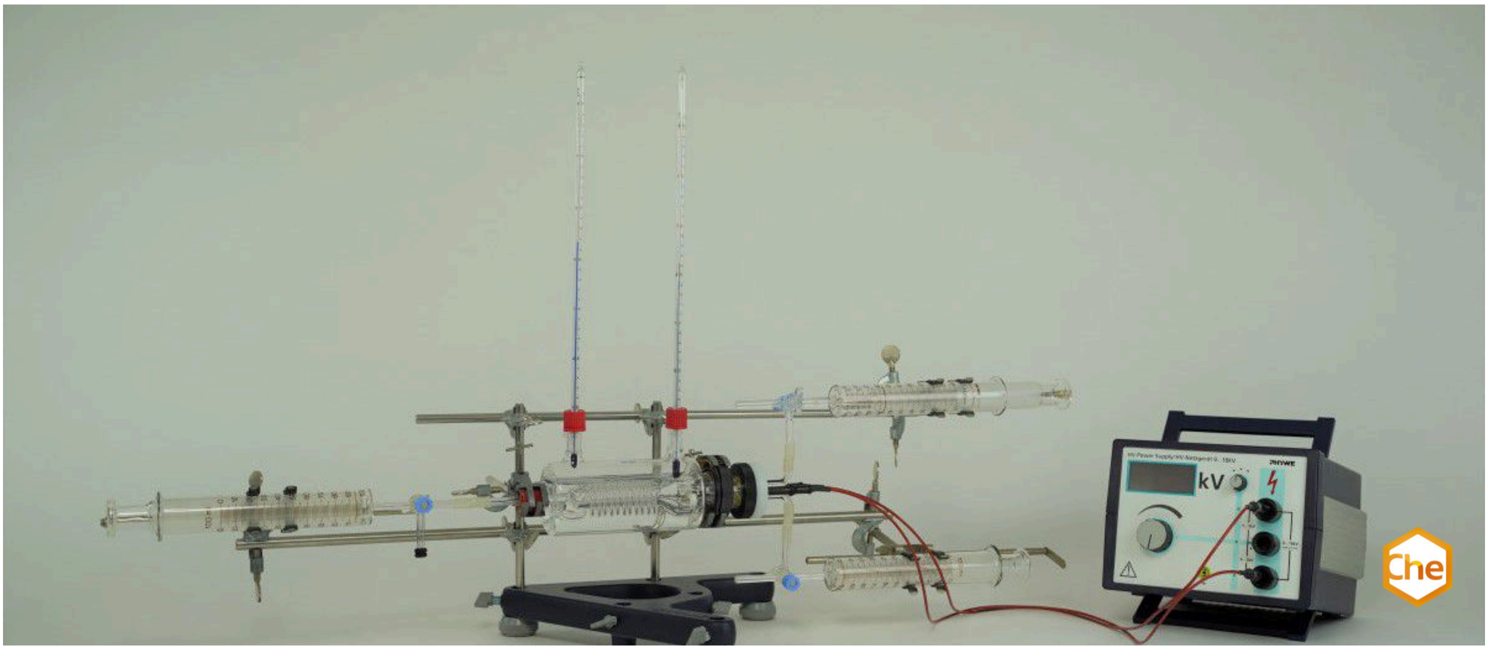
Determination of the heat of formation of water



Chemistry > Physical chemistry > Thermochemistry, calorimetry

Applied Science > Engineering > Renewable Energy > Hydrogen technology & fuel cells

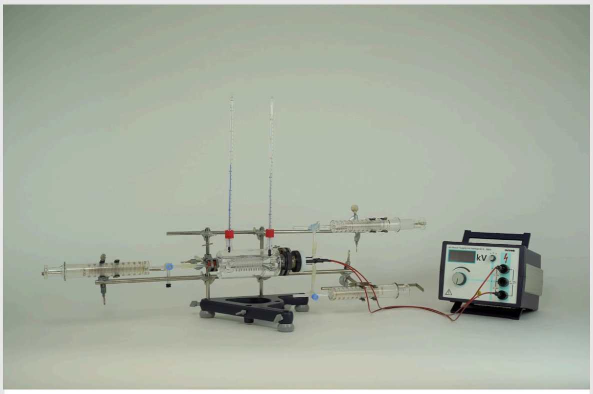
Difficulty level	Group size	Preparation time	Execution time
hard	2	20 minutes	20 minutes

This content can also be found online at:

http://localhost:1337/c/603e5123e4d8480003e1e0b2

General information

Application



Experimental Setup

Standard molar enthalpies of formation $\Delta_B H^0$ are important compiled thermodynamic tabulation quantities for calculating standard enthalpies of reaction for any arbitrary reaction. They are defined as the heat of reaction occurring in the direct formation of one mole of the pertinent pure substance from the stable pure elements at constant pressure. For spontaneous and quantitative formation reactions, e.g. the conversion of hydrogen and oxygen to water, standard enthalpies of formation can be measured directly using calorimetry.

In this experiment, the enthalpy of water is determined by burning 100 ml H_2.

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Other information (1/3)

Prior knowledge

Students should be familiar with the laws of thermodynamics, the definition of enthalpy and entropy. Furthermore, they should know good and save laboratory practice, working with chemicals and especially with volatile gases such as hydrogen.

Scientific principle

To determine the molar heat of formation of water $\Delta_f H^0_{H_2O}$, hydrogen and oxygen are mixed, safely ignited using the PHYWE glass jacket system and H_2O is formed. Released energy is quantified as increase in temperature.

Other information (2/3)

Learning objective

The students learn to determine and calculate the molar heat of formation of a substance (here: H_2O).

Tasks

Determine the enthalpy of formation of water by burning 100 ml H_2 in a closed glass jacket calorimeter.

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Other information (2/3)

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Determine the enthalpy of formation of water by burning 100 ml H_2 in a closed glass jacket calorimeter.

Other information (3/3)

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Note

If you do not want to use the mean value of $(= 410 J K^{-1})$ to analyse a measurement, you must determine the heat capacity C_{cal} of the calorimeter used separately before carrying out the experiment. The procedure for this is described in the operating instructions for the glass jacket.

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Safety instructions

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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 (1/3)

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Molar enthalpies of reaction $\Delta_r H$ characterise the heat balance of substance transformations. They are defined as the heat of reaction $Q_P = \Delta h$ occurring per mole formula conversion $\Delta\xi$ at constant pressure p and constant temperature T.

$$\Delta_r H = \frac{(\Delta h)}{(\Delta \xi)}_{p,T} \qquad (1)$$

The standard enthalpy of formation $\Delta_f H$ or standard heat of formation of a compound, is defined as the change of enthalpy Δh during the formation of 1 mole of the substance from its constituent elements, with all substances in their standard states (heat of reaction at constant p and T).

The heat of formation is measured in units of energy per amount of substance, usually stated in kilojoule per mole $(kJmol^{-1})$, but also in kilocalorie per mole, joule per mole or kilocalorie per gram (any combination of these units conforming to the energy per mass or amount guideline).

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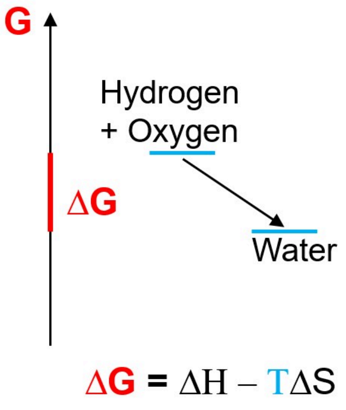
Theory (2/3)



Change in free enthalpy

Thermochemical equations are just like other balanced equations except they also specify the heat flow (ΔH) for the reaction. Reaction enthalpy changes of the conversion of hydrogen and oxygen to water can be determined by calorimetry for many reactions and utilizes a calorimeter. The change in enthalpy (Δh) of the reacting system expressed here corresponds to the heat absorbed by the calorimeter which is accessible via equation:

$$-\Delta h = Q_{cal} = \sum m_i c_i \Delta T = (m(H_2O) \cdot c(H_2O) + C_{cal})\Delta T \qquad (2)$$

Where:

$m(H_2O)$	Mass of water in the calorimeter
$c(H_2O)$	Specific heat capacity of water $(= 4.1868 J g^{-1} K^{-1})$
C_{cal}	Mean heat capacity of glass jacket calorimeter used $(= 410 J K^{-1})$
ΔT	Temperature difference in K $(T2 - T1)$

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Equipment

Position	Material	Item No.	Quantity
1	Support base DEMO	02007-55	1
2	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	2
3	Support rod, stainless steel, 500 mm	02032-00	1
4	Support rod, stainless steel, 750 mm	02033-00	1
5	Right angle boss-head clamp	37697-00	10
6	Universal clamp	37715-01	3
7	Gas-syringe holder with stop	02058-00	3
8	Glass jacket	02615-00	1
9	Calorimeter insert for glass jacket	02615-01	1
10	Lid for calorimeter insert	02615-02	1
11	Gas syringe, 100 ml, with 3-way cock	02617-00	3
12	Thermometer -10...+50 °C	38034-00	2
13	Techn. magnifier, 10x, d:23mm	64598-00	1
14	Silicone tubing i.d. 7mm, 1 m	39296-00	1
15	Magnetic stirring bar 30 mm, cylindrical	46299-02	1
16	Magnet, d = 10 mm, l = 200 mm	06311-00	1
17	PHYWE High voltage power supply with digital display, 10 kV DC: 0... ± 10 kV, 2 mA	13673-93	1
18	Connecting cord, 30 kV, 1000 mm	07367-00	2
19	Funnel, glass, top dia. 50 mm	34457-00	1
20	Graduated beaker with handle, 1000 ml, plastic (PP)	36640-00	1
21	Steel cylinder hydrogen, 2 l, full	41775-00	1
22	Steel cylinder oxygen, 2 l, filled	41778-00	1
23	Reducing valve for hydrogen	33484-00	1
24	Reducing valve f.oxygen	33482-00	1
25	Table stand for 2 l steel cylinders	41774-00	2
26	Wrench for steel cylinders	40322-00	1
27	Rubber tubing, i.d. 6 mm	39282-00	3
28	Weather monitor, 6 lines LCD	87997-10	1
29	Water, distilled 5 l	31246-81	1

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3	Support rod, stainless steel, 500 mm	02032-00	1
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5	Right angle boss-head clamp	37697-00	10
6	Universal clamp	37715-01	3
7	Gas-syringe holder with stop	02058-00	3
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11	Gas syringe, 100 ml, with 3-way cock	02617-00	3
12	Thermometer -10...+50 °C	38034-00	2

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Setup and procedure

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Setup (1/4)

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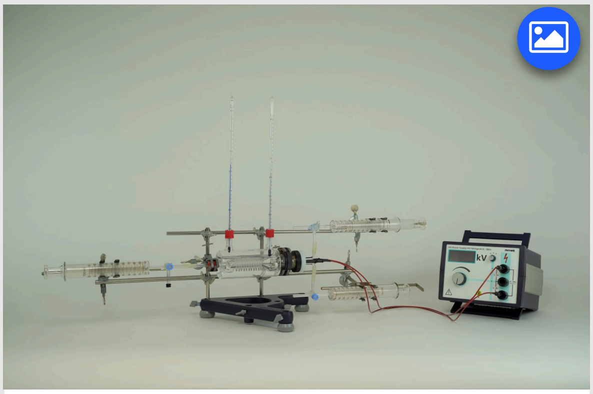

Fig. 1: Experimental setup

Set up the experiment as shown in Fig. 1 and Fi. 2 (next page).
Fit the calorimeter insert into the glass jacket as described in the instruction manual. Place the lid of the calorimeter onto the insert. The lid has two capillary tubes bent at right angles to one another as gas inlets, one of which is fitted with two platinum electrodes. This one must be situated below the tube without electrodes when the calorimeter is set up. The assembled glass jacket calorimeter is held by two clamps on the vertical short support rods. The two long support rods are also attached to these short rods, with the longer one at the bottom and the slightly shorter one at the top. The gas syringe holders are attached to the crossbars with double boss heads.

Setup (2/4)

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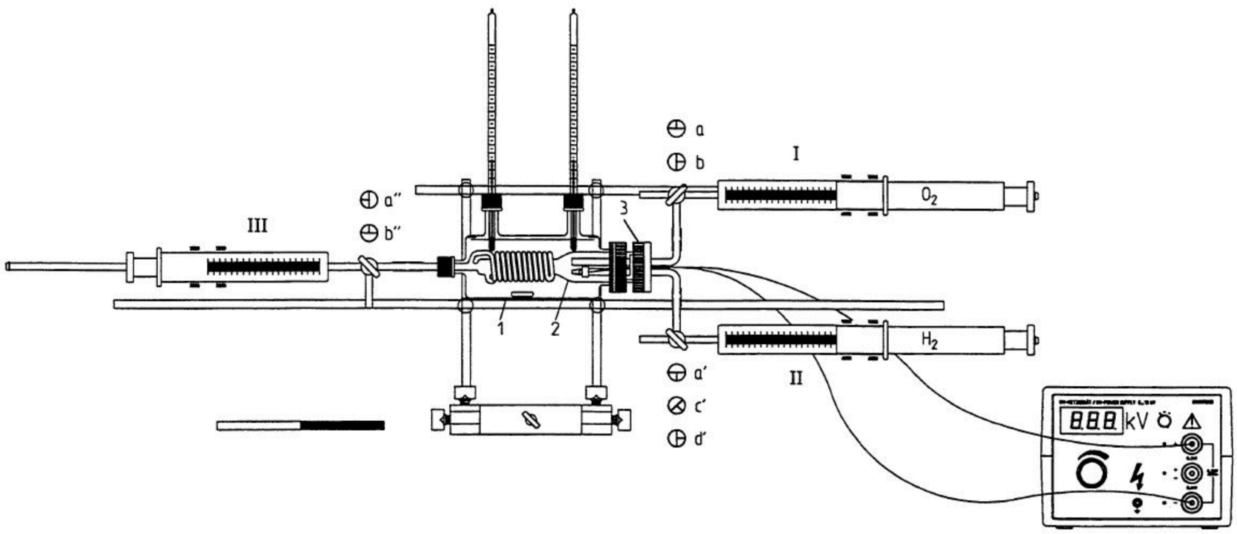

Fig. 2: Schematic setup

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Setup (3/4)

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The glass jacket is filled with about 500 g of water via one of the two vertical glass tube nozzles (using a funnel), and the exact mass of the water poured in must be determined. To do this, fill the measuring beaker with about 500 g of water, determine the mass of the filled beaker with a balance $(= m_1)$. Carefully pour the water into the glass jacket without spilling anything and then weigh the beaker again $(= m_2)$. The difference between the weighings results in the mass of the filled water $(m_{H_2O} = m_1 - m_2)$.

A magnetic stirring rod (30 mm long) is then inserted into the glass jacket via one of the nozzles and the thermometers are inserted into the nozzles. Now connect the calorimeter to the 3 gas syringes with three-way valves (I ... III) as shown in Fig. 1 and 2, making sure that glass meets glass in the short connecting tubing. The gas syringes are inserted into the gas syringe holders for holding, and the piston stops of the holders are adjusted so that each gas syringe can hold exactly 100 ml of gas.

Setup (4/4)

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Finally, connect the electrodes of the calorimeter lid to the high-voltage 10 kV instrument via high-voltage leads, switch on the instrument and check whether a continuous spark is formed at the electrode tips. This check is very important because the spark must never break off during hydrogen combustion, otherwise there is a risk of formation of an oxyhydrogen gas mixture.

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Procedure (1/3)

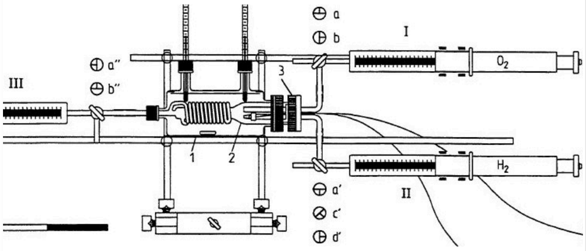

Fig. 3: Schematic setup

The three-way cocks of the gas syringes are set to position a, a' and a'' (Fig. 3). Fill gas syringe I with exactly 100 ml of oxygen and, after removing the oxygen source, move the stopcock of the syringe to position b. Then move the stopcock of gas syringe III to position b'' and transfer the oxygen from syringe I to syringe III and back again. This causes the oxygen to mix with the air in the calorimeter. Additionally, the tightness of the calorimeter can be checked in this way.

Once 100 ml of gas (oxygen/air mixture) has arrived in gas syringe I, gas syringe II can be filled with 100 ml of hydrogen. Then set the stopcock of this syringe in position c', which closes all the channels of this stopcock.

Procedure (2/2)

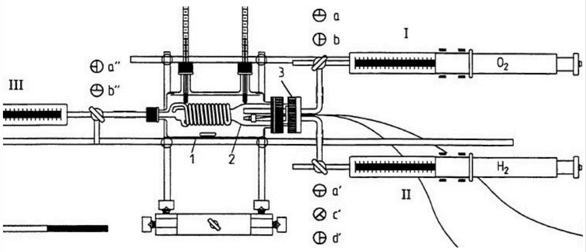

Fig. 3: Schematic setup

With the aid of a bar magnet, the stirring rod in the calorimeter is now moved back and forth from the outside until both thermometers show the same temperature, meaning that the water is at the same temperature everywhere. This initial temperature $(T1)$ is noted. The continuous spark is then switched on by switching on the high-voltage device. The cock of gas syringe II is set to position d', and the pistons of gas syringes I and II are pressed in evenly and quickly (time for combustion: approximately 4 to 5 seconds).

The hydrogen flowing into the calorimeter is ignited by the spark and combusts to water (droplets on the calorimeter insert).

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Procedure (3/3)

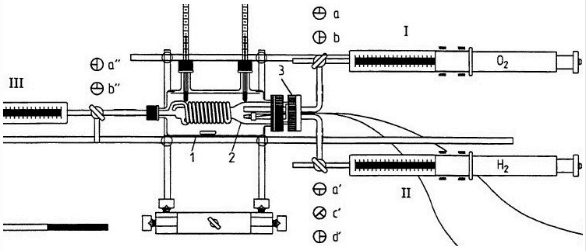

Fig. 3: Schematic setup

After combustion, the stopcock of the gas syringe II is immediately returned to position a' and the high-voltage unit is switched off. The stirring rod is moved back and forth in the water until both thermometers indicate the same temperature.

Record this temperature as $(T2)$ (it should be approximately 0.5 K above the initial temperature $(T1)$). In addition, record the room temperature T (digital temperature meter) and the atmospheric pressure p (barometer).

Evaluation (1/2)

The hydrogen flowing into the calorimeter ignites and immediately burns up to water. The excess oxygen accumulates in gas syringe III.

In a successful experiment, the temperature difference ΔT is about 0.5 K.

Calculation of the enthalpy of formation of water $\Delta_f H^0_{H_2O}$ from the measured values of an experiment can be calculated by implementing the formulas shown in the "Theory" part:

$$\Delta_f H^0_{H_2O} = \frac{(\Delta h)}{(\Delta \xi)}_{p,T} \qquad (1)$$

The change in enthalpy (Δh) of the reacting system expressed here corresponds to the heat absorbed by the calorimeter which is accessible via equation:

$$-\Delta h = Q_{cal} = \sum m_i c_i \Delta T = (m(H_2O) \cdot c(H_2O) + C_{cal})\Delta T \qquad (2)$$

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