Avogadro's law (Item No.: P3111000)

Curricular Relevance

Area of Expertise: Chemistry | **Education Level:** University | **Topic:** General Chemistry | **Subtopic:** Stoichiometry | **Experiment:** Avogadro's Law

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	1 Hour	1 Hour	2 Students

Additional Requirements:

- Precision balance, 620 g / 0.001 g

Experiment Variations:

Keywords:

Carbon monoxide/oxygen reaction, Hydrogen/oxygen reaction

Task and equipment

Introduction

Principle:
In 1811, Avogadro stated his hypothesis that under the same conditions of pressure and temperature, equal volumes of all gases contain equal numbers of components (molecules, atoms). He derived this from the uniformity of the behaviour of (ideal) gases on increases in temperature and pressure (see the Gas Laws) and the Law of Volumes.
When Avogadro's supposition is correct, then 6 parts by volume of CO and 3 parts by volume of O_2 must form 6 parts by volume of CO_2 when pressure and temperature are the same before and after the reaction.
Similarly, at a temperature a little above 100 °C, a gas mixture containing 6 parts by volume of H_2 and 3 parts by volume of O_2 must give 6 parts by volume of steam, and a mixture containing 5 parts by volume of H_2 and 5 parts by volume of Cl_2 must give 10 parts by volume of HCl.
In the following experiments we will carry out the reactions named above to test the correctness of the hypothesis.

Safety instructions

    

Hydrogen forms explosive mixtures with air. It is imperative that you carefully follow the directions for use for the plunger eudiometer when working with it. The eudiometer must be perfectly clean, so that the plunger slides easily, without any possibility of stickage (danger of shattering!).
Protective clothing (protective glasses, etc.) must be worn.
The gas mixture for hydrogen/oxygen reactions in the cold eudiometer must always be so chosen that one of the gases is present in excess. The residual gas must act as a buffer to the forward rush of the plunger and prevent it from hitting hard against the front of the eudiometer with resulting glass breakage. It is preferable to work with an excess of oxygen.
Alternatively, a little air can first be introduced into the eudiometer, so that this brakes the plunger movement. In this case, a stoichiometric gas mixture can be used.
Stoichiometric gas mixtures can also be used with gas reactions which produce gaseous products (e.g. for carbon monoxide/oxygen reactions), as the reaction product then acts as buffer.

When the eudiometer is used alone, not in the glass jacket, place it a plastic bag of not too thin wall thickness before ignition, and tighten the bag around it. The bag not only provides some protection against splinters, but also gives the rubber cap an additional hold against the pressure of the explosion, so that it is not blown off of the tube.
The volume of the gas mixture used for the reaction should be kept quite small. Good results are obtained with the volumes given for the experiments.
During the insertion of the plunger eudiometer into the glass jacket, check that the sealing rings are properly positioned. Be sure that the connecting caps are sufficiently tightened to prevent movement of the eudiometer within the glass jacket when the explosion occurs.
Carbon monoxide is a colourless, odourless, flammable and poisonous gas. All experiments which are carried out with this gas should therefore be performed in a fume cupboard.
Chlorine is a poisonous, strongly corrosive gas which causes burns, is heavier than air, has a good solubility in water and a biting smell. It irritates the respiratory tract, the eyes and skin. In the presence of moisture (mucous membranes), chlorine forms "active" oxygen and hydrochloric acid, both of which strongly attack tissue. Experiments in which chlorine is used must therefore be carried out in a fume cupboard with a very good draught of air.
Concentrated acids are very corrosive. They attack skin and clothing. When diluting, first the water, then the acid (protective glasses, laboratory coat, gloves).
First aid: Wash the skin (eyes etc.) affected thoroughly with plenty of water. On injury to the eyes, immediately seek medical assistance.
When inhaled: fresh air, keep respiratory passages free and open. On difficulty in breathing, transport to the doctor in a semireclined position.
Waste disposal: Dilute solutions with water, neutralize (pH 6–8) and rinse to drain. Collect solutions which contain heavy metal ions in a container for solutions of heavy metal salts.

Potassium permanganate
H272: May intensify fire; oxidizer.
H302: Harmful if swallowed.
H410: Very toxic to aquatic life with long-lasting effects.
P220: Keep/Store away from clothing/…/combustible materials.
P273: Avoid release to the environment.
P280: Wear protective gloves/protective clothing/eye protection/face protection.

Carbon monoxide
H220: Extremely flammable gas.
H331: Toxic if inhaled.
H360D: May damage the unborn child
P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P260: Do not breathe dust/fumes/gas/mist/vapours/spray.

Hydrochloric acid, 37%
H290: May be corrosive to metals.
H314: Causes severe skin burns and eye damage.
H335: May cause respiratory irritation.
P280: Wear protective gloves/protective clothing/eye protection/face protection.

Sulphuric acid, 95%
H290: May be corrosive to metals.
H314: Causes severe skin burns and eye damage.
P280: Wear protective gloves/protective clothing/eye protection/face protection.

Hydrogen
H220: Extremely flammable gas.

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H280: Contains gas under pressure; may explode if heated.
P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
P377: Leaking gas fire – do not extinguish unless leak can be stopped safely.

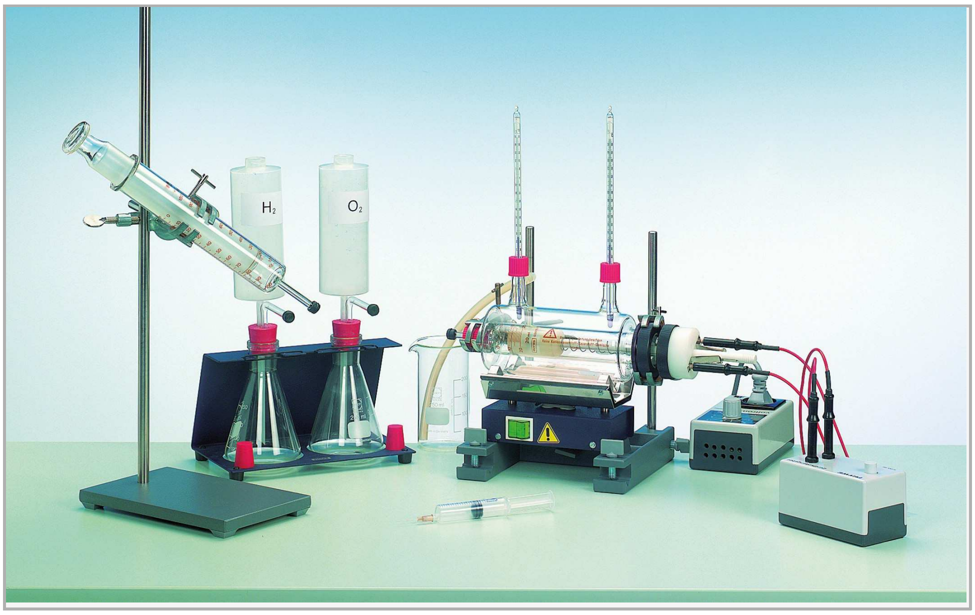
Oxygen
H270: May cause or intensify fire; oxidizer
H280: Contains gas under pressure; may explode if heated
P220: Keep/Store away from clothing/…/combustible materials.

Formic acid, 75%
H226: Flammable liquid and vapour.
H290: May be corrosive to metals.
H314: Causes severe skin burns and eye damage.
P260: Do not breathe dust/fumes/gas/mist/vapours/spray.

Chlorine
H270: May cause or intensify fire; oxidizer.
H315: Causes skin irritation.
H400: Very toxic to aquatic life.
EUH071: Corrosive to the respiratory tract.
P220: Keep/Store away from clothing/…/combustible materials.
P260: Do not breathe dust/fumes/gas/mist/vapours/spray.

Task

Determine: Avogadro's Law: The carbon monoxide/oxygen reaction and the hydrogen/oxygen reaction at above 100°C



Equipment

Position No.	Material	Order 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	37715-00	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, 10 pcs	02590-03	1
18	Cannula 0,45x13 mm, Luer, 20 pcs	02598-04	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. 55 mm	34457-00	1
32	Beaker, high, BORO 3.3, 250 ml	46027-00	1
33	Graduated vessel, 1 l, with handle	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, 95-98% 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

Set-up and procedure

Set-up

Preparation of carbon monoxide and chlorine

- 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.
- 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 (in a fume cupboard!), drop sulphuric acid into the formic acid.
- 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 (of the gas bar).
- 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.
- Disassembly of the apparatus and cleaning must be carried out in the fume cupboard.
- 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.
- Place 5 or 6 spoonfuls 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.
- Disassembly of the apparatus and cleaning must be carried out in the fume cupboard.

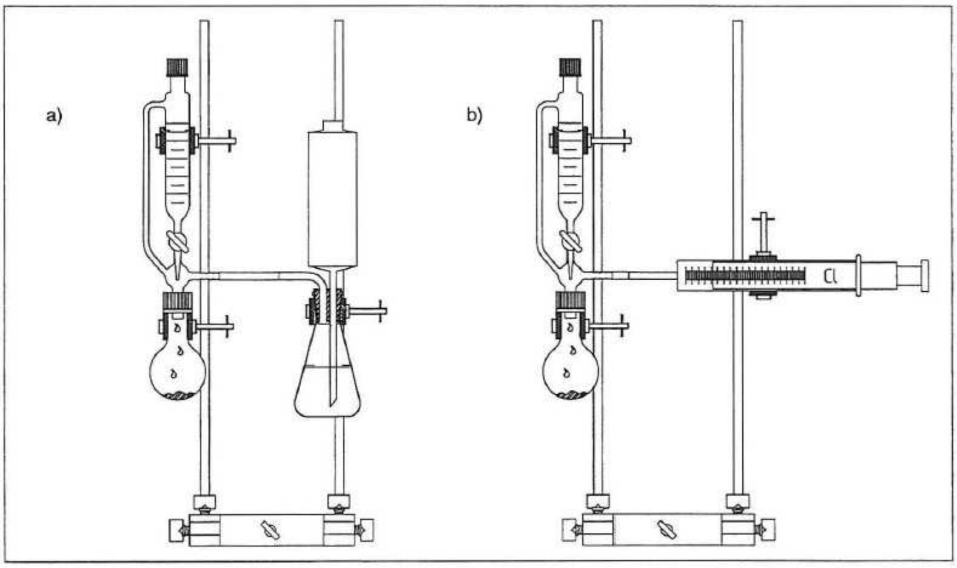


Fig. 1

Procedure

1. The carbon monoxide/oxygen reaction

- Fill the gas bar (Fig. 2) with oxygen (from a steel cylinder) and carbon monoxide (see "Set-up".).
- Using a 10 ml injection syringe with a thin cannula (*d* = 0.45 mm, *l*= 13 mm), draw 3 ml of oxygen and 6 ml of carbon monoxide out of the corresponding gasometers.
- Inject this stoichiometric mixture in the plunger eudiometer (Fig. 2), 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 it into a transparent (not too thin foil thickness) 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.

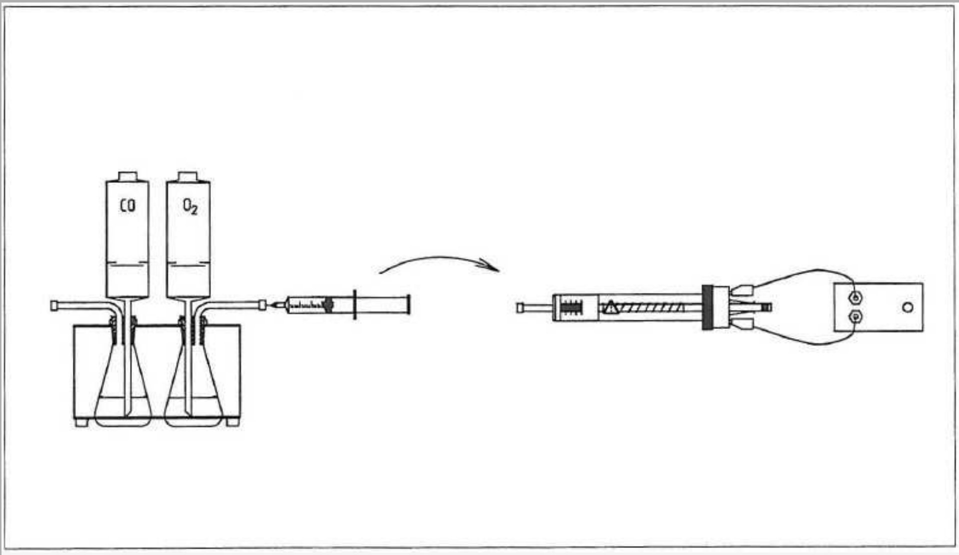


Fig. 2

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

The experiment is carried out in a heated eudiometer, set up as shown in Fig. 3.

- 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 (see Fig. 3).
- 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.
- 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 (Fig. 3) with hydrogen and oxygen (from steel cylinders).
- 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.

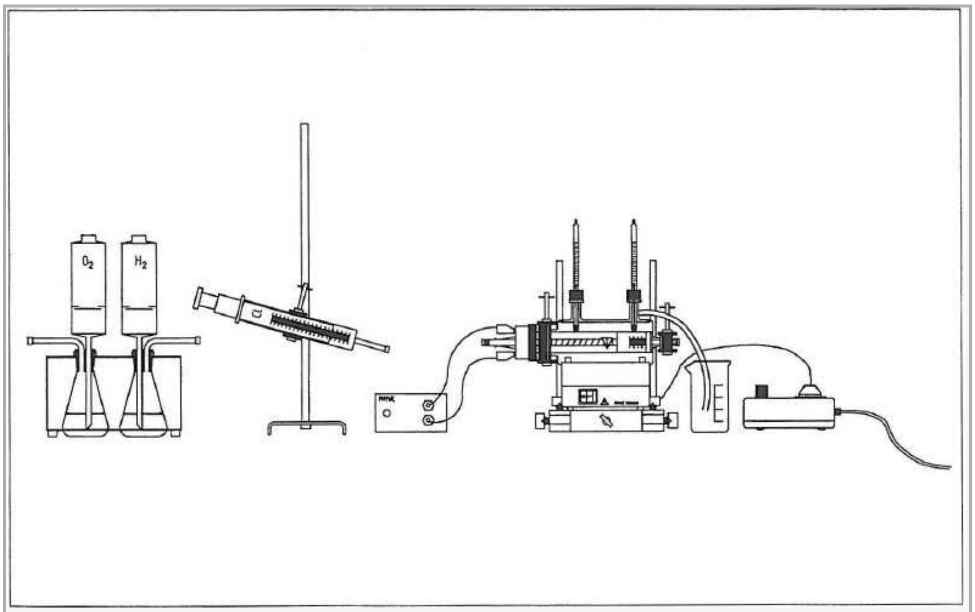


Fig. 3

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

The product of this reaction is gaseous HCl, so that theoretically the reaction could be carried out in a cold eudiometer, in the same way as the CO/CO_2 reaction. In practice, however, such an experiment would not give a meaningful quantitative result, as the first prerequisite for such a result would be absolutely dry gases for the reaction, and an absolutely dry reaction chamber after the reaction. Small amounts of air, i.e. oxygen, are generally present in the eudiometer and in the syringe used for injection. These would be converted to traces of water during the reaction which, as HCl gas is extremely soluble in water, would falsify the result. This effect can be avoided by carrying out the hydrogen/chlorine reaction in an eudiometer which is heated up to above 100 °C, as then any traces of water are themselves in gaseous form and do not affect the result.

- Fix the gas syringe containing chlorine (see "Set-up") in a slightly inclined position on a stand (Fig. 3) and fill hydrogen (from a steel cylinder) into a gas bar.
- Heat the eudiometer up to 103 °C, as described under 3. Inject a stoichiometric mixture of hydrogen and chlorine (= volume ratio 1:1) 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. There is no danger of this when the experiment is carried out under normal scattered light.
- 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.

Results and evaluation

1. The carbon monoxide/oxygen reaction

Observation:
A small explosion occurs. The plunger is first forced out a few centimetres but then immediately comes back again. A gas volume of 6 ml of carbon dioxide remains in the eudiometer.

Results:
According to the equation

$$2\,CO + O_2 \rightarrow 2\,CO_2$$

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.

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

Observation:
After the reaction the plunger shows a residual volume of 6 ml. This consists of water in vapour form (steam).

Results:
The mixture of 6 ml H_2 and 3 ml O_2 has reacted according to the equation

$$2\,H_2 + O_2 \rightarrow 2\,HO_2$$

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.

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

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

Results:
This result corresponds exactly with the equation

$$Cl_2 + H_2 \rightarrow 2\,HCl$$

When the reaction has been completed, there are the same number of diatornie 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.

Note
The sensitivity to light of the chlorine/hydrogen mixture can be used as a show effect. The mixture can be ignited in the eudiometer by using a photo flash light.