CONFORMATIONAL ANALYSIS WITH SCIGRESS

During this laboratory period you will use two computational chemistry methods to carry out conformational analysis experiments on butane, cyclohexanol and cis*-1,3-cyclohexanediol.* Mechanics *is a method which uses classical Newtonian mechanics to compute the energies of molecules. Bonds are treated as springs and atoms as balls attached to these springs.* MOPAC *is a method which uses quantum mechanics to calculate the energies of molecules and determine their optimum geometries and other properties; MOPAC is an acronym for Molecular Orbital PACkage*

Conformational Energy of Butane

1. Build and beautify a molecule of butane. Save your drawing with the name "butane."

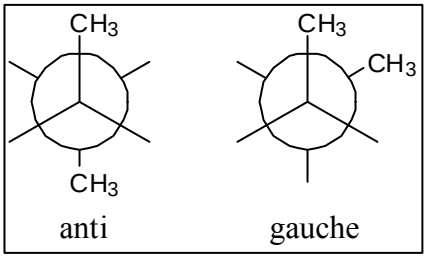
2. Highlight (select) the four carbon atoms (in order). All other atoms should be grayed out. Choose **Adjust→Dihedral Angle** from the menu bar. Select "*Define Geometry Label*" and "*Search*". **Apply** and then click **OK**. The workspace containing the butane molecule will reappear with the dihedral angle written in blue across it. The letter S will appear next to the value of the dihedral angle indicating that it is a search label. Re-save the drawing

3. Choose **Experiment→New** from the menu bar; the experiment dialog box should appear. Choose **chemical sample conformations (CAChe 5.0 experiments)** from the "*Property of*" box. Choose **optimized map** in the "*Property*" box. Click **Start (**if an error appears click **OK** and re-try).

4. Two adjacent windows should appear presenting the results of the calculation. The left window is a plot of potential energy versus dihedral angle for the butane molecule. The graph colors represent the relative energies of the butane molecule with various dihedral angles. For example, red represents high energy states for the molecule, while blue represents low energy structures. A small spherical marker on the graph indicates the corresponding energy in the graph in the left window. The right window displays the lowest-energy conformation for the butane molecule. Both windows contain a tool palette of manipulation tools which function in the same way as the workspace manipulation tools. Both windows also display a parameter bar at the bottom of the window. Different menu bar options are displayed in the application window depending on which window is active.

5. Select the entire butane molecule. Choose **View→Geometry Label Attributes**, and de-select "*Display Geometry Label*". Click **OK** and the dihedral angle geometry label should no longer be displayed.

6. Rotate the molecule to the *anti* conformation (see right). Click the **Select** tool. In the parameter bar located beneath the structure window, choose **energy**. The number to the right is the Mechanics conformational strain energy for butane in its lowest energy conformation. Record this number.



7. Click on the background in the graph window; it will become the active window. Choose **Edit→Animate Along Axis**; the dialog box should appear. Move this dialog box out of the way and click the play button to start the animation. Observe the structure move through various conformations as the corresponding energy of that conformation is indicated on the graph. When finished, stop the animation and click **Done**.

8. Use the right arrow key on the keyboard to move the spherical marker to one of the two higher energy minimums on the graph. The energy at this point is the strain energy for the *gauche* conformation of

butane. Record the energy of this conformation. Note that as you move the marker in the graph window with the arrow keys, the molecule in the structure window changes to the conformation corresponding to the energy represented by the marker.

9. Determine the energy difference between the *gauche* and *anti* conformations of butane and record this number in the appropriate space on your data sheet. Compare your calculated energy difference with that in the text (1 kcal = 4.184 kJ). Calculate the difference between the two differences and record it in the appropriate space on your data sheet.

10. Rotate the butane molecule so that you are looking at a side view (looking at the chain). Choose **View/Space Filling** to see atoms with relative radii. Repeat the animation for the space filling model and note the steric hindrance as the methyl groups bump into each other.

Conformational Analysis on Cyclohexanol

11. Open the **Alkane** folder in the **Fragment Library**. Open the file named **cyclohexane-chair.csf** and maximize the screen.

12. Select one of the equatorial hydrogens and change it to an oxygen (red) atom. Select and beautify the entire molecule; save this drawing as **cyclohexanol-equatorial.** If asked, replace any existing file.

13. Choose **Experiment→New** from the menu bar; choose heat of formation in the "*Property*" box. **Start** the experiment to calculate the heat of formation of cyclohexanol in the equatorial conformation. Record it to one decimal place and close the experiment dialog boxes.

14. Select the OH group and delete it. Select an **axial hydrogen** and make it an oxygen. Select and beautify the entire molecule (make sure all hydrogens are shown). Save this drawing as **cyclohexanol-axial**.

15. Rotate the molecule until the axial hydroxyl group is pointing out towards you (you will be looking down the C—O bond). Maximize the screen and then **View→Space Filling**; the atoms in the molecule should swell to their Van der Waals radii. Note the steric crowding between the axial hydroxyl group and the axial hydrogens. Choose **View→Ball & Cylinder** from the menu bar; the molecule should now appear in its normal ball and cylinder representation.

16. Choose **Experiment→New** from the menu bar. From the "*Property*" drop-down list choose **heat of formation**. Click on **Start** to begin the experiment. Obtain the heat of formation of cyclohexanol in the axial conformation from the data in the Experiment Status dialog box, round it off to one decimal place and record it in the appropriate space on your data sheet.

17. Determine the energy difference between the axial and equatorial conformations of cyclohexanol. Divide this number by two to obtain the steric strain of a single 1,3-diaxial interaction between H and OH. Record this new number in the appropriate space on your data sheet. Compare your calculated 1,3-diaxial strain energy with the known literature value (see table on last page). Use units of kcal/mol. Calculate the difference and record it on your data sheet. Close the dialog boxes.

Conformational Analysis on *cis*-1,3-Cyclohexanediol

18. Maximize the workspace then **View→Center in Window**. Rotate the molecule to its normal chair structure. Select an **axial hydrogen on the same side of the cyclohexane ring as the OH group**. And convert it to an oxygen atom as done before. Select and beautify the entire molecule.

19. Select one of the **hydrogen atoms bonded to** one of **the oxygen atoms.** Choose **Edit→Move Selected**. Move the hydrogen atom in between the two oxygens.

20. Choose the **Select** tool (the bond should re-form between the H and the O) and select that hydrogen and the oxygen to which it is not bonded. **Edit→Connect Atoms** to bond the two atoms. Change the bond type to *weak* (the bond will change to a dotted line to represent the hydrogen bond). Save this drawing as **cyclohexanediol-axial-Hbond** (replace files if asked).

21. Determine the heat of formation of this hydrogen-bonded molecule and record its value.

22. Select the hydrogen bond and delete it. Rotate the molecule until the axial OH groups are pointing out towards you. Select the hydrogen lying between the two oxygens and move it (**Edit→Move Selected**) to the other side of the oxygen to which it was previously covalently bonded, farthest away from the other oxygen it was not bonded to.

23. Choose the **Select** tool (the bond will be restored) and select one of the OH hydrogens and then shift click on the oxygen to which it is not bonded. Choose **Adjust→Atom Distance**; the *Set Atom Distance* dialog box will appear. Set the *Distance* to 3.3 (Å ngstroms). Select "*Define Geometry Label*" and "*Lock Geometry*". Click **Apply** then **OK**.

24. Now select the other H and O pair (the O to which the H is not bonded). Set the bond distance between these atoms to the same value as above. Determine the heat of formation of this non-hydrogen bonded structure.

25. Calculate the difference between the energies of cyclohexanediol in the axial conformation with and without hydrogen bonding; this is an estimate of the energy that is lowered when hydrogen bonding occurs.

26. Select both of the OH groups and delete them. Beautify the molecule, and you should be back to a cyclohexane drawing.

27. Convert this chair structure to *cis*-1,3-cyclohexanediol (OH groups di-equatorial). Determine the heat of formation of this molecule.

28. Using the information on your data sheet, compare the energies of di-equatorial *cis*-1,3-cyclohexanediol to the hydrogen bonded and non-hydrogen bonded di-axial conformations. Based on the heats of formation, rank the three conformations of cyclohexanediol and draw them on the data sheet in order, from most stable to least stable; label most and least stable conformations. Defend your rankings based on the structural differences between each conformation.

Data Sheet
Conformations with Scigress

Name _____

A. Conformational Energy of Butane

Anti strain energy for butane	
Gauche strain energy for butane	
Difference between *anti* and *gauche* strain energies	
Difference from the literature value	

B. Conformational Analysis on Cyclohexanol

Heat of formation of equatorial cyclohexanol	
Heat of formation of axial cyclohexanol	
Calculated H and OH 1,3-diaxial strain energy	
Difference from the literature value	

C. Conformational Analysis on *cis*-1,3-Cyclohexanediol

Heat of formation of di-axial, hydrogen bonded cyclohexanediol	
Heat of formation of di-axial, non-hydrogen bonded cyclohexanediol	
Difference between di-axial, hydrogen bonded and di-axial, non-hydrogen bonded heats of formation	
Heat of formation of *cis*-1,3-cyclohexanediol in the equatorial conformation	

Based on your data above, provide chair drawings for each of the conformations in order from most stable to least stable; label the drawings. Explain your rankings. Do this on the back of the sheet.