Chemistry 4021/8021 **Computational Chemistry** 3/4 Credits

Spring Semester 2011

(Due 2 / 21 / 11)

Using PC Model, answer the questions below.

1. Consider the water molecule, H_2O. Using the data for the force field in the PC Model manual and/or parameter files, write the complete MMX energy expression that must be evaluated for this molecule in terms of force field functional forms, constants, and variables. Next, for a geometry having both H–O bond lengths at 1 Å and the H–O–H angle at 110 deg, compute the energy from your expression. Compare this value to what is predicted by the software. In the event of disagreement, assess what may be wrong and summarize your results.

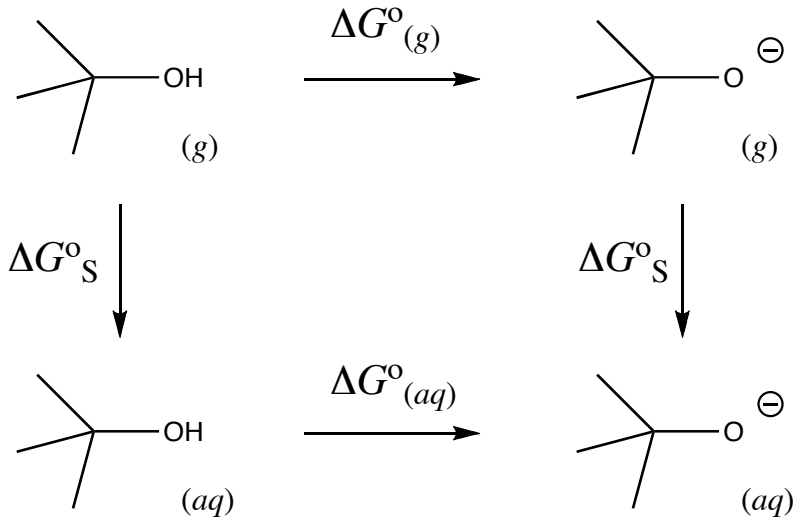
   Now, let us take a particular set of cartesian coordinates for a water molecule having the geometry listed above. Thus, we will place the various atoms at the coordinates listed in the table.

	Cartesian coordinates, Å		
Atom	*x*	*y*	*z*
H_a	–0.458861	0.819152	0.000000
O	0.114715	0.000000	0.000000
H_b	–0.458861	–0.819152	0.000000

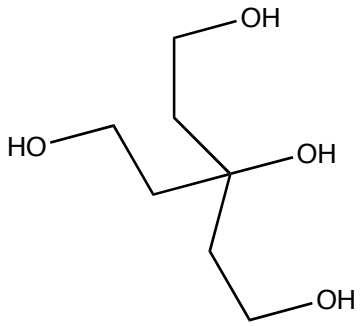
   Considering *only* the bond stretching contributions, what is the force on atom H_a in the *x* direction. (Note that while it is convenient to define energies in terms of internal coordinates like bond lengths, angles, torsions, etc., these are *not* very useful coordinates for geometry optimization because of strong coupling between the internal degrees of freedom and non-bonded distances. Instead, it is more convenient to compute geometry changes in cartesian coordinates, taking account of each degree of internal freedom's contribution to a cartesian move.) While you do not have to derive a number, explain in general what would need to be done to include the contribution from the angle bending term to the force on atom H_a in the *x* direction.

2. What is the experimentally measured 298 K free energy required to deprotonate *tert*-butanol in the gas-phase? What is the aqueous pK_a of *t*-butanol? Given that pK_a, what is the 298 K free energy of deprotonation of *t*-butanol in aqueous solution? The two quantities may be related by the below free energy cycle, which has as its vertical legs the free energies of aqueous solvation of neutral *t*-butanol

and negatively charged *t*-butoxide. What is the difference in solvation free energies for these two species?

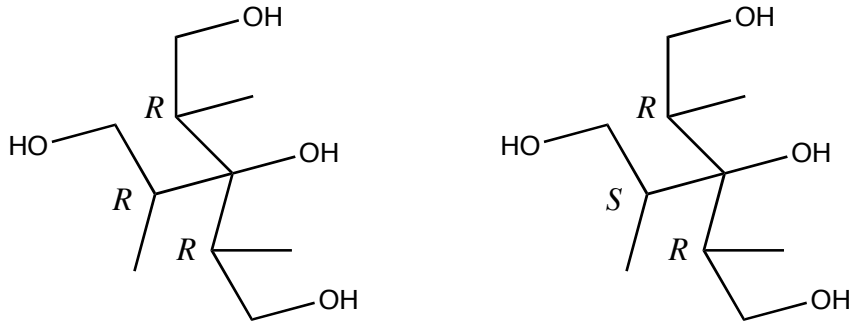


In ongoing work in the Chemistry department of the University of Minnesota, the Kass group is exploring the fascinating influence of internal hydrogen bonding on the acidity of groups commonly regarded as poor acids or bases. Consider the simple example below:



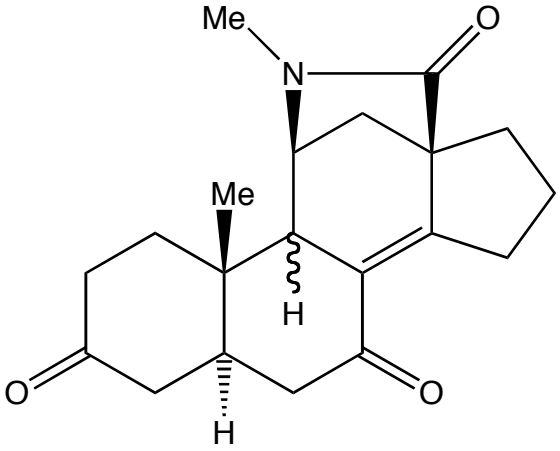
What would you expect the gas-phase deprotonation energy of this compound to be? (Hint: Consider a thermodynamic cycle similar in spirit to the one shown above, albeit with different vertical legs, and note the experimental data that you already have in hand.) If we now consider a dipolar aprotic solvent (e.g., dimethylsulfoxide (DMSO) or acetonitrile (MeCN)), how much more acidic would you expect the Kass compound to be than *t*-butanol?

What can you say about the relative acidities of the parent tetraol shown above, and the two isomeric trimethylated species shown below? Rationalize any trend (or lack thereof).



Note that this is a research-like question. There are not "perfect" answers, per se—a number of different logical analyses and approaches to addressing this question might be valid. While the answer key will present the instructor's approach, well reasoned alternative applications of PC Model to answer this question will be considered equally correct from a grading perspective. Thus, please be detailed in your answers as to the kinds of calculations you do and *why* you did them. Persuade the reader of your logic.

3. You have made the steroid derivative shown below, but are not certain of the stereochemistry of the indicated ring-junction proton. Happily, this proton is readily seen in the NMR spectrum, since it is allylic and coupled to only a single other proton. The doublet coupling constant is 3.6 Hz. Which isomer did you make? Explain how you arrived at your answer.



If you had carried out the reaction under thermodynamic conditions (i.e., conditions that would give an equilibrium distribution of the two epimers) what ratio of the two products would you expect at 298 K based on default MMX, MM3, and MMFF calculations (show your computations, please)? What

assumption(s) did you use in arriving at these answers? Finally, for the MMX force field, switch from using a charge-charge electrostatic term to a bond-dipole/bond-dipole term. How would your answer change vis a vis the equilibrium distribution? What if with all three force fields you maintain the default electrostatic method (charge-charge or dipole-dipole), but change the internal dielectric constant to 4.0? (Note that as you switch between force fields, you may want to use the H-A/D menu button to ensure that lone pairs on oxygen atoms are properly represented as a function of force field.)