

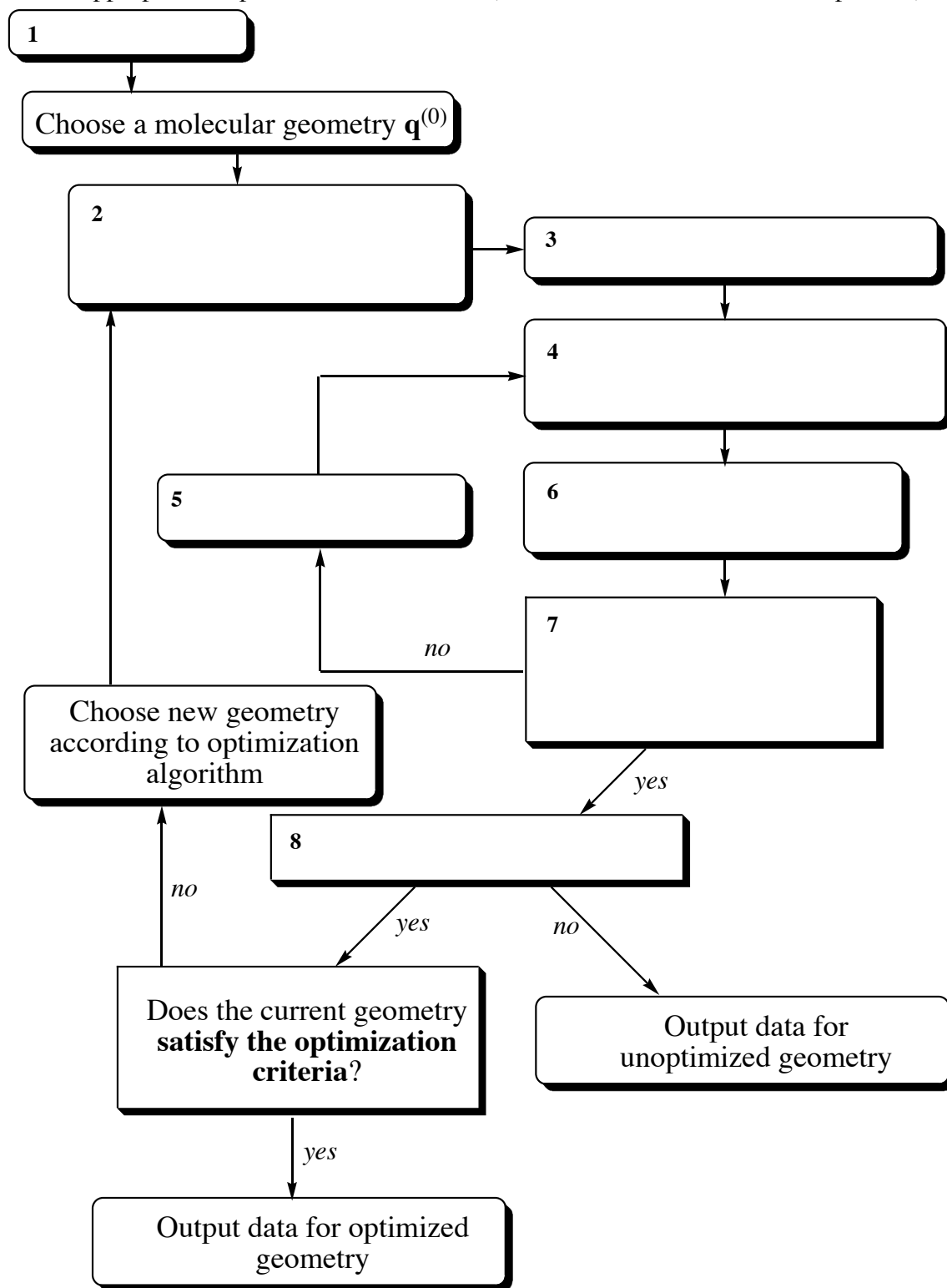
**Chemistry 3502/4502****Exam IV****April 19, 2006**

- 1) Fill in the blank on each question with the correct answer, by letter, from the list provided on the last page of the exam (you may tear the list off if you like).**
- 2) There is *one* correct answer to every fill-in-the-blank problem. There is no partial credit. No answer will be used more than once. There *are* answers that are *not* used, however.**
- 3) On the short-answer problem, show your work in full.**
- 4) You should try to go through all the problems once quickly, saving harder ones for later.**
- 5) There are 25 fill-in-the-blank problems. Each is worth 3 points. The short-answer problem is worth 25 points.**
- 6) There is no penalty for guessing.**
- 7) Please write your name at the bottom of each page.**
- 8) Please mark your exam with a pen, not a pencil. If you want to change an answer, cross your old answer out and circle the correct answer. Exams marked with pencil or correction fluid will not be eligible for regrade under any circumstances.**

**Score on Next Page after Grading**

NAME: \_\_\_\_\_

Fill in the numbered boxes on the HF calculation flowchart (from lecture 28) with the appropriate steps from the answer list (use the letters—don't write the phrases).



NAME: \_\_\_\_\_

9. A Hartree-product many-electron wave function: \_\_\_\_\_
10. The Coulomb integral  $J_{ab}$  between an electron in orbital  $a$  and another electron in orbital  $b$ : \_\_\_\_\_
11. The exchange integral  $K_{ab}$  involving orbitals  $a$  and  $b$ : \_\_\_\_\_
12. An operator  $H = h_1 + h_2 + h_3$  where  $h_1\psi_1 = 4\psi_1$ ,  $h_2\psi_2 = 2\psi_2$ , and  $h_3\psi_3 = 1\psi_3$ .  
If  $\psi_1$ ,  $\psi_2$ , and  $\psi_3$  are normalized,  
what is  $\langle \psi_1\psi_2\psi_3 | H | \psi_1\psi_2\psi_3 \rangle$ ? \_\_\_\_\_
13. A generic Fock matrix element  $F_{\mu\nu}$  (atomic units): \_\_\_\_\_
14. A generic overlap matrix element  $S_{\mu\nu}$ : \_\_\_\_\_
15. A generic density matrix element  $P_{\mu\nu}$ : \_\_\_\_\_
16. A generic 4-index integral  $(\mu\nu | \lambda\sigma)$ : \_\_\_\_\_
17. An integral equal to zero: \_\_\_\_\_
18. Equating the ionization potential of a molecule with the negative of the energy of the highest occupied molecular orbital (HOMO) is known as: \_\_\_\_\_
19. An integral equal to  $-1$ : \_\_\_\_\_
20. An antisymmetric, many-electron wave function  
with normalization implicit: \_\_\_\_\_

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The following 5 questions refer to a HF/STO-6G calculation on neutral hydroxylamine,  $\text{H}_2\text{NOH}$ . The atomic numbers of H, N, and O are 1, 7, and 8 respectively.

21. How many occupied orbitals will be used to construct the Slater determinantal many-electron wave function that would result from a restricted Hartree-Fock calculation? \_\_\_\_\_
  
22. As a linear combination of how many contracted basis functions will each molecular orbital be expressed? \_\_\_\_\_
  
23. Ignoring symmetry and the turnover rule, how many two-electron integrals over contracted basis functions would need to be evaluated in the calculation? \_\_\_\_\_
  
24. By what factor will the number of one-electron integrals over primitive basis functions exceed the number of one-electron integrals over contracted functions? \_\_\_\_\_
  
25. What is a reasonable value for the final HF energy in a.u.? \_\_\_\_\_

NAME: \_\_\_\_\_

## Hückel Theory

Consider the simplest possible Hückel system, ethylene,  $\text{H}_2\text{C}=\text{CH}_2$ , which has  $2\pi$  electrons.

How many basis functions are needed to carry out a Hückel theory calculation of the molecular orbitals of ethylene? What are the basis functions, specifically?

In terms of  $0$ ,  $1$ ,  $\alpha$ , and  $\beta$ , what are the specific values of all matrix elements that will appear in the secular determinant for ethylene? To what experimental quantities do  $\alpha$  and  $\beta$  refer, specifically?

Write the Hückel theory secular equation for ethylene. What values of  $E$  permit solution of the secular equation? You may find the equation  $a^2 - b^2 = (a + b)(a - b)$  to be helpful.

NAME: \_\_\_\_\_

What does Hückel theory predict for the singlet-triplet splitting in ethylene? Explain your answer.

NAME: \_\_\_\_\_

<b>A:</b>	$\left\langle \mu \left  -\frac{1}{2}\nabla^2 \right  \nu \right\rangle - \sum_k^{\text{nuclei}} Z_k \left\langle \mu \left  \frac{1}{r_k} \right  \nu \right\rangle + \sum_{\lambda\sigma} P_{\lambda\sigma} \left[ (\mu\nu   \lambda\sigma) - \frac{1}{2}(\mu\lambda   \nu\sigma) \right]$	<b>R:</b>	Optimize molecular geometry?
<b>B:</b>	Choose a basis set	<b>S:</b>	36
<b>C:</b>	21	<b>T:</b>	$\iint a(1)b(2) \frac{1}{r_{12}} a(1)b(2) d\mathbf{r}(1)d\mathbf{r}(2)$
<b>D:</b>	$\langle 1s_{H_a}   1s_{H_b} \rangle$ where $H_a$ and $H_b$ are the two H atoms in water	<b>U:</b>	Is new density matrix $\mathbf{P}^{(n)}$ sufficiently similar to old density matrix $\mathbf{P}^{(n-1)}$ ?
<b>E:</b>	Koopmans' theorem	<b>V:</b>	-130.505 204 660
<b>F:</b>	16	<b>W:</b>	7
<b>G:</b>	$-\frac{1}{2}\nabla_i^2 - \sum_{k=1}^M \frac{Z_k}{r_{ik}}$	<b>X:</b>	Compute and store all overlap, one-electron, and two-electron integrals
<b>H:</b>	$2 \sum_i^{\text{occupied MOs}} a_{\mu i} a_{\nu i}$	<b>Y:</b>	$\iint a(1)b(1) \frac{1}{r_{12}} a(2)b(2) d\mathbf{r}(1)d\mathbf{r}(2)$
<b>I:</b>	$13^4$	<b>Z:</b>	Construct and solve Hartree-Fock secular equation
<b>J:</b>	Construct density matrix from occupied MOs	<b>AA:</b>	13
<b>K:</b>	$\iint \phi_\mu(1)\phi_\nu(1) \frac{1}{r_{12}} \phi_\lambda(2)\phi_\sigma(2) d\mathbf{r}(1)d\mathbf{r}(2)$	<b>BB:</b>	$\Psi =  \chi_1\chi_2\chi_3 \cdots \chi_N\rangle$ where the various $\chi_i$ are one-electron spin orbitals
<b>L:</b>	Guess initial density matrix $\mathbf{P}^{(0)}$	<b>CC:</b>	$\pi$
<b>M:</b>	41.818 911 429	<b>DD:</b>	$\Psi = \psi_1\psi_2 \cdots \psi_N$ where the various $\psi_i$ are one-electron orbitals
<b>N:</b>	$\langle -2p_{x,N}   2p_{x,N} \rangle$	<b>EE:</b>	Replace $\mathbf{P}^{(n-1)}$ with $\mathbf{P}^{(n)}$
<b>O:</b>	$\langle 2p_{x,N}   2p_{z,O} \rangle$ where N and O are both on the x axis	<b>FF:</b>	$21^4$
<b>P:</b>	The Born-Oppenheimer approximation	<b>GG:</b>	8
<b>Q:</b>	$16^4$	<b>HH:</b>	$\int \phi_\mu(\mathbf{r})\phi_\nu(\mathbf{r}) d\mathbf{r}$

NAME: \_\_\_\_\_