Group Member: Brodric **Group Member:** Chris
Group Member: ____________ **Group Member:** Clark

15 minutes to next solid line

Information: Gases have neither a fixed shape nor a fixed volume. They will fill any container in which they are placed. The density of gases is much smaller than liquids or solids (the gaseous particles are far apart). There are several laws which relate the properties of gases.

Model 1: The Ideal Gas Law

$$PV = nRT \qquad R = 0.08206\,\frac{atm\cdot L}{mol\cdot K}$$

Key Questions:

1. For the ideal gas law, what do the letters *P*, *V*, *n*, and *T* indicate?

   P=pressure, V=volume, n=moles, T=temperature

2. What is the required scale for *T*? Kelvin
3. The ideal gas law can be used to predict what will happen to one property if another is changed.
   - Using the gas law, will the volume increase or decrease if the number of moles increases (assume the other properties don't change)? increase
   - Will the pressure increase or decrease if the temperature decreases? decrease
   - Will the pressure increase or decrease if the volume decreases? increase
4. With the knowledge of any three properties, the value of the fourth property can be solved from the equation. What is the temperature of 2.10 moles of a gas in a 35.00 L container at 914 torr? Remember to use the correct units when using the ideal gas law. Note: 1 atm = 760 torr.

$$T = \frac{\left(\frac{914}{760}\,atm\right)(35L)}{(2.1mol)\left(0.08206\,\frac{atm\cdot L}{mol\cdot K}\right)} = 244K$$

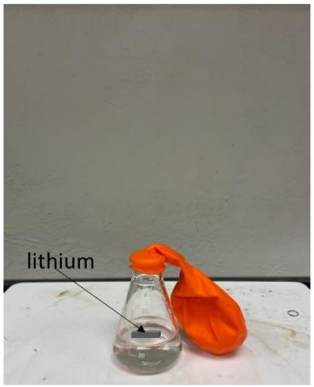
Information: For a mixture of gases in a container, the total pressure exerted is the sum of the pressures that each gas would exert if it were alone. This is called Dalton's law of partial pressures. $P_{TOTAL} = P_1 + P_2 + P_3 + \ldots$

Dalton's law is used when a gas is produced over water. The volume over the water is not only composed of the gas that was produced by the reaction but also water vapor, $H_2O(g)$. This is because molecules of water escape from the surface of the liquid and enter the gas phase. The pressure contribution from the water vapor to the total pressure is call the vapor pressure of water. The vapor pressure of water increases with temperature.

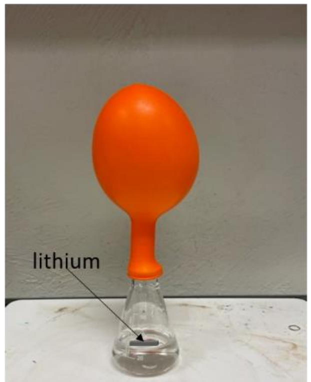
Model 2: Collecting a gas over water (an application of Dalton's law)

P_{atm} = 0.898 atm
Temp (water and gas) = 28.0°C
(after reaction is finished)

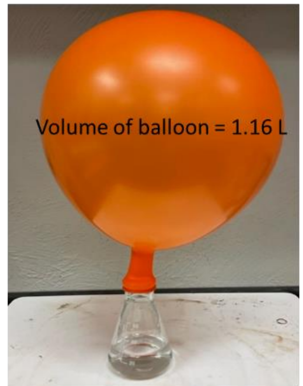
$$2Li(s) + 2H_2O(l) \rightarrow H_2(g) + 2LiOH(aq)$$



Reaction after 0 seconds



Reaction after 45 seconds



Reaction finished

Key Questions:

5. What is the identity of the gas collected in the balloon from the reaction? $H_2\,(g)$

6. Since the gas mentioned above is being collected over water, what other gas (besides H_2) is in the balloon? $H_2O\,(g)$

7. Examine the table. How does the vapor pressure of water change with temperature?

   As temperature gets higher,
   the vapor pressure gets higher

8. What is the vapor pressure of water in the balloon after the reaction is finished?

   $28.4 torr$

9. Using P_{atm} as the total pressure inside the balloon, determine the partial pressure of hydrogen in the balloon. Show your work.

$$0.898 - \frac{28.4}{760} = 0.861 atm$$

Temp (°C)	Vapor pressure (Torr)
21	18.7
22	19.8
23	21.1
24	22.4
25	23.8
26	25.2
27	26.7
28	28.4
29	30.0
30	31.8
31	33.7
32	35.7
33	37.7

10. Using the ideal gas law, calculate the moles of H_2 gas in the balloon.

$$n = \frac{0.861 atm \cdot 1.16 L}{R \cdot 301.15 K} = 0.0404 mol, H_2$$

Exercise:

11. The aqueous solution in the flask increased to 45°C.
    - What happens to the volume of the balloon?

      It increases

    - How does this change the partial pressure of $H_2O(g)$ in the balloon?

      It will also increase

Entire class discussion:

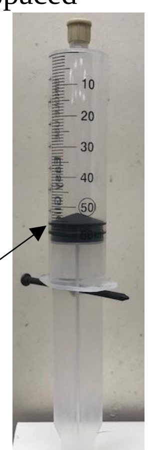
Method development:

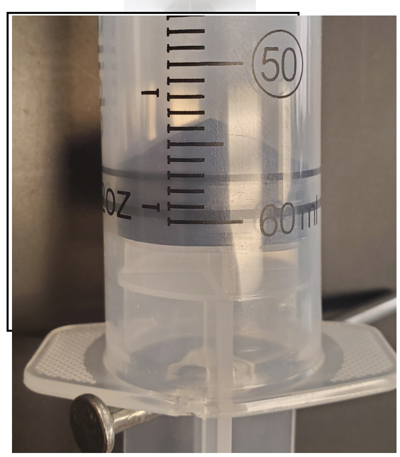
Items needed for *each* member of the group: 60 mL syringe, nail, syringe cap, plastic tip for syringe, and can of electronics duster (one for each group, one first bench).

12. You will determine the molar mass and density of air and an electronics duster.
    a. What are the two units for molar mass? g/mol and kg/mol
    b. What are the two units for density? g/cm^3 and g/mL
13. Each member of your group needs to acquire a 60 mL syringe, a nail, and a syringe cap. Keep track of this syringe. You will use the same syringe for all the measurements below. Examine the volume units on the side of the syringe. Based on the closest spaced increments, determine the place of the estimated digit. tenths place
14. The syringe is filled with air by performing the following (each group member needs to practice this). Notice that the plunger in the syringe has a hole.
    - *With the cap off*, pull out the plunger slightly beyond the hole in the plunger.
    - Push the nail through the hole in the plunger and push in the plunger until the nail is flush against the barrel of the plunger.
    - *Replace the cap* (see picture).

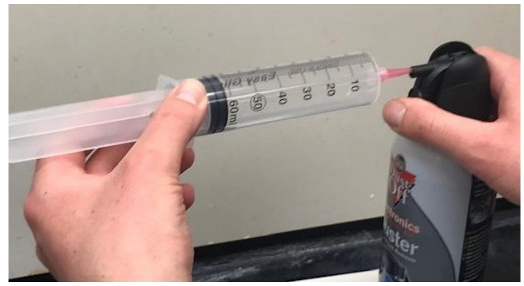
    You have just filled your syringe with air.

    a. Determine the volume of the gas in your syringe (*the gas in the syringe is air*). Read the volume where the top of the gasket contacts the barrel. 57.0 mL Convert this to liters. 0.057 L
    b. Take a clear picture of the syringe filled with air. The picture should clearly show the volume of the gas in the syringe.
    c. The volumes will differ slightly within your group, but every person in your group should have a similar value. Verify this.





15. The syringe is filled with the gas from the electronics duster by performing the following (each group member needs practice doing this).



- *Remove the cap* from the syringe and push the plunger all the way into the barrel of the syringe (the volume measurement will be 0 mL).
- Attach the tapered plastic tip to the syringe via the Luer fitting (twist until snug) and push the plastic tip into the nozzle of the duster gas until there is a tight fit.
- Depress the trigger slightly to fill the syringe with duster gas. The plunger will be pushed out of the barrel. Keep filling the syringe until it is slightly beyond the hole in the plunger (see picture).
- Remove the syringe from the duster can and push the nail through the hole in the plunger. Push in the plunger until the nail is flush against the barrel, remove the plastic tip from the syringe, and *replace the cap*.

You have just filled your syringe with the gas from the duster. Make sure that you can do this.

16. You prepare an <u>evacuated syringe</u> by doing the following with the syringe (each group member needs to practice this).

- *Remove the cap*, push the plunger all the way into the barrel, *and replace the cap*.
- You may need another person to assist with the next part (a group member). Pull out the plunger (*with the cap on*) until you or your group member can place the nail through the hole in the plunger. Allow the plunger to slide into the barrel until the nail is flush against the barrel. Make sure that you can do this.

This is how you properly prepare a syringe containing no gas. Comparing the mass of the evacuated syringe to that of a syringe filled with a gas (air or a duster gas) will allow the mass of the gas in the syringe to be determined. Explain how this is determined. THIS IS IMPORTANT!

The mass of the syringe with gas inside will be more than the mass of one without gas inside, so you subtract the one without from the one with and you get the mass of the gas inside

Let's suppose that an evacuated syringe with no gas has a mass of 35.41 g. The same syringe, filled with a gas, has a mass of 35.58 g. What is the mass of the gas *only* in the syringe?

0.17 g

17. The temperature and the barometric pressure in the room can be read from the gauge on the wall. Record them below. Convert the temperature to Kelvin and the pressure to atmosphere.

   a. Temperature of room (in Kelvin): 294.15 K
   b. Barometric pressure in room (in atmosphere): 0.834 atm

18. From the information above, determine the moles of gas in the syringe filled with a gas. This will be the same for any gas in the syringe. Show your work.
Moles of gas in syringe: 0.00197 mol

$$n = \frac{0.834 \cdot 0.0570}{R \cdot 294.15} = 0.00197 mol$$

19. Explain how you will determine the molar mass and density of a gas in the syringe.

Evacuate a syringe, get the mass of the syringe and fill it with gas to get the mass of the gas and the syringe will say the volume so then you can calculate density and using the ideal gas law you can find moles and molar mass

<u>Individual data collection (each person in the group will acquire their own data):</u>

20. Using the procedure outlined previously, *newly* prepare the <u>evacuated syringe</u>. Take a mass measurement in grams of the evacuated syringe. For a mass measurement, the base of the plunger should be flat on the balance with the syringe tip pointing upward. Newly prepare the evacuated syringe again and take a mass measurement. The two measurements should be close. Calculate an average mass and put this value in the table below.
Mass measurement 1: 42.216 g Mass measurement 2: 42.221 g
Average mass of evacuated syringe: 42.219

21. Using the procedure outlined previously, fill your syringe with *air from the room*. Take the following measurements and perform the indicated calculations. Place the data in the table below.
    a. Take a mass measurement in grams of the syringe filled with air. Newly prepare a syringe with air and take another mass measurement. These two values should be close. Take an average of these two values and place it in the table below.
    Mass measurement 1: 42.273 g Mass measurement 2: 42.277 g
    Average mass of syringe filled with air: 42.275 g

    b. Now, determine the mass of the air only in the syringe. Note: **The difference between the mass of the evacuated syringe and the syringe filled with air should be between 0.05 g and 0.07 g. If this is not the case, you need to acquire the masses of the evacuated syringe and the air-filled syringe again.**

$$42.275 - 42.219 = 0.056g$$

c. Calculate the density of the gas in g/L. The volume of a filled syringe was determined previously.

$$\frac{0.0560}{0.0570} = 0.982$$

d. Calculate the experimental molar mass. Remember, the units for molar mass are g/mol.

$$\frac{0.0560}{0.00197} = 28.4\,\frac{g}{mol}$$

Mass of evacuated syringe	42.219 g
Mass of gas (air) and syringe	42.275 g
Mass of gas (air) only in syringe	0.056 g
Density of gas (air) in syringe (in g/L)	0.982 g/L
Experimental molar mass of gas (air) (in g/mol)	28.4 g/mol
Percent error (in %)	-2.07%

e. The accepted molar mass of air is 29.0 g/mol. Calculate the percent error in your experimental value by using the equation below. Put this value in the table above.

$$percent\ error = \frac{(experimental\ value - accepted\ value)}{accepted\ value} \times 100.0\%$$

$$\frac{28.4 - 29.0}{29.0} \cdot 100\% = -2.07\%$$

22. Using the procedure outlined previously, fill your syringe with *electronics duster gas*. Fill in the table by taking the indicated measurements and performing the necessary calculations. Empty your syringe, fill it again with the duster gas, and acquire another mass measurement for the gas and syringe. Your two values should be close. Determine an average mass and place this value in your table.

Mass of duster gas and syringe (in g)	42.348 g
Mass of duster gas only in syringe (in g)	0.129 g
Density of duster gas in syringe (in g/L)	2.26 g/L
Experimental molar mass of duster gas (in g/mol)	65.5 g/mol

<u>Compilation of group data and group analysis</u>:

23. In the table below, input the experimental molar mass for air for each group member. You will then need to calculate an average molar mass value for the group.

	Molar Mass (Air)
Group member	28.4 g/mol
Group member	25.3 g/mol
Group member	27.7 g/mol
Group member	
AVERAGE MOLAR MASS	27.1 g/mol

24. In the table below, input the experimental molar mass for the duster gas (including your own). You will then need to calculate an average molar mass value for the group.

	Molar Mass (Duster Gas)
Group member	65.5 g/mol
Group member	64.0 g/mol
Group member	64.2 g/mol
Group member	
AVERAGE MOLAR MASS	64.6 g/mol

Ask the teacher or lab assistant to check your work above before proceeding.

25. Are the molar mass values determined by your group members precise? If the molar mass values aren't precise, suggest a reason.
    - Precision of molar mass values for air (yes/no) No

      Measurement errors, or different syringes may affect it

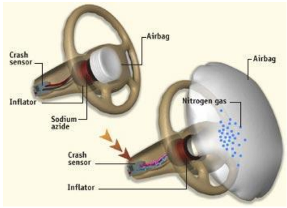
    - Precision of molar mass values for duster gas (yes/no) Yes

26. Common duster gases are propane (C_3H_8), difluoroethane ($C_2H_4F_2$), and trifluoroethane ($C_2H_3F_3$), and tetrafluoroethane ($C_2H_2F_4$). From your molar mass data of the duster gas, what is the most likely identify of the duster gas?

    Difluoroethane $\left(C_2H_4F_2\right)$

Class data: In the class data sheet (link in Canvas), input the average molar mass values and the most likely duster gas.

Information: Airbags are safety devices found in cars. They are filled by a fast decomposition reaction of sodium azide (NaN_3) to produce nitrogen gas.



$$2NaN_3(s) \rightarrow 2Na(s) + 3N_2(g)$$

It is the nitrogen gas that inflates the airbag to create the safety cushion to protect car passengers. The reaction to fill a typical airbag occurs quicker than the blink of an eye.

Since sodium azide is toxic, we will work with a similar gas producing agent, sodium bicarbonate ($NaHCO_3$). The compound reacts with acetic acid to produce carbon dioxide and two other products.

$$NaHCO_3(s) + HC_2H_3O_2(aq) \rightarrow H_2O(l) + CO_2(g) + NaC_2H_3O_2(aq)$$

Instead of an airbag, you will capture the carbon dioxide gas in a "Ziploc" type sandwich bag. The moles of sodium bicarbonate needed to properly fill the bag will be determined.

Method Development:

Items needed for *each* member of the group: 3 Ziploc sandwich bags (located on first bench), 1000 mL graduated cylinder (one for each group, on first bench), 1.5 M $HC_2H_3O_2$ (one container per group), scoopula, 50 mL graduated cylinder, funnel, $NaHCO_3$ (containers by balances). large tub (one per group).

27. Carbon dioxide gas will be collected in a sealed Ziploc bag from the reaction depicted above. The volume of the Ziploc sandwich bag will be determined by completely filling it with water and sealing the bag. The contents of the Ziploc bag will then be determined by using a 1000 mL graduated cylinder. Determine the place of the estimated digit for the graduated cylinder? ones place Note: You cannot have any air pockets in the Ziploc bag since it will introduce error in your volume measurement. Each member of the group will perform this measurement and put their value in the table. An average for the group will then be calculated.

	Volume in Ziploc bag (mL)
Group member	755 mL
Group member	738 mL
Group member	734 mL
Group member	
AVERAGE VOLUME	742 mL

28. Determine the moles of carbon dioxide needed to fill the bag. The average bag volume will be used. Use the temperature and pressure of the room determined previously. Show your work.

$$n = \frac{0.834 \cdot 0.742}{0.08206 \cdot 294.15} = 0.0256mol$$

29. Calculate the mass of sodium bicarbonate needed to produce the carbon dioxide determined above. Show your work by using dimensional analysis.

$$0.0256mol \cdot \left(84.007\,\frac{g}{mol}\right) = \underline{2.15g}$$

30. The acetic acid solution is 1.50 M. Based on this, calculate the volume, in mL, needed to react with all the sodium bicarbonate. Show your work by using dimensional analysis.

$$\frac{0.0256mol}{1.50\,\frac{mol}{L}} = 17.1mL$$

31. Describe a method to perform the reaction in the Ziploc bag.

Put the sodium bicarbonate and the acetic acid in the bag but separated until you seal the bag and then after it's sealed mix them

<u>Individual data collection (each person in the group will acquire their own data):</u>

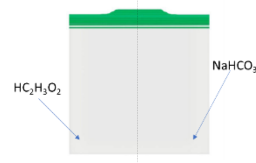
32. The below steps will assist you in performing the experiments.
    a. Use a weigh boat to measure out the amount of sodium bicarbonate determined above.

Mass of sodium bicarbonate	2.149 g

    b. Use the 50 mL graduated cylinder to measure out the amount of 1.50 M acetic acid determined above. <u>Note:</u> Add around 10 extra milliliters so that the acetic acid is in excess. You will use this same volume for all reactions.

Volume of 1.50 M acetic acid	27.1 mL

c. Acquire a new Ziploc bag. Pinch it from the bottom such that the bag is divided into two roughly equal parts. Place the sodium bicarbonate into one corner of the bag. Carefully seal the bag except for a small portion opposite the corner containing the sodium bicarbonate. Insert the funnel into the small hole you left. Have a group member assist you if needed.



d. Carefully pour the acetic acid solution into the other corner of the bag, opposite the sodium bicarbonate. Avoid mixing the acetic acid solution and the sodium bicarbonate until the acetic acid solution is added. Quickly remove the funnel and seal the bag.

e. After the bag is sealed, remove your hand, and thoroughly mix the contents of the bag until no more solid is visible and the solution stops bubbling. Keep the bag over the provided plastic tub, or over one side of a lab sink, until the reaction is complete.

f. Once your reaction is complete, compare your results with those of your group members. What is the quality of your airbag? Is the bag fully inflated, with the sides of the bag taut or does it appear to partially deflated or did your bag's seal rupture? Write down your observations.

Partially deflated

g. Take a clear picture of your filled bag.

h. Empty the contents of your bag into the sink and throw the bag away.

Compilation of group data and group analysis:

33. Fill in the following table for your group. The status of the bag after reaction will be: 1) was fully inflated with sides taut; 2) was partially deflated; or 3) seal was ruptured.

	Status of bag after reaction
Group member	Partially deflated
Group member	Partially deflated
Group member	Partially deflated
Group member	

34. Carbon dioxide is being generated over an aqueous solution. Being the situation, what is present as a gas besides carbon dioxide? ___water vapor___ Determine the partial pressure of carbon dioxide needed in the bag. Vapor pressures for water are given in the table in Model 2. The atmospheric (or total pressure) is the barometric pressure. Show your work.

$$0.834 - \frac{18.7}{760} = 0.809atm$$

35. Additionally, the volume of the bag determined previously doesn't factor in the volume of the acetic acid solution added. Recalculate the volume of the new volume of the bag which is filled with the carbon dioxide gas. Show your work.

$$742 - 27.1 = 714.9mL$$

36. Now, determine the grams of sodium bicarbonate needed to fill the bag based on the partial pressure of carbon dioxide and the new volume of the bag which needs to be filled. Show your work.

$$n = \frac{0.809 \cdot 0.7149}{0.08206 \cdot 294.15} = 0.0240mol \left(84.007 \frac{g}{mol}\right) = 2.02g$$

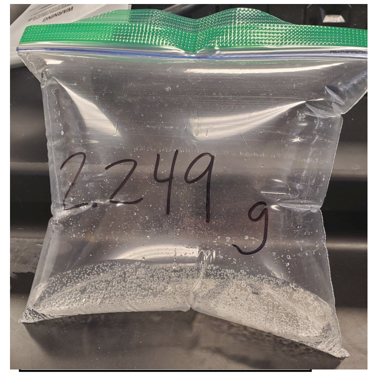
37. If you used this amount of sodium bicarbonate, what do you think will be the status of the bag after reaction? Explain your answer. Note: Be sure to compare with the mass you actually used for your experiment performed previously.

It should fill the bag so the sides are taut, but it's less sodium bicarbonate than the experiment before so it feels like it shouldn't

38. Determine the amount of sodium bicarbonate needed to produce *just enough* CO_2 gas to fill the bag so that the *sides are completely taut* (this makes the best airbag). Make assignments to your group members to determine this. This will start with an estimated amount of sodium bicarbonate which will be just below making the sides of the bag taut. Place these in the table below. It is OK if the seal on the bag ruptures while making the determination. Base your assigned amounts on the actual experiment performed previously.

	Amount of $NaHCO_3$ (in grams)
Group member	2.25 g
Group member	2.35 g
Group member	2.45 g
Group member	

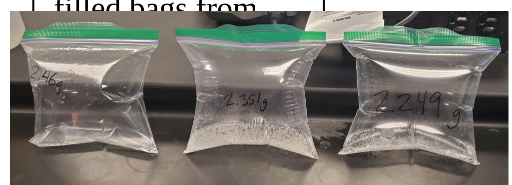
Individual data collection (each person in the group will acquire their own data):



39. Perform the experiment with the adjustment for the vapor pressure of water and the volume of acetic acid solution. Be sure to use a new Ziploc bag and write the mass of the $NaHCO_3$ on the bag with a Sharpie. Take a clear picture of the bag after this reaction. If desired, you can put your Ziploc bag in the plastic tub just in case it explodes.
40. Now, perform the experiment with your assigned amount of $NaHCO_3$. Was your bag fully inflated with sides taut, partially deflated, or ruptured? Partially deflated

Compilation of group data and group analysis:

Insert picture of filled bags from



appearance.

41. Line up the Ziploc bags for your group after performing the reaction with the assigned amount of sodium carbonate. They need to be in order from the lowest to the highest amount. Each group member needs to take a clear picture which includes all the bags.
42. Based on your observations, what is the **optimized** amount of sodium carbonate in grams which will fill the bag so that the sides are taut? 2.46 g

Class data: In the class data sheet (link in Canvas), input the amount of sodium carbonate in grams which would fill the bag so that the sides are taut.

Make sure all items are clean and return them to the drawer or bench. Finish cleaning any glassware used by rinsing with distilled water. Before you leave, ask the teacher or lab assistant to examine your data and laboratory space. Note: Your data must be entered into the spreadsheet before you leave.

Application of principles (to be completed individually):

43. The elevation of Mt. Everest base camp, where adventurers begin their quest to summit the world's highest peak, is 5364 m (17598 ft). At this altitude, the average atmospheric pressure is 400 torr, while the average temperature is -17 ^oC. Use the *combined gas law* to predict what would happen to your airbag if you performed the experiment with the optimized amount of $NaHCO_3$ determined above. You must show your work by writing below or inserting a picture of your work. Note: At -17 ^oC, the vapor pressure of water is low enough that we can ignore it for this exercise.

$$n = \frac{2.46g}{84.007\,\frac{g}{mol}} = 0.0293 \qquad V = \frac{0.0293 \cdot 0.08206 \cdot 256.15}{\left(\frac{400}{760}\right)} = 1.17L$$

The volume here would be about 430 mL greater than the volume of the bag so it will explode

44. Suppose that, instead of using sodium hydrogen carbonate, you used sodium carbonate in your airbag. Below, write the balanced chemical equation for the reaction of sodium carbonate and acetic acid that yields carbon dioxide and water. What other product must be produced? (Sodium carbonate is commonly referred to as "washing soda", and is used as a water softening agent in laundry applications when soft water is not readily available.)

$$Na_2CO_3 + 2HC_2H_3O_2 \rightarrow CO_2 + H_2O + 2NaC_2H_3O_2$$

sodium acetate

45. Using your balanced chemical equation from above, calculate the amount of carbon dioxide that would be generated using a mass of sodium carbonate equal to the optimized mass of sodium hydrogen carbonate determined in your experiments. What will happen to your airbag in this case, and why?

$$\frac{2.46g}{\frac{105.989g}{mol}} = 0.0232mol \qquad 0.0232mol, CO_2$$

46. You are now going to compare your individual values with the average values of the class in the *Class Data Sheet*. Make sure the *Class Data Sheet* is complete before doing this. You will have to wait until the end of the lab period. Fill in the following table below.

	Your individual value	**Average value of class**
Molar mass of air	28.4 g	28.6 g
Molar mass of duster gas	65.5 g	66.6 g

The agreement between a measured value and an accepted value can be analyzed by performing a percent error calculation (equation given below). For this calculation, the measured value is your individual value, and the accepted value is the class average (in Google Sheet).

$$Percent\ Error = \frac{(measured\ value - accepted\ value)}{accepted\ value} \times 100.0\%$$

a. Calculate a percent error for your duster gas.

	Percent error
Molar mass of duster gas	-1.65%

$$\frac{65.5 - 66.6}{66.6} \cdot 100\% = -1.65\%$$

b. If your percent error is greater than 10% (or less than -10%), suggest at least one reason for your individual value being significantly different than the accepted value.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** 1.008																	2 **He** 4.0026
3 **Li** 6.94	4 **Be** 9.0122											5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
11 **Na** 22.990	12 **Mg** 24.305											13 **Al** 26.982	14 **Si** 28.085	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.948
19 **K** 39.098	20 **Ca** 40.078	21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.845	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.723	32 **Ge** 72.630	33 **As** 74.922	34 **Se** 78.97	35 **Br** 79.904	36 **Kr** 83.798
37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.95	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57-71 *	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89-103 #	104 **Rf** (265)	105 **Db** (268)	106 **Sg** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (280)	112 **Cn** (285)	113 **Nh** (286)	114 **Fl** (289)	115 **Mc** (289)	116 **Lv** (293)	117 **Ts** (294)	118 **Og** (294)

* Lanthanide series	57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
# Actinide series	89 **Ac** (227)	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)