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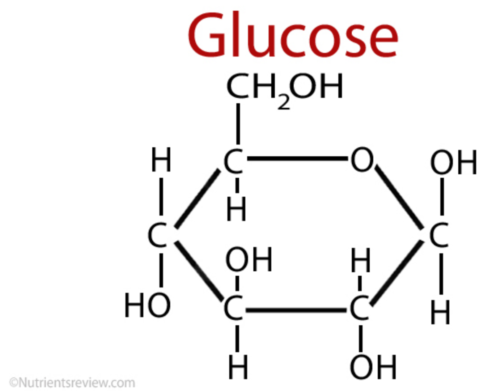
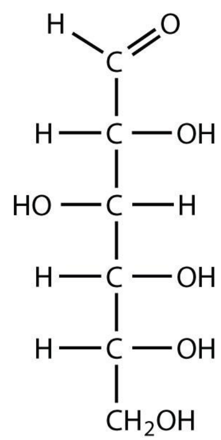
Sample Questions for the Chemistry of Food Topic Exam

1. When food turns a delicious golden brown, it undergoes a process known as the Maillard reaction. This reaction occurs between an amino acid and a sugar.

a. For an example reaction, we will use glucose as the sugar. The structure of cyclic glucose is shown.



However, the reaction proceeds with the open-chain form, which is shown below.



i. Using the bond energies of the bonds broken and formed, what is the change in enthalpy of the conversion from ring glucose to open-chain glucose?
Bond energies in kJ/mol:
C-C = 347; C=O = 736; C-O = 360; O-H = 463; C-H = 413

Net: 1 C=O bond formed, 2 C-O bonds broken

$\Delta H = 2*377 - 736 = 18$ kJ/mol

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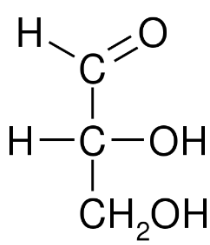
ii. Though the two forms of glucose have similar properties, one form has a significantly higher entropy than the other. Which one is it, and why?

The open-chain form has greater entropy because it has greater freedom to rotate, which means it can form many more microstates than ring glucose.

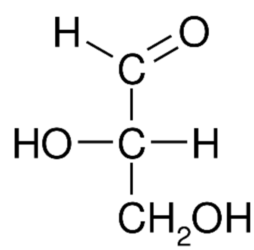
iii. Qualitatively describe how the amounts of glucose that are in open-chain and ring form change as the temperature increases.

The conversion from ring to open-chain glucose is in an equilibrium with a positive ΔH and a positive ΔS. Since $\Delta G = \Delta H - T\Delta S$, the amount of glucose in open-chain form will increase as temperature increases.

iv. Sugars can be classified as D (dextrorotary) or L (levorotary) depending on how they rotate plane polarized light. Given that they are assigned their classification based on whether or not they are converted to D or L-glyceraldehyde, determine the rotational isomerism of this form of glucose. D-glyceraldehyde is shown on the left, and L-glyceraldehyde is shown on the right. Circle the letter corresponding to your answer.



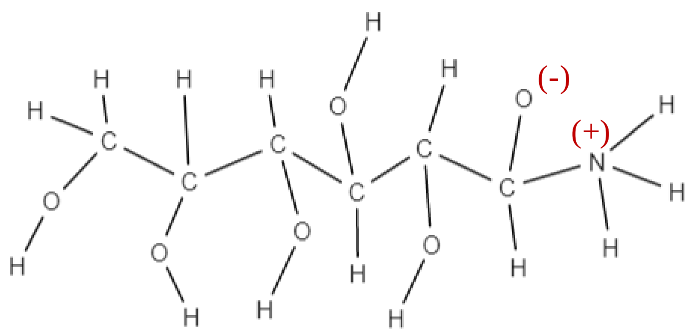
D



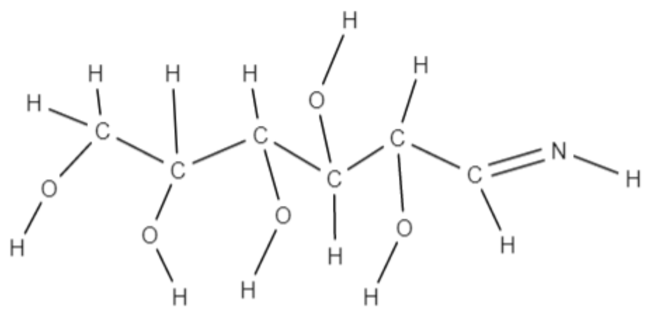
L

b. The Maillard reaction will now be shown in its early steps when glucose reacts with an amino acid, which in this case is glycine.

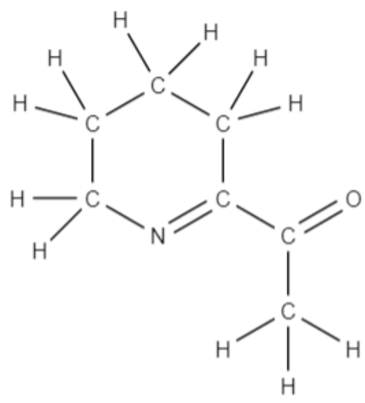
i. Complete the Lewis structure of the first intermediate structure by filling in any formal charges on the atoms. All atoms have a filled octet.

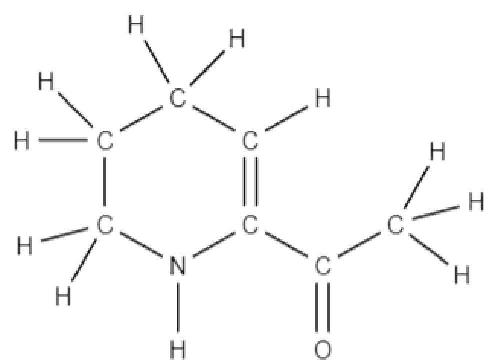


ii. The reaction will continue by undergoing dehydration intermolecularly, where an H2O is removed from the intermediate. Draw the most stable structure of the molecule that could occur by removing a water molecule.



c. One product of the Maillard reaction is 6-acetyl-2,3,4,5-tetrahydropyridine, shown on the left, which is responsible for the odor of baked goods. It can also interconvert to 6-Acetyl-1,2,3,4-tetrahydropyridine, shown on the right.





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i. What are the hybridizations of the atoms on the rings?

Sp2 for the double bonded atoms and sp3 for the rest of the ring. (The nitrogen on the compound to the right is closer to sp2 hybridization in reality due to the NH group.)

ii. Though the two compounds readily interconvert to one another's forms, they are not resonance structures. Instead, they are known as tautomers. Explain why the two classifications are different.

The two molecules shown above are not the same, as the atoms in each molecule are joined differently. As a result, the two molecules are both real structures that can form and exist independently from each other in certain conditions. Resonance structures are not separate molecules; rather, they are representations of distributions of the electrons of a single molecule.

iii. The chemical equilibrium that the interconversion exists in a 2:1 equilibrium at 25 *C with the product on the right being the more favored compound. Find the change in free energy of the conversion from the left structure to the right structure.

$\Delta G = -RT\ln k$

$k = 2/1$

$\Delta G = -1717$ J/mol $= -1.72$ kJ/mol

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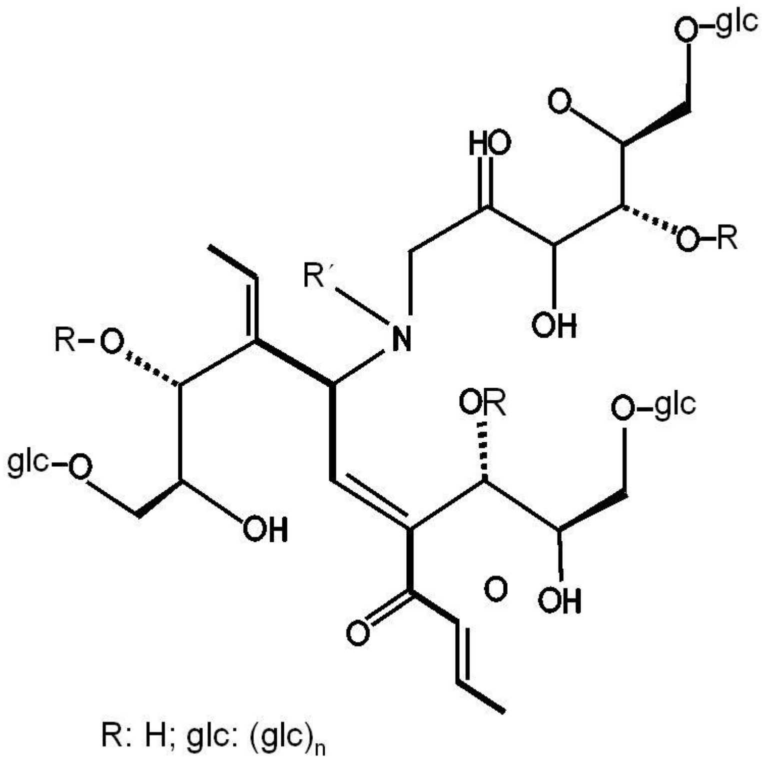
d. Another important final product of the Maillard reaction is melanoidins, which contribute to the dark brown color and rich flavor of foods like bread crusts. Production of melanoidins is greatly favored in conditions where the temperature is high and water activity is low. Propose why might these conditions be preferred when trying to produce melanoidins. An example of a melanoidin is shown below.



Higher temperatures are favored because the molecules will move more quickly and collide with more force, causing polymerization to occur more frequently and at a greater rate. As melanoidins are large polymers, dry conditions favor the polymerization of the amino acids and sugars required to undergo the reaction, as if water is included in the reaction it will react with and hydrolyze the other reactants, causing the polymer to break apart.

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2. To make rock candy, the first step is bringing a pot of water to a boil. Then, add sugar to the water until no more sugar can be dissolved.

a. As the solution cools, there are no changes in the appearance of the solution. What kind of solution is formed when the water is allowed to cool to room temperature?

A supersaturated solution

b. After turning off the heat, a string hanging from a pencil is partly submerged in the water. Now what happens? If there is initially 1000 g of sucrose sugar dissolved in 0.4 kg of boiling water, and the solubility of sucrose in water at room temperature is 202 g of sucrose per 100 g of water, how much rock candy will you make?

At room temperature, maximum amount of sucrose in solution:

(0.4 kg water)(1000 g / kg)(202 g sucrose / 100 g water) = 808 g sucrose

Since there is 1000 g of sucrose total, we make 1000 – 808 = 192 g of rock candy

c. What is the purpose of adding sugar to the water while it is boiling? (Instead of adding the sugar before we boil the water)

The solubility of sucrose in water is much higher at 100 C than at room temperature, so by adding sucrose when the water is boiling, we can make a supersaturated solution, so when the sucrose cools, it crystallizes forming rock candy.

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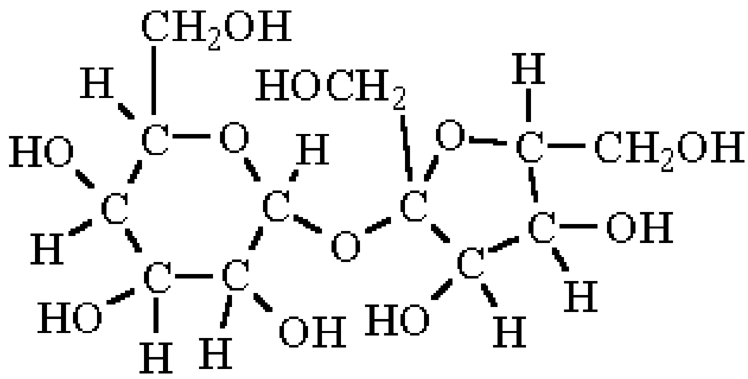
d. We were able to dissolve a large quantity of sucrose in the water. Use the structure of sucrose shown below to explain why sucrose has such a high solubility in water.



Sucrose contains many polar –OH groups, which interacts favorably with water.

e. On the structure above, draw a water molecule next to the sucrose molecule, and orient it such that you can draw a dotted line showing the strongest noncovalent interaction between the sucrose molecule and water molecule.

Draw any hydrogen bonds from water to an –OH group on the sucrose

f. The general method of creating a saturated solution at high temperature and then cooling to allow crystal to form is called recrystallization. It is a common laboratory technique used to purify compounds. Why does this technique work as a purification method?

When the solution is allowed to form, the crystals that form are pure because impurities are not incorporated into the crystal structure.

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3. You are on an island and need to make food to survive. The only promising plant you can find is the castor bean, which contains the poisonous compound ricin. Although purified ricin is safe to ingest, consuming the amount of untreated ricin in two castor beans can kill an adult.

Given: Castor beans are 5% ricin by weight. Ricin has a molecular weight of 60kg/mol.
Recall: $\Delta H = q$ at constant pressure, specific heat of water is 4.184 J/g*K

a. Ricin is composed of two monomers: lectin and RIP, which are joined by a disulfide bridge. Breaking this bond inactivates the poisonous abilities of ricin. You think to use the heat from 80 °C water in a hot spring to break this bond. If you want to cook 300g of castor beans in 50g of water, what final temperature of the water would signal that the beans are safe to eat? Assume that 1% of the water's heat is transferred to the castor beans. Assume there is sufficient energy for all the ricin to overcome the reaction's activation energy barrier.

Compound	Enthalpy of Formation (kJ/mol)
Ricin	624959
Lectin	312500
RIP	312710

$$\Delta H_{rxn} = \frac{251kJ}{mol}$$

$$300g\ castorbeans\ \frac{.05g\ ricin}{1\ g\ castor\ beans}\frac{1\ mol\ ricin}{60000g\ ricin}\frac{251kJ}{mol}\frac{1000J}{1kJ} = 62.75J = q_{rxn}$$

$$q_{water} = MC\Delta T = (.01)50g\frac{4.184J}{g}(353 - T_f) = 62.75J$$

323K = 50*C

b. Another possible option to obtain nutrients from the castor bean is to extract the castor bean oil within the bean because ricin is water-soluble. To do this, you mix mashed castor beans with water. Ricin has a solubility in water of 92mg/mL at 25 °C.

i. Given the abbreviated chemical equation, $R(OH)_{3(s)} \leftrightarrow R^{3+}_{(aq)} + 3OH^{-}_{(aq)}$, calculate the K_{sp} of the dissociation of ricin in water.

$$\frac{92mg\ ricin}{1mL\ water}\frac{1g\ ricin}{1000mg\ ricin}\frac{1\ mol\ ricin}{60000g\ ricin}\frac{1000mL\ water}{1L\ water} = 0.0015M$$

$$K_{sp} = (s)(3s)^3 = 1.49 \times 10^{-10}$$

ii. How much water (in mL) must be added to 300g of castor beans in order to ensure the ricin is dissolved in water?

$$15g\ ricin \frac{1\ mol\ ricin}{60000g\ ricin} \frac{1}{(X)\ L\ water} = 0.0015M$$

167 mL

iii. How would the required amount of water change if you used the 80 °C spring water instead? Please include a justification for the direction of change (if any) in complete sentences as well as the calculation of the new required volume of water (if different) in liters. Given: ΔH_{rxn} = 200kJ/mol

This is an **endothermic** reaction because ΔH_{rxn} is positive. Compounds with endothermic dissociation reactions **increase in solubility** with increasing temperature. Increasing solubility means that **less water** is required to dissolve the same amount of ricin.

$$In\left(\frac{K_{353K}}{1.49 \times 10^{-10}}\right) = \frac{-\frac{200000J}{mol}}{\frac{8.314J}{molK}}\left(\frac{1}{353} - \frac{1}{298}\right)$$

$$K_{353K} = 0.000043 = (s)(3s)^3$$

$$s = 0.0356M = \frac{0.005mol}{(X)\ L}$$

0.14 L water

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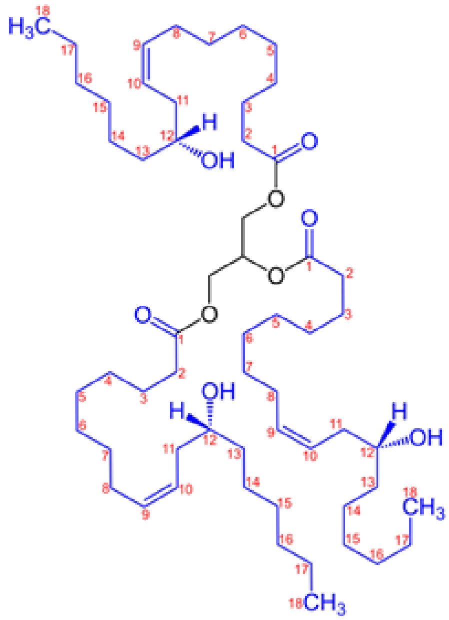
c. Shown below is the skeletal structure of a major component of castor oil. Skeletal diagrams are often used in organic chemistry as a concise way to describe a molecule. Each red number labels a carbon molecule. Although not drawn, many hydrogens are implied by the diagram because every carbon has a filled octet.



i. How many hydrogens are bonded to carbon 16?

2

ii. What is the geometry of carbon 12?

Tetrahedral

iii. What is the geometry of carbon 9?

Trigonal pyramidal

iv. Dissolving the castor beans in water was an efficient way to separate the castor oil from ricin because castor oil has such a low solubility. Use the skeletal structure to justify castor oil's solubility of less than 1g/L.

Castor oil has a low solubility because the majority of the bonds in the molecule are C-C and C-H which are both nonpolar bonds. The few polar bonds (O-H and C-O) create dipole moments that are oriented in opposite directions about the center of the molecule, dampening their effect.