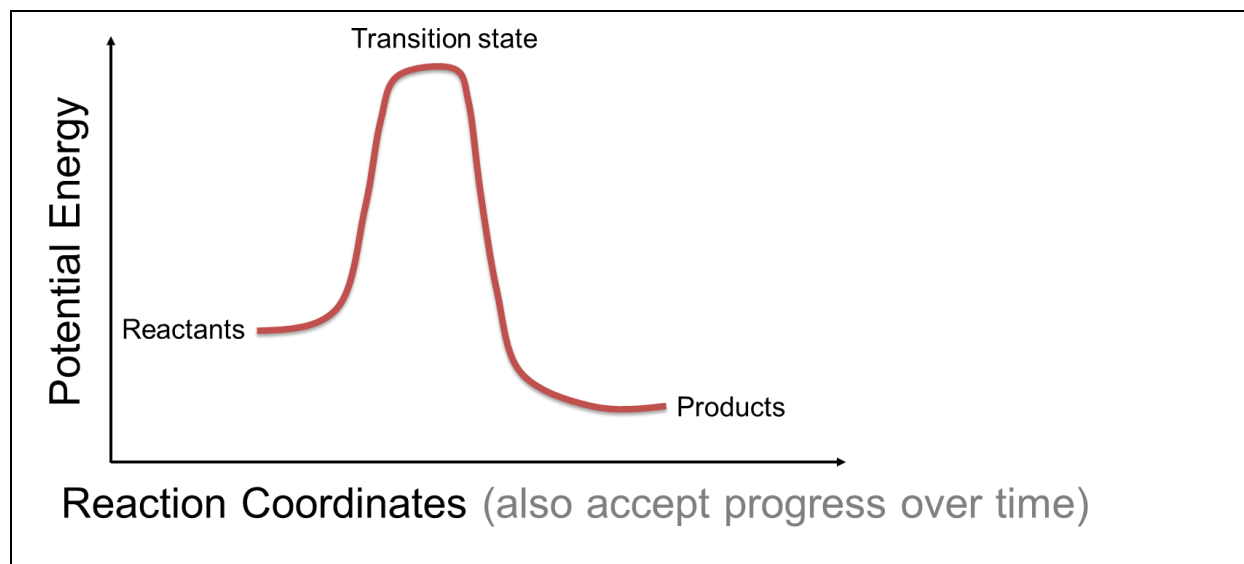
Q11) Draw the products of the reactions (carbon skeleton). **8 points**



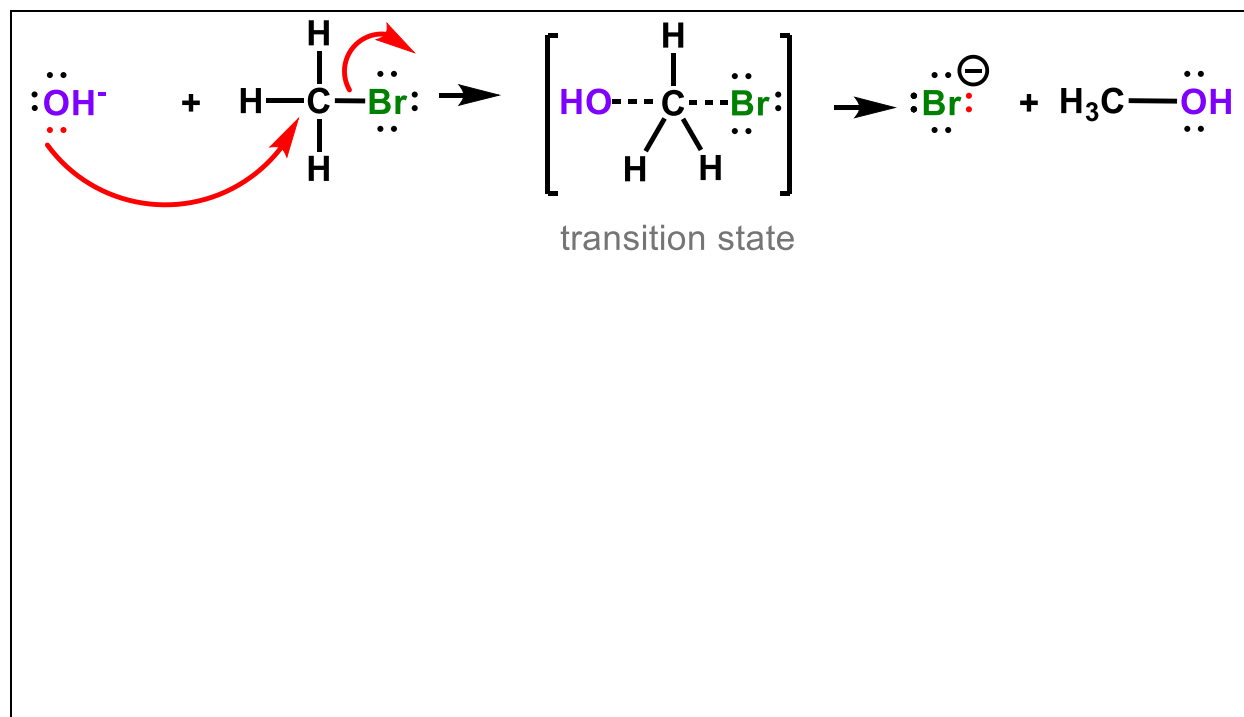
Q12) 10 points

a) Draw a reaction energy diagram for a concerted, exothermic reaction. Include all the necessary labels.

5 points

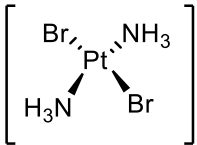


b) Complete the S_N2 reaction below. If there is a key intermediate or transition state, be sure to draw this and label if it is a transition state or an intermediate. Draw the curved arrows to show the movement of electrons (making and breaking bonds). **5 points**



Q13) 8 points

a) What is the coordination number of the complex and oxidation state of the transition metal in the following coordination complexes? **6 points** (no part marks)

Coordination complex	Oxidation state	Coordination number
$[\text{Co}(\text{en})_2\text{Cl}_2]\text{OH}$	+3 (overall charge of the complex is +1 since the complex interacts with -1 hydroxyl)	6 (note en is a bidentate ligand!)
	+2 (the overall complex is neutral so 2 bromines of negative charge balance with a +2 Pt charge)	4
tetraamminebromochloroplatinum(IV) chloride	+4 (it says in the name!)	6

b) In $[\text{Cr}(\text{OH})_6]^{3-}$, is the chromium ion diamagnetic or paramagnetic? Show the electron configuration to explain why chromium is either diamagnetic or paramagnetic. **2 points**

Paramagnetic.

Electron configuration of Cr = $[\text{Ar}] 4s^1 3d^5$

Cr in this complex = oxidation state 3+

Electron configuration of Cr^{3+} = $[\text{Ar}] 3d^3$

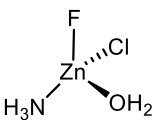
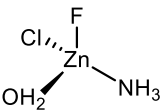
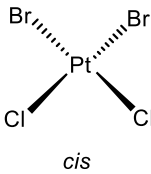
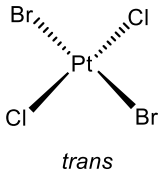
→ These 3 electrons are unpaired and therefore are paramagnetic

Q14) 8 points

a) Provide the systematic name for the following two coordination compounds. **2 points** (no part marks)

$K_4 \left[\begin{array}{c} \text{NC} \quad \text{CN} \\ \diagdown \quad \diagup \\ \text{Fe} \\ \diagup \quad \diagdown \\ \text{NC} \quad \text{CN} \end{array} \right]$ <p>Potassium hexacyanoferrate(II)</p>	<p>$[Zn(H_2O)Cl(en)_2]Br$</p> <p>aquachlorobis(ethylenediamine)zinc(II) bromide</p>
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b) If any of the following complexes can exist as isomers, state the type of isomerism and draw the structures. **6 points**

<p>$[Zn(en)F_2]$</p> <p>not isomers</p>	<p>$[Zn(H_2O)(NH_3)FCl]$</p> <p>This is a tetrahedral complex, and there are four different ligands – so it's like a "chiral center". As such, we see enantiomers.</p> <div style="display: flex; justify-content: space-around; align-items: center;">   </div>	<p>$[PtCl_2Br_2]^{2-}$ (square planar)</p> <p>since this is square planar we can have geometric (cis/trans) isomers</p> <div style="display: flex; justify-content: space-around; align-items: center;">   </div>
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Q15) 5 points

a) In each set of coordination complexes, circle which coordinate complex has the largest crystal field splitting energy. **2 points** (no part marks)

i.		ii.
Coordination complex	Maximum absorbance λ	
$[\text{Fe}(\text{A})_6]^{3+}$	700 nm	$[\text{Ti}(\text{NH}_3)_6]^{3+}$
$[\text{Ti}(\text{A})_6]^{3+}$	510 nm	$[\text{TiF}_6]^{3-}$
$[\text{Cr}(\text{B})_6]^{3-}$	400 nm	$[\text{Ti}(\text{CN})_6]^{3-}$
$[\text{Fe}(\text{B})_6]^{3-}$	305 nm	$[\text{Ti}(\text{H}_2\text{O})_6]^{3+}$

b) Why is the +2 oxidation state so common among transition elements? **1 point**

The outermost (ns²) electrons are easily lost, producing the +2 oxidation state.
(simply saying because the s electrons are easily lost is fine too)

c) How does the variation in atomic size across a transition series contrast with the variation across the main group elements of the same period? Briefly explain why there is a difference for the transition series. **2 points**

For the main-group elements, size decreases as you move to the right. For the transition elements, the size decreases at first and then is fairly constant since inner orbitals are being filled.