LIMESTONE RESCUE!

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Type of Activity: Case Study

Content: stoichiometry, limiting reagent and the ideal gas law (*i.e.*, pV=nRT)

Courses: Secondary V Chemistry (Remedial, 001), General Chemistry (NYA)

Learning Objectives:

(i) apply three important concepts (namely, stoichiometry, limiting reagent and the ideal gas law) in one summative, multistep problem

(i) (ii) prepare a flow chart for solving related multistep problems.

Unit of work: Groups of 3-4 students

Technology: If using an online collaborative platform (e.g., SMART amp) each group can work on a shared personal device or a SMART board in a high-tech AL room.

Can also hand out large sheets of paper and markers. Each group should access to the internet to get started on the problem as well.

INSERT “EVIL SCIENTIST” PHOTO HERE

Introduction:

An evil scientist has captured and imprisoned 6 researchers in 6 separate laboratories at an isolated facility. They have been tied up and cannot escape. Furthermore, the rooms have been chained and bolted shut from the outside. Thus, it will be very difficult to break in and save them.

You are the only person for miles and have only one bolt cutter to start working at unlocking the doors.

INSERT “EVIL SCIENTIST ESCAPING” PHOTO HERE

Complication:

The evil scientist wants to ensure the captive researchers will NOT escape their respective rooms. Thus he places a combination of limestone and concentrated acetic acid in each room, setting off a potentially fatal reaction. He then rides off with the keys to each room. Note that all room's are air-tight, with the exception of one vent on the ceiling.

INSERT “HERO” PHOTO HERE

The Hero:

As you arrive on the scene, you hear your colleagues calling for help. You can communicate through the vents in the ceiling to their rooms. You quickly grab your bolt cutters (errr, which you randomly had...).

As you are alone and freeing each captive will take time, it is essential to determine (i) who is at risk and (ii) the order in which to save those at risk.

Each captive tells you the dimensions of their room and the amount of limestone and acetic acid the crazed scientist combined before running off.

INSERT PHOTO HERE

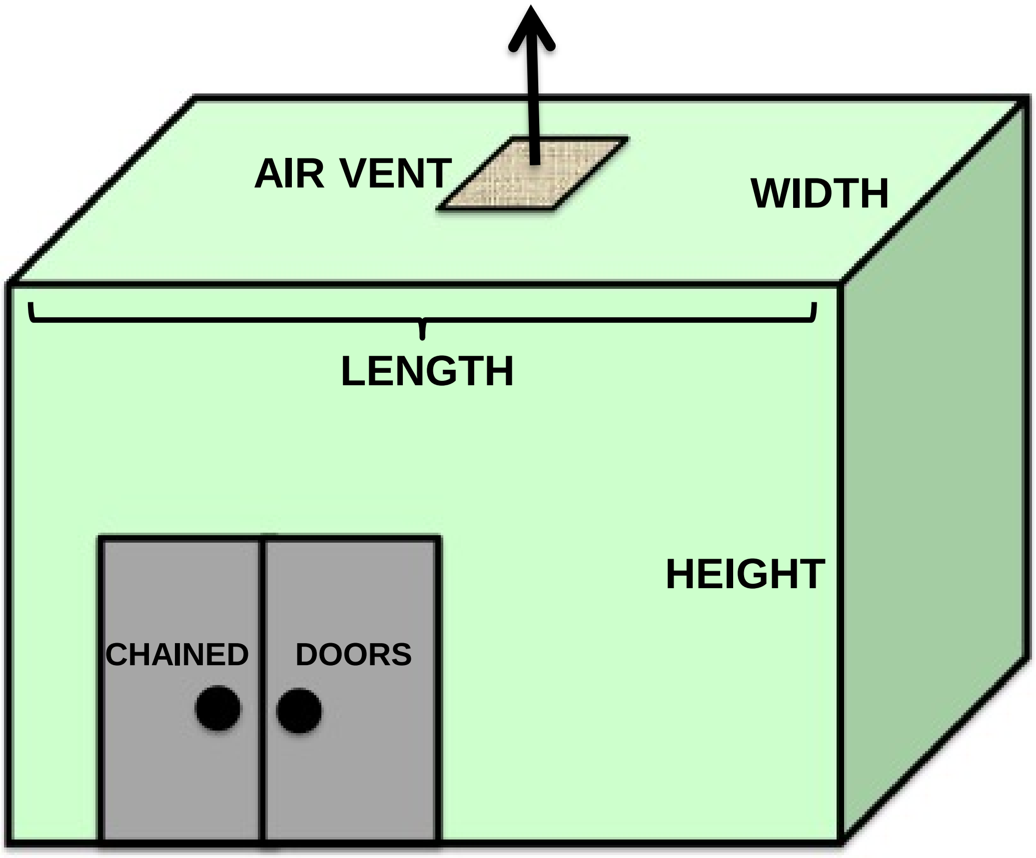
Your mission:

1. With your assigned group, determine whether your assigned captive is at risk of death due to the reaction taking place in their room.

2. If your captive is at risk, determine how much time you have to rescue her/him based on the fact that the limestone is reacting at 1.00×10^2 mol/min (express your response in minutes).

3. As a class, determine in what order to rescue the captives!

Queue music- quickly now!



All captives are tied up in rooms with chained doors. The reaction between the concentrated acetic acid and limestone has begun.

NOTE: Only one air vent is present, on the ceiling. Dimensions of the rooms are provided by each of the captives.

HINTS/SCAFFOLDING (to provide at instructors discretion):

1. The (unbalanced) reaction taking place is:

$2\ CH_3COOH + CaCO_3 \rightarrow Ca(CH_3COO)_2 + CO_2 + H_2O$

2. The potentially deadly component is CO_2 (gas) as the person in the room may be asphyxiated if enough is generated.

3. We assume that as CO_2 is heavier than O_2. Thus, the O_2 in the room will rise and escape through the air vent on the ceiling as CO_2 is generated by the reaction.

4. A person is considered to be at risk of dying if enough CO_2 is generated to fill the entire room.

5. To rescue someone successfully, they must be freed before sufficient CO_2 is generated to fill the entire room.

SAMPLE CAPTIVE

Room 1:

Thank goodness you're here!

The dimensions of the rectangular room are 7.00 m by 4.50 m by 3.00 m high.

Note: 1.00 m^3 = 1.00×10^3 L.

The crazed scientist combined 355 kg of limestone with 4820 L of 100% (*i.e.*, 1.00×10^2 g/L) acetic acid!

The temperature of the room is 27.5^{o}C, the relative humidity is 66.0% and atmospheric pressure is 99 300 Pa!!!

Quickly- it's getting hard to breathe!!!

INSERT “CAPTIVE” PHOTO HERE

Room 2:

Thank goodness you're here!

The dimensions of the rectangular room are 6.00 m by 5.00 m by 3.50 m high.

Note: 1.00 m^3 = 1.00×10^3 L.

The crazed scientist combined 475 kg of limestone with 5250 L of 100% (i.e., 1.00×10^2 g/L) acetic acid!

The temperature of the room is 27.5oC, the relative humidity is 66.0% and atmospheric pressure is 99 300 Pa!!!

Quickly- it's getting hard to breathe!!!

INSERT “CAPTIVE” PHOTO HERE

Room 3:

Thank goodness you're here!

The dimensions of the rectangular room are 6.50 m by 4.00 m by 4.00 m high.

Note: 1.00 m^3 = 1.00×10^3 L.

The crazed scientist combined 452 kg of limestone with 5020 L of 100% (i.e., 1.00×10^2 g/L) acetic acid!

The temperature of the room is 27.5^{o}C, the relative humidity is 66% and atmospheric pressure is 99 300 Pa!!!

Quickly- it's getting hard to breathe!!!

INSERT “CAPTIVE” PHOTO HERE

Room 4:

Thank goodness you're here!

The dimensions of the rectangular room are 6.00 m by 6.00 m by 3.50 m high.

Note: 1.00 m^3 = 1.00×10^3 L.

The crazed scientist combined 491 kg of limestone with 5250 L of 100% (i.e., 1.00×10^2 g/L) acetic acid!

The temperature of the room is 27.5^{o}C, the relative humidity is 66% and atmospheric pressure is 99 300 Pa!!!

Quickly- it's getting hard to breathe!!!

INSERT “CAPTIVE” PHOTO HERE

Room 5:

Thank goodness you're here!

The dimensions of the rectangular room are 8.00 m by 4.50 m by 4.00 m high.

Note: 1.00 m^3 = 1.00×10^3 L.

The crazed scientist combined 575 kg of limestone with 7500 L of 100% (i.e., 1.00×10^2 g/L) acetic acid!

The temperature of the room is 27.5^{o}C, the relative humidity is 66% and atmospheric pressure is 99 300 Pa!!!

Quickly- it's getting hard to breathe!!!

INSERT “CAPTIVE” PHOTO HERE

Room 6:

Thank goodness you're here!

The dimensions of the rectangular room are 5.00 m by 5.00 m by 3.50 m high.

Note: 1.00 m^3 = 1.00×10^3 L.

The crazed scientist combined 375 kg of limestone with 4300 L of 100% (i.e., 1.00×10^2 g/L) acetic acid!

The temperature of the room is 27.5^{o}C, the relative humidity is 66% and atmospheric pressure is 99 300 Pa!!!

Quickly- it's getting hard to breathe!!!

FLOWCHART PREPARATION

Now that you have successfully rescued your captive (nor not):

Consider the steps you took to solve the problem.

(i) **As a group**, prepare a flow chart outlining **ALL** the steps necessary in solving such a multistep problem. Write it out in general terms (i.e., don't be too specific).

e.g., write "make all necessary unit conversions (*e.g.*, convert Pa to kPa)" instead of simply "convert Pa to kPa". The former is always valid whereas the latter is specific to this problem.

(ii) **As a group**, examine the flow chart prepared by another group. Add comments in different coloured ink. Are they are missing anything? Are their steps in a logical order?

FLOWCHART PREPARATION

Now that you have successfully rescued your captive (nor not):

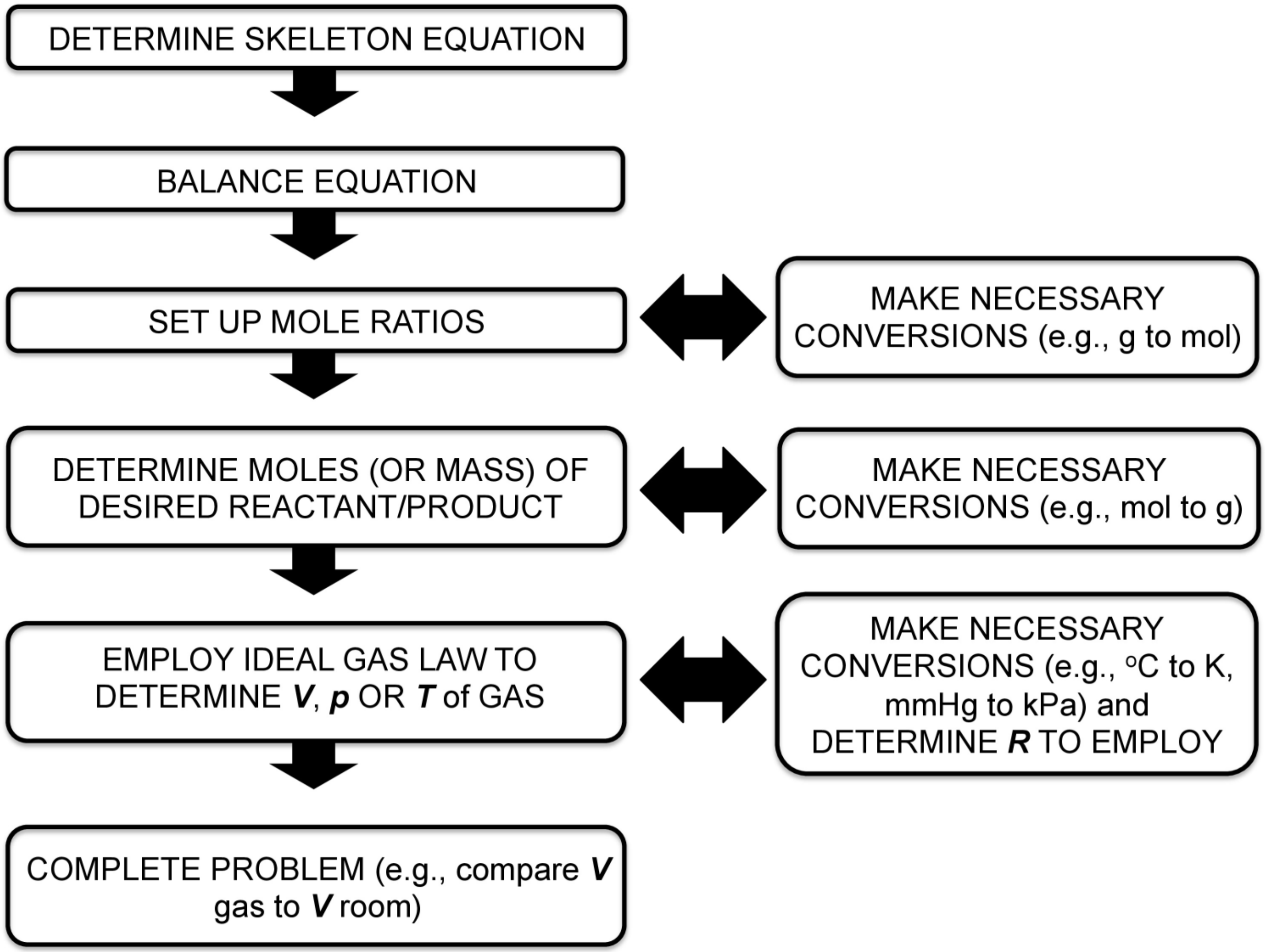
Consider the steps you took to solve the problem.

(iii) Prepare a **final draft of your flow chart**. Analyze the comments made by the other group. Do you agree with them? If so, incorporate their comments into your flow chart.

NOTE: At this point, the instructor can either ask that groups submit their flow charts or that they post them into an online collaborative platform (*e.g.*, SMART amp).

NOTE: The instructor can also determine whether they want to hand out a completed flow chart or have the students test the robustness of their own flow charts individually with select problems.

SAMPLE FLOWCHART



REACTION $1\ CaCO_3 + 2\ C_2H_4O_2 \rightarrow Ca(C_2H_3O_2)_2 + H_2O + CO_2$

Room Number	Length (m)	Width (m)	Height (m)	Volume (m3)	Volume (L)
1	7	4,5	3	94,5	94500
2	6	5	3,5	105	105000
3	6,5	4	4	104	104000
4	6	6	3,5	126	126000
5	8	4,5	4	144	144000
6	5	5	3,5	90	90000

MW $CaCO_3$ 100.0869 g/mol

MW $C_2H_4O_2$ 60.05 g/mol

$1\ m^3 = 1000\ L$

$T = 27.5^oC = 300.65\ K$

$p = 99300\ Pa = 99.3\ kPa$

$R = 8.3143\ kPaLK^{-1}mol^{-1}$

$n = pV/RT$

Important Numbers to keep in Mind

Room Number	Room Volume (L)	moles CO_2 required to fill room	Assuming limiting reagent, min kg $CaCO_3$ required to fill room with CO_2	min kg $C_2H_4O_2$ required to fill room with CO_2
1	94500	3754	375,726	450,855
2	105000	4171,1	417,462	500,949
3	104000	4131,4	413,499	496,181
4	126000	5005,3	500,965	601,137
5	144000	5720,4	572,537	687,02
6	90000	3575,2	357,831	429,382

if mass (kg) for both reagents ≥ min to fill room	AT RISK
if mass (kg) one reagent ≥ min to fill room	NO RISK
if mass (kg) neither reagent ≥ min to fill room	NO RISK

SAMPLE NUMBERS

DETERMINING LIMITING REAGENT

Room Number	Room Volume (L)	kg $CaCO_3$ present	kg $C_2H_4O_2$ present	mols $CaCO_3$ present	mols $C_2H_4O_2$ present	mols CO_2 produced based on $CaCO_3$	moles CO_2 produced based on $C_2H_4O_2$
1	94500	355	482	3547	8027	3547	4013,5
2	105000	475	525	4746	8743	4746	4371,5
3	104000	452	502	4516	8360	4516	4180
4	126000	491	525	4906	8743	4906	4371,5
5	144000	575	750	5745	12490	5745	6245
6	90000	375	430	3747	7161	3747	3580,5

RED = LIMITING REAGENT

DETERMINING RISK

Room Number	Actual moles CO_2 produced	Volume occupied by CO_2 (L)	Room Volume (L)	Volume Comparison	RISK
1	3547	89289	94500	$V_{CO2} < V_{ROOM}$	NO RISK
2	4371,5	110044	105000	$V_{CO2} > V_{ROOM}$	RISK
3	4180	105224	104000	$V_{CO2} > V_{ROOM}$	RISK
4	4371,5	110044	126000	$V_{CO2} < V_{ROOM}$	NO RISK
5	5745	144620	144000	$V_{CO2} > V_{ROOM}$	AT RISK
6	3580,5	90132	90000	$V_{CO2} > V_{ROOM}$	AT RISK

$T = 27.5^oC = 300.65\ K$

$p = 99300\ Pa = 99.3\ kPa$

$R = 8.3143\ kPaLK^{-1}mol^{-1}$

TIME TO FILL ROOM/RESCUE SEQUENCE

Limestone (arbitrarily) reacts at $1.00x10^2$ mol/min or 100 mol/min

Room Number	Room Volume (L)	moles CO_2 required to fill room	time to generate moles CO_2 required to fill room (min)	RISK	Sequence to rescue captives
1	94500	3754	37,54	NO RISK	N/A
2	105000	4171,1	41,711	RISK	3
3	104000	4131,4	41,314	RISK	2
4	126000	5005,3	50,053	NO RISK	N/A
5	144000	5720,4	57,204	AT RISK	4
6	90000	3575,2	35,752	AT RISK	1