"A red dragonfly hovers above a backwater of the stream, its wings moving so fast that the eye sees not wings in movement but a probability distribution of where the wings might be, like electron orbitals: a quantum-mechanical effect that maybe explains why the insect can apparently teleport from one place to another, disappearing from one point and reappearing a couple of meters away, without seeming to pass through the space in between. There sure is a lot of bright stuff in the jungle. Randy figures that, in the natural world, anything that is colored so brightly must be some kind of serious evolutionary badass."


1 (16 points) The planar, cyclic molecule 1,3,5-cyclohexatriene, (benzene, 1) is shown below. For each part state whether it is a resonance form of 1 or not. If it is, a simple “yes” will suffice, but if the answer is “no,” please tell us (briefly!) why. All molecules save (b) and (h) are planar, and there is one undrawn H at every vertex.
2 (9 points).

a) Draw a Lewis “dot” structure for molecule 2:

\[
\begin{array}{c}
\text{CH}_3\text{O} \\
\text{H} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{C} \\
\text{N(CH}_3\text{)}_2 \\
\end{array}
\]

Draw resonance forms for molecule 2 in which:

b) the nitrogen is positive.

c) the CH\text{3O} oxygen is positive and the C=O oxygen is negative.

3 (24 points).

a) Draw all cyclic isomers of cyclohexane, C\text{6H}12. Thus, cyclohexane and methylcyclopentane are a legitimate answers, but 2-methyl-1-pentene is not.

\[
\begin{array}{c}
\text{legitimate answers} \\
\text{C}_6\text{H}_{12} \text{ but NOT} \\
\text{an answer to this question}
\end{array}
\]

b) label all isomers capable of cis/trans isomerism with the notation “c/t.” Draw one c/t pair in three dimensions.

c) label all isomers capable of optical (R/S) isomerism with an asterisk (*). Be clear: if only one member of a c/t pair can be optically active, tell us: c* or t* would work.

d) show one pair of diastereomers and one meso compound.
4 (15 points). The molecule acetylene (C₂H₂, HCCH) exists.

a) Use the hybridization model to sketch out the sigma (σ) bond system. Show what atomic or hybrid orbitals are used to make the bonds.

b) Show the pi (π) system. You may use wedges to show the p orbitals schematically.

c) Alkanes are very weak acids, with pKₐ values too high to measure, but estimated in the 50s and 60s. Remember that the pKₐ is a measure of the ease of removing a proton, thus of the ease of the following reaction:

\[
\text{C–H} \quad \text{H}^+ \quad \text{HB} + \quad \text{C}^- 
\]

By contrast, alkynes are quite strong acids, at least for hydrocarbons, with pKₐ values of about 25. They are, therefore, about \(10^{25}\) more acidic than alkanes. Give a very short explanation of why.
5 (26 points).

a) Draw the molecular orbitals (MOs) for square H₄. You can do this from memory or build them from the MOs for linear H₄ (which, in turn, can be constructed from the MOs of H₂). Then, order the MOs for the square, clearly showing which are bonding, which are nonbonding, and which are antibonding. Finally, put in the correct number of electrons.

Certain special molecules, including square H₄, undergo what is called “Jahn-Teller distortion.” What is this phenomenon, you ask? Well, in the case of square H₄ the square distorts to become a rectangle.

\[
\begin{array}{c}
\text{H--H} \\
\text{H--H} \\
\text{H--H} \\
\end{array}
\text{Jahn-Teller distortion}
\begin{array}{c}
\text{H--H} \\
\text{H--H} \\
\end{array}
\]

b) Show what happens to the energy of the MOs of square H₄ as it is stretched to become rectangular H₄. Do this by using dashed lines to connect the MOs of square H₄ with those of the related rectangular H₄, showing whether the orbital goes up or down in energy, or stays the same. Fill in the proper number of electrons.

Now explain why the rectangular form is favored.

6 (10 points). Calculations tell us that the indicated angle, α, in the ethyl cation (shown below, +CH₂CH₃) is close to 90°. Thus, it is far from the ideal for \( sp^3 \) hybridization, ~109.5°. In addition, the structure shown is the energy minimum for this ion. Explain briefly why the angle α closes from 109° to 90°.

\[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{H} \\
\end{array}
\alpha \sim 90°
\begin{array}{c}
\text{C} \\
\text{H} \\
\text{H} \\
\end{array}
\]

I pledge that I have not violated the Honour Code on this examination.”