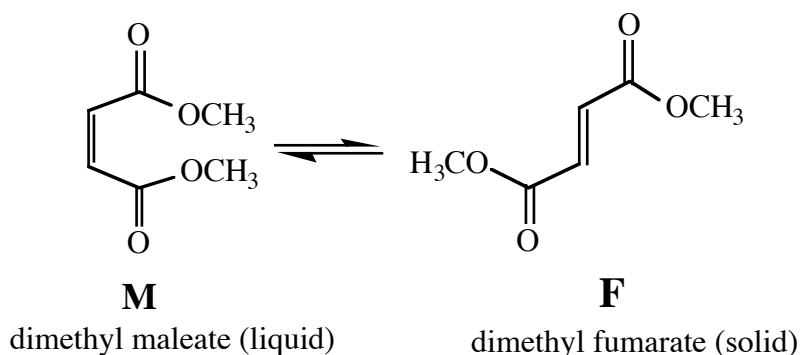
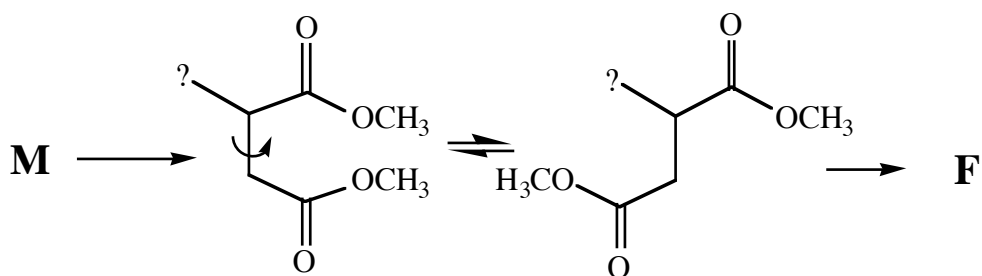


The Investigation of a Mechanism

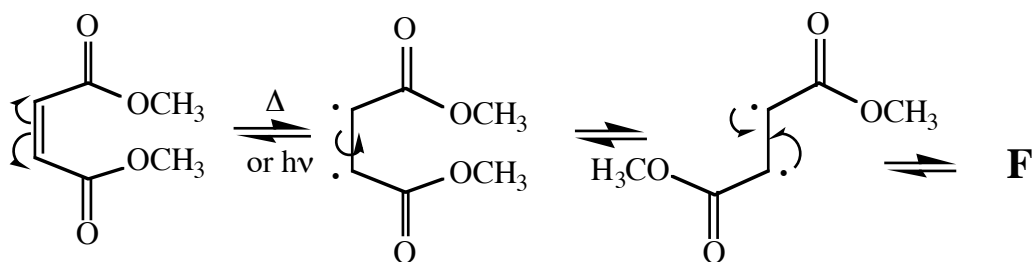


Introduction

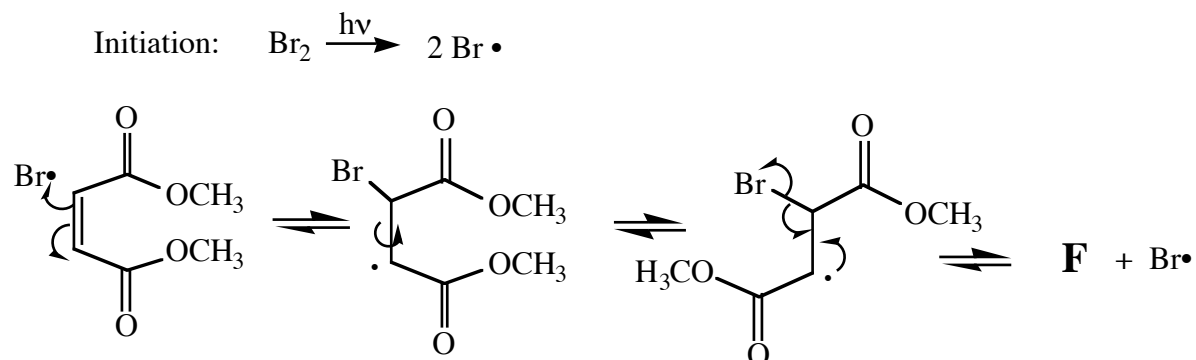
This experiment deals with the investigation of the mechanism (or possible mechanisms) for the isomerization of dimethyl maleate (**M**) to dimethyl fumarate (**F**). It should be noted that there is no way to prove a particular mechanism is the one (we can't look and see the electrons moving around in a nice ordered mechanism). Rather, we have to propose several possible mechanisms, and then run experiments where we can disprove a proposed mechanism. That is what we will be doing in this experiment. This isomerization involves the transformation of the *cis* isomer of a double bond to the *trans* isomer of a double bond. As you know, these isomers can be isolated because there is no rotation about a carbon-carbon double bond at room temperature. In order for this isomerization to occur, the π bond must break to allow free rotation about the single bond, and then the π bond must be able to reform. This is shown below.



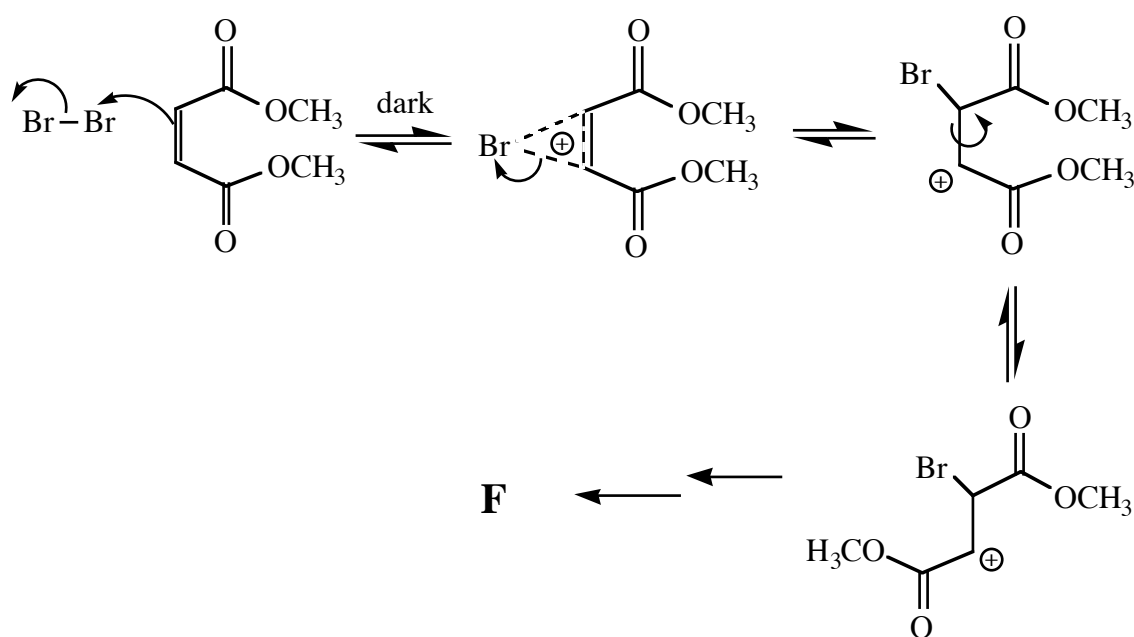
The question mark shown above will change depending on the possible mechanism. The strength of a typical π bond is roughly 65 kcal/mole, which means that if we were to simply break the π bond in a homolytic sense (involving radicals - an equal sharing of electrons), we would have to heat the compound to almost 500 °C, or we would have to use light of just the right frequency to do a π to π^* transition. Then the mechanism shown below could occur.



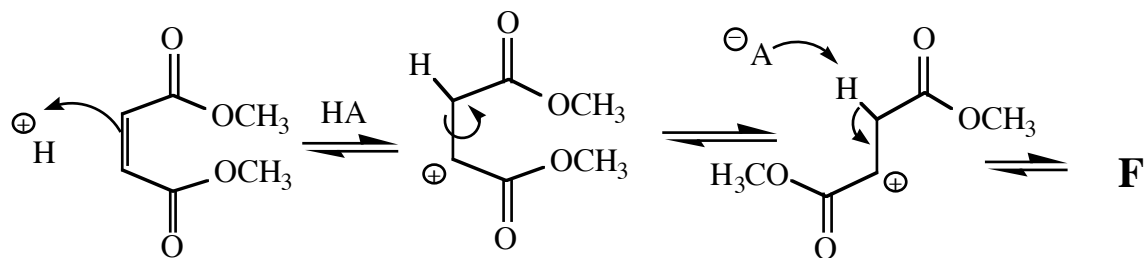
Another way in which we could cause this radical mechanism to occur is to use an initiator such as bromine. Then the isomerization could occur as shown below:



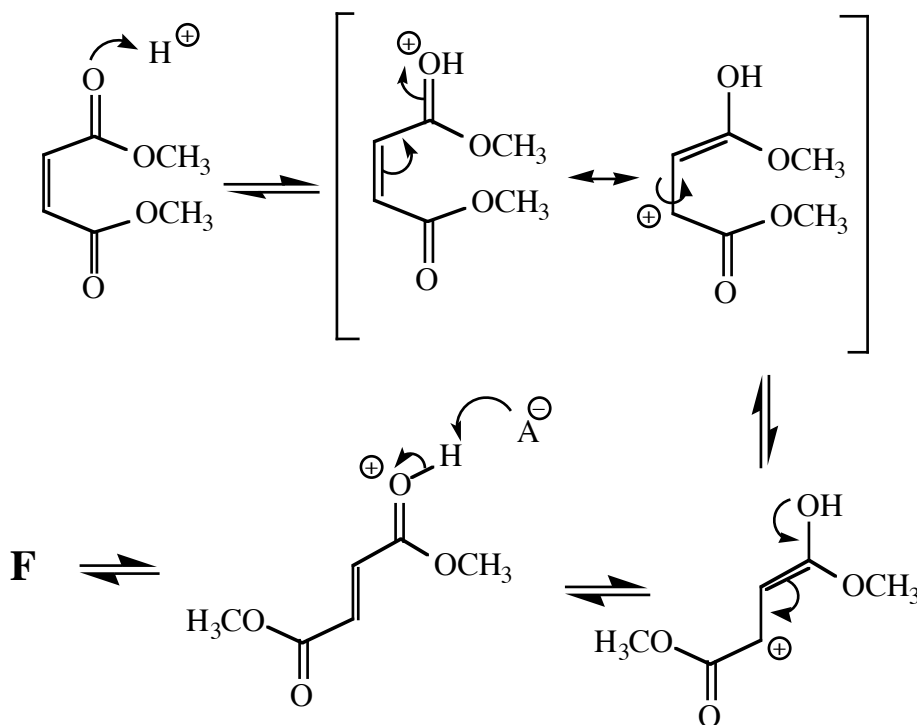
There are other types of mechanisms for isomerization that we can propose. These involve a heterolytic (involving charges - unequal sharing of electrons) cleavage of the π bond. In theory we could attack the carbon-carbon double bond directly with either bromine (without light, to prevent the mechanism shown above) or a strong acid (HA). This would lead to the possible mechanisms shown below.



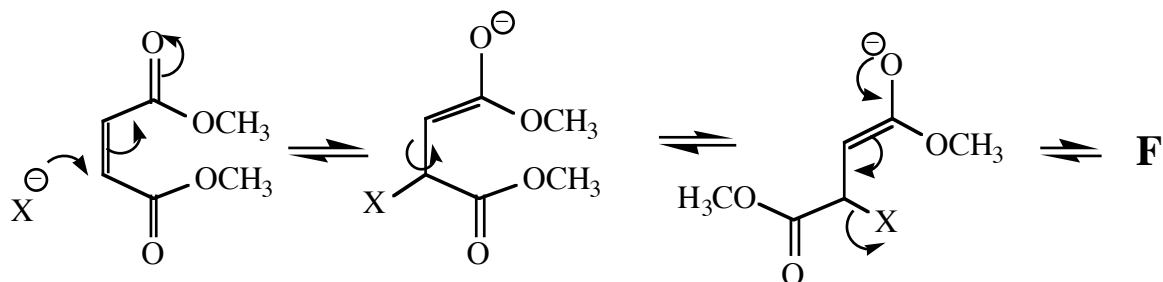
Using a strong acid (HA):



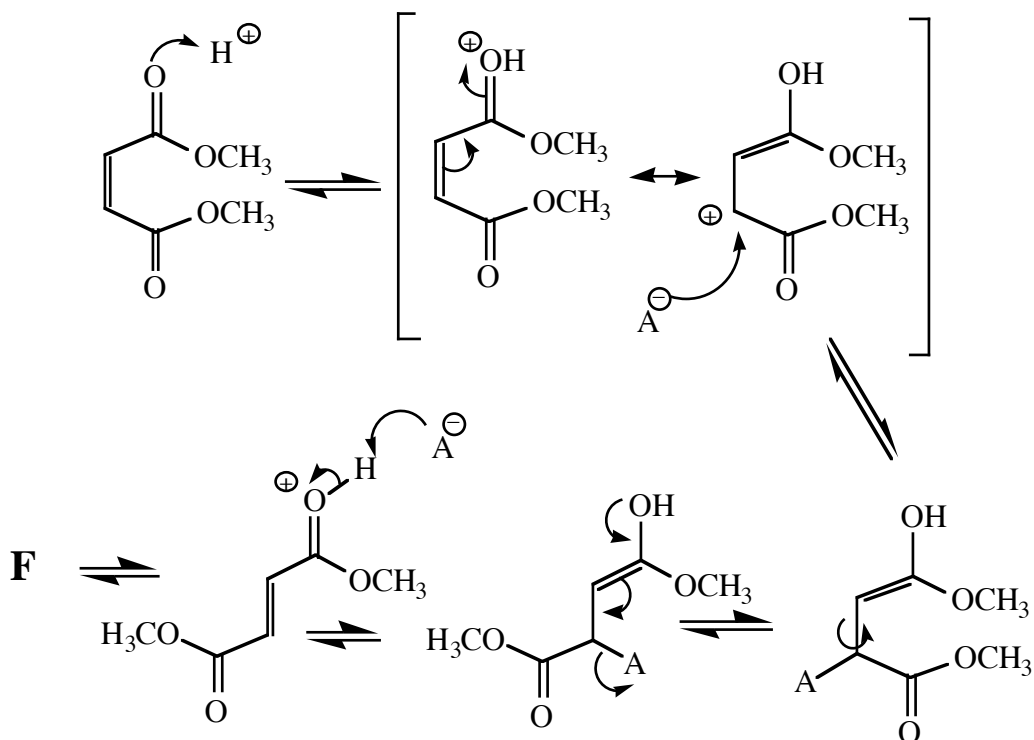
There is an alternative way in which a strong acid could react with dimethyl maleate. Instead of reacting with the carbon-carbon double bond, the acid could react with the carbonyl oxygen of one of the esters. Then we can draw a resonance structure in which the key carbon-carbon bond is now a single bond. This resonance structure tells us that there is a partial single-bond character to the bond about which we need to rotate. If there is enough of a single-bond character to allow rotation, then the mechanism shown below could allow isomerization to **F**.



Another way in which we could break the pi bond is by a 1,4 attack of a nucleophile under a non-acidic mechanism (Remember, the carbons of the double bond have a partial positive charge from resonance with the carbonyl groups). This nucleophile must be easily eliminated in the final step in order to reform the double bond, so a good choice for a nucleophile would be a halide ion (X^-). Then the mechanism shown below could allow isomerization, if the nucleophile is strong enough to add to the double bond.



One final mechanism (this is the last one, I swear!) involves a strong acid whose counter ion is a good nucleophile (such as HX). The acid could protonate the carbonyl, which would make it even easier for the X^- to attack. Then the mechanism shown below could facilitate isomerization.



At this point, you don't know which mechanisms will work under the conditions we will use in lab, and you don't know which mechanisms won't work under our laboratory conditions. But, by analyzing the nature of the carbon-carbon double bond, we can start to possibly eliminate some of the proposed mechanisms. The carbon-carbon double bond of a maleate has two electron withdrawing carbonyl groups attached to it. Therefore, this double bond is extremely electron poor, and is very unlikely to act as a nucleophile and attack a plus charge or a partial positive charge (although radical reactions can readily occur at this double bond). So which of the mechanisms can you eliminate as a possibility?

In fact, the carbon-carbon double bond of dimethyl maleate is so electron poor that it will not react with bromine (to form the dibromide via the bromonium ion in the absence of light) as a normal double bond would. Additionally, protonation of dimethyl maleate with a strong acid occurs exclusively on the carbonyl oxygen of either one of the esters (there are additional resonance structures!)

Based on the results of the reactions you will perform in lab, you will be able to determine which of these possible mechanisms can occur. So, let's do the experiment! (You must be dying of curiosity by now. But curiosity killed the cat, so be careful in lab!)

Experimental Procedure

Possible Reactions with acid or NaI

Place a 150 mL beaker of water on your sand bath, and heat it so that the temperature stays between 60-70 °C.

Place 0.75 mL of dimethyl maleate in each of 3 reaction tubes and add 0.5 mL of methanol to each of these tubes, and mix these solutions. Be sure to label each of these reaction tubes (1, 2, and 3)! Add 0.5 mL of concentrated HCl to reaction tube #1, and add 0.5 mL of concentrated sulfuric acid to reaction tube #2. Add 100 mg of sodium iodide to reaction tube #3. Mix each tube thoroughly, add a boiling chip to each, place these three tubes in your 60-70 °C water bath, and heat them for one hour.

After one hour at this temperature, cool the reaction tubes in an ice-water bath. Do you see crystals in any of these tubes? Discard the contents of any tubes which do not contain crystals in the appropriate waste container.

Recrystallization of Product(s)

Reheat any tubes which contain crystals in your hot water bath, adding a little methanol if necessary to dissolve the crystals. Transfer the solution(s) to separate 10 mL Erlenmeyer flask(s) and reheat them to dissolve any crystals which might have come out of solution. Add 1 mL of warm water (warm the water in a reaction tube in your water bath) to the methanol solution in your Erlenmeyer flask(s) and allow the solution(s) to cool slowly to room temperature so that you get nice pure crystals. Cool the solutions in an ice-water bath, filter the crystals, and wash them with a small amount of an ice-cold solution of 50% methanol - 50% water. Determine the weight, yield, and melting point of your product(s).

Based on your results, which of the possible mechanisms involving acids or halide nucleophiles (or both) will cause the isomerization to occur under the conditions we employed in lab?

Potassium Permanganate Test

To prove that your solid(s) do indeed contain a double bond, test them with potassium permanganate solution. To do this, place about 25-50 mg of your solid(s) in a small test tube, add 1-2 mL of acetone, and slowly add 4-5 drops of 1% aqueous potassium permanganate solution drop by drop with shaking. Allow the solution to stand 1-2 min, then record your observations. KMnO_4 will react with a double bond to form a diol and MnO_2 . MnO_2 is a brown solid, and if there is a double bond in your compound, you should see a brown solid.

Possible reactions with Bromine

Put 0.75 mL of dimethyl maleate in each of 2 reaction tubes and label them #4 and #5 (you can substitute a small test tube if you are running out of reaction tubes). Add 0.6 M bromine in dichloromethane dropwise to reaction tubes #4 and #5 until an orange solution results. It should only take a few drops to give the solution an orange color. Place tube #4 in a dark drawer in your locker (remember to close the drawer!), and expose tube #5 to direct sunlight (let's hope it's a sunny day!) If you can hold your tube outside in direct sunlight, keep a close eye on it, it just might react very quickly! After 30 minutes, cool tubes #4 and #5 in an ice-water bath (**Before proceeding any further, read the experimental note on the next page**), collect any precipitates by vacuum filtration, and wash the crystals with a small amount of ice-cold dichloromethane.

Recrystallization

Transfer the crystals to a 10 mL Erlenmeyer flask, add 0.5 mL of methanol, and heat in your hot water bath until the crystals dissolve (you may have to add a little more methanol). Add 0.5 mL of

warm water (heat the water in a reaction tube in your water bath) with stirring, and allow the solution to cool slowly to room temperature. Cool the solution in an ice-water bath, filter the crystals, and wash them with a small amount of an ice-cold solution of 50% methanol - 50% water. Determine the weight, yield, and melting point of the crystals.

experimental note:

If any of your solutions have completely solidified, the filtration and washing techniques should be omitted, and you should recrystallize your products exactly as described in the procedure for the reactions with strong acids or NaI.

Test any solid products with Potassium Permanganate as before.

Based on your results of the reactions with bromine, which of the possible mechanisms will cause the isomerization to occur under the conditions we employed in lab?

Cleaning Up

Before you discard your solutions from the bromine reactions, add a few drops of cyclohexene to any orange solutions until they are discolored (so there is no Br₂ remaining - it can react with acetone to form a powerful lachrymator: 1-bromo-2-propanone. What is the mechanism of this reaction?). Discard all of these solutions in the halogenated waste containers.

Questions

1. Based on your results, identify which of the possible mechanisms is occurring in our experiments. Does it make sense that some of these mechanisms occur and some don't? Rationalize your answers (i.e. why do some mechanisms work and others don't?).
2. One possible side-product can arise from hydrolysis of the esters in dimethyl maleate and fumarate to the corresponding carboxylic acids. This would form maleic acid or fumaric acid. How do you know this has not occurred? Hint: look up the physical constants for maleic and fumaric acid.
3. Compare this type of investigative lab with the more traditional "synthesize a compound" lab.