

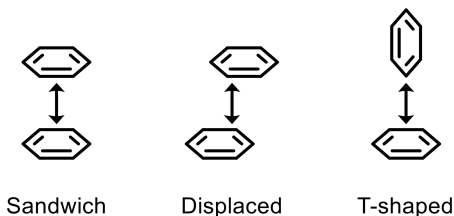
3 Noncovalent Interactions and Thermodynamics

11/13: The questions pertain to the material covered from Noncovalent Interactions (Oct 24) to Isotope Effects (Nov 5).

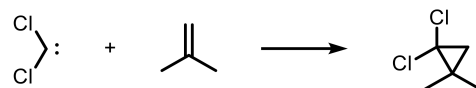
1. The π - π interaction in aromatic systems plays an important role in the fields of chemistry and biology. It affects the crystal packing of organic molecules, molecular recognition processes, and the three-dimensional structures of proteins and DNA.

a) Please use Rowan to complete this question.

- i. Using any means, build a molecular model for benzene in Rowan. Then, perform a geometry optimization and charge calculation using the r²SCAN-3c method. Take a screenshot of the webpage before submitting the job and paste it here.
 - Note: this job should not take more than 1 minute to run (not including queue time). If it takes significantly longer, consider adjusting your initial bond lengths/angles.
 - ii. Convert the optimized structure into cartesian (XYZ) coordinates and paste them here.
 - iii. How are the charges distributed on the molecule?
- b) As mentioned in class, benzene rings can interact through various geometries. Explain why the displaced and T-shaped configurations may exhibit lower energies compared to the sandwich geometry. In your discussion, include considerations of polarization effects and electrostatic interactions.

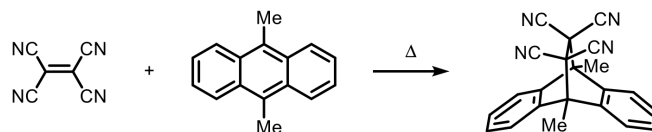


2. The reaction of dichlorocarbene with isobutylene is known to be one of the exceptions where the reaction has a negative activation enthalpy (ΔH^\ddagger).



- Consider the reverse reaction. Conduct a thought experiment in which we gradually pull dichlorocarbene away from isobutylene. How would ΔH vary with distance? How would ΔS vary with distance? Draw an energy diagram depicting both ΔH and $-T\Delta S$ as functions of distance on a single plot. Assume that ΔH and ΔS are zero at infinite distance.
- If ΔH dominates at a short distance, and ΔS dominates at a large distance between the molecules, how would ΔG change as a function of distance? Draw an energy diagram for ΔG on the plot from part (a).
- Indicate ΔG^\ddagger , ΔH^\ddagger , and $T\Delta S^\ddagger$ on the diagram and explain why this reaction exhibits a negative activation enthalpy.

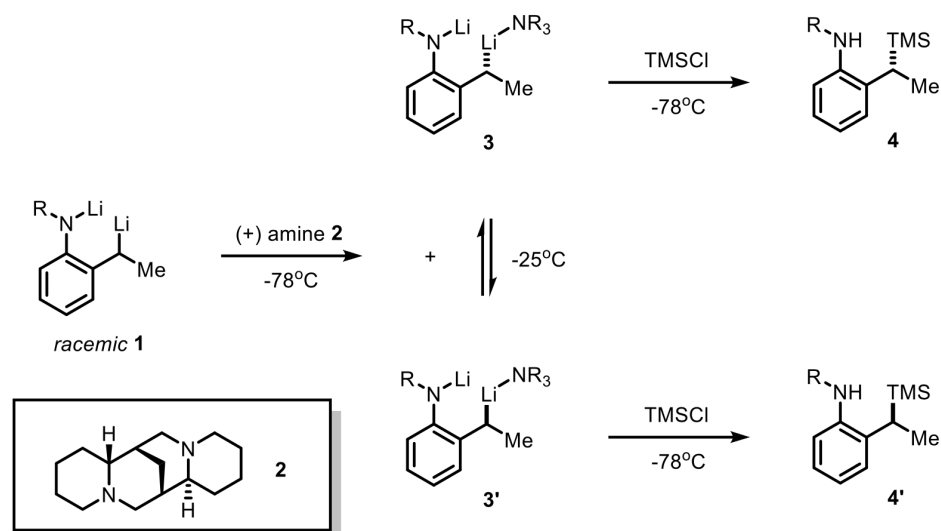
3. The following table presents the experimentally measured kinetic data for a Diels-Alder reaction between tetracyanoethylene (TCNE) and 9,10-dimethylantracene (DMA).



<i>solvent</i>	<i>[TCNE](M)</i>	<i>temperature</i> (°C)	<i>k_{exp}</i> (M ⁻¹ s ⁻¹)
<i>toluene</i>	8.44×10^{-4}	13.5	2.29×10^3
		25.0	2.81×10^3
		39.4	3.79×10^3
		40.2	3.81×10^3
<i>1,2 – dichloroethane</i>	8.90×10^{-4}	12.4	9.60×10^4
		24.9	8.90×10^4
		36.1	8.36×10^4
		43.1	8.13×10^4

- Use this data to determine the observed activation enthalpy (ΔH^\ddagger) and activation entropy (ΔS^\ddagger) for the reaction in the following solvents. Use Excel or a similar program to answer the question, and give your answers in units of kcal mol⁻¹ and/or e.u. (cal K⁻¹ mol⁻¹).
 - Toluene.
 - 1,2-dichloroethane.
- Considering that ΔH^\ddagger is positive for most reactions, what is notable about the observed ΔH^\ddagger value(s) in the above case(s)?
- Both experiments and theory support the existence of an intermediate between the starting materials and the product in this reaction, known as an electron donor-acceptor molecular complex. Draw a potential energy diagram with ΔH (change in enthalpy) on the *y*-axis to rationalize the observed abnormality in part (b).
- The mechanism of this reaction is known to be the same in toluene and 1,2-dichloroethane. Based on your answers from part (a) and your energy diagram from part (c), explain how the solvent can make a difference in observed ΔH^\ddagger .

4. Beak has reported an example of ‘dynamic thermodynamic resolution’ in the asymmetric silylation of benzylic carbanions. In this work, a racemic mixture of dianion **1** is ligated with 1 equivalent of enantiopure amine **2** at -78°C to form equal amounts of two new diastereomeric amine-lithium complexes (**3** and **3'**) that have unequal energy. Although the C–Li stereocenter in **3** and **3'** is configurationally stable at -78°C , upon warming to -25°C , these two complexes readily equilibrate. Upon cooling back to -78°C , these anions both react stereospecifically with trimethylsilyl chloride (TMSCl) to form enantiomeric products **4** and **4'**. Use this description and the data provided below to answer the following questions. (Equivalents of TMSCl are with respect to **1**).



reaction	warm to -25°C ?	equiv. TMSCl	4 : 4'
1	No	2.1	50 : 50
2	No	0.1	91 : 9
3	Yes	2.1	92 : 8
4	Yes	0.1	99 : 1
5	Yes	0.5	98 : 2

- Calculate ΔG° for **3** and **3'** at -25°C .
- Calculate $\Delta\Delta G^{\ddagger}$, for the reactions of **3** and **3'** with TMSCl at -78°C .
- If one first added 0.5 equiv. of TMSCl to an equilibrated mixture of **3** and **3'**, and then subsequently added 2 equiv. of triethylsilyl chloride (TESCl), what would be the enantiomeric ratio of the TES-containing products? What would the ratio of TES-containing products be if one first warmed the reaction to -25°C before adding the 2 equiv. of TESCl?
- Derive expressions to predict the ratio of **4** and **4'** at both very low conversion ($< 1\%$) and at very high conversion ($> 99\%$) from an equilibrated mixture of **3** and **3'**. Which elementary step(s) is selectivity-determining in each regime?