Determination of molar mass using the ideal gas law

(Item No.: P3010401)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Chemistry	University	General Chemistry	Molar Mass	Determination of molar mass using the ideal gas law

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	10 Minutes	20 Minutes	2 Students

Additional Requirements:

- Precision balance, 620 g / 0.001 g

Experiment Variations:

Keywords:

molar mass and relative molar mass, properties of gases, ideal and ordinary gases, equations of state

Overview

Short description

Principle

All gases may be considered, to a first approximation, to obey the ideal gas equation which relates the pressure *p*, volume *V*, temperature *T* and amount of substance *n* of a gas. The amount of gas *n* is expressed as the number of moles and is equal to *m*/*M* where *m* is the mass of gas present and is the mass of one mole of the gas. The volume occupied by a known mass of gas is to be measured at a given temperature and pressure, so that the ideal gas equation can be used to estimate the molar mass of the gas.

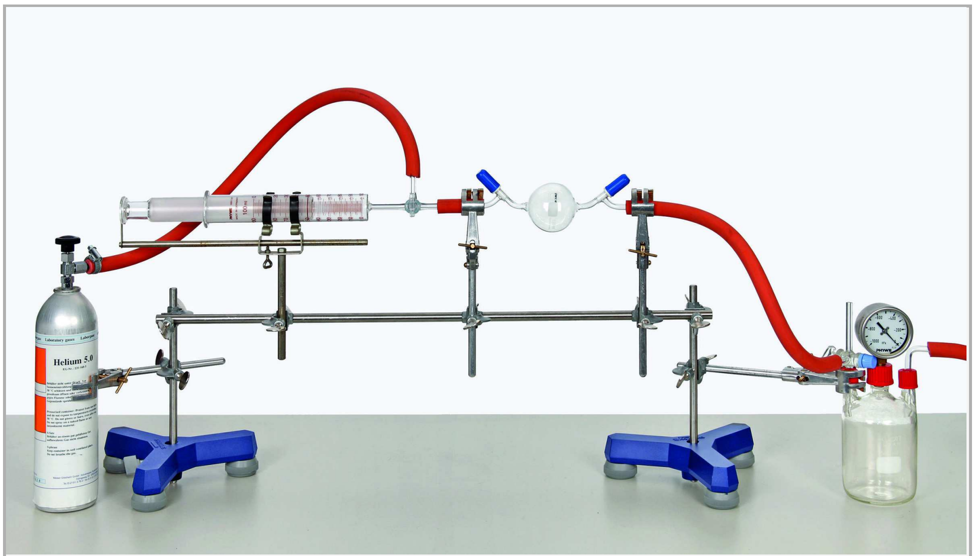
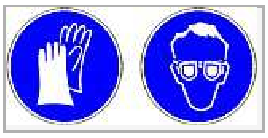


Fig. 1: Experimental set-up.

Safety instructions:



When handling chemicals, you should wear suitable protective gloves, safety goggles, and suitable clothing.

Equipment

Position No.	Material	Order No.	Quantity
1	Rotary valve vacuum pump, one stage	02740-95	1
2	Oil mist filter, DN 16 KF	02752-16	1
3	Weather monitor, 6 lines LCD	87997-10	1
4	Secure bottle, 500 ml, 2 x Gl 18/8, 1 x 25/12	34170-01	1
5	Tripod base PHYWE	02002-55	2
6	Glass sphere, 2 stopcocks, 100 ml	36810-00	1
7	Gas syringe, 100 ml, with 3-way cock	02617-00	1
8	Adapter for vacuum pump	02657-00	1
9	Fine control valve	33499-00	1
10	Compressed gas, nitrogen, 12 l	41772-04	1
11	Compressed gas,CO2,21 g	41772-06	1
12	Compressed gas, methane, 12 l	41772-08	1
13	Compressed gas, helium, 12 l	41772-03	1
14	Spring manometer, 0...-1000 mbar	34170-02	1
15	Gas-syringe holder with stop	02058-00	1
16	Stopcock,3-way,t-shaped, glass	36731-00	1
17	Silicon grease Molykote, 50 g	31863-05	1
18	Support rod, stainless steel, 750 mm	02033-00	1
19	Universal clamp	37715-00	4
20	Rubber tubing,vacuum,i.d.6mm	39286-00	3
21	Rubber tubing,vacuum,i.d.8mm	39288-00	1
22	Right angle clamp	37697-00	7
23	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	2
24	Glass tube, right-angled	36701-07	1
25	Hose clip, diam. 8-16 mm, 1 pc.	40996-02	4
26	Hose clip f.12-20 diameter tube	40995-00	2

Task

Determine the molar masses of the gases helium, nitrogen, carbon dioxide and methane.

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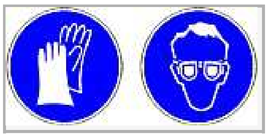
Set-up and procedure

Safety instructions:



When handling chemicals, you should wear suitable protective gloves, safety goggles, and suitable clothing.

Thoroughly clean and dry the syringe and the glass bulb and lightly grease the three-way stopcock (do not grease the syringe plunger!). Assemble the apparatus as shown in Fig. 1. Make sure that the plunger stop is positioned to prevent the plunger from being fully removed from the syringe barrel whilst still allowing the syringe to be filled to its maximum volume of 100 ml.

In the following, S1 is the three-way stopcock on the gas syringe, S2 is the Teflon stopcock between S1 and the glass bulb and S3 is the Teflon stopcock between the glass bulb and the pump.

To determine the mass of the glass bulb, close S2, open S3 and evacuate the glass bulb by pumping for 10 minutes, close S3, disconnect the bulb from the vacuum line and weigh it. Following this, reconnect the bulb to the vacuum line and open S2 and S3. Turn S1 to connect both the syringe and the bulb to the gas bottle and evacuate the entire vacuum line for a further 5–10 minutes. Close S2 and S3 and carefully open the needle valve regulator on the gas bottle to fill the syringe with gas.

Record the volume of gas introduced into the syringe (between 95 ml and 100 ml) to the nearest 0.5 ml. Fill the bulb with gas by turning S1 through 180° and slowly open S2. After closing S2, remove the bulb from the vacuum line and re-weigh it.

Calculate the mass of the gas in the bulb and record it together with the ambient pressure and temperature. Replace the bulb and repeat the procedure twice before measuring the next gas.

Theory and evaluation

The molecules of a hypothetical perfect gas do not interact (do not attract or repel each other), so the ideal gas equation is obeyed exactly.

$$p \cdot V = n \cdot R \cdot T \qquad (1)$$

where

R = Gas constant

For ordinary gases (whose particles do interact), equation (1) represents a limiting law. An ordinary gas behaves more and more like an ideal gas as its density is reduced, since at low densities the intermolecular distance is so large that the interactions between the gas molecules become insignificant.

Even at standard temperature and pressure (*T* = 298 K, *p* = 1 bar) many gases obey equation (1) remarkably well and it may be used to determine the molar masses of gases in a simple way. Rearranging equation (1) gives:

$$M = \frac{m \cdot R \cdot T}{p \cdot V} \qquad (2)$$

Data and results

The results of a typical experiment are shown in Table 1. Given the simple nature of the determination, the agreement is very satisfactory. However, the student should be aware of possible sources of random and systematic error in this experiment, such as the volume between the end of the syringe barrel and the bulb that is neglected here, the accuracy of the reading of the gas volume in the syringe and fluctuations in the temperature.

The size and relevance of these and other errors should be critically discussed.

Table 1

Gas	Volume V / ml	Mass m / g	Ambient pressure p / mm Hg	Ambient Temperature T / K	Molar mass M / g $\cdot$ mol^{-1}	
					Exp.	Lit.
He	98.5	0.017	746.6	294.2	4.2	
	99.0	0.018	746.6	294.2	4.5	
	100.0	0.019	746.6	294.2	4.7	
					mean: 4.5	4.00
N_2	98.5	0.115	746.6	294.2	28.7	
	99.5	0.115	746.6	294.2	28.4	
	99.0	0.118	746.6	294.2	29.3	
					mean: 28.3	28.02
CO_2	99.0	0.178	746.0	294.7	44.3	
	99.0	0.175	746.0	294.7	43.5	
	98.0	0.179	746.0	294.7	45.0	
					mean: 44.3	44.01
CH_4	99.5	0.066	744.5	294.7	16.4	
	100.0	0.072	744.5	294.7	17.8	
	98.0	0.069	744.5	294.7	17.7	
					mean: 17.3	16.04