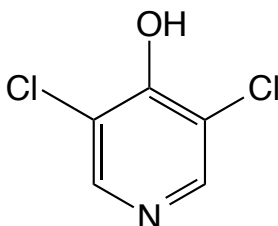


1. What is the aqueous pK_a predicted for the below hydroxypyridine at the M06-2X/6-31+G(d,p) level? For this problem, be certain to include in *all* calculations the keyword `integral(grid=ultrafine)`; use the SMD solvation model to compute aqueous solvation effects. To the extent that there is some error in the computed value, in which direction do you expect the error to be? Justify your answer, and based on that justification, suggest possible improvements in the computational protocol that might be employed, noting the consequences of such improvements from a computational resources standpoint.



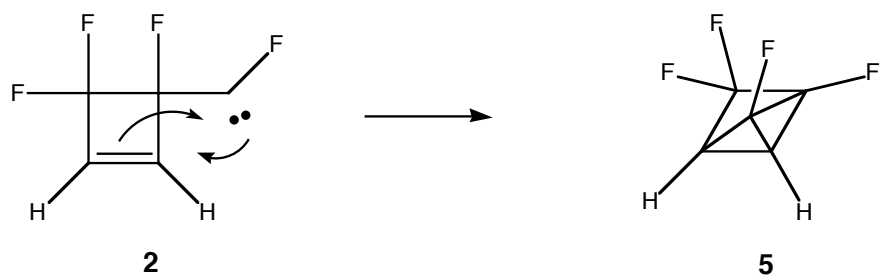
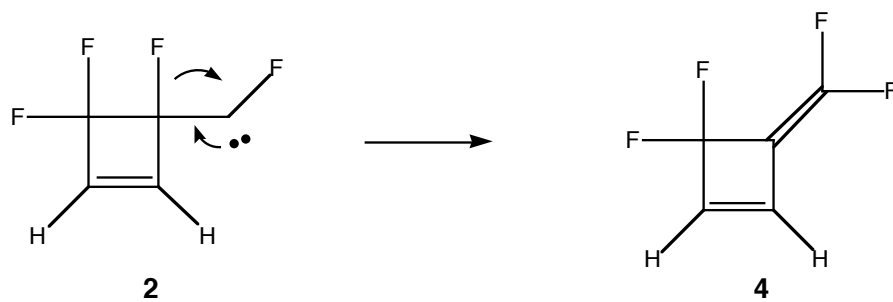
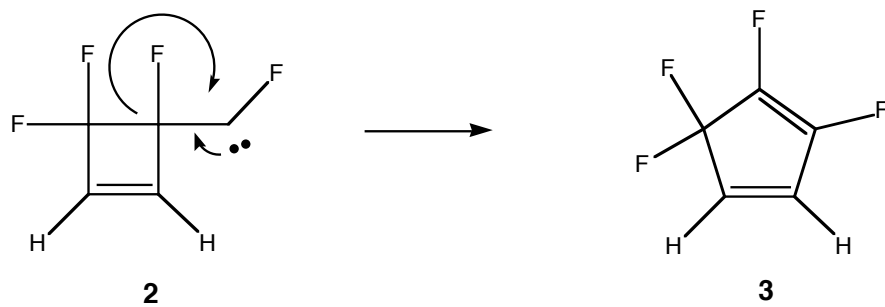
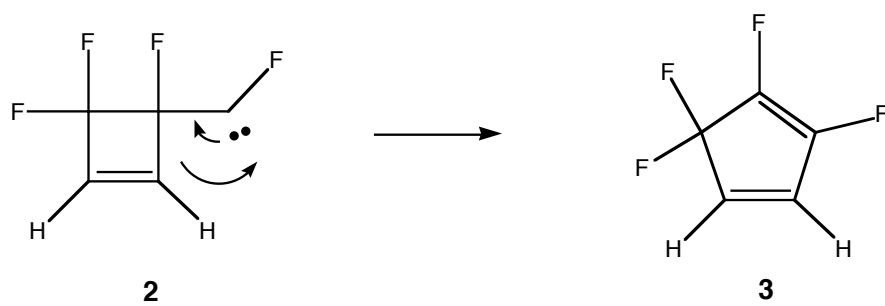
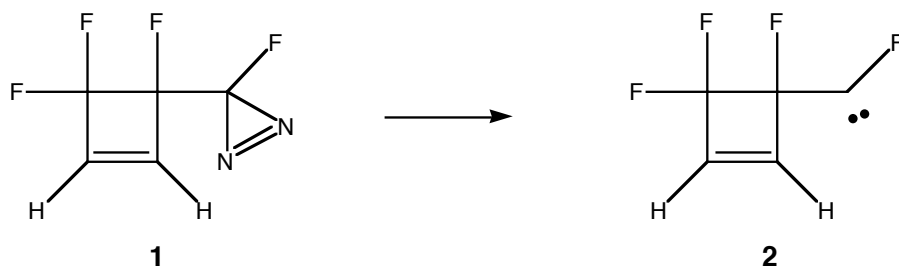
If you wanted to measure the pK_a , one approach might be to titrate the phenol dissolved in D_2O in an NMR tube and to follow the chemical shift of the 2 protons on the pyridine ring (the OH proton is exchangeable, and will be washed out by the HOD signal) as a function of added base (or acid). What limiting δ values are predicted for these protons in the conjugate acid and base forms of the molecule? Note that you may find the file in `~cm8021pr/templates` called `tmsnmropt.out` helpful.

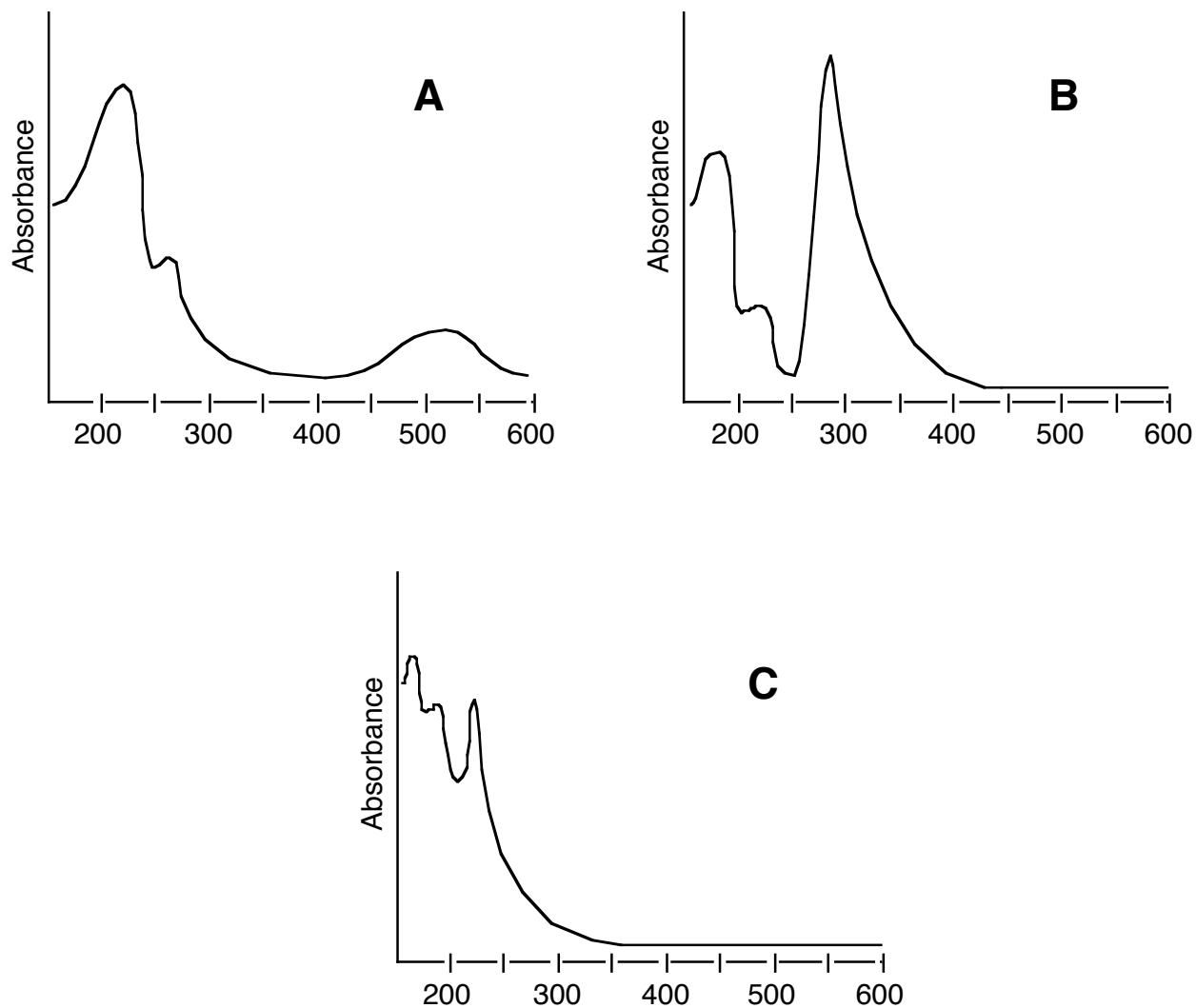
2. Congratulations! After years of trying, you have finally succeeded in making the unusual diazirine **1** shown below. You deposit **1** on a neon matrix at 10 K and irradiate it with UV light in the hopes of blowing out N_2 and making carbene **2**. Is the ground state of **2** expected to be a singlet or a triplet? Calculate the energies of both states (at their optimized geometries, of course) at the `mPW1PW91/MIDI!` level to answer this question (note that the MIDI! basis set is accessed using the G98 keyword “`midix`”, *not* “`midi!`”).

From its singlet state, carbene **2** may rearrange in 3 possible ways (two different 1,2-alkyl shifts leading to the same product **3** and a 1,2-fluorine atom shift leading to product **4**) and it may add across the cyclobutene double bond to make the wildly strained polycyclic **5**.

After your initial radiation, you take the UV spectrum **A** shown below. You tune your laser to 510 nm (the long wavelength absorption band in **A**) and blast away again. Afterwards, you observe the new UV spectrum **B**. You tune your laser down to the new “long” wavelength band at 290 nm, and once again flash the matrix. Afterwards, you record the UV spectrum **C**. You then crank your laser down to its lowest setting, 220 nm, and take your last shot at your poor molecule. When you are done, the spectrum is completely bleached (no peaks observed down to 160 nm, the limit of your window). However, when you warm the matrix up and allow the effluent to pass into a mass spectrometer, you record a dominant mass peak at 138 amu.

Using time-dependent density functional theory, predict the 3 longest wavelength UV absorptions for the ground state of **2** and possible products **3-5**. The keywords line to use, after having optimized each geometry, is `# td mpw1pw91/midix guess=read geom=checkpoint`, where you will simply change the checkpoint file each time to reflect which molecule you are computing. Based on these calculations, explain what structures you cycled through in your experiment. In addition, describe, using visualized orbitals, the nature of the 510 nm absorption in structure **A**.





Now, still at the *mPW1PW91/MIDI!* level of theory, find any *one* of the transition state structures connecting the ground state of **2** to its possible products **3** to **5**. Provide a picture of the structure with key heavy-atom bond lengths labeled. What is the imaginary frequency associated with your TS structure? What is the free energy difference (i.e., ΔG) between **2** and your TS structure? Based on that difference, what is the rate constant for your unimolecular rearrangement that would be predicted from transition-state theory at 10 K? At 298 K? If this reaction were to be the *only* reaction by which **2** reacted, what would be the half-life for disappearance of **2** at 10 K? At 298 K?