Slide 1

Another example

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Slide 2

What is the pH of 0.100 M citric acid?

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Slide 3

What are you thinking…?

A. I am thinking absolutely nothing.
B. I am waiting for you to tell me what to think.
C. I'm thinking it must be equilibrium because that's all we talk about.
D. I'm thinking it must be equilibrium because it is asking about the pH

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Slide 4

What is the pH of 0.100 M citric acid?

Citric acid is $H_3C_6H_5O_7$

Now, I'm thinking…

A. Must be an acid
B. Must be diprotic
C. Must be triprotic
D. Must be a strong acid
E. Must be a weak acid

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Slide 5

What is the pH of 0.100 M citric acid?

$K_{a1}=7.1\times10^{-4}$
$K_{a2}=1.7\times10^{-5}$
$K_{a3}=4.1\times10^{-7}$
Now, I'm thinking:

A. Must be a weak acid
B. Must be a strong acid
C. Must be a triprotic weak acid
D. I don't get paid to think, you do.

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Slide 6

What is the pH of 0.100 M citric acid?

$K_{a1}=7.1\times10^{-4}$
$K_{a2}=1.7\times10^{-5}$
$K_{a3}=4.1\times10^{-7}$
Now, I'm thinking:

A. 3 parts
B. 2 parts
C. $pH = \frac{pK_{a1}+pK_{a2}+pK_{a3}}{3}$
D. I've had about enough of your nonsense.

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Slide 7

What is the pH of 0.100 M citric acid?

K_{a1}=7.1x10^{-4}
K_{a2}=1.7x10^{-5}
K_{a3}=4.1x10^{-7}

$H_3C_6H_5O_7$ (aq) + H_2O (l) ↔ H_3O^+ (aq) + $H_2C_6H_5O_7^-$ (aq)
$H_2C_6H_5O_7^-$ (aq) + H_2O (l) ↔ H_3O^+ (aq) + $HC_6H_5O_7^{2-}$ (aq)
$HC_6H_5O_7^{2-}$ (aq) + H_2O (l) ↔ H_3O^+ (aq) + $C_6H_5O_7^{3-}$ (aq)

Take them one at a time…or do I?

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	$H_3C_6H_5O_7$ (aq)	+H_2O (l)	↔	H_3O^+ (aq)	+ $H_2C_6H_5O_7^-$ (aq)
I	0.100 M	-		0	0
C	-x	-x		+x	+x
E	0.100 –x	-		X	X

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Slide 9

$$K_{a1} = 7.1 \times 10^{-4} = \frac{(x)(x)}{0.100 - x}$$

Always try the assumption, we only have 30 seconds to lose.

Assume x<<0.100

$$K_{a1} = 7.1 \times 10^{-4} = \frac{(x)(x)}{0.100 - x} \approx \frac{x^2}{0.100}$$

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$$K_{a1} = 7.1 \times 10^{-4} = \frac{(x)(x)}{0.100 - x} \approx \frac{x^2}{0.100}$$

$$7.1 \times 10^{-4} = \frac{x^2}{0.100}$$

$$7.1 \times 10^{-5} = x^2$$

$$x = \sqrt{7.1} \times 10^{-5} = 8.43 \times 10^{-3}$$

Check

$\frac{0.100}{20} = 0.005 = 5 \times 10^{-3}$ close but no cigar

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$$K_{a1} = 7.1 \times 10^{-4} = \frac{(x)(x)}{0.100 - x}$$

$$7.1 \times 10^{-5} - 7.1 \times 10^{-4}x = x^2$$

$$0 = x^2 + 7.1 \times 10^{-4}x - 7.1 \times 10^{-5}$$

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

$$= \frac{-7.1 \times 10^{-4} \pm \sqrt{(7.1 \times 10^{-4}) - 4(1)(-7.1 \times 10^{-5})}}{2(1)}$$

$$x = -0.00879, 0.00808$$

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	$H_2C_4H_4O_7$ (aq)	$+H_2O$ (l)	$\leftrightarrow$	H_3O^+ (aq)	$+ H_2C_4H_2O_7^-$ (aq)
I	0.100 M	-		0	0
C	-0.00808	-0.00808		+0.00808	+0.00808
E	0.092	-		0.00808	0.00808

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Slide 13

Start where the first one leaves off

	$H_2C_6H_5O_7^-$ (aq)	$+H_2O$ (l)	$\leftrightarrow$	H_3O^+ (aq)	$HC_6H_5O_7^{-2}$(aq)
I	0.00808			0.00808	0
C	-x	-x		+x	+x
E	0.00808-x			0.00808+x	x

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Slide 14

$$K_{a2} = 1.7 \times 10^{-5} = \frac{(x)(0.00808 + x)}{0.00808 - x}$$

Always try the assumption, we only have 30 seconds to lose.

Assume x<<0.00808

$$1.7 \times 10^{-5} = \frac{(x)(0.00808 + x)}{0.00808 - x} \approx \frac{(x)(0.00808)}{0.00808}$$

$$x = 1.7 \times 10^{-5}$$

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Check

$$\frac{0.00808}{20} = 4.04 \times 10^{-4}$$

$$x = 1.7 \times 10^{-5}$$

YAY! It works.

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Slide 16

Start where the first one leaves off

	$H_2C_6H_5O_7^-$ (aq)	$+H_2O$ (l)	$\leftrightarrow$	H_3O^+ (aq)	$HC_6H_5O_7^{-2}$(aq)
I	0.00808			0.00808	0
C	$-x = -1.7 \times 10^{-5}$	-x		$x = 1.7 \times 10^{-5}$	$x = 1.7 \times 10^{-5}$
E	0.00806			0.00810	1.7×10^{-5}

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Let's take a moment for some deep reflection….

	$H_2C_6H_5O_7^-$ (aq)	$+H_2O$ (l)	$\leftrightarrow$	H_3O^+ (aq)	$HC_6H_5O_7^{-2}$(aq)
I	0.00808			0.00808	0
C	$-x = -1.7 \times 10^{-5}$	-x		$x = 1.7 \times 10^{-5}$	$x = 1.7 \times 10^{-5}$
E	0.00806			0.00810	1.7×10^{-5}

Did anything change during the second equilibrium?

A. Yes, EVERYTHING changed.
B. No, NOTHING changed.
C. Some things changed, some things didn't
D. What are these "things" of which you speak?

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Slide 18

Nothing changed…

…to 2 sig figs.

Which is a good thing! If it had changed, I would upset the first equilibrium!

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Slide 19

First equilibrium

	$H_2C_6H_5O_7$ (aq)	$+H_2O$ (l)	↔	H_3O^+ (aq)	$+ H_2C_6H_5O_7^-$ (aq)
I	0.100 M	-		0	0
C	-0.00808	-0.00808		+0.00808	+0.00808
E	0.092	-		0.00808	0.00808

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Second equilibrium

	$H_2C_6H_5O_7^-$ (aq)	$+H_2O$ (l)	↔	H_3O^+ (aq)	$HC_6H_5O_7^{-2}$(aq)
I	0.00808			0.00808	0
C	$-x = -1.7 \times 10^{-5}$	-x		$x = 1.7 \times 10^{-5}$	$x = 1.7 \times 10^{-5}$
E	0.00806			0.00810	1.7×10^{-5}

They BOTH have to be satisfied if I'm truly at equilibrium.

Let's pretend this second equilibrium turned out differently…

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Imaginary second equilibrium

	$H_2C_6H_5O_7^-$ (aq)	$+H_2O$ (l)	↔	H_3O^+ (aq)	$HC_6H_5O_7^{-2}$(aq)
I	0.00808			0.00808	0
C	-0.004	-x		+0.004	0.004
E	0.00508			0.0121	0.004

Now, look back at the first equilibrium…two of these compounds are the same!

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Imaginary first equilibrium

	$H_3C_6H_5O_7$ (aq)	$+H_2O$ (l)	↔	H_3O^+ (aq)	+ $H_2C_6H_5O_7^-$ (aq)
I	0.100 M	-		0	0
C	-0.00808	-0.00808		+0.00808	+0.00808
E	0.092 still same	-		0.00808 Now 0.0121	0.00808 Now 0.004

It can't be at equilibrium anymore.

The assumption that I can treat the equilibria separately relies on them not undoing each other. The bigger the K difference, the better. Otherwise, you have to solve both K's simultaneously rather than consecutively.

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