## 12BL Experiment 1: The Diels-Alder Reaction

Safety: Proper lab goggles/glasses must be worn (even over prescription glasses). As always, ask where organic waste containers are located in the lab.

Background: The Diels-Alder reaction is one of the most powerful tools used in the preparation of important organic molecules. Conjugated dienes undergo a cycloaddition reaction with certain double bonds (called *dienophiles* – "lover of dienes") to produce cyclohexenes and related compounds. The simplest Diels-Alder reaction is between 1,3-butadiene and ethylene:
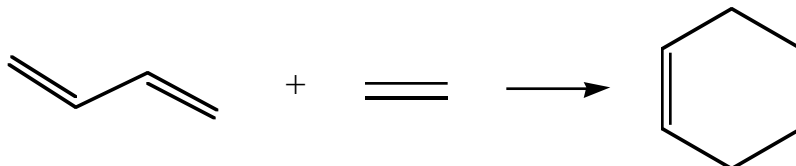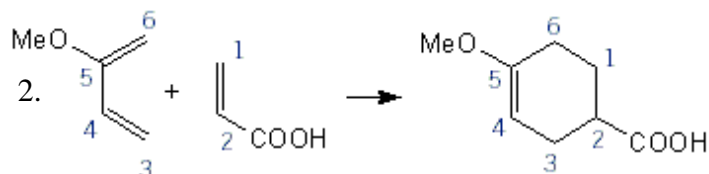
The mechanism of the reaction begins with the diene assuming the higher energy, but more reactive, *cis* conformation. If the diene is unable to form a cis-like form, then the Diels-Alder reaction will not occur. As the diene and the dienophile approach each other, the two terminal carbons of the diene meet the two carbons of the dienophile:
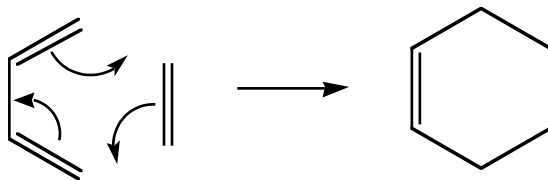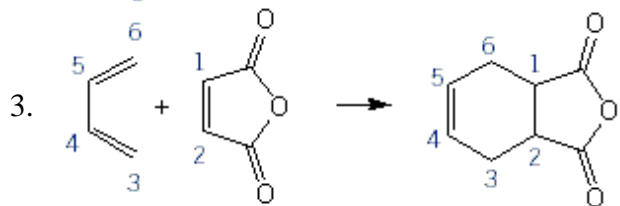
The Diels-Alder reaction is sped up by the presence of electron donating groups on the diene and by the presence of electron withdrawing groups on the dienophile – recall that "electron-rich species love electron-deficient species."
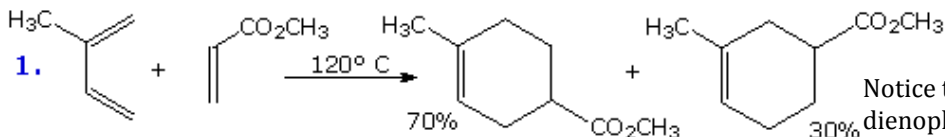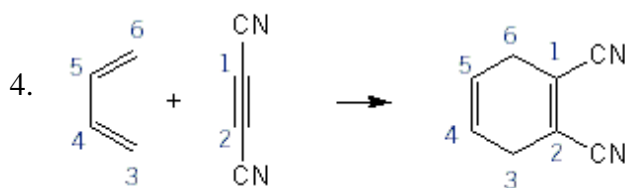
Notice that the diene & dienophile may approach each other in two different ways resulting in two different products – the more abundant product being the one with the substituents further away from one another.

Image https://www2.chemistry.msu.edu

2. MeO [diene with C-5, C-6, C-4, C-3] + [acrylic acid with C-1, C-2 COOH] → MeO [cyclohexene product with C-6, C-1, C-5, C-4, C-3, C-2 COOH]

Substituents on C-2 and C-5 remain on those carbons after the reaction.

3. [diene C-6, C-5, C-4, C-3] + [maleic anhydride C-1, C-2] → [bicyclic anhydride product]

The dienophile was itself a ring, so our product is bicyclic.

4. [diene C-6, C-5, C-4, C-3] + [dicyanoacetylene, CN, C-1, C-2, CN] → [cyclohexadiene product with CN on C-1, CN on C-2]
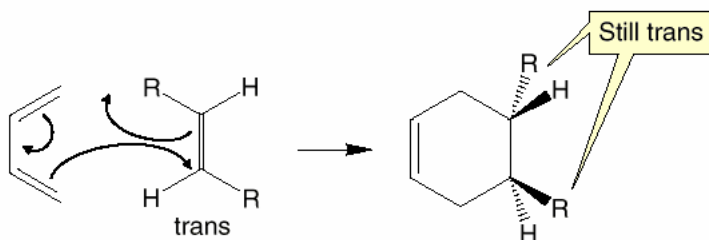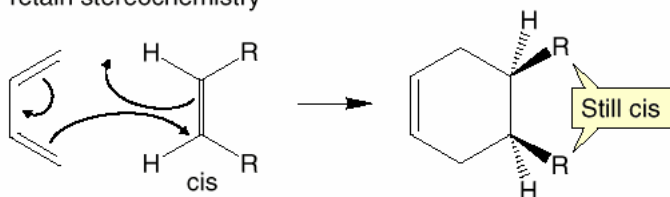
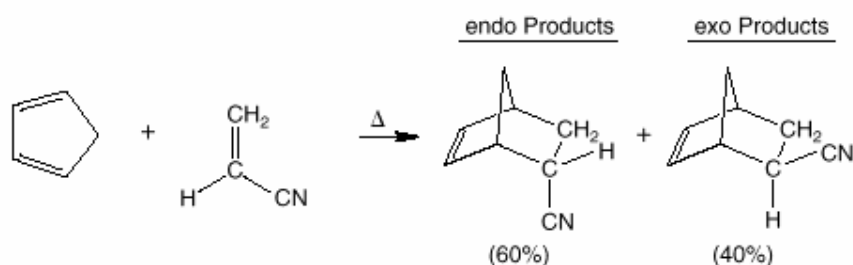Notice that the dienophile was a triple bond, so the product had a double bond.
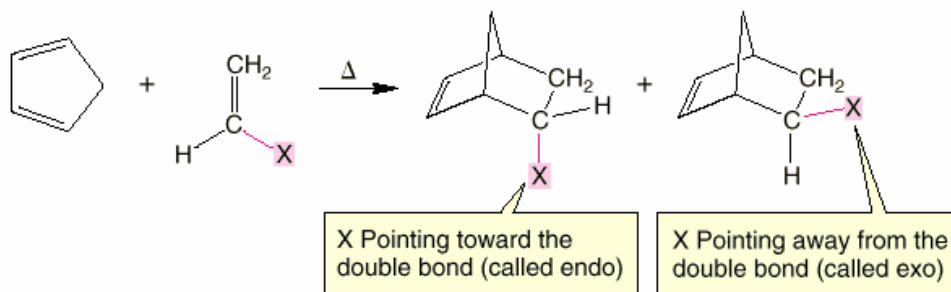
Image www.mendelset.com

The Diels-Alder reaction is also *stereospecific* – meaning the stereochemistry of the products will be the same as the reactants.

A one-step, concerted mechanism must retain stereochemistry

Still cis

Still trans

In addition, if cyclic dienes are used in the Diels-Alder reaction, two types of products may form – the *endo*-product (kinetically favored/fast) and the *exo*-product (thermodynamically favored/slow). Although the stability of the *endo*-product is less than the *exo*-product, the *transition state* of the endo-rxn is more stable due to hyperconjugation – interactions of the diene's pi orbitals with the nearby substituents of the dienophile.

| X Pointing toward the double bond (called endo) | X Pointing away from the double bond (called exo) |

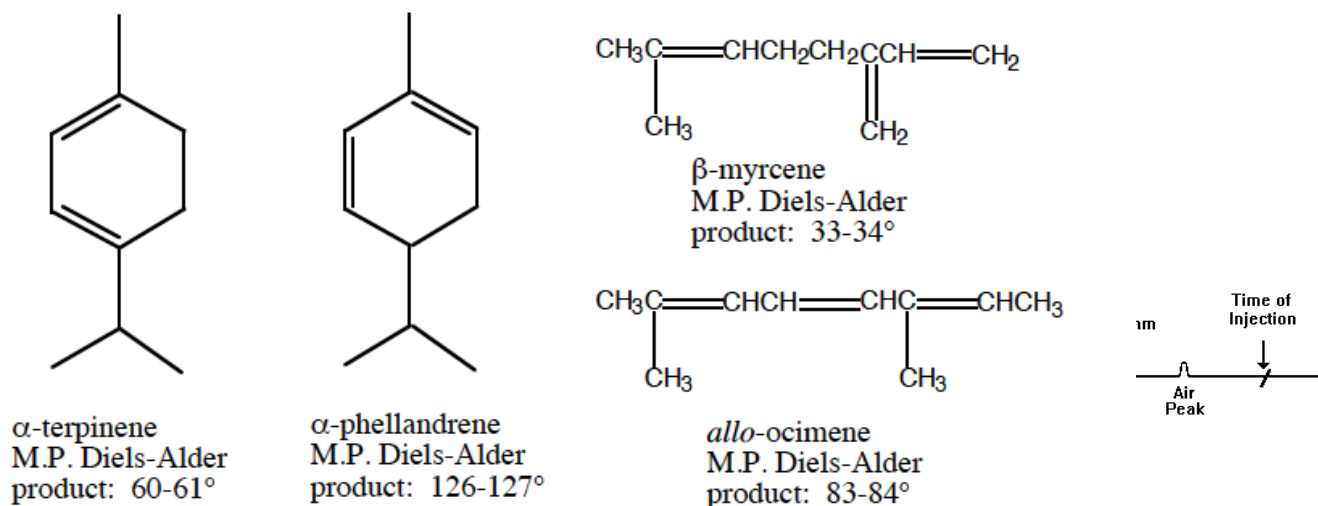endo Products   exo Products

(60%)   (40%)

https://webspace.utexas.edu/jrz272/Spring_2010/The%20Diels-Alder%20Reaction.pdf

Today you will be using maleic anhydride, a very good dienophile because it contains two highly electron withdrawing carbonyl groups. The reaction of maleic anhydride and cyclohexadiene is another example of the *Endo Rule*:

ENDO (favored)   EXO (disfavored)
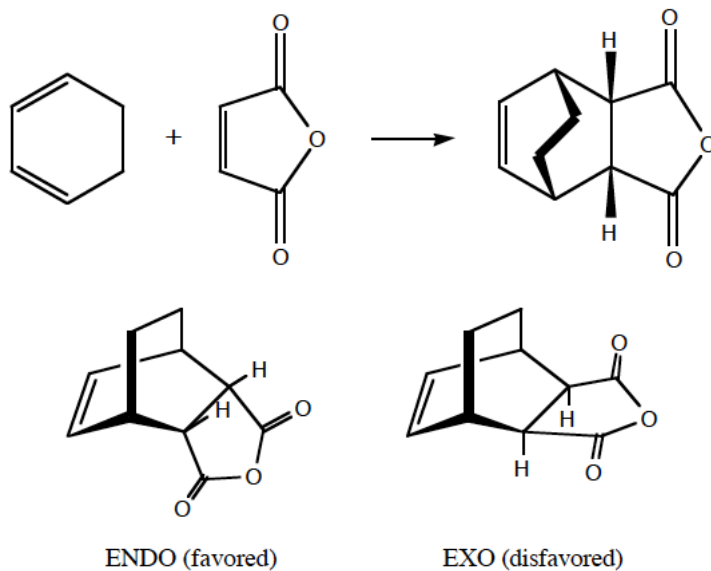
You will determine the identity of the conjugated diene that is present in eucalyptus oil by reacting it with maleic anhydride and isolating the resulting Diels-Alder product. The structures of the possible dienes in eucalyptus oil are shown below with the potential DA product melting points also given.

$$CH_3C{=\!=}CHCH_2CH_2CCH{=\!=}CH_2$$
$$CH_3 \qquad CH_2$$

β-myrcene
M.P. Diels-Alder
product: 33-34°

$$CH_3C{=\!=}CHCH{=\!=}CHC{=\!=}CHCH_3$$
$$CH_3 \qquad CH_3$$

α-terpinene
M.P. Diels-Alder
product: 60-61°

α-phellandrene
M.P. Diels-Alder
product: 126-127°

allo-ocimene
M.P. Diels-Alder
product: 83-84°

Time of Injection
Air Peak

Peak A: 28.2 mm ˄ 3.5 mm = 98.7 mm^2

http://www.bc.edu/schools/cas/chemistry/undergrad/org/spring/DielsAlder.pdf

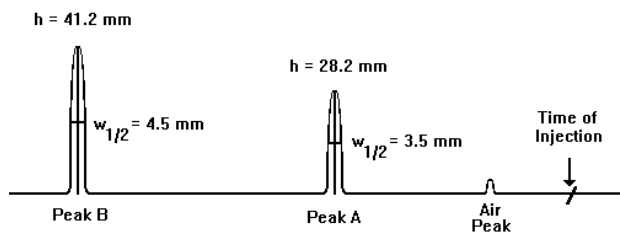Peak B: 41.2 mm * 4.5 mm = 185.4 mm^2

Objective: 1. To perform a Diels-Alder Reaction successfully. 2. To determine identity of the diene in eucalyptus oil. 3. To understand the mechanism and requirements of the Diels-Alder Reaction.

Procedure:

(*Prelab) Gas Chromatogram of Eucalyptus 0il:
1) Use the gas chromatogram report given in this lab to determine the mass of the unknown conjugated diene in eucalyptus oil. Instructions below:

    a. Assume the unknown diene corresponds to the largest peak and that peak areas are proportional to component masses.

    b. Get out your ruler and treat the peak as a triangle to find the approximate area. The area of a triangle is calculated by multiplying the height of the peak times its width at half height. (example to your right)

h = 41.2 mm
h = 28.2 mm
w$_{1/2}$ = 4.5 mm
w$_{1/2}$ = 3.5 mm
Time of Injection
Peak B
Peak A
Air Peak

    c. Do this for all the peaks.

$$Area = h * w_{1/2}$$

Peak A: 28.2 mm * 3.5 mm = 98.7 mm^2

Peak B: 41.2 mm * 4.5 mm = 185.4 mm^2

d. Use this formula to find the percent of the unknown compound in our sample: Percent of unknown conjugated diene in our eucalyptus oil=Area of tallest peak/ total area of all peaks X 100.

e. Use this percentage to figure out how much of our unknown diene is present in the 3mL (2.5g) of eucalyptus oil. Once you know that, calculate the mass of maleic anhydride needed to react with that much diene. Don't forget your Gen Chem!

> NOTE: Use these conversion factors:
> - Unknown Diene * (136.2g/mol)
> - Maleic anhydride (98.1 g/mol)
> - Mole ratio 1mol diene = 1mol maleic anhydride

Diels-Alder Reaction:

2) Tare a 25mL round bottom flask. Pour in 3mL (approx. 2.5g) of eucalyptus oil. Record the exact mass (take mass to *at least* 3 sig figs).

3) Dissolve the eucalyptus oil in 5 mL of anhydrous diethyl ether.

4) Add the amount of maleic anhydride calculated in step 1 (double check your calculations with your instructor first). NOTE: your solution should be neon yellow.

5) Put a stir bar in your rxn flask. Set up a reflux apparatus and gently heat the mixture using a hot water bath for 45 minutes.

6) While the reaction mixture is still warm, transfer it to a small beaker, cover with a watch glass, and let cool to room temperature.

7) Scratch with a glass stirring rod to induce crystallization. Filter your solid diene & WASH with cold ether multiple times to remove impurities.

8) Air dry (or very low temp oven) your solid diene.

Characterization:

9) Measure the melting point to determine the identity of your product. Make sure your product is dry!

10) Weigh your product. Calculate theoretical and percent yield.

11) Run an IR on your product and analyze. The structure of your product should be drawn on your IR and every unique bond wavenumber labeled on the spectrum.
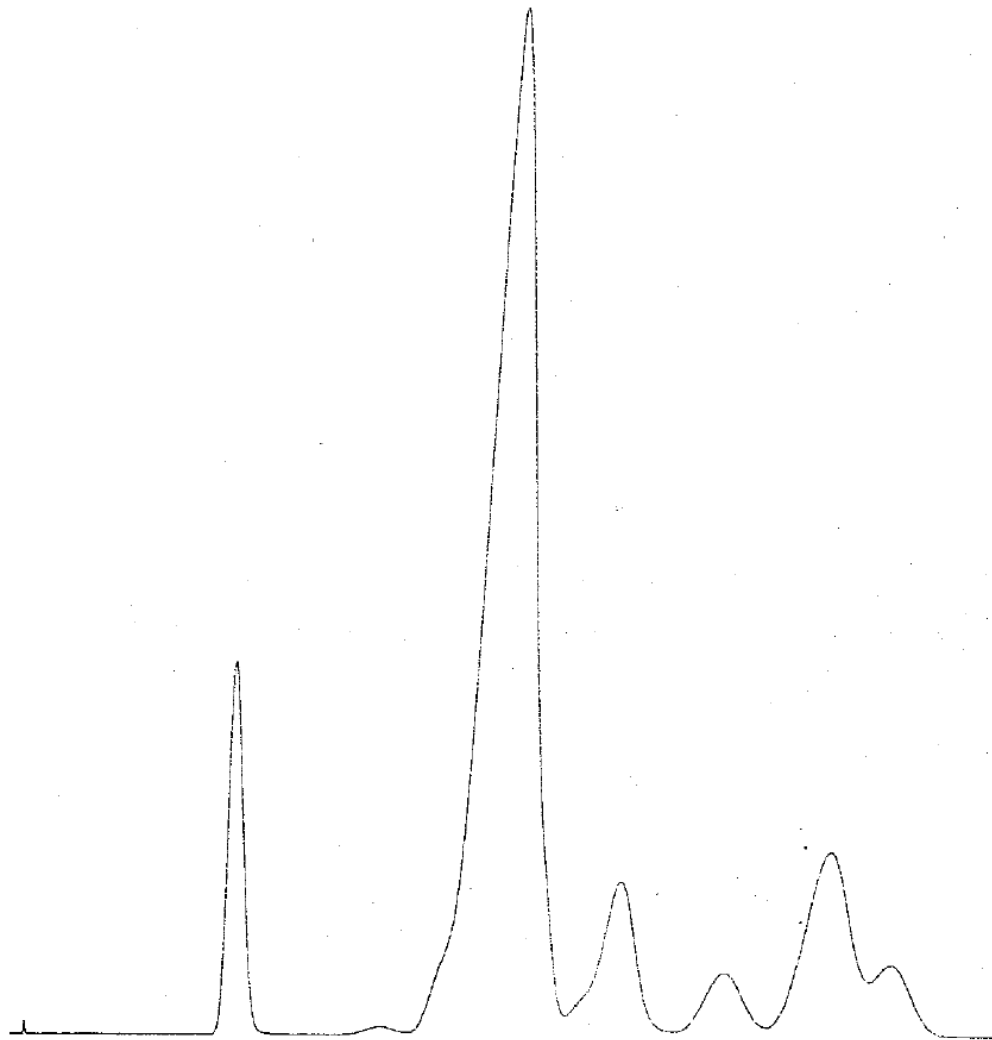
12BL Prelab Experiment 1: The Diels-Alder Reaction

1. What are the requirements for all reactants for a Diels-Alder reaction to proceed easily?

2. What is conjugation AND how does it affect the stability of a molecule? Explain clearly.

3. Research an example of a diene that is unable to twist into a cis-like conformation in order to undergo a Diels-Alder reaction. Show its structure and briefly explain.

4. Estimate the mass of the unknown diene present in 2.5 g of eucalyptus oil using the following GC chromatogram. Assume that the unknown conjugated diene corresponds to the largest peak on the chromatogram and that the peak areas are proportional to the component masses. Then calculate the mass of maleic anhydride needed to react with that much diene. All calculations must be shown with names and units clearly.

12BL Postlab Experiment 1: The Diels-Alder Reaction

Melting Point Range of Product: _____°C

*Attach your completely analyzed IR with your product structure drawn on it. Make sure all bonds and wavenumbers in your product are labeled in the appropriate positions on the IR.

1. What is the structure of your Diels-Alder product? (perform the reaction on paper so you can easily determine it!)
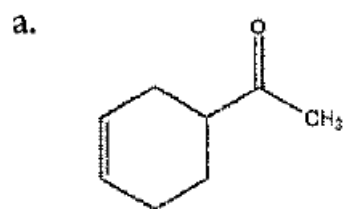

2. What is the identity of the diene in eucalyptus oil? (give name and structure)

3. Give the major product for the following Diels-Alder Reactions. Draw your structures clearly!
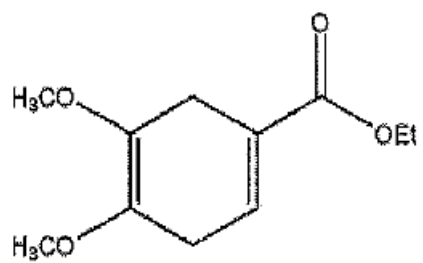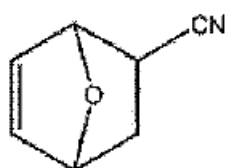
a.

b.

c.

d.

e.

f.
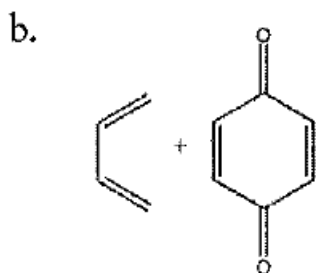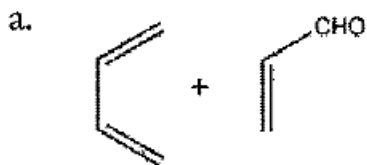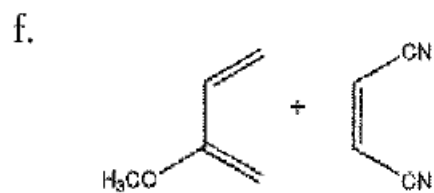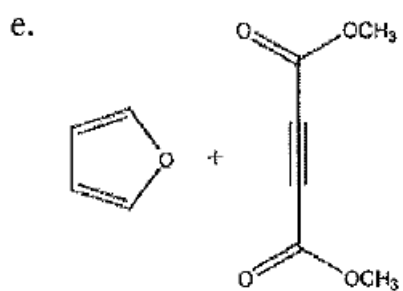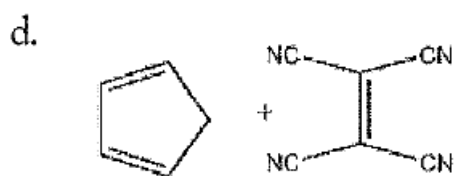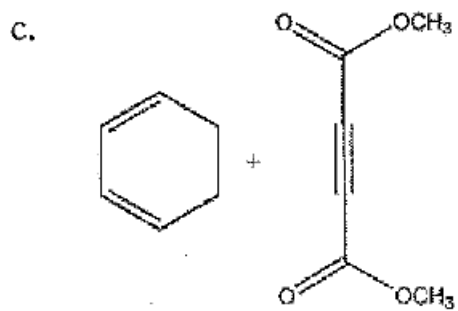
2. Give the diene and the dienophile that produced the given Diels-Alder product for each below. Draw your structures clearly!

a.

b.

c.

d.
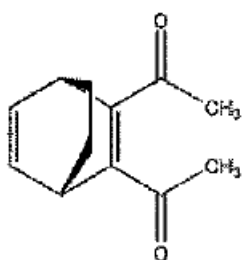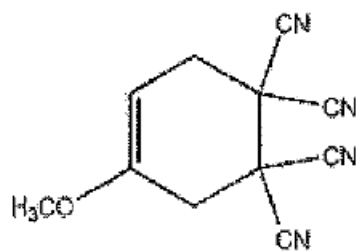

e.

f.