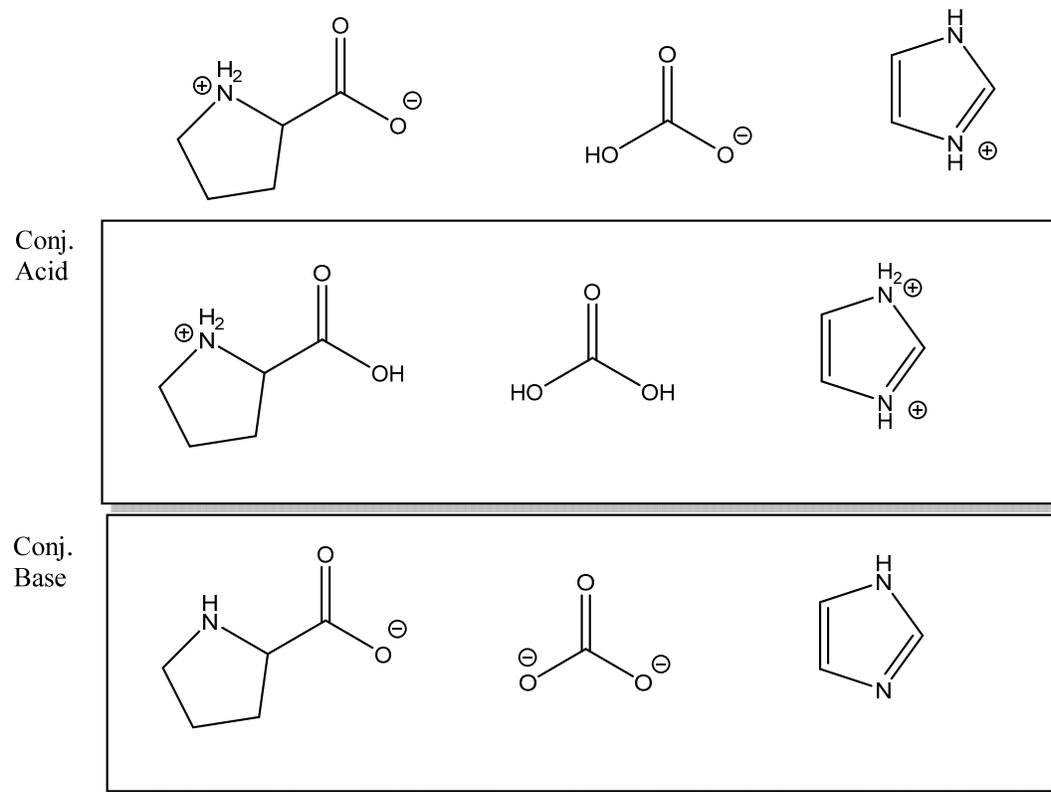


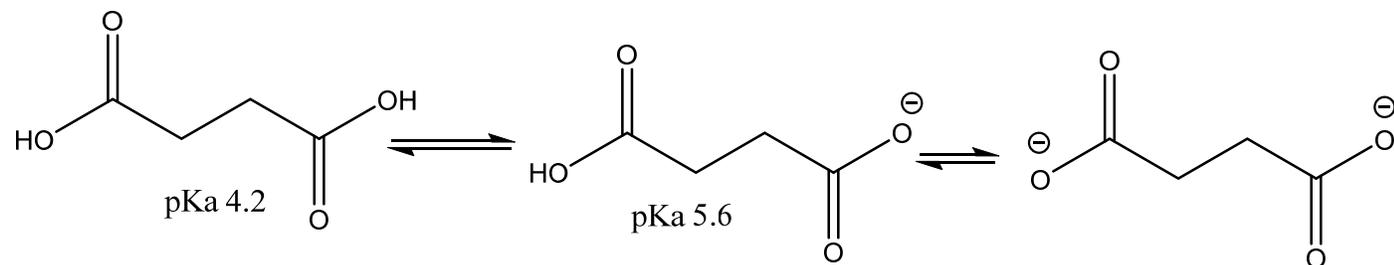
## Discussion Exercise 2: Polyprotic Acids

### Answer key

**Problem 1:** Draw the conjugate acid and the conjugate base of each of these compounds.  
(Consider the pKa values of the functional groups!)

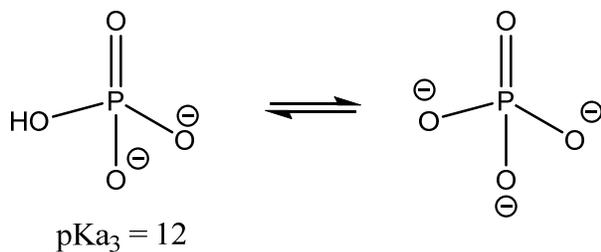
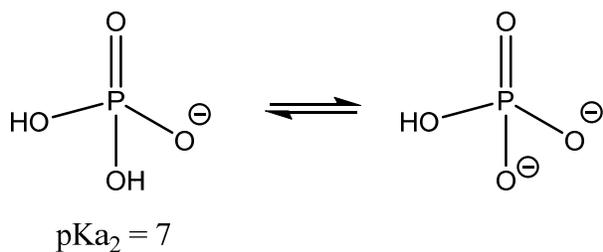
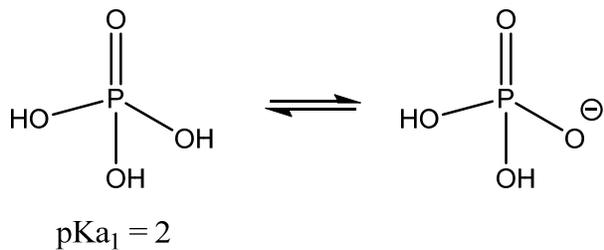


**Problem 2:** The first pKa of succinic acid is 4.2 and the second pKa of succinic acid is 5.6. How can the same functional group have different pKa values?

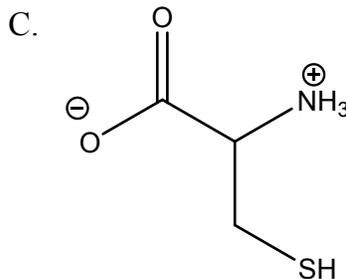
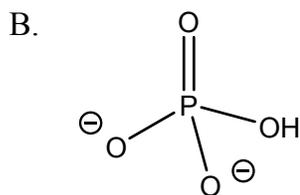
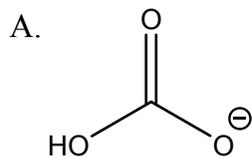


After the loss of the first proton, the “new” acid is already negatively charged, making loss of a second proton harder. This is reflected in the higher pKa value.

**Problem 3:** Phosphoric acid has three pKa values, at approximately 2, 7, and 12. Draw the conjugate acid/base pair for each of these three pKa values.

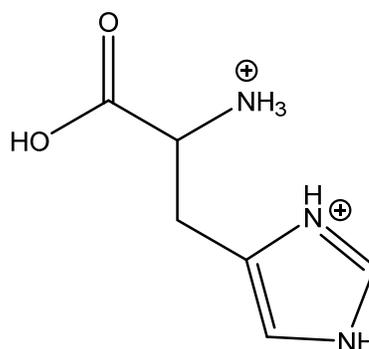
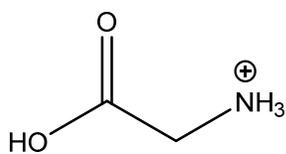


**Problem 4:** Draw the following molecules in the correct major ionization state at pH 7. Use Figure 2.11, Table 3.1, and the pKa values given in the problem.

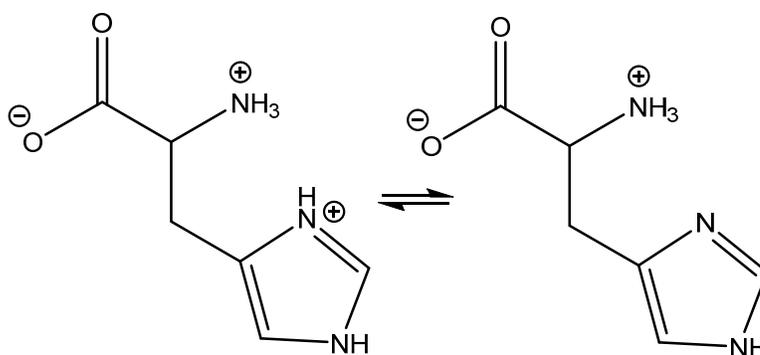
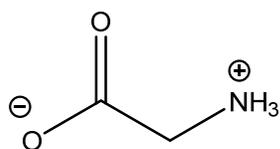


Problem 5. Draw the following molecules in their major ionization state(s) at pH 2.3, 6.0, 9.6, and 12.0.

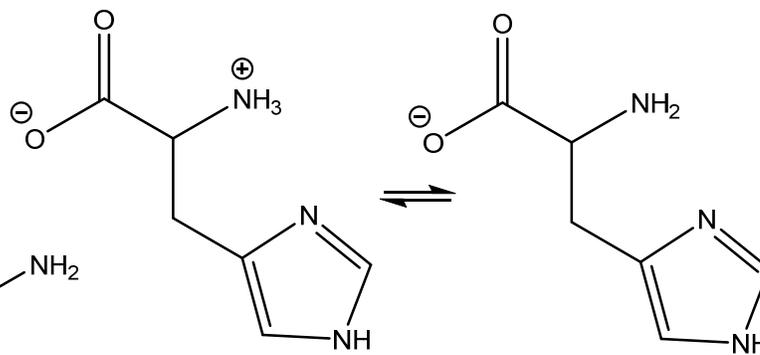
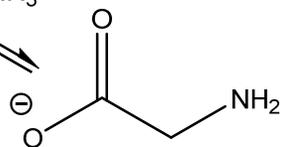
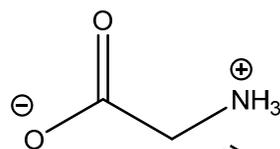
at pH 2.3



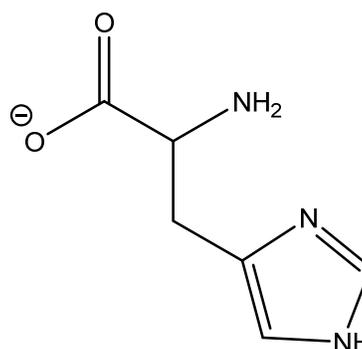
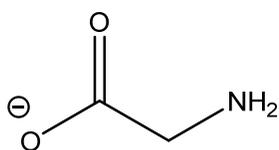
at pH 6.0



at pH 9.6

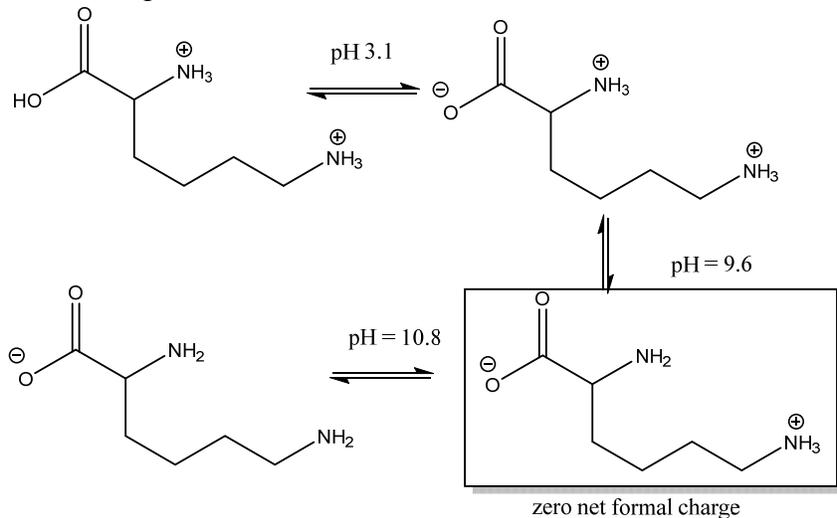


at pH 12

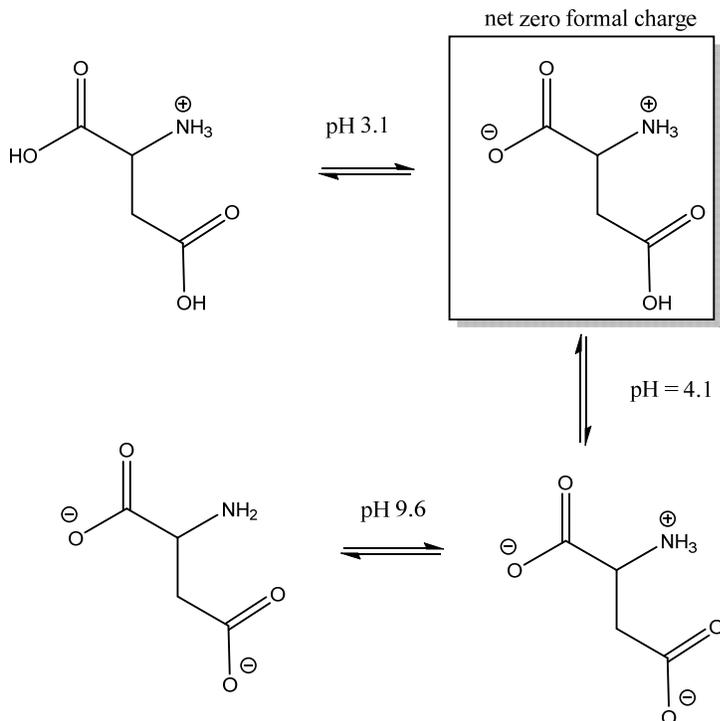


**Problem 6.** What is the isoelectric point for lysine and aspartic acid? (See Table 3.1)

For lysine, the net zero charge species occurs half way between pH 9.6 and 10.8, so the isoelectric point is 10.2



For aspartic acid, the net zero charge species occurs half way between pH 3.1 and 4.1, so the isoelectric point is 3.6



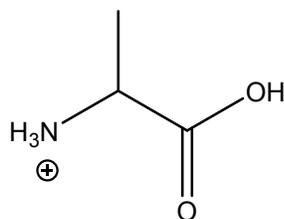
**Problem 7.** The titration chart below is for the amino acid alanine.

a. What is the first pKa of alanine? **About 2.2**

What is the second pKa? **About 9.9**

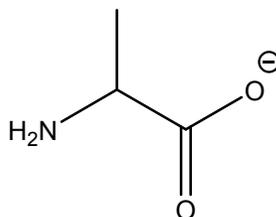
b. At point A, alanine is in its completely protonated form. At point J, it is completely deprotonated. Refer to Figure 3.3 and draw these two structures.

Fully protonate



net charge +1

Fully deprotonate

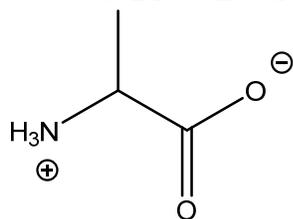


net charge -1

c. What is the point at which alanine has a net zero charge? **At the inflection point, about half way between 2.2 and 9.9, about 6.1**

d. What is the isoelectric point of alanine? **The isoelectric point is where the net charge is zero, so the isoelectric point is 6.1.**

e. Draw the structure of alanine at its isoelectric point.



net charge zero