An Approach to Stoichiometry

- It begins with an analogy…

- It uses a grid…

- And it builds…

The ACME Trike Co.

The challenge: make 6,000 trikes

Each trike needs: one frame
three wheels
two handle-bar grips

Suppliers ship in these quantities: 12 frames/case
100 wheels/box
15 grips/lbs

How many cases, boxes and lbs need to be ordered?

Suggested strategy…

- Be intelligent—be a chemist.
- Write a chemical equation.

  $F + W + G \rightarrow FW_3G_2$

- Balance the equation

  $F + 3\,W + 2\,G \rightarrow FW_3G_2$

- Construct a grid: ***Bill's Box!***

Constructing *Bill's Box*

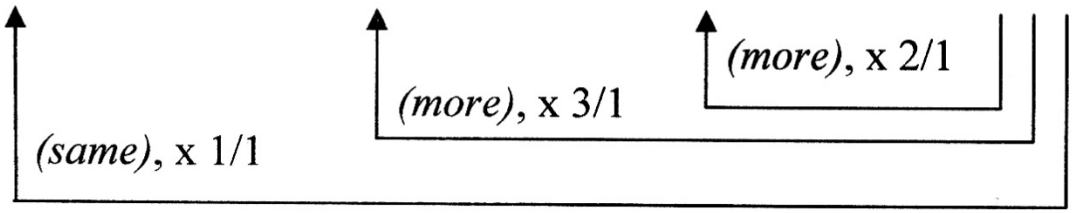
- Underneath the equation, draw 3 rows
- Draw columns
  # columns = # reactants + # products + 1
- Label rows:
  - Top row “amount”
  - Bottom row “count”
- Define the problem
  - Enter the given information
  - Identify the question(s)

$$F + 3W + 2G \rightarrow FW_3G_2$$

amount	? cases	? boxes	? lbs	
count				6,000

- Calculate the # of each component
- Use the coefficients to move along the bottom line

	F +	3 W +	2 G →	FW_3G_2
amount	? cases	? boxes	? lbs	
count	**6,000**	**18,000**	**12,000**	6,000



- Label the middle row “conversion information”
- Enter the information needed to go from count to amount:

12 frames/case 100 wheels/box 15 grips/lbs

	F +	3 W +	2 G →	FW_3G_2
amount	? cases	? boxes	? lbs	
conv info	**12 F/case**	**100 W/box**	**15 G/lbs**	
count	6,000	18,000	12,000	6,000 ★

	F +	3 W +	2 G →	FW_3G_2
amount	**500 cases**	**180 boxes**	**800 lbs**	
conv info	12 F/case	100 W/box	15 G/lbs	
count	6,000	18,000	12,000	6,000 ★

- Calculate amounts: cases, boxes, and lbs
- You have done it! Congratulations!

Emphasize the bottom line

- Using the coefficients, you can move from any bottom line box to any other.
- Move up & down (↕) using conversion information.
- Move along the top line at your own risk!

	F +	3 W +	2 G →	FW_3G_2
amount				
conv info				
count	**3,000**	**9,000**	6,000 ✱	**3,000**

(less), x 1/2 *(more)*, x 3/2 *(less)*, x 1/2

From Trikes to “Stoichiometry”

- Let’s apply this to a chemistry problem:
  23.45 g of octane is burned
- How much oxygen is required?
- How much of each product is produced?
  “How much” means *what mass (g)*?

Use Bill's Box

Start with the chemical equation
First identify reactants & products
Be sure to have the *correct formulas*!
THEN balance the equation.

$$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$$

Finish the set up

- Top line → amount (grams)
- Bottom line → moles (mol)
- Conversion information → g/mol

  Alert – when calculating g/mol:

  - Consider ***<u>just</u>*** the formula
  - Ignore the coefficient
- Identify starting point & destinations (?'s)

$$2\ C_8H_{18} + \quad 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$$

amount	23.45 g✱	? g	? g	? g
conv info	114.2 g/mol	32.00 g/mol	44.01 g/mol	18.02 g/mol
moles	mol	mol	mol	mol

Do your calculations

- Use at least 3 significant figures

$$2\ C_8H_{18} + 25\ O_2 \rightarrow 16\ CO_2 + 18\ H_2O$$

amount	23.45 g ★	82.14 g	72.30 g	33.30 g
conv info	114.2 g/mol	32.00 g/mol	44.01 g/mol	18.02 g/mol
moles	*0.2053 mol*	*2.567 mol*	*1.643 mol*	*1.848 mol*

- Add up the mass of the reactants **105.59 g**
- Add up the mass of the products **105.60 g**
- How do these sums compare?
- What law predicts this?

Acid/base, Solutions & Molarity

- A more challenging problem:
  Using phenolphthalein as an indicator, 0.01500 L **of** 0.1876 M **H_2SO_4 is titrated with** 0.03456 L **of NaOH**
- What is the concentration of the NaOH?
- How much Na_2SO_4 is produced?

Once again, use Bill's Box

- Start with the chemical equation.
- First identify reactants & products.
- Be sure to have the *correct formulas*!!
- THEN balance the equation.

$$H_2SO_4(aq) + 2\ NaOH(aq) \rightarrow Na_2SO_4 + 2\ H_2O$$

Finish the set up

- Top line is amount:
  - grams (g) for mass
  - liters (L) for solutions
- As always, bottom line is moles (mol)
- Conversion information is:
  - g/mol for mass
  - moles/liter (M) for volume of solutions
- Identify starting point & destinations (?'s)

H_2SO_4 (aq) + 2 NaOH (aq) → Na_2SO_4 + 2 H_2O

amount	0.01500 L ★	0.03456 L	? g	
conv info	0.1876 M	? mol/L	142.0 g/mol	
moles	mol	mol	mol	

Do your calculations

- Use at least 3 significant figures
- In titrations, equivalence point (color change) occurs when the acid/base molar ratio matches the ratio of the coefficients.
- **Recall:**

  molarity = moles/liter (M = mol/L)

  moles = molarity·liter (mol = M·L)

H_2SO_4 (aq) + 2 NaOH (aq) → Na_2SO_4 + 2 H_2O

amount	0.01500 L ★	0.03456 L	**0.3996 g**	
conv info	0.1876 M	**0.1628 mol/L**	142.0 g/mol	
moles	*0.002814 mol*	*0.005628 mol*	*0.002814 mol*	

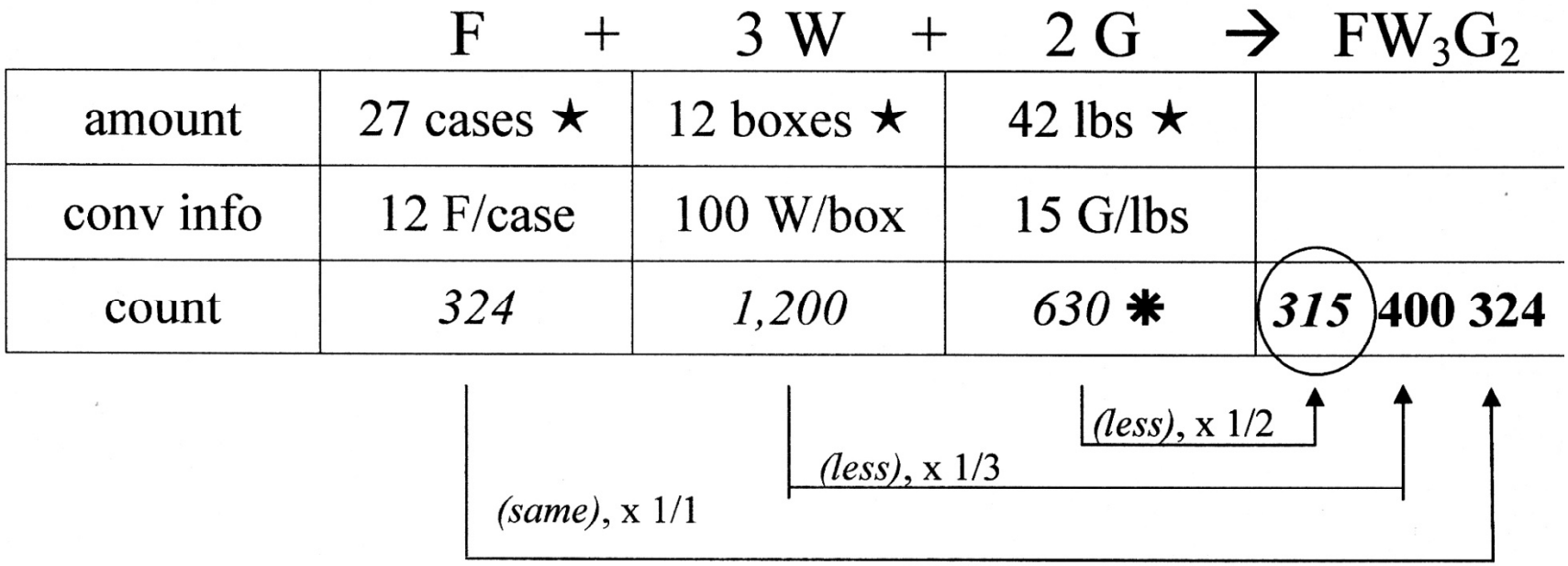
Back to Trikes—Limiting Reactants

- There have been problems at Acme:
  Part orders have been delayed.
  Suppliers have under & over shipped.
- Talented Will is recruited to do an inventory.
- The results are: 27 cases of frames
  12 boxes of wheels
  42 lbs of grips
- Now how many trikes *can* be made?
- What part will be completely consumed?

- Set up Bill's Box
- Starting from **<u>each</u>** part, calculate the number of trikes that can be produced.
- You will have three different answers.

  They can't all be right.

  Which one is correct?



- The smallest answer is correct.
  You will run out of grips.
  You have extra frames and wheels.
- Grips are the ***"limiting reactant."***
- Frames & wheels are ***"in excess."***

The Full Monty

- **Four copper pennies (**12.3 g**) react with** 0.0405 L 16.0 M **HNO_3.**
- Which reactant is in excess and by how much?
- At 25.0 ˚C and 0.987 atm what volume of NO_2 gas is produced?
- What mass of $Cu(NO_3)_2$ and H_2O is produced?

Do the usual setup

- Use the ideal gas equation to relate moles of gas to volume.
- Conversion information for IGE includes temp (K), pressure & the appropriate R.

$Cu\ (s) + 4\ HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\ NO_2(g) + 3\ H_2O\ (l)$

amount	12.3 g ★	0.0405 L ★	? g	? L	? g
conv info	63.6 g/mol	16.0 M	188 g/mol	25.0°C=298K 0.987 atm	18.02 g/mol
moles	mol	mol	mol	mol	mol

Determine the Limiting Reactant

$Cu\ (s) + 4\ HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\ NO_2(g) + 3\ H_2O\ (l)$

amount	12.3 g ★	0.0405 L ★	? g	? L	? g
conv info	63.6 g/mol	16.0 M	188 g/mol	25.0°C=298K 0.987 atm	18.0 g/mol
moles	***0.193 mol***	***0.648 mol*** ✱	*0.193 mol* ***0.162 mol***		

Calculate—Utilizing the IGE

$Cu\ (s) + 4\ HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\ NO_2(g) + 3\ H_2O\ (l)$

amount	12.3 g ★	0.0405 L ★	**30.5 g**	**8.03 L**	**8.75 g**
conv info	63.6 g/mol	16.0 M	188 g/mol	25.0°C=298K 0.987 atm	18.0 g/mol
moles	*0.193 mol*	*0.648 mol* ✱	*0.162 mol*	*0.324 mol*	*0.486 mol*

−0.162 mol (consumed)

0.031 mol (excess) x 63.6 g/mol = **2.0 g excess Cu**

Hints for Students

- Start with correct formulas
- Balance the equation
- Enter given information
- For g/mol calculations, ignore coefficients
- Identify targets
- Include units
- Maximize sig. figs. (3+)
- Stick to the bottom line for "horizontal" calculations.
- Are answers reasonable?
- Considering coefficients, do moles increase/decrease?
- For mass, is it more than a mole or less than a mole?
- Calculations of products are "*theoretical yields.*"
- For IGE calculations:
  - Identify P & T conditions
  - Use temperatures in K
  - Use appropriate R

Student Feedback

- “I still put Bill’s box to good use… “
- “I've taught Bill's Box to five or six of my classmates and they absolutely love it.”
- “…Bill’s box is the greatest invention ever.”
- “I am still using Bill's Box.”
- “I have found Bill's box to be very very helpful! I actually taught my discussion TA how to do Bill's box and he has used it to teach my discussion group how to do certain calculations.”
- “I have been teaching the students in my lecture that I sit near how to do Bill's box and they absolutely love it!”

Additional Resources

- CD
  - This PowerPoint
  - Draft of article (Word & PDF)
  - Refresher sent to graduates (Word & PDF)
- Practice sites
  - http://science.widener.edu/svb/tutorial/index.html
  - http://docott.com/files.141/screencasts/
  - http://www2.hn.psu.edu/faculty/dmencer/combustion/combust_app.htm
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