

Slide 1

**Acid/Base Properties of  
Salts**

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Hiding in plain sight

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Slide 2

**Recognizing Bases**

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Sometimes it seems that all acids and bases are labeled with  $H^+$  or  $OH^-$

Acids do have an  $H^+$

But a base is ANYTHING that can accept a proton – it doesn't have to have an  $OH^-$ . Anything with a negative charge or just non-bonding electrons (N, O, P) can act as a base.

The salt formed by the dissociation of an acid is the "conjugate base" of the acid. This must mean that the salt is a base, whether it has an  $OH^-$  or not.

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Slide 3

**Pick a salt, any salt**

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- How about ammonium acetate,  $NH_4OAc$ ?  
An excellent choice.
- **SALT = IONIC**
- Ammonium acetate is an ionic solid.
- Ionic solids **dissociate** in aqueous solution
- Aqueous  $NH_4OAc$  will exist as anions and cations.

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Slide 4

The MOST important thing about salts!

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$$\text{NH}_4\text{OAc}_{(aq)} \rightarrow \text{NH}_4^+_{(aq)} + \text{OAc}^-_{(aq)}$$

So what can we say about  $\text{NH}_4^+$  and  $\text{OAc}^-$  in aqueous solution?

We need to think "backwards". How did  $\text{NH}_4\text{OAc}$  get the  $\text{NH}_4^+$  in the first place? (Or, more accurately, what is one way it could have gotten it?)

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Slide 5

Salts are products of acid/base reactions

You might recall that the reaction of an acid and a base yields a salt and water:

$$\text{NH}_4\text{OH} + \text{HOAc} \rightarrow \text{H}_2\text{O} + \text{NH}_4\text{OAc}$$

$$\text{NH}_3 + \text{HOAc} \rightarrow \text{NH}_4\text{OAc}$$

These are the same reaction!

Hey, look!  
It's our salt!

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Slide 6

These two reactions are identical

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$$\text{NH}_3 + \text{H}_2\text{O} \leftrightarrow \text{NH}_4^+ + \text{OH}^- \quad K_b(\text{NH}_3)$$

$$\text{NH}_3 + \text{H}_2\text{O} = \text{NH}_4\text{OH}$$

$$\text{NH}_4\text{OH} + \text{HOAc} \rightarrow \text{H}_2\text{O} + \text{NH}_4\text{OAc}$$

$$\text{NH}_3 + \text{H}_2\text{O} + \text{HOAc} \rightarrow \text{H}_2\text{O} + \text{NH}_4\text{OAc}$$

$$\text{NH}_3 + \text{HOAc} \rightarrow \text{NH}_4\text{OAc}$$

$\text{NH}_4\text{OH}$  is just another way to write aqueous  $\text{NH}_3$

This is why I often say that bases don't need to have an  $\text{OH}^-$  because they borrow one from water. The whole acid + base = salt + water is a slight exaggeration. Sometimes you borrow  $\text{OH}^-$  from water!

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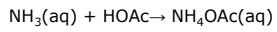
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Slide 7

### A more detailed reaction

Let's stick to the more plain:



But what are  $\text{NH}_3(\text{aq})$  and  $\text{HOAc}(\text{aq})$ ?

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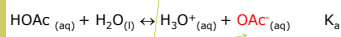
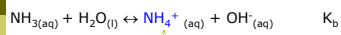
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Slide 8

### Acid (and Base) Dissociation Reactions



Hey, look! It's pieces of our salt!

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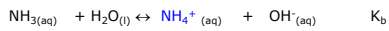
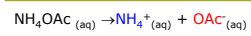
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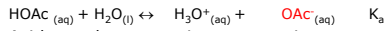
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Slide 9

### Putting it all together...



Base      acid      conjugate      conjugate  
                acid                  base



Acid      base      conjugate      conjugate  
                                acid                  base

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Slide 10

In short...

We have the conjugate acid ( $\text{NH}_4^+$ ) of a base ( $\text{NH}_3$  or  $\text{NH}_4\text{OH}$ ), and the conjugate base ( $\text{OAc}^-$ ) of an acid ( $\text{HOAc}$ ).

THIS IS A GENERAL RULE!

All salts are the combination of a (conjugate) acid and a (conjugate) base!

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Slide 11

An acid is an acid.

A base is a base.

"Conjugate" or not.

And water is both!

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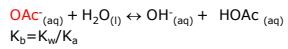
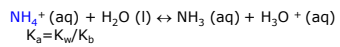
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Slide 12

$K_b$  becomes  $K_a$  as  $K_a$  becomes  $K_b$

Just because you're a "conjugate acid" doesn't mean you're not an acid!



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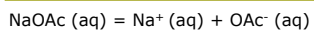
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Slide 16

### Salts dissociate in water



It's a little less obvious what's going on here. But ALL SALTS are made up of an acid (cation) part and a base (anion) part.

It's just that  $\text{Na}^+$  doesn't look like much of an acid. But again, that's because it borrows from water!

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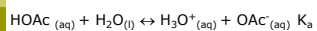
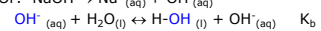
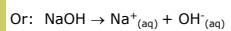
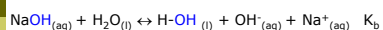
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Slide 17

### Acid (and Base) Dissociation Reactions



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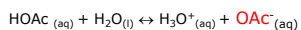
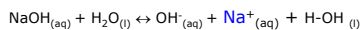
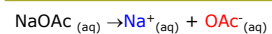
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Slide 18

### Putting it all together...



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Slide 19

Putting it all together...

$$\text{NaOAc}_{(aq)} \rightarrow \text{Na}^+_{(aq)} + \text{OAc}^-_{(aq)}$$
$$\text{NaOH}_{(aq)} + \text{H}_2\text{O}_{(l)} \leftrightarrow \text{OH}^-_{(aq)} + \text{Na}^+_{(aq)} + \text{H-OH}_{(l)}$$

Base      acid      conjugate base      conjugate acid

$$\text{HOAc}_{(aq)} + \text{H}_2\text{O}_{(l)} \leftrightarrow \text{H}_3\text{O}^+_{(aq)} + \text{OAc}^-_{(aq)}$$

Base      acid      conjugate acid      conjugate base

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Slide 20

In short...

We have the conjugate acid ( $\text{Na}^+$ ) of a base ( $\text{NaOH}$ ), and the conjugate base ( $\text{OAc}^-$ ) of an acid ( $\text{HOAc}$ ).

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Slide 21

$K_b$  becomes  $K_a$  as  $K_a$  becomes  $K_b$

$$\text{NaOAc}_{(aq)} \rightarrow \text{Na}^+_{(aq)} + \text{OAc}^-_{(aq)}$$
$$\text{Na}^+_{(aq)} + 2 \text{H}_2\text{O}_{(l)} \leftrightarrow \text{NaOH}_{(aq)} + \text{H}_3\text{O}^+_{(aq)}$$

(or, if you prefer)

$$\text{Na}^+_{(aq)} + \text{H}_2\text{O}_{(l)} \leftrightarrow \text{NaOH}_{(aq)} + \text{H}^+_{(aq)} \quad K_a = K_w / K_b$$
$$\text{OAc}^-_{(aq)} + \text{H}_2\text{O}_{(l)} \leftrightarrow \text{OH}^-_{(aq)} + \text{HOAc}_{(aq)} \quad K_b = K_w / K_a$$

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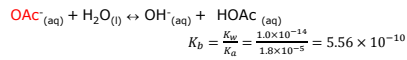
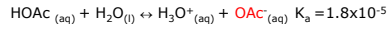
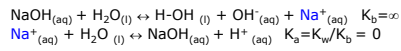
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Slide 22

But one is strong and the other weak.




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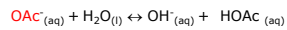
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Slide 23

Net Result

NaOAc gives rise to a single equilibrium reaction that must be considered:



$$K_b = 5.56 \times 10^{-10}$$

The salt is a base!!!!

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Slide 24

What is the pH of a 0.100 M NaOAc solution?

We need to recognize this as a salt solution.

As soon as we recognize it as a salt, it has an acid half and a base half.

In this case, we can ignore the Na<sup>+</sup> because it comes from a strong base (it ain't going back!) and so it is only the OAc<sup>-</sup> that matters.

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Slide 25

What is the pH of a 0.100 M NaOAc solution?

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It's a base equilibrium so...THERE'S 3 PARTS!

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Slide 26

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$$\text{OAc}^-_{(\text{aq})} + \text{H}_2\text{O}_{(\text{l})} \leftrightarrow \text{OH}^-_{(\text{aq})} + \text{HOAc}_{(\text{aq})}$$
$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} = 5.56 \times 10^{-10} = \frac{[\text{OH}^-][\text{HOAc}]}{[\text{OAc}^-]}$$

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Slide 27

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ICE-ICE-BABY-ICE-ICE

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$$\text{OAc}^-_{(\text{aq})} + \text{H}_2\text{O}_{(\text{l})} \leftrightarrow \text{OH}^-_{(\text{aq})} + \text{HOAc}_{(\text{aq})}$$

I	0.100 M	-	0	0
C	-x	-	+x	+x
E	0.100-x	-	x	x

$$5.56 \times 10^{-10} = \frac{[\text{OH}^-][\text{HOAc}]}{[\text{OAc}^-]} = \frac{(x)(x)}{0.100 - x}$$

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Slide 28

How do we solve it?

$$5.56 \times 10^{-10} = \frac{(x)(x)}{0.100 - x}$$

Assume  $x \ll 0.100$

$$5.56 \times 10^{-10} = \frac{(x)(x)}{0.100}$$
$$5.56 \times 10^{-11} = x^2$$
$$x = 7.46 \times 10^{-6}$$

Pretty darn good assumption!

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Slide 29

ICE-ICE-BABY-ICE-ICE

$$\text{OAc}^-_{(\text{aq})} + \text{H}_2\text{O}_{(\text{l})} \leftrightarrow \text{OH}^-_{(\text{aq})} + \text{HOAc}_{(\text{aq})}$$

I	0.100 M	-	0	0
C	-x	-	+x	+x
E	0.0999925	-	$7.46 \times 10^{-6}$	$7.46 \times 10^{-6}$

$$pOH = -\log(7.46 \times 10^{-6}) = 5.12$$
$$pH = 14 - pOH = 14 - 5.12 = 8.88$$

That's a pretty basic little solution we have!

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Slide 30

Sample Problem

What is the pH of a solution of 0.0707 M potassium phosphate in water?

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Slide 31

1<sup>st</sup> we need...

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Slide 32

...a balanced equation

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$$\text{K}_3\text{PO}_4 \text{ (aq)} \rightarrow 3 \text{K}^+ \text{ (aq)} + \text{PO}_4^{3-} \text{ (aq)}$$

Now, potassium is the conjugate acid of KOH – a strong base.

$\text{PO}_4^{3-}$  is the conjugate base of hydrogen phosphate,  $\text{HPO}_4^{2-}$  (which is the conjugate base of  $\text{H}_2\text{PO}_4^-$ , which is the conjugate base of  $\text{H}_3\text{PO}_4$ )

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Slide 33

So, there may be 3 equilibria to consider

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$$\text{H}_3\text{PO}_4 \text{ (aq)} + \text{H}_2\text{O} \text{ (l)} \leftrightarrow \text{H}_2\text{PO}_4^- \text{ (aq)} + \text{H}_3\text{O}^+ \text{ (aq)}$$
$$K_{a1} = 7.5 \times 10^{-3}$$
$$\text{H}_2\text{PO}_4^- \text{ (aq)} + \text{H}_2\text{O} \text{ (l)} \leftrightarrow \text{HPO}_4^{2-} \text{ (aq)} + \text{H}_3\text{O}^+ \text{ (aq)}$$
$$K_{a2} = 6.2 \times 10^{-8}$$
$$\text{HPO}_4^{2-} \text{ (aq)} + \text{H}_2\text{O} \text{ (l)} \leftrightarrow \text{PO}_4^{3-} \text{ (aq)} + \text{H}_3\text{O}^+ \text{ (aq)}$$
$$K_{a3} = 5.8 \times 10^{-13}$$

But, of course, we need the reverse reactions

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Slide 34

So, there may be 3 equilibria to consider

$$\text{H}_2\text{PO}_4^- (\text{aq}) + \text{H}_2\text{O} (\text{l}) \leftrightarrow \text{H}_3\text{PO}_4 (\text{aq}) + \text{OH}^- (\text{aq})$$
$$K_{b1} = \frac{K_w}{K_{a1}} = \frac{1 \times 10^{-14}}{7.5 \times 10^{-3}} = 1.33 \times 10^{-12}$$
$$\text{HPO}_4^{2-} (\text{aq}) + \text{H}_2\text{O} (\text{l}) \leftrightarrow \text{H}_2\text{PO}_4^- (\text{aq}) + \text{OH}^- (\text{aq})$$
$$K_{b2} = \frac{K_w}{K_{a2}} = \frac{1 \times 10^{-14}}{6.2 \times 10^{-8}} = 1.61 \times 10^{-7}$$
$$\text{PO}_4^{3-} (\text{aq}) + \text{H}_2\text{O} (\text{l}) \leftrightarrow \text{HPO}_4^{2-} (\text{aq}) + \text{OH}^- (\text{aq})$$
$$K_{b3} = \frac{K_w}{K_{a3}} = \frac{1 \times 10^{-14}}{5.8 \times 10^{-13}} = 1.72 \times 10^{-2}$$

This is the thing I have!

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Slide 35

Just take them 1 at a time...

$$\text{PO}_4^{3-} (\text{aq}) + \text{H}_2\text{O} (\text{l}) \leftrightarrow \text{HPO}_4^{2-} (\text{aq}) + \text{OH}^- (\text{aq})$$

I	0.0707 M	-	0	0
C	-x	-	+x	+x
E	0.0707 - x	-	x	x

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$$K_{b3} = 1.72 \times 10^{-2} = \frac{[\text{OH}^-][\text{HPO}_4^{2-}]}{[\text{PO}_4^{3-}]} = \frac{(x)(x)}{(0.0707 - x)}$$

Try  $x < 0.0707$

$$1.72 \times 10^{-2} = \frac{(x)(x)}{(0.0707 - x)} \approx \frac{x^2}{0.0707}$$

$1.22 \times 10^{-3} = x^2$   
 $x = 0.0349$  which is NOT much less than 0.0707

We have to do it the Quadratic Way!

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$$K_{b3} = 1.72 \times 10^{-2} = \frac{[\text{OH}^-][\text{HPO}_4^{2-}]}{[\text{PO}_4^{3-}]} = \frac{(x)(x)}{(0.0707 - x)}$$

$$1.216 \times 10^{-3} - 1.72 \times 10^{-2} x = x^2$$

$$0 = x^2 + 1.72 \times 10^{-2} x - 1.216 \times 10^{-3}$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$x = \frac{-1.72 \times 10^{-2} \pm \sqrt{(1.72 \times 10^{-2})^2 - 4(1)(-1.216 \times 10^{-3})}}{2(1)}$$

$$x = \frac{-1.72 \times 10^{-2} \pm \sqrt{5.16 \times 10^{-3}}}{2}$$

$$x = \frac{-1.72 \times 10^{-2} + 7.18 \times 10^{-2}}{2}$$

$$x = 2.73 \times 10^{-2} \text{ M}$$


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The 1<sup>st</sup> equilibrium...

$$\text{PO}_4^{3-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{HPO}_4^{2-}(\text{aq}) + \text{OH}^-(\text{aq})$$

I	0.0707 M	-	0	0
C	- 2.73x10 <sup>-2</sup>	-	+ 2.73x10 <sup>-2</sup>	+ 2.73x10 <sup>-2</sup>
E	0.0434	-	2.73x10 <sup>-2</sup>	2.73x10 <sup>-2</sup>

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Slide 39

...leads to the second

$$\text{HPO}_4^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \leftrightarrow \text{H}_2\text{PO}_4^-(\text{aq}) + \text{OH}^-(\text{aq})$$

I	2.73x10 <sup>-2</sup> M	-	0	2.73x10 <sup>-2</sup>
C	- x	-	+ x	+ x
E	2.73x10 <sup>-2</sup> - x	-	x	2.73x10 <sup>-2</sup> + x

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Slide 40

$$K_{b2} = 1.61 \times 10^{-7} = \frac{[OH^-][H_2PO_4^-]}{[HPO_4^{2-}]}$$


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$$K_{b2} = 1.61 \times 10^{-7} = \frac{(x)(x + 2.73 \times 10^{-2})}{(2.73 \times 10^{-2} - x)}$$

Try  $x \ll 0.0273$

$$1.61 \times 10^{-7} = \frac{(x)(x + 2.73 \times 10^{-2})}{(2.73 \times 10^{-2} - x)} \approx \frac{(x)(2.73 \times 10^{-2})}{2.73 \times 10^{-2}}$$

$$1.61 \times 10^{-7} \approx x$$

$$1.61 \times 10^{-7} = x$$

This is not only small relative to 0.0273, it is just completely insignificant!

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Slide 41

...leads to the second

$$HPO_4^{2-} (aq) + H_2O (l) \leftrightarrow H_2PO_4^- (aq) + OH^- (aq)$$

I	$2.73 \times 10^{-2} M$	-	0	$2.73 \times 10^{-2}$
C	$-1.61 \times 10^{-7}$	-	$+1.61 \times 10^{-7}$	$+1.61 \times 10^{-7}$
E	$2.73 \times 10^{-2}$	-	$1.61 \times 10^{-7}$	$2.73 \times 10^{-2}$

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Slide 42

If we needed a 3<sup>rd</sup> chart...it starts there:

$$H_2PO_4^- (aq) + H_2O (l) \leftrightarrow H_3PO_4 (aq) + OH^- (aq)$$

I	$1.61 \times 10^{-7} M$	-	0	$2.73 \times 10^{-2}$
C	-x	-	+x	+x
E	$1.61 \times 10^{-7} - x$	-	x	$2.73 \times 10^{-2} + x$

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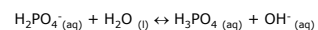
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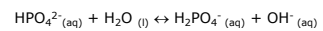
Slide 43

But if the 2<sup>nd</sup> one didn't matter...

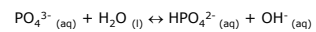
...the 3<sup>rd</sup> one matters even less...



$$K_{b1} = \frac{K_w}{K_{a1}} = \frac{1 \times 10^{-14}}{7.5 \times 10^{-3}} = 1.33 \times 10^{-12}$$



$$K_{b2} = \frac{K_w}{K_{a2}} = \frac{1 \times 10^{-14}}{6.2 \times 10^{-8}} = 1.61 \times 10^{-7}$$



$$K_{b3} = \frac{K_w}{K_{a3}} = \frac{1 \times 10^{-14}}{5.8 \times 10^{-13}} = 1.72 \times 10^{-2}$$

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Slide 44

Calculating the pH

The result of our 2<sup>nd</sup> ICE chart is that:

$$[\text{OH}^-] = 2.73 \times 10^{-2}$$

What do we do with this number?

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Slide 45

Calculating the pH

The result of our ICE chart (1<sup>st</sup> or 2<sup>nd</sup>) is that:

$$[\text{OH}^-] = 2.73 \times 10^{-2}$$

What do we do with this number?

1. To calculate the pH directly, we need  $[\text{H}_3\text{O}^+]$
2. We can calculate the pOH, and then get the PH from that.

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Slide 49

**Consider 0.100 M NaCl**

Is it acid, basic or neutral?  
Separate into ions.  
 $\text{NaCl} = \text{Na}^+ + \text{Cl}^-$   
The cation ( $\text{Na}^+$ ) is the conjugate acid.  
The anion ( $\text{Cl}^-$ ) is the conjugate base.

- A. Acid
- B. Base
- C. Neutral
- D. Both an acid and a base
- E. Your mother

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Slide 50

**Consider 0.100 M NaCl**

Is it acid, basic or neutral?

- For the cation: either add  $\text{OH}^-$  or, if there is one, remove the  $\text{H}^+$  to see what base "it came from".

$\text{Na}^+ + \text{OH}^- = \text{NaOH}$

For the anion: add an  $\text{H}^+$  to see what acid "it came from".

$\text{Cl}^- + \text{H}^+ = \text{HCl}$

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Slide 51

**Consider 0.100 M NaCl**

Is it acid, basic or neutral?  
Look up the  $K_a$  and  $K_b$  of the "parent" acid/base.

$\text{NaOH}$  - strong base  
 $\text{HCl}$  - strong acid

We can ignore both of them so the salt is neutral!

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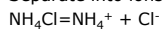
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Slide 52

Consider 0.100 M  $\text{NH}_4\text{Cl}$

Is it acid, basic or neutral?

Separate into ions.



The cation ( $\text{NH}_4^+$ ) is the conjugate acid.

The anion ( $\text{Cl}^-$ ) is the conjugate base.

- A. Acid
- B. Neutral
- C. Basic
- D. None of the Above
- E. All of the above

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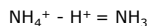
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Slide 53

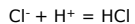
Consider 0.100 M  $\text{NH}_4\text{Cl}$

Is it acid, basic or neutral?

□ For the cation: either add  $\text{OH}^-$  or, if there is one, remove the  $\text{H}^+$  to see what base "it came from".



For the anion: add an  $\text{H}^+$  to see what acid "it came from".



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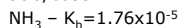
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Slide 54

Consider 0.100 M  $\text{NH}_4\text{Cl}$

Is it acid, basic or neutral?

Look up the  $K_a$  and  $K_b$  of the "parent" acid/base.



$\text{HCl}$  - strong acid

We ignore the  $\text{HCl}$ . The  $\text{NH}_3$  counts.

Clickers!

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Slide 55

What is the pH of 0.100 M  $\text{NH}_4\text{Cl}$

- A. 2.88
- B. 11.12
- C. 4.75
- D. 5.12
- E. 8.88
- F. 1.00
- G. 0.100
- H. 2.00
- I. None of the above

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