Acid / Base Equilibrium

Jan 17th

Acid / Base Definitions

1. Functional Definition

	Acid	Base
taste	sour	bitter
metal	reacts w metals	cleans metals
litmus	turns litmus pink	turns litmus blue
ions	$[H^+]$	$[OH^-]$

3. Lewis Acid/Base

- a definition that works for substances that do not contain H^+, but are capable of being acidic
- Acid is an electron pair acceptor
- Base is an electron pair donor

e.g. $SnCl_2 \rightarrow Sn^{2+} + 2Cl^-$ ⇝ $Sn + 2H_2O \rightleftharpoons Sn(OH)_2 + 2H^+$

(Sn^{2+}: Lewis acid; $Sn(OH)_2$: accepts lone pairs from OH^-; provides the acidic property)

$NH_3 + H^+ \rightarrow NH_4^+$

(NH_3: acting as electron pair donor)

2. Brønsted-Lowry Acid-Base

- Acid is a proton donor
- Base is a proton acceptor

- $HCl \rightarrow H^+ + Cl^-$ (H^+: available for donation)
- $NaOH \rightarrow Na^+ + OH^-$

$OH^- + H^+ \rightarrow H_2O$ (OH^-: proton acceptor)

H^+ - hydrogenion
- PROTON

Conjugate Acid/Base Pair Theory

- For every acid, there is a conjugate base (subtract one PROTON)

acid	conjugate base
HCl	Cl^-
H_2SO_4	HSO_4^-
HSO_4^-	SO_4^{2-}
HNO_2	NO_2^-
CH_3COOH	CH_3COO^-

(subtract an H and a +ve charge!)

CH_3COOH: not acidic

$O^{2-} \rightarrow$ ✕ *there are limitations, there are no available protons here to give

$H_2O \rightarrow OH^-$

$OH^- \rightarrow O^{2-}$ *

} this CAN happen → following the "acid donates a proton" rule, it is possible

- For every base, there is a conjugate acid (add one proton)

base → conjugate acid (add an H and a +ve charge!)

$CO_3^{2-} \rightarrow HCO_3^{1-}$

$HCO_3^{1-} \rightarrow H_2CO_3$

$OH^{1-} \rightarrow H_2O$

$Cl^{1-} \rightarrow HCl$

$NH_2^{1-} \rightarrow NH_3$

$NH_3 \rightarrow NH_4^{1+}$

$NH_4^{1+} \rightarrow$ NA * cannot work (p^+ has nowhere to go)

* $H_2O \rightarrow H_3O^{1+}$

hydronium; we will see this quite often

Treat Acid-Base Reactions as a Pair of Pairs! ☺

consider reactions with water

exam eg. (strong acid)

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

a1 b2 b1 a2

proton goes from HCl to H_2O

↓ Cl^{1-} ↓ H_3O^{1+}

↔ identify the pairs

〰 find the bases that "compete" for protons

◯ circle better base (refer to relative strengths chart)

→ better base gets the proton (H_2O becomes H_3O^{1+}) ∴ acidic ↔ H_3O^{1+}

∴ equilibrium lies right basic ↔ OH^{1-}

- this is an acidic solution

Acid-Base Example Exam Questions

Jan. 20th

eg. 1 (weak acid) (4 mark Q)

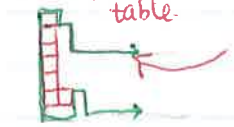
$HCN + H_2O \rightleftharpoons H_3O^{1+} + CN^{1-}$

a1 b2 a2 b1

equilibrium lies LEFT ∴ acidic (H_3O^{1+})

Ion "Activity"

- cations / anions can be loosely categorized into active vs. inactive:
  - ↳ Inactive: no effect on acid/base chemistry (neutral pH = 7)
  - ↳ Active Cation: will react with water to make acidic solution - either H^{1+} or H_3O^{1+} will form / charge on cation has been displaced to a charge on H^+/H_3O^+
  - ↳ Active Anion: will react with water to make basic solution - OH^{1-} will form / charge on anion has been displaced to a charge on OH^{1-}



- Inactive cations are: lithium, sodium, potassium, rubidium, cesium, barium (Li^{1+}, Na^{1+}, K^{1+}, Rb^{1+}, Cs^{1+}, Ba^{2+})
- Active cations are: all others

- Inactive anions are: above the "water line"
- Active anions are: below the "water line" (with the exception of SO_4^{2-})

ex $NaCl \longrightarrow Na^{1+} + Cl^{1-}$ ☺ neutral, pH = 7

(Na^{1+}: inactive; Cl^{1-}: inactive)

eg. 2 (5 mark Q)

salt: compound with ionic character such that the cation is not hydrogen

$NaIO_3 \longrightarrow Na^{1+} + IO_3^{1-}$ DISSOCIATE FIRST

($NaIO_3$: salt; Na^{1+}: inactive; IO_3^{1-}: active)

$IO_3^{1-} + H_2O \rightleftharpoons HIO_3 + OH^{1-}$

b1 a2 a1 b2 (better base)

equilibrium lies left ∴ basic (OH^{1-})

Acid-Base Example Exam Questions

Jan. 20th

eg. 1 (weak acid) (4 mark Q)

$HCN + H_2O \rightleftharpoons H_3O^{1+} + CN^{1-}$

HCN: a1 | H_2O: b2 | H_3O^{1+}: a2 | CN^{1-}: b1

equilibrium lies LEFT
∴ acidic (H_3O^{1+})

Ion "Activity"

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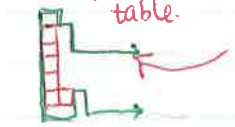

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$IO_3^{1-} + H_2O \rightleftharpoons HIO_3 + OH^{1-}$

IO_3^{1-}: b1 | H_2O: a2 | HIO_3: a1 | OH^{1-}: b2 (better base)

equilibrium lies left
∴ basic (OH^{1-})

eg. 3 $Al(NO_3)_3 \rightarrow Al^{3+} + 3NO_3^{1-}$

(3-mark Q)

Al^{3+} active ☹ $3NO_3^{1-}$ inactive ☺

$Al^{3+} + 3H_2O \rightleftharpoons Al(OH)_3 + 3H^{1+}$ ∴ acidic — done! - no conjugate acid-base pair theory

alternate:

$Al^{3+} + 6H_2O \rightleftharpoons Al(OH)_3 + 3H_3O^{1+}$ ∴ acidic — done!

* 3 dissociate; 3 'piggyback' the H^{1+}

Hydronium ion H_3O^{1+}

- form that all acids take in aqueous solution

$H_2O + H^{1+} \rightleftharpoons H_3O^{1+}$ lies very far to the right

* chemists use these interchangeably *

- H_3O^{1+} – conjugate acid base pair theory
- H^{1+} – equilibrium calculations (less writing)

Amphiprotic Substances

"goes both ways"

eg. $NaHCO_3 \rightarrow Na^{1+} + HCO_3^{1-}$

HCO_3^{1-}: H_2CO_3 (gain H^+), CO_3^{2-} (lose H^+)

H_2O: H_3O^{1+}, OH^{1-}

NH_3: NH_4^{1+}, NH_2^{1-}

eg. 4 THE BIG ONE

(lots of marks)

$NaHCO_3 \rightarrow Na^{1+} + HCO_3^{1-}$ must dissociate first

Na^{1+} inactive; HCO_3^{1-} amphiprotic

as an acid: $HCO_3^{1-} + H_2O \rightleftharpoons H_3O^{1+} + CO_3^{2-}$ (better base)

a1 (90%) b2 a2 (1%) b1

as a base: $HCO_3^{1-} + H_2O \rightleftharpoons OH^{1-} + H_2CO_3$ (better base)

b1 a2 b2 (9%) a1

lies further left

lies left

$[OH^{1-}] > [H_3O^{1+}]$

∴ basic

(refer to table and all 4 bases, gap size between b1 + b2 of each equation accounts for more "dramatic" lie to the left)

Acid Base Equilibrium Questions

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2. a) $HCl + H_2O \rightleftharpoons Cl^{1-} + H_3O^{1+}$ (a1, b2, b1, a2)
- lies right ✓
- H_3O^{1+} ∴ acidic ✓

b) $HNO_3 + H_2O \rightleftharpoons NO_3^{1-} + H_3O^{1+}$ (a1, b2, b1, a2)
- lies right ✓
- acidic ✓

c) $H_2SO_4 + H_2O \rightleftharpoons HSO_4^{1-} + H_3O^{1+}$ (a1, b2, b1, a2)
- lies right ✓
- acidic ✓

d) $HClO_4 + H_2O \rightleftharpoons ClO_4^{1-} + H_3O^{1+}$ (a1, b2, b1, a2)
- lies right ✓
- acidic ✓

e) $H_2S + H_2O \rightleftharpoons HS^{1-} + H_3O^{1+}$ (a1, b2, b1, a2)
- lies left ✓
- acidic ✓

f) $H_3PO_4 + H_2O \rightleftharpoons H_2PO_4^{1-} + H_3O^{1+}$ (a1, b2, b1, a2)
- lies left ✓
- acidic ✓

6. $HB + X^{1-} \rightleftharpoons HX + B^{1-}$ (a1, b2, a2, b1)
- lies very far to the right

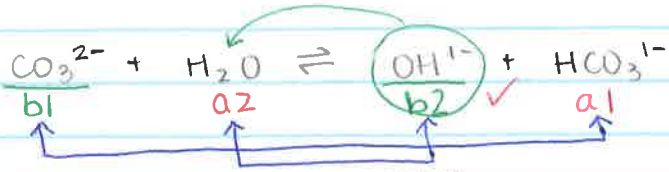
S: ↑$[B^{1-}]$
R: ↓$[B^{1-}]$
H: use B^{1-}
D: shift left

a) X^{1-} and B^{1-} are competing for protons
b) X^{1-} is stronger because it becomes HX more
c) HX is weaker because it stays HX instead of donating protons
d) K for this system will have a large value because [products] > [reactants] as it lies far to the right. $K = \frac{[HX][B^{1-}]}{[HB][X^{1-}]}$
e) NaB will dissociate into Na^{1+} and B^{1-}; an addition of B^{1-} will result in an increase in HB, ∴ shifting slightly left

→ the stronger the base, the weaker the conjugate acid

8. a) $Na_2CO_3 \rightarrow 2Na^{1+} + CO_3^{2-}$

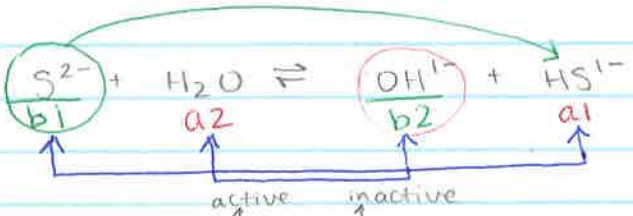
(inactive: $2Na^{1+}$; active: CO_3^{2-})



- shift left ✓
- OH^{1-} ∴ basic ✓

* b) $Na_2S \rightarrow 2Na^{1+} + S^{2-}$

(inactive: $2Na^{1+}$; active: S^{2-})



- shift right ✗
- basic ✓

c) $FeCl_3 \rightarrow Fe^{3+} + 3Cl^{1-}$

(active: Fe^{3+}; inactive: $3Cl^{1-}$)

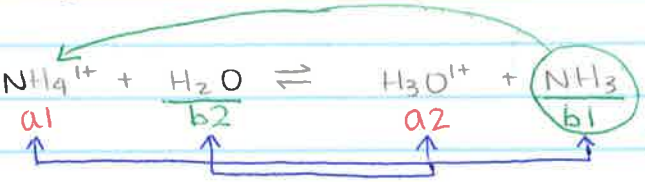
$Fe^{3+} + 3H_2O \rightleftharpoons Fe(OH)_3 + 3H^{1+}$ - acidic (H^{1+})

OR $Fe^{3+} + 6H_2O \rightleftharpoons Fe(OH)_3 + 3H_3O^{1+}$ ✓ - acidic (H_3O^{1+}) ✓

d) $(NH_4)_2SO_4 \rightarrow 2NH_4^{1+} + SO_4^{2-}$

(active: $2NH_4^{1+}$; inactive: SO_4^{2-})

*so we aren't basing SO_4^{2-} off the answers? It is inactive?



- shift left
- acidic ✓

e) $Al_2(SO_4)_3 \rightarrow 2Al^{3+} + 3SO_4^{2-}$

(active: $2Al^{3+}$; inactive: $3SO_4^{2-}$)

$Al^{3+} + 3H_2O \rightleftharpoons Al(OH)_3 + 3H^{1+}$ - acidic (H^{1+})

OR $Al^{3+} + 6H_2O \rightleftharpoons Al(OH)_3 + 3H_3O^{1+}$ ✓ - acidic (H_3O^{1+}) ✓

f) $MgSO_4 \rightarrow Mg^{2+} + SO_4^{2-}$

(active: Mg^{2+}; inactive: SO_4^{2-})

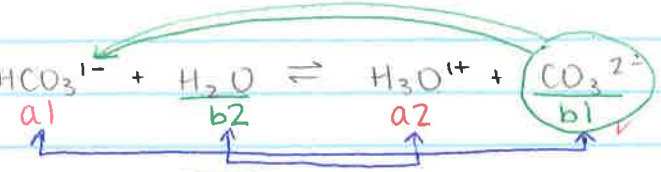
$Mg^{2+} + 2H_2O \rightleftharpoons Mg(OH)_2 + 2H^{1+}$ - acidic (H^{1+})

OR $Mg^{2+} + 4H_2O \rightleftharpoons Mg(OH)_2 + 2H_3O^{1+}$ ✓ - acidic (H_3O^{1+}) ✓

g) $KHCO_3 \rightarrow K^{1+} + HCO_3^{1-}$

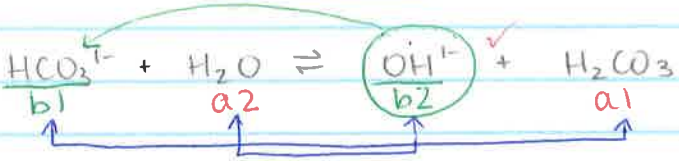
(inactive: K^{1+}; *amphiprotic: HCO_3^{1-})

acid



- shift more left ✓
- acidic

base



- shift left ✓
- basic

$[OH^{1-}] > [H_3O^{1+}]$

∴ BASIC ✓

exam: 2/a, b, c or d
8/a, Na_2CO_3, KF
8/ c, h
8/ g

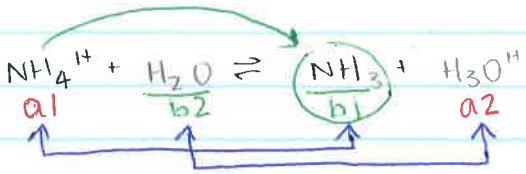
4
5
3
9

8. h) $AgNO_3 \rightarrow Ag^{1+}$ (active) + NO_3^{1-} (inactive)

OR $Ag^{1+} + H_2O \rightleftharpoons AgOH + H^{1+}$ ∴ acidic (H^{1+}) ✓

$Ag^{1+} + 2H_2O \rightleftharpoons AgOH + H_3O^{1+}$ ∴ acidic (H_3O^{1+}) ✓

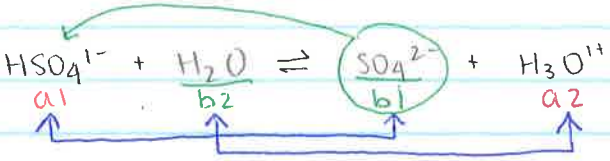
i) $NH_4I \rightarrow NH_4^{1+} + I^{1-}$



- yes right ✓
- acidic ✓

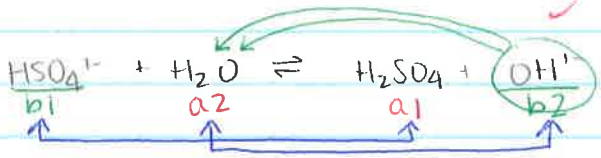
j) $NaHSO_4 \rightarrow Na^{1+}$ (inactive) + HSO_4^{1-} (amphiprotic) ✓

as acid



- shifts left ✓
- acidic ✓

as base



- shifts more left ✓
- basic

$[H_3O^{1+}] > [OH^{1-}]$

∴ ACIDIC ✓

* conjugate pair stuff not shown in answer

1. a) Cl^{1-} ✓
   b) CH_3^{1-} ✓
   c) SO_3^{2-} ✓
   d) HSO_4^{1-} ✓, SO_4^{2-} *
   e) NH_2^{1-} ✓
   f) ClO_4^{1-} ✓