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5.111 Principles of Chemical Science  
Fall 2008

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**5.111 Principles of Chemical Science**  
**Solutions to selected biology-related questions from problem sets for lectures 10-20**

Electron configurations

**A.**

*A class of enzymes called the cytochromes P450 are found in the liver. These important enzymes catalyze the oxidation of small molecules (such as drugs) to enable excretion from the body. Person-to-person variations in the amounts of certain cytochrome P450 enzymes can account for drastic differences in the way individuals respond to the same dosage of a drug.*

*Like many enzymes, cytochrome P450 enzymes require association with metal atoms for activity. Specifically, the oxidation of target molecules by cytochromes P450 requires iron.*

(a) Give the electron configuration of neutral iron.

Provide the electron configuration for the following iron ions. Iron in its +2, +3, and +4 oxidation state are all involved in cytochrome P450 catalysis.

(b)  $Fe^{2+}$

(c)  $Fe^{3+}$

(d)  $Fe^{4+}$

(a)  $[Ar]3d^64s^2$

(b)  $[Ar]3d^6$

(c)  $[Ar]3d^5$

(d)  $[Ar]3d^4$

Lewis structures

**B.**

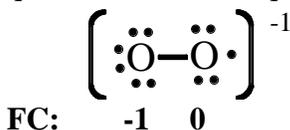
*The following molecules, which form as a byproduct of natural metabolic processes in the body, are highly reactive and can cause oxidative damage to DNA. Write the Lewis structure for each molecule and indicate whether or not it is a radical. Calculate the formal charge on every atom.*

(a) the superoxide ion,  $O_2^-$

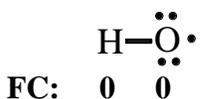
(b) OH

(a) **radical**

(Note:  $O_2^-$  has a resonance structure with the radical electron on the other oxygen, but this question does not require that you include the resonance structure.)



(b) **radical**



**C.**

Proteins are macromolecules that play an enormous variety of roles in our body, including catalyzing reactions such as metabolism and DNA synthesis. All proteins are made up of building blocks called amino acids. Proteins typically consist of hundreds of amino acids linked together in a chain. The skeleton structures of two amino acids, **serine** and **tyrosine**, are drawn below.

Provide the most important Lewis structure(s) for these molecules, drawing all single and multiple bonds, lone pairs and formal charges. If there are equivalent resonance forms, include them.

**(a)**

1) skeletal structure given

**2) valence electrons: N + C + O + H**

$$5 + 3(4) + 3(6) + 7(1) = 42$$

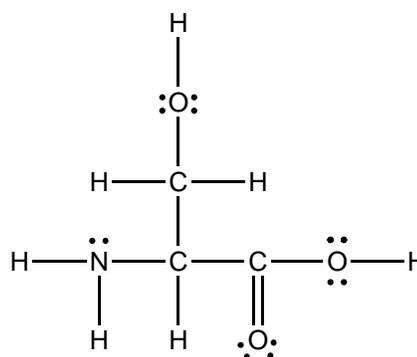
3) electrons needed for full octets:  $7(8) + 7(2) = 70$ 4) bonding electrons:  $70 - 42 = 28$ 

5) assign two electrons to each bond

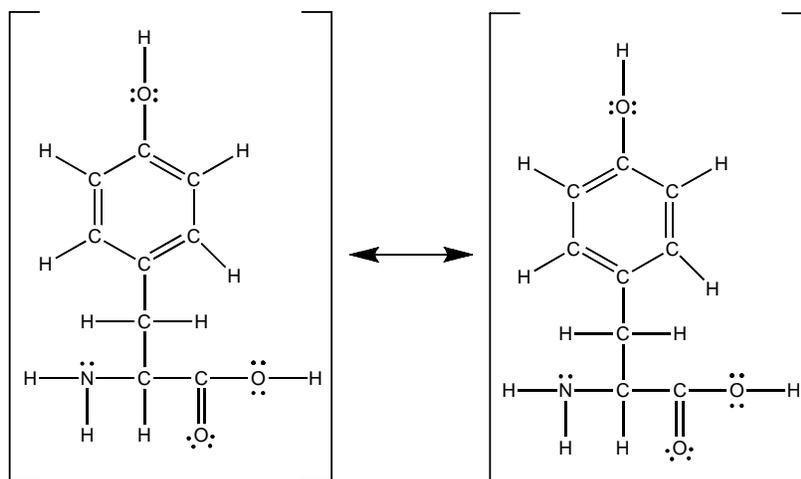
6) 2 extra bonding electrons

7) 14 extra lone pair electrons

8) FC = 0 for every atom

**(b)**

1) skeletal structure given

**2) valence electrons: N + C + O + H: 5 + 9(4) + 3(6) + 11(1) = 70**3) e<sup>-</sup>s needed for full octets:  $13(8) + 11(2) = 126$ 4)  $126 - 70 = 56$  bonding electrons5) Assign 2 electrons to each bond (48 total). 6)  $56 - 48 = 8$  extra bonding electrons7)  $70 - 56 = 14$  extra lone pair electrons 8) FC = 0 for every atom

## Valence bond theory and hybridization

### D.

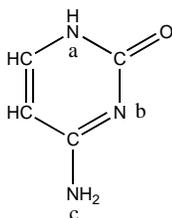
The genetic code includes four different DNA bases. The structures of two of these bases, cytosine and adenine, are shown below. (Note that lone pairs are not pictured, but may be present in the structures.) Assign the hybridization and geometry to:

(a) the nitrogen atoms in cytosine.

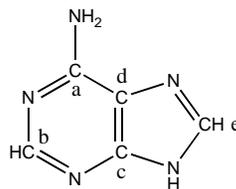
**N<sub>a</sub>: sp<sup>3</sup>, trigonal pyramidal, N<sub>b</sub>: sp<sup>2</sup>, bent, N<sub>c</sub>: sp<sup>3</sup>, trigonal pyramidal**

(b) the carbon atoms in adenine.

**All of the carbon atoms are sp<sup>2</sup>, trigonal planar.**



cytosine

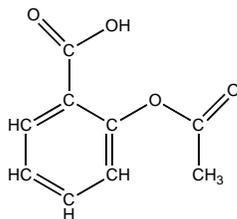


adenine

### E.

Pi-bonds between atoms prevent rotation around the bond axis, which makes double and triple bonds rigid. In contrast, single bonds can freely rotate around the bond axis. In many drugs, rigidity helps lower the barrier to binding a target enzyme in the body by pre-organizing the drug into the exact shape necessary to bind the enzyme.

The structure of acetylsalicylic acid (aspirin) is shown below. (a) How many pi-bonds are present in aspirin? How many sigma-bonds? (b) Name one other factor that restricts bond rotation in part of aspirin.



(a) 5  $\pi$ -bonds, 21  $\sigma$ -bonds

(b) Either one of the following answers is acceptable: the **ring structure** increases rigidity within the ring. **Resonance** increases rigidity across 3 atoms instead of two.

## Thermodynamics

### F.

Acetyl phosphate is a molecule that plays a role in the formation of certain fatty acids in the body. For the formation of acetyl phosphate from acetic acid under conditions in the body,  $\Delta G = +41 \text{ kJ/mol}$ . If acetyl phosphate formation is driven by coupling it to the hydrolysis of ATP (to ADP), what is the minimum amount of ATP (in moles) that must be hydrolyzed to form 6.0 mol of acetyl phosphate? See Lecture #18 notes for the  $\Delta G$  of ATP hydrolysis and assume 100% coupling efficiency.

$\Delta G$  of ATP hydrolysis is  $-31 \text{ kJ/mol}$

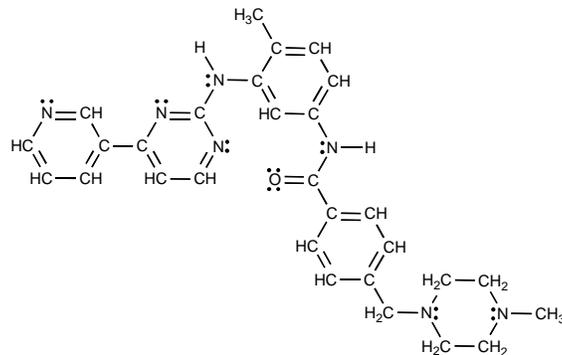
$$6.0 \text{ mol} \times (41 \text{ kJ/mol}) / (31 \text{ kJ/mol}) = \mathbf{7.9 \text{ mol of ATP}}$$

### Hydrogen bonds

#### G.

Gleevec® (Novartis) is cancer drug that was first approved in 2001 to treat patients with a specific type of leukemia. Gleevec works by selectively binding to a cancer-causing mutant protein, essentially turning the cancerous protein “off” by stabilizing an inactive form of the protein. Gleevec binds the protein through several types of intermolecular interactions, including hydrogen bonding.

Consider the Gleevec molecule below and put a triangle around all atoms that could be hydrogen bond donors. Circle the atoms that could be hydrogen bond acceptors.



There are 7 possible H-bond acceptors and 2 possible H-bond donors. Note that H-bonding requires the proper orientation and distance between interacting molecules, so not all potential atoms will form H-bonds. For Gleevec, there are five hydrogen bonds believed to form between Gleevec and the target protein.

