1. Give retrosynthetic analyses for the following molecules that go back to the given starting materials, and then provide the synthesis in the forward direction. Assume you have access to the usual other reagents (HBr, HNO₃, NaBH₄, etc.) in the lab.

   a. **Retrosynthesis**

   ![Retrosynthesis Diagram]

   **Synthesis**

   ![Synthesis Diagram]

   If the alcohol is inexpensive and readily available then the Fischer esterification works well, however if the alcohol is expensive, it is better to convert the carboxylic acid to the acid chloride (X = Cl) using SOCl₂/pyridine or the anhydride (X = OCOPh) by heating and removing H₂O. Both of these reactive carboxylic acid derivatives require 1 equivalent of alcohol to give the ester (with pyridine as a base).
The most straightforward way to make an anhydride from a volatile (i.e. easily distillable) carboxylic acid is to heat it up with a small amount of a mineral acid and remove the water that is formed. You could also form the acid chloride from a portion of the carboxylic acid (using SOCl/pyridine) and then react that with more of the remaining carboxylic acid.

All of the required carbon atoms for the product are found in the given starting material, which needs to be manipulated to introduce oxygen. The system has to be oxidized to produce the lactone (cyclic ester) so the Baeyer-Villager oxidation is appropriate.
d. **Retroanalysis**

\[
\text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]}
\]

**Synthesis**

\[
\text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]}
\]

\[
\text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]}
\]

e. **Retroanalysis**

\[
\text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]} \rightarrow \text{[structure]}
\]
2. Give the major organic product(s) from each step of the following synthetic sequence.

1. Na$_2$Cr$_2$O$_7$, H$_2$SO$_4$
2. xs CH$_3$OH, cat. H$_2$SO$_4$
3. NaOCH$_3$, CH$_3$OH
4. aq. NH$_4$Cl (quench)
5. NaOCH$_3$, THF
6. CH$_3$CH$_2$Br
7. NaOH, aq. THF
8. dil. HCl (quench)
9. 180 °C (-CO$_2$)
10. LDA, THF, -78 °C
11. PhCH$_2$Br
3. In the boxes provided, give the products from each step in the following “road-map” scheme. Predict the $^1$H NMR spectra of each of the organic products from each step.
4. Give complete mechanisms, including any important resonance structures for intermediates where applicable, that explain the bond-making and bond-breaking events in the following conversions.

a. 

\[
\text{H}_3\text{CO} \quad \overset{-\text{O}}{\text{CH}} \quad \overset{-\text{O}}{\text{CH}} \quad \text{1. NaOCH}_3, \text{CH}_3\text{OH} \quad \text{Ph} \quad \overset{\text{O}}{\text{CO}} \quad \text{3. NaOCH}_3, \text{THF} \\
\text{CH}_3\text{O} \quad \text{2. dilute HCl (quench)} \quad \text{4. PhCH}_2\text{Br} \quad \text{5. NaOH, aq. THF} \quad \text{6. dilute HCl (quench)} \quad \text{7. 180°C (-CO}_2) \\
\text{H}_3\text{CO} \quad \overset{-\text{O}}{\text{CH}} \quad \overset{-\text{O}}{\text{CH}} \quad \text{contd...}
\]
tautomerism
b.

1. Na$_2$Cr$_2$O$_7$, H$_2$SO$_4$

2. xs CH$_3$OH, cat. HCl

3. NaOCH$_3$, CH$_3$OH

4. dilute HCl (quench)

5. NaOH, aq. THF

6. dilute HCl (quench)