1) Identify the class of compounds that the following molecules belong to (12pts).

\[
\begin{align*}
&\text{Carboxylic Acid} \\
&\text{Peroxy Acid} \\
&\text{Ether} \\
&\text{Isocyanate} \\
&\text{Aldehyde} \\
&\text{Alkyl} \\
&\text{Aryl Diazonium} \\
&\text{Azide} \\
&\text{Ion} \\
&\text{Cyclobutane}
\end{align*}
\]

2) Draw Lewis structures (lone pairs not required) for the following classes of compound. (12pts).

3) Circle the molecule in question (2) with the lowest pH (3pts).
4) The following reactions are named after their inventors - give the names of the following reactions (16pts)

(a) 

(b) 

(c) 

(d) 

(e) 

(f) 

(g) 

(h)
5) Define the following terms (15pts).

**CONDENSATION REACTION**

**AROMATICITY**

**KINETIC CONTROL**

**THERMODYNAMIC PRODUCT**

**CONJUGATED DOUBLE BONDS**

6) Give one use of Molecular Orbital theory, and draw a species whose bonding is not accurately described by a Lewis structure. (4pts).

7) Draw all the resonance structures for the below species (don’t need curly arrows) (6pts).

\[
\text{Br} \quad \text{\text{H}} \quad \text{CH}_3
\]
8) Indicate which of the following molecules are aromatic, non-aromatic or anti-aromatic. *(Assume all the molecules are planar).* (15pts)

9) Pick one of the above aromatic molecules, and use the polygon rule to demonstrate its aromaticity. (8pts)
10) Give the products in six of the following reactions, paying attention to regio/stereochemistry where applicable. (18pts)

1) NaOH

2) Excess HI

3) Heat

1) NO₂

2) Br₂, uv light

3) CH₃Cl, AlCl₃

1) HOCH₂CH₂CH₂OH; H₃O⁺

2) NaBH₄

3) H₃O⁺

1) Zn, HCl

2) NaNO₂, HCl

3) CuCl, HCl

1) Ph

2) Br₂, uv light

3) Excess HI

1) 1) NaOH

2) CH₃OCH₂CH₂-Br
11) Design a synthetic scheme for the below transformation (5pts)

\[
\text{CH}_2\text{CH}_3
\]

12) Write the mechanism for the electrophilic aromatic substitution reaction below. (8pts)

\[
\text{NO}_2^+ \quad \text{HSO}_4^- \quad \text{NO}_2
\]
13) Provide reagents to accomplish five of the following transformations. (15pts)

- \( \text{H}_2\text{N} - \text{CO}_2\text{H} \rightarrow \text{H}_2\text{N} - \text{CHO} \)
- \( \text{CH}_2=\text{CH}-\text{CHO} \rightarrow \text{CH}_2=\text{CH}-\text{CO}_2\text{H} \)
- \( \text{Ph} \rightarrow \text{Ph}-\text{NO}_2 \)
- \( \text{Ph}-\text{Br} \rightarrow \text{Ph}-\text{Br} \)
- \( \text{Ph} \rightarrow \text{Ph}-\text{O}_2\text{N} - \text{CO}_2\text{H} \)
- \( \text{CH}_3\text{CH}=\text{CH}-\text{CHO} \rightarrow \text{Ph}-\text{N} - \text{CH}_2-\text{CHO} \)
14) Circle the most **basic** nitrogen in each molecule. (9pts)

![Molecules](image1)

15) Circle the **strongest acid** in the following threesomes. (9pts)

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

(b) \( \text{CH}_3\text{OH} \quad \text{NH}_3 \quad \text{CH}_4 \)

(c) ![Chemical structures](image2)

16) Name the following compounds in IUPAC form (14pts).

![Chemical structures](image3)
17) Fill in the blanks for **two** of the following reactions. (6pts)

(a) \[\text{H} \quad \text{O} \quad \text{Ph} \quad \text{H} \quad \text{Ph} \quad \xrightarrow{\text{H}_2\text{SO}_4, \text{CH}_3\text{OH}}\]

(b) \[\text{NH}_2 \quad \text{Ph} \quad \xrightarrow{\text{1) excess CH}_3\text{-Br} \quad \text{2) Ag}_2\text{O, H}_2\text{O, heat}}\]

(c) \[\text{H} \quad \text{O} \quad \text{Ph} \quad \text{H} \quad \text{Ph} \quad \xrightarrow{\text{NaOCH}_3, \text{CH}_3\text{OH}}\]

18) When one equivalent of hydrogen chloride is added to the following conjugated diene, a mixture of two products is formed.

\[
\text{H} = \text{Cl} \\
\xrightarrow{\text{H-Cl}}
\]

i) Draw the two products.

ii) Provide the step-by-step mechanism which explains the generation of both products.

iii) One of the products contains a chiral center. Asterix (*) that chiral carbon. (9pts)
19) Give the mechanism for two of the below conversions. (16pts)

(a)\[\begin{align*}
&\text{CH}_3\text{OH, NaOH} \\
\end{align*}\]

(b)\[\begin{align*}
\text{NaNO}_2, \text{HCl} \\
\end{align*}\]

(c)\[\begin{align*}
\text{HOCH}_2\text{CH}_2\text{OH} \\
\text{H}_2\text{SO}_4 \\
\end{align*}\]
*Bonus question* (up to 2 points)

Name two countries that share borders with ENGLAND.
1) Identify the class of compounds that the following molecules belong to (12pts).

- \( \text{R-C=O-R} \) Ester
- \( \text{R-C=H} \) Aldehyde
- \( \text{R-C=Cl} \) Acid Chloride
- \( \text{R-O-O-R} \) Peroxide
- \( \text{R-C=N}\text{H}_2 \) Amide
- \( \text{R-O-H} \) Alcohol

2) Draw Lewis structures (lone pairs not required) for the following classes of compound. (12pts).

- \( \text{R-C=O-H} \) Carboxylic Acid
- \( \text{R-C=O-H} \) Peroxy Acid
- \( \text{R-O-R} \) Ether
- \( \text{R-N=\text{C}=\text{O}} \) Isocyanate
- \( \text{HO-\text{OH}} \) Aldehyde Hydrate
- \( \text{R-N=\text{N}=\text{N}} \) Alkyl Azide
- \( \text{Ar-N=\text{N}} \) Aryl Diazonium Ion
- \( \text{\square} \) Cyclobutane

3) Circle the molecule in question (2) with the lowest pH (3pts).
4) The following reactions are named after their inventors - give the names of the following reactions (16pts)

(a) $\text{Diels Alder Cycloaddition}$

(b) $\text{Fisher Esterification}$

(c) $\text{Sandmeyer Reaction}$

(d) $\text{Huffman Rearrangement}$

(e) $\text{Grignard Reaction}$

(f) $\text{Wittig Reaction}$

(g) $\text{Huffman Elimination}$

(h) $\text{Friedel Craft Acylation}$
5) Define the following terms (15pts).

**CONденSATION REACTION**
A reaction where two species add together, along with the expulsion of a small molecule (usually water).

**AROMATICITY**
An especially stable π bonding arrangement which occurs in cyclic systems with interacting π orbitals in a closed loop which contain \((4n+2)\) π electrons (where \(n = 0, 1, 2, 3, \ldots\)).

**KINETIC CONTROL**
Products are generated based on how quickly they are formed.

**THERMODYNAMIC PRODUCT**
The most stable product.

**CONJUGATED DOUBLE BONDS**
Double bonds whose π orbitals overlap with one another, usually found in double bond-singly bond-double bond arrangements.

6) Give one use of Molecular Orbital theory, and draw a species whose bonding is not accurately described by a Lewis structure. (4pts).

Accurate description of delocalised bonding.
Aromaticity explanation.

7) Draw all the resonance structures for the below species (don’t need curly arrows) (6pts).

\[
\begin{align*}
\text{Br} & \quad \text{CH}_3 \\
\text{H} & \\
\end{align*}
\]
8) Indicate which of the following molecules are aromatic, non-aromatic or anti-aromatic. (Assume all the molecules are planar). (15pts)

- Non
- Non
- Non
- Aromatic
- Non

- Aromatic
- Anti Aromatic
- Aromatic
- Anti Aromatic
- Aromatic

9) Pick one of the above aromatic molecules, and use the polygon rule to demonstrate its aromaticity. (8pts)

All 6π, give closed bonding shells = very stable.
10) Give the products in **six** of the following reactions, paying attention to regio/stereochemistry where applicable. (18pts)

\[
\begin{align*}
\text{heat} & \quad \Rightarrow \\
1) \text{Zn, HCl} \\
2) \text{NaNO}_2, \text{HCl} \\
3) \text{CuCl, HCl}
\end{align*}
\]

\[
\begin{align*}
\text{CH}_3\text{Cl, AlCl}_3 & \quad \Rightarrow \text{No Reaction}
\end{align*}
\]

\[
\begin{align*}
1) \text{HOCH}_2\text{CH}_2\text{CH}_2\text{OH}, \text{H}_3\text{O}^+ \\
2) \text{NaBH}_4 \\
3) \text{H}_3\text{O}^+ 
\end{align*}
\]

\[
\begin{align*}
\text{Br}_2, \text{uv light} & \quad \Rightarrow \\
\text{Excess Hl}
\end{align*}
\]

\[
\begin{align*}
1) \text{NaOH} \\
2) \text{CH}_3\text{OCH}_2\text{CH}_2\text{-Br}
\end{align*}
\]
11) Design a synthetic scheme for the below transformation (5pts)

\[
\text{C}_6\text{H}_5 + \text{CH}_2\text{CH}_3 \rightarrow \text{C}_6\text{H}_5\text{Cl} \leftarrow \text{Z} \left(\text{CH}_3\right)_2, \text{HCl}
\]

12) Write the mechanism for the electrophilic aromatic substitution reaction below. (8pts)

\[
\text{C}_6\text{H}_5 + \text{NO}_2^+ + \text{HSO}_4^- \rightarrow \text{C}_6\text{H}_5\text{NO}_2
\]
13) Provide reagents to accomplish \textbf{five} of the following transformations. (15pts)

\[ \text{PhCO}_2\text{H} \xrightarrow{\text{SOCl}_2, \text{LiAlH}_4(\text{OR})_3} \text{PhCHO} \]

\[ \text{CH}_2=\text{CHCH}=\text{CH}_2 \xrightarrow{\text{Ag}_2\text{O}} \text{CH}_2=\text{CHCH}(_2\text{CH}_2\text{CO}_2\text{H}) \]

\[ \text{Ph} \xrightarrow{\text{HNO}_3, \text{H}_2\text{SO}_4} \text{PhNO}_2 \xrightarrow{\text{Br}_2, \text{FeBr}_3} \text{BrPhNO}_2 \xrightarrow{\text{Fe}, \text{cHCl}} \text{BrPh} \xrightarrow{\text{NaNO}_2, \text{HCl}, \text{O}_2 \text{C}} \text{BrPh} \xrightarrow{\text{CaBr}_2, \text{HBr}} \text{BrPh} \]

\[ \text{Ph} \xrightarrow{\text{HNO}_3, \text{H}_2\text{SO}_4} \text{PhNO}_2 \xrightarrow{\text{KmO}_4, \text{H}_2\text{SO}_4, \text{Heat}} \text{PhCO}_2\text{H} \]

\[ \text{CH}_2=\text{CHCH}=\text{CH}_2 \xrightarrow{\text{H}_2\text{SO}_4, \text{H}_2\text{O}} \text{Ph-NCH}(_2\text{CH})\text{CO}_2\text{H} \xrightarrow{\text{H}_2\text{O}_2, \text{H}^+} \text{Ph-NCH}(_2\text{CH})\text{CO}_2\text{H} \xrightarrow{\text{Ph-NCH}_3\text{H}, \text{H}^+} \text{Ph-NCH}(_2\text{CH})\text{CO}_2\text{H} \xrightarrow{\text{H}_2\text{O}_2, \text{H}^+} \text{Ph-NCH}(_2\text{CH})\text{CO}_2\text{H} \]
14) Circle the most **basic** nitrogen in each molecule. (9pts)

15) Circle the **strongest acid** in the following threesomes. (9pts)

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

(b) \( \text{CH}_3\text{OH} \quad \text{NH}_3 \quad \text{CH}_4 \)

(c)

16) Name the following compounds in IUPAC form (14pts).

- 5-**Bromo-2-pentanone**

- Trifluoro-a**ctanoic Octanoic Anhydride**

- C15-2,3-**dimethyl cyclohexanone**

- S-**aminopentanoic Acid**.
17) Fill in the blanks for two of the following reactions. (6pts)

(a) \[
\begin{array}{c}
\text{H} \\
\text{O} \\
\text{Ph} \\
\text{H} \\
\text{Ph} \\
\end{array}
\xrightarrow{\text{H}_2\text{SO}_4, \text{CH}_3\text{OH}}
\begin{array}{c}
\text{H} \\
\text{O} \\
\text{Ph} \\
\text{H} \\
\text{Ph} \\
\end{array}
\]

(b) \[
\begin{array}{c}
\text{NH}_2 \\
\text{Ph}
\end{array}
\xrightarrow{1) \text{excess CH}_3\text{-Br}}
\begin{array}{c}
\text{Ph}
\end{array}
\xrightarrow{2) \text{Ag}_2\text{O}, \text{H}_2\text{O}, \text{heat}}
\begin{array}{c}
\text{Ph}
\end{array}
\]

(c) \[
\begin{array}{c}
\text{H} \\
\text{O} \\
\text{Ph} \\
\text{H} \\
\text{Ph} \\
\end{array}
\xrightarrow{\text{NaOCH}_3, \text{CH}_3\text{OH}}
\begin{array}{c}
\text{H} \\
\text{O} \\
\text{Ph} \\
\text{H} \\
\text{OCH}_3 \\
\end{array}
\]

18) When one equivalent of hydrogen chloride is added to the following conjugated diene, a mixture of two products is formed.

\[
\begin{array}{c}
\text{Ph}
\end{array}
\xrightarrow{\text{H-Cl}}
\begin{array}{c}
\text{Cl}
\end{array}
\]

i) Draw the two products.

ii) Provide the step-by-step mechanism which explains the generation of both products.

iii) One of the products contains a chiral center \(*\) that chiral carbon. (9pts)
19) Give the mechanism for **two** of the below conversions. (16pts)

(a) \( \text{CH}_3\text{OH, NaOH} \rightarrow \text{HO-} - \text{O-CH}_3 \)

(b) \( \text{NaNO}_2, \text{HCl} \rightarrow \text{N=O} \)

(c) \( \text{H}_3\text{C-} - \text{Ph} \text{ HOCH}_2\text{CH}_2\text{OH} \rightarrow \text{H}_3\text{C-} - \text{Ph} \)

\[ \text{CH}_3\text{-O-} \rightarrow \text{CH}_3\text{O} \rightarrow \text{CH}_3\text{O} \rightarrow \text{CH}_3\text{O} \rightarrow \text{H}_2\text{O-CH}_3 \]

\[ \text{Na}\rightarrow \text{H-} - \text{N=O} \rightarrow \text{H-} - \text{O-} - \text{N=O} \rightarrow \text{H-} - \text{O-} - \text{N=O} \rightarrow \text{H-} - \text{O-} - \text{N=O} \rightarrow \text{N=O} \rightarrow \text{H} \rightarrow \text{Ar-} - \text{NH}_2 \rightarrow \text{Ar-} - \text{N=O} \rightarrow \text{Ar-} - \text{N=O} \]}