Determining the Molar Mass of a Gas

TEACHER

I have always determined pressure using the pressure on the weather phone app. Thanks to Ray Lesniewski, I have learned that the pressure reported by phone apps is calibrated to sea level. This is because the weather folks want to think about air pressure changes ONLY caused by moving air masses, and not due to elevation. Thus to report the correct pressure from your phone, you need to subtract **26 mmHg for every 1000 ft of elevation**. You can get elevation of where you are located on the compass app on your phone.
Look up the altitude of where you are located by using the compass app on the phone. Look up the air pressure on your phone. Convert to mmHg if reported in inches (25.4 mm = 1 inch). Divide the altitude by 1000, then multiply by 26 to get the actual air pressure ar your location.

Dust-Off is a brand of dust cleaner (refrigerant-based propellant cleaner, which is not compressed air and incorrectly called "canned air") containing difluoroethane; it is used to remove particulates and dust from computers and electronic equipment. Dust-Off products are used to remove dust, debris, fingerprints, and smudges from hard to reach areas of keyboards, screens, and other components of electronic equipment. Dust-Off is manufactured by Falcon Safety Products.

Dust-Off

The Dust-Off brand also encompasses a line of electronics and home office cleaning supplies, including LCD/Plasma screen sprays, microfiber cleaning cloths, and the Dust-Off Screen Shammy.

The compressed gas duster product gained attention for its abuse as an inhalant, such as by teenagers in the movie *Thirteen*. A warning email circulated by Jeff Williams, a police officer in Cleveland, whose son, Kyle, died after inhaling Dust-Off in Painesville Township, Ohio. [1]

Wrestler Mike "Mad Dog" Bell died of an inhalation-induced heart attack brought on by an accidental inhalation of difluoroethane in Dust-Off.[2]

Falcon has added a bitterant to the product to deter inhalation. Though a bitterant has been added, many people still inhale the product to get a quick high.

Butane C_4H_{10}

MM = 4(12) + 10(1) = 58 g/mol

LAD D1 (pg 2 of 14) Determining the Molar Mass of a Gas

Name________________________Per___

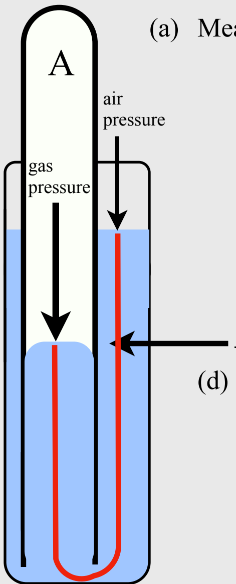
In this lab, as with any lab, you must show work to support any calculations.

Introduction

Your objective in this LAD is to determine the molar mass of a gas, using the ideal gas law. You will measure mass, and use volume and pressure and temperature to calculate moles, which of course will allow the calculation of mass per moles. If you measure the mass of a gas and its corresponding number of moles, you can calculate its molar mass.

PreLab

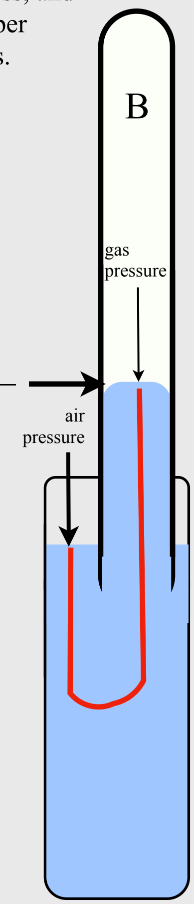
1. Let's learn about pressure in a sealed container.



(a) Measure and record the volume of the gas in your gas tube on the line in diagram A.

(b) Then raise the gas tube up as far as possible without raising above the surface of the water in the cylinder as shown in diagram B. Read the volume of gas in the gas tube and record it on the line in the diagram B.

Vol gas in situation B________



(c) Is the volume of gas in the eudiometer B more or less than in diagram A?
circle one

________Vol of gas in situation A

(d) Since you didn't let any air in or out between situation A and B, and the temperature has not changed from situation A to situation B, yet the volume HAS changed, the pressure of the gas in the eudiometer in diagram B **must** be different than in the eudiometer A. Would you predict that the **pressure** of the gas in diagram B is more or less than the **pressure** of the gas in diagram A?
circle one

(e) Put an (↑ or ↓) arrow on the equation below for the pressure in B to justify your response.

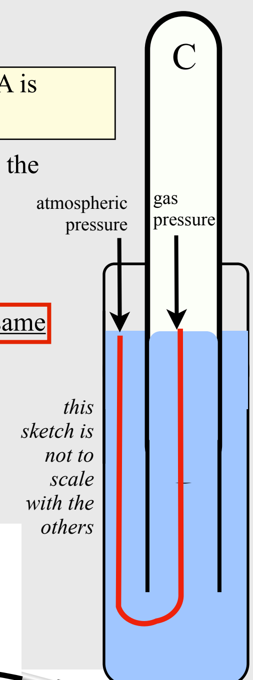
$$\overset{\#}{P_A}\;\overset{\#}{V_A} = \overset{\downarrow}{P_B}\;\overset{\uparrow}{V_B}$$

(f) In diagram A is the gas pressure inside the eudiometer, more or less than the air pressure outside the tube? How can you tell, or how did you decide?
circle one

Consider the level of water in the tubes as a manometer as shown with the red line. The pressure in A is "winning" the push on the water and thus the pressure in A is more than outside pressure.

(g) In diagram B is the gas pressure inside the eudiometer, more or less than the air pressure outside the tube? How can you tell, or how did you decide?
circle one

Consider the level of water in the tubes as a manometer as shown with the red line. The pressure in B is "losing" the push on the water and thus the pressure in B is less than outside pressure.



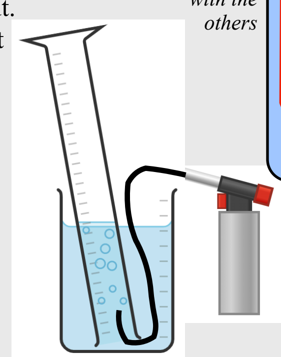
(h) Now, consider diagram C, is the gas pressure inside the eudiometer more than, less than, or the same as the air pressure outside the tube? How can you tell, or how did you decide?
circle one

Consider the level of water in the tubes as a manometer as shown with the red line. The pressure in C is must be the same as the outside since the level is a "tie."

Voila! If we want to know the pressure of gas in a closed container, we can know what the pressure is if we move the eudiometer so the water level is the same inside and out. Of course this requires that we know what the atmospheric pressure is, but we can get atmospheric barometer pressure from the weather app on our phones.

2. Consider the diagram below in which gas from the canister is collected over water. The graduated cylinder collecting the gas actually contains two gases. What is the other gas and how does that gas get into the container?

Inside the grad cylinder there is both gas from the canister and WATER VAPOR



Some facts to help you understand vapor pressure of gas over a liquid in a sealed container.

- When a liquid evaporates to a gas (vapor) in a closed container, and the gaseous molecules cannot escape, some of the vaporized molecules will strike the liquid phase or sides of container and condense back into liquid.
- When the rate of condensation of the vapor becomes equal to the rate of evaporation of the liquid, the amount of vapor will have reached a *maximum* and the vapor pressure will no longer change. The gas in the sealed container is said to be in ***equilibrium*** with the liquid.
- The pressure exerted by the water vapor in equilibrium with liquid water in a closed container at a given temperature is called the ***equilibrium water vapor pressure***, and if the temp is constant, equilibrium will be achieved very quickly.
- ***Equilibrium vapor pressure is dependent only on temperature***: at a higher temperature, more molecules have enough energy to escape from the liquid or solid. At a lower temperature, fewer molecules have sufficient energy to escape from the liquid or solid. The vapor pressure of a liquid is independent of any other gas molecules in the space above the liquid.

3. You know that water evaporates, and thus some of the water will evaporate into the eudiometer tube in which we collected the gas, meaning there are actually two gases in the eudiometer, H_2 and H_2O. Sometimes a chemist would say that the gas is not "dry." Fortunately, the amount of water that will evaporate is caused only by the temperature of the water, this allows the pressure of the water vapor to be looked up in a chart.

   (a) So if our lab room today was at 21.0ºC, what will be the equilibrium vapor pressure of water in a closed eudiometer?

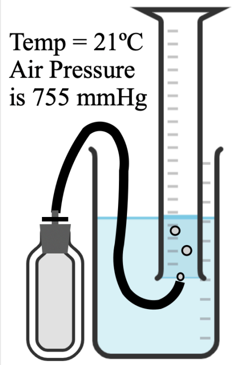
   17.5 mmHg (or torr)

   (b) So if the pressure of the space containing gases over water was 755.0 torr, what is the pressure of the "dry" H_2 collected in the eudiometer.

   755 mmHg − 17.5 mmHg = 737.5 mmHg (or torr)

Equilibrium Water Vapor Pressure

Temp (ºC)	Pressure (mm Hg)	Temp (ºC)	Pressure (mm Hg)
0	4.6	27	26.7
5	6.5	28	28.4
10	9.2	29	30.0
11	9.8	30	31.8
12	10.5	35	42.2
13	11.2	40	55.3
14	12.0	45	71.9
15	12.8	50	92.5
16	13.6	55	118.0
17	14.5	60	149.4
18	15.5	65	187.5
19	16.5	70	233.7
20	17.5	80	355.1
21	18.6	90	525.8
22	19.8	92	567.0
23	21.1	94	610.9
24	22.4	96	657.6
25	23.8	98	707.3
26	25.2	100	760.0



4. Write the Ideal Gas Law in the space below,
   - and then substitute for moles: n = mass/molar mass
   - remember that mass of gas is the canister before and after
   - and then manipulate the variables and isolate for molar mass.

$P_{air} - P_{wvp}$ → P

$n = \frac{M}{MM}$ ← mass of gas (M canister before − M canister after)

$PV = nRT$

$PV = \frac{M}{MM} RT$

$$MM = \frac{(M_{canister\ before} - M_{canister\ after}) RT}{(P_{air} - P_{wvp}) V}$$

5. Make a data/results table in your Google Sheets Lab Document. Use the same spreadsheet, just make a new sheet in a new tab at the bottom. Be sure and LABEL that Tab D1. Be sure and make a row for each measurement and processing the data item. Be sure a title at the top which includes the Lab number and a descriptive title.

Materials – on trays per lab group

- 100 ml glass graduated cylinder
- gas containers
  (lighter, butane canister, and/or Dust-Off)
- matches
- thermometer
- "hot hands" grippers
- sink drain stop or large tub
- bucket and sponges for bench clean-up

 Determining the Molar Mass of a Gas *TEACHER*

Procedure

A. Weigh the canister.

B. Prepare the graduated cylinder to collect gas by filling the cylinder with water and inverting the cylinder mouth down into the sink. Try not to get any air bubbles. Place the hose under water and allow butane to flow out of the lighter until you have collected almost full cylinder of gas (DO NOT GO BEYOND FULL, or you will not have any markings to read the volume).

C. Measure the volume of gas when you have raised or lowered the cylinder so that the level of water inside the tube and the surface of water in the sink are the same. At that moment, read the volume of gas in the cylinder.

D. Remove the hose, dry off the canister/lighter, the weigh the gas canister.
Fill in the missing procedural item.

E. Use the thermometer to record the temperature of water in the sink and the temperature of the air in the room - we hope that they are the same. (If they are not, take an average, since you can use only one value in your calculation.)

F. Using the vapor pressure chart, record the equilibrium vapor pressure of water for the temperature of water/air in the room on your data table.

G. Record the air pressure in the room. It has been checked on-line and recorded on the whiteboard.

Process the Data – ***Be sure and record your data and embedded formulas to calculate these results on your Google sheet. Your second gas should be a second trial in your Google sheet.***

(a) Calculate & correct the air pressure in mmHg from the inches value recorded from your phone. (25.4 mm = 1 inch) (Look up the elevation, divide by 1000 then multiply by 26 and subtract that from the air pressure on the phone.)

(b) Convert the temperature of the air / water (average if necessary) into Kelvin.

(c) Calculate the mass of gas that was released into the cylinder.

(d) Calculate the partial pressure of the gas in the cylinder. Use the water vapor pressure table given in the PreLab and provided for your convenience at the end of this lab .

(e) Using your literal equation in which you solved for molar mass in the preLab, calculate the molar mass of butane.

(f) After Googling the formula for butane, and the most common component in Dust Off, write out the chemical formulas for these two chemicals. Use the periodic table to calculate the molar mass.

(g) Calculate the percent error for your experimental molar mass calculations.

$$MM = \frac{(m_{start} - m_{end})RT}{PV}$$

Post-LAD Questions - ***to be answered on this sheet in the spaces provided. Calculations must be shown.***

You may want to consider / refer to your literal equation from PreLAD #3 to help justify your responses.

2. Shrek suggested that the molar mass of the gas turned out too large because when he measured the canister's mass after letting out the gas, the canister was wet from the lab procedure. Do you agree or disagree? Justify your response. (3)

Disagree, a wet canister would make canister after gas let out heavier, upon subtraction, mass would appear as if less butane were let out, thus **smaller** molar mass

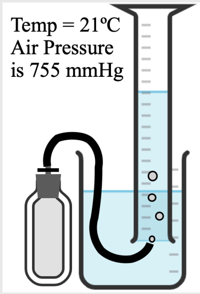
$$MM \downarrow = \frac{(m_{start} - \uparrow m_{end}) \downarrow RT}{PV}$$

3. If you had a goofy lab partner who decided to open the gas canister's valve and let out some gas on the way to the balance before the final weighing of the canister, would the calculated molar mass be larger, smaller, or no change? (3)

extra butane released makes canister lighter, upon subtraction, mass of gas would be larger *(and appear as if more butane were let out)*, thus **larger** molar mass

$$MM \uparrow = \frac{(m_{start} - \downarrow m_{end}) \uparrow RT}{PV}$$

4. Fiona measured the volume of the butane when the graduated cylinder looked like the diagram to the right, would the calculated molar mass be larger, smaller, or no change? (3)



volume recorded would be inaccurately large,
(or gas pressure used is inaccurately high)
and since Vol is in the denominator
thus **smaller** molar mass

$$MM \downarrow = \frac{(m_{start} - m_{end})RT}{PV\uparrow}$$

5. Donkey said that gases are more soluble than others, and he suggested that if the gas used in this lab procedure were quite soluble, the calculated molar mass would be smaller than the theoretical molar mass? Do you agree or disagree with Donkey? Justify your response. (3)

Disagree with Donkey.
volume would be **smaller**, because the gas would be dissolved in the water and not in the gas space to be measured and since vol is in the denominator, thus a **larger** molar mass

$$MM \uparrow = \frac{(m_{start} - m_{end})RT}{PV\downarrow}$$

6. I hope you remember the combined gas law, PV/T = PV/T . Calculate the volume of a mole of gas at room conditions, (22ºC and 760 torr) and report your answer with units in the box below.

$$\frac{PV}{T} = \frac{PV}{T} \qquad \frac{760\,torr \cdot 22.4\,L/mol}{273\,K} = \frac{760\,torr \cdot V}{295\,K} \qquad V_{molar} = 24.2\,L/mol$$

7. Most *Bic* lighters hold 5 ml of liquified butane (density = 0.6 g/ml) Calculate the minimum size container you would need to "catch" all of the butane (from a lighter) at room conditions , if you released all of the butane from the lighter. *Show your work. (Hint: you could use the molar volume that you calculated in #8 to make your work easier.)*

$$5\,mlButane \times \frac{0.6g}{1ml} = 3gButane \qquad 3g \times \frac{1mol}{58g} = 0.0517\,molButane$$

$$V = \frac{nRT}{P} \qquad V = \frac{0.0517\,mol \times 62.36 \times 295\text{ K}}{760\,torr} \qquad V = 1.25\text{ L}$$

OR $0.0517\,mol \times \frac{24.2\,L}{1\,mol} = 1.25\,L$

8. Write a balanced equation for the combustion of butane. (3)

$2\ C_4H_{10} + 13\ O_2 \rightarrow 8\ CO_2 + 10\ H_2O$

9. What volume of air at room conditions (20ºC,760 torr) would be required to combust a full lighter of butane. Remember that air is only ~20% oxygen. *Show your work. (Hint: You can just work with stoichiometric ratios from your calculation in #6 since the pressure and temperature are constant.)* (3)

$$1.25\text{ L}\ ofC_4H_{10} \times \frac{13O_2}{2C_4H_{10}} = 8.12\text{ L}\ ofO_2 \qquad 8.12\text{ L}\ ofO_2 \times \frac{5LofAir}{1LofO_2} = 40.3LofAir$$

10. What would be the total volume of gases produced at room conditions (20ºC,760 torr) by the combustion described in the previous question. *Show your work. (Hint: You can just work with stoichiometric ratios from your calculation in #6 since the pressure and temperature are constant.)* (3)

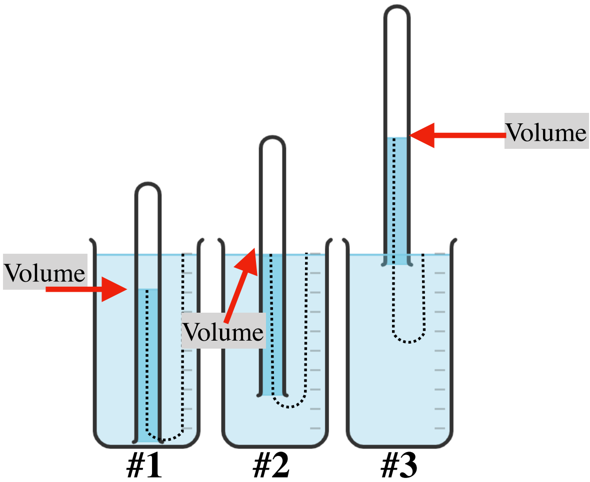
$$1.25\text{ L}\ ofC_4H_{10} \times \frac{18Product}{2C_4H_{10}} = 11.2LofProduct$$

$$OR \quad 1.25\text{ L}\ ofProduct \times \frac{8CO_2}{2C_4H_{10}} = 5.00\text{ L}\ ofCO_2 \quad 1.24LofProduc \times \frac{10H_2O}{2C_4H_{10}} = 6.25\text{ L}\ ofH_2O$$

Opener: Partial Pressures

Sally's lab was at 750 torr air pressure and 21.0ºC. She wanted to determine the volume of gas that she collected in an upside down graduated cylinder as shown in the picture. Which scenario would be the best arrangement for measuring the volume? Explain why.

Show you work needed to determine the pressure of the "dry" gas inside the cylinder.



Equilibrium Water Vapor Pressure

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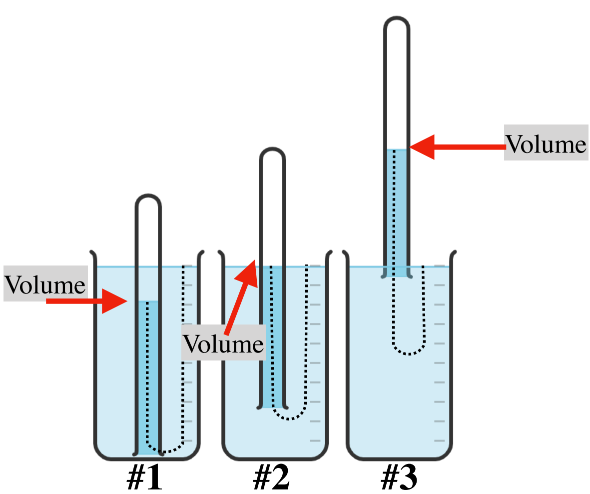

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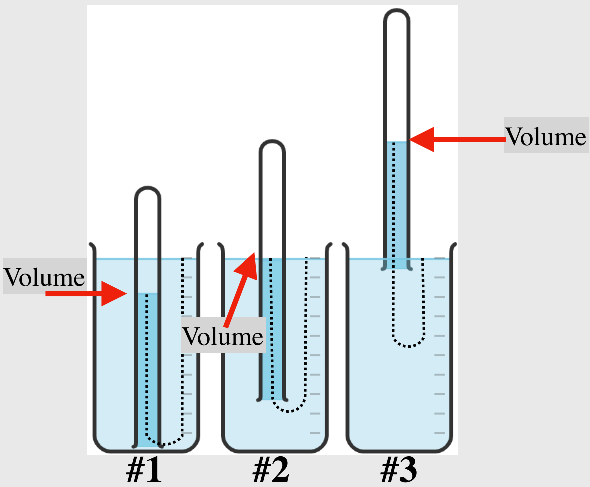

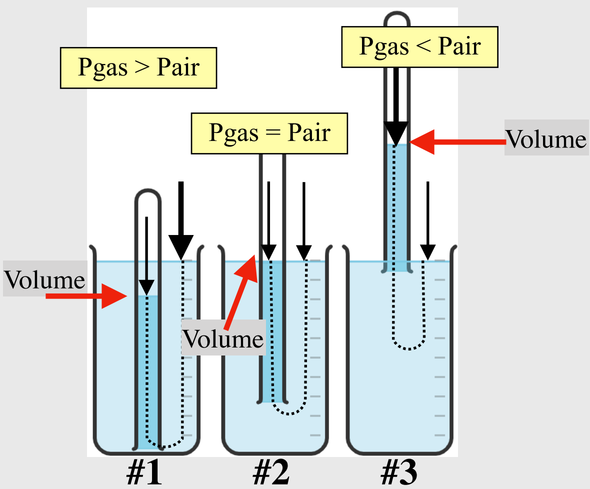

We need to know the pressure of the gas collected in the cylinder.

How can we know the pressure without a pressure gauge?

Only in #2 is the $P_{air} = P_{gas}$, thus we can measure the volume that is correct for the $P_{air} = P_{gas}$

Look up the room's air pressure with barometer (or look up on the weather app), allowing us to use Dalton's law of partial pressures to determine the pressure of the gas to put into out ideal gas law formula.

Opener: Combined gas Law

1. Bonnie had 250 ml of gas in a syringe at 22.0ºC with a pressure of 1 atm was then cooled down to 11ºC and compressed to 125 ml, what would be the new pressure in the syringe?

2. Clyde had a rigid 500. ml container at 100ºC at 1.5 atm and he the heated the container up to 400ºC, what is the new pressure?

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Opener: Using Gas Volumes to do Stoichiometry

1. Boomer intends on reacting ammonia gas with oxygen gas producing nitrogen monoxide and water vapor. Write the balanced equation below.

2. Boomer measures 12 L of ammonia at some fixed temperature and pressure. What volume of oxygen gas (at the same fixed temperature and pressure) would be required to react completely with this nitrogen monoxide?

3. What volume of gaseous products should boomer expect to collect at the same fixed temperature and pressure?

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Opener: Using Gas Volumes to do Stoichiometry

1. Boomer intends on reacting ammonia gas with oxygen gas producing nitrogen monoxide and water vapor. Write the balanced equation below.

   $2\ NH_3 + 5/2\ O_2 \rightarrow 2\ NO + 3\ H_2O$
   $4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$

2. Boomer measures 12 L of ammonia at some fixed temperature and pressure. What volume of oxygen gas (at the same fixed temperature and pressure) would be required to react completely with this nitrogen monoxide?

$$12L\ NH_3 \times \frac{5O_2}{4NH_3} = 15L\ O_2 \quad OR \quad n = \frac{PV}{RT} \quad thus \quad \frac{1atm \times 12L}{0.08206 \times 298K} \times \frac{5O_2}{4NH_3} \times \frac{0.08206 \times 298K}{1atm} = 15L\ O_2$$

3. What volume of gaseous products should boomer expect to collect at the same fixed temperature and pressure?

$$12L\ NH_3 \times \frac{10\,\mathrm{Pr}oducts}{4NH_3} = 30L\ \mathrm{Pr}oducts$$

Opener: Using Gas Volumes to do Stoichiometry

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Opener: Using Gas Pressures to do Stoichiometry

1. Write the balanced chemical equation for the formation of ammonia, NH_3 from ammonia's gaseous elements.

2. The reaction was run in sealed a rigid container at a constant temperature. 6.0 atm of nitrogen was reacted with 15.0 atm of hydrogen. Calculate the partial pressure of all gases after the reaction goes to completion and the total pressure.

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Opener: Using Gas Pressures to do Stoichiometry

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   $N_2 + 3\,H_2 \rightarrow 2\,NH_3$

2. The reaction was run in sealed a rigid container at a constant temperature. 6.0 atm of nitrogen was reacted with 15.0 atm of hydrogen. Calculate the partial pressure of all gases after the reaction goes to completion and the total pressure.

Reaction	N_2	$3\,H_2$	$2\,NH_3$	
Initial	6	15	0	
Change	− 5 $= \frac{1\,N_2}{3\,H_2} \times 15\,H_2$	− 15	$15\,H_2 \times \frac{2\,NH_3}{3\,H_2}$ + 10	
End	1 +	0 +	10 =	11 atm total

Daltons Law of Partial Pressures – Add up the pressures.

Opener: Using Gas Pressures to do Stoichiometry

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Determining the Molar Mass of a Gas

TEACHER

measurements / calculations	difluoro ethane	butane	
Mass of Gas in Container at start (g)	**164.15**	**154.25**	
Mass of Gas in Container after release (g)	**163.89**	**151.94**	
Volume of Gas in Cylinder (ml)	**96.5**	**986**	
Temperature of Water and Air (°C)	**21.2**	**26.0**	
Air Pressure in Room (inches)	**29.72**	**29.47**	
Water Vapor Pressure (mmHg)	**18.65**	**25.2**	
Theoretical molar mass of gas (g/mol)	58.00	66.05	
air pressure (mmHg)	754.89	748.54	
pressure of “dry” gas (mmHg)	736.24	723.34	
air / water temp (K)	294.35	299.15	
mass of gas released (g)	0.26	2.31	
moles of gas released	0.003871	0.038232	
Exp molar mass of gas (g/mol)	67.17	60.42	
Percent Error (%)	15.82	-8.52	
Chemical Formula of Gas	$C_2H_4F_2$	C_4H_{10}	

Sample Data

measurements / calculations	butane	difluoroethane
Mass of Gas in Container (g)	**297.193**	**270.656**
Volume of Gas in Cylinder (ml)	**73.3**	**74.0**
Mass of Container (g)	**296.993**	**270.436**
Temperature of Water and Air (ºC)	**18.2**	**18.2**
Water Vapor Pressure (mmHg)	**15.48**	**15.48**
Air Pressure in Room (mmHg)	**774.7**	**774.7**

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