11.3: Computation Assignment and Exercise Questions

For this exercise you will be provided with data from calculations performed in Orca. All the computations have already been completed for these structures; you do not need to further optimize them. Use the provided results of the energy calculations to determine the influence of electron withdrawing or donating groups on the regiochemistry of electrophilic aromatic substitution.

Part 1: Nitration of Toluene

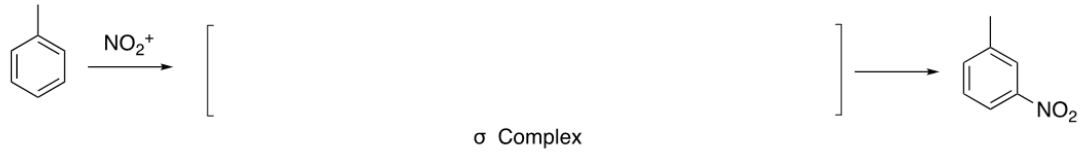
1. Please use the supplied energy values to complete the following table. You should normalize all these energy values to the starting materials energy values by subtracting the energy of each species by the energy of the starting material in kcal/mol. If you have done this correctly, the normalized energy of the starting materials should be 0 kcal/mol.

Species	Energy (Eh)	Energy (kcal/mol)	Normalized Energy (kcal/mol)
Starting Material (Benzene and Nitronium Ion)	-62.001583		
Ortho Transition State	-61.992944		
σ Complex, Ortho Addition	-62.008034		
Meta Transition State	-61.991557		
σ Complex, Meta Addition	-62.008034		
Para Transition State	-61.994192		
σ Complex, Para Addition	-62.008034		

2. Please show the structure of the σ complexes in the nitration of toluene with ortho, meta, and para selectivity in the space provided below.

A. Ortho Nitration

B. Meta Nitration



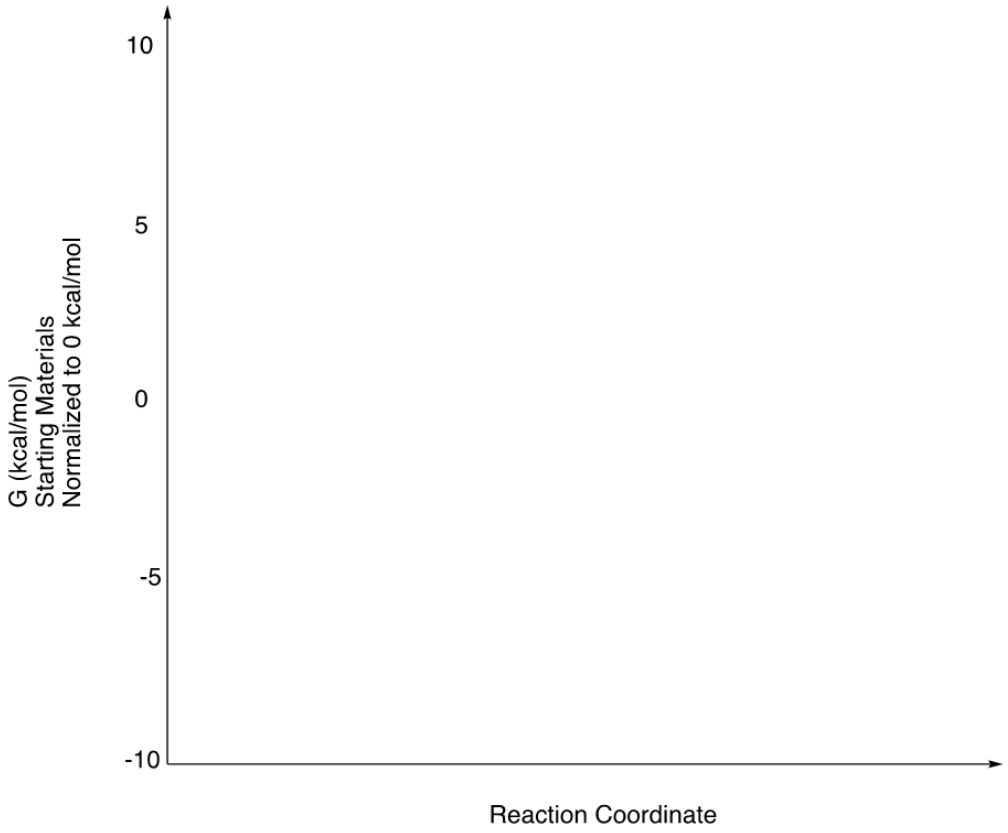
C. Para Nitration

3. Using your energy numbers from question 1, which of the formed complexes is the most stable? Which is the least stable? Do these answers match the stability that you would expect from the structure of the σ complexes that you drew in question 2? Please explain.
4. Please determine the ΔG° and $\Delta G^\ddagger$ of the first step of the electrophilic aromatic nitration of toluene for ortho, meta, and para-addition of the electrophile.

Reaction Selectivity	ΔG° (kcal/mol)	$\Delta G^\ddagger$ (kcal/mol)

Reaction Selectivity	ΔG° (kcal/mol)	$\Delta G^{\ddagger}$ (kcal/mol)
Ortho nitration		
Meta nitration		
Para nitration		

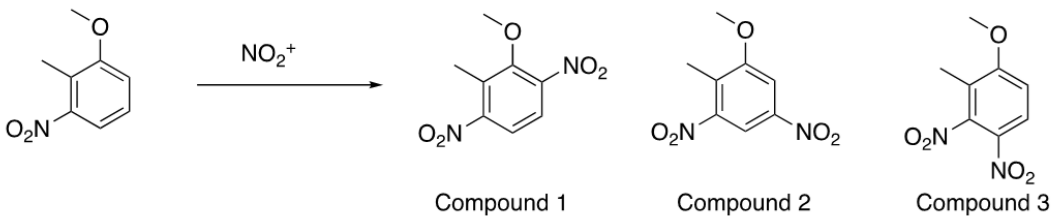
5. Please construct a reaction coordinate diagram showing the data for ortho, meta, and para-nitration that you determined in question 4. You should use different colors for ortho meta and para selectivity. For full credit please label the ΔG° and $\Delta G^{\ddagger}$ of each reaction.



6. Assuming that the nitration of toluene will yield all possible isomers, please indicate the relative (in broad terms) amounts of each product that you should obtain. Compare these to the experimental results for nitration of toluene which can be found in *J. Am. Chem. Soc.* 1941, 63, 11, 3230-3231. Do relative amounts of ortho, meta, and para product that you predicted match the experimental results? Please explain.

Part 2: Nitration of 1-methoxy-2-methyl-3-nitrobenzene

In this part of the computational exercise, we will be examining the nitration of 1-methoxy-2-methyl-3-nitrobenzene, a molecule whose directing groups do not reinforce each other.



7. Using your knowledge of directing groups in EAS reactions, predict the relative amounts of product 1, 2 and 3 would one expect from the reaction shown above, assuming that all three isomers are detected. Please explain.
8. Please use the supplied energy values to complete the following table. You should normalize all these energy values to the starting materials energy values by subtracting the energy of each species by the energy of the starting material in kcal/mol. If you have done this correctly, the normalized energy of the starting materials should be 0 kcal/mol.

Species	Energy (Eh)	Energy (kcal/mol)	Normalized Energy (kcal/mol)
Starting Materials	-105.15579		
Transition State, Compound 1	-105.09292		
σ Complex, Compound 1	-105.10636		
Transition State, Compound 2	-105.09415		
σ Complex, Compound 2	-105.10478		
Transition State Compound 3	-105.10492		
σ Complex, Compound 3	-105.11378		

9. Please determine the ΔG° and $\Delta G^{\ddagger}$ of the first step of the electrophilic aromatic nitration of 1-methoxy-2-methyl-3-nitrobenzene to produce compound 1, 2, and 3.

Reaction Selectivity	ΔG° (kcal/mol)	$\Delta G^{\ddagger}$ (kcal/mol)
Compound 1		
Compound 2		
Compound 3		

10. Using the data from Question 9, please indicate the relative amounts of compounds 1, 2, and 3 that you would expect from a nitration reaction assuming that all products are produced and the reaction is kinetically controlled.
11. Given the computational data, do you expect the nitration of toluene or 1-methoxy-2-methyl-3-nitrobenzene to be more selective? Please explain.
12. Comparing the nitration reaction of toluene with that of 1-methoxy-2-methyl-3-nitrobenzene, which do you think would be nitrated faster, assuming similar reaction conditions. Please explain.
