Strength of Acids

How does the molecular structure of an acid influence its strength?

Why?

Bronsted-Lowry acids (H^{1+} ion) are proton donors. A stronger acid is more likely to give up a proton. The structure of an acid molecule, and the atoms remaining behind have a lot to do with the ease of donating the proton.

Model 1 – Donating a Hydrogen Ion

$$HCl + H_2O \rightarrow H_3O^{1+} + Cl^{1-}$$

1. Refer to Model 1.
   a. Which reactant acts as the acid?

   b. Which reactant acts as the base?

   c. What is the conjugate base to the reactant acid?

2. Add a curved arrow in Model 1 to show the transfer of the proton (H^{1+} ion) from the acid to the base in the reaction.

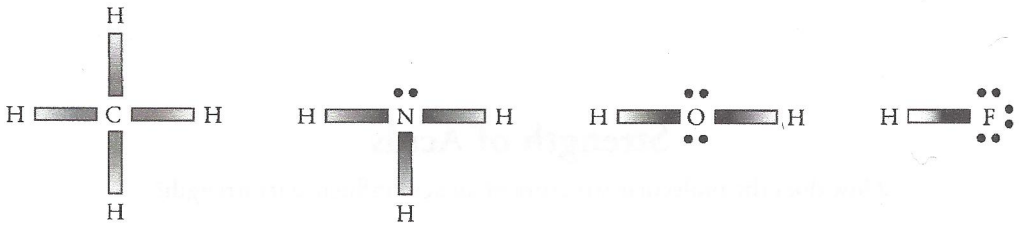
3. Describe the bonds that are broken and formed during the reaction in Model 1.

4. If the bond that was broken was a relatively strong bond, would you expect the acid to be a stronger or weaker acid? Justify your reasoning.

5. During the reaction in Model 1, one atom loses an electron and another gains an electron. Which atom lost the electron, and which atom gained the electron?

6. If the atom receiving the electron (the conjugate base) was more electronegative (and thus could hold the extra electron more tightly) would you expect the acid to be a stronger or weaker acid? Justify your reasoning.

Model 2 – Comparing Binary Acid Strength



$K_a = 1.0 \times 10^{-48}$ $K_a = 1.0 \times 10^{-38}$ $K_w = 1.0 \times 10^{-14}$ $K_a = 6.3 \times 10^{-4}$

7. Which acid in Model 2 is most likely to donate a proton (H^{1+} ion)? Justify your reasoning.

8. Consider the center atoms in the molecules in Model 2. Locate those atoms on the periodic table. Based on their location on the periodic table, which center atom is the most electronegative?

9. Consider Model 2.

   a. Which molecule contains bonds that are the most polar?

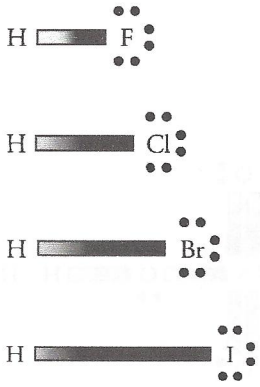
   b. How is the extent of bond polarity illustrated in Model 2?

10. According to the data in Model 2, how does the polarity of the bond between the hydrogen atom and the center atom of a binary acid affect the strength of the acid?

11. How might the polarity of the bond and the electronegativity of the center atom make it more likely for the hydrogen ion to leave the molecule? *Hint:* Consider what is left behind when the hydrogen ion leaves.

12. Predict which substance would be the stronger acid: hydrosulfuric acid (H_2S) or hydrochloric acid (HCl). Explain your reasoning.

Model 3 – More Binary Acids



$K_a = 6.3 \times 10^{-4}$

$K_a = 1.0 \times 10^{7}$

$K_a = 1.0 \times 10^{9}$

$K_a = 1.0 \times 10^{10}$

13. Which acid in Model 3 is least likely to donate a proton (H^{1+} ion)? Justify your reasoning.

14. Consider the atoms in the molecules in Model 3 that are bonded to hydrogen. Locate those atoms on the periodic table. Based on their location on the periodic table, which atom is the most electronegative?

15. Can bond polarity and electronegativity of the nonhydrogen atom explain the trend in acid strength shown in Model 3? Use complete sentences to explain why or why not.

16. Notice the bond lengths in Model 3 are not shown as equal or similar. Explain why the hydroiodic acid molecule would have a longer bond length than the hydrofluoric acid molecule.

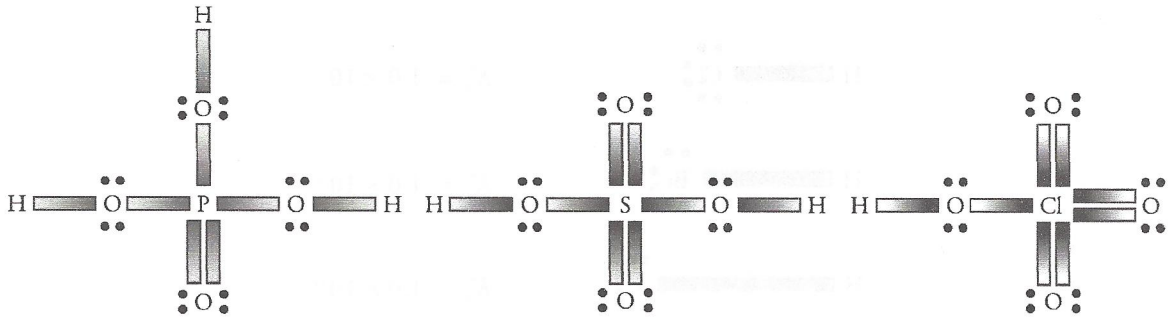
17. Are bonds stronger or weaker when they are longer? Justify your reasoning using the principles of Coulombic attraction.

18. According to the data in Model 3, how does the length of the bond between the hydrogen atom and the center atom of a binary acid affect the strength of the acid?

19. Which factor has more impact on the strength of an acid, the polarity of the bond or the length of the bond, when both are varied?

20. Predict which substance is more acidic: hydrosulfuric acid (H_2S) or hydroselenic acid (H_2Se). Explain your reasoning.

Model 4 – Comparing Oxo Acids



21. Refer to Model 4.
    a. Write the names and chemical formulas for each acid below the structures shown.

    b. Why are these acids considered "oxo-acids"?

22. Of the three center atoms in Model 4, which is most electronegative? Justify your reasoning.

23. Even though the acidic hydrogen atoms are not bonded directly to the center atom in an oxo-acid, does the center atom affect the polarity of the O—H bond in oxo-acid molecules? Support your answer with evidence from Model 4.

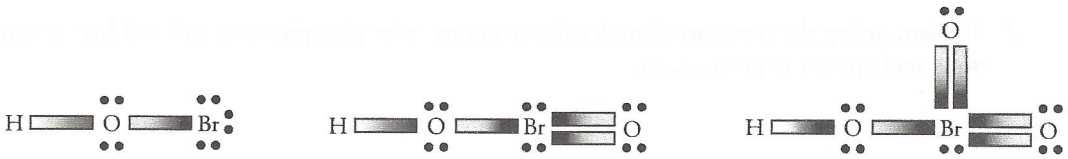
24. Based on what you have learned in Models 2 and 3, which acid in Model 4 is likely to be the strongest acid? Justify your reasoning.

Read This!

Normally, when a bond is analyzed for polarity, it is only the electronegativity of the atoms on either end of the bond that are considered. In reality, however, a highly electronegative atom can affect a bond's polarity two or three bonds away. This effect is called the **inductive effect**.

25. Predict which substance would be more acidic, bromic acid ($HBrO_3$) or iodic acid (HIO_3). Explain your reasoning.

Model 5 – More Oxygen Atoms



26. Write the names and chemical formulas for each acid under the structures shown in Model 5.

27. According to Model 5, how does the addition of oxygen atoms on the central atom of an oxo-acid affect the polarity of the O—H bond to the acidic hydrogen?

28. Use the idea of the inductive effect to explain the changes in the polarity of the O—H bonds in Model 5.

29. Which acid in Model 5 would you predict to be the strongest acid? Explain your reasoning.

30. Chlorine makes four stable oxo-acids: hypochlorous acid, chlorous acid, chloric acid and perchloric acid. Match each acid with its acid dissociation constant (K_a) below.

3.0×10^{-8} 1.1×10^{-2} 1.0×10^{-1} 1.0×10^{8}

Extension Questions

31. Sometimes the chemical formula of an acid can be misleading. Phosphoric acid (H_3PO_4) is a triprotic acid, but phosphorous acid (H_3PO_3) is a diprotic acid, and hypophosphorous acid (H_3PO_2) is a monoprotic acid.

    a. Draw Lewis dot-diagrams for each of these three acids. All of the structures include a double bonded oxygen. Consider carefully where the hydrogen atoms are positioned so that only the proper number would be acidic.

    b. Explain, using the concepts of molecular structure, why phosphorous acid and hypophosphorous acid are not triprotic acids.

32. Consider the two substances below. One is an acid, and the other is classified as an alcohol.

CH_3COOH	CH_3CH_2OH
Acetic Acid	*Ethanol*

    a. Draw Lewis dot-diagrams for each substance.

    b. Use the Internet to find the acid dissociation constant (K_a) for these two substances.

    c. Explain why one is much more acidic than the other in terms of molecular structure.