1) Explain in a simple sentence what is meant in a chemical sense by the following arrows. (7.5 pts)

(a) 

(b) 

(c) 

(d) 

(e)
2) Name the classes of compound that the following molecules belong to (E.g. alkane, amide, etc). (13.5pts)

R–O–H

R–O–R

R–O–O–R

O

R\'\text{CO}–\text{OH}

O

R\'\text{CO}–O–O–H

O

R\text{CH}

O

R\text{CR}

R–S–H

O

R\text{CO}–O–R
3) Classify each of the following reactions as an Elimination, Addition or Substitution. (5pts)

(a) \[
\text{H}_3\text{C} = \text{C} = \text{H} \xrightarrow{\text{Br}} \text{H}_3\text{C} = \equiv \text{H}
\]

(b) \[
\text{CH}_3\text{CH}_3 \rightarrow \text{CH}_3\text{CH}_2\text{I}
\]

(c) \[
\text{H}_3\text{C} = \equiv \text{CH}_3 \rightarrow \text{H}_3\text{C} - \text{Br} - \text{CH}_3
\]

(d) \[
\text{H}_3\text{C} = \text{C} = \text{H} \xrightarrow{\text{Br}} \text{H}_3\text{C} - \text{Br} - \text{CH}_3
\]

(e) \[
\text{F}_3\text{C} - \text{C} = \text{C} - \text{F}_3 \rightarrow \text{F}_3\text{C} = \text{C} = \text{F}_3\]

4) Draw Lewis structures (sticks for bonds, and dots for lone pairs) for the below two molecules. (8.5pts)

\[
\text{CH}_3\text{CO}_2\text{H} \quad \text{CH}_3\text{CO}_2\text{H}
\]
5) For the previous two molecules, label the hybridization of all the **carbons** and **oxygen**s. (5pts)

6) Explain **why** phenol is a much stronger acid than cyclohexanol. (10pts)
7) On the below energy level diagram, label (a) the axes (b) the reactants and products (c) any transitions states (d) $\Delta H^\circ$ for the overall reaction (e) the rate determining step (f) is this reaction exothermic or endothermic? (9pts)

8) Ammonia (NH$_3$) and the methyl cation (CH$_3^+$) both have three hydrogen atoms bound to a central atom. Explain why these species have different three-dimensional shapes. (12pts)
9) Briefly explain which of the two previous geometries most closely resembles that of $\text{H}_3\text{O}^+$? (3pts)

10) Name the following molecules in IUPAC form. (16pts)

(a)  

(b)  

(c)  

(d)  

(e)
11) **Asterix** (star, *) the chiral atoms in these molecules, and assign R or S to each chiral center. (13pts)

(a)

(b)

(c)

(d)

12) Which of the above **molecules** are **achiral**, and in a sentence explain what makes them achiral. (3pts)
13) Circle the more stable member of each pair, and in a sentence explain your choice. (12.5pts)

(a) \( \text{CH}_3\text{CH}_2\text{O}^- \quad \text{CH}_3\text{CO}_2^- \)

(b) \( \text{CH}_3\text{CH}_2\text{O}^- \quad \text{CF}_3\text{CH}_2\text{O}^- \)

(c) 

(d) 

(e) 

14) Name and draw any two geometrical conformations that a cyclohexane molecule can adopt. (10pts)
15) Which is the lowest energy conformation possible for a cyclohexane molecule, and what is the approximate ring strain energy (in kJ/mol) associated with C₆H₁₂ in that conformation? (3pts)

16) An E2 type elimination can only proceed if the two species that are eliminated are oriented in which two special geometrical alignments? (4pts)

17) Why, on the other hand, can E1 type elimination occur with any geometrical arrangement of the two removed species? (3pts)

18) Provide a mechanistic explanation for the observed mixture of products in the following S_N1 reaction. (10pts)

\[
\begin{align*}
\text{CH}_3\text{OH} & \quad \text{SN}_1 \quad \text{H}_3\text{C} \quad \text{CH}_3 \\
\text{H}_3\text{C} & \quad \text{CH}_3 \quad \text{Br} \quad \rightarrow \quad \text{H}_3\text{C} \quad \text{CH}_3 \\
\text{H}_3\text{C} & \quad \text{CH}_3 \quad \text{OCH}_3 \quad \text{H}_3\text{CO}
\end{align*}
\]
19) In the previous reaction, the starting material and the two products each have one chiral center, so if a single enantiomer of the starting material was used in this reaction, would each of the two products be formed as racemates or single enantiomers? (2pts)

20) Give the products of 5 of the 6 following reactions. (15pts)

(a) \[ \text{CH}_3\text{CH}_2-\text{CH}≡\text{CH}_3 \xrightarrow{\text{1 equiv. H}_2, \text{Lindlar's catalyst}} \]

(b) \[ \text{Cyclohexane-I} \xrightarrow{\text{1) Mg, Ether}} \xrightarrow{\text{2) H}_2\text{C}=\text{O}} \xrightarrow{\text{3) H}_3\text{O}^+} \]

(c) \[ \text{Cyclopentene} \xrightarrow{\text{1) PhCO}_3\text{H}} \xrightarrow{\text{2) H}_3\text{O}^+} \]

(d) \[ \text{Ethene} \xrightarrow{\text{1) BH}_3\cdot\text{THF}} \xrightarrow{\text{2) H}_2\text{O}_2, \text{NaOH}} \]

(e) \[ \text{Cyclopentene} \xrightarrow{\text{Br}_2} \]

(f) \[ \text{Propane} \xrightarrow{\text{1) Na, NH}_3} \]
20b) Write the mechanism for one of the preceding anti additions (that is anti addition NOT anti-Markovnikov addition). (10pts)

21) Give reagents to perform 5 of the 6 following transformations. (15pts)

(a) \[
\begin{array}{c}
\text{Cyclohexanol} \\
\text{Cyclohexanone}
\end{array}
\]

(b) \[
\begin{array}{c}
\text{Cyclohexanol} \\
\text{Cyclohexyl bromide}
\end{array}
\]

(c) \[
\begin{array}{c}
\text{PROPA} \\
\text{Acetone}
\end{array}
\]

(d) \[
\begin{array}{c}
\text{Cyclohexanol} \\
\text{Cyclohexyl methyl ketone}
\end{array}
\]

(e) \[
\begin{array}{c}
\text{Cyclopentene} \\
\text{Bicyclo[2.1.0]pentan-1-ol}
\end{array}
\]

(f) \[
\begin{array}{c}
\text{Propane} \\
\text{2-Bromopropane}
\end{array}
\]
21b) Write the mechanism for one of the preceding cyclohexanol reactions. (10pts)
1) Explain in a simple sentence what is meant in a chemical sense by the following arrows. (7.5 pts)

(a) \[ \rightarrow \quad "Reacts\ to\ give" \]

(b) \[ \quad "Is\ in\ equilibrium\ with" \]

(c) \[ \quad "Is\ a\ resonance\ structure" \]

(d) Movement of Two electrons

(e) Movement of One electron
2) Name the classes of compound that the following molecules belong to (E.g. alkane, amide, etc). (13.5pts)

\[ \text{R-O-H} \quad \text{alcohol} \]

\[ \text{R-O-R} \quad \text{ether} \]

\[ \text{R-O-O-R} \quad \text{ester} \]

\[ \text{R-\overset{\text{\scriptsize O}}{\text{O}}-\overset{\text{\scriptsize H}}{\text{H}}} \quad \text{carboxylic acid} \]

\[ \text{R-\overset{\text{\scriptsize O}}{\text{O}}-\overset{\text{\scriptsize O}}{\text{O}}-\overset{\text{\scriptsize H}}{\text{H}}} \quad \text{peroxy acid} \]

\[ \text{R-H} \quad \text{alcohol} \]

\[ \text{R-\overset{\text{\scriptsize O}}{\text{O}}-R} \quad \text{ester} \]

\[ \text{R-S-H} \quad \text{thiol} \]

\[ \text{R-\overset{\text{\scriptsize O}}{\text{O}}-R} \]
3) Classify each of the following reactions as an Elimination, Addition or Substitution. (5pts)

(a) \[ \text{H}_3\text{C} = \text{CH} \rightarrow \text{H}_3\text{C} = \equiv \text{H} \quad \text{Elim} \]

(b) \[ \text{C}_6\text{H}_6 \rightarrow \text{C}_6\text{H}_6 - \text{I} \quad \text{Add} \]

(c) \[ \text{H}_3\text{C} = \equiv \text{CH}_3 \rightarrow \text{H}_3\text{C} - \text{Br} - \text{CH}_3 \quad \text{Add} \]

(d) \[ \text{H}_3\text{C} = \text{CH}_3 \rightarrow \text{H}_3\text{C} - \text{Br} - \text{CH}_3 \quad \text{Add} \]

(e) \[ \text{F}_3\text{C} = \equiv \text{C} - \text{CF}_3 \rightarrow \text{F}_3\text{C} - \text{C} - \text{F}_3 - \text{F}_3 \quad \text{Add} \]

4) Draw Lewis structures (sticks for bonds, and dots for lone pairs) for the below two molecules. (8.5pts)

\[ \text{CH}_3\text{CO}_2\text{H} \quad \text{CH}_3\text{CO}_3\text{H} \]

\[ \text{H} - \text{C} - \equiv \text{C} - \text{O} - \text{H} \quad \text{H} - \text{C} - \equiv \text{O} - \text{O} - \text{H} \]
5) For the previous two molecules, label the hybridization of all the carbons and oxygens. (5pts)

\[ \text{Red} = \text{sp}^3 \]
\[ \text{Green} = \text{sp}^2 \]

6) Explain why phenol is a much stronger acid than cyclohexanol. (10pts)

\[
\begin{align*}
\text{pK}_a &= 18 \\
\text{pK}_a &= 10
\end{align*}
\]

Phenol, when deprotonated, generates phenoxyde, which is a resonance stabilized anion, and therefore much more stable than anion from cyclohexanol.
7) On the below energy level diagram, label (a) the axes (b) the reactants and products (c) any transitions states (d) $\Delta H^0$ for the overall reaction (e) the rate determining step (f) is this reaction exothermic or endothermic? (9pts)

![Energy Level Diagram]

8) Ammonia ($\text{NH}_3$) and the methyl cation ($\text{CH}_3^+$) both have three hydrogen atoms bound to a central atom. Explain why these species have different three-dimensional shapes. (12pts)

Ammonia:
- 3 $\sigma$ bonds: $\text{N} \equiv \text{H}$
- 1 lone pair
- $\Rightarrow$ $sp^3$ hybridized nitrogen
- Bond angles: $109.5^\circ$

Methyl cation:
- 3 $\sigma$ bonds: $\text{C} \equiv \text{H}$
- 0 lone pairs
- $\Rightarrow$ $sp^2$ Carbon
- Bond angles: $120^\circ$

Molecule has bond angles less than $109.5^\circ$ due to more repulsion from the lone pair than bond pairs.
9) Briefly explain which of the two previous geometries most closely resembles that of $\text{H}_3\text{O}^+$? (3pts)

$\text{H}_3\text{O}^+$ resembles $\text{NH}_3$ because the $\text{O}$ is $sp^3$ hybridized (3, $\phi$ 1pt).

10) Name the following molecules in IUPAC form. (16pts)

(a) 

(b) 

(c) 

(d) $\text{Fluoro HEX(42)EN-1-YNE}$

(e) $\text{4-bromocyclohex-3-enol}$
11) Asterix (star, *) the chiral atoms in these molecules, and assign R or S to each chiral center. (13pts)

(a) 
\[ \begin{align*} &\text{Cl} \\
&\text{H} \\
&\text{Cl} \\
&\text{CH}_3 \\
&\text{F} \\
&\text{F} \\
\end{align*} \]

NO CHIRAL ATOMS

(b) 
\[ \begin{align*} &\text{Br} \\
&\text{Br} \\
&\text{CH}_3 \\
&\text{CF}_3 \\
\end{align*} \]

\[ \begin{align*} &\text{R} = R \\
&\text{S} = S \\
\end{align*} \]

(c) 
\[ \begin{align*} &\text{F} \\
&\text{F} \\
&\text{H} \\
&\text{H} \\
\end{align*} \]

\[ \begin{align*} &\text{R} = R \\
&\text{S} = S \\
\end{align*} \]

(d) 
\[ \begin{align*} &\text{Cl} \\
&\text{Cl} \\
&\text{CH}_2\text{F} \\
&\text{CH}_2\text{F} \\
\end{align*} \]

\[ \begin{align*} &\text{G} = R \\
\text{for Ritter.} \\
\end{align*} \]

12) Which of the above molecules are achiral, and in a sentence explain what makes them achiral. (3pts)

\[ \text{cos} \] Has a superimposable mirror image (No chiral elements).
13) Circle the more stable member of each pair, and in a sentence explain your choice. (12.5pts)

(a) CH₃CH₂O⁻  CH₃CO⁻  CH₃⁻ is resonance stabilized
(b) CH₃CH₂O⁻  CF₃CH₂O⁻  Electron withdrawing CF₃ stabilizes anion
(c) More highly allyl substituted  \(2^\text{nd}\) vs \(1^\text{st}\)
(d) Resonance stabilized cation
(e) Resonance stabilized radical

14) Name and draw any two geometrical conformations that a cyclohexane molecule can adopt. (10pts)
15) Which is the lowest energy conformation possible for a cyclohexane molecule, and what is the approximate ring strain energy (in kJ/mol) associated with C₆H₁₂ in that conformation? (3pts)

Chair, 0 kJ/mol

16) An E₂ type elimination can only proceed if the two species that are eliminated are oriented in which two special geometrical alignments? (4pts)

anti coplanar or syn coplanar

17) Why, on the other hand, can E₁ type elimination occur with any geometrical arrangement of the two removed species? (3pts)

It proceeds via a cation, which can then adopt the required geometry for H⁺ removal.

18) Provide a mechanistic explanation for the observed mixture of products in the following S₅₁ reaction. (10pts)
19) In the previous reaction, the starting material and the two products each have one chiral center, so if a **single** enantiomer of the starting material was used in this reaction, would each of the two products be formed as racemates or single enantiomers? (2pts)

RACEMATES

20) Give the products of **5 of the 6** following reactions. (15pts)

(a) \( \text{CH}_3\text{CH}_2\equiv\text{CH}_3 \rightarrow 1 \text{ equiv. H}_2, \text{ Lindlar catalyst} \)

(b) \( \text{I} \rightarrow 1) \text{ Mg, Ether} \)
   \( \rightarrow 2) \text{ H}_2\text{C}=\text{O} \)
   \( \rightarrow 3) \text{ H}_3\text{O}^+ \)

(c) \( \text{ } \rightarrow 1) \text{ PhCO}_3\text{H} \)
   \( \rightarrow 2) \text{ H}_3\text{O}^+ \)

(d) \( \text{H} = \text{CH}_3 \rightarrow 1) \text{ BH}_3\text{-THF} \)
   \( \rightarrow 2) \text{ H}_2\text{O}_2, \text{ NaOH} \)

(e) \( \text{ } \rightarrow \text{Br}_2 \)

(f) \( \text{H}_3\text{C}=\equiv\text{CH}_3 \rightarrow 1) \text{ Na, NH}_3 \)
20b) Write the mechanism for one of the preceding *anti* additions (that is *anti* addition NOT anti-Markovnikov addition). (10pts)

21) Give reagents to perform 5 of the 6 following transformations. (15pts)

(a) \( \text{Cyclohexanol} \xrightarrow{\text{H}_2\text{C}=\text{O}} \text{Cyclohexanone} \)

(b) \( \text{Cyclohexanol} \xrightarrow{\text{PBr}_3, \cdot \cdot \cdot \text{HBr}} \text{Cyclohexyl bromide} \)

(c) \( \text{Propanal} \xrightarrow{\text{H}_2\text{SO}_4, \text{H}_2\text{O}} \text{Propanaldehyde} \)

(d) \( \text{Cyclohexanol} \xrightarrow{1) \text{Pb(OAc)}_2, \text{TosCl}} \text{Cyclohexyl acetylene} \)

(e) \( \text{Cyclopentene} \xrightarrow{\text{Br}_2, \text{H}_2\text{O}} \text{Cyclopentyl alcohol} \)

(f) \( \text{Propanal} \xrightarrow{\text{Peroxide, HBr}} \text{3-Bromo-2-propanol} \)
21b) Write the mechanism for one of the preceding cyclohexanol reactions.
(10pts)