General and inorganic chemistry

Material properties

Determination of molar mass

LD Chemistry Leaflets

C1.1.1.1

Determination of the relative atomic mass of metals

Aims of the experiment

- To observe base metals dissolving in hydrochloric acid
- To determine the relative atomic mass from the resulting gas volume
- To recognise that the mass of a substance is not sufficient for quantitative chemical analysis
- To establish the proportionality between volume and substance amount (keyword: stoichiometry)
- To determine the molar masses of metals

Principles

Every type of atom has a defined mass, the so-called atomic mass. However, individual atoms cannot be weighed due to their small size. It is therefore easier to determine the relative masses of the atoms in comparison with each other. Whereas hydrogen served for a long time as the reference element, the carbon isotope $^{12}_{6}C$ is used today. The relative atomic mass naturally has no units. However, the atomic mass unit u for the absolute atomic mass does. It is defined as 1/12 of the mass of $^{12}_{6}C$.

The relative atomic mass makes it possible to weigh equivalent numbers of particles of various atoms. The relative atomic mass of hydrogen is around 1, that of carbon around 12. So, 1 g of hydrogen and 12 g of carbon contain the same number of particles. 12 g of the carbon isotope $^{12}_{6}C$ contain $6.022 \cdot 10^{23}$ particles. This number is referred to as Avogadro's number N_A and defines the amount of substance of 1 mol. 1 mol is therefore the amount of substance from as many particles as the number of atoms in 12 g of $^{12}_{6}C$. The term particle does not only refer to atoms, but also to ions and molecules, for example. The molar mass describes the mass of a mole, therefore of $6.022 \cdot 10^{23}$ particles of an element or a compound. The molar mass of $^{12}_{6}C$ is 12 g/mol, that of hydrogen 1 g/mol.

The determination of atomic masses by chemical means is simple in the case of base metals. Metals (Me) dissolve in acids. Hydrogen is created according to the following general formula.

$$Me + 2\,H^{+} \rightleftharpoons Me^{2+} + H_2$$

In the case of divalent metals, a mole of hydrogen is formed per mole of metal. The volume of hydrogen is measured with a gas syringe. Various metals of the same weight produce different volumes of hydrogen. If the weight of a piece of

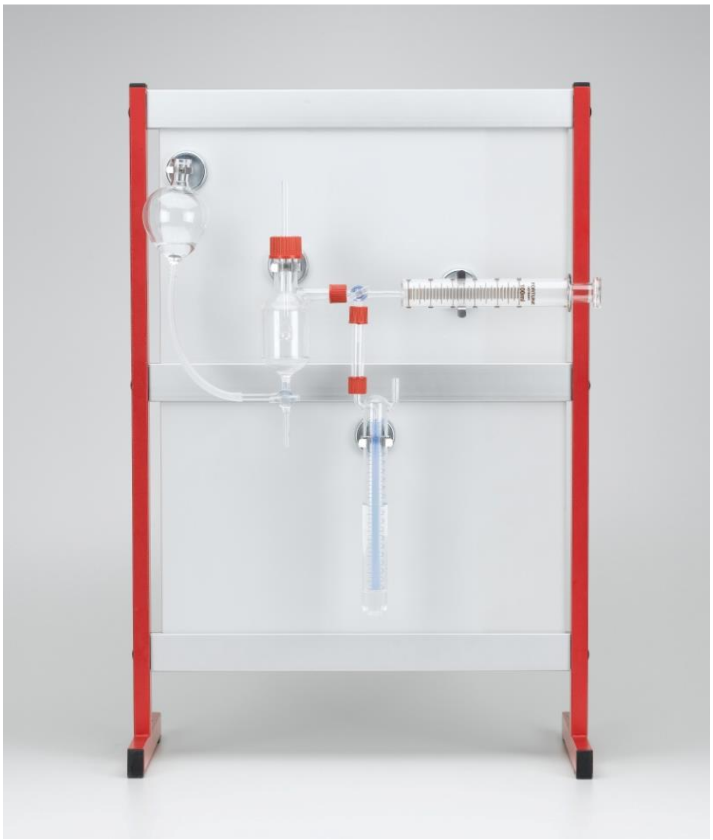

Fig. 1: Set-up of the experiment.

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metal used is known, the molar mass and with it also the relative atomic mass of the metal can be determined.

Risk assessment

Magnesium is combustible. Therefore, keep away from sources of ignition such as open flames. Do not touch calcium with the bare hands, as it can also react with skin moisture which, in the process, can result in the generation of heat. Wear protective glasses.

The hydrochloric acid used is corrosive! Wear gloves and protective goggles when pouring.

The resulting hydrogen gas is extremely flammable. Keep away from sources of ignition.

Magnesium, ribbon	
Signal word: Caution	**Hazard statements** H228 Flammable solid. **Precautionary statements** P370+P378 In case of fire: Use metal fire extinguisher / sand for extinction.

Calcium, granulated	
Signal word: Hazard	**Hazard statements** H261 In contact with water releases flammable gas. **Precautionary statements** P402+P404 Store in a closed container in a dry place.

Hydrochloric acid, 10 %	
Signal word: Caution	**Hazard statements** H290 May be corrosive to metals. H315 Causes skin irritation. H319 Causes serious eye irritation. H335 May cause respiratory irritation. **Precautionary statements** P280 Wear protective gloves. P261 Avoid breathing mist/vapour/ spray. P304+P340 IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. P305+P351+P338 IF IN EYES: Rinse continuously with water for several minutes. Remove contact lenses if present and easy to do. Continue rinsing. P312 Call a POISON CENTRE or doctor/physician if you feel unwell. P403+P233 Store in a well ventilated place. Keep container tightly closed.

Hydrogen	
Signal word: Hazard	**Hazard statements** H220 Extremely flammable gas. **Precautionary statements** P210 Keep away from heat/sparks/ open flames/hot surfaces. No smoking. P377 Leaking gas fire – do not extinguish unless leak can be stopped safely. P381 Eliminate all ignition sources if safe to do so.

Equipment and chemicals

1	Stoichiometric reaction vessel	664 097
1	Gas syringe 100 mL with three-way stopcock	665 914
1	Schiele immersion tube manometer	665 936
1	Topping-up reservoir, 250 mL	664 352
1	Silicone tubing 7 mm diam., 1 m	667 194
1	Stirring thermometer, -30...+110 °C/1 K	382 21
1	Glass connector, 2 x GL 18	667 312
1	Scissors, 125 mm	667 017
1	Tweezers, blunt, 130 mm	667 027
1	Beaker, Boro, 400 mL, squat	664 131
1	Measuring cylinder 50 mL, with plastic base	665 753
2	Adhesive magnetic board 500 mm	666 4659
1	Holder, magnetic, size 2, 11...14 mm	666 4662
3	Holder, magnetic, size 5, 30...32 mm	666 4665
1	Panel frame C50, two-level, for CPS	666 425
1	Analytical balance 220: 0.0001 g	667 7990
1	Hydrochloric acid, 10 %, 1 l	674 6810
1	Magnesium, ribbon, 25 g	673 1000
1	Aluminium, Foil, 1 roll	661 081
1	Calcium, shavings, 25 g	671 2000

Set-up and preparation of the experiment

Construction of the apparatus

First place the adhesive magnetic boards into the panel frame. As shown in Figure 1, fix the stoichiometric reaction vessel, gas syringe and topping-up reservoir to the boards with magnetic holders. Open the three-way stopcock on the gas syringe to all sides.

Note: Connect the components with glass connectors containing GL screw connectors. If these are screwed on loosely, the inserted glass tubes can still be moved. Only when screwed up tight a gas-tight connection results.

Connect the topping-up reservoir to the stoichiometric reaction vessel using the silicone tube.

Fill the Schiele immersion tube manometer to around halfway with water. It serves to balance the pressure of the resulting hydrogen with the environmental pressure. Fix the filled manometer with a magnetic holder to the adhesive magnetic board and connect to the apparatus with a glass connector (see Fig. 1).

Performing the experiment

1. Close the three-way stopcock on the reaction vessel. Pour hydrochloric acid into the topping-up reservoir.

2. Open the three-way stopcock on the reaction vessel so there is only a connection from the topping-up reservoir to the reaction chamber.

3. Carefully allow hydrochloric acid to flow into the reaction chamber from the topping-up reservoir until the liquid level is around 1 cm below the piston of the reaction vessel. Close the stopcock on the reaction vessel.

4. Firstly, weigh out a maximum of 0.08 g of magnesium ribbon.

5. Unscrew the lid of the stoichiometric reaction vessel together with the piston. Lay the magnesium ribbon onto this.

6. Screw the lid back onto the reaction vessel. When the lid is almost screwed down tightly, press the piston into the hydrochloric acid. Screw the lid down completely. The reaction starts.

7. Wait until the reaction has finished and the gas volume collected in the gas syringe remains constant and has cooled slightly. Note the room temperature (on the thermometer).

8. Check using the immersion tube manometer whether the pressure in the apparatus corresponds to the outside pressure. This is the case when the liquid level in the glass tube is equal to that of the surroundings. Open the three-way stopcock on the gas syringe completely and regulate the level if necessary using the gas syringe. Only then note the resulting volume of hydrogen (see Table 1).

9. Drain off the used hydrochloric acid into a beaker through the drain opening on the reaction vessel. The three-way stopcock then only has a connection between the reaction chamber and the drain.

Repeat the experiment using a maximum of 0.08 g of calcium and a maximum of 0.05 g of aluminium. For this, open out the aluminium foil as far as possible, do not to place it rolled in a ball.

Note: If too much aluminium foil is used, the volume of the gas syringe will not be sufficient.

Observation

As soon as the metals come into contact with the acid, they react strongly with the formation of bubbles. The resulting gas (hydrogen) is collected in the gas syringe. The reactions last around 2 to 5 minutes. The vessel becomes warm in the process.

The reaction with aluminium foil only starts after a warm-up time. A grey deposit also results.

The resulting gas volumes differ. If roughly the same mass of magnesium and calcium is used, distinctly more hydrogen results in the reaction of magnesium than in the reaction of calcium (see Table 1).

Evaluation

Evaluation of the observations

The reactions with calcium and magnesium start immediately, whilst a warm-up time is noticeable with the reaction with aluminium. Therefore, it should preferably be inserted as an open leaf, not as a ball. In addition, a grey deposit of aluminium oxide forms here. Both observations illustrate the role of the oxide layer on aluminium, which protects this reactive metal and only for this reason makes it possible to use it in everyday life.

Calcium and magnesium react at different rates. This can be initially attributed to the different chemical properties of the metals. Furthermore, the physical form also plays a large role. Magnesium is present as ribbon and calcium as shavings, it therefore has a greater surface to volume ratio.

Determination of the atomic mass

In order to determine the relative atomic mass of the metals being investigated, they will be dissolved in hydrochloric acid and the resulting volume of hydrogen is measured. The reaction equations are as follows:

$Mg + 2\,H^+ \rightleftharpoons Mg^{2+} + H_2$

$Ca + 2\,H^+ \rightleftharpoons Ca^{2+} + H_2$

$2\,Al + 6\,H^+ \rightleftharpoons 2\,Al^{3+} + 3\,H_2$

Initially, the hydrogen volume *V* can be converted into the amount of substance *n* using the ideal gas law and the gas constant. For this, the ideal gas constant R = 8.3145 (kPa · l)/(mol · K) is used. The room temperature T, which is also required, is read from the thermometer, the air pressure *p* is obtained from current weather data (see Table 1). The measured hydrogen volume *V* is given in L.

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

$$n = \frac{p \cdot V}{R \cdot T}$$

Using the example of magnesium, this means:

$$n(\text{Mg}) = \frac{102{,}7\ \text{kPa} \cdot 0{,}0715\ \text{l}}{8{,}3145\,\frac{\text{kPa}\cdot\text{l}}{\text{mol}\cdot\text{K}} \cdot 294\text{K}}$$

$$= 0{,}0030\ \text{mol}$$

0.073 g of magnesium produces 0.003 mol of hydrogen. According to the reaction equation, the substance amount of hydrogen is equal to the substance amount of the metal used. Thus, *n* = 0.003 mol of magnesium weighs *m* = 0.073 g. The molar mass *M* or atomic mass can be calculated using the following equation.

$$M = \frac{m}{n}$$

The following then applies to magnesium:

$$M(\text{Mg}) = \frac{0{,}073\ \text{g}}{0{,}0030\ \text{mol}} = 24{,}33\ \text{g/mol}$$

Tab. 1: Measured and calculated values.

Air pressure p	1027 hPa = 102.7kPa
Temperature T	21 °C = 294 K

Metal (Me)	Magnesium	Calcium	Aluminium
Mass used *m*(Me)	0.073 g	0.074 g	0.044 g
Hydrogen volume *V*(H_2)	71.5 ml = 0.0715 l	47 ml = 0.047 l	61 ml = 0.061 l
Quantity of hydrogen *n*(H_2)	0.0030 mol = 3.0 mmol	0.0020 mol = 2.0 mmol	0.0026 mol = 2.6 mmol
Quantity of metal *n*(Me)	3.0 mmol	2.0 mmol	1.7 mmol
Molar mass of metal *M*(Me)	24.33 g/mol	37.48 g/mol	25.75 g/mol
Literature value of molar mass	24.31 g/mol	40.08 g/mol	26.98 g/mol

Calcium can be calculated in the same way, as the reaction equations match. However, when calculating the molar mass of aluminium, it must be taken into account that from 2 equivalents of aluminium 3 equivalents of hydrogen are formed. The substance amount of hydrogen therefore corresponds to only 2/3 of the substance amount of aluminium. The following applies:

$n(H_2) = 2/3\ n(Al)$

All calculations are summarised in Table 1.

Result

The resulting hydrogen gas volume on dissolving the metal is proportional to the substance amount of the metal used, not, however, to the weight of the metal. Metal pieces of about the same weight therefore produce different gas volumes.

With this experiment, the relative atomic mass or the molar mass of metals can be determined. The molar mass of magnesium is determined as 24.3 g/mol (literature: 23.31 g/mol). The values for the other metals also differ very little from the literature values from the periodic table (see Table 1). The relative atomic masses have the same numerical value, but no units.

Cleaning and disposal

Neutralise the used hydrochloric acid with sodium hydroxide solution and dispose of it in the container for inorganic waste. Unused hydrochloric acid can be used for further experiments.

For longer storage, remove the taps from the three-way stopcocks, degrease the three-way stopcock and store with a piece of paper inserted as a separator.