

# Determination of molar mass using the ideal gas law



Students will be able to determine the molar mass by using the ideal gas law.

Chemistry

General Chemistry

Stoichiometry



Difficulty level

medium



Group size

2



Preparation time

10 minutes



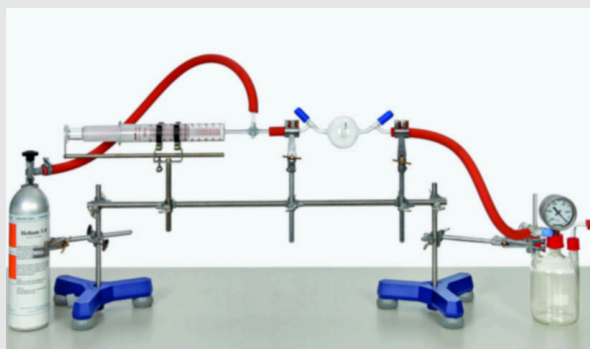
Execution time

20 minutes

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## General information

### Application

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Experimental set-up

In this experiment, the students will learn the determination of molar mass using the ideal gas law. They will determine the molar masses of the gases helium, nitrogen, carbon dioxide and methane.

The ideal gas law describes the state of the gas in terms of pressure, volume, temperature and amount of substance (or number of particles or mass).

## Other information (1/2)

### Prior knowledge

Students should be familiar with molar and relative molar mass, properties of gases, ideal and ordinary gases and equations of state.



### Scientific principle

By using the ideal gas law it is possible to determine the molar mass.

$$M = \frac{m \cdot R \cdot T}{p \cdot V}$$



## Other information (2/2)

### Learning objective



Students will be able to determine the molar mass by using the ideal gas law.

### Tasks



The students will determine the molar masses of the gases helium, nitrogen, carbon dioxide and methane.

## Safety instructions

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- When handling chemicals, you should wear suitable protective gloves, safety goggles, and suitable clothing.
- For this experiment the general instructions for safe experimentation in science lessons apply.

## Theory

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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  $M$  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.

## Equipment

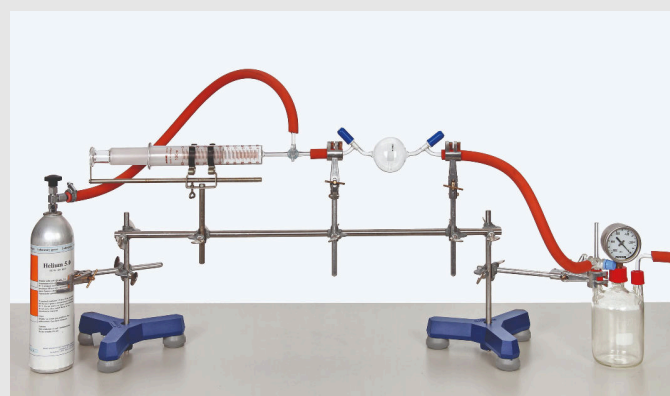
Position	Material	Item No.	Quantity
1	Tripod base PHYWE	02002-55	2
2	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	2
3	Support rod, stainless steel, 750 mm	02033-00	1
4	Universal clamp	37715-01	4
5	Right angle boss-head clamp	37697-00	7
6	Gas-syringe holder with stop	02058-00	1
7	Gas syringe, 100 ml, with 3-way cock	02617-00	1
8	Glass sphere, 2 stopcocks, 100 ml	36810-00	1
9	Secure bottle, 500 ml, 2 x GI 18/8, 1 x 25/12	34170-01	1
10	Spring manometer, 0...-1000 mbar	34170-02	1
11	Glass tubes, right-angled, 10	36701-57	1
12	Stopcock, 3-way, t-shaped, glass	36731-00	1
13	Rotary valve vacuum pump, two stages, 115 V / 230 V	02741-95	1
14	Adapter for vacuum pump	02657-00	1
15	Rubber tubing, vacuum, i.d. 6mm	39286-00	3
16	Rubber tubing, vacuum, i.d. 8mm	39288-00	1
17	Hose clip, diam. 8-16 mm, 1 pc.	40996-02	4
18	Hose clip f. 12-20 diameter tube	40995-00	2
19	Weather monitor, 6 lines LCD	87997-10	1
20	Silicon grease Molykote, 50 g	31863-05	1
21	Fine control valve	33499-00	1
22	Compressed gas, nitrogen, 12 l	41772-04	1
23	Compressed gas, CO <sub>2</sub> , 22 g	41772-06	1
24	Compressed gas, methane, 12 l	41772-08	1
25	Compressed gas, helium, 12 l	41772-03	1



## Setup and procedure

### Setup

- 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. right. 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.



Experimental set-up

## Procedure

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- 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.

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## Evaluation

## Evaluation (1/6)

### 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.

$$p \cdot V = n \cdot R \cdot T$$

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.

### Theory and evaluation

Even at standard temperature and pressure ( $T = 298 \text{ K}$ ,  $p = 1 \text{ bar}$ ) 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:

$$M = \frac{m \cdot R \cdot T}{p \cdot V}$$

## Evaluation (2/6)

### Data and results

The results of a typical experiment are shown in Table 1 (next slide). 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.



## Evaluation (3/6)

Gas	Volume $V / \text{ml}$	Mass $m / \text{g}$	Ambient pressure $p / \text{mm Hg}$	Ambient Temperature $T / \text{K}$	Molar mass $M / \text{g} \cdot \text{mol}^{-1}$	
					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 <sub>2</sub>	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 <sub>2</sub>	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 <sub>4</sub>	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

## Evaluation (4/6)

What is described by the ideal gas law?

The packaging unit in which gas is delivered.

It is the worldwide law on how a gas must be delivered.

None of the answers is correct.

The state of the gas in terms of pressure, volume, temperature and amount of substance (or number of particles or mass).

✓ Überprüfen

## Evaluation (5/6)

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Mark the formula that describes the ideal gas law for a perfect gas.

The formula is  $p \cdot V = n \cdot R \cdot T$  .

The formula is  $M = \frac{m \cdot R \cdot T}{p \cdot V}$  .

There is no formula that describes the ideal gas law for a perfect gas, because there is no ideal gas law.

None of the answers is correct.

✓ Überprüfen

## Evaluation (6/6)

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Drag the words into the correct boxes!

All  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  and is equal to  $m/M$  where  $m$  is the mass of gas present and  $M$  is the mass of one mole of the gas. The  occupied by a known mass of gas is to be measured at a given temperature and pressure, so that the  can be used to estimate the molar mass of the gas.

gases

number of moles

volume

ideal gas equation

✓ Überprüfen

Slide	Score/Total
Slide 15: Ideal gas law	0/1
Slide 16: ideal gas law for a perfect gas	1/1
Slide 17: Ideal gas equation: Drag Text	0/4

Total Score  1/6

 Show solutions

 Retry