The Molecular Weight of a Gas

From the ideal gas law, \( PV = nRT \), it is easy to show that the density of an ideal gas is:

\[
D_{\text{gas}} = \frac{m}{V} = \frac{PM_w}{RT}
\]

where \( M_w \) is the molecular weight of the gas.

From this we get:

\[
M_w = \frac{mRT}{PV}
\]

Thus, the molecular weight of a gas can be determined from direct measurements of the mass and volume of the gas at the laboratory temperature and pressure.

To find the mass of the gas in a container we must weigh a container filled with gas and then subtract the mass of the empty container. In most experiments the mass of the “empty” container is in actuality the mass of the container plus the air it holds. This is generally not a problem since the mass of the air is relatively small compared to the liquid or solid samples that we are weighing. However when we need to weigh a gas, not accounting for the mass of the air in the flask would be a serious systematic error. To determine the mass of the air in the flask we will first obtain the weight of a flask filled with “dry air” (air from which all water vapor from the atmosphere has been removed). The weight of air in the flask will be calculated from the volume of the flask and the known density of air. The weight of the “empty” flask will then be determined by subtracting the calculated mass of the “dry air” from the measured mass of the flask on the balance. After the container has been filled with the gas whose molecular weight is to be determined, it will be weighed, and the weight of the gas will be determined by difference.

Various gases can be used in an experiment of this type; we will use carbon dioxide, \( \text{CO}_2 \), generated from the addition of acid to calcium carbonate:

\[
\text{CaCO}_3 (s) + 2 \text{HCl (aq)} \rightarrow \text{CO}_2 (g) + \text{CaCl}_2 (aq) + \text{H}_2\text{O (l)}
\]

Procedure

Use crucible tongs to hold the neck of the clean, "dry" 250 mL Erlenmeyer flask to be used for collecting the CO\(_2\) (flask B in the diagram). Begin heating the bottom of the flask in a Bunsen burner flame, whereupon you will see moisture beginning to condense on the upper surfaces of the flask. Gradually move the flame up the sides of the flask to "follow" the condensed moisture until all parts of the flask have been heated and the moisture has been driven out of the flask.

Immediately set the hot flask on a wire gauze (to avoid scorching the bench top) and insert a one–hole rubber stopper connected to a CaCl\(_2\) drying tube. Allow the flask to cool completely to room temperature, at least 20 minutes. Remove the stopper and cover the mouth of the flask with the aluminum foil. You can now weigh the "flask, foil, and dry air." After this weighing avoid all unnecessary handling of the flask as your fingerprints do weigh something; use a paper towel to handle the flask. Placing the flask on a piece of paper instead of directly on the lab bench will
also help. Record the temperature of the air inside the flask by inserting a thermometer under the foil and into the flask.

While you are waiting for flask B to cool, start to prepare the carbon dioxide generating flask (A in the diagram). Place about 25 grams of calcium carbonate in a 200–300 mL Erlenmeyer flask (flask A). Add about 10 mL of water, or enough to cover the chips completely. Insert the stopper with the thistle tube and the bent tube into flask A, making sure that the thistle tube is adjusted so that it is beneath the water but not crammed against the bottom of flask. The stopper must fit tightly into the flask. Also obtain about 25 mL of dilute hydrochloric acid, HCl, in a small, labeled beaker.

Once flask B has cooled and has been weighed, you can finish assembling the apparatus shown in the diagram below. Insert the straight glass tube into flask B by placing it between the foil and the flask and pressing the foil against it to hold it in place.

When all is ready pour 5 – 10 mL of the dilute hydrochloric acid into the top of the thistle tube and allow it to run through the tube and into flask A. You should note an immediate reaction as evidenced by gas evolution. Allow the reaction to continue for at least twenty minutes to displace all of the air in flask B with carbon dioxide gas. During this time you should pay attention to what is happening in flask A; if the gas evolution ceases, add additional HCl solution through the thistle tube. After the twenty minutes remove the tube from flask B (keep the foil in place) and immediately weigh the flask containing carbon dioxide.

Reassemble the apparatus and allow gas evolution to continue and flow into flask B for an additional fifteen minutes. Again, weigh flask B (with the foil). The two weights (before and
after the fifteen minutes) should agree closely. Record the temperature of the carbon dioxide in the flask. Use the barometer to read the atmospheric pressure (your instructor will show you how to read the room’s barometer).

Measure the exact volume of flask B by filling it with distilled water to the brim, wiping any water from the outside of the flask and weighing it to the nearest gram (with the foil). You will have to use the less accurate triple-beam-balance for this weighing as the weight of the flask with water exceeds the maximum weight allowed for the analytical balances; fortunately, great precision is not required for this weight determination. Measure the temperature of the water in the flask with your thermometer.

*Clean up.* Neutralize the contents of flask A by adding sodium bicarbonate until the solution no longer fizzes upon addition of the bicarbonate. You may want to do this in the sink as it tends to overflow. Decant off the liquid, leaving any solid marble chips behind. Rinse the chips with water and decant off the water. Pour the chips into the labeled recovery beaker.

**Density of Dry Air**

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Density, g/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P = 750$ torr.</td>
</tr>
<tr>
<td>17</td>
<td>1.201</td>
</tr>
<tr>
<td>18</td>
<td>1.197</td>
</tr>
<tr>
<td>19</td>
<td>1.193</td>
</tr>
<tr>
<td>20</td>
<td>1.189</td>
</tr>
<tr>
<td>21</td>
<td>1.185</td>
</tr>
<tr>
<td>22</td>
<td>1.181</td>
</tr>
<tr>
<td>23</td>
<td>1.177</td>
</tr>
<tr>
<td>24</td>
<td>1.173</td>
</tr>
<tr>
<td>25</td>
<td>1.169</td>
</tr>
</tbody>
</table>

Information from the *CRC Handbook of Chemistry and Physics*, 64th ed., 1983-4

**Density of Liquid Water**

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Density, g/mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.9991</td>
</tr>
<tr>
<td>16</td>
<td>0.9989</td>
</tr>
<tr>
<td>17</td>
<td>0.9988</td>
</tr>
<tr>
<td>18</td>
<td>0.9986</td>
</tr>
<tr>
<td>19</td>
<td>0.9984</td>
</tr>
<tr>
<td>20</td>
<td>0.9982</td>
</tr>
<tr>
<td>21</td>
<td>0.9980</td>
</tr>
<tr>
<td>22</td>
<td>0.9978</td>
</tr>
<tr>
<td>23</td>
<td>0.9975</td>
</tr>
<tr>
<td>24</td>
<td>0.9973</td>
</tr>
<tr>
<td>25</td>
<td>0.9970</td>
</tr>
<tr>
<td>26</td>
<td>0.9968</td>
</tr>
<tr>
<td>30</td>
<td>0.9957</td>
</tr>
</tbody>
</table>
Molecular Weight of a Gas Report

Data:

Weight of foil and flask filled with dry air _________________ g
Temperature of dry air in flask ___________________ °C
Barometric pressure _______________ torr = ______________ atm
Density of dry air at experimental temperature and pressure __________ g/L = ________ g/mL
Weight of flask filled with CO₂, after first twenty minutes _________________ g
Weight of flask filled with CO₂, after second fifteen minutes _________________ g
Temperature of CO₂ in flask _______________ °C = ______________ K
Weight of foil and flask filled with water _________________ g
Mass of water (only) (flask + water + foil) – (empty flask + foil) ________________ g
Temperature of water ______________ °C
Density of water at above temperature ______________ g/mL

Calculations (show work and put a box around each answer)

Volume of flask

Weight of dry air in flask

Weight of empty flask
Weight of carbon dioxide in flask

Experimental molecular mass

Actual molecular mass (from periodic table)

Percent error

Questions

1. Because the mass of the flask with water exceeds the amount that can be weighed on our digital balances, we use the triple-beam-balance which only weighs to ±0.01 g. Why doesn't using this balance affect the number of significant digits to which we can report the experimental molecular weight of carbon dioxide?

2. Why can we neglect the weight of the air in the flask when obtaining the weight of the water in the flask (as we do when weighing most things) but not neglect the weight of the air when we calculate the weight of carbon dioxide in the flask?
3. List three potential errors in this experiment that may have affected your results.

   a. 

   b. 

   c. 

4. How would each of these errors affect your experimental molecular mass of CO$_2$ you determined (would your calculated molecular mass be higher or lower as a result)? Show your supporting calculations in each case.

   a. 

   b. 

   c. 

5. Estimate the magnitude of each error below and compare it to the number of significant digits in your experimental results – based on this, which of these errors might have affected the numeric value of your experimentally determined molecular mass. Show your supporting calculations.

   a. 

   b. 

   c.