Chemistry 125 First Semester Final Examination - Answer Key

December 15, 1999

1. (36 minutes) Give as specific an example as you can for each of 8 of the following 11 items. Make your answers as brief and clear as possible, but try to make them **specific** - e.g. real molecules, real numbers. Continue on the back of this page. **OMIT 3.** ONLY YOUR FIRST 8 ANSWERS WILL BE GRADED Write your answers on this page and the next, using the backs if necessary.

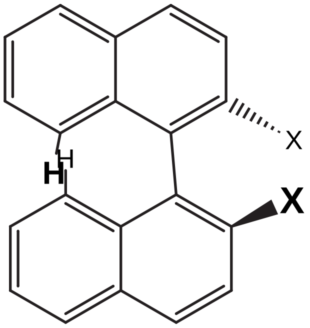
a) Operation of the reactivity-selectivity principle.
b) A situation in which one should use average bond energies rather than bond dissociation energies.
c) An experimental technique that reveals the position of *individual* atoms (not average positions)
d) A pair of conformational enantiomers that do not racemize at room temperature.
e) The source of radical theory in organic chemistry in the early 19th century.
f) Determination of the heat of formation of an atom.
g) Evidence that cyclopropane rings have bent bonds.
h) Two cases where work with tartaric acid isomers contributed in a fundamental way to organic chemistry
i) A case of stabilization due to "resonance"
j) An experiment by Lavoisier involving an organic substance.
k) A type of isomerism that was predicted long before it was observed.

(a) In selecting between primary and secondary, or primary and tertiary, C-H bonds for H abstraction the slowly reacting Br atom is much more choosy than the highly reactive Cl atom. [There are a number of other examples of this "principle" that we will encounter, and a significant number of counter examples. To be a really good answer for this question, one should cite specific ratios of products from these free radical substitution reactions, e.g. chlorination of propane gives 43:57 n-propyl:isopropyl produce, while bromination gives 8:92]

(b) Average Bond Energies are used to predict the stability (heats of atomization, or relative heats of formation) for normal molecules (say methane). For predicting the stability of a reactive intermediates (say, methyl radical), which has an unsatisfied valence, it is more accurate to use actual bond dissociation energies.

(c) Scanning Tunneling Microscopy (for example the circle of iron atoms manipulated into position on a copper substrate with STM). Generally AFM tips are not sharp enough to show individual atoms. X-ray diffraction reveals the position of atoms in molecules with great resolution, but they are not individual atoms, but rather the average over a large number of molecules in a crystal (remember that the scattering of x-rays in a particular direction comes from the coordinated action of lots of molecules).

(d) A twisted "binap" molecule like the one shown below with large X groups that prevent rotation about the central bond, and its enantiomer. (The specific molecule discussed in class had X = $P\phi_2$, where ϕ is phenyl.)



(e) The benzoyl radical was inferred by Liebig and Wöhler from the persistence of the C7H5O unit in the analysis of benzaldehyde (oil of bitter almonds) and its products from numerous reactions (for example with oxygen and chlorine). Berzelius then fitted radicals into his structure of dualistic attraction to explain organic transformations as double decompositions.

(f) Dr. Chupka discussed in class how he determined the heat of formation of the carbon atom by measuring its equilibrium concentration in the gas phase above graphite heated strongly in a small oven. [He used mass spectroscopy to make the determination.]

(g) The clearest evidence that cyclopropane bonds are bent is that the maximum density in electron difference density plots from x-ray diffraction on substituted cyclopropanes falls outside of the straight line joining adjacent carbon atoms. [The fact that cyclopropane has high reactivity and strain energy can be rationalized by postulating bent bonds, but does not provide direct evidence for them. For example Baeyer himself did not consider the bonds themselves to be bowed but rather the angles between adjacent straight bonds to be distorted; i.e. the carbon atom, not the bond, was distorted.]

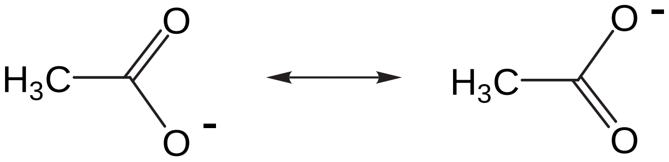
(h) Berzelius proposed the existence of isomers in connection with his observation that racemic and tartaric acids had the same chemical analysis (1830).

Pasteur (1848) discovered the existence of enantiomers by resolving racemic acid (as the potassium-ammonium salt) to obtain previously unknown l- as well as normal d-tartaric acid.

Pasteur (1850s) discoverd biological resolution of racemates by isolating l-tartaric acid from a sample of racemic acid that had been partially destroyed by a mold (penicillium glaucum).

van't Hoff explained the existence of tartaric acid isomers in his first publication on configurational isomerism involving tetrahedral carbon (1874).

(i) Many possible examples. One of the easiest to support with good quantitative evidence is the special stability of the acetate anion, which is evidenced by the low pK_a (~5) of CH_3COOH, 10^{11} times as acidic as normal alcohols ROH. [Actually some of this extra acidity is due to the electron stabilizing effect of the additional electronegative oxygen atom, rather than to resonance.]



(j) Good examples are Lavoisier's combustion of organic oils to determine their content of carbon and hydrogen, and his fermentation of sugar to demonstrate the conservation of the elements during this complex transformation (in which he innocently cooked the data a bit).

(k) The best example of this is vzn't Hoff's prediction of enantiomerism of disubstituted allenes, which was not demonstrated experimentally until more than 40 years later (RHC=C=CHR).

Sachse's prediction of what we now call the chair and boat forms of cyclohexane is another example, but of course the twist-boat form does not really have the symmetrical conformation he proposed.

2. (6 min) What does it mean to solve a problem in quantum mechanics? That is, what are you given, and what do you have to find? [You might want to illustrate your answer with an example such as the hydrogen atom]

You are **given** a set of particles, that is **masses** and **potential energy** as a function of their position, or what is equivalent, the force between pairs of them as a function of distance, *e.g.* Coulomb's Law and their charges).

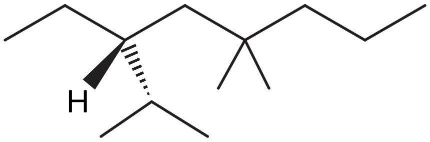
You must find one or more (wave)function(s) of the particle positions such that changes in the kinetic energy (calculated from curvatures and masses by Schrödinger's method) offset changes in potential energy to give a constant total energy for all sets of positions of the particles. The solutions are sets of wave functions and their respective energies.

Thus you must **find wave functions and total energies**.

[A really distressing number of answers indicated that one is given total energy. Where in the world would it come from? The Deity? Lots of people said that you were given potential and total energies and had to find kinetic energy. If this were quantum mechanics, it wouldn't be very challenging. No need for powerful computers here, just subtraction. Remember that in *Goldilocks* you were not given total energy, you had to guess it, and when the energy was quantized you essentially always chose wrong, but you could tell when your guess was pretty good. This guessing was the essence of solving the quantum mechanical problem.

Of course there are other artifical ways to pose "quantum mechanical" problems, such as being given the wave functions and trying to find the potential. There can also be "spin", as well as cartesian, coordinates, and one can also attack time-dependent problems, but that's not for us now.]

3. (5 minutes) Draw "3-isopropyl-5,5-dimethyloctane" and give the correct constitutional **and configurational** name to what you have drawn.



(R)-3-ethyl-2,5,5-trimethyloctane

[You had to draw a configuration unambiguously and name it properly with CIP notation]

4. (3 minutes) How does one identify a first-order reaction experimentally?

By seeing that the rate is proportional to the amount of material (*e.g.* existence of a constant half-life, decrease of the rate by a factor of two when the concentration falls by a factor of two, exponential decay of starting material, etc.)

[There can be ambiguity (pseudo first-order reaction) when a potentially relevant concentration, such as that of solvent, cannot readily be changed.]

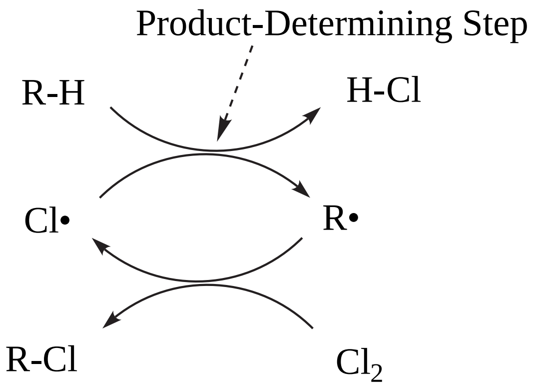
5. (6 minutes) Explain how the rate at which A is converting to B might be zero-order in A for high concentration of A and first-order in A for lower concentrations?

This is the case of the gate-keeper at a museum of archaeology *vs.* at a popular event. If few people are trying to get in, the rate of entrance is proportional to the number of individuals trying, because the amount of time the gate-keeper spends taking the ticket is negligible compared to the time spent waiting for the next visitor to arrive. But if the gate is swamped, the rate is independent of the number of applicants waiting (zero-order), because the gate-keeper can only collect tickets so fast. This can happen chemically when a catalyst is required for reaction and it can become swamped by a large concentration of "substrate" (material on which it operates) so that it works as fast as it can, spending a negligible fraction of its time waiting to find another substrate molecule. A common case involves enzyme catalysis. Late in the day (when the crowd thins out) the zero-order reaction can become first-order because the gate-keeper (or catalyst) is waiting for the next applicant to arrive. Early or late the reaction would be first-order in catalyst (as opposed to substrate), but upon first investigating a particular process one might be unaware that there is a catalyst (or how much of it there is).

[Many answers thought the question was aimed at pseudo first-order processes, where it is difficult or impossible to establish the order for a component at high, unchanging concentration. This case is not zero order for high A, just indeterminate order. In the case described above the reaction truly is zero order in A at high A. Halving the concentration of A would not affect the rate until the catalyst is able to "catch its breath" between encounters with A.]

6. Free Radical Halogenation

A. (4 minutes) Draw the mechanism for the propagation "machine" of free-radical chlorination and use it to show where the structure of the product is determined.



The first of the two propagation step determines the structure of the product, because in most cases radicals (unlike cations, see 6J) are unable to rearrange their bonds. Thus whichever carbon loses H in the first step is the one that gains Cl in the second.

B. (3 minutes) The rate of free-radical chlorination depends on the rate of initiation, but the relationship is not usually linear (i.e. doubling the initiation rate does not double the rate of product formation). Explain.

The rate depends on total radical concentration, which is of course increased by increasing the rate of radical production (initiation). But total radical concentration is decreased by radical-radical reaction (termination) which is second-order in the amount of radical. As you increase the concentration of radicals by increasing initiation, individual radicals become shorter-lived, so the number of reactions per radical generated falls.

[For something curious consider this: When the reaction is going along steadily its rate is proportional to the total concentration of radicals $[R_T]$ which is not changing much with time. There is a balance between the rate at which radicals are being formed (k_{init}) and the rate at which they are going away ($k_{term} * [R_T]^2$).

One can rewrite $k_{init} = k_{term} * [R_T]^2$ (k_{init}) as $[R_T] = \text{Sqrt}(k_{init} / k_{term})$. This means that the rate of the chain reaction, which is proportional to $[R_T]$ is proportional to the square root of the rate of initiation. The reaction is thus **1/2 order** in the amount of initiator.]

C. (4 minutes) The yield of isomeric alkyl halides from free-radical chlorination of suitable alkanes can be understood in terms of primary (RCH_2-H), secondary (R_2CH-H) and tertiary (R_3C-H) bond dissociation energies (BDEs), where R is an alkyl group. Values for the 1°, 2°, 3° BDEs vary smoothly from 101 to 98 to 96 kcal/mole, respectively. Provide an explanation for these differences in terms of bonding theory.

There are two plausible sources of this trend. The most likely one is that 3° radicals, where the sp^3 carbon atom forms bonds to three other carbons, profits more from the increase in bond strength that accompanies an increase in s-character than do 2° or 1° radicals where some of these bonds are to hydrogen. This is to say that the difference is primarily due to changes in radical stability. Another possibility is that in the tetrahedral starting material there is strain between alkyl groups that are attached to a common carbon (the one that will give up an H atom). The more alkyl groups, the more strain to be relieved when the central carbon becomes flat. This explanation attributes the different to differences in the starting material rather than in the radical. Both factors are operative.

D. (4 minutes) Use the BDEs for primary and tertiary C-H bonds to predict the EQUILIBRIUM CONSTANT between isobutyl [$(CH_3)_2CHCH_2$] and t-butyl [$(CH_3)_3C$] radicals at room temperature.

The difference in energy between the radicals is 101-96 = 5 kcal/mole. At room temperature this would contribute a factor of $10^{3/4 * 5} = 10^{3.75} \sim 6000$ **in favor of the 3° radical**. (Some answers did not indicate which isomer should be favored, or indicated the wrong one by not thinking carefully about what sign of the energy difference made sense.) But there is a statistical factor of 9 in favor of the 1° radical, because there are 9 H atoms in isobutane whose loss would give it, vs. only 1 for the 3°. Thus the predicted equilibrium constant is about 700.

E. (5 minutes) When 2-methylpropane reacts with Cl_2, the relative yields of t-butyl chloride and isobutyl chloride are 36% and 64%. Show how to use these values to reckon the relative reactivity of primary and tertiary C–H bonds.

The ratio of primary to tertiary products is 64/36 = 1.78, but there are 9 times as many primary as tertiary C-H groups for a Cl atom to react with. So in fact the primary to tertiary reactivity ratio is 1.78 / 9 = 0.198 or, viewed upside down, the tertiary to primary ratio is 5:1.

F. (7 minutes) Use the Hammond Postulate to relate the ratio you calculated in Question E to the equilibrium constant you calculated in Question D, **AND** to explain how things would be different in the case of bromination rather than chlorination.

The 5 kcal/mole difference between the radicals would predict a tertiary to primary reactivity ratio of 6000 (Question D) but the actual ratio is only 5 ($=10^{3/4*0.93}$), thus instead of 5 kcal/mole the energy difference in the transition state is more like 1 kcal/mole (it might be somewhat larger that 0.93 kcal/mole since the reaction was carried out above room temperature where the factor of 3/4 would be reduced). The energy difference in the transition state is less than 1/4 of the difference in bond dissociation energies.

The Hammond Postulate states that the transition state in exothermic reactions resembles the starting materials, thus that differences in product stability should be only faintly reflected in differences in activation energy. This seems to be the case for these H abstractions by Cl atoms.

By contrast H abstraction by Br atoms is endothermic, so the activation energy differences should reflect more fully the 5 kcal/mol, and the tertiary:primary ratio should be much larger. [The actual ratio of tertiary to primary product in bromination is something like 200:1, corresponding to a relative reactivity per C-H of about 1800:1, or a difference in activation energy of about 4.3 kcal/mole, a very substantial fraction of the difference in BDEs.]

G. (6 minutes) One could imagine chlorinating propene (CH_2=CH-CH_3) to give either 1-chloropropene (ClCH=CH-CH_3) or 3-chloropropene (CH_2=CH-CH_2Cl). Use the following heats of formation (kcal/mole) to calculate or estimate relevant **BDE** values, **and** then use these values to predict the **relative yield** of these two potential products.

molecule	$CH_2=CH_2$	12.5	$CH_2=CH-CH_3$	4.9
radical	$CH_2=CH$	71.5	$CH_2=CH-CH_2$	40.9
	H	52.1		

The BDE is the difference in heat of formation between the products (Radical + H) and the starting molecule:

BDE(vinylic) = 71.5 + 52.1 - 12.5 = 111.1 ; BDE(allylic) = 40.9 + 52.1 - 4.9 = 88.1 kcal/mole

Thus the difference in activation BDEs is enormous, 23 kcal/mole. Even if this were reduced at the transition to 1/4 of the total BDE difference (as in Question F above for chlorination) the difference of about 6 kcal/mole would predict a per C-H reactivity difference of 103/4 * 6 = 32,000, which the statistical factor of 3/2 would only enhance. There would be no significant yield of vinylic chlorination product.

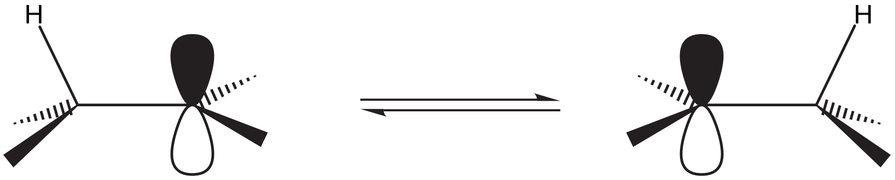
H. (4 minutes) Rationalize the BDE of $CH_2=CH-H$ (called a vinylic bond) relative to that of a normal primary C–H in terms of bonding theory.

The vinylic bond is particularly strong because of the sp^2 hybridization of the carbon atom, which gives better overlap with the 1s H AO than would the normal sp^3 hybrid.

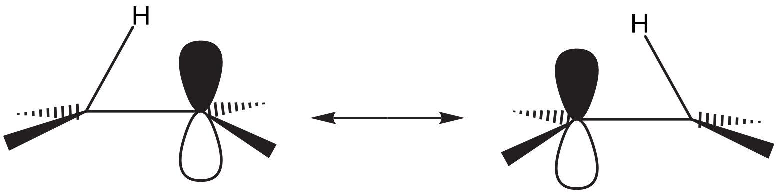
I. (6 minutes) Rationalize the BDE of $CH_2=CH-CH_2-H$ (called an allylic bond) relative to that of a normal primary C-H in terms of bonding theory. In this case consider orbital energy both for the orginal C-H bond and for the resulting radical.

The allylic bond is special because it is adjacent to, and can overlap with, the π and π^* orbitals of the C=C double bond. This has no special advantage in the starting molecule, where doubly occupied C-C σ-orbital has poor energy match with the vacant π^* orbital. But in the radical the singly occupied p AO of the CH_2 group has much better energy match with the π^* orbital, and there is resulting, which is also seen in the existence of two equivalent resonance structures $CH_2=CH-CH_2$ and $CH_2-CH=CH_2$.

J. (8 minutes) We will soon see that positively charged reaction intermediates often rearrange as shown below, whereas the corresponding free radicals rarely rearrange. Rationalize this difference in terms of the orbital mixing that goes on as the "migrating" hydrogen shifts from left to right. It would help to talk about overlap and orbital occupancy.



Consider the transition state where the "migrating" hydrogen atom is half way across, so that the structure may be written as the following resonance hybrid:



In the cation the indicated p-orbital would be vacant (LUMO), in the radical it would contain a single electon (SOMO).

For the resonane to correspond to special stabilization there must in orbital language be favorable overlap between a high HOMO and a low LUMO. The HOMO is the sigma bond between carbon and the migrating hydrogen atom. In the cation case there is an obvious very low LUMO, the p-orbital, which is especially low in energy because of the positive charge. In the radical case this orbital is not particularly low because there is no positive charge, and the orbital is not vacant, so the energy of its electron must rise as the orbitals are mixed to lower the energy of the pair of electrons in the C-H bond.

So the rearrangement should be much easier for the cation than for the radical.

K. (4 minutes) Explain the analogy between the behavior of the cation in Question J and the reason that BH_3 dimerizes.

Both cases involve a vacant orbital mixing with an X-H sigma bond to give a "Y" shaped 3-center, 2-electron bond.

Most of our insight about organic chemistry comes not from measuring a property of an individual molecule, but rather from following the trend in how a property changes through a series of related molecules. One good example is the monotonic trend in BDEs in Question 6C above. **Questions 7 to 9** provide additional example of this style of thinking in cases where the trend is not monotonic.

7. (5 minutes) The A-value that expresses the conformational preference for monohalogenated cyclohexanes does not follow a monotonic trend as one goes from F to Cl to Br to I. How can one rationalize this behavior.

The A-values for F, Cl, Br, I, are 0.25, 0.5, 0.5, and 0.45, respectively, whereas the van der Waals radii increase smoothly [1.35, 1.8, 1.95, 2.15 Å]. But the C-X bond lengths are also increasing [1.39, 1.78, 1.93, 2.14 Å]. Apparently in going from Br to I, the larger atomic radius is more than compensated by the greater distance from the center of the atom. [The non-spherical shape of the halogens may play a role here as well.]

[for a full 10 points the answer had to have a special virtue, such as citing the proper A-values.]

Many answers refered to the electronegativity of the halogens. Electronegativity is not directly relevant to the conformational preference, which depends mostly on 1,4- (and 1,5-) van der Waals repulsion. My best guess is that this kind of answer reflects a misunderstanding of the "ANMERIC EFFECT", in which an electronegative group tends to be axial when the adjacent atom in the ring has AN UNSHARED PAIR OF ELECTRONS. The explanation for this is that for the axial substituent there can be overlap of its σ^* LUMO with the axial unshared pair. But in this question there is no unshared pair next door. You have to be careful about invoking a phenomenon (like electronegative prefers axial) when you have not really understood it.

8. (7 minutes) We have belabored why chair cyclohexane is less strained than cyclopentane, but why is it less strained than cycloheptane? Baeyer had predicted that the difference would be due to bond bending, but according to Chem3D only 1/3 of the 6-8 kcal of additional strain in cycloheptane is due to bond bending. **You may examine the models** of chair cyclohexane and cycloheptane to answer the following questions.

What are the sources of extra strain in cycloheptane?

The minimum-energy twist-chair structure of cycloheptane shows two principal sources of strain:
(1) Torsional strain because the angles cannot all be staggered, and
(2) 1,4-van der Waals strain from H atoms that point toward the "axis" of the ring from the terminal carbons of the four-carbon chains closest to being eclipsed.

[three points assigned for each source]

Why should there be **any** bond bending strain in cycloheptane? (there is practically none in chair cyclohexane)

Feeling the plastic model quickly convinces one that, other things being equal, there is no intrinsic necessity of angle bending strain (as there is in cyclopentane or cyclobutane). But, for the reasons in the previous part, other things are not equal. Twisting that removes the 1,4-interaction mentioned as (2) above creates an equivalent interaction for another set of 1,4-hydrogens. The only way to reduce all such interactions is to flatten the ring by expanding the C-C-C bond angles, which, in a structure minimized in energy by Chem 3D, vary from 113° to 116.5°. So in a sense Baeyer was right that large rings should be strained by having expanded bond angles. [four points]

Explain what would you predict for the relative entropy of cycloheptane and chair cyclohexane?

The model of cycloheptane is as flexible as twist-boat cyclohexane, while that of chair cyclohexane is quite rigid because bond angle strain is generated by deforming it. Thus the entropy of cycloheptane should be much greater (in cyclohexane the entropy factor favoring twist-boat is about 7). [four points]

9. (7 minutes) As shown below, the entropy of XH_3 molecules (in cal/moleK) does not follow a uniform trend upon increasing the mass of X from B to C to N. Explain how entropy is related to the concept of a potential energy surface and vibrational quantum states, **and** rationalize the fact that the entropy of CH_3 is higher than that of either of its neighbors.

BH_3 44.9 CH_3 46.4 NH_3 46.1

A large accessible region on the potential energy surface, resulting from weak opposition to distortion, results in closely spaced quantum levels, and thus to a statistically favorable situation corresponding to high entropy. BH_3 is rigidly planar (because its bonds get much weaker on out-of-plane bending), and NH_3 is fairly rigidly bent in a double minimum (because its unshared pair becomes much more unstable on flattening to create a p-orbital). By contrast out-of-plane bending of CH_3 (with one electron in the 4th orbital) is relatively easy. These differences are reflected in the stretching frequencies of 1141, 606, and 950/cm for B, C, N, respectively. The extra vibrational entropy for CH_3 accounts for its excess entropy over NH_3.

[An appropriate calculation shows that at room temperature in going from 606 to 950/cm (or 1141/cm) there is a vibrational entropy decrease of 0.3 entropy units, exactly the difference between CH_3 and NH_3. There is only a tiny difference between NH_3 and BH_3, because neither has appreciable population of the higher vibrational level at room temperature. However there are other sources of larger differences that I didn't expect you to see. One is that CH_3 has an odd electron which can have two different spins, corresponding to a doubling of the numer of quantum states and an entropy increase of R ln2 = 1.377 e.u. On the other hand NH_3 has two minima giving it an entropy increase of R ln2 (this factor is often taken into account by including what is called a "symmtery number" correction.). Thus between CH_3 and NH_3 the R ln2 factors cancel out and one is left with the vibrational entropy difference that the question was designed to elicit as an answer. The absence of R ln2 is the largest source of the lowered entropy of BH_3.]

10. (8 minutes) For the uninitiated tunneling is one of the most puzzling concepts in chemistry. We hoped to demystify it by becoming familiar with one-dimensional quantum mechanics through *Erwin Meets Goldilocks.* Explain what it is about quantum mechanics that makes tunneling through a barrier in a double minimum potential no more curious than the probability distribution for the lowest energy level in a parabolic (harmonic oscillator) potential. Diagrams would help.

What is curious about tunneling is passing through a region where the system doesn't have enough energy to surmount a potential energy barrier, that is, where total energy < potential energy, or kinetic energy < 0. The solution to this conundrum is that kinetic energy can be negative! The hallmark of negative kinetic energy in a one-dimensional wave function is curvature away from the baseline (psi=0) for either psi or its square (probability). This occurs in every wave function for a potential that is bounded on both sides, like an harmonic oscillator. [It also occurs in every H-like orbital, as seen in the exponential factor that they all share.]

11. (12 minutes) Complete the structures below to show the two chair forms of trans- and of cis-1,3-dimethylcyclohexane. You need not draw hydrogens, but draw the directions of the bonds to methyl precisely.

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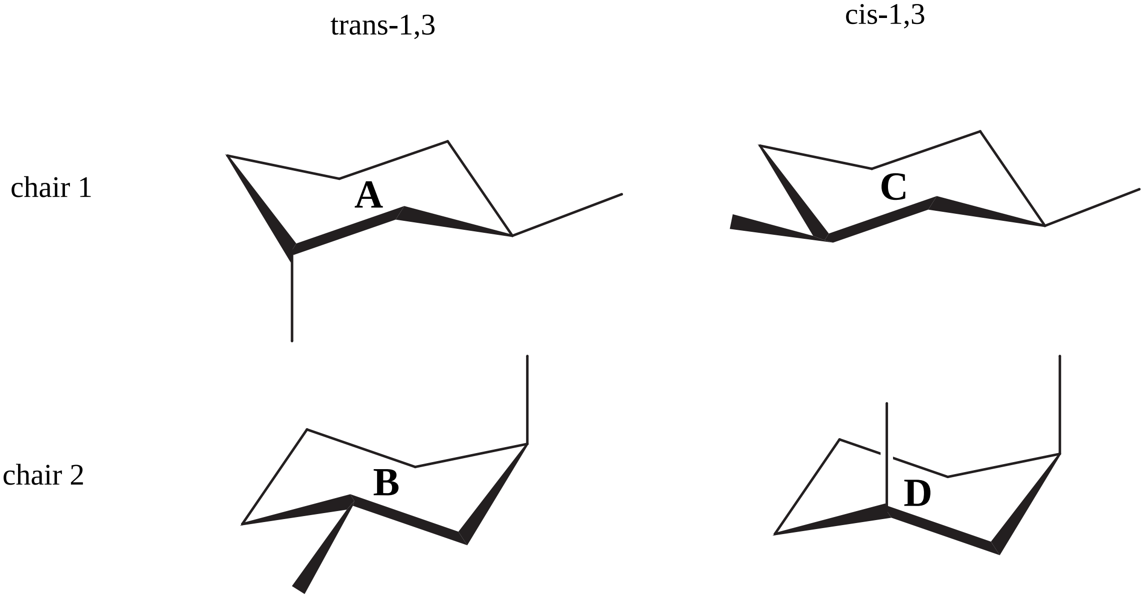

[Two points for each structure. There are in fact four versions of trans-1,3-dimethylcyclohexane, because A and B, which are conformational isomers, have configurational enantiomers. Any combination of these four was given credit for A and B, but of course no credit was given when a structure was repeated in a different orientation.]

Taking the energy of A to be 0, assign values for the energies of B, C, and D (kcal/mole, give a phrase of explanation for each to be eligible for partial credit)

B ____**0**____ Same as A (one methyl axial, one equatorial)

D ___**>1.7**__ Two methyls axial, in addition to having another axial methyl (A-value 1.7 kcal/mole) there is the repulsion between the two axial methyls. [In Chem3D this coincidentally results in an extra increase of 1.7 kcal in strain energy.]

C ___**-1.7**___ Both methyls equatorial (*i.e.* one axial becomes equatorial)

[Two points each]

In the line below, **circle the structures which are chiral** (configurationally or

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A __ **B** **(C and D have mirrors)**

In the line below, **circle the structures with conformationally diasteriotopic methyls**

[✓ **A**] [✓ **B**] **(C and D have mirrors)**

In the line below, **circle the structures with configurationally homotopic methyls**

[✓ **A**] [✓ **B**] **C** **D**

In both A and B both carbons bearing methyls are of (R) configuration, in C and D one is (R), one (S), i.e. they are enantiotopic.

In the line below, **circle the structures with methyls that could probably be discriminated by free radical bromination in a real experiment (not just a thought experiment)**

A **B** **C** **D**

None. The methyls in C and D could of course not be discriminated because they are configurationally and conformationally enantiotopic. In a real free-radical bromination the 13 kcal/mole activation energy for H-abstraction would be greater than the ~6 kcal/mole barrier for chair-chair interconversion (via twist-boat), so the conformationally diastereotopic methyls would interconvert locations faster than Br atom could discriminate them.

In the line below, **circle the structures with methyls that could probably be discriminated by an enzyme in a real experiment (not just a thought experiment)**

A **B** [✓ **C**] [✓ **D**]

Enzymes are a single enantiomer so they can discriminate between configurationally enantiotopic groups.