Recitation Worksheet Eleven

Name: key

MyID:

Textbook:

Chemistry & Chemical Reactivity
by John C. Kotz, Paul M. Treichel, John R. Townsend, David Treichel
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Instructions:

- This recitation worksheet covers Ch. 16.4, 16.8-16.9
- Please enter your first and last name as it appears on the eLC roster (do not use a nickname that is not reflected in eLC).
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  - You may use an app to annotate the worksheet by placing your answers in the answer boxes and showing your work when appropriate. Afterward, submit the worksheet to Gradescope. You will not need to upload anything to eLC.
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  - If you do not have access to a printer, you may type your answers directly into the worksheet PDF and then submit it to Gradescope. Write your work on separate sheets of paper, convert them to a PDF, and upload to the appropriate dropbox on eLC.
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- The following criteria **must** be met to be eligible for full credit:
  - You must make sure the pages are in the correct order and have the same layout as the original worksheet when submitting to Gradescope regardless of your submission type.
  - Answers must be written in the corresponding answer boxes.
  - You must show your work when appropriate.
- This worksheet is due no later than **12:00 PM (noon) on the Saturday, November 9th.**
- A periodic table and formula sheet are attached to the end of this worksheet. Please keep these attached to your worksheet in the correct order when submitting to Gradescope.

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.**

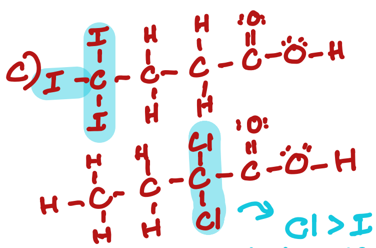
BDE

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 with the same central atom but different number of oxygens. The greater number of oxygens increases the inductive effect (makes the O–H bond more polarizable) & contributes to the stability of the oxyanion ∴ $HClO_3$ is the stronger acid → Also more oxygens would result in more resonance structures ∴ more stable oxyanion & a stronger acid

B) Both H_3PO_4 & H_2SiO_3 are oxyacids but the difference between the two acids is the number of oxygens & the central atoms. H_3PO_4 has more oxygen atoms compared to H_2SiO_3. Phosphorous is more electronegative compared to Si ∴ H_3PO_4 is the stronger acid

C)

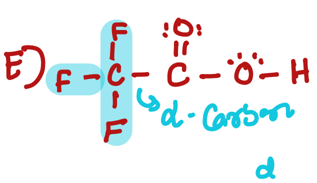


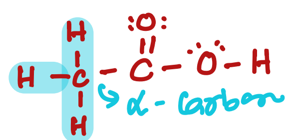
Both are organic acids with electronegative atoms on the molecule

→ Cl > I in term of electronegativity & closer to the Carbonyl group ∴ stronger inductive effect & stronger acid

D) Both are negatively charged species. The higher the negative charge the more basic the molecule becomes ∴ $H_2PO_4^- > HPO_4^{2-}$

E)





Acetic acid

→ The two molecules are very similar but in the first molecule, the hydrogens on the α-carbon are replaced by fluorines which are highly electronegative ∴ enhances the inductive effect on the molecule ∴ CF_3COOH is the stronger acid

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

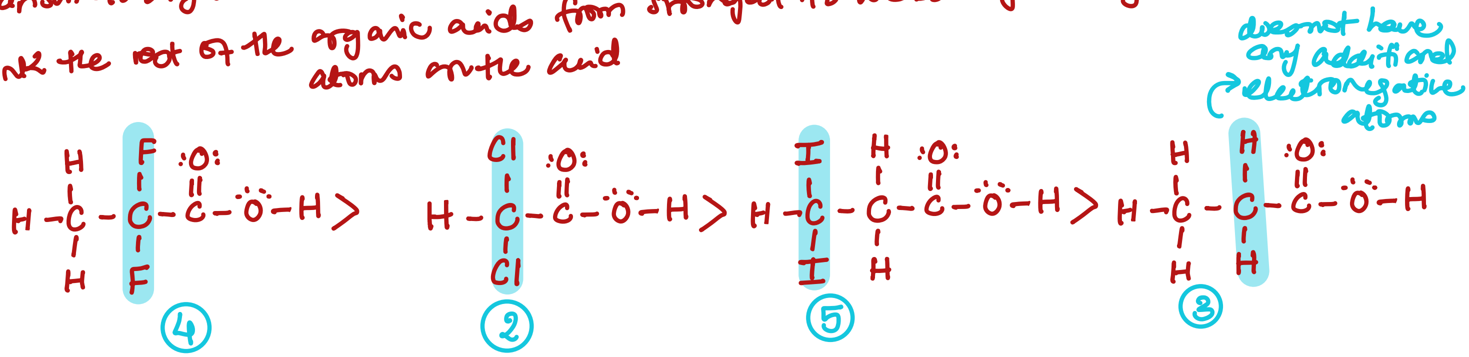
① HBr, ② $CHCl_2COOH$, ③ CH_3CH_2COOH, ④ CH_3F_2CCOOH, ⑤ I_2CHCH_2COOH

Answer: 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

① HBr is an organic acid & the rest of the acids are organic acids which are weaker in comparison to organic acids

② Rank the rest of the organic acids from strongest to weakest by looking at the electronegative atoms on the acid



Basic solution (weak base)

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^{2-} = 4.47 x 10^{-13}

A

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

Strategy: choose the salt that will hydrolyze in water to give a weak base solution (Basic salt)

(A) $KNO_2(aq) \rightarrow K^+(aq) + NO_2^-(aq)$

K^+: comes from KOH (strong base); pH-neutral (spectator ion). NO_2^-: conjugate base of HNO_2 which is a weak acid

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

(B) $NH_4Cl(aq) \rightarrow NH_4^+(aq) + Cl^-(aq)$

NH_4^+: conjugate acid of NH_3 which is a weak base $\therefore$ reacts with water. Cl^-: pH-neutral (spectator ion)

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

(C) $NaNO_3(aq) \rightarrow Na^+(aq) + NO_3^-(aq)$ → conjugate base of HNO_3 (strong acid) $\therefore$ pH-neutral. Neutral salt

Na^+: comes from NaOH (strong base) $\therefore$ pH-neutral (spectator ion)

(D) $KH_2PO_4 \rightarrow K^+(aq) + H_2PO_4^-(aq)$

K^+: comes from KOH (strong base) $\therefore$ spectator ion. $H_2PO_4^-$: conjugate base of H_3PO_4 (polyprotic acid) $\therefore$ amphoteric species

to determine the pH of a solution of an amphoteric salt you can use one of two methods:

Method 1: React $H_2PO_4^-$ as an acid & determine K_b then react it as a base & determine K_b the compare K_a & K_b. If $K_a > K_b$ $\therefore$ acidic if $K_b > K_a$ $\therefore$ basic

As an acid:

$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(l)$ $K_{a2} = 6.31 \times 10^{-8}$

As a base:

$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons H_3PO_4(aq) + OH^-(l)$ $K_b = \frac{1.0 \times 10^{-14}}{7.08 \times 10^{-3}} = 1.41 \times 10^{-12}$ (↳ K_{a1})

$K_a > K_b$ $\therefore$ will produce an acidic solution

Method 2:

Simply compare Ka1 & Ka2 in the question if Ka1 > Ka2 ∴ the amphoteric salt will yield an acidic solution.

(E) $CH_3NH_3Cl(aq) \rightarrow CH_3NH_3^+(aq) + Cl^-(aq)$

$CH_3NH_3^+$ → Conjugate acid of CH_3NH_2 (weak base)

Cl^- → Conjugate base of HCl (strong acid) → pH-neutral (spectator ion)

Acidic solution

(F) $FeCl_3(aq) \rightarrow Fe^{3+}(aq) + Cl^-(aq)$

Fe^{3+} → small highly charged metal cation

Cl^- → pH-neutral (spectator ion)

Acidic solution

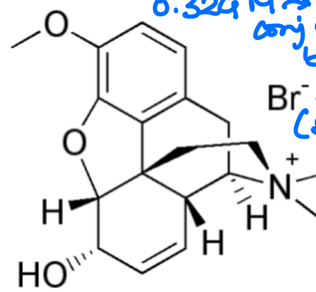
4. The salt of codeine, codeine bromide ($C_{18}H_{21}O_3NH^+Br^-$) has analgesic and antitussive properties. Calculate the pH of a 0.324 M codeine bromide solution. pK_b of $C_{18}H_{21}O_3N$ is 7.95.

3.270

① $C_{18}H_{21}O_3NH^+Br^-(aq) \rightarrow C_{18}H_{21}O_3NH^+(aq) + Br^-(aq)$

0.324 M → 0.324 M → conjugate acid of $C_{18}H_{21}O_3NH$ ∴ reactive

Br^-: 0.324 M → conjugate base of HBr (strong acid) ∴ pH-neutral



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

Initial	0.324	–	0	0
Change	– x	–	+x	+x
Equilibrium	0.324 – x	–	x	x

② ∴ $K_a = \frac{[C_{18}H_{21}O_3N][H_3O^+]}{[C_{18}H_{21}O_3NH^+]}$

→ Calculate Ka from pKb

$pKa + pKb = 14.00$

∴ $pKa = 14.00 - 7.95 = 6.05$

∴ $Ka = 10^{-6.05} = 8.912509381 \times 10^{-7}$

③ $8.9 \times 10^{-7} = \frac{[x][x]}{[0.324 - x]}$ C/K >> 100 ∴ x is dropped

∴ $x^2 = 8.9 \times 10^{-7} [0.324]$ → take the square root of both sides

∴ $x = \pm 5.3736887 \times 10^{-4}$

∴ $[H_3O^+] = 5.37 \times 10^{-4}$ M

④ ∴ $pH = -\log[5.37 \times 10^{-4}]$
$= 3.270$

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

E

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

(A) $CaBr_2(aq) \rightarrow Ca^{2+}(aq) + 2Br^-$ Neutral salt

Ca^{2+}: source is $Ca(OH)_2$ (strong base) → pH-neutral; Br^-: conjugate base of HBr (strong acid) → pH-neutral

(B) $NH_4I(aq) \rightarrow NH_4^+(aq) + I^-(aq)$ Acidic salt

NH_4^+: conjugate acid of NH_3 (weak base) → reactive; I^-: conjugate base of HI (strong acid) ∴ pH-neutral

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

(C) $N_2H_5Cl(aq) \rightarrow N_2H_5^+(aq) + Cl^-(aq)$ Acidic salt

$N_2H_5^+$: conjugate acid of N_2H_4 (weak base) → reactive; Cl^-: conjugate base of HCl (strong acid) → pH-neutral

(D) $Sr(NO_3)_2(aq) \rightarrow Sr^{2+}(aq) + 2NO_3^-(aq)$ Neutral salt

Sr^{2+}: comes from $Sr(OH)_2$ (strong base) ∴ pH-neutral; NO_3^-: conjugate base of HNO_3 (strong acid) ∴ pH neutral

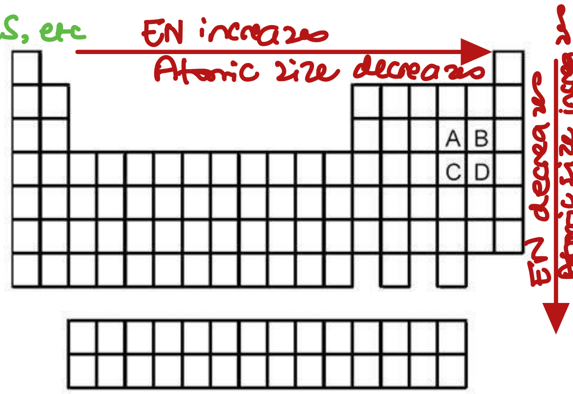
(E) $C_6H_5COONa(aq) \rightarrow C_6H_5COO^-(aq) + Na^+(aq)$ Basic salt

$C_6H_5COO^-$: conjugate base of C_6H_5COOH (weak acid) → reactive; Na^+: comes from NaOH (strong base) ∴ pH-neutral

$C_6H_5COO^-(aq) + H_2O(l) \rightarrow C_6H_5COOH(aq) + OH^-(aq)$

6. Use the picture below to answer the following questions

*For binary acids ex: HCl, HF, H_2S, etc the strength of the binary acid depends on:
1) the polarity of the H–X bond (if in the same period)
2) the size of the X atom (if in the same group)
3) size is more important than polarity



*For oxyacids, ex: H_2SO_4, H_3PO_4, $HClO_4$ the strength of oxyacids depends on:
1) Electronegativity of X, the more electronegative X is, the stronger the acid
2) the number of oxygens: the higher number of oxygens the stronger the acid

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

1) B>A in electronegativity
D>C in electronegativity
∴ Eliminate A & C
2) Between B & D, D has a larger atomic size ∴ HD is the strongest binary acid

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

the reverse of the trend explained above
A<B in electronegativity
C<D in electronegativity
∴ Between A & C, A has a smaller size
∴ HA is the 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

Most electronegative atom:
B>A & D>C
∴ B is the most electronegative atom

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

Least electronegative atom:
A<B
C<D
& C<A in electronegativity

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

organic acids with hydrogen attached to the highlighted atoms are treated like binary acids

1)

	C	N	O
			S

the strongest acid will have it's proton attached to the most electronegative atom ∴ between A, B, D, D is the most electronegative atom

2) S>O in size ∴ between A & C, C is the strongest acid

8. You are given the two sets of acids and each set consists of two acids:

Set I: a) H_2Se and b) H_2Te **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: a

Se < Te in size (binary acid) ∴ H_2Se is the weaker acid

Set II: b

Same no. of oxygens ∴ compare central atom (oxyacid) As < P in electronegativity

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

-0.699

* In solutions of 1.0 M or higher the pH of H_2SO_4 is calculated only from the first step as the H_3O^+ from the first step shifts the equilibrium of the second step according to Le-Chatelier's principle

* ∴ $pH = -\log[5.00] = -0.699$

conc. < 1.0 M ∴ the second ionization step of H_2SO_4 must be included

B. 0.075 M

1.07

1) First step: $H_2SO_4(aq) + H_2O(l) \longrightarrow HSO_4^-(aq) + H_3O^+(aq)$

0.075 M → 0.075 M, 0.075 M

2) Second step: $HSO_4^-(aq) + H_2O(l) \rightleftharpoons SO_4^{2-}(aq) + H_3O^+(aq)$ $K_a = 1.2 \times 10^{-2}$

	HSO_4^-	H_2O	SO_4^{2-}	H_3O^+
I	0.075	–	0	0.075
C	$-x$	–	$+x$	$+x$
E	$0.075-x$	–	x	$0.075+x$

3) $K_a = \frac{[SO_4^{2-}][H_3O^+]}{[HSO_4^-]}$ ∴ $1.2 \times 10^{-2} = \frac{[x][0.075+x]}{[0.075-x]}$

∴ $1.2 \times 10^{-2}[0.075 - x] = 0.075x + x^2$

$9.0 \times 10^{-4} - 1.2 \times 10^{-2}x = 7.5 \times 10^{-2}x + x^2$

∴ $x^2 + 8.7 \times 10^{-2}x - 9.0 \times 10^{-4} = 0$

∴ $x = 0.009341748$ or $x = -0.09634174$

∴ $[H_3O^+] = 0.009341748 + 0.075 = 0.08434178$ ∴ pH $= -\log[0.084] = 1.07$

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. $[H_3O^+]$

0.022 M

the difference between K_{a1} & K_a greater than 10^3 ∴ pH is calculated as any weak acid

1) ∴ $H_2SO_3(aq) + H_2O(l) \rightleftharpoons HSO_3^-(aq) + H_3O^+(l)$

Initial	0.054	–	0	0
Change	$-x$	–	$+x$	$+x$
Equilibrium	$0.054-x$	–	x	x

2) $K_{a1} = \frac{[HSO_3^-][H_3O^+]}{[H_2SO_3]}$

$1.54 \times 10^{-2} = \frac{[x][x]}{[0.054-x]}$

∴ $8.316 \times 10^{-4} - 1.54 \times 10^{-2}x = x^2$

∴ $x^2 + 1.54 \times 10^{-2}x - 8.316 \times 10^{-4} = 0$

∴ $x = 0.022147 78049$

$x = -0.03754 7780$

B. $[SO_3^{2-}]$

1.02×10^{-7} M

$HSO_3^-(aq) + H_2O(l) \rightleftharpoons SO_3^{2-}(aq) + H_3O^+(aq)$ $K_{a2} = 1.02 \times 10^{-7}$

conjugate base in the second step ∴ $[SO_3^{2-}] = K_{a2} = 1.02 \times 10^{-7}$

C. pH

1.65

3) pH $= -\log[0.022] = 1.65$

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^-, $C_6H_5O^-$

↳ comes from HBr which is a strong acid

A

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

→ 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 & 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.

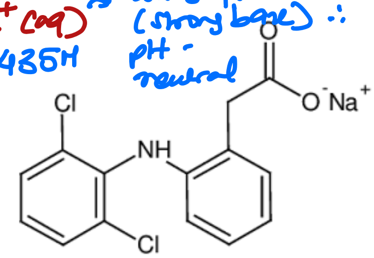
8.894

1) $C_{14}H_{11}Cl_2NO_2^-Na^+(aq) \rightarrow C_{14}H_{11}Cl_2NO_2^-(aq) + Na^+(aq)$ (salt)

0.435M → 0.435 M + 0.435M

Na^+ comes from NaOH (strong base) ∴ pH - neutral

$C_{14}H_{11}Cl_2NO_2^-$: conjugate base of $C_{14}H_{11}Cl_2NO_2H$ (weak acid ∴ reactive)



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

Initial	0.435	–	0	0
Change	−x	–	+x	+x
Equilibrium	0.435−x	–	x	x

3) $K_b = \frac{[C_{14}H_{11}Cl_2NO_2H][OH^-]}{[C_{14}H_{11}Cl_2NO_2^-]}$

↳ calculated from pKa

$pKa + pKb = 14.00$

∴ $pKb = 14.00 - 4.15 = 9.85$

∴ $Kb = 10^{-9.85} = 1.41253754 \times 10^{-10}$

4) $1.4 \times 10^{-10} = \frac{[x][x]}{[0.435 - x]}$ $\frac{C}{K} >> 100$

∴ $x^2 = 6.14453832 \times 10^{-11}$

∴ $x = 7.838710557 \times 10^{-6}$

∴ $[OH^-] = 7.84 \times 10^{-6}$ M 3 sig figs

∴ $pOH = -\log[7.84 \times 10^{-6}] = 5.106$ 3 decimal places

∴ $pH = 14.00 - 5.106 = 8.894$ 3 decimal places

13. 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. $CH_3NH_2 > CH_3NH^- > CH_3O^- > CH_3OH > CH_3COO^-$

* Note: you can also think from the point view of an acid

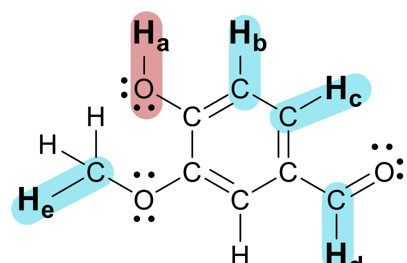
* A strong base will have a high affinity to protons ∴ a negatively charged molecule will be a strong base

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

* N<O in terms of electronegativity ∴ cannot stabilize the negative charge & CH_3NH^- is a stronger base compared to CH_3O^-. $CH_3-\overset{O}{\overset{\|}{C}}-O$ is a weaker base because of resonance stabilization. CH_3NH_2 is less electronegative than O ∴ stronger base than CH_3OH

14. The primary chemical responsible for the flavor associated with vanilla is vanillin.

A



vanillin

Which of the labeled hydrogens would be the most likely to generate H^+ in solution?

A. H_a
B. H_b
C. H_c
D. H_d
E. H_e

o For a hydrogen to be acidic the bond between the hydrogen and the element it's attached to MUST be polar

o Note that Hb, Hc, Hd, He are attached to a Carbon ∴ they are non-acidic due to C–H bonds being non-polar

o the difference in electronegativity between O & H is large ∴ it's non-polar

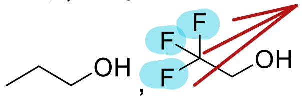
15. Which pair of acids lists the **stronger** acid first? Select all that apply.

ACF

A. H_2CO_3, HCO_3^- — neutral molecule is more acidic than a negatively charged molecule

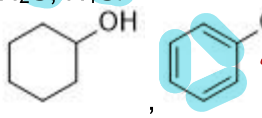
B. HOCl, $HClO_2$ (oxyacids) same central atom ∴ stronger acid has oxygens ($HClO_2$ is a stronger acid)

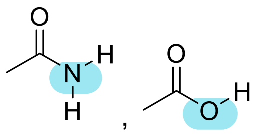
C. NH_4^+, NH_3

D.  — Inductive effect ∴ it is the stronger acid

E. HBr, HI

F. H_2S, H_4Si — S > Si in electronegativity (binary acids) → H_2S is the stronger acid

G.  ~ conjugated system will display resonance

H.  O–H bond is more polar than N–H

C) positively charged molecule is more acidic than a neutral molecule

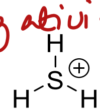
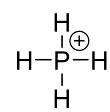
E) HBr & HI are binary acids (I > Br in size ∴ HI is the stronger acid)

16. Which statement most accurately explains what would be observed about the acidic nature of these compounds?

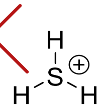
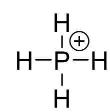
C

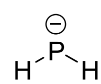
Both will be treated as binary acids (hydrogen is directly attached to one element).

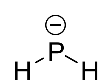
S > P in electronegativity ∴ is able to negative charge on the oxyanion better

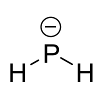
A. A solution of H_2S would be more acidic because  is more stable than 

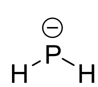
incorrect because an acid loses a proton

B. A solution of PH_3 would be more acidic because  is more stable than 

C. A solution of H_2S would be more acidic because H–S ⊖ is more stable than 

D. A solution of PH_3 would be more acidic because H–S ⊖ is more stable than 

E. A solution of H_2S would be more acidic because  is more stable than H–S ⊖

F. A solution of PH_3 would be more acidic because  is more stable than H–S ⊖

H–S⊖ will be more stable than H–P⊖–H

17. For each of these, define the resulting aqueous solutions as either acidic (A), basic (B) or neutral (N).

A. CH_3CO_2Na (salt)

B

Na^+ comes from NaOH (strong base) ∴ neutral

$CH_3CO_2^-$ is the conjugate base of CH_3COOH (weak acid) ∴ basic

B. $LiNO_2$ (salt)

B

Li^+ is from LiOH (strong base)

NO_2^- is the conjugate base of HNO_2 (nitrous acid is a weak acid) ∴ basic

C. potassium sulfite K_2SO_3 (salt)

B

K^+ is from KOH (strong base) ∴ neutral

SO_3^{2-} is the conjugate base of HSO_3^- (weak acid) ∴ basic

D. ammonium bromide (salt)

A

NH_4Br

NH_4^+ is the conjugate acid of NH_3 ∴ acidic

Br^- is the conjugate base of HBr (strong acid) ∴ neutral

E. potassium chloride (salt)

N

KCl

K^+ comes from KOH (strong base) ∴ neutral

Cl^- comes from HCl (strong acid) ∴ neutral

18. What will be the pH of an aqueous solution made up of 0.514 g potassium cyanide KCN in 125 mL water. K_a HCN = 6.2×10^{-10}.

11.004

KCN: K^+ comes from KOH ∴ neutral; CN^- is the conjugate base of HCN ∴ basic

① Calculate the molarity of KCN:

$$0.514\text{ g KCN} \times \frac{1\text{ mol KCN}}{65.12\text{ g KCN}} = 7.893120393 \times 10^{-3}\text{ mol}$$

$$[KCN] = \frac{7.893120393 \times 10^{-3}\text{ mol}}{0.125\text{ L}} = 6.314496314 \times 10^{-2}\text{ M}$$

② $CN^-(aq) + H_2O(l) \rightleftharpoons HCN(aq) + OH^-(aq)$

	CN^-	H_2O	HCN	OH^-
I	6.31×10^{-2}	–	0	0
C	$-x$	–	$+x$	$+x$
E	$6.31 \times 10^{-2} - x$	–	x	x

③ Since this is a base we need to calculate Kb

$$\therefore K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{6.2 \times 10^{-10}} = 1.6 \times 10^{-5}$$

$$K_b = \frac{[HCN][OH^-]}{[CN^-]}$$

④ $$1.6 \times 10^{-5} = \frac{[x][x]}{6.31 \times 10^{-2} - x}$$ $\frac{C}{K} \gg 100$

$$\therefore x^2 = 1.018467148 \times 10^{-6}$$

$$\therefore x = \pm 1.009191334 \times 10^{-3}$$

↳ disregard the negative value

$$\therefore [OH^-] = x = 1.009191334 \times 10^{-3}$$

$$\therefore pOH = -\log [OH^-] = 2.996026487$$

$$\therefore pH = 14.00 - 2.996026487$$

$$= 11.00397851$$

$$\approx 11.004$$

19. Each of these pairs contains one strong acid and one weak acid EXCEPT:

D

A. H_2SO_4 and H_2CO_3
B. HNO_3 and $HClO_2$
C. HBr and H_3PO_3
D. $H_2PO_3^{2-}$ and HCN
E. HCl and H_2Se

A) H_2SO_4 (strong), H_2CO_3 (weak)
B) HNO_3 (strong), $HClO_2$ (weak)
C) HBr (strong), H_3PO_3 (weak)
D) $H_2PO_3^{2-}$ (weak), HCN (weak)
E) HCl (strong), H_2Se (weak)

20. Which of the choices represent the substances below arranged in the correct order of increasing pH? All solutions have the same concentration of 0.10 M.

↳ from lowest to highest pH

HI, $NaNO_2$, NaOH, NH_4ClO_4, $LiNO_3$

B

A. NaOH < $NaNO_2$ < NH_4ClO_4 < HI < $LiNO_3$
B. HI < NH_4ClO_4 < $LiNO_3$ < $NaNO_2$ < NaOH
C. NH_4ClO_4 < HI < $NaNO_2$ < $LiNO_3$ < NaOH
D. $NaNO_2$ < NH_4ClO_4 < $LiNO_3$ < NaOH < HI
E. $LiNO_3$ < NH_4ClO_4 < NaOH < HI < $NaNO_2$

- HI → strong acid ∴ lowest pH
- $NaNO_2$ → Na^+ (neutral) comes from NaOH
  NO_2^- (basic) conjugate base of HNO_2 (weak acid)
  Basic salt
- NaOH → strong base (highest pH)
- NH_4ClO_4 → NH_4^+ (acidic) conjugate acid of NH_3 (weak base)
  ClO_4^- (neutral) conjugate base of $HClO_4$ (strong acid)
  acidic salt
- $LiNO_3$ → Li^+ (neutral) comes from LiOH (strong base)
  NO_3^- (neutral) conjugate base of HNO_3 (strong acid)
  neutral salt

HI < NH_4ClO_4 < $LiNO_3$ < $NaNO_2$ < NaOH

21. Which of these would you predict to be the strongest acid?

A

A. FCH_2CO_2H
B. $ClCH_2CO_2H$
C. $BrCH_2CO_2H$
D. ICH_2CO_2H
E. CH_3CO_2H → does not contain a halogen ∴ weakest acid

Halogens result in an inductive effect

F > Cl > Br > I in terms of electronegativity
∴ the more electronegative the halogen atom the stronger the inductive effect
∴ FCH_2CO_2H is the strongest acid

Extra Practice Questions: these questions will not be graded

1. When ammonium perchlorate, NH_4ClO_4, is dissolved in water, will it give an acidic, basic, or neutral solution?

A

A. Acidic
B. Basic
C. Neutral

NH_4ClO_4 → NH_4^+ (acidic) conjugate acid of NH_3 (weak base)
acidic salt ClO_4^- (neutral) conjugate base of $HClO_4$ (strong acid)

2. Which of these would you predict to be the **strongest base**? → will have the strongest affinity to hydrogen

B

A. Cl^- → conjugate base of HCl ∴ neutral
B. ClO^-
C. ClO_2^- } the more oxygens the more stable the negative charge ∴ weaker base
D. ClO_3^- ∴ ClO^- is the strongest base
E. ClO_4^- → conjugate base of $HClO_4$ (strong acid) ∴ neutral

3. Which of the salts is(are) considered **basic** when dissolved in water?

B

I. $NaNO_3$ neutral
II. K_3PO_4 basic
III. NH_4Cl acidic

A. I only
B. II only
C. I and II
D. I and III
E. II and III

I. $Na^+ | NO_3^-$ → (overall neutral salt) conjugate base of HNO_3 (strong acid) ∴ neutral
Na^+ from NaOH (strong base) ∴ neutral

II. $K_3^+ | PO_4^{3-}$ → (overall a basic salt) conjugate base of HPO_4^{2-} (weak acid) ∴ basic
K^+ from KOH (strong base) ∴ neutral

III. $NH_4^+ | Cl^-$ → (overall acidic) conjugate base of HCl (strong acid)
NH_4^+ conjugate acid of NH_3 (weak base)

4. Farmers who raise cotton once used arsenic acid, H_3AsO_4, as a defoliant at harvest time. Arsenic acid is a polyprotic acid with $K_{a1} = 2.5 \times 10^{-4}$, $K_{a2} = 5.6 \times 10^{-8}$, and $K_{a3} = 3 \times 10^{-13}$. What is the pH of a 0.500 *M* solution of arsenic acid?

B

A. 0.85
B. 1.95
C. 3.90
D. 4.51

polyprotic acid
(if the difference between Ka1 & Ka2 is greater than 10^3
∴ the first step mainly contributes to $[H_3O^+]$

① $H_3AsO_4(aq) + H_2O(l) \rightleftharpoons H_2AsO_4^-(aq) + H_3O^+(aq)$

	H_3AsO_4	H_2O	$H_2AsO_4^-$	H_3O^+
I	0.500	—	0	0
C	$-x$	—	$+x$	$+x$
E	$0.500-x$	—	x	x

② $K_{a1} = \frac{[H_2AsO_4^-][H_3O^+]}{[H_3AsO_4]}$

$2.5 \times 10^{-4} = \frac{[x][x]}{[0.500 - x]}$ $\frac{C}{K} \gg 100$

$\therefore x^2 = 2.5 \times 10^{-4} \times [0.500]$

$\therefore x = \sqrt{1.25 \times 10^{-4}} = \pm 1.118033989 \times 10^{-2}$
↳ ignore the negative value

③ $[H_3O^+] = x = 1.118033989 \times 10^{-2}$

$\therefore pH = -\log[H_3O^+] = 1.951544993$
≈ 1.951

All solutions are the same concentration

5. Arrange these 0.10 M aqueous solutions in order of **increasing pH**:

NaOH, HBr, $NaCH_3CO_2$, KBr, NH_4Br

D

A. HBr, KBr, NH_4Br, $NaCH_3CO_2$, NaOH
B. NaOH, $NaCH_3CO_2$, NH_4Br, KBr, HBr
C. NaOH, $NaCH_3CO_2$, KBr, NH_4Br, HBr
D. HBr, NH_4Br, KBr, $NaCH_3CO_2$, NaOH

- NaOH: strong base (highest pH)
- HBr: strong acid (lowest pH)
- $Na^+ | CH_3CO_2^-$: overall basic salt (Na^+ → neutral, $CH_3CO_2^-$ → basic)
- $K^+ | Br^-$: neutral salt (K^+ → neutral, Br^- → neutral)
- $NH_4^+ | Br^-$: acidic salt (NH_4^+ → Acidic, Br^- → neutral)

HBr < NH_4Br < KBr < $NaCH_3CO_2$ < NaOH

6. Determine the pH of a 0.22 M NaF solution at 25 °C. The K_a of HF is 3.5 × 10^{-5}.

8.90

basic salt: $Na^+ | F^-$ (Na^+ → neutral, F^- → conjugate base of HF (weak acid))

① $F^-(aq) + H_2O(l) \rightleftharpoons HF(aq) + H_3O^+(aq)$

	F^-	H_2O	HF	H_3O^+
I	0.22	–	0	0
C	$-x$	–	$+x$	$+x$
E	$0.22-x$	–	x	x

② $K_b = \frac{K_w}{K_a} = \frac{1.0\times10^{-14}}{3.5\times10^{-5}} = 2.9\times10^{-10}$

$\therefore K_b = \frac{[HF][H_3O^+]}{[F^-]}$

$\therefore 2.9\times10^{-10} = \frac{[x][x]}{[0.22-x]}$ C/K

③ $\therefore x^2 = 6.28571429\times10^{-11}$

$\therefore x = \pm 7.928249674\times10^{-6}$

$\therefore [OH^-] = 7.928249674\times10^{-6}$

$pOH = -\log[OH^-] = 5.100822682$

$\therefore pH = 14.00 - pOH$
$= 8.899177318$
≈ 8.90

7. When blue litmus paper is placed in a substance that is acidic, it will turn red. Which solution would cause blue litmus to turn red? Acidic

C

A. a solution of 0.10 M NaBr neutral salt
B. a solution of 0.01 M NH_3 weak base
C. a solution of 0.01 M NH_4ClO_4 acidic salt
D. a solution of 0.005 M KF basic salt
E. a solution of 0.10 M $Ca(CH_3CO_2)_2$ basic salt

Acidic ↖ ↗ neutral

8. Calculate the pH of a 0.59 M solution of NH_4Cl. K_b for $NH_3 = 1.8 \times 10^{-5}$.

4.74

① $NH_4^+(aq) + H_2O(l) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$

	NH_4^+	H_2O	NH_3	H_3O^+
I	0.59	–	0	0
C	$-x$	–	$+x$	$+x$
E	$0.59-x$	–	x	x

② $K_a = \frac{K_w}{K_b} = \frac{1.0\times10^{-14}}{1.8\times10^{-5}} = 5.6\times10^{-10}$

$K_a = \frac{[NH_3][H_3O^+]}{[NH_4^+]}$ ∴ $5.6\times10^{-10} = \frac{[x][x]}{[0.59-x]}$ $\frac{C}{K} \gg 100$

∴ $x^2 = 3.304\times10^{-10}$

∴ $x = \pm 1.817690843$

③ $[H_3O^+] = 1.817690843$

∴ $pH = -\log[H_3O^+] = 4.7404799 81 \approx 4.74$

9. What is the pH of an aqueous solution of 0.184 M carbonic acid, H_2CO_3? ($K_{a1} = 4.2 \times 10^{-7}$, $K_{a2} = 4.8 \times 10^{-11}$) → the difference between Ka1 & Ka2 is $>10^3$

E

A. 2.69
B. 2.80
C. 2.97
D. 3.50
E. 3.56

① $H_2CO_3(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq)$

	H_2CO_3	H_2O	HCO_3^-	H_3O^+
I	0.184	–	0	0
C	$-x$	–	$+x$	$+x$
E	$0.184-x$	–	x	x

② $K_{a1} = \frac{[HCO_3^-][H_3O^+]}{[H_2CO_3]}$ ∴ $4.2\times10^{-7} = \frac{[x][x]}{[0.184-x]}$ $\frac{C}{K} \gg 100$

∴ $x^2 = 4.2\times10^{-7}[0.184]$

∴ $x = \pm 2.779928057\times10^{-4}$

∴ $[H_3O^+] = 2.779928057\times10^{-4}$

∴ $pH = -\log[H_3O^+] = 3.555966443 \sim 3.556$

10. Which solution has the highest pH? → weakest acid

C

A. 0.10 M HBr(aq) } strong acid
B. 0.10 M HI(aq) } strong acid
C. 0.10 M HF(aq) → weak acid
D. 0.10 M HCl(aq) } strong acid
E. 0.10 M $HClO_4$(aq) } strong acid

Formula Sheet

Length
1 kilometer = 0.62137 mile
1 inch = 2.54 centimeters (exactly)
1 Ångstrom = 1×10^{-10} meter

Energy
1 joule = 1 $kg \cdot m^2/s^2$
1 calorie = 4.184 joules
1 Calorie = 1 kilocalorie = 1000 calories
1 L·atm = 101.325 joules

Pressure
1 pascal = 1 N/m^3 = 1 $kg/m \cdot s^2$
1 atmosphere = 101.325 kilopascals = 760 mm Hg = 760 torr = 14.70 lb/in^2
1 bar = 1×10^5 Pa (exactly)

Temperature
0 K = −273.15°C
K = °C + 273.15
°C = (5/9)(°F − 32)

Mass
1 kg = 2.205 lbs

Volume
1 mL = 1 cm^3 = 1 cc

Constants
c = 2.998×10^8 m/sec
h = 6.626×10^{-34} $J \cdot sec^{-1}$
R = 0.08206 L·atm/mol·K = 8.314 J/mol·K
Specific heat of water = 4.184 J/g·K
Mass of an electron: 9.109×10^{-31} kg
Mass of a proton: 1.673×10^{-27} kg
RH = 2.18×10^{-18} J
Specific heat of water = 4.184 J/g·K
STP = 273.15 K and 1 atm
Avogadro's number: 6.022×10^{23}

Equations
d (density) = m/V
$P_1V_1=P_2V_2$
$V_1/T_1=V_2/T_2$
$P_1V_1/n_1T_1=P_2V_2/n_2T_2$
PV=nRT
$(P + a(n^2/V^2))\cdot(V - nb) = nRT$
molar mass (M) = mRT/PV
density (d) = MP/RT
$x_A = n_A/n_{tot} = P_A/P_{tot} = V_A/V_{tot}$
$P_{tot} = P_A + P_B + \ldots$
$n_{tot} = n_A + n_B + \ldots$

$$\mu_{rms} = \sqrt{\frac{3RT}{M}}$$

$$\frac{Rate\ of\ effusion\ A}{Rate\ of\ effusion\ B} = \sqrt{\frac{MW_B}{MW_A}}$$

$Q = C \times \Delta T = c_{specific} \times m \times \Delta T$
$Q = n \times \Delta H$ (kJ/mol) $= m \times \Delta H$ (kJ/g)
$w = -P\Delta V$
$\Delta E = q + w$
$\Delta H° = \Sigma n\Delta Hf°$(products) $- \Sigma n\Delta Hf°$(reactants)
$\Delta H° = \Sigma n\Delta H°$(bonds broken) $- \Sigma n\Delta H°$(bonds formed)
$E=h\nu$
$c=\lambda\nu$
$\lambda = h/mv$

$$\Delta E = -2.18 \times 10^{-18} J(\frac{1}{n_f^2} - \frac{1}{n_i^2})$$

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{\Delta H_{vap}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$C_g = kP_g$
$P_{solution}=P_{solvent}\ X_{solvent}$
$P_{solution}=\sum P_j=\sum P_jX_j$
$\Delta T_b = K_b m i$
$\Delta T_f = K_f m i$
$\pi = MRTi$

Thermodynamic and Electrochemistry

$S = k_b \times \ln(W)$
$k_b = 1.381 \times 10^{-23}$ J/K
$\Delta S = q_{rev}/T$
$\Delta S_{surr} = q_{surr}/T = -q_{rev}/T$
$\Delta S_{univ} = \Delta S_{sys} + \Delta S_{surr}$
$\Delta S°_{rxn} = \Sigma v S°_{products} - \Sigma v S°_{reactants}$
$\Delta H°_{rxn} = \Sigma v H°_{products} - \Sigma v H°_{reactants}$
$\Delta G°_{rxn} = \Sigma v G°_{products} - \Sigma v G°_{reactants}$
$\Delta G = \Delta H - T\Delta S$
$\Delta G = \Delta G° + RT\cdot\ln Q$
R=8.314 J/mol.K
$\Delta G° = -RT\cdot\ln K$
$\Delta G = -nFE_{cell}$
F = 96485 J/(V·mol e^-)
$E°_{cell} = RT/nF \ln K$
$E°_{cell} = (0.0257/n) \ln K = (0.0592/n) \log K$
$E_{cell} = E°_{cell} - (RT/nF) \ln Q$
$E_{cell} = E°_{cell} - (0.0257/n) \ln Q$
Electrolysis: Q (total charge) = I × t = n × F

Integrated Rate Laws & half-life

$$\ln\frac{[A]}{[A]_0} = -kt$$

$$\frac{1}{[A]} = kt + \frac{1}{[A]_0}$$

$$[A] = -kt + [A]_0$$

$$t_{1/2} = \frac{[A]_0}{2k}$$

$$t_{1/2} = \frac{\ln 2}{k} = \frac{0.693}{k}$$

$$t_{1/2} = \frac{1}{k[A]_0}$$

$$ln\frac{k_2}{k_1} = -\frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Equilibrium and Acid / Base

$K_P = K_c \times (RT)^{\Delta n}$

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

$K_w = 1.0 \times 10^{-14}$ at 25 °C

$K_w = [H_3O^+] \times [OH^-]$

$K_w = K_a \times K_b$

$pK_a = -\log[K_a]$

Buffer: $pH = pK_a + \log\frac{[A^-]}{[HA]}$

$$ln\frac{K_2}{K_1} = \frac{\Delta H^{\circ}_{rxn}}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.01																	2 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.87	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.63	33 As 74.92	34 Se 78.97	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.95	43 Tc [97]	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
37 Cs 132.91	56 Ba 137.33		72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po [209]	85 At [210]	86 Rn [222]
87 Fr [223]	88 Ra [226]		104 Rf [267]	105 Db [268]	106 Sg [269]	107 Bh [270]	108 Hs [269]	109 Mt [277]	110 Ds [281]	111 Rg [282]	112 Cn [285]	113 Nh [286]	114 Fl [290]	115 Mc [290]	116 Lv [293]	117 Ts [294]	118 Og [294]
		57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm [145]	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.05	71 Lu 174.97	
		89 Ac [227]	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np [237]	94 Pu [244]	95 Am [243]	96 Cm [247]	97 Bk [247]	98 Cf [251]	99 Es [252]	100 Fm [257]	101 Md [258]	102 No [259]	103 Lr [262]	