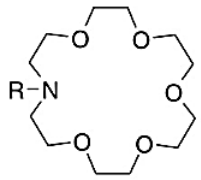
How to be a good Host?

Elementary Problem 1 - 10 points

Deadline: 19^{th} August, 9 PM IST

Experimentally determined Log (K_{11}) values (binding constants for 1:1 binding event in methanol at 25 degree Celsius) for different cationic guests by a heterocyclic host (structure shown below) are given in the following table. Point out the **major** trends in variation of the binding constant and suggest probable justifications behind those.

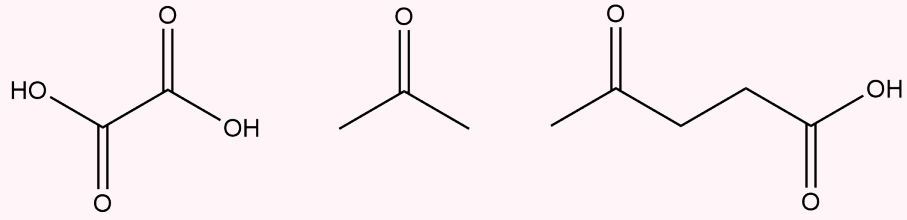
	Log K_{11}			
	Na^+	K^+	NH_4^+	Ca^{2+}
				
R = H	2.69	3.98	–	3.96
R = CH_2CH_2OMe	4.58	5.67	4.21	4.34
R = $(CH_2CH_2O)_2Me$	4.33	6.07	4.75	4.23
R = $(CH_2CH_2O)_3Me$	4.28	5.81	4.56	4.11
R = $(CH_2CH_2O)_4Me$	4.27	5.86	4.40	4.13
R = $(CH_2CH_2O)_5Me$	4.22	–	4.04	4.11

Not a Bed of Roses

Elementary Problem 2 - 10 points

Deadline: 8:30 PM IST, 21^{st} August

Rose oil is an essential oil obtained by distillation of roses. It has antibacterial and antifungal properties. One of its components **A** belongs to a class of compounds called terpenes and has a molecular formula $C_{10}H_{18}O$. Upon oxidation, **A** can give either a ten-carbon aldehyde or a ten-carbon carboxylic acid. **A** reacts with bromine under appropriate conditions to give tetrabromide **B**. **A** reacts with Hydrobromic acid, under appropriate conditions, to give two bromides of formula $C_{10}H_{17}Br$. When **A** undergoes ozonolysis, three products are formed:

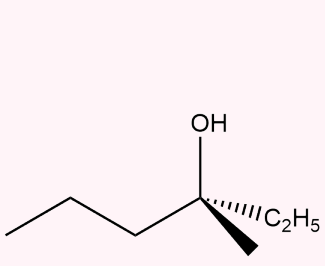


a) Give the structures of A, B and the two bromides formed when A reacts with HBr.

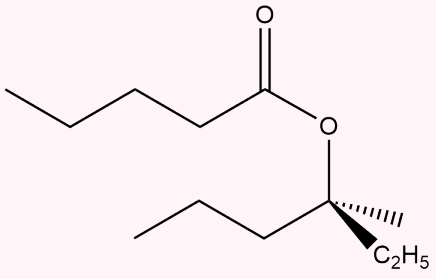
b) Which of the two bromides is do you expect to be formed in a higher proportion?

c) Draw the structures of the isoprene units that constitute A.

Taking great pains, you have managed to separate the three ozonolysis products (given above) of **A**. Using any or all of these products along with compound **D**, your guide asks you prepare near-quantitatively the molecule **E**.



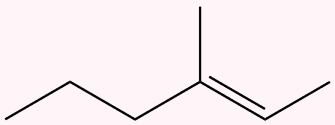
D



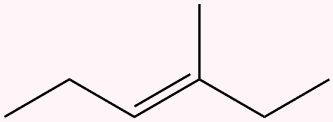
E

d) Devise a short scheme (not exceeding 4 steps) to synthesize E. Show mechanisms for non-trivial transformations.

You have now been instructed to perform a dehydration of **D**. You have managed to obtain and somehow isolate two pure alkenes **F** and **G**.



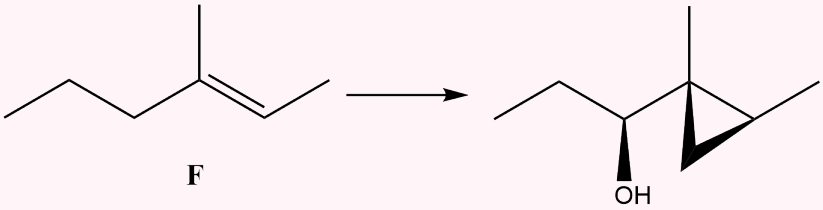
F



G

Arbitrarily, we choose **F**.

e) Perform the following conversion:



F

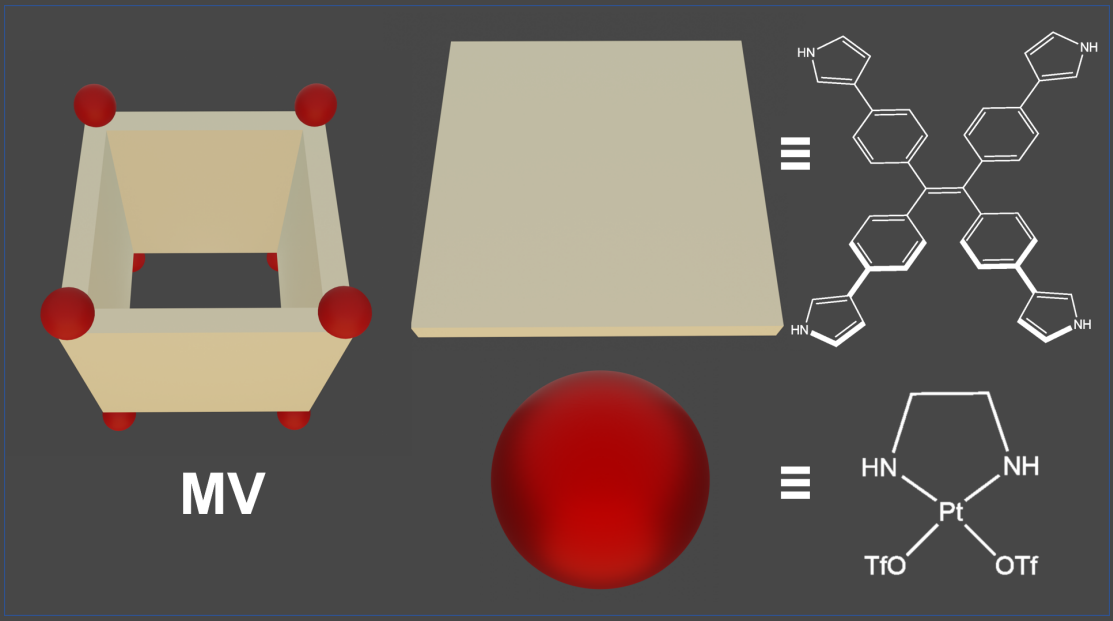
You can use normal resolution methods to resolve the enantiomers during synthesis if you so desire. Try to make the synthesis scheme as efficient as possible. Provide necessary details and show the mechanism for the transformation. Justify that your synthesis scheme produces the desired compound using the mechanism outlined by you.

A Case of Catalysis

Elementary Problem 3 - 10 points

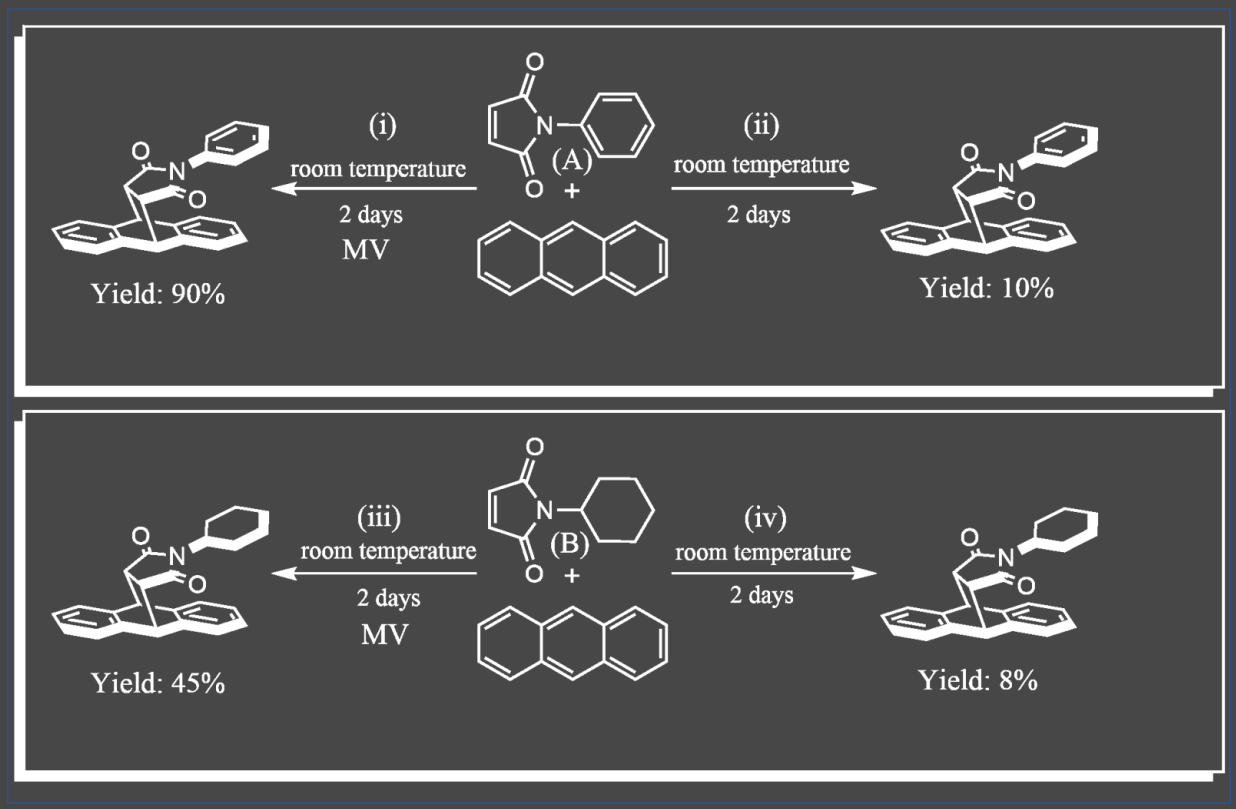
Deadline: August 24th at 8:30 PM IST

A developing area of supramolecular chemistry focuses on synthesis of molecular vessels that can encapsulate molecules and can simultaneously catalyze their reactions. One such molecular vessel is MV with aromatic ligands walls and metal acceptors at the corners.



To investigate its catalytic activity in Diels-Alder reaction, anthracene was reacted with two molecules (A) and (B) and the yields in presence and absence of MV were recorded.

Explain the difference in yield (two **distinct** reasons for full credit) between reactions (i) and (iii) and provide a logical sequence of reasoning as to why the presence of MV is the main reason for this discrepancy.



It's in Your Blood!

Elementary Problem 4 - 10 points

Deadline: 8:30 PM IST, 27^{th} August

Bio-Inorganic Chemistry deals not only with the naturally available bio-inorganic systems but also with bio-mimetic systems. Let's now try to explore the chemistry of biomimetic systems and see if we can rationalise the electronic structure, structure and reactivity of bio-mimetic systems through the following question.

One of the most widely studied bio-mimetic systems is Fe(TPP)(2-MeIm). TPP is tetraphenyl porphyrin, and 2-MeIm is 2-methyl imidazole. Suppose you have been provided with Fe(TPP)(2-MeIm):

1. Imagine you are a research student at the lab of some bio-inorganic chemist. You have somehow managed to prepare O_2^{2+}:

   a) What do you expect the persistence of O_2^{2+} to be?

   b) Suppose you are now studying the structure of the complex of O_2^{2+} with Fe(TPP)(2-MeIm). What do you expect the binding mode (linear, perpendicular, bent, or any other mode you can think of) of O_2^{2+} with Fe(TPP)(2-MeIm) to be? Justify your answer.

2. You have been given a sample of iron protoporphyrin-IX complex. Can this complex serve as an oxygen carrier? Why/Why not?

3. Suppose you have somehow managed to substitute the Fe^{2+} ion in the complex with Co^{2+}. Can this cobalt-protoporphyrin IX complex act as an effective oxygen carrier? Justify. Also, what can be the possible mode of binding of NO with the cobalt-protoporphyrin complex?

A Race to Racemize

Elementary Problem 5 - 10 points

Deadline: August 31^{st} at 8:30 PM IST

At ambient temperatures, amino acid racemization is a slow reaction. As such, it can be used for dating biological objects and, moreover, for studying their thermal history. Let us consider L-isoleucine (L-Ile) or (2S,3S)-2-amino-3-methylpentanoic acid as an example. It isomerizes and forms (2R,3S)-2-amino-3-methylpentanoic acid, also known as D-allo-isoleucine.

Note: The term 'racemization' may be used here in a rather broad manner.

1. Racemization rates for different free (i.e., in aqueous solution; not in polymerised form) amino acids differ substantially. An interesting experiment shows:

   (i) The racemization rate of free serine is significantly more than that of free valine.

   (ii) Substitution on the carboxylate moiety enhances the racemization rates of both free serine and free valine.

   What conclusion can you draw about the racemization process from these crucial observations? (Strictly within 200 words)

2. Amino acids with a single chiral centre undergo racemization, e.g. L-arginine racemizes:

   $$\text{L-arginine} \rightleftharpoons \text{D-arginine}$$

   (The forward rate constant is k_1 and the backward rate constant is k_2)
   The time evolution of concentrations is governed by:

   $$\left[ln \ \frac{1 + \frac{[D]}{[L]}}{1 - \frac{[D]}{[L]}} \right] = 2kt + c$$

   Here [D] and [L] are concentrations of D- and L-arginine at time t, k is the corresponding rate constant, and the term c is set according to the initial concentrations. Emperor Proteinus passed away during his journey to Aminoland in 1000 AD. To facilitate the repatriation of the remains, his body was boiled in water (373 K) immediately after his death for a certain time. Let us try to estimate the boiling time with the help of chemical kinetics.

   We know that the rate constant k_1 of arginine racemization within a protein at 373 K and pH = 7 has the value of $5.10 * 10^3 \ h^{-1}$. In order to analyse the isomeric composition of arginine in

the Emperor's bones, we need to start with transferring arginine into solution. His bones were hydrolyzed in a highly acidic environment for 4 hours at 383 K. The ratio of the optical isomers was [D]: [L] = 0.090. His wife Peptidia's body was not boiled after her death. Her bones were hydrolyzed using the same procedure and in this case the ratio was [D]: [L] = 0.059. (Note that the racemization also takes place during the hydrolysis, with the rate constant k_h, different from k_1). **How long was Emperor Proteinus boiled in water in 1000 AD?**

[**Note:** The racemization of arginine is an extremely slow process at temperatures typically encountered in graves. As both bodies are only some 1000 years old, we can neglect the natural racemization during this time.]

3. In fact, the reverse reaction cannot be neglected. Rate constant for the backward reaction is k_2. Let us define the deviation of concentration from its equilibrium value $[L]_{eq} : x = [L] - [L]_{eq}$. It is possible to derive that x evolves with time according to the following equation:

$$x = x_0 e^{-k_1 t} e^{-k_2 t}$$

Where x_0 is the deviation from equilibrium at $t = 0\ h$. The rate constant for the forward reaction is $k_{1_{374K}} = 9.02 * 10^{-5}\ h^{-1}$.
Let us boil 1.00 mol dm^{-1} L-isoleucine solution for 1943 hours at 374 K. The rate constant for the forward reaction is $k_{1_{374k}} = 9.02 * 10^{-5} h^{-1}$, K_{conv} for L-isoleucine conversion has the value of 1.38 (at 374 K). In the following calculation, abbreviate the concentration of L-isoleucine as [L] and that of D-allo-isoleucine as [D].
Evaluate (with three significant figures): $[L]_{eq}$ **and diastomeric excess** d_e **after boiling.**

4. At the start of the reaction, we can neglect the reverse reaction. The epimerization then follows the first-order kinetics:

$$\text{L-isoleucine} \rightarrow \text{D-allo-isoleucine}$$

The value of the rate constant for above reaction at 374 K is $k_{1_{374K}} = 9.02 * 10^{-5}\ h^{-1}$ and at 421 K is $k_{1_{421K}} = 1.18 * 10^{-2}\ h^{-1}$. In the following calculation, abbreviate the concentration of L-isoleucine as [L] and of D-allo-isoleucine as [D]. We can define a quantity d_e (diastereomeric excess):

$$d_e = \left| \frac{[D] - [L]}{[D] + [L]} \right| * 100$$

We propose to boil L-isoleucine for 1943 hours at 374 K. **What is the value of** d_e **(with three significant figures) for L-isoleucine before boiling and after boiling?**

A Shiver down the Spine-l

Elementary Problem 6 - 10 points

Deadline: September 7^{th} at 8:30 PM IST

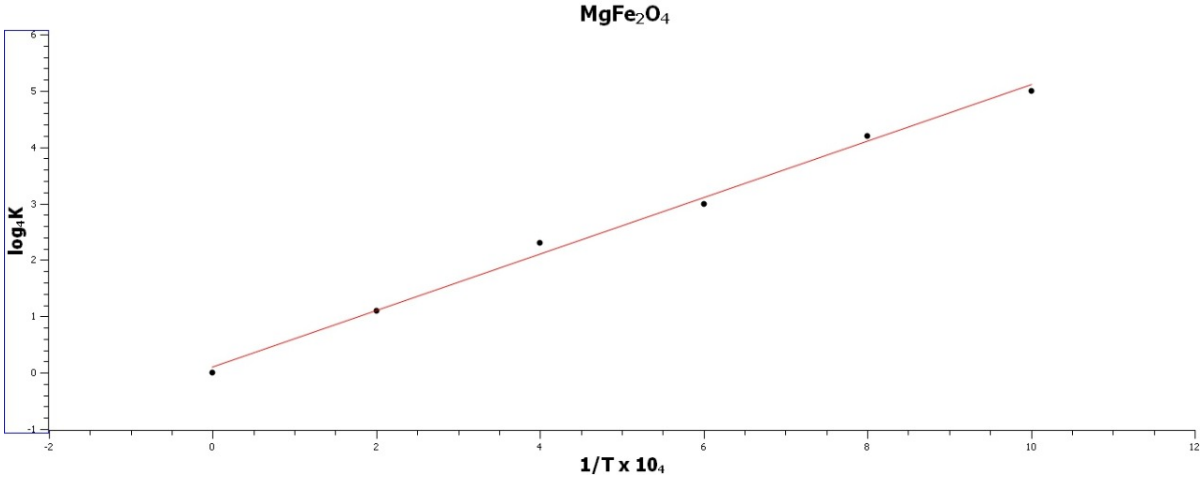
1. Let A and B be two divalent cations and C be a trivalent cation and $0 < d < 1$. $A_{1-d}B_dO.C_2O_3$ forms a normal spinel structure. For each unit, there is one tetrahedral site and two octahedral sites. Consider v molecules of this compound. Let there be two parameters x and y which define the distribution of A^{2+} and B^{2+} ions in tetrahedral sites, such that there are xv A^{2+} ions in tetrahedral sites and yv B^{2+} ions in tetrahedral sites. Write the distribution of each cation in both tetrahedral and octahedral sites and find the number of ways such a distribution ($A_{1-d}B_dO.C_2O_3$) can be achieved (denote that with w).

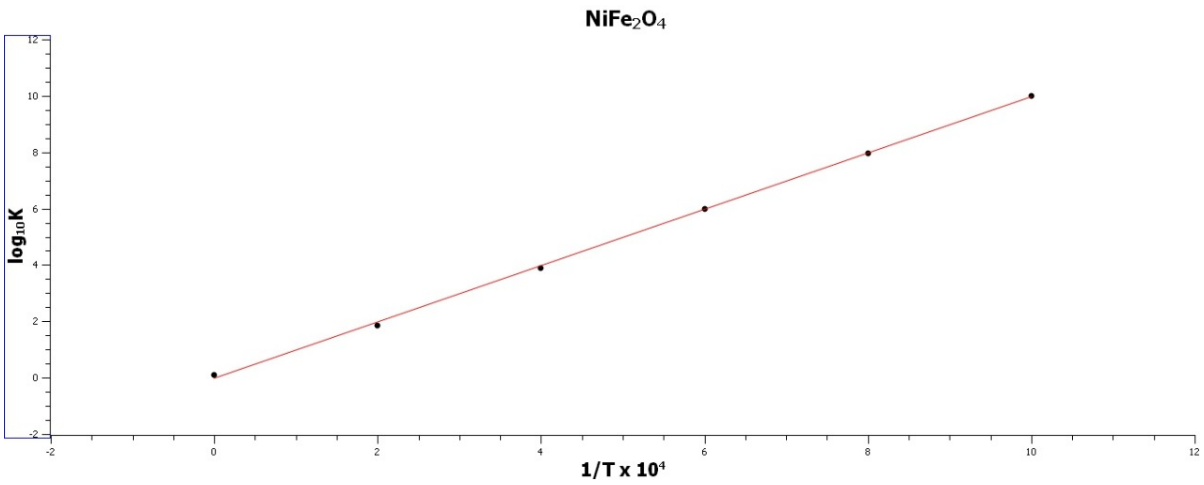
2. Consider a compound $A_{1-x}B_x(A_xB_{2-x})O_4$ where x is the fraction of tetrahedral sites occupied by B^{2+} ions. Initially, the compound exists as a normal spinel. Consider the inversion of the structure:

$$A + (B) \rightleftharpoons (A) + B$$

   a. Write the equilibrium constant (K) in terms of x.

   b. From the plots deduce the entropy due to non-configuration changes (ΔS°). (T denotes the absolute temperature)





c. Derive the expression for configurational entropy (-R ln$w$) for this compound and plot its variation with x. (Hint: try using the same method as in Part 1)

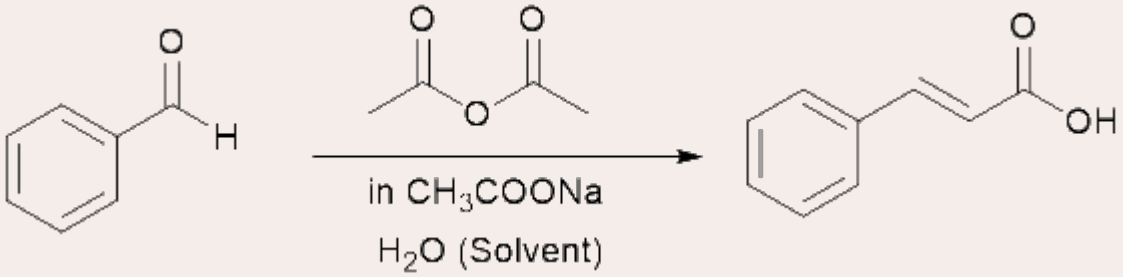
3. Which structure will Co_3O_4 adopt and why?

Almonds, Cinnamon, and everything in between

Elementary Problem 7 - 10 points

Deadline: 10^{th} September, 8:30 PM IST

In the 19^{th} Century or early 20^{th} century, when there were no advanced Spectroscopic techniques available, Chemists only used to depend on reaction outcomes and isotopic studies to decipher the plausible mechanisms. One of such reactions whose probable mechanism can be deciphered through these ways is the well-known *Perkin Reaction*. The reaction scheme is provided below for a molecule of Benzaldehyde as the substrate and Acetic Anhydride in Sodium Acetate being the reagent. The reaction is carried in an aqueous solvent and it generates Cinnamic Acid as the end product.



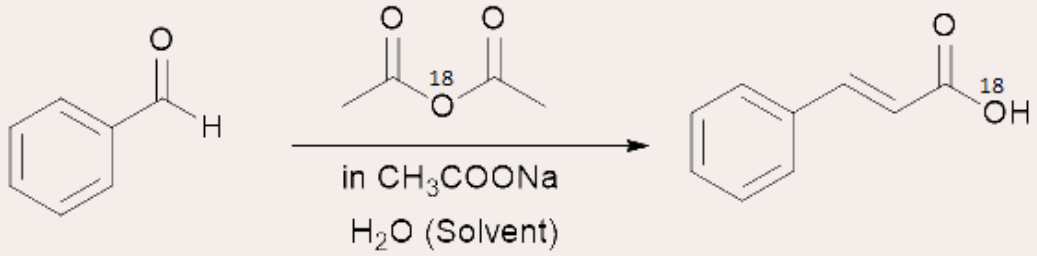
This reaction is one of the C-C bond forming reactions, hence it's believed that the initial step of the reaction occurs through the attack of the carbanion of the anhydride used, generated *in situ*, at the Carbonyl carbon of the aldehyde. However, there can be various pathways that can lead to the final product from the initial step. They are listed as follows,

- **Mechanism A:**
  Elimination of a water molecule after the initial attack to generate a double bond followed by hydrolysis to generate the corresponding acid.
- **Mechanism B:**
  Acyl transfer to the hydroxyl moiety via a six-membered cyclic intermediate after the initial attack. Then a molecule of acid is eliminated to generate a double bond followed by protonation to generate the corresponding acid.
- **Mechanism C:**
  Formation of a four-membered cyclic Wittig type intermediate after the initial stage. At the next step, abstraction of a proton breaking the cyclic structure followed by protonation to generate the acid.

The three mechanisms thus been listed above, the job boils down to find out the one which supports all the experimental evidence. The questions below will help you out to reach the correct mechanism based on some simple experimental results.

1. When isotopically labelled water (H_2O^{18}) was used as the solvent, no isotopically labelled oxygen was found to be present in the Cinnamic Acid. Based on this observation, which mechanism(s) can be rejected out of the three mentioned above. Justify your answer with proper explanation.
   (For simplicity, assume that no exchange occurs between the initial reactants and reagents with the solvent).

2. To further investigate, instead of normal Acetic Anhydride, isotopically labelled molecules of Acetic Anhydride are used, the following result was obtained.



   Based on this particular observation, which mechanism(s) can be rejected. Justify your answer with proper explanation.
   (Again, for simplicity, assume that no exchange occurs within the initial reactants and reagents).

3. Combining the above two results, which of the three can be most suitable mechanism? Write out the steps of the corresponding mechanism.

4. Assuming the mechanism deduced from the previous three questions to be the correct one, what should be the outcome for the following set of reagents ?