Slide 1

Titrations

An Introduction

Slide 2

Have a cookie…

Does anyone remember my delicious cookie recipe…

1 cup flour + 24 choc. chips → 3 cookies

(NO SUGAR ADDED! ☺)

Slide 3

Titrations

This is the purpose of a titration: determining the thing you can't see based on the thing you know.

Usually, chemical titrations involve relating the reactants to each other rather than relating the reactants to the product (as we just did)

Slide 4

Back to the Cookies

If I used 8 cups of flour to make these cookies, how many chocolate chips did I have?

8 cups flour * $\frac{24 \text{ choc. chips}}{1 \text{ cup flour}}$ = 192 chips

You're sure?

Of course you are! Even though we didn't count the chips

Slide 5

How many chips do you have?

You know how many chips, without counting them because you know how many chips in each cookie!

2 cookies * $\frac{24 \text{ choc. chips}}{3 \text{ cookies}}$ = 16 choc chips

Slide 6

Titrations

It's all about the moles, folks! (Isn't it always…)

Suppose I have a solution of waste water and I need to know how much Compound A (like chocolate chips only toxic! ☹) is in it. How would you do it?

Find something that reacts with Compound A in a known chemical reaction:

$A + 2\,B \rightarrow C$

This is a recipe, it gives an exact ratio between the moles of A and B. So if I know how much B I add to the sample to get it to all react, then I know how much A was there when I started!

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Known vs. Unknown

$A + 2\,B \rightarrow C$

Well, if I add "B" to the sample, what will happen?

If I add "B" to the sample, it should form "C" but only if…

…I have "A"

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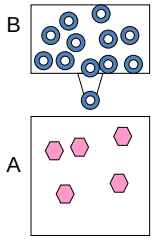
$A + 2\,B \leftrightarrows C$

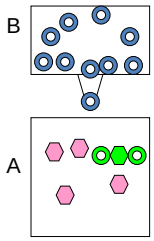


So, I start with "5 As" in my beaker and then add B to it.

What happens?

Slide 9

$A + 2\,B \leftrightarrows C$



After I add 2 Bs, I get one C…

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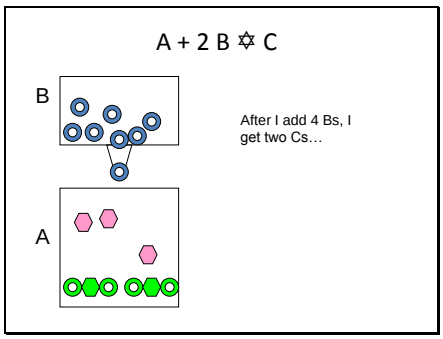

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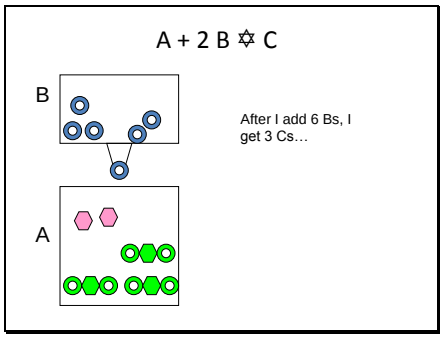

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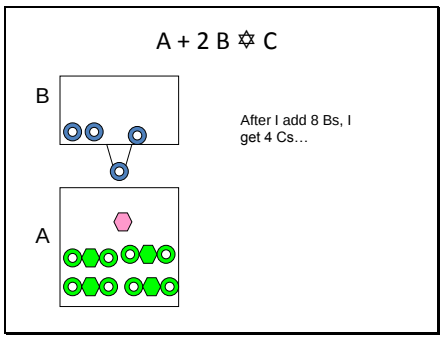

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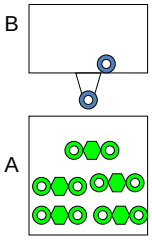
Watching A:



After I add 10 Bs,
I get 5 Cs…

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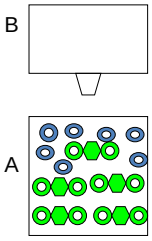
A + 2 B ✡ C



After I add 1,000,000 Bs, I get 5 Cs.

As soon as I ran out of A, the amount of B becomes irrelevant! I can't make C without both A and B!

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Completion of the Reaction

A + 2 B → C

So, if I think A is there, I can add known amounts of B. If I form C, then there was A there. If I gradually add more known amounts of B until I stop forming C, then I'll know how much A was originally there.

How much?

Slide 16

Equivalence Point

$A + 2\ B \rightarrow C$

I stop making C when

Moles of B added = 2x moles of A original there!

This is called the equivalence point!

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Titrations

ALL titrations work the same way:

You have an unknown amount of one compound (call it A).

You have a known amount of a different compound (call it B).

You know a chemical reaction that occurs between A and B.

Add B until no more reaction occurs.

The amount of A is stoichiometrically equivalent to B!

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The "tough part":

How do I know the reaction has stopped?

1. I get no new C.
2. I have no B left.
3. I have extra A left over.

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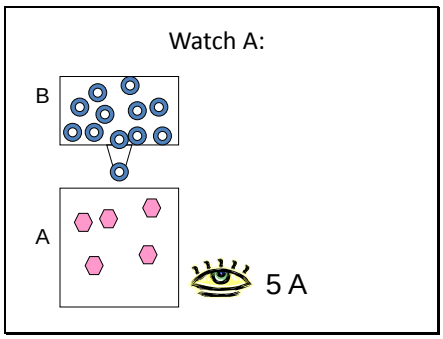

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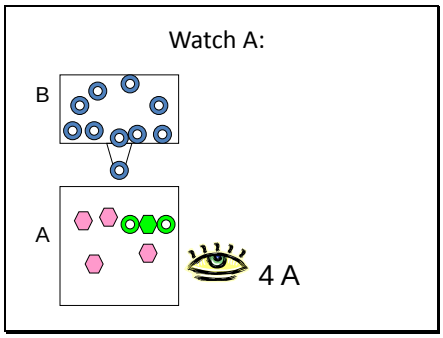

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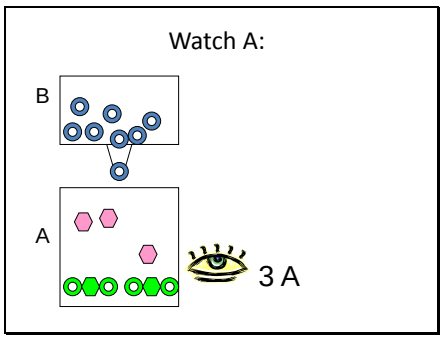

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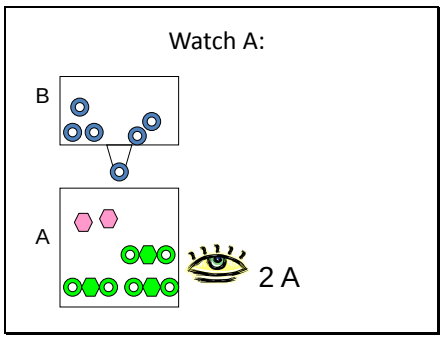

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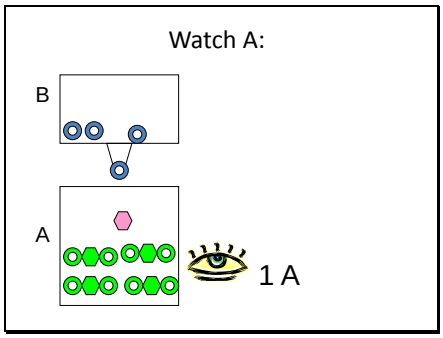

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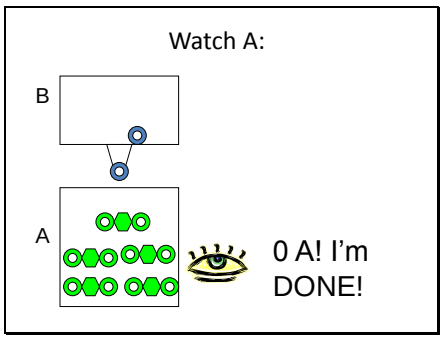

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Or you could watch B

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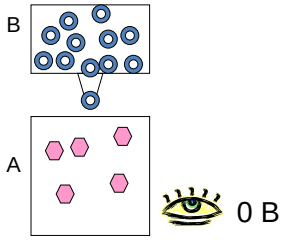
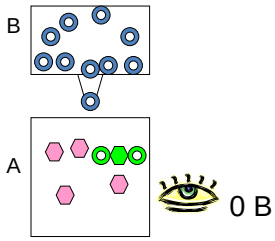
Watch B:



Slide 27

Watch B:



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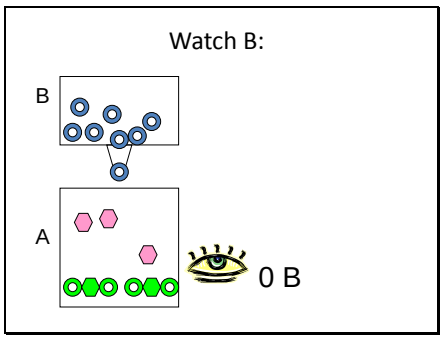

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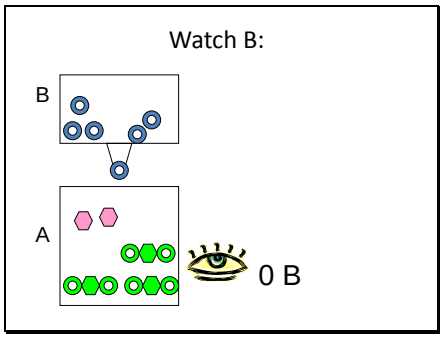

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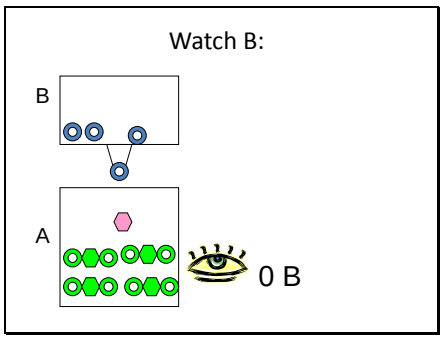

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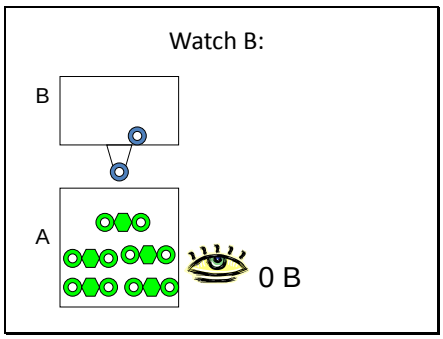

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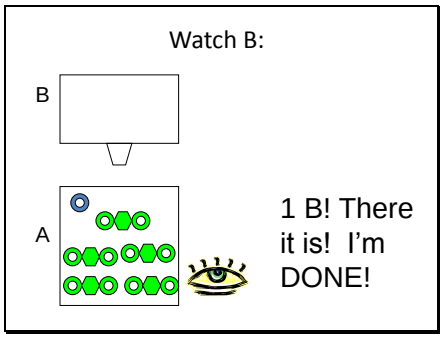

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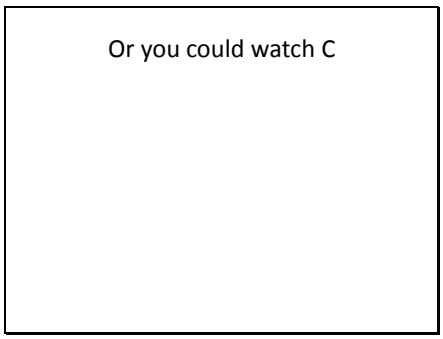

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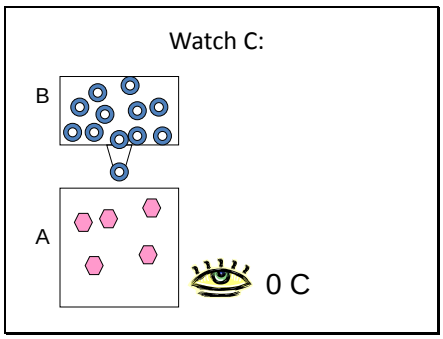

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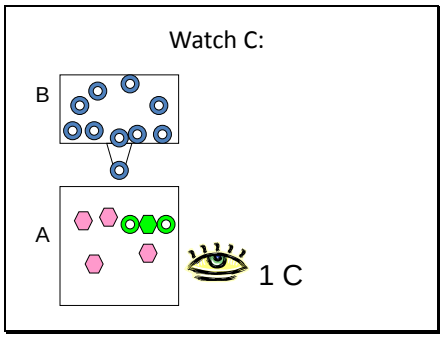

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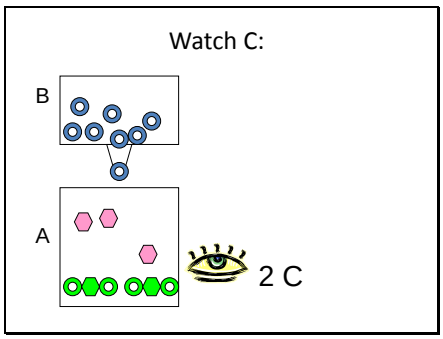

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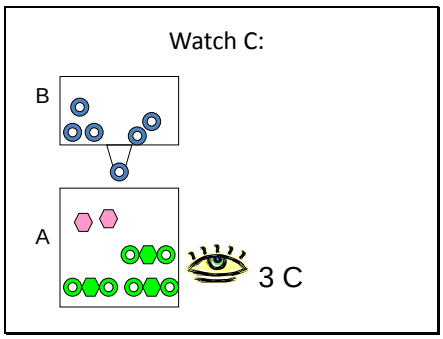

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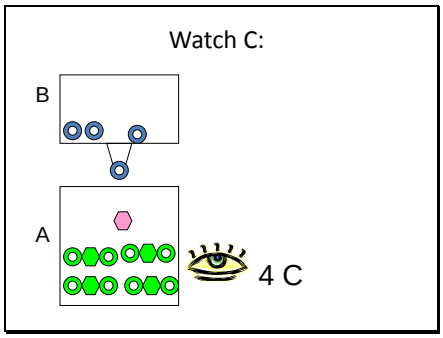

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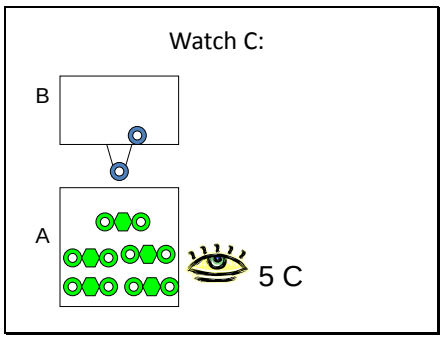

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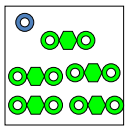
Watch C:

B



A

Still 5 C!
I'm DONE!

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A and B are easier to watch…

…it's more obvious if there is none vs. some.

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Acid/Base Titrations

How does this work for an acid/base titration?

What is the first thing we need to know?

EXACTLY! The Chemical Reaction

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Acid-base Reaction

In an acid/base titration, the generic reaction is:

$H^+ + OH^- \rightarrow H_2O$

$H_3O^+ + OH^- \rightarrow 2\ H_2O$

An acid is a proton donor (H^+)

A base is a proton acceptor, is it always an OH^-? Does it matter?

Slide 44

$H^+ + OH^- \rightarrow H_2O$

As I make water, by adding OH^- to H^+ (or H^+ to OH^-), the pH changes.

How do I know that I'm done adding…?

When I reach "equivalence" (I'm "done"), the pH should be…

7 (for strong acids/bases)

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Indicators of the endpoint

- You can use a pH meter to monitor pH.
- You can use chemical indicators to monitor pH. Some dyes change color when the pH changes. If you add a little bit of one of these dyes that changes color around pH = 7, then it will change color when you reach equivalence.

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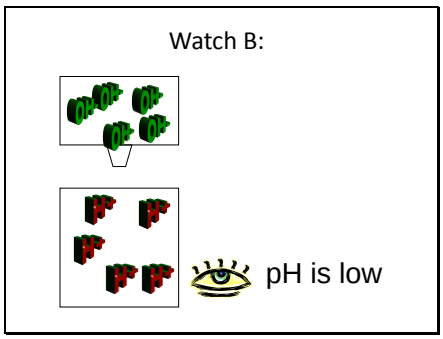

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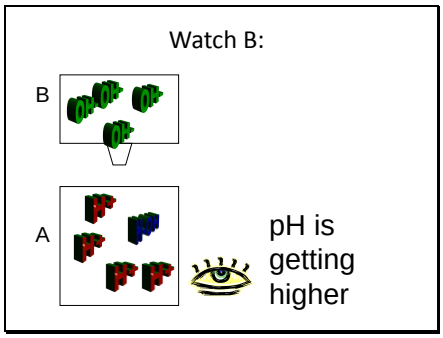

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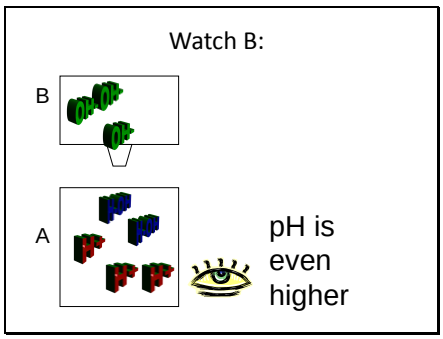

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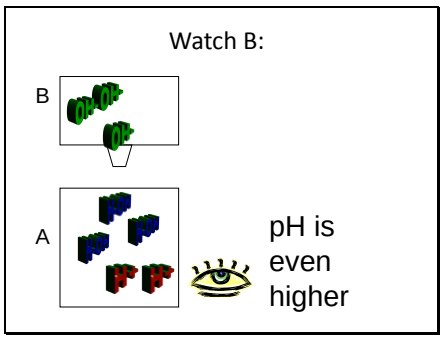

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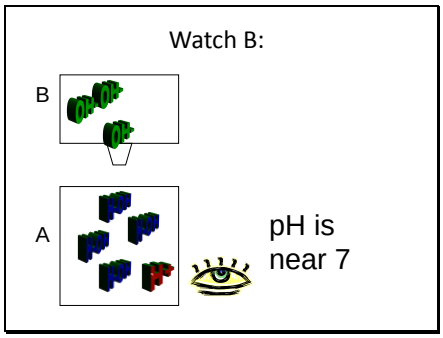

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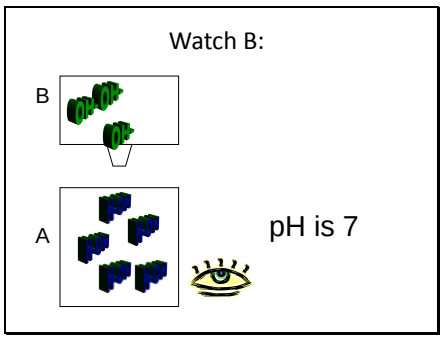
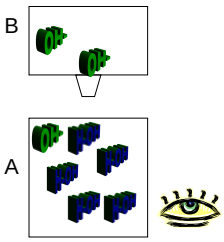


Slide 52

Watch B:



pH is over 7

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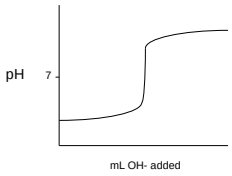
pH vs. mL Base added



Slide 54

An example of titration.

I have a 25.00 mL sample of an acid of unknown concentration. After addition of 13.62 mL of a 0.096 M NaOH solution, equivalence was reached. What was the concentration of acid in the original wastewater sample?

Where do I start?

Slide 55

Chemical Reaction:

$H^+ + OH^- \rightarrow H_2O$

At equivalence…?

Moles of H^+ = Moles of OH^- added

Slide 56

An example of titration.

I have a 25.00 mL sample of an acid of unknown concentration. After addition of 13.62 mL of a 0.096 M NaOH solution, equivalence was reached. What was the concentration of acid in the original wastewater sample?

What do I need to determine?
Moles of OH^- added!
How do I figure that out?
Molarity combined with volume!

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The solution

$$13.62 \text{ mL NaOH} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.01362 \text{ L NaOH added}$$

$$0.096 \text{ M NaOH} = \frac{0.096 \text{ moles NaOH}}{1 \text{ L solution}}$$

$$\frac{0.096 \text{ moles NaOH}}{1 \text{ L solution}} * 0.01362 \text{ L} = 1.308 \times 10^{-3} \text{ moles NaOH}$$

What does that number tell us?
How many moles of H^+ were originally there!
1.308×10^{-3} moles NaOH added = 1.308×10^{-3} moles H^+ in original sample

Slide 58

An example of titration.

I have a 25.00 mL sample of an acid of unknown concentration. After addition of 13.62 mL of a 0.096 M NaOH solution, equivalence was reached. What was the concentration of acid in the original wastewater sample?

1.308×10^{-3} moles H^+ in original sample
Am I done?
Not quite. We need the concentration of acid:
How do I calculate that?
Molarity = moles/L

Slide 59

An example of titration.

I have a 25.00 mL sample of an acid of unknown concentration. After addition of 13.62 mL of a 0.096 M NaOH solution, equivalence was reached. What was the concentration of acid in the original wastewater sample?

$\frac{1.308 \times 10^{-3} \text{ moles } H^+ \text{ in original sample}}{0.02500 \text{ L original sample`}} = 0.0523 \text{ M } H+$

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Clicker Question

Does that make sense?

A. Move on
B. Go Back
C. Drop dead

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Another little problem

A 10.00 mL sample of waste water is titrated to its phenolphthalein endpoint by addition of 36.32 mL of 0.0765 M NaOH. What is the pH of the original waste water sample?

36.32 mL * 0.0756 M = 10.00 mL * X M

X = 0.2745 M

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

Does the [H+] = [acid]?

What if it's a polyprotic acid?

0.2745 M of what?

Of $[H^+]$ – we reacted the waste water with OH^-, all we know is the equivalent amount of H^+ - which is all we need to know to get the pH

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

pH = - log (0.2745 M)

pH = 0.56

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Another Little Problem

Titration of 25.00 mL of an unknown sulfuric acid solution required 43.57 mL of 0.1956 M NaOH to reach equivalence. What is the concentration of the sulfuric acid?

What do you need to notice about this problem?

Sulfuric Acid (H_2SO_4) is a diprotic acid.

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If it helps…

…write the balanced equation (a chemist would).

$H_2SO_{4\,(aq)} + 2\ NaOH_{\,(aq)} \rightarrow Na_2SO_{4\,(aq)} + 2\ H_2O_{\,(l)}$

This is sometimes written as a "net ionic equation":

$H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{\,(l)}$

Slide 66

Stoichiometry ALWAYS Matters

1*43.57 mL*0.1956 M = 2*25.00 mL * X M

X = 0.1704 M H_2SO_4

If you wanted to calculate the pH…?

You need to again consider stoichiometry: each H_2SO_4 gives 2 protons

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2 $[H_2SO_4]$ = [H+]

2*0.1704 M = 0.3408 M H^+

pH = - log (0.3408) = 0.47

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Acid-base Reaction

Acid + Base ✡ H_2O + salt

HA + MB ✡ H-B + MA

An acid is a proton donor (H^+)

A base is any proton acceptor – where'd the OH^- come from?

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Acid-base Reaction

It could come from the base:

HCl + NaOH ✡ H_2O + NaCl

But, not all bases have an OH:

HCl + NH_3 ✡???

NH_3 + H_2O ❁ NH_4OH

HCl + NH_4OH ✡ H_2O + NH_4Cl

You can always generate OH^- in water, because water can always act as an acid.

Slide 70

A little bitty problem…

A 10.00 mL sample of waste water is titrated to its phenolphthalein endpoint by addition of 36.32 mL of 0.0765 M NaOH. What is the pH of the original waste water sample?

(This is just another way to phrase the question.)

Slide 71

Solution

A 10.00 mL sample of waste water is titrated to its phenolphthalein endpoint by addition of 36.32 mL of 0.0765 M NaOH. What is the pH of the original waste water sample?

36.32 mL * 0.0756 M = 10.00 mL * X M

X = 0.2745 M

Slide 72

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

Does the [H+] = [acid]?

What if it's a polyprotic acid?

0.2745 M of what?

Of $[H^+]$ – we reacted the waste water with OH^-, all we know is the equivalent amount of H^+ - which is all we need to know to get the pH

Slide 73

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

pH = - log (0.2745 M)

pH = 0.56

Slide 74

A Little Clicker Problem

Titration of 25.00 mL of an unknown sulfuric acid solution required 21.78 mL of 0.1956 M NaOH to reach equivalence. What is the concentration of the sulfuric acid?

A. 0.1704 M
B. 0.3408 M
C. 0.0852 M
D. 0.2245 M
E. 0.1123 M

Slide 75

If it helps…

…write the balanced equation (a chemist would).

$H_2SO_{4\,(aq)} + 2\ NaOH_{(aq)} \rightarrow Na_2SO_{4\,(aq)} + 2\ H_2O_{(l)}$

This is sometimes written as a "net ionic equation":

$H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$

Slide 76

Stoichiometry ALWAYS Matters

1*21.78 mL*0.1956 M = 2*25.00 mL * X M

X = 0.0852 M H_2SO_4

If you wanted to calculate the pH…?

You need to again consider stoichiometry: each H_2SO_4 gives 2 protons

Slide 77

Another Little Problem

Titration of 25.00 mL of an unknown sulfuric acid solution required 43.57 mL of 0.1956 M NaOH to reach equivalence. What is the concentration of the sulfuric acid?

What do you need to notice about this problem?

Sulfuric Acid (H_2SO_4) is a diprotic acid.

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If it helps…

…write the balanced equation (a chemist would).

$H_2SO_{4\,(aq)} + 2\ NaOH_{(aq)} \rightarrow Na_2SO_{4\,(aq)} + 2\ H_2O_{(l)}$

This is sometimes written as a "net ionic equation":

$H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$

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Stoichiometry ALWAYS Matters

1*43.57 mL*0.1956 M = 2*25.00 mL * X M

X = 0.1704 M H_2SO_4

If you wanted to calculate the pH…?

You need to again consider stoichiometry: each H_2SO_4 gives 2 protons

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2 [H_2SO_4] = [H+]

2*0.1704 M = 0.3408 M H^+

pH = - log (0.3408) = 0.47