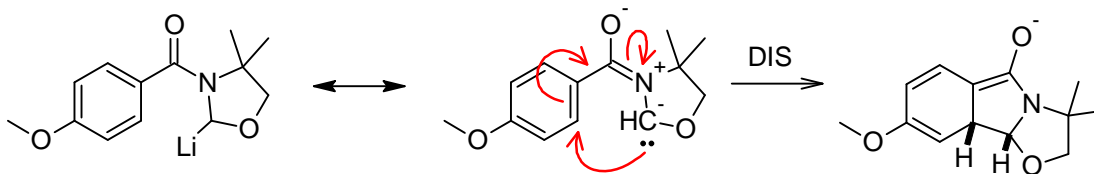


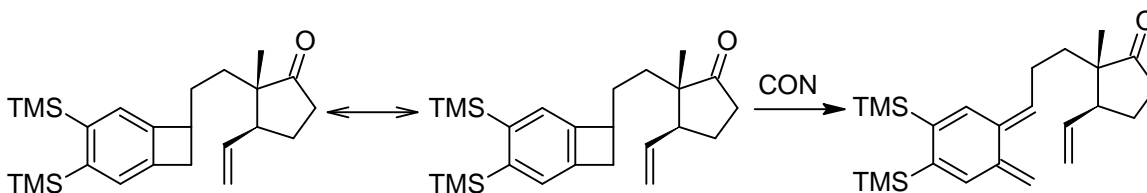
## Exam 2 – Selected Answers

1. To analyze the pericyclic reaction: redraw the C-Li bond as an ionic bond and redraw the benzene and amide Lewis structures to create a cyclic pi system. When this is done, you obtain a 6 electron pi system that requires a Huckel transition state (disrotatory ring-closure).

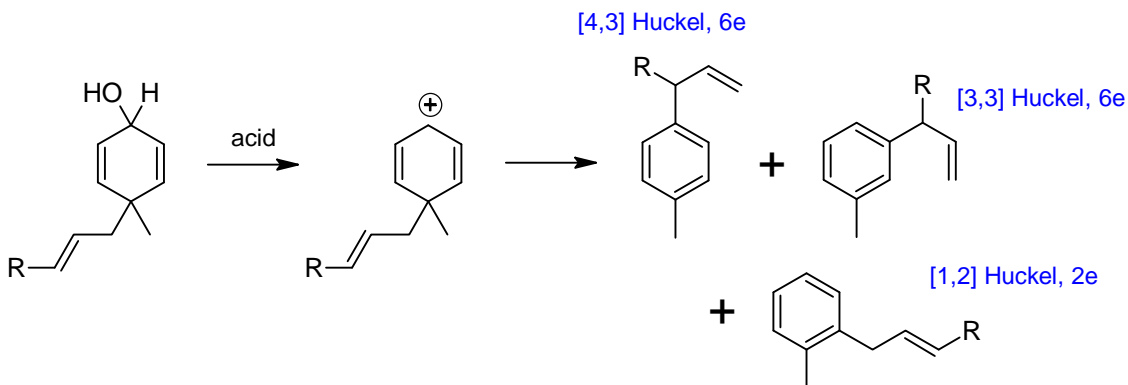


Treating the product with aqueous acid protonates the amide enolate to restore the neutral amide. The rest of the mechanism (not shown) is standard aqueous hydrolysis of an enol ether: electrophilic addition of water to alkene (protonate  $C_\beta$  of enol ether, add water to carbocation ( $C_\alpha$ ), remove proton from O) followed by loss of methanol from hemiketal (protonate O, lose methanol to re-generate carbocation, lose proton from O). None of these steps involve chiral carbons, so the all-*cis* product is expected.

2. To analyze the pericyclic reaction: redraw benzene Lewis structure to create a "cyclobutene." Conrotatory ring-opening is allowed and gives the product shown below (expect alkyl groups to rotate outward). Subsequent Diels-Alder gives observed product (the stereochemistry of the final product was not shown, but the 3 bridgehead H end up trans to each other).



3. All of the rearrangements are thermally allowed.



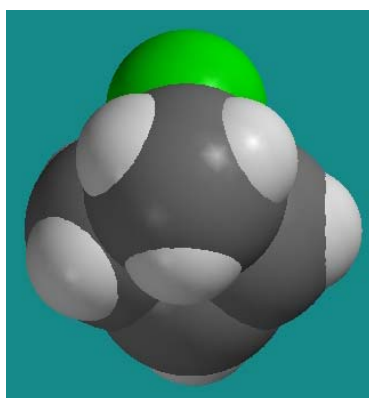
4. HW #8 covered the case of X = H. For the exam, you needed to calculate transition states for X = F. Data for all four transition states (HF/3-21G) are summarized in the table.

Me torque	X	$E_{\text{elec}}$ (au)	$E_{\text{rel}}$ (kcal/mol)	$\Delta E^\ddagger$ (kcal/mol)	$R_{\text{CC}}$ (Å)
In	H	-192.777737	6.47	47.3	2.175
Out	H	-192.788042	$\equiv 0$	40.9	2.143
In	F	-291.113967	$\equiv 0$	40.4	2.157
Out	F	-291.095291	11.72	52.1	2.165

Replacing X = H with X = F reverses the calculated torquoselectivity of the reaction. Whereas with X = H, we predict the methyl group will rotate outwards (and we explain this by citing the steric bulk of the methyl group), with X = F, we predict the methyl will rotate inwards and F will rotate outwards.  $\Delta(\Delta E^\ddagger)$  is large for both molecules, so F is exerting a really strong influence. You can also see this if you compare computed barriers; H  $\rightarrow$  F lowers the “in” barriers by 7 kcal/mol and raises the “out” barrier by 12 kcal/mol. How can F lower the “in” barrier? Does it make the methyl group smaller?

The table presents just one geometrical parameter, the length of the breaking (partial) CC single bond, but I looked at other parameters and didn't see striking variations in transition state geometry. Looking only at this CC distance, we see that X affects distance the same way it affects the barrier. F lowers the “in” barrier and it shrinks the “in” distance by 0.02 Å (we expect a shorter bond distance to yield a more stable transition state). Likewise, F raises the “out” barrier and lengthens the “out” distance.

Finally, if we check a space-filling model (see below), we see that F is *smaller* than CH<sub>3</sub>. Therefore, we cannot explain these results by appealing to steric repulsion from F.<sup>1</sup>



Space-filling model (HF/3-21G) of 3-fluoro-3-methylcyclobutene looking down axis of C<sub>Me</sub>-C<sub>ring</sub> bond. The methyl group's diameter is substantially greater than that of fluorine..

<sup>1</sup> See E.V. Anslyn, D.A. Dougherty, “Modern Physical Organic Chemistry”, University Science Books, 2006, p. 908-9, for an explanation and (some very surprising) experimental support for this prediction.