Avogadro's law

Students will be able to test the correctness of the Avogadro's hypothesis and carry out the carbon monoxide/ oxygen reaction and the hydrogen/ oxygen reaction at above 100°C.

Chemistry | General Chemistry | Stoichiometry

Difficulty level	Group size	Preparation time	Execution time
medium	2	45+ minutes	45+ minutes

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

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General information

Application

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A balloon filled with helium is lighter than one filled with air and it goes up in the sky

Avogadro's Law states that the volume of a gas is directly proportional to the number of moles of gas. There are a lot of everyday examples where this law is used, as presented below.
As you blow up a basketball, you are forcing more gas molecules into it. The more molecules, the greater the volume. The basketball inflates.
A flat tire takes up less space than an inflated tire because it contains less air. Lungs expand as they fill with air. Exhaling decreases the volume of the lungs.
A balloon filled with helium weights much less than an identical balloon filled with air. Both balloons contain the same number of molecules. Helium atoms have lower mass than either oxygen molecules or nitrogen molecules in air, so the helium balloon is lighter.

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Other information (1/2)

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Prior knowledge

The ideal gas is a concept that should be clear in this experiment. An ideal gas is a theoretical gas composed of many randomly moving point particles that are not subject to interparticle interactions. At standard temperature and pressure, most real gases behave like an ideal gas. Another important concept is the law of volume which states that the temperature and volume will be in direct proportion when the pressure on a sample is held constant.

Scientific principle

In this experiment the Avogadro's Law is seen as a hypothesis. The students will carry out different reactions in order to prove its correctness.

Other information (2/2)

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Learning objective

- Students will be able to test the correctness of the Avogadro's hypothesis.
- When temperature and pressure are the same before and after the reaction, 6 parts by volume of CO and 3 parts by volume of O_2 must form 6 parts by volume of CO_2.
- Similary, at a temperature a little above 100 °C, a gas mixture containing 6 parts by volume of H_2 and 5 parts by volume of Cl_2 must give 10 parts by volume of HCl.

Tasks

- The students will determine the Avogadro's Law.
- They will carry out the carbon monoxide/ oxygen reaction and the hydrogen/ oxygen reaction at above 100°C.

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Safety instructions

- Use protective glasses.
- Use protective gloves.
- For this experiment the general instructions for safe experimentation in science lessons apply.
- For H- and P-phrases please consult the safety data sheet of the respective chemical.

Theory

In 1811, Avogadro stated his hypothesis that under the same conditions of pressure and temperature, equal volumes of all gases contain equal number of components (molecules, atoms). He derived this from the uniformity of the behaviour of (ideal) gases on increases in temperature and pressure and the law of Volumes.

As an example, equal volumes of molecular hydrogen and nitrogen contain the same number of molecules when they are at the same temperature and pressure and observe ideal gas behavior.

In practice, real gases show small deviations from the ideal behavior and the law holds only approximately, but is still very useful for scientists.

Due to this law, it was later able to calculate the quantity of gas in a receptacle. In 1865, Loschmidt was able to estimate the size of a molecule. These calculations led to the determination of Avogadro's number as the number of molecules in one gram-molecule of oxygen.

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Equipment

Position	Material	Item No.	Quantity
1	Glass jacket	02615-00	1
2	Plunger eudiometer	02611-00	1
3	Ignition spark generator	11155-00	1
4	Connecting cord, 30 kV, 1000 mm	07367-00	2
5	Gas bar	40466-00	2
6	Heating apparatus for glass jacket system	32246-93	1
7	Power regulator	32288-93	1
8	Support base DEMO	02007-55	1
9	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	2
10	Support rod, stainless steel, l = 600 mm, d = 10 mm	02037-00	2
11	Retort stand, h = 750 mm	37694-00	1
12	Right angle boss-head clamp	37697-00	3
13	Universal clamp	37715-01	3
14	Round bottom flask, 100ml, GL 25/12	35841-15	1
15	Funnel for gas generator, 50 ml, GL18	35854-15	1
16	Gas syringe, 100 ml	02614-00	1
17	Syringe 10ml, Luer, 100 pcs	02590-10	1
18	Cannula 0,45x13 mm, Luer, 20 pcs	02598-10	1
19	Lab thermometer,-10..+150C	38058-00	2
20	Steel cylinder oxygen, 2 l, filled	41778-00	1
21	Steel cylinder hydrogen, 2 l, full	41775-00	1
22	Reducing valve f.oxygen	33482-00	1
23	Reducing valve for hydrogen	33484-00	1
24	Table stand for 2 l steel cylinders	41774-00	2
25	Wrench for steel cylinders	40322-00	1
26	Teclu burner, DIN, natural gas	32171-05	1
27	Safety gas tubing, DVGW, sold by metre	39281-10	1
28	Hose clip f.12-20 diameter tube	40995-00	2
29	Lighter f.natural/liquified gases	38874-00	1
30	Silicone tubing i.d. 7mm, 1 m	39296-00	2
31	Funnel, glass, top dia. 50 mm	34457-00	1
32	Beaker, Borosilicate, tall form, 250 ml	46027-00	1
33	Graduated beaker with handle, 1000 ml, plastic (PP)	36640-00	1
34	Spoon, special steel	33398-00	1
35	Boiling beads, 200 g	36937-20	1
36	Formic acid 75% 250 ml	30023-25	1
37	Sulphuric acid, 95-97%, 500 ml	30219-50	1
38	Hydrochloric acid 37 %, 1000 ml	30214-70	1
39	Potassium permanganate, chem. pur., 250 g	30108-25	1
40	Sodium chloride, 500 g	30155-50	1
41	Water, distilled 5 l	31246-81	1
42	Lab protecting glasses with UV filter	39315-00	1
43	Base plate for support base DEMO	02007-01	1

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Setup and procedure

Setup (1/3) - Carbon monoxide/chlorine production

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- Fill the 100 ml round bottomed flask about one quarter full with formic acid and about half-fill the dropping funnel with concentrated sulphuric acid.
- Warm gently and drop sulphuric acid into the formic acid (in a fume cupboard).
- When the development of gas starts, wait until all air has been expelled out of the apparatus, then connect the tubing to the dropping funnel hose nipple and collect gas in the small gasometer.
- When the gasometer is full, stop dropping sulphuric acid, put a stopper in the opening of the cylindrical funnel, remove the tubing from the right angled glass tube and close it with a rubber cap.

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Setup (2/3) - Carbon monoxide/chlorine production

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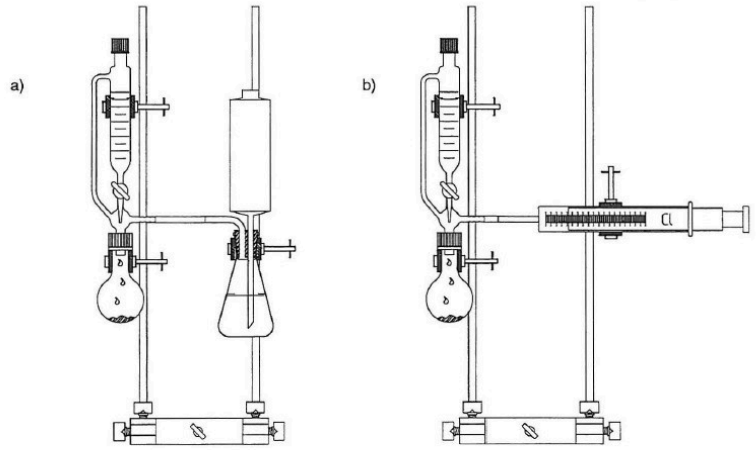

Experiment setup

- The set-up for the preparation of carbon monoxide is as in Figure 1a, except that the tubing is not connected to the dropping funnel to start with.
- The set-up for the preparation of chlorine is as in Figure 1b, but here again the tubing is not connected to the dropping funnel to start with.

Setup (3/3) - Carbon monoxide/chlorine production

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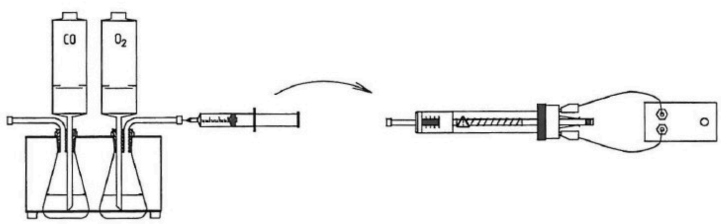
- Place 5 or 6 spoon of potassium permanganate in the 100 ml round-bottomed flask and half- fill the dropping funnel with concentrated hydrochloric acid.
- Drop hydrochloric acid slowly onto the potassium permanganate (in a fume cupboard).
- When the development of gas starts, wait until all air has been expelled out of the apparatus, then connect the tubing to the dropping funnel hose nipple and collect gas in the gas syringe.
- When it is about 60- 70% filled, stop dropping hydrochloric acid, remove the tubing from the gas syringe and close it with a rubber cap.

Procedure (1/6) - The carbon monoxide/oxygen

- Fill the gas bar with oxygen and carbon monoxide.
- Using a 10 ml injection syringe with a thin cannula, draw 3 ml of oxygen and 6 ml of carbon monoxide out of the corresponding gasometers.
- Inject this stoichiometric mixture in the plunger eudiometer which is also closed with a tightfitting rubber cap and whose plunger has been exactly adjusted to the zero mark on the scale.
- Connect the prepared eudiometer electrically to the ignition spark generator, and, as a safety precaution, put into a transparent plastic bag.
- Grasp it, together with the plastic bag, with one hand in the area of the black screw cap. Hold it as horizontally as possible and a little bit away from you.
- Ignite the mixture by operating the spark generator.

Procedure (2/6) - The carbon monoxide/oxygen

Experiment setup



Experiment setup

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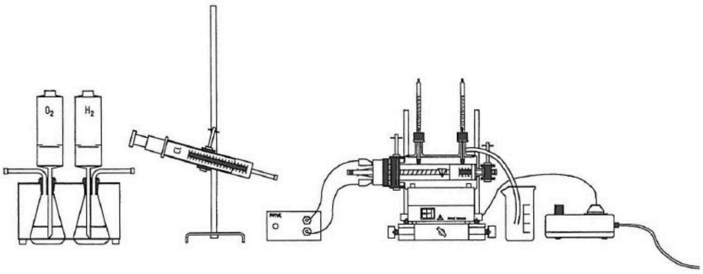
Procedure (3/6) - The hydrogen/oxygen reaction at above 100°C

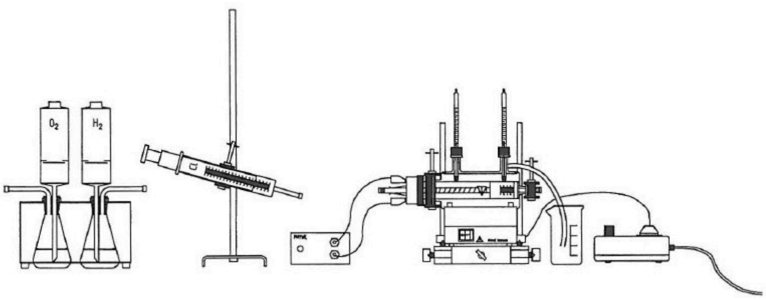


Experiment setup

- Insert the eudiometer in the glass jacket as explained in the directions for use. Check that the sealing rings are properly positioned, and that the connecting caps are screwed tightly enough to prevent the eudiometer from moving about in the glass jacket when the explosion occurs.
- Also check that the rubber cap is up tight against the connecting cap of the glass jacket, so that the whole length of the capillary tube of the eudiometer is heated up.

Procedure (4/6) - The hydrogen/oxygen reaction at above 100°C

- Fix this combination horizontally on the rods. Fill the glass jacket with a 3 to 4 molar salt solution (dissolve between 100 and 120 g of sodium chloride in 500 ml of water) and add a few boiling stones (beads).
- Position thermometers in each of the vertical screw cap adapters. Position the heating apparatus under the glass jacket and connect it to the power regulator.



Experiment setup

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Procedure (5/6) - The hydrogen/oxygen reaction at above 100°C

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- Connect the eudiometer to the ignition spark generator with the two connecting wires. Attach a length of rubber tubing to the hose nipple of the glass jacket to lead steam out and down into a glass beaker. Fill the gas bar with hydrogen and oxygen.
- When construction has been completed, heat the apparatus up to boiling point (approx. 103 °C) with the electrical heater. Uniform heating-up of the eudiometer is attained about 5 minutes after boiling started.
- Adjust the plunger to the zero mark on the scale. Close the capillary tube end of the eudiometer with a tight-fitting rubber cap and inject so much of a stoichiometric hydrogen/oxygen mixture (= volumes in the ratio 2:1) through this, that the eudiometer contains exactly 9 ml of the mixture at the prevailing 103 °C temperature. 9 ml at 103 °C corresponds to a volume of 7 ml at 20 °C. Ignite the mixture with the spark generator.

Procedure (6/6) - The hydrogen/chlorine reaction at above

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- Fix the gas syringe containing chlorine in a slightly inclined position on a stand and fill hydrogen into a gas bar.
- Heat the eudiometer up to 103 °C.
- Inject a stoichiometric mixture of hydrogen and chlorine into the eudiometer.
- For safety reasons, the volume of the mixture injected into the eudiometer should not be more than 10 ml.
- Do not carry out the experiment in direct sunlight or under a spotlight, as the gas mixture could spontaneously ignite itself.
- When the reaction has taken place, push the resulting HCl gas out of the eudiometer as quickly and as completely as possible, to avoid corrosion of the tips of the spark gap electrodes.

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Evaluation

Evaluation (1/5)

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The carbon monoxide/oxygen reaction

A small explosion occurs. The plunger is first forced out a few centimeters but then immediately comes back again. A gas volume of 6 ml of carbon dioxide remains in the eudiometer.
one CO_2 molecule is formed from each CO molecule. There must therefore be the same number of molecules in 6 ml of CO_2 as in 6 ml of CO. The experiment confirms the validity of Avogadro's Hypothesis.

The hydrogen/oxygen reaction at above 100°C

After the reaction the plunger shows a residual volume of 6 ml. This consists of water in vapour form (steam).
The mixture of 6 ml H_2 and 3 ml O_2 has reacted so that every hydrogen molecule combines with oxygen to form a water molecule. The 6 ml of H_2 combines with 3 ml of O_2 to form 6 ml of water in the vapour phase. The experiment therefore confirms the validity of Avogadro's Hypothesis.

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Evaluation (2/5)

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The hydrogen/chlorine reaction at above 100°C

After ignition and reaction, there are just as many ml of gas in the eudiometer as were previously injected into it.

When the reaction has been completed, there are the same number of diatornic molecules present as were present in the injected gas mixture. As these take up the same space, this experiment also confirms the validity of Avogadro's Hypothesis. As Avogadro's Hypothesis has shown itself up to now to be correct for all sufficiently ideal gases, it is also called Avogadro's Law.

It is of great importance in analytical chemistry for the determination of molar masses of gases and vapours, as well as for the calculation of stoichiometric gas portions.

Evaluation (3/5)

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Complete the reactions that take place during the experiment.

1. The carbon monoxide/oxygen reaction

$2CO + O_2 -> $ ____

2. The hydrogen/oxygen reaction at above 100°C

$2H_2 + O_2 -> $ ____

3. The hydrogen/chlorine reaction at above 100°C

$Cl_2 + H_2 -> $ ____

$2HCl$

$2CO_2$

$2HO_2$

Check

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Evaluation (4/5)

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Does an explosion occur during the carbon monoxide/oxygen reaction?

- Yes
- No

Evaluation (5/5)

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Drag the words into the correct boxes!

In 1811, ________ stated his hypothesis that under the same conditions of pressure and temperature, equal volumes of all gases contain equal number of components (molecules, atoms). He derived this from the uniformity of the behaviour of (ideal) gases on ________ in temperature and pressure and the law of ________.
As an example, equal volumes of molecular hydroogen and ________ contain the same number of molecules when they are at the same temperature and pressure, and observe ideal gas behavior.

- nitrogen
- Volumes
- Avogadro
- increases

Check

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Slide	Score / Total
Slide 21: Reaction scheme	**0/3**
Slide 22: Carbon monoxide/oxygen reaction	**0/3**
Slide 23: Avogadro: Summary	**0/4**

Total Score **0/10**

Show solutions

Retry

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