Recitation Worksheet 10: Acid and Bases (14.7 – 14.9/Structure and Properties of Organic Acids)

Name: key MyID:

Instructions:

1. Please enter your first and last name as it appears on the eLC classlist (do not use a nickname).
2. Your UGA myID is a combination of letters and numbers (example: Dr. Abdelrahman MyID is ema88805). **Do not use your 81x number.**
   a. If you do not have access to a printer, type your answers in the worksheet PDF and then upload it to **Gradescope** by Friday, April 7th at 11:59 pm. Write your work on separate sheets of paper, convert to a PDF and upload to the "Recitation Worksheet 10 Dropbox" on eLC.
   b. If you are using an app to annotate the worksheet, make sure the pages are in the correct order and have the same layout as the original or Gradescope will not be able to read it.
   c. If you have access to a printer, print out the worksheet, write your answer in the answer boxes, and show your work on it when appropriate. Then convert it to a PDF and upload to **Gradescope** by Friday, April 7th at 11:59 pm. You do not need to upload anything to eLC. The pages must be in the correct order and have the same layout as the original, or Gradescope will not be able to read it.
   d. There is a **Gradescope App** available for both iOS and Android devices that allows you to scan and submit your printed work or you can submit your fillable PDF directly. Detailed instructions on how to access and use the app can be found on your CHEM 1212 class eLC page under content ⟶ Welcome module ⟶ Gradescope ⟶ Gradescope new mobile app.
3. Answers must be written in the corresponding answer box, or no credit will be awarded.
4. The instructions for uploading worksheets to Gradescope can be found in the Content area of eLC in the Welcome Module.

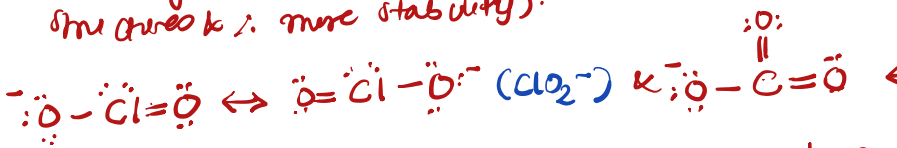
1. Which of the pairs below has the **stronger acid** listed **first**? Select all that apply. Insert letters without spaces in the answer box, example **ABCD.**

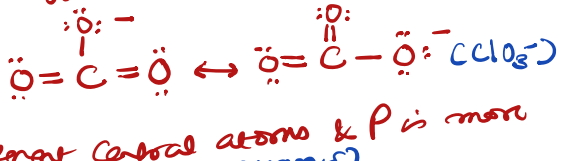
BDE

A. $HClO_2$ and $HClO_3$
B. H_3PO_4 and H_2SiO_3
C. $I_3CCH_2CH_2COOH$ and $CH_3CH_2CCl_2COOH$
D. $H_2PO_4^-$ and HPO_4^{2-}
E. CF_3COOH and CH_3COOH

(A) Both $HClO_2$ & $HClO_3$ are oxyacids. the strength of oxyacids depends on the electronegativity of the central atom & the no. of oxygens. Both acids have Cl as the central atom ∴ the acid with more oxygens is the stronger acid ($HClO_3$)

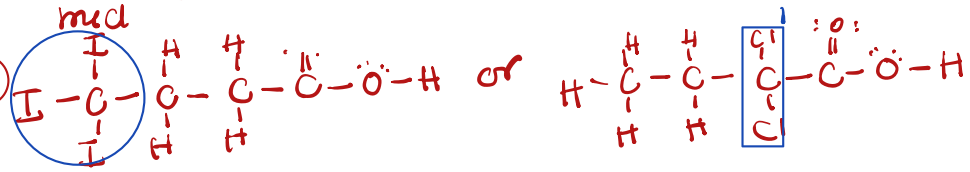
(A) the greater no. of oxygens results in a more stable oxyanion (more oxygen provides more resonance structures & ∴ more stability).





(B) Comparing H_3PO_4 & H_2SiO_3 both acids have different central atoms & P is more electronegative than Si ∴ H_3PO_4 is the stronger acid (also has more oxygens).

(C) mcd



$CH_3CH_2CCl_2COOH$ → Inductive electron withdrawing is the stronger acid as Cl is more EN than I & it is closer to the carboxyl group

(D) the higher the negative charge the more difficult it is more difficult to lose a proton $H_2PO_4^- > HPO_4^{2-}$

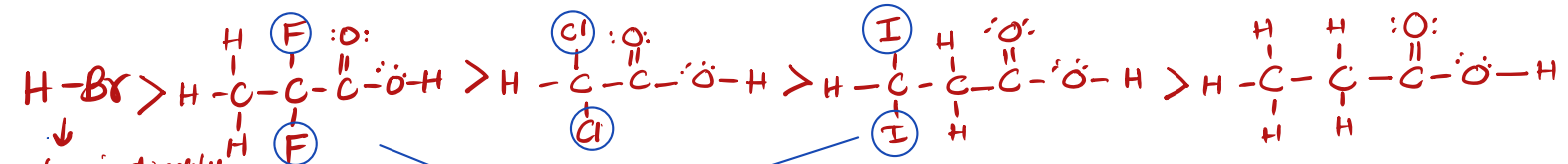
(E) Inductive electron withdrawal makes CCl_3COOH the stronger acid

2. Which of the choices represents the correct order of the acids below in order of **strongest to weakest**?

$HBr, CHCl_2COOH, CH_3CH_2COOH, CH_3F_2CCOOH, I_2CHCH_2COOH$

C

A. $HBr > CHCl_2COOH > CH_3F_2CCOOH > I_2CHCH_2COOH > CH_3CH_2COOH$
B. $CH_3CH_2COOH > I_2CHCH_2COOH > CH_3F_2CCOOH > CHCl_2COOH > HBr$
(C.) $HBr > CH_3F_2CCOOH > CHCl_2COOH > I_2CHCH_2COOH > CH_3CH_2COOH$
D. $HBr > I_2CHCH_2COOH > CH_3F_2CCOOH > CHCl_2COOH > CH_3CH_2COOH$
E. $CHCl_2COOH > CH_3F_2CCOOH > I_2CHCH_2COOH > CH_3CH_2COOH > HBr$



proton is directly attached an electronegative atom ∴ this is the strongest acid

All these molecules have one or more electronegative atom. the strength of the acid depends on the proximity of the electronegative group to the ionizable group (Carboxyl group) & the electronegativity of the atom (F > Cl > I in term of electronegativity).

basic solution

3. You were asked to prepare an aqueous solution of pH ~ 8.5 and you are provided with a list of salts below. Which of these salts would you use? (K_{a1} H_3PO_4 = 7.08 x 10^{-3}, K_{a2} $H_2PO_4^-$ = 6.31 x 10^{-8}, K_{a3} HPO_4^- = 4.47 x 10^{-13}).

A

(A.) KNO_2
B. NH_4Cl
C. $NaNO_3$
D. KH_2PO_4
E. CH_3NH_3Cl
F. $FeCl_3$

same as B

↓ hydrated small cations of highly charged metal ions yield an acidic solution

(A) KNO_2 → the cation is the conjugate acid of strong base (KOH) & the anion the conjugate base of a weak acid (HNO_2)

$NO_2^-(aq) + H_2O(l) \rightleftharpoons HNO_2(aq) + OH^-(aq)$

↓ would give a basic solution

(B) NH_4Cl → the cation is the conjugate acid of a weak base (NH_4OH) & the anion is the conjugate base of a strong acid (HCl)

$NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$

↓ gives an acidic solution

(C) $NaNO_3$ → the cation is a conjugate acid of a strong base (NaOH) & the anion is the conjugate base of a strong acid (HNO_3) ⇒ gives a neutral solution with a neutral pH

(D) KH_2PO_4 → the cation is the conjugate acid of a strong base (KOH) & the anion is $H_2PO_4^-$ is amphiprotic (can act as an acid and as a base ∴ compare ka to kb to find if it would produce an acid or a base

As an acid: $H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$

$ka = 6.31 \times 10^{-8}$

As a base: $H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons H_3PO_4(aq) + OH^-(aq)$

$kw = ka \times kb$

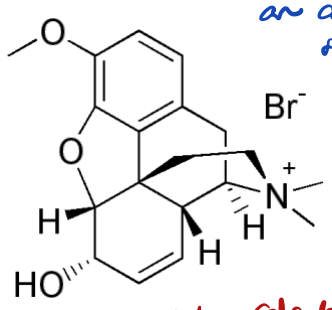
$\therefore kb = \frac{kw}{ka} = \frac{1.0 \times 10^{-14}}{7.08 \times 10^{-8}} = 1.41 \times 10^{-12}$

$Ka > kb$ ∴ gives an acidic solution

the cation is a conjugate acid of a weak base & the anion is a conjugate base of a strong acid

4. The salt of codeine, codeine bromide ($C_{18}H_{21}O_3NH^+Br^-$) has analgesic and antitussive properties. Calculate the pH of a 0.324 M codeine bromide solution. pK_b of $C_{18}H_{21}O_3N$ is 7.95. Keep your answer to 3 decimal places.

should yield an acidic solution



3.270

① $C_{18}H_{21}O_3NH^+(aq) + H_2O(l) \rightleftharpoons C_{18}H_{21}O_3N(aq) + H_3O^+(aq)$

I	0.324	–	0	0
C	$-x$	–	$+x$	$+x$
E	$0.324-x$	–	x	x

∴ you need to calculate

② Since codeine bromide yields an acidic solution

pKa & then Ka

$pK_a + pK_b = 14.00$

$\therefore pK_a = 14.00 - 7.95 = 6.05$

$-\log K_a = 6.05$

$\therefore K_a = 10^{-6.05} = 8.91 \times 10^{-7}$

$K_a = \frac{[C_{18}H_{21}O_3N][H_3O^+]}{[C_{18}H_{21}O_3NH^+]}$

$8.91 \times 10^{-7} = \frac{[x][x]}{[0.324 - x]}$ $\frac{C}{K} >> 100$

$\therefore x = \sqrt{8.91 \times 10^{-7} \times 0.324}$

$= 5.3736 \times 10^{-4}$

$[H_3O^+] = 5.37 \times 10^{-4}$ M (3 sig figs)

$\therefore pH = -\log[5.37 \times 10^{-4}] = 3.2697 \sim 3.270$ (3 decimal places)

5. Which of the following ionic compounds when dissolved in water produce a solution with the **highest** pH?

E

A. $CaBr_2$ neutral salt
B. NH_4I acidic salt
C. N_2H_5Cl acid salt
D. $Sr(NO_3)_2$ neutral salt
E. $C_6H_5CH_2COONa$

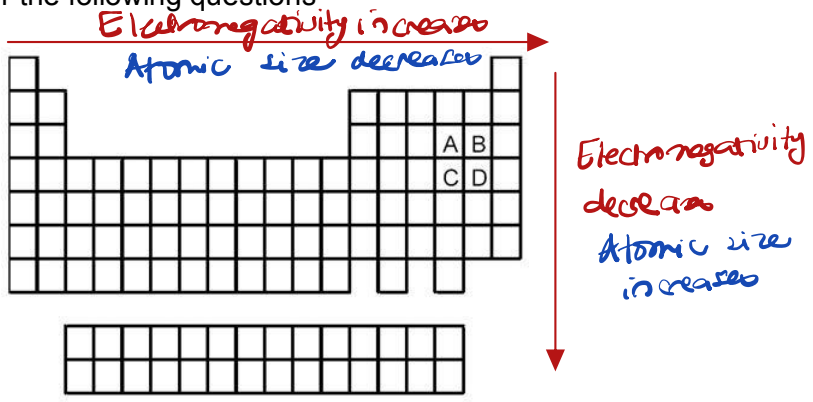
highest pH → Basic pH

the cation is the conjugate acid of a strong base ($NaOH$) & the anion is the conjugate base of a weak acid

$C_6H_5CH_2COONa$

$C_6H_5CH_2COO^-(aq) + H_2O(l) \rightleftharpoons C_6H_5CH_2COOH(aq) + OH^-(aq)$

6. Use the picture below to answer the following questions



A. Of the elements indicated on the periodic table shown above, which forms the strongest binary acid, H_2X or HX, where X = A, B, C, or D?

D

- B > A & C > D in term of Electronegativity
- comparing B & D, D > B in term of size.
- For binary acids: if atoms are in the same row ∴ electronegativity is more important & if atoms are in the same column ∴ size more important

B. Of the elements indicated on the periodic table shown above, which forms the weakest binary acid, H_2X or HX, where X = A, B, C, or D?

A

Smallest atomic size (A < B & C < D in electronegativity
∴ between A & C, A is the smaller size ∴ weakest binary acid).

C. Of the elements indicated on the periodic table shown above, which forms the strongest oxoacid acid with the formula H_2XO_3 or HXO_3, where X = A, B, C, or D?

B

When comparing oxyacids with the same number of oxygens we consider the electronegativity of the central atom
the ↑ EN ↑ strength of the acid

D. Of the elements indicated on the periodic table shown above, which forms the weakest oxoacid acid with the formula H_2XO_3 or HXO_3, where X = A, B, C, or D?

C

7. Which of the following will be the strongest acid?

C

A. CH_3CH_2OH
B. $CH_3CH_2NH_2$
C. CH_3CH_2SH
D. $CH_3CH_2CH_3$
E. All the above acids have the same strength

} these organic acids are treated the same ways as Binary acids.

the difference between all molecules are the atoms highlighted

the ↑ EN ↑ acid strength

C < N < O

Between sulfur & oxygen sulfur has a larger size than oxygen ∴ would provide a more stable conjugate base

8. You are given the two sets of acids and each set consists of two acids:
Set I: a) HIO_3 and b) $HClO_2$ **Set II:** a) H_3PO_4 and b) H_3AsO_4,

Use the two sets of acids to answer the question below:

Which of the acids is the **weaker acid** in each set?

Set I $HClO_2$

Both acids are oxyacids & although I is less electronegative compared to Cl but the presence of oxygen creates a more stable oxyanion in HIO_3 ∴ it is the stronger acid & $HClO_2$ is the weaker acid.

Set II H_3AsO_4

Phosphorous is more electronegative than Arsenic (both oxyacids have the same number of oxygen) ∴ H_3AsO_4 is the weaker acid.

→ strong acid ∴ H_3O^+ is directly related to the concentration of acid

9. Calculate the pH of a sulfuric acid (H_2SO_4, K_a HSO_4^- = 1.2 x 10^{-2}) solution that has a concentration of:
A. 5.00 M (Keep your answer to 3 decimal places).

-0.699

Except dilute solutions of H_2SO_4 < 1.0 M

$$H_2SO_4\,(aq) + H_2O\,(l) \rightarrow H_3O^+\,(aq) + HSO_4^-\,(aq)$$

5.00 M 5.00 M

∴ $pH = -\log[H_3O^+] = -\log[5.00]$

$= -0.6987$

~ -0.699

↳ 3 decimal places

B. 0.075 M (Keep your answer to 2 decimal places).

→ dilute H_2SO_4 solution (< 1.0 M) ∴ 2nd step must be considered in your calculations

1.07

$$H_2SO_4\,(aq) + H_2O\,(l) \rightarrow H_3O^+\,(aq) + HSO_4^-\,(aq) \quad \text{Strong}$$

$$HSO_4^-\,(aq) + H_2O\,(l) \rightleftharpoons H_3O^+\,(aq) + SO_4^{2-}\,(aq) \quad K_{a_2} = 0.012$$

From the first step:

→ H_2SO_4 is a strong acid in the first step

$$H_2SO_4\,(aq) + H_2O\,(l) \rightarrow H_3O^+\,(aq) + HSO_4^-\,(aq)$$

0.075M – 0.075M 0.075M

From the second step:

→ 2nd step is at equilibrium

$$HSO_4^-\,(aq) + H_2O\,(l) \rightleftharpoons H_3O^+\,(aq) + SO_4^{2-}\,(aq) \quad K_{a_2} = 0.012$$

I	0.075	–	0.075	0
C	$-x$	–	$+x$	$+x$
E	$0.075-x$	–	$0.075+x$	x

$$K_a = \frac{[H_3O^+][SO_4^{2-}]}{[HSO_4^-]}$$

$$0.012 = \frac{[0.075+x][x]}{[0.075-x]}$$

$$0.012[0.075-x] = [0.075+x]x$$

$$9.0\times10^{-4} - 1.2\times10^{-2}x = 7.5\times10^{-2}x + x^2$$

$$x^2 + 8.7\times10^{-2} - 9.0\times10^{-4} = 0$$

$x = 0.009841744\,8$ or $x = -0.096841744$ (negative dropped)

∴ total $[H_3O^+] = 0.075 + 0.009841744\,8 = 0.084\,13417448$

$pH = -\log[0.084\,13417448] = 1.07$

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when calculating the $[H_3O^+]$ & pH of polyprotic acids the first step is the only step considered in the calculations

10. What is the $[H_3O^+]$, $[SO_3^{2-}]$, and pH of 0.054 M H_2SO_3? ($K_{a1} = 1.54 \times 10^{-2}$, $K_{a2} = 1.02 \times 10^{-7}$)

A. $[H_3O^+]$ (Keep your answer to 2 significant figures).

0.022 or 2.2×10^{-2}

$x = [H_3O^+] = 0.022$

$$H_2SO_3\,(aq) \rightleftharpoons H^+\,(aq) + HSO_3^-\,(aq)$$

→ only step considered

$$HSO_3^-\,(aq) \rightleftharpoons H^+\,(aq) + SO_3^{2-}\,(aq)$$

$$H_2SO_3\,(aq) \rightleftharpoons H^+\,(aq) + HSO_3^-\,(aq)$$

I	0.054	0	0
C	$-x$	$+x$	$+x$
E	$0.054-x$	x	x

$$K_a = \frac{[H^+][HSO_3^-]}{[H_2SO_3]}$$

$$0.0154 = \frac{[x][x]}{[0.054-x]}$$

→ using the "100" rule $\frac{C}{K} < 100$ ∴ x cannot be dropped

B. $[SO_3^{2-}]$ (Keep your answer to 3 significant figures).

1.02×10^{-7}

$[SO_3^{2-}] = K_{a2} = 1.02\times10^{-7}$

$0.0154(0.054-x) = x^2$

$8.316\times10^{-4} - 1.54\times10^{-2}x = x^2$

$x^2 + 1.54\times10^{-2}x - 8.316\times10^{-4} = 0$

$x = 0.022147780\,49$ or $x = -0.037647780$

C. pH (Keep your answer to 2 decimal places).

1.65

$pH = -\log[H_3O^+]$

$= -\log[0.022147780\,49]$

$= 1.65$

11. Using the table below for the relative acid strength, arrange the following species in order of **decreasing** relative **base strength**: ClO_2^-, Br^-, H_2O, OCl^-, $C_6H_5O^-$

A

A strong acid will produce a weak conjugate base & a weak acid will produce a strong conjugate base

↳ comes from HBr which is a strong acid

acid strength can be quantified using Ka

Formula	Name	Value of K_a*
HSO_4^-	Hydrogen sulfate ion	1.2×10^{-2}
$HClO_2$	Chlorous acid	1.2×10^{-2}
$HC_2H_2ClO_2$	Monochloracetic acid	1.35×10^{-3}
HF	Hydrofluoric acid	7.2×10^{-4}
HNO_2	Nitrous acid	4.0×10^{-4}
$HC_2H_3O_2$	Acetic acid	1.8×10^{-5}
$[Al(H_2O)_6]^{3+}$	Hydrated aluminum(III) ion	1.4×10^{-5}
HOCl	Hypochlorous acid	3.5×10^{-8}
HCN	Hydrocyanic acid	6.2×10^{-10}
NH_4^+	Ammonium ion	5.6×10^{-10}
HOC_6H_5	Phenol	1.6×10^{-10}

Increasing acid strength

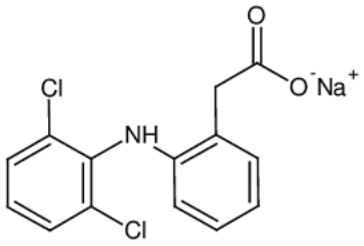
*water is a stronger base than the conjugate base of a strong acid b/c it is a weaker base than the conjugate base of a weak acid

A. $C_6H_5O^- > OCl^- > ClO_2^- > H_2O > Br^-$
B. $Br^- > H_2O > ClO_2^- > OCl^- > C_6H_5O^-$
C. $ClO_2^- > OCl^- > Br^- > H_2O > C_6H_5O^-$
D. $OCl^- > Br^- > ClO_2^- > C_6H_5O^- > H_2O$
E. $H_2O > OCl^- > Br^- > > C_6H_5O^- > ClO_2^-$

12. Diclofenac sodium is the active ingredient in Voltaren®, is a non-steroidal anti-inflammatory drug used in a gel form for arthritis pain relief. Calculate the pH of 0.435 M diclofenac sodium ($C_{14}H_{11}Cl_2NO_2^-Na^+$) solution. pK_a of $C_{14}H_{11}Cl_2NO_2H$ is 4.15. Keep your answer to 3 decimal places.

8.894

$(C_{14}H_{11}Cl_2NO_2^-Na^+)$
Diclofenac sodium is a salt the cation is the conjugate acid of a strong base (NaOH) & the anion is the conjugate base of a weak acid



① $C_{14}H_{11}Cl_2NO_2^-(aq) + H_2O(l) \rightleftharpoons C_{14}H_{11}Cl_2NO_2H(aq) + OH^-$

	$C_{14}H_{11}Cl_2NO_2^-$	H_2O	$C_{14}H_{11}Cl_2NO_2H$	OH^-
I	0.435	–	0	0
C	$-x$	–	$+x$	$+x$
E	$0.435-x$	–	x	x

Since this is a base ∴ we need to find pK_b

$pK_a + pK_b = 14.00$

$pK_b = 14.00 - 4.15 = 9.85$

$K_b = 10^{-pK_b} = 10^{-9.85} = 1.4 \times 10^{-10}$

② $K_b = \dfrac{[C_{14}H_{11}Cl_2NO_2H][OH^-]}{[C_{14}H_{11}Cl_2NO_2^-]}$

$1.4 \times 10^{-10} = \dfrac{[x][x]}{[0.435-x]}$ $\frac{c}{K} \gg 100$

$\sqrt{x^2} = \sqrt{1.4 \times 10^{-10}(0.435)}$

$\therefore x = 7.84 \times 10^{-6}\ M = [OH^-]$

③ $K_w = [OH^-][H_3O^+]$

$1.0 \times 10^{-14} = [7.84 \times 10^{-6}][H_3O^+]$

$[H_3O^+] = 1.28 \times 10^{-9}$

$pH = -\log[1.28 \times 10^{-9}]$

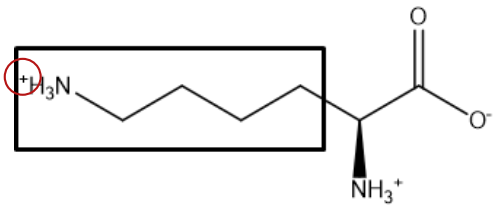
$= 8.894$ ↓ 3 decimal places

13. Which amino acid would have the **lowest pK_a** for its side chain, which is emphasized by the black box? (Only compare the part of the molecule in the black box).

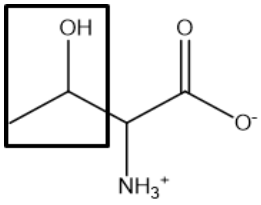
E

↓ pka most acidic

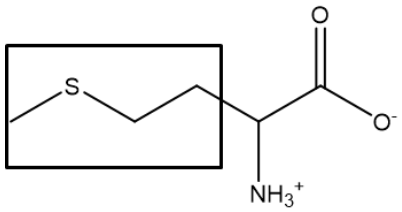
A.



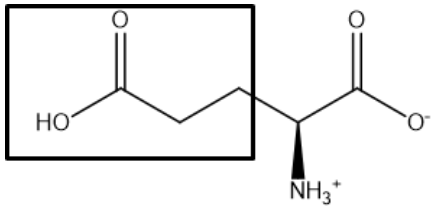
C.



B.

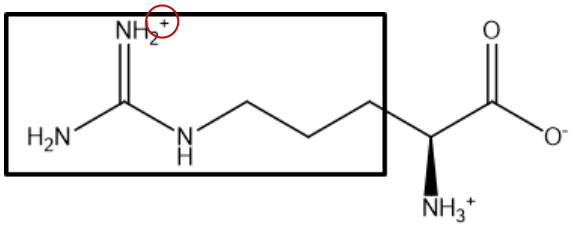


D.



* Choices A & E both have a positive charge ∴ both are stronger acids than choices B, C, and D

E.



* Between choices A & E choice E the conjugate base is more stable because of resonance. Also E has more nitrogens than A ∴ more electronegative & therefore more acidic

14. Rank the following species from **strongest to weakest base**. Select an answer choice from A-E.

CH_3NH_2, CH_3NH^-, CH_3OH, CH_3O^-, CH_3COO^-

A

A. $CH_3NH^- > CH_3O^- > CH_3COO^- > CH_3NH_2 > CH_3OH$
B. $CH_3OH > CH_3COO^- > CH_3NH_2 > CH_3O^- > CH_3NH^-$
C. $CH_3NH^- > CH_3O^- > CH_3NH_2 > CH_3COO^- > CH_3OH$
D. $CH_3O^- > CH_3NH^- > CH_3COO^- > CH_3NH_2 > CH_3OH$
E. $CH_3NH_2 > CH_3NH^- > CH_3O^- > CH_3OH > CH_3COO^-$

* A strong base will have a high affinity to protons ∴ a negatively charged molecule will be a strong base

* Electronegativity of the atom accepting the proton is important. the lower the electronegativity the stronger the base