

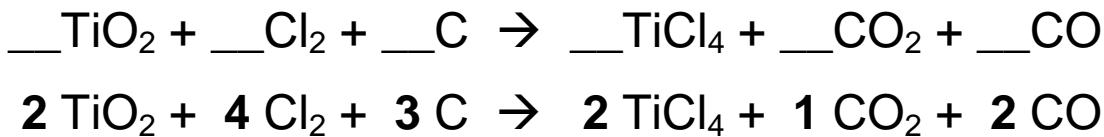
Unit 8: Stoichiometry -- involves finding amts. of reactants & products in a reaction

What can we do with stoichiometry?

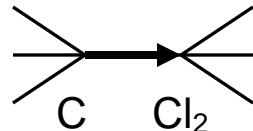
For generic equation: $R_A + R_B \rightarrow P_1 + P_2$

Given the...	...one can find the...
amount of R_A (or R_B)	amount of R_B (or R_A) that is needed to react with it
amount of R_A or R_B	amount of P_1 or P_2 that will be produced
amount of P_1 or P_2 you need to produce	amount of R_A and/or R_B you must use



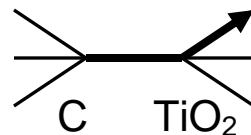


How many mol chlorine will react with 4.55 mol carbon?



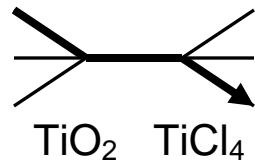
$$X \text{ mol Cl}_2 = 4.55 \text{ mol C} \left(\frac{4 \text{ mol Cl}_2}{3 \text{ mol C}} \right) = \boxed{6.07 \text{ mol Cl}_2}$$

What mass titanium (IV) oxide will react with 4.55 mol carbon?



$$X \text{ g TiO}_2 = 4.55 \text{ mol C} \left(\frac{2 \text{ mol TiO}_2}{3 \text{ mol C}} \right) \left(\frac{79.9 \text{ g TiO}_2}{1 \text{ mol TiO}_2} \right) = \boxed{242 \text{ g TiO}_2}$$

How many molecules titanium (IV) chloride can be made from 115 g titanium (IV) oxide?



$$X \text{ m}'\text{c} \text{ TiCl}_4 = 115 \text{ g TiO}_2 \left(\frac{1 \text{ mol TiO}_2}{79.9 \text{ g TiO}_2} \right) \left(\frac{2 \text{ mol TiCl}_4}{2 \text{ mol TiO}_2} \right) \left(\frac{6.02 \times 10^{23}}{\text{m}'\text{c} \text{ TiCl}_4} \right)$$

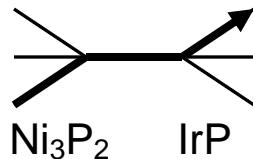
$$= \boxed{8.7 \times 10^{23} \text{ m}'\text{cules TiCl}_4}$$

Island Diagram helpful reminders:

1. Use coefficients from the equation only when crossing the middle bridge. The other six bridges always have “1 mol” before a substance’s formula.
2. The middle bridge conversion factor is the only one that has two different substances in it. The conversion factors for the other six bridges have the same substance in both the numerator and denominator.
3. The units on the islands at each end of the bridge being crossed appear in the conversion factor for that bridge.

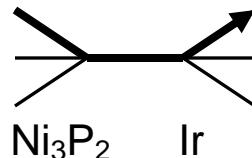


If 5.33×10^{28} molecules nickel (II) phosphide react w/excess iridium, what mass iridium (III) phosphide are produced?



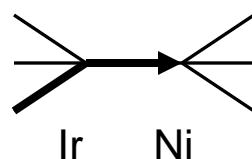
$$\begin{aligned} X \text{ g IrP} &= 5.33 \times 10^{28} \text{ molecules Ni}_3\text{P}_2 \left(\frac{1 \text{ mol Ni}_3\text{P}_2}{6.02 \times 10^{23} \text{ molecules}} \right) \left(\frac{2 \text{ mol IrP}}{1 \text{ mol Ni}_3\text{P}_2} \right) \left(\frac{223.2 \text{ g IrP}}{1 \text{ mol IrP}} \right) \\ &= \boxed{3.95 \times 10^7 \text{ g IrP}} \end{aligned}$$

How many grams iridium will react with 465 grams nickel (II) phosphide?



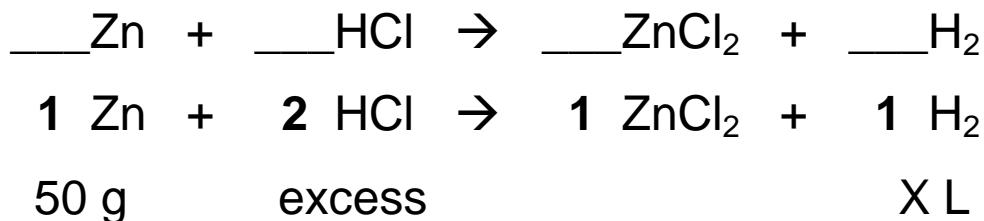
$$\begin{aligned} X \text{ g Ir} &= 465 \text{ g Ni}_3\text{P}_2 \left(\frac{1 \text{ mol Ni}_3\text{P}_2}{238.1 \text{ g Ni}_3\text{P}_2} \right) \left(\frac{2 \text{ mol Ir}}{1 \text{ mol Ni}_3\text{P}_2} \right) \left(\frac{192.2 \text{ g Ir}}{1 \text{ mol Ir}} \right) \\ &= \boxed{751 \text{ g Ir}} \end{aligned}$$

How many moles of nickel are produced if 8.7×10^{25} atoms of iridium are consumed?



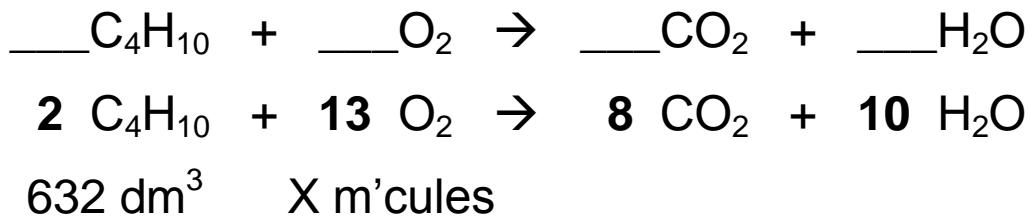
$$\begin{aligned} X \text{ mol Ni} &= 8.7 \times 10^{25} \text{ atoms Ir} \left(\frac{1 \text{ mol Ir}}{6.02 \times 10^{23} \text{ atoms Ir}} \right) \left(\frac{3 \text{ mol Ni}}{2 \text{ mol Ir}} \right) \\ &= \boxed{217 \text{ mol Ni}} \end{aligned}$$

What volume hydrogen gas is liberated (at STP) if 50 g zinc react w/excess hydrochloric acid (HCl)?



$$XL\text{H}_2 = 50\text{ g Zn} \left(\frac{1\text{ mol Zn}}{65.4\text{ g Zn}} \right) \left(\frac{1\text{ mol H}_2}{1\text{ mol Zn}} \right) \left(\frac{22.4\text{ L H}_2}{1\text{ mol H}_2} \right) = \boxed{17.1\text{ L H}_2}$$

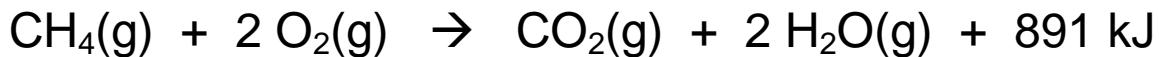
At STP, how many m'cules oxygen react w/632 dm³ butane (C₄H₁₀)?



$$X\text{ m'c O}_2 = 632\text{ dm}^3 \text{ C}_4\text{H}_{10} \left(\frac{1\text{ mol C}_4\text{H}_{10}}{22.4\text{ dm}^3 \text{ C}_4\text{H}_{10}} \right) \left(\frac{13\text{ mol O}_2}{2\text{ mol C}_4\text{H}_{10}} \right) \left(\frac{6.02 \times 10^{23}}{1\text{ mol O}_2} \right)$$

$$= \boxed{1.10 \times 10^{26} \text{ m'cules O}_2}$$

Energy and Stoichiometry



How many kJ of energy are released when 54 g methane are burned?

$$X \text{ kJ} = 54 \text{ g CH}_4 \left(\frac{1 \text{ mol CH}_4}{16 \text{ g CH}_4} \right) \left(\frac{891 \text{ kJ}}{1 \text{ mol CH}_4} \right) = \boxed{3007 \text{ kJ}}$$

At STP, what volume oxygen is consumed in producing 5430 kJ of energy?

$$X \text{ L O}_2 = 5430 \text{ kJ} \left(\frac{2 \text{ mol O}_2}{891 \text{ kJ}} \right) \left(\frac{22.4 \text{ L O}_2}{1 \text{ mol O}_2} \right) = \boxed{273 \text{ L O}_2}$$

What mass of water is made if 10,540 kJ are released?

$$X \text{ g H}_2\text{O} = 10,540 \text{ kJ} \left(\frac{2 \text{ mol H}_2\text{O}}{891 \text{ kJ}} \right) \left(\frac{18 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} \right) = \boxed{426 \text{ g H}_2\text{O}}$$

The Limiting Reactant

A balanced equation for making a Big Mac® might be:



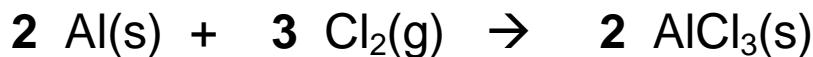
With...	...and...	...one can make...
30 M	excess B and excess EE	15 $\text{B}_3\text{M}_2\text{EE}$
30 B	excess M and excess EE	10 $\text{B}_3\text{M}_2\text{EE}$
30 M	30 B and excess EE	10 $\text{B}_3\text{M}_2\text{EE}$

A balanced equation for making a tricycle might be:



With...	...and...	...one can make...
50 P	excess of all other reactants	25 $\text{W}_3\text{P}_2\text{SHF}$
50 S	excess of all other reactants	50 $\text{W}_3\text{P}_2\text{SHF}$
50 P	50 S and excess of all other reactants	25 $\text{W}_3\text{P}_2\text{SHF}$

Solid aluminum reacts ^w/chlorine gas to yield solid aluminum chloride.



If 125 g aluminum react ^w/excess chlorine, how many g aluminum chloride are made?

$$\begin{aligned} X \text{ g AlCl}_3 &= 125 \text{ g Al} \left(\frac{1 \text{ mol Al}}{27 \text{ g Al}} \right) \left(\frac{2 \text{ mol AlCl}_3}{2 \text{ mol Al}} \right) \left(\frac{133.5 \text{ g AlCl}_3}{1 \text{ mol AlCl}_3} \right) \\ &= \boxed{618 \text{ g AlCl}_3} \end{aligned}$$

If 125 g chlorine react ^w/excess aluminum, how many g aluminum chloride are made?

$$\begin{aligned} X \text{ g AlCl}_3 &= 125 \text{ g Cl}_2 \left(\frac{1 \text{ mol Cl}_2}{71 \text{ g Cl}_2} \right) \left(\frac{2 \text{ mol AlCl}_3}{3 \text{ mol Cl}_2} \right) \left(\frac{133.5 \text{ g AlCl}_3}{1 \text{ mol AlCl}_3} \right) \\ &= \boxed{157 \text{ g AlCl}_3} \end{aligned}$$

If 125 g aluminum react ^w/125 g chlorine, how many g aluminum chloride are made?

$$\boxed{157 \text{ g AlCl}_3}$$

We're out of Cl₂.

limiting reactant (LR): the reactant that runs out first

Amount of product is based on LR.

Any reactant you don't run out of is an

excess reactant (ER).

Example	Limiting Reactant	Excess Reactant(s)
Big Macs	buns	meat
tricycles	pedals	W, S, H, F
Al / Cl ₂ / AlCl ₃	Cl ₂	Al

How to Find the Limiting Reactant

For the generic reaction $R_A + R_B \rightarrow P$,

assume that the amounts of R_A and R_B are given.

Should you use R_A or R_B in your calculations?

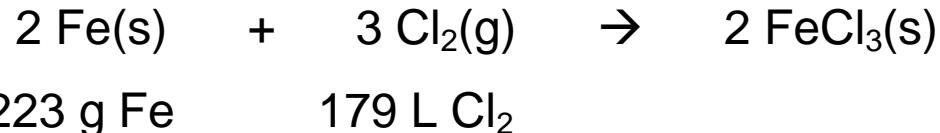
1. Calc. # of mol of R_A and R_B you have.
2. Divide by the respective coefficients in balanced equation.
3. Reactant having the smaller result is the LR.

For the Al / Cl₂ / AlCl₃ example:

$$X \text{ mol Al} = 125 \text{ g Al} \left(\frac{1 \text{ mol Al}}{27 \text{ g Al}} \right) = \underline{\underline{4.63 \text{ mol Al (HAVE)}}} \div 2 = 2.31$$

$$X \text{ mol Cl}_2 = 125 \text{ g Cl}_2 \left(\frac{1 \text{ mol Cl}_2}{71 \text{ g Cl}_2} \right) = \underline{\underline{1.76 \text{ mol Cl}_2 (HAVE)}} \div 3 = 0.58$$

Cl₂ is LR



Which is the limiting reactant: Fe or Cl₂?

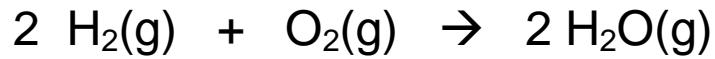
$$X \text{ mol Fe} = 223 \text{ g Fe} \left(\frac{1 \text{ mol Fe}}{55.8 \text{ g Fe}} \right) = \underline{\underline{4.0 \text{ mol Fe (HAVE)}}} \div 2 = 2.00$$

$$X \text{ mol Cl}_2 = 179 \text{ L Cl}_2 \left(\frac{1 \text{ mol Cl}_2}{22.4 \text{ L Cl}_2} \right) = \underline{\underline{8.0 \text{ mol Cl}_2 (HAVE)}} \div 3 = 2.66$$

Fe is LR

How many g FeCl₃ are produced?

$$X \text{ g FeCl}_3 = 4.0 \text{ mol Fe} \left(\frac{2 \text{ mol FeCl}_3}{2 \text{ mol Fe}} \right) \left(\frac{162.3 \text{ g FeCl}_3}{1 \text{ mol FeCl}_3} \right) = \boxed{649 \text{ g FeCl}_3}$$



13 g H₂ 80 g O₂

Which is LR: H₂ or O₂?

$$X \text{ mol H}_2 = 13 \text{ g H}_2 \left(\frac{1 \text{ mol H}_2}{2 \text{ g H}_2} \right) = \underline{\underline{6.5 \text{ mol H}_2 (\text{HAVE})}} \div 2 = 3.25$$

$$X \text{ mol O}_2 = 80 \text{ g O}_2 \left(\frac{1 \text{ mol O}_2}{32 \text{ g O}_2} \right) = \underline{\underline{2.5 \text{ mol O}_2 (\text{HAVE})}} \div 1 = 2.50$$

O₂ is LR

How many g H₂O are formed?

$$X \text{ g H}_2\text{O} = 2.5 \text{ mol O}_2 \left(\frac{2 \text{ mol H}_2\text{O}}{1 \text{ mol O}_2} \right) \left(\frac{18 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} \right) = \boxed{90 \text{ g H}_2\text{O}}$$

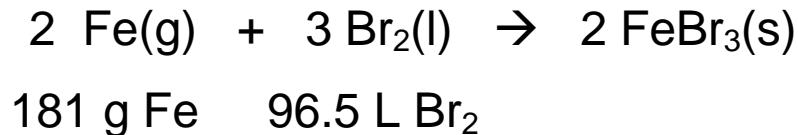
How many g O₂ are left over?

zero; O₂ is all used up

How many g H₂ are left over?

$$X \text{ g H}_2 (\text{USED}) = 2.5 \text{ mol O}_2 \left(\frac{2 \text{ mol H}_2}{1 \text{ mol O}_2} \right) \left(\frac{2 \text{ g H}_2}{1 \text{ mol H}_2} \right) = 10 \text{ g H}_2 (\text{USED})$$

3 g H₂ left over



Find LR.

$$X \text{ mol Fe} = 181 \text{ g Fe} \left(\frac{1 \text{ mol Fe}}{55.8 \text{ g Fe}} \right) = \underline{\underline{3.24 \text{ mol Fe (HAVE)}}} \div 2 = 1.62$$

$$X \text{ mol Br}_2 = 96.5 \text{ L Br}_2 \left(\frac{1 \text{ mol Br}_2}{22.4 \text{ L Br}_2} \right) = \underline{\underline{4.31 \text{ mol Br}_2 (HAVE)}} \div 3 = 1.44$$

Br₂ is LR

How many g FeBr₃ are formed?

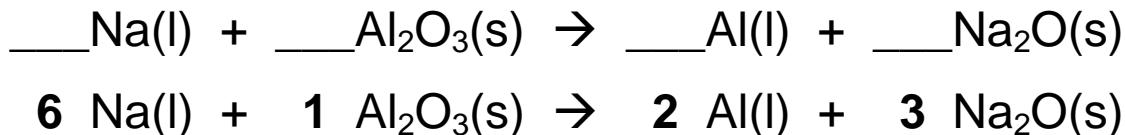
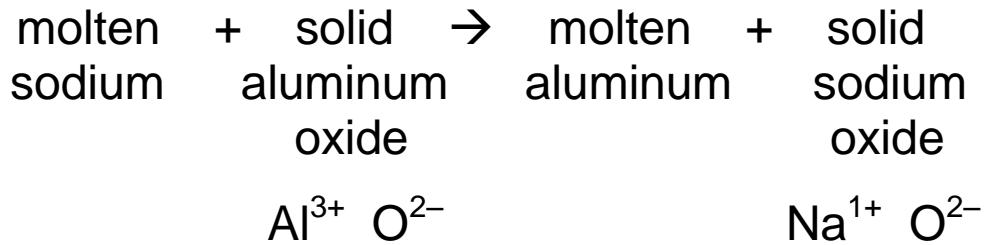
$$X \text{ g FeBr}_3 = 4.31 \text{ mol Br}_2 \left(\frac{2 \text{ mol FeBr}_3}{3 \text{ mol Br}_2} \right) \left(\frac{295.5 \text{ g FeBr}_3}{1 \text{ mol FeBr}_3} \right) = \boxed{849 \text{ g FeBr}_3}$$

How many g of the ER are left over?

$$X \text{ g Fe (USED)} = 4.31 \text{ mol Br}_2 \left(\frac{2 \text{ mol Fe}}{3 \text{ mol Br}_2} \right) \left(\frac{55.8 \text{ g Fe}}{1 \text{ mol Fe}} \right) = 160 \text{ g Fe (USED)}$$

21 g Fe left over

Percent Yield



Find mass of aluminum produced if you start w/ 575 g sodium and 357 g aluminum oxide.

$$X \text{ mol Na} = 575 \text{ g Na} \left(\frac{1 \text{ mol Na}}{23 \text{ g Na}} \right) = \underline{\underline{25 \text{ mol Na (HAVE)}}} \div 6 = 4.17$$

$$X \text{ mol Al}_2\text{O}_3 = 357 \text{ g Al}_2\text{O}_3 \left(\frac{1 \text{ mol}}{102 \text{ g}} \right) = \underline{\underline{3.5 \text{ mol Al}_2\text{O}_3 (HAVE)}} \div 1 = 3.5$$

$$X \text{ g Al} = 3.5 \text{ mol Al}_2\text{O}_3 \left(\frac{2 \text{ mol Al}}{1 \text{ mol Al}_2\text{O}_3} \right) \left(\frac{27 \text{ g Al}}{1 \text{ mol Al}} \right) = \boxed{189 \text{ g Al}}$$

This amount of product is the theoretical yield.

-- amt. we get if reaction is perfect

-- found by calculation

Now suppose that we perform this reaction in the lab and get only 172 grams of aluminum. Why?

- couldn't collect all Al
- not all Na and Al₂O₃ reacted
- some reactant or product spilled and was lost

$$\% \text{ yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

% yield can never be > 100%.

Find % yield for previous problem.

$$\% \text{ yield} = \frac{\text{act. yld.}}{\text{theo. yld.}} \times 100 \rightarrow \frac{172 \text{ g Al}}{189 \text{ g Al}} \times 100 = \boxed{91.0\%}$$

Reaction that powers space shuttle is:



From 100 g hydrogen and 640 g oxygen, what amount of energy is possible?

$$X \text{ mol H}_2 = 100 \text{ g H}_2 \left(\frac{1 \text{ mol H}_2}{2 \text{ g H}_2} \right) = \underline{\underline{50 \text{ mol H}_2 (\text{HAVE})}} \div 2 = 25$$

$$X \text{ mol O}_2 = 640 \text{ g O}_2 \left(\frac{1 \text{ mol O}_2}{32 \text{ g O}_2} \right) = \underline{\underline{20 \text{ mol O}_2 (\text{HAVE})}} \div 1 = 20$$

$$X \text{ kJ} = 20 \text{ mol O}_2 \left(\frac{572 \text{ kJ}}{1 \text{ mol O}_2} \right) = 11,440 \text{ kJ}$$

What mass of excess reactant is left over?

$$X \text{ g H}_2 (\text{USED}) = 20 \text{ mol O}_2 \left(\frac{2 \text{ mol H}_2}{1 \text{ mol O}_2} \right) \left(\frac{2 \text{ g H}_2}{1 \text{ mol H}_2} \right) = 80 \text{ g H}_2 (\text{USED})$$

20 g H₂ left over

On NASA spacecraft, lithium hydroxide “scrubbers” remove toxic CO₂ from cabin.



For a seven-day mission, each of four individuals exhales 880 g CO₂ daily. If reaction is 75% efficient, how many g LiOH should be brought along?

$$X \text{ g CO}_2 = \frac{880 \text{ g CO}_2}{\text{person-day}} (4 \text{ p})(7 \text{ d}) = 24,640 \text{ g CO}_2$$

$$X \text{ g LiOH} = 24,640 \text{ g CO}_2 \left(\frac{1 \text{ mol CO}_2}{44 \text{ g CO}_2} \right) \left(\frac{2 \text{ mol LiOH}}{1 \text{ mol CO}_2} \right) \left(\frac{23.9 \text{ g LiOH}}{1 \text{ mol LiOH}} \right) = \\ = 26,768 \text{ g LiOH (if reaction is perfect)}$$

Need more than this, so $\rightarrow \frac{26,768 \text{ g LiOH}}{0.75} = \boxed{35,700 \text{ g LiOH}}$

** Reality: Take 80,000 g – 100,000 g, just in case.

Automobile air bags inflate with nitrogen via the decomposition of sodium azide:



At STP and a % yield of 85%, what mass sodium azide is needed to yield 74 L nitrogen?

$$\text{Shoot for...} \rightarrow \frac{74 \text{L N}_2}{0.85} = 87.1 \text{L N}_2$$

$$\begin{aligned} X \text{ g NaN}_3 &= 87.1 \text{L N}_2 \left(\frac{1 \text{ mol N}_2}{22.4 \text{ L N}_2} \right) \left(\frac{2 \text{ mol NaN}_3}{3 \text{ mol N}_2} \right) \left(\frac{65 \text{ g NaN}_3}{1 \text{ mol NaN}_3} \right) = \\ &= \boxed{169 \text{ g NaN}_3} \end{aligned}$$

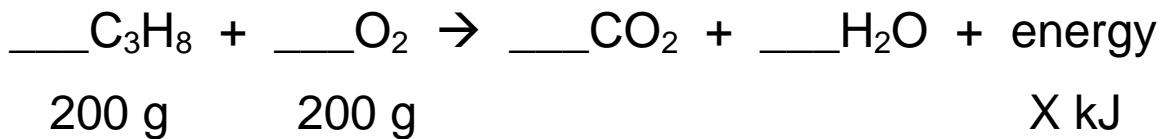


$$10 \text{ g} \quad 30 \text{ g} \quad X \text{ g}$$

$$X \text{ mol B}_2\text{H}_6 = 10 \text{ g B}_2\text{H}_6 \left(\frac{1 \text{ mol}}{27.6 \text{ g}} \right) = \underline{\underline{0.362 \text{ mol B}_2\text{H}_6 (\text{HAVE}) \div 1}} = 0.362$$

$$X \text{ mol O}_2 = 30 \text{ g O}_2 \left(\frac{1 \text{ mol O}_2}{32 \text{ g O}_2} \right) = \underline{\underline{0.938 \text{ mol O}_2 (\text{HAVE}) \div 3}} = 0.313$$

$$X \text{ g B}_2\text{O}_3 = 0.938 \text{ mol O}_2 \left(\frac{1 \text{ mol B}_2\text{O}_3}{3 \text{ mol O}_2} \right) \left(\frac{69.6 \text{ g B}_2\text{O}_3}{1 \text{ mol B}_2\text{O}_3} \right) = \boxed{21.8 \text{ g B}_2\text{O}_3}$$



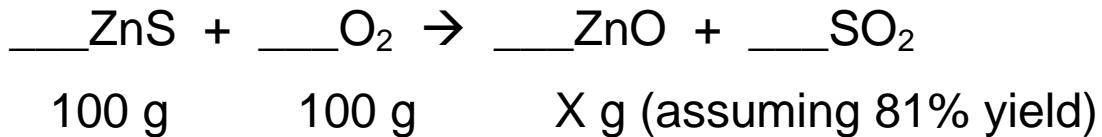
Strategy: 1. Find LR.

2. Use LR to calc. X kJ.

$$X \text{ mol C}_3\text{H}_8 = 200 \text{ g C}_3\text{H}_8 \left(\frac{1 \text{ mol}}{44 \text{ g}} \right) = \frac{4.55 \text{ mol C}_3\text{H}_8 (\text{HAVE})}{1} = 4.55$$

$$X \text{ mol O}_2 = 200 \text{ g O}_2 \left(\frac{1 \text{ mol O}_2}{32 \text{ g O}_2} \right) = \underline{\underline{6.25 \text{ mol O}_2 (\text{HAVE}) \div 5 = 1.25}}$$

$$X \text{ kJ} = 6.25 \text{ mol O}_2 \left(\frac{248 \text{ kJ}}{5 \text{ mol O}_2} \right) = \boxed{310 \text{ kJ}}$$



Strategy:

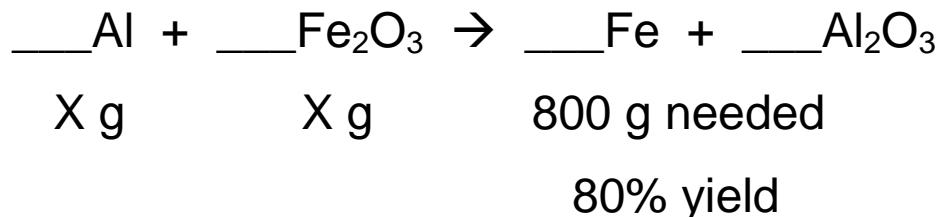
1. Find LR.
2. Use LR to calc. X g ZnO (theo. yield)
3. Actual yield is 81% of theo. yield.

$$X \text{ mol ZnS} = 100 \text{ g ZnS} \left(\frac{1 \text{ mol}}{97.5 \text{ g}} \right) = \underline{\underline{1.026 \text{ mol ZnS (HAVE)}}} \div 2 = 0.513$$

$$X \text{ mol O}_2 = 100 \text{ g O}_2 \left(\frac{1 \text{ mol O}_2}{32 \text{ g O}_2} \right) = \underline{\underline{3.125 \text{ mol O}_2 (HAVE)}} \div 3 = 1.042$$

$$X \text{ g ZnO} = 1.026 \text{ mol ZnS} \left(\frac{2 \text{ mol ZnO}}{2 \text{ mol ZnS}} \right) \left(\frac{81.4 \text{ g ZnO}}{1 \text{ mol ZnO}} \right) = 83.5 \text{ g ZnO}$$

Actual yield is... $83.5 \text{ g ZnO} (0.81) =$ 67.6 g ZnO



$$\text{Shoot for...} \rightarrow \frac{800 \text{ g Fe}}{0.80} = 1000 \text{ g Fe}$$

$$X \text{ g Al} = 1000 \text{ g Fe} \left(\frac{1 \text{ mol Fe}}{55.8 \text{ g Fe}} \right) \left(\frac{2 \text{ mol Al}}{2 \text{ mol Fe}} \right) \left(\frac{27 \text{ g Al}}{1 \text{ mol Al}} \right) = \boxed{484 \text{ g Al}}$$

$$X \text{ g Fe}_2\text{O}_3 = 1000 \text{ g Fe} \left(\frac{1 \text{ mol Fe}}{55.8 \text{ g Fe}} \right) \left(\frac{1 \text{ mol Fe}_2\text{O}_3}{2 \text{ mol Fe}} \right) \left(\frac{159.6 \text{ g Fe}_2\text{O}_3}{1 \text{ mol Fe}_2\text{O}_3} \right) =$$

= 1430 \text{ g Fe}_2\text{O}_3