

The law of fixed mass ratios in chemical reactions - quantitative studies on oxides and sulfides



Students learn in a hands-on way that chemical compounds are made up of the elements according to fixed mass ratios.

Chemistry

General Chemistry

Chemical reactions

Basics of chemical reaction



Difficulty level

hard



Group size

1



Preparation time

10 minutes



Execution time

20 minutes

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General information

Application

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Test setup

With stoichiometry, mathematics is used to perform chemical calculations. For example, reactions and the required ratios and amounts of substances can be calculated in advance.

The starting point for stoichiometry is the so-called "law of fixed mass ratios in chemical reactions", which was discovered by Joseph Louis Proust.

Other information (1/2)

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Previous



Students should already know the law of fixed mass ratios in chemical reactions in theory.

Principle



The proof of this law is given in the first experiment by quantitatively following the synthesis of metal sulfides, but in the second and third experiments by reductions of metal oxides.

Other information (2/2)

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Learning



Students learn in a hands-on way that chemical compounds are made up of the elements according to fixed mass ratios.

Tasks



Students investigate the mass ratios in the preparation of metal sulfides from the elements. They then determine the mass ratios of copper and lead to oxygen in the oxides by reduction with hydrogen and also between silver and oxygen in silver oxide.

Safety instructions

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- Wear gloves and protective goggles!
- Hydrogen is a colourless, flammable gas which forms explosive mixtures with air. Reactions in apparatus must be tested for the absence of oxygen (oxyhydrogen test).
- Disposal: Collect solutions containing heavy metal ions in a heavy metal salt solution container. All solid heavy metal wastes are also collected in this container.
- For the H- and P-phrases please refer to the corresponding safety data sheets.
- The general instructions for safe experimentation in science lessons apply to this experiment.

Theory

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The law of fixed mass ratios is: "Chemical compounds are composed of the elements according to fixed mass ratios."

The discoverer of this law was Joseph Louis Proust (1754-1826). After him, this law is also called Proust's law.

For example, a water molecule as we know it is always composed of the same mass of hydrogen atoms and the same mass of oxygen atoms, so that the ratio between the two is always the same in terms of weight.

Thus, by this law it is always possible to calculate how heavy an element will be and how much mass there is of a given atom.

Equipment

Position	Material	Item No.	Quantity
1	Retort stand, h = 750 mm	37694-00	1
2	Support base DEMO	02007-55	1
3	Support rod, stainless steel, l = 600 mm, d = 10 mm	02037-00	2
4	Right angle boss-head clamp	37697-00	4
5	Universal clamp	37715-01	4
6	Ring with boss head, i. d. = 10 cm	37701-01	1
7	Triangle w.pipeclay, l 60mm	33278-00	1
8	Porcelain dish, lid, low, 29 ml	46449-00	6
9	Combustion tube, 300 mm, quartz, ns	33948-01	1
10	Connecting tube IGJ 19/26-GL 18/8	35678-01	2
11	Clamp f.ground joint,plastic,NS19	43614-00	2
12	Teflon sleeve IGJ 19, 10 pcs	43616-00	1
13	Stopcock,3-way,t-shaped, glass	36731-00	1
14	Glass tube,right-angled, 10 pcs.	36701-52	1
15	Porcelain boats, 10 pcs	32471-03	1
16	Gasometer 1000 ml	40461-00	2
17	Weather monitor, 6 lines LCD	87997-10	1
18	Test tube, 160 x 16 mm, 100 pcs	37656-10	1
19	Test tube,180x20 mm, PN19	36293-00	1
20	Rubber stopper, d = 22/17 mm, 1 hole	39255-01	1
21	Desiccator, vacuum, diam. 150 mm	34126-00	1
22	Porcelain plate f.desiccator150mm	32474-00	1
23	Precision Balance, Sartorius, 620 g : 1 mg	49311-99	1
24	Teclu burner, DIN, natural gas	32171-05	1
25	Safety gas tubing, DVGW, sold by metre	39281-10	1
26	Hose clip f.12-20 diameter tube	40995-00	2
27	Lighter f.natural/liquified gases	38874-00	1
28	Steel cylinder hydrogen, 2 l, full	41775-00	1
29	Reducing valve for hydrogen	33484-00	1
30	Table stand for 2 l steel cylinders	41774-00	1
31	Wrench for steel cylinders	40322-00	1
32	Scissors, straight,180 mm	64798-00	1
33	Crucible tongs, 200 mm, stainless steel	33600-00	1
34	Spoon, special steel	33398-00	1
35	Tweezers,straight,blunt, 200 mm	40955-00	1
36	Rubber tubing, i.d. 6 mm	39282-00	1
37	Emery paper, medium	01605-00	1
38	Silica gel, orange, granular, 500 g	30224-50	1
39	Copper foil, 0.1 mm, 100 g	30117-10	1
40	Copper-II oxide,powder 100 g	30125-10	1
41	Sulphur, purified, tech.gr.,1000g	30216-70	1
42	Lead, granular 250 g	30040-25	1
43	Lead-II oxide -litharge- 500 g	31121-50	1
44	Silver foil, 150 x150 x 0.1 mm, 25 g	31839-04	1
45	Silver oxide, a.r., 5 g	31846-02	1



Structure and implementation

Set-up and execution (1/5) - Experiment 1

- Six porcelain crucibles with lids are annealed in a gas flame to constant weight and then placed in a desiccator where they are allowed to cool slowly and kept dry until the lesson.
- To carry out the experiment, the mass of each of these crucibles is first determined by weighing (= 1st weighing).
- Then put a piece of bare copper sheet (about 1.2 g) into each of 2 crucibles, a piece of silver sheet (about 1.2 g) into each of 2 other crucibles, and about 3 to 4 g of lead (granulated) into each of the last two crucibles. The latter should be as oxide-free as possible. It is best to take it from a new pack.
- The masses of the metal portions are determined by a second weighing of the crucibles. Then sulphur (sulphur bloom) is added to the metals in excess (approx. 1.5 g per crucible), the lids are placed on the crucibles and each crucible is now vigorously annealed under a fume cupboard until no more sulphur vapour escapes from under the lid.


Set-up and execution (2/5) - Experiment 1


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- Then open the lid and continue to anneal for about 1 minute so that all residues of unreacted sulphur evaporate from the crucible.
- After cooling, the crucibles are weighed again (3rd weighing). From the masses found, the mass ratios in which the metals react with sulphur can now be calculated. Table 1 shows values as they can be obtained in a school experiment.

Masse des Tiegels/ g (1. Wägung)	Masse des Tiegels + Metall/ g (2. Wägung)	Metallmasse, Metallart	Masse des Tiegels mit Sulfid/ g (3. Wägung)	Masse des gebundenen Schwefels/ g	Massenverhältnis Me : S
14,46	15,68	1,22 g Cu	16,00	0,32	3,81 : 1
15,35	16,36	1,01 g Cu	16,62	0,26	3,88 : 1
15,13	16,26	1,13 g Ag	16,43	0,17	6,65 : 1
14,90	16,22	1,32 g Ag	16,417	0,197	6,70 : 1
15,65	20,40	4,75 g Pb	21,10	0,70	6,786 : 1
15,72	18,95	3,23 g Pb	19,446	0,496	6,51 : 1

Table for task 1

 For a larger view, press the button on the right.
 

Set-up and execution (3/5)- Experiment 2


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- Copper(II) oxide and lead(II) oxide must be absolutely dry for this experiment. Drying can be carried out in a drying oven at about 105°C or in a desiccator. A porcelain boat which has been annealed to constant weight and cooled down again is weighed empty. A small portion of copper(II) oxide (or lead(II) oxide) is then added to this boat and its exact mass determined by a second weighing.
- Subsequently, this oxide portion is reduced completely in a quartz tube with a measured quantity of hydrogen (for this purpose, the two gasometers are adjusted in such a way that they display introduced gas portions in standard volumes; see operating instructions).



Attention. Before carrying out the reduction, the apparatus must be rinsed with hydrogen. Oxyhydrogen test!

Set-up and execution (4/5)- Experiment 2

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- After reduction and subsequent cooling, the volume of hydrogen consumed is read off and the mass loss due to oxygen removal is determined by a further weighing (3rd weighing) of the porcelain boat.
- From the mass of the oxide used and the mass loss determined, the mass ratio of metal and oxygen is calculated. From the values found for the hydrogen loss and the mass of oxygen, the mass ratio of hydrogen to oxygen in the compound water can be determined at the same time.

Masse des Schiffchens/g (1. Wägung)	Masse des Schiffchens + Oxid/ g (2. Wägung)	Masse des Oxids/ g	Masse des Schiffchens nach Reduktion/ g (3. Wägung)	Massenverlust durch Sauerstoffentzug/ g	Masse des Metalls/ g	Massenverhältnis Metall/ Sauerstoff	Wasserstoffverbrauch / ml bzw. g	Massenverhältnis von H : O im Wasser
8,78	10,47	CuO 1,69	10,12	0,35	Cu 1,34	Cu : O 3,83 : 1	480 ml 0,0439 g	1 : 7,973 (1 : 8)
8,61	15,88	PbO 7,27	15,365	0,515	Pb 6,755	Pb : O 13,12 : 1	720 ml 0,0648 g	1 : 7,95 (1 : 8)



The table shows an example of a measurement.

Set-up and execution (5/5) - Experiment 3

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- A mass of silver oxide weighed into a refractory test tube (Duran) is completely thermally decomposed.
- The separated oxygen is collected in a gasometer, the scales of which are set in such a way that the standard volume of the gas flowing in can be read off from them (cf. operating instructions).
- The mass ratio can be calculated from the values of initial mass and mass of the collected oxygen.

Example:

Weighing-in of Ag₂O = 3.0 g

Standard volume of oxygen split off: 290 ml

Mass of 290 ml of oxygen = $\frac{1.43 \text{ g} \cdot 290 \text{ ml}}{1000 \text{ ml}} = 0.415 \text{ g}$

Mass of silver (3,000 g - 0,415 g) = 2,585 g

Mass ratio Ag:O = 2.585:0.415 = 6.23:1



Evaluation

Evaluation (1/4)

Observation and evaluation

The metals combine with sulphur in certain fixed mass ratios. On average, they combine:

Copper and sulphur in the ratio 3,96 : 1

Silver and sulphur in the ratio 6,73 : 1

Lead and sulphur in the ratio 6,46 : 1

Data

Litre mass of oxygen: 1.43 g/l

Litre mass of hydrogen: 0,09 g/l

Literature values of mass ratios:

Cu:O in CuO = 3.97:1

Pb:O in PbO = 12.95:1

H:O in H₂O = 1:8

Evaluation (2/4)

What is the law of fixed mass ratios in chemical reactions?

- Chemical compounds are always composed of water (H) and other elements.
- Chemical compounds are composed of the elements according to fixed mass ratios.
- Chemical compounds are composed of elements according to variable mass ratios.

✓ Check

Evaluation (3/4)

In which agent do copper and sulfur combine?

- On average, copper and sulfur combine in a ratio of 3.69:1.
- On average, copper and sulfur combine in a ratio of 6.46:1.
- On average, copper and sulfur combine in a ratio of 6.73:1.
- None of the answers is correct. Copper and sulfur can not combine under any circumstances, because they repel each other.

✓ Check

Evaluation (4/4)

In which agent do lead and sulfur combine?

- On average, lead and sulfur combine in a ratio of 6.73:1.
- None of the answers is correct. Lead and sulfur belong to the noble metals, which, like the noble gases, are not reactive.
- On average, lead and sulfur combine in a ratio of 6.46:1.
- On average, lead and sulfur combine in a ratio of 3.96:1.

✓ Check

Slide	Score/Total
Slide 16: law of fixed mass ratios	0/1
Slide 17: Ratio 1	0/1
Slide 18: Ratio 2	0/1

Total  0/3

 Solutions

 Repeat