**STUDENT SHEETS AND TEACHERS GUIDES OF THE THIRD SCHOOL YEAR (2018/2019)**

**MTA-ELTE Research Group on Inquiry-Based Chemistry Education**

**Content Pedagogy Research Program of the Hungarian Academy of Sciences**

It is important to note that the student sheets are not intended to be stand alone. They were used in class with an accompanying dialogue from the teacher. In other words, the teachers talked students through the sheets. Each following student sheet and teacher notes was part of a teacher guide file that contained detailed instructions for teachers how to prepare and guide the students through the activities. Those files are available in Hungarian at the following links:

Student sheet 13: **The other benefits of firework** [13. feladatlap: Mire jó még a tűzijáték?](http://ttomc.elte.hu/rails/active_storage/blobs/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaHBBcFVJIiwiZXhwIjpudWxsLCJwdXIiOiJibG9iX2lkIn19--adf6dba54c8e89d81a4993c350b294aa438c19a1/13Langfestes2019_08_05_HONLAPRA.docx?disposition=attachment)

Student sheet 14: **A drop in the sea** [14. feladatlap: Csepp a tengerben](http://ttomc.elte.hu/rails/active_storage/blobs/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaHBBcFlJIiwiZXhwIjpudWxsLCJwdXIiOiJibG9iX2lkIn19--2157bd2f7123a7144a0d8536e4f614d2f8216eb7/14_Csepp_a_tengerben2019_08_05_HONLAPRA.docx?disposition=attachment)

Student sheet 15: **Hot chocolate in winter, ice tea in summer** [15. feladatlap: Forró csoki télen, jeges tea nyáron](http://ttomc.elte.hu/rails/active_storage/blobs/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaHBBcGNJIiwiZXhwIjpudWxsLCJwdXIiOiJibG9iX2lkIn19--856840bc31fc9154ae38f611fa457f3d0073c993/15Oldasho2018_09_08NYOMTATNI.docx?disposition=attachment)

Student sheet 16: **Speedometer at the chemistry lesson** [16. feladatlap: Traffipax a kémiaórán](http://ttomc.elte.hu/rails/active_storage/blobs/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaHBBcGdJIiwiZXhwIjpudWxsLCJwdXIiOiJibG9iX2lkIn19--9a38fe134ac4be0fc36569ad9d63d1c105796741/16Reakciosebesseg2019_08_06_HONLAPRA.docx?disposition=attachment)

Student sheet 17: **From the indicators to a country flag** [17. feladatlap: Az indikátoroktól az országzászlóig](http://ttomc.elte.hu/rails/active_storage/blobs/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaHBBcGtJIiwiZXhwIjpudWxsLCJwdXIiOiJibG9iX2lkIn19--f625cf592ae7e3f3204fc4828a77831e84f46fd2/17Sav_bazis2019_08_06_HONLAPRA.docx?disposition=attachment)

Student sheet 18: **The Janus-faced hydrogen peroxide** [18. feladatlap: A Janus-arcú hidrogén-peroxid](http://ttomc.elte.hu/rails/active_storage/blobs/eyJfcmFpbHMiOnsibWVzc2FnZSI6IkJBaHBBcG9JIiwiZXhwIjpudWxsLCJwdXIiOiJibG9iX2lkIn19--df9199cc7cf366c07f6fd4783860c9bafee4f9ca/18Redoxireakciok_2019_08_06_HONLAPRA.docx?disposition=attachment)

**13. Student sheet: The other benefits of firework**

(type 1: ‘step-by-step’ version for Group 1 students)

When the hot soup is boiling over on the gas cooker, it makes the blue flame yellow. The sodium vapour street lights glow in the same yellow colour. In both cases sodium atoms colour the flame to a characteristic yellow. The fabulous colour mix of the fireworks is caused by the **different atoms making different colour flames**. Since the **atoms of a chemical element always give the same colour flame test**, the presence of the element can be proved with it. Therefore, the flame test is one of the oldest methods of the **chemical analysis**. The instrumental methods based on this phenomena play an important role in the **qualitative identification and quantitative measurement** of the constituents of mixtures.

To explain the flame tests, you have to know that the **most stable** energy state of the atoms is called **ground state**. In this state their electrons are at the lowest possible energy levels. When the electrons gain energy they can get to a higher energy level. At these times the atom gets to a so called **excited state** that is not stable. So, the atom soon gets back to the ground state and it **emits the energy that it had gained before**.

The difference between the ground state and excited state is the **excitation energy** (that equals the energy that is radiated back when the excitation is over) that has a constant value for a **given atom**. Therefore the **photons of the electromagnetic waves emitted have always got the same energy** too. If the energy of these photons is in the visible part of the electromagnetic spectrum, then we can see **a flame colour that is characteristic of the atom**.

**Experiment 1**: There is sodium chloride dissolved in ethanol (ethyl alcohol) in one of the sprayers on your tray. Light the burner, spray the solution into the flame and observe the change.

**Observation:** The colour of the flame became …………………………..…….… as an effect of the spraying the sodium chloride solution.

**Explanation:** Due to heating the metal ion in the salt was atomised and its electrons got to a ……………………………….

……………………………………… atomic orbital. Once the …………………………………………….…………… state ceased, the atom

emitted the energy gained earlier in the form of ………………………………………………………………………………, while it got

back to ………………………………………………………………………..

Visible light is an electromagnetic radiation that has got **380-760 nanometre** wavelength. (The symbol of nanometre is nm and it is the one billionth part of a metre.) In this wavelength region the different **colours** are caused by light of different wavelength (its symbol is *λ –* pronounced as “lambda”)[[1]](#footnote-1).

|  |  |
| --- | --- |
| **Colour of the flame test** | **Wavelength, *λ* (nm)** |
| violet | 380 – 420 |
| blue | 420 – 490 |
| green | 490 – 575 |
| yellow | 575 – 585 |
| orange | 585 – 650 |
| red | 650 – 750 |

Not only the wavelength of the different electromagnetic radiation is different, but the energy of their photons too. **The energy of a photon of the radiation is inversely proportional with the wavelength**:

$$E\~\frac{1}{λ}$$

Therefore the longer the wavelength of the emitted radiation (i.e. the closer the colour is to the red), the smaller is the energy of their photons. This means that the closer the colour of the flame test of an element to the red, the smaller energy is needed for the excitation of its electrons.

Let us have a look at a few examples. While completing the worksheet, **underline or frame the correct or cross the not correct parts of the text.**

|  |  |
| --- | --- |
| **Name of the element** | **Colour of the flame test** |
| caesium | blue |
| potassium | violet |
| strontium | crimson red |
| barium | pale green |

A caesium atom can be excited by **lower/higher** energy than a potassium atom, because the wavelength of the blue light emitted after the excitation of the caesium atom is **shorter/longer** than the wavelength of the violet light emitted after the excitation of the potassium atom.

The **caesium/potassium/strontium/barium** atom can be excited by the lowest energy among the listed ones. This can be assumed on the ground that the **blue/violet/crimson red/pale green** colour light has the **shortest/longest** wavelength electromagnetic radiation.

The **caesium/potassium/strontium/barium** atom can be excited by the highest energy among the listed ones. This can be assumed on the ground that the **blue/violet/crimson red/pale green** colour light has the **shortest/longest** wavelength electromagnetic radiation.

**Experiment 2**: You have to decide whether the electrons of the copper atom or the calcium atom can be excited by an energy that is higher than the energy needed for the excitation of the electrons of the sodium atom. There are two more sprayers on your tray. There is copper (II) sulphate in one of them and calcium chloride in the other, both dissolved in ethanol. Do the flame test with these solutions too.

**Observation:**

|  |  |
| --- | --- |
| **Name of the salt** | **Colour of the flame test** |
| copper (II) sulphate |  |
| calcium chloride |  |

The copper atom can be excited by a **lower/higher** energy than the sodium atom, because the wavelength of the

………………………………….. colour light emitted by the excited copper atom is ………………………………………..………… than

the wavelength of the………………………………….. colour light emitted when the sodium atom returns to the ground state.

The calcium atom can be excited by a **lower/higher** energy than the sodium atom, because the wavelength of

the ………………………………….. colour light emitted by the excited calcium atom is …………………………………………… than

the wavelength of the………………………………….. colour light emitted when the sodium atom returns to the ground state.

**13. Student sheet: The other benefits of firework**

(type 2: ‘step-by-step’ version + explanation of experiment-design for Group 2 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), but after the Experiment 2 the worksheet also contains the text below that the students have to read and discuss with their teacher.*

While filling in this worksheet you applied the **principles and the practice of the scientific investigations**:

* When you tried to identify the chemical constitution of unknown substances, you accomplished **qualitative** analysis. The “**tests**” e.g. the flame tests are its important methods that you learnt to do while you examined the known colour of the flame test of the sodium.
* Then you could begin to think about the **question of the problem solving task** on the work sheet: How could you work out the relative extent of the excitation energy from the comparison of the colours of the flame tests?
* To do this, first you had to study the followings found in the **literature**, based on other people earlier results:
	+ **Correlations** between the colour of the flame test and the excitation energy. (The excitation energy equals with the emitted energy and it is a given value. Therefore the wavelength of the emitted light is characteristic of the atom. The wavelength of the emitted light is inversely proportional with the energy of the photons of the emitted light.)
	+ **Concrete data.** (The colours belonging to the various wavelength regions.)
	+ **Results of earlier experiments.** (The colours of the flame tests of some atoms.)
* Then you did the **experiments** (the flame tests with the other two compounds).
* The results of the experiments were **evaluated** (compared to the facts found in the literature).
* After **logical inference** you could answer the question of the problem solving task concerning the copper and calcium.

**13. Student sheet: The other benefits of firework**

(type 3: experiment-designing version for Group 3 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), except the Experiment 2 that goes as follows.*

**Experiment 2**: There are two unknown solutions in two sprayers on your tray. They were made of dissolving two different compounds in ethanol. (There is only one compound in one sprayer.) **Design an experiment** to answer the following **questions of a problem-solving task**:

a) Which metals formed the unknown compounds?

b) Is the excitation energy of the electrons of the first and the second unknown metal lower or higher than the excitation energy of the sodium atom?

While looking for the answers, you have to apply the **principles and the practice of the scientific investigations**:

* Think of the fact that the “**tests**” are important methods of the **qualitative** analysis. You have learnt how to do the flame tests while you examined the known colour of the flame test of the sodium.
* This worksheet contains the following facts found in the **literature**, based on other people earlier works:
	+ **Results of earlier experiments.** (The colours of the flame tests of some atoms.)
	+ **Concrete data.** (The colours belonging to the various wavelength regions.)
	+ **Correlations** between the colour of the flame test and the excitation energy.
* Knowing all of this you can design and do the **experiments**.
* The results of the experiments have to be **evaluated** (compared to the facts found in the literature).
* After **logical inference** you can answer the questions of the problem solving task.

**Plan of the series of experiments**:………………………………………………………….…………………………….………………………………

…………………………………………………………………………………………………………………………………………………………………………….

**Observations**:

|  |  |
| --- | --- |
| **Number of the unknown solution** | **The colour of the flame test** |
| 1. |  |
| 2. |  |

**Answers**:

The No. 1 unknown solution contains …………………………..…, because ………………………………………………….……………….

The No. 2 unknown solution contains …………………………..…, because ………………………………………………….……………….

Among the two metals, the electrons of the …………………………………………… atom can be excited by a lower energy

than the electrons of the sodium atom, because …………………………………………………………………………………………………..

…………………………………………………………………………………………………………………………………………………………………………….

Among the two metals, the electrons of the …………………………………………… atom can be excited by a higher energy

than the electrons of the sodium atom, because …………………………………………………………………………………………………..

…………………………………………………………………………………………………………………………………………………………………………….

**13. Student sheet: The other benefits of firework**

(teacher notes)

When the hot soup is boiling over on the gas cooker, it makes the blue flame yellow. The sodium vapour street lights glow in the same yellow colour. In both cases sodium atoms colour the flame to a characteristic yellow. The fabulous colour mix of the fireworks is caused by the **different atoms making different colour flames**. Since the **atoms of a chemical element always give the same colour flame test**, the presence of the element can be proved with it. Therefore, the flame test is one of the oldest methods of the **chemical analysis**. The instrumental methods based on this phenomena play an important role in the **qualitative identification and quantitative measurement** of the constituents of mixtures.

To explain the flame tests, you have to know that the **most stable** energy state of the atoms is called **ground state**. In this state their electrons are at the lowest possible energy levels. When the electrons gain energy they can get to a higher energy level. At these times the atom gets to a so called **excited state** that is not stable. So, the atom soon gets back to the ground state and it **emits the energy that it had gained before**.

The difference between the ground state and excited state is the **excitation energy** (that equals the energy that is radiated back when the excitation is over) that has a constant value for a **given atom**. Therefore the **photons of the electromagnetic waves emitted have always got the same energy** too. If the energy of these photons is in the visible part of the electromagnetic spectrum, then we can see **a flame colour that is characteristic of the atom**.

**Experiment 1**: There is sodium chloride dissolved in ethanol (ethyl alcohol) in one of the sprayers on your tray. Light the burner, spray the solution into the flame and observe the change.

**Observation:** The colour of the flame became ***yellow*** as an effect of the spraying the sodium chloride solution.

**Explanation:** Due to heating the metal ion in the salt was atomised and its electrons got to ***a higher energy level*** atomic orbital. Once the ***excited*** state ceased, the atom emitted the energy gained earlier in the form of ***yellow light***, while it got back to ***ground state***.

Visible light is an electromagnetic radiation that has got **380-760 nanometre** wavelength. (The symbol of nanometre is nm and it is the one billionth part of a metre.) In this wavelength region the different **colours** are caused by light of different wavelength (its symbol is *λ –* pronounced as “lambda”)[[2]](#footnote-2).

|  |  |
| --- | --- |
| **Colour of the flame test** | **Wavelength, *λ* (nm)** |
| violet | 380 – 420 |
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| yellow | 575 – 585 |
| orange | 585 – 650 |
| red | 650 – 750 |

Not only the wavelength of the different electromagnetic radiation is different, but the energy of their photons too. **The energy of a photon of the radiation is inversely proportional with the wavelength**:

$$E\~\frac{1}{λ}$$

Therefore the longer the wavelength of the emitted radiation (i.e. the closer the colour is to the red), the smaller is the energy of their photons. This means that the closer the colour of the flame test of an element to the red, the smaller energy is needed for the excitation of its electrons.

Let us have a look at a few examples. While completing the worksheet, **underline or frame the correct or cross the not correct parts of the text.**

|  |  |
| --- | --- |
| **Name of the element** | **Colour of the flame test** |
| caesium | blue |
| potassium | violet |
| strontium | crimson red |
| barium | pale green |

A caesium atom can be excited by **lower/higher** energy than a potassium atom, because the wavelength of the blue light emitted after the excitation of the caesium atom is **shorter/longer** than the wavelength of the violet light emitted after the excitation of the potassium atom.

The **caesium/potassium/strontium /barium** atom can be excited by the lowest energy among the listed ones. This can be assumed on the ground that the **blue/violet/crimson red/pale green** colour light has the **shortest/ longest** wavelength electromagnetic radiation.

The **caesium/potassium/strontium/barium** atom can be excited by the highest energy among the listed ones. This can be assumed on the ground that the **blue/violet/crimson red/pale green** colour light has the **shortest/longest** wavelength electromagnetic radiation.

[Only for type 1 and 2 student sheets.]

**Experiment 2**: You have to decide whether the electrons of the copper atom or the calcium atom can be excited by an energy that is higher than the energy needed for the excitation of the electrons of the sodium atom. There are two more sprayers on your tray. There is copper (II) sulphate in one of them and calcium chloride in the other, both dissolved in ethanol. Do the flame test with these solutions too.

**Observation:**

|  |  |
| --- | --- |
| **Name of the salt** | **Colour of the flame test** |
| copper (II) sulphate | ***green*** |
| calcium chloride | ***brick red*** |

The copper atom can be excited by a **lower/higher** energy than the sodium atom, because the wavelength of the ***green*** colour light emitted by the excited copper atom is ***shorter*** than the wavelength of the ***yellow*** colour light emitted when the sodium atom returns to the ground state.

The calcium atom can be excited by a **lower/higher** energy than the sodium atom, because the wavelength of the ***brick red*** colour light emitted by the excited calcium atom is ***longer*** than the wavelength of the ***yellow*** colour light emitted when the sodium atom returns to the ground state.

[Only for type 2 student sheets.]

While filling in this worksheet you applied the **principles and the practice of the scientific investigations**:

* When you tried to identify the chemical constitution of unknown substances, you accomplished **qualitative** analysis. The “**tests**” e.g. the flame tests are its important methods that you learnt to do while you examined the known colour of the flame test of the sodium.
* Then you could begin to think about the **question of the problem solving task** on the work sheet: How could you work out the relative extent of the excitation energy from the comparison of the colours of the flame tests?
* To do this, first you had to study the followings found in the **literature**, based on other people earlier results:
	+ **Correlations** between the colour of the flame test and the excitation energy. (The excitation energy equals with the emitted energy and it is a given value. Therefore the wavelength of the emitted light is characteristic of the atom. The wavelength of the emitted light is inversely proportional with the energy of the photons of the emitted light.)
	+ **Concrete data.** (The colours belonging to the various wavelength regions.)
	+ **Results of earlier experiments.** (The colours of the flame tests of some atoms.)
* Then you did the **experiments** (the flame tests with the other two compounds).
* The results of the experiments were **evaluated** (compared to the facts found in the literature).
* After **logical inference** you could answer the question of the problem solving task concerning the copper and calcium.

[Only for type 3 student sheets.]

**Experiment 2**: There are two unknown solutions in two sprayers on your tray. They were made of dissolving two different compounds in ethanol. (There is only one compound in one sprayer.) **Design an experiment** to answer the following **questions of a problem-solving task**:

a) Which metals formed the unknown compounds?

b) Is the excitation energy of the electrons of the first and the second unknown metal lower or higher than the excitation energy of the sodium atom?

While looking for the answers, you have to apply the **principles and the practice of the scientific investigations**:

* Think of the fact that the “**tests**” are important methods of the **qualitative** analysis. You have learnt how to do the flame tests while you examined the known colour of the flame test of the sodium.
* This worksheet contains the following facts found in the **literature**, based on other people earlier works:
	+ **Results of earlier experiments.** (The colours of the flame tests of some atoms.)
	+ **Concrete data.** (The colours belonging to the various wavelength regions.)
	+ **Correlations** between the colour of the flame test and the excitation energy.
* Knowing all of this you can design and do the **experiments**.
* The results of the experiments have to be **evaluated** (compared to the facts found in the literature).
* After **logical inference** you can answer the questions of the problem solving task.

**Plan of the series of experiments**: ***The flame test has to be done using the two different solutions that are in the two sprayers on the tray.***

**Observations**:

|  |  |
| --- | --- |
| **Number of the unknown solution** | **The colour of the flame test** |
| 1. | ***green*** |
| 2. | ***brick red*** |

**Answers**:

The No. 1 unknown solution contains ***copper***, because ***its flame test is green***.

The No. 2 unknown solution contains ***calcium***, because ***its flame test is brick red.***

Among the two metals, the electrons of the ***calcium*** atom can be excited by a lower energy than the electrons of the sodium atom, because ***wavelength of the brick red colour light emitted by the excited calcium atom is longer than the wavelength of the yellow colour light emitted when the sodium atom returns to the ground state.***

Among the two metals, the electrons of the ***copper*** atom can be excited by a higher energy than the electrons of the sodium atom, because ***wavelength of the green colour light emitted by the excited copper atom is shorter than the wavelength of the yellow colour light emitted when the sodium atom returns to the ground state.***

END OF THE 13. STUDENT SHEETS AND TEACHER NOTES

**14. Student sheet: A drop in the sea**

(type 1: ‘step-by-step’ version for Group 1 students)

What do you think, how many drops of water is in the global see? Obviously, you cannot count them, but you can make an estimation. The starting point could be that there is 1383 million km3 water on the Earth. 97.4% of that is in the global sea. Now, you only have to determine the volume of 1 drop of water, so that you could calculate the approximate result. (Why only approximate? What do you need to simplify and neglect?) While filling in this worksheet, you will investigate the drops of liquids: their volume and shape, and you will also calculate the amount of matter and the number of particles in them. Based on the volume of the drops (using the density of the liquid) the surface tension of the liquid can be calculated, that is related to the intermolecular forces (cohesion) among the particles.

**Experiment 1**: Measure the volume of one drop water by using the equipment you find on your tray.

a) Fill your Pasteur pipette (or syringe or pipette) with water and press out 1.0 cm3 from it drop-by-drop into a beaker. Count the number of drops. Observe the shape of drops. You can also make a photograph of a drop.

b) Repeat the measurement twice. Calculate the average of the measured data.

c) Calculate the volume of one drop of water.

Fill in the following table. The density of water (at 20 °C) is *ρ*water = 0.998 g/cm3. Think of the precision of your measurement when writing down the result. (How many significant places should be given in the numbers?)

|  |
| --- |
| number of drops in 1.0 cm3 water: ……… drops, ……… drops, ……… drops average: **……….** drops |
| in 1 drop … |
| volume of water | mass of water | amount of matter in the water | number of water molecules in the water |
| *V* = …..…….. cm3 | *m* = ……..…..g | *n* = …..……… mol | *N* = ……..…… molecules |

Why do you think you had to do the measurements at least 3 times?

…………………………………………………………………………………….……………………………………………………………………………………..

……………………………………………………………………………………………………….……………………………………………………………………

How many drops of water are in the global sea? ..................................................................................................................................................................................

……………………………………………………………………………………………………….………………………………………………......................

**Experiment 2:** Determine the data of one drop of water-free (absolute) ethanol (ethyl alcohol, C2H5-OH) by following the sameprocedure you used in Experiment 1, but using ethanol instead of water. (Rinse the pipette or syringe with the new liquid before the measurement.) Observe the shape of drops again. You can also make a photograph of a drop. Fill in the following table. The density of absolute ethanol (at 20 °C) is

*ρ*ethanol = 0.789  g/cm3.

|  |
| --- |
| number of drops in 1.0 cm3 ethanol: ……… drops, ……… drops, ……… drops average: **……….** drops |
| 1 drop … |
| volume of ethanol | mass of ethanol | amount of matter in the ethanol | number of water molecules in the ethanol |
| *V* = …..…….. cm3 | *m* = ……..…..g | *n* = …..……… mol | *N* = ……..…… molecules |

**Explanations**: Read the following text and **underline or frame the correct or cross the not correct parts** andfinish the notcomplete sentences**.**

a) In the case of the particles in the inner part of the liquid, cohesion forces are exerted from each direction, therefore the resultant force is zero. On the contrary, the particles on the surface of the liquid are attracted to the inner part of the liquid. Therefore the resultant force is not zero, but it points toward the centre of the liquid. That is why the drop has a spherical shape without gravitation. The **surface tension** (its symbol: *γ*, its unit: N/m) is directly proportional with the resultant force exerted on the particles being on the surface. Its value is the bigger the stronger the interactions are among the particles of the liquid. The mass of the drop of the liquid is directly proportional with the surface tension. The volume of the drop of water is **smaller/bigger** than the volume of the ethanol and the density of the water is **lower/higher** than that of the ethanol. Consequently, the surface tension of the water is **lower/higher** than that of the ethanol. It could be concluded that intermolecular forces between the water molecules are **stronger/weaker** than between the ethanol molecules.

Compare the proportion of the volumes and the proportion of the number of molecules of 1 drop of water and 1 drop of ethanol.

*V*(1 drop water) : *V*(1 drop ethanol) = ................. *N*water : *N*ethanol = .............

b) What is the reason of the above determined proportions?

……………………………………………………………………………………………………………………………………………………………………………

……………………………………………………………………………………………………….…………………………………………………...………………

c) What is the difference between the shape of the water drops and ethanol drops?

…………………………………………………………………………………………………………………………………………………………………………….

……………………………………………………………………………………………………….……………………………………………………………………

**Explanations**: The **lower/higher** is the surface tension of the liquid, the less stretched is the shape of the drop and the more it resembles to a sphere.

|  |  |
| --- | --- |
| **mass%** | ****(g/cm3)** |
| 30 | 0,9538 |
| 35 | 0,9449 |
| 40 | 0,9352 |
| 45 | 0,9247 |
| 50 | 0,9138 |
| 55 | 0,9026 |
| 100 | 0,7893 |

*Ethanol content of the ethanol-water mixture in per cent by mass and its density (g/cm3)*

**Experiment 3:** You will examine a mixture of 10.0 cm3 water (A) és 10.0 cm3 ethanol (B).

a) What is the mass of the mixture? *m* = *m*A + *m*B = ( ............ + ...............) g = ...... g

b) What is its ethanol content in per cent by mass? *w*B = *m*B / *m* = ............. = .........%

c) Determine the density of the mixture, using the data of this table: *ρ* = .............g/cm3

d) What is the volume of the mixture? *V* = *m*/*ρ* = ..................... cm3

e) Measure the volume of one drop of the mixture by applying the method you used earlier.

The number of the drops in 1,0 cm3 mixture: ……… drops, ……… drops, ……… drops average: **……….** drops.

*V*1 drop = ….... cm3

f) If the same volume of two liquids are dropped (by using the same equipment) and the number of drops are counted (their symbol is *n* that should not be mixed with the symbol of the amount of matter), then the following rule is true for the surface tension (*γ*):

$$\frac{γ\_{1}}{γ\_{2}}=\frac{n\_{2}∙ρ\_{1}}{n\_{1}∙ρ\_{2}}$$

Calculate the surface tension of the water-free ethanol and that of the ethanol-water mixture, if it is known that the surface tension of the water is 72⋅10-3 N/m (=72 mN/m, i.e. millinewton/meter)!

*γ*ethanol = …………mN/m *γ*mixture = …………mN/m

g) What can you conclude from the calculated values? ………………………………………………………………………..……………

……………………………………………………………………………………………………………………………………………………………………………

Have a look at the following diagram.

h) What relationship does this diagram show?

……………………………………………………………………………………

……………………………………………………………………………………

i) How do the values measured by yourself agree with the values you can read from the diagram? What could be the reason of the differences?

……………………………………………………………………………………

……………………………………………………………………………………

……………………………………………………………………………………

**14. Student sheet: A drop in the sea**

(type 2: ‘step-by-step’ version + explanation of experiment-design for Group 2 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), but there are the two differences.*

*Between the Experiment 1 and Experiment 2 the worksheet also contains the text below that the students have to read and discuss with their teacher.*

While designing the experiment, we had to consider that the volume of one drop of liquid only could be determined with a great deal of uncertainty. You could have measured the volume of 10, 20 etc. drops, but the reading of volume would have been even more uncertain, because the volume of 10, 20 etc. drops could have easily been in between two marks of the pipette or syringe and then you could have only estimated the volume. Therefore you rather measured the number of drops in the volume of liquid between two marks and this way you could calculate the average volume. **Each measurement has got an error**. The **random error can be decreased by increasing the number of measurements**. Therefore the measurements should be done at least three times. The **systematic error** can be decreased by the application of the most precise equipment and method and the **calibration of the equipment** (comparing it with a more precise equipment).

*The following sentence is inserted in Experiment 3.f, after the formula:*

The same volume of liquids were used in the previous three experiments to count the number of drops, so that the formula above could be used.

**14. Student sheet: A drop in the sea**

(type 3: experiment-designing version for Group 3 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), except the Experiment 1 and Experiment 2 that goes as follows.*

**Experiment 1:** Measure the volume of one drop water by using the equipment you find on your tray. Observe the shape of drops. You can also make a photograph of a drop.

Measuring the volume of one drop of liquid is very difficult, extremely precise instruments are needed for that. Those are not available now, but you can find equipment on your tray that are suitable to measure the **volume of more drops**. Just think about it: how could you measure and calculate the volume of an average drop in the most precise way? **Each measurement has got an error**. The **random error can be decreased by increasing the number of measurements**. The **systematic error** can be decreased by the application of the most precise equipment and method and the **calibration of the equipment** (comparing it with a more precise equipment).

**The plan of the measurement:** ................................................................................................................................

...................................................................................................................................................................................

How have you increased the precision of your measurement? How have you tried to decrease the random

error? ........................................................................................................................................................................

...................................................................................................................................................................................

Fill in the following table. The density of water (at 20 °C) is *ρ*water = 0.998 g/cm3. Think of the precision of your measurement when writing down the result. (How many significant places should be given in the numbers?)

|  |  |
| --- | --- |
| The volume of water: *V* (cm3) | Number of drops in that volume: |
|  | average: ………….drops |
| 1 drop … |
| volume of water | mass of water | amount of matter in the water | number of water molecules in the water |
| *V* = …..…….. cm3 | *m* = ……..…..g | *n* = …..……… mol | *N* = ……..…… molecules |

How many drops of water are in the global sea?

..................................................................................................................................................................................

……………………………………………………………………………………………………….………………………………………………......................

**Experiment 2:** Determine the data of one drop of water-free (absolute) ethanol (ethyl alcohol, C2H5-OH) by following the sameprocedure you used in Experiment 1, but using ethanol instead of water. (Rinse the pipette or syringe with the new liquid before the measurement.) Observe the shape of drops again. You can also make a photograph of a drop. To be able to compare the results of the measurements more easily, it is worth using the same volume of ethanol as the volume of water used in the previous experiment.

Fill in the following table. The density of absolute ethanol (at 20 °C) is

*ρ*ethanol = 0.789  g/cm3.

|  |  |
| --- | --- |
| The volume of ethanol: *V* (cm3) | Number of drops in that volume: |
|  | average: ………….drops |
| 1 drop … |
| volume of ethanol | mass of ethanol | amount of matter in the ethanol | number of water molecules in the ethanol |
| *V* = …..…….. cm3 | *m* = ……..…..g | *n* = …..……… mol | *N* = ……..…… molecules |

**14. Student sheet: A drop in the sea**

(teacher notes)

What do you think, how many drops of water is in the global see? Obviously, you cannot count them, but you can make an estimation. The starting point could be that there is 1383 million km3 water on the Earth. 97.4% of that is in the global sea. Now, you only have to determine the volume of 1 drop of water, so that you could calculate the approximate result. (Why only approximate? What do you need to simplify and neglect?) While filling in this worksheet, you will investigate the drops of liquids: their volume and shape, and you will also calculate the amount of matter and the number of particles in them. Based on the volume of the drops (using the density of the liquid) the surface tension of the liquid can be calculated, that is related to the intermolecular forces (cohesion) among the particles.

[Only for type 1 and 2 student sheets.]

**Experiment 1**: Measure the volume of one drop water by using the equipment you find on your tray.

a) Fill your Pasteur pipette (or syringe or pipette) with water and press out 1.0 cm3 from it drop-by-drop into a beaker. Count the number of drops. Observe the shape of drops. You can also make a photograph of a drop.

b) Repeat the measurement twice. Calculate the average of the measured data.

c) Calculate the volume of one drop of water.

[Only for type 3 student sheets.]

**Experiment 1:** Measure the volume of one drop water by using the equipment you find on your tray. Observe the shape of drops. You can also make a photograph of a drop.

Measuring the volume of one drop of liquid is very difficult, extremely precise instruments are needed for that. Those are not available now, but you can find equipment on your tray that are suitable to measure the **volume of more drops**. Just think about it: how could you measure and calculate the volume of an average drop in the most precise way? **Each measurement has got an error**. The **random error can be decreased by increasing the number of measurements**. The **systematic error** can be decreased by the application of the most precise equipment and method and the **calibration of the equipment** (comparing it with a more precise equipment).

**The plan of the measurement:** ***A given volume of liquid has to be pressed out drop-by-drop from a pipette to a beaker, while the number of drops have to be counted. The volume divided by the number of drops will give the volume of one drop. The measurement has to be repeated at least twice.***

How have you increased the precision of your measurement? ***How have you tried to decrease the random error? The random error can be decreased by repeating the measurement more than once and avoiding the pollution of materials and equipment. The systematic error can be decreased by choosing the most precise equipment available/by trying to measure the volume precisely/by measuring the number of drops in a relatively big volume/by avoiding any changes of the conditions.***

[Only for type 1 and 2 student sheets.]

Fill in the following table. The density of water (at 20 °C) is *ρ*water = 0.998 g/cm3. Think of the precision of your measurement when writing down the result. (How many significant places should be given in the numbers?)

|  |
| --- |
| number of drops in 1.0 cm3 water: ***e.g. 23*** drops, ***24*** drops, ***23*** drops average: ***23.3*** drops |
| in 1 drop … |
| volume of water | mass of water | amount of matter in the water | number of water molecules in the water |
| *V* = **0,043** cm3 | *m* = **0,043** g | *n* = **0,0024** mol | *N* = **1,4⋅1021** molecules |

***Calculation if the measurements are done e.g. a 5 cm3 syringe:***

***1,0 cm3 water consisted of 23, 24, 23 drops, therefore the average is 23.3 drop. So, the average volume of one drop is 1.0 cm3/23.3 = 0.043 cm3. Its mass: 0.043 cm3 × 0.998 g/cm3 = 0.043 g. There are***

***0.043 g/18 g/mol = 0.0024 mol, i.e. 0.0024 ⋅ 6 ⋅ 1023 = 1.4⋅1021 water molecules in one drop of water.***

Why do you think you had to do the measurements at least 3 times? ***To decrease the random error/to increase the precision of the measurement.***

[Only for type 3 student sheets.]

Fill in the following table. The density of water (at 20 °C) is *ρ*water = 0.998 g/cm3. Think of the precision of your measurement when writing down the result. (How many significant places should be given in the numbers?)

|  |  |
| --- | --- |
| The volume of water: *V* (cm3) | Number of drops in that volume: |
| **1.0** | **23, 24, 23**average: ***23.3*** drops |
| 1 drop … |
| volume of water | mass of water | amount of matter in the water | number of water molecules in the water |
| *V* = **0.043** cm3 | *m* = **0.043**g | *n* = **0.0024** mol | *N* = **1.4⋅1021** molecules |

[For all type of student sheets.]

How many drops of water are in the global sea?

**The volume of the global sea: 1383 ⋅ 106 ⋅ 1015 ⋅  0.974 cm3 = 1,347⋅1024 cm3. This value is divided by the volume of one drop of water: 1.347⋅1024 cm3 : 0.043 cm3 = 3.1⋅1025  drops.**

[Only for type 2 student sheets.]

While designing the experiment, we had to consider that the volume of one drop of liquid only could be determined with a great deal of uncertainty. You could have measured the volume of 10, 20 etc. drops, but the reading of volume would have been even more uncertain, because the volume of 10, 20 etc. drops could have easily been in between two marks of the pipette or syringe and then you could have only estimated the volume. Therefore you rather measured the number of drops in the volume of liquid between two marks and this way you could calculate the average volume. **Each measurement has got an error**. The **random error can be decreased by increasing the number of measurements**. Therefore the measurements should be done at least three times. The **systematic error** can be decreased by the application of the most precise equipment and method and the **calibration of the equipment** (comparing it with a more precise equipment).

[Only for type 1 and 2 student sheets.]

**Experiment 2:** Determine the data of one drop of water-free (absolute) ethanol (ethyl alcohol, C2H5-OH) by following the sameprocedure you used in Experiment 1, but using ethanol instead of water. (Rinse the pipette or syringe with the new liquid before the measurement.) Observe the shape of drops again. You can also make a photograph of a drop. Fill in the following table. The density of absolute ethanol (at 20 °C) is

*ρ*ethanol = 0.789  g/cm3.

|  |
| --- |
| number of drops in 1.0 cm3 ethanol: ***46*** drops, ***46*** drops, ***45*** drops average: ***46.7*** drops |
| 1 drop … |
| volume of ethanol | mass of ethanol | amount of matter in the ethanol | number of water molecules in the ethanol |
| *V* = **0.022** cm3 | *m* = **0.017**g | *n* = **0.38**millimol = 0.00038 mol | *N* = **2.3⋅1020** molecules |

***Calculation if the measurements are done e.g. a 5 cm3 syringe:***

***1.0 cm3 ethanol consisted of 46, 46, 45 drops, therefore the average is 46.7 drop. So, the average volume of one drop of ethanol is 1.0 cm3/46.7 = 0.022 cm3. Its mass: 0.022 cm3 × 0.789 g/cm3 = 0.017 g. There are***

***0.017 g/46 g/mol = 0.00038 mol, i.e. 0.00038 ⋅ 6 ⋅ 1023 = 2.3⋅1021 ethanol molecules in one drop of water.***

[Only for type 3 student sheets.]

**Experiment 2:** Determine the data of one drop of water-free (absolute) ethanol (ethyl alcohol, C2H5-OH) by following the sameprocedure you used in Experiment 1, but using ethanol instead of water. (Rinse the pipette or syringe with the new liquid before the measurement.) Observe the shape of drops again. You can also make a photograph of a drop. To be able to compare the results of the measurements more easily, it is worth using the same volume of ethanol as the volume of water used in the previous experiment.

Fill in the following table. The density of absolute ethanol (at 20 °C) is

*ρ*ethanol = 0.789  g/cm3.

|  |  |
| --- | --- |
| The volume of ethanol: *V* (cm3) | Number of drops in that volume: |
| ***1.0*** | **46, 46, 45** dropsaverage: **46.7** drops |
| 1 drop … |
| volume of ethanol | mass of ethanol | amount of matter in the ethanol | number of water molecules in the ethanol |
| *V* = **0.022** cm3 | *m* = **0.017**g | *n* = **0.38** millimol = 0,00038 mol | *N* = **2.3⋅1020** molecules |

[For all type of student sheets.]

**Explanations**: Read the following text and **underline or frame the correct or cross the not correct parts** andfinish the notcomplete sentences**.**

a) In the case of the particles in the inner part of the liquid, cohesion forces are exerted from each direction, therefore the resultant force is zero. On the contrary, the particles on the surface of the liquid are attracted to the inner part of the liquid. Therefore the resultant force is not zero, but it points toward the centre of the liquid. That is why the drop has a spherical shape without gravitation. The **surface tension** (its symbol: *γ,* its unit: N/m) is directly proportional with the resultant force exerted on the particles being on the surface. Its value is the bigger the stronger the interactions are among the particles of the liquid. The mass of the drop of the liquid is directly proportional with the surface tension. The volume of the drop of water is **smaller/bigger** than the volume of the ethanol and the density of the water is **lower/higher** than that of the ethanol. Consequently, the surface tension of the water is **lower/higher** than that of the ethanol. It could be concluded that intermolecular forces between the water molecules are **stronger/weaker** than between the ethanol molecules.

Compare the proportion of the volumes and the proportion of the number of molecules of 1 drop of water and 1 drop of ethanol.

*V*(1 drop water) : *V*(1 drop ethanol) = ***2.0*** *N*water : *N*ethanol = ***6.1***

b) What is the reason of the above determined proportions? ***The proportion of the volume of the drops is determined by the surface tension (and the proportion of the densities). When calculating the proportions of the amount of matter (proportions of the number of molecules) the proportions of the mass of the drops and the proportions of the molecular masses of the molecules have to be taken into consideration.***

c) What is the difference between the shape of the water drops and ethanol drops? ***The drop of the ethanol is smaller and the neck of the drop of water is thinner.***

**Explanations**: The **lower/higher** is the surface tension of the liquid, the less stretched is the shape of the drop and the more it resembles to a sphere.

|  |  |
| --- | --- |
| **mass%** | ****(g/cm3)** |
| 30 | 0,9538 |
| 35 | 0,9449 |
| 40 | 0,9352 |
| 45 | 0,9247 |
| 50 | 0,9138 |
| 55 | 0,9026 |
| 100 | 0,7893 |

*Ethanol content of the ethanol-water mixture in per cent by mass and its density (g/cm3)*

**Experiment 3:** You will examine a mixture of 10.0 cm3 water (A) és 10.0 cm3 ethanol (B).

a) What is the mass of the mixture? *m* = *m*A + *m*B = (***9.98*** + ***7.89***) g = ***17.87*** g

b) What is its ethanol content in per cent by mass? *w*B = *m*B / *m* = ***0.441*** = ***44.1***%

c) Determine the density of the mixture, using the data of this table:

***cca.*** *ρ* = ***0.925*** g/cm3 or exactly *ρ* = ***0.927*** g/cm3

d) What is the volume of the mixture? *V* = *m*/*ρ* = ***19.3*** cm3

e) Measure the volume of one drop of the mixture by applying the method you used earlier.

The number of the drops in 1,0 cm3 mixture: ……… drops, ……… drops, ……… drops average: **……….** drops.

*V*1 drop = **0.024** cm3

***Calculation if the measurements are done e.g. a 5 cm3 syringe: The number of drops in 1.0 cm3 mixture: 41, 42, 41 drops, i.e. the average is 41.3 drops, therefore the volume of one drop is 1 cm3/41.3 =0.024 cm3.***

f) If the same volume of two liquids are dropped (by using the same equipment) and the number of drops are counted (their symbol is *n* that should not be mixed with the symbol of the amount of matter), then the following rule is true for the surface tension (*γ*):

$$\frac{γ\_{1}}{γ\_{2}}=\frac{n\_{2}∙ρ\_{1}}{n\_{1}∙ρ\_{2}}$$

[Only for type 2 student sheets.]

The same volume of liquids were used in the previous three experiments to count the number of drops, so that the formula above could be used.

[For all type of student sheets.]

Calculate the surface tension of the water-free ethanol and that of the ethanol-water mixture, if it is known that the surface tension of the water is 72⋅10-3 N/m (=72 mN/m, i.e. millinewton/meter)!

*γ*ethanol =  ***28*** mN/m *γ*mixture = ***38*** mN/m

g) What can you conclude from the calculated values? ***The surface tension decreases as the concentration of ethanol decreases. (The reason is that there are weaker intermolecular interactions in the ethanol than in the water.)***

Have a look at the following diagram.

h) What relationship does this diagram show?

***The relationship between the surface tension and the constitution of the mixture. The surface tension decreases by the increase of the concentration of ethanol.***

i) How do the values measured by yourself agree with the values you can read from the diagram? What could be the reason of the differences?

***There is an error because of the not precise measurement/the evaporation of alcohol/the size of the capillary/the measured volume was too small.***

END OF THE 8. STUDENT SHEETS AND TEACHER NOTES

**15. Student sheet: Hot chocolate in winter, ice tea in summer**

(type 1: ‘step-by-step’ version for Group 1 students)

“*Soon we do not need a cold box to keep the drinks cold that we carry with us*.” you can read this on a Hungarian website.[[3]](#footnote-3) On another homepage you can find the following advertisement (in Hungarian): “*TermoKlik: It produces the heat itself, it can be regenerated and used again several thousand times. It does not need electricity or any other source of energy*.” Nowadays you can see more and more products in the web shops and on the shelves of the real shops that utilise an **endothermic** or **exothermic** process following some **physical/chemical change** for cooling or heating. While filling in this worksheet you will investigate, how some of these products work. (Just as in many other texts on the internet, there are several chemical and grammatical mistakes in the quotes above.)

While completing the worksheet, **underline or frame the correct or cross the not correct parts of the text.**

**Experiment 1: Hot chocolate or ice tea**

separating layer

separating layer

spike

drink

water

salt

water

salt

drink

There are products that utilise the giving off/ gaining of heat that happens at dissolution to reach a certain temperature. On this figure you can see the draft drawing of a simple self-heating or self-cooling cup. Pushing the bottom of the cup, the spike tears the separating layer and then the salt falls into the water. If **heat is given off** at the time of the dissolution of the salt, then it **warms up** the drink above it. If the **heat of dissolution is** **positive,** then the solution gains heat from the drink, therefore it **cools** it.

The following **experiment** will model the product described above works. You have to decide, what salt could be applied to warm up the chocolate drink and to cool down the tea. Therefore you find the same amount (0.03 mol) of the following salts in separate beakers on your tray: potassium nitrate, sodium chloride, calcium chloride.

Measure the temperature of the water in the big baker and write it in the table below. Then add 20 cm3 distilled water to each salt. Stir the content of the beakers until the salts dissolve. Then measure the temperature of the solutions and write those data in the table too. What mass of salt contain the beakers? Write the result of your calculations in the table.

**Calculations, observations, explanations:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Formula of the salt | *M* (g/mol) | Mass (g) | Temperature of water (°C) | Temperature of solution (°C) | **Explanation** |
|  |  |  |  |  | The dissolution of potassium nitrate is **exothermic/endothermic** process. |
|  |  |  |  | The dissolution of sodium chloride is **exothermic/endothermic** process. |
|  |  |  |  | The dissolution of calcium chloride is **exothermic/endothermic** process. |

**Conclusions:** The ………………………………………………. is suitable to make self-heating cups, because its dissolution is

an …………………………………………………… process, the system ………………………….………………………. its environment. The

…………………………………………………………….…………. is suitable to make self-cooling cups, because its dissolution is an

……………………………………………………………… process, the system ………………………………….………………. its environment.

Compare the **absolute values** of the lattice energy and the heat of hydration in the case of all the three salts. Use these signs: **=, <, >, ≃**.

Potassium nitrate: [lattice energy] ……. [heat of hydration].

Sodium chloride: [lattice energy] ……. [heat of hydration].

Calcium chloride: [lattice energy] ……. [heat of hydration].

**Experiment 2: How does the ”salt heat pad” work?**

Sometimes you can find fake information on the websites advertising self-cooling and self-heating products. For instance, you can read the following about a self-heating baby food: “*The liquid in the bottle warms up as a consequence of the thermic reaction of the calcium hydroxide and water that are in the bottom of the bottle and it keeps its temperature for 20 minutes*.” You have already learnt that the lime slaking is an exothermic process indeed (although its proper name is not “thermic reaction”, but it is called an “**exothermic** reaction”). However, you must remember that the calcium hydroxide is the slaked lime itself. Therefore the description of the operation of the product is not correct. Write down the chemical name of the quicklime (burnt lime) and the equation of the lime slaking.

…………………………………………………………………………………………………………………………………………………………………………….

This is a quote from another website: “*The Heating Salt Pad is one of a group of products that allow us to conjure nice warmth at various places by using a special physical phenomena. The Salt Pad contains the not poisonous sodium acetate, a salty solution that is able to make warmth in a few seconds up to 54 °C, when it changes from liquid to solid.*” Looking at the grammatical mistakes and the not precise composition of the sentences, you can suspect that this is a cheating, based on pseudoscientific explanation and the product does not work in the reality. You will investigate the truth by doing the following experiment.

**Experiment 2**: There are sodium acetate trihydrate crystals in one of the test tubes and distilled water in the other test tube. Add the water to the sodium acetate. Carefully shake the test tube and touching its wall from outside find it out whether it warms up or cool down while the salt is dissolving. Warm up the content of the test tube in the flame of the burner until all the salt dissolves. Then place the test tube carefully in a beaker that has got room temperature water in it. It is important that you should not move at all the test tube while it is cooling down. After waiting for a few minutes, lift the test tube out of the water bath, wipe its outside wall dry and drop a crystal of sodium acetate in it. What sort of change do you experience? How does the temperature of the test tube change meanwhile? (You should touch the test tube from outside to find this out.)

**Observations:** **At the time of the dissolution** the wall of the test tube **warms up/cools down**, therefore the dissolution of the sodium acetate is an **exothermic/endothermic** process. What change did you notice in the cold solution after adding the sodium acetate crystal?

A …………………………………………………. began in the test tube and a ………………………………………………………………………….

system formed, while the wall of the test tube **cooled down/warmed up/the temperature of the wall of the test tube did not change at all**.

**Explanations:** Can you say what had been the constitution of the solution in the test tube **before the heating**?

N**o**, because …………………………………………………………………………………………………………………………………………………………

**Yes,** the solution was **saturated/unsaturated/supersaturated**, because………………………………………………………………

**Explanations:** Can you say what was the constitution of the solution after the cooling, before the solid crystal was placed in it?

N**o**, because …………………………………………………………………………………………………………………………………………………………

**Yes,** the solution was **saturated/unsaturated/supersaturated**, because………………………………………………………………

**Conclusion:** We **have managed/have not managed** to justify that the heating salt pad can work, because **cooling/warming** happened at the time of the **dissolution/crystallization** in the test tube. There is probably a **saturated/unsaturated/supersaturated** solution of sodium acetate in these heat pads. Its crystallization is an **endothermic/exothermic** process when heat is **released/absorbed**.

**Homework**: You can also read this about the salt pad on the internet: “*It can be quickly and simply regenerated after the usage.”* How can the salt pad be regenerated (so that it would work again)? Why? **Physical** or **chemical** process happens? Is that true that there is no need of any source of energy?

…………………………………………………………………………………………………………………………………………………………………………….

…………………………………………………………………………………………………………………………………………………………………………….

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What do you think, the products that utilise **physical** or **chemical** processes cause more severe **environmental pollution**?

…………………………………………………………………………………………………………………………………………………………………………….

…………………………………………………………………………………………………………………………………………………………………………….

**15. Student sheet: Hot chocolate in winter, ice tea in summer**

(type 2: ‘step-by-step’ version + explanation of experiment-design for Group 2 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), but after the Experiment 2 and before the homework the worksheet also contains the text below that the students have to read and discuss with their teacher.*

The question of the **problem-solving task** could be answered by doing a **model experiment**. To do so, we had to decide, what could be the **essence** of the operation of the salt pad, because that had to be **modelled** by an experiment. Reading its description, it could be concluded that heat is released when the crystallization happen in the sodium acetate solution. Therefore we had to justify that the crystallization of the sodium acetate is an exothermic process. (It is **not important** that it happens in a plastic bag or in a test tube.) First we had to make a solution that was supersaturated at room temperature. Since there was not any metal disc available that could have replaced the nucleation sites and triggered the crystallization, its effect was **modelled** by the added small sodium acetate crystal. We have managed to start the crystallization in the supersaturated solution and it really warmed up the content of the test tube. So, we could **conclude** from **the result of the** **model experiment** that we have managed to **justify** that the product can work.

**15. Student sheet: Hot chocolate in winter, ice tea in summer**

(type 3: experiment-designing version for Group 3 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), except the Experiment 2 that goes as follows.*

**Experiment 2**: Sometimes you can find fake information on the websites advertising self-cooling and self-heating products. For instance, you can read the following about a self-heating baby food: “*The liquid in the bottle warms up as a consequence of the thermic reaction of the calcium hydroxide and water that are in the bottom of the bottle and it keeps its temperature for 20 minutes*.” You have already learnt that the lime slaking is an exothermic process indeed (although its proper name is not “thermic reaction”, but it is called an “**exothermic** reaction”). However, you must remember that the calcium hydroxide is the slaked lime itself. Therefore the description of the operation of the product is not correct. Write down the chemical name of the quicklime (burnt lime) and the equation of the lime slaking.

…………………………………………………………………………………………………………………………………………………………………………….

This is a quote from another website: “*The Heating Salt Pad is one of a group of products that allow us to conjure nice warmth at various places by using a special physical phenomena. The Salt Pad contains the not poisonous sodium acetate, a salty solution that is able to make warmth in a few seconds up to 54 °C, when it changes from liquid to solid.*” Looking at the grammatical mistakes and the not precise composition of the sentences, you can suspect that this is a cheating, based on pseudoscientific explanation and the product does not work in the reality. You will investigate the truth by doing the following experiment.

The question of the **problem-solving task** that whether the salt pad could work or not can be answered by doing a **model experiment**. To do so, you had to decide, what could be the **essence** of the operation of the salt pad, because that had to be **modelled** by an experiment. Thinking of its description, what do you think this essence is?

…………………………………………………………………………………………………………………..............................................................

What do you need to **justify** by the model experiment? ..........................................................................................

…………………………………………………………………………………………………………………………………………………………………………….

What type of solution has to be made first? ………………………………………………………………………………………………………..

Why?..........................................................................................................................................................................

…………………………………………………………………………………………………………………………………………………………………………….

There is not any metal disc available that could replace the nucleation sites and trigger the crystallization. What do you think, how could the crystallization be started (how could its effect be **modelled**)?

………………………………………………………………………………………………………………………………………………………………………….

Write an example of any condition that is **not important** in the aspect of the working of the salt pad and therefore it is not a problem if the model experiment is different from the real salt pad.

………………………………………………………………………………………………………………………………………........................................

If you manage to make the process happen that goes on in the salt pad and you indeed observe warming meanwhile, then you can **conclude from the result of the model experiment** that you have managed to **justify** that the product can work.

Materials and equipment available for the experiment: the necessary amount of sodium acetate trihydrate and distilled water in two different test tubes, burner, test tube holder, room temperature tap water in a big beaker and crystals of sodium acetate on a watch glass. Design an experiment to **model** how the warming salt pad might work.

**Plan of the series of experiments**:………………………………………………………….…………………………….………………………………

…………………………………………………………………………………………………………………………………………………………………………….

…………………………………………………………………………………………………………………………………………………………………………….

**Observations**:……………………………………………………………………………………….……………………………………………………………..

…………………………………………………………………………………………………………………………………………………………………………….

**Explanations**: ………………………………………………………………………………………………………………………………………………………

**Conclusion:** We **have managed/have not managed** to justify that the heating salt pad can work, because **cooling/warming** happened at the time of the **dissolution/crystallization** in the test tube. There is probably a **saturated/unsaturated/supersaturated** solution of sodium acetate in these heat pads. Its crystallization is an **endothermic/exothermic** process that heat is **released/absorbed**.

**15. Student sheet: Hot chocolate in winter, ice tea in summer**

(teacher notes)

“*Soon we do not need a cold box to keep the drinks cold that we carry with us*.” you can read this on a Hungarian website.[[4]](#footnote-4) On another homepage you can find the following advertisement (in Hungarian): “*TermoKlik: It produces the heat itself, it can be regenerated and used again several thousand times. It does not need electricity or any other source of energy*.” Nowadays you can see more and more products in the web shops and on the shelves of the real shops that utilise an **endothermic** or **exothermic** process following some **physical/chemical change** for cooling or heating. While filling in this worksheet you will investigate, how some of these products work. (Just as in many other texts on the internet, there are several chemical and grammatical mistakes in the quotes above.)

While completing the worksheet, **underline or frame the correct or cross the not correct parts of the text.**

**Experiment 1: Hot chocolate or ice tea**

separating layer

separating layer

spike

drink

water

salt

water

salt

drink

There are products that utilise the giving off/ gaining of heat that happens at dissolution to reach a certain temperature. On this figure you can see the draft drawing of a simple self-heating or self-cooling cup. Pushing the bottom of the cup, the spike tears the separating layer and then the salt falls into the water. If **heat is given off** at the time of the dissolution of the salt, then it **warms up** the drink above it. If the **heat of dissolution is** **positive,** then the solution gains heat from the drink, therefore it **cools** it.

The following **experiment** will model the product described above works. You have to decide, what salt could be applied to warm up the chocolate drink and to cool down the tea. Therefore you find the same amount (0.03 mol) of the following salts in separate beakers on your tray: potassium nitrate, sodium chloride, calcium chloride.

Measure the temperature of the water in the big baker and write it in the table below. Then add 20 cm3 distilled water to each salt. Stir the content of the beakers until the salts dissolve. Then measure the temperature of the solutions and write those data in the table too. What mass of salt contain the beakers? Write the result of your calculations in the table.

**Calculations, observations, explanations:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Formula of the salt | *M* (g/mol) | Mass (g) | Temperature of water (°C) | Temperature of solution (°C) | **Explanation** |
| ***KNO3*** | ***101*** | ***3.03*** | ***26.0*** | ***18.0*** | The dissolution of potassium nitrate is **exothermic/endothermic** process. |
| ***NaCl*** | ***58.5*** | ***1.75*** | ***25.5*** | The dissolution of sodium chloride is **exothermic/endothermic** process. |
| ***CaCl2*** | ***111*** | ***3.33*** | ***33.0*** | The dissolution of calcium chloride is **exothermic/endothermic** process. |

**Conclusions:** The ***calcium chloride*** is suitable to make self-heating cups, because its dissolution is

an ***exothermic*** process, the system ***significantly warms up*** its environment. The ***potassium nitrate*** is suitable to make self-cooling cups, because its dissolution is an ***endothermic*** process, the system ***significantly cools down*** its environment.

Compare the **absolute values** of the lattice energy and the heat of hydration in the case of all the three salts. Use these signs: **=, <, >, ≃**.

Potassium nitrate: [lattice energy] ***>*** [heat of hydration].

Sodium chloride: [lattice energy] ***≃*** [heat of hydration].

Calcium chloride: [lattice energy] ***<*** [heat of hydration].

**Experiment 2: How does the ”salt heat pad” work?**

Sometimes you can find fake information on the websites advertising self-cooling and self-heating products. For instance, you can read the following about a self-heating baby food: “*The liquid in the bottle warms up as a consequence of the thermic reaction of the calcium hydroxide and water that are in the bottom of the bottle and it keeps its temperature for 20 minutes*.” You have already learnt that the lime slaking is an exothermic process indeed (although its proper name is not “thermic reaction”, but it is called an “**exothermic** reaction”). However, you must remember that the calcium hydroxide is the slaked lime itself. Therefore the description of the operation of the product is not correct. Write down the chemical name of the quicklime (burnt lime) and the equation of the lime slaking.

***calcium-oxid (CaO), CaO + H2O = Ca(OH)2***

This is a quote from another website: “*The Heating Salt Pad is one of a group of products that allow us to conjure nice warmth at various places by using a special physical phenomena. The Salt Pad contains the not poisonous sodium acetate, a salty solution that is able to make warmth in a few seconds up to 54 °C, when it changes from liquid to solid.*” Looking at the grammatical mistakes and the not precise composition of the sentences, you can suspect that this is a cheating, based on pseudoscientific explanation and the product does not work in the reality. You will investigate the truth by doing the following experiment.

**Experiment 2**: There are sodium acetate trihydrate crystals in one of the test tubes and distilled water in the other test tube. Add the water to the sodium acetate. Carefully shake the test tube and touching its wall from outside find it out whether it warms up or cool down while the salt is dissolving. Warm up the content of the test tube in the flame of the burner until all the salt dissolves. Then place the test tube carefully in a beaker that has got room temperature water in it. It is important that you should not move at all the test tube while it is cooling down. After waiting for a few minutes, lift the test tube out of the water bath, wipe its outside wall dry and drop a crystal of sodium acetate in it. What sort of change do you experience? How does the temperature of the test tube change meanwhile? (You should touch the test tube from outside to find this out.)

**Observations:** **At the time of the dissolution** the wall of the test tube **warms up/cools down**, therefore the dissolution of the sodium acetate is an is **exothermic/endothermic** process. What change did you notice in the cold solution after adding the sodium acetate crystal?

A ***crystallization*** began in the test tube and a ***two-phase*** system formed, while the wall of the test tube **cooled down/warmed up/the temperature of the wall of the test tube did not change at all**.

**Explanations:** Can you say what had been the constitution of the solution in the test tube **before the heating**?

N**o**, because ***-***

**Yes,** the solution was **saturated /unsaturated/supersaturated**, because ***there was a solid phase in the test tube beside the solution, therefore the solution is surely saturated.***

**Explanations:** Can you say what was the constitution of the solution after the cooling, before the solid crystal was placed in it?

N**o**, because ***-***

**Yes,** the solution was **saturated/unsaturated/supersaturated**, ***because an immediate, easily noticeable crystallization started after adding the solid crystal to it.***

**Conclusion:** We **have managed/have not managed** to justify that the heating salt pad can work, because **cooling/warming** happened at the time of the **dissolution/crystallization** in the test tube. There is probably a **saturated/unsaturated/supersaturated** solution of sodium acetate in these heat pads. Its crystallization is an **endothermic/exothermic** process when heat is **released/absorbed**.

**Homework**: You can also read this about the salt pad on the internet: “*It can be quickly and simply regenerated after the usage.”* How can the salt pad be regenerated (so that it would work again)? Why? **Physical** or **chemical** process happens? Is that true that there is no need of any source of energy?

***It has to be warmed up in hot water, until all the salt dissolves. More salt is dissolved at higher temperature, so eventually the solid dissolves. The energy needed for dissolution is provided by the environment, so a source of energy is necessary. The dissolution is a physical process.***

What do you think, the products that utilise **physical** or **chemical** processes cause more severe **environmental pollution**?

***The products that could be only used once that cannot be regenerated (based on either physical or chemical processes) cause more environmental pollution. Their wrapping and their content both can pollute the environment. The products utilising chemical processes can always to be used only once. Therefore, their huge environmental pollution is unavoidable.***

[Only for type 2 student sheets.]

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), but after the Experiment 2 and before the homework the worksheet also contains the text below that the students have to read and discuss with their teacher.*

The question of the **problem-solving task** could be answered by doing a **model experiment**. To do so, we had to decide, what could be the **essence** of the operation of the salt pad, because that had to be **modelled** by an experiment. Reading its description, it could be concluded that heat is released when the crystallization happen in the sodium acetate solution. Therefore we had to justify that the crystallization of the sodium acetate is an exothermic process. (It is **not important** that it happens in a plastic bag or in a test tube.) First we had to make a solution that was supersaturated at room temperature. Since there was not any metal disc available that could have replaced the nucleation sites and triggered the crystallization, its effect was **modelled** by the added small sodium acetate crystal. We have managed to start the crystallization in the supersaturated solution and it really warmed up the content of the test tube. So, we could **conclude** from **the result of the** **model experiment** that we have managed to **justify** that the product can work.

[Only for type 3 student sheets.]

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), except the Experiment 2 that goes as follows.*

**Experiment 2**: Sometimes you can find fake information on the websites advertising self-cooling and self-heating products. For instance, you can read the following about a self-heating baby food: “*The liquid in the bottle warms up as a consequence of the thermic reaction of the calcium hydroxide and water that are in the bottom of the bottle and it keeps its temperature for 20 minutes*.” You have already learnt that the lime slaking is an exothermic process indeed (although its proper name is not “thermic reaction”, but it is called an “**exothermic** reaction”). However, you must remember that the calcium hydroxide is the slaked lime itself. Therefore the description of the operation of the product is not correct. Write down the chemical name of the quicklime (burnt lime)and the equation of the lime slaking.

***calcium oxide (CaO), CaO + H2O = Ca(OH)2***

This is a quote from another website: “*The Heating Salt Pad is one of a group of products that allow us to conjure nice warmth at various places by using a special physical phenomena. The Salt Pad contains the not poisonous sodium acetate, a salty solution that is able to make warmth in a few seconds up to 54 °C, when it changes from liquid to solid.*” Looking at the grammatical mistakes and the not precise composition of the sentences, you can suspect that this is a cheating, based on pseudoscientific explanation and the product does not work in the reality. You will investigate the truth by doing the following experiment.

The question of the **problem-solving task** that whether the salt pad could work or not can be answered by doing a **model experiment**. To do so, you had to decide, what could be the **essence** of the operation of the salt pad, because that had to be **modelled** by an experiment. Thinking of its description, what do you think this essence is?

***Heat is released at the time of the crystallization of sodium acetate that warms up the environment.***

What do you need to **justify** by the model experiment? ***The crystallization of sodium acetate is an exothermic process and the environment warms up while the crystallization happens.***

What type of solution has to be made first? ***A supersaturated solution.***

Why? ***Because it is not in equilibrium, and therefore the crystallization is very fast, which is escorted by a measurable heat release.***

There is not any metal disc available that could replace the nucleation sites and trigger the crystallization. What do you think, how could the crystallization be started (how could its effect be **modelled**)?

***Some solid material that starts the nucleation. In the experiment it is the best to put a little sodium acetate crystal in it.***

Write an example of any condition that is **not important** in the aspect of the working of the salt pad and therefore it is not a problem if the model experiment is different from the real salt pad.

***The material and the colour of the pad containing the sodium acetate solution is not important. Therefore the experiment can be done in any vessel, so e.g. in a test tube too.***

If you manage to make the process happen that goes on in the salt pad and you indeed observe warming meanwhile, then you can **conclude from the result of the model experiment** that you have managed to **justify** that the product can work.

Materials and equipment available for the experiment: the necessary amount of sodium acetate trihydrate and distilled water in two different test tubes, burner, test tube holder, room temperature tap water in a big beaker and crystals of sodium acetate on a watch glass. Design an experiment to **model** how the warming salt pad might work.

**Plan of the series of experiments**: ***The sodium acetate has to be dissolved in the distilled water that is also provided. The solution has to be cooled down in a water bath. A little sodium acetate crystal has to be put into the solution. The changes have to be observed. The temperature of the outside wall of the test tube has to be checked by touching.***

**Observations**: ***The given amount of sodium acetate could only be dissolved in the given amount of water by heating. A fast crystallization happened in the solution after adding the little sodium acetate crystal, while the test tube warmed up.***

**Explanations**: ***Heat is released at the time of the crystallization of sodium acetate/the crystallization is an exothermic process.***

**Conclusion:** We **have managed/have not managed** to justify that the heating salt pad can work, because **cooling/warming** happened at the time of the **dissolution/crystallization** in the test tube. There is probably a **saturated/unsaturated/supersaturated** solution of sodium acetate in these heat pads. Its crystallization is an **endothermic/exothermic** process when heat is **released/absorbed**.

END OF THE 15. STUDENT SHEETS AND TEACHER NOTES

**16. Student sheet: Speedometer at the chemistry lesson**

(type 1: ‘step-by-step’ version for Group 1 students)

A speedometer measures the speed of the vehicles on the road, so that nobody endanger the life of the other people by driving too fast. In the aspect of the chemical reactions, you also want to avoid any danger, e.g. the explosion of a chemical factory or plant. Sometimes it is better, if a process goes faster (e.g. at the time of cooking), but at other times you want to slow it down (e.g. to avoid the going off of any food). The speed of the vehicles (the distance that they take in a certain time unit) can easily be regulated by using the accelerator or the brake pedals. But **how could the rate of reaction be regulated**, so that **a given amount of starting material would react in a time unit**? To be able to do that, you have to learn about the **factors** that can be used to accelerate or slow down the chemical reactions.

While completing the worksheet, **underline or frame the correct or cross the not correct parts of the text.**

**Experiment 1 (teacher demonstration):** First concentrated hydrogen peroxide is poured into the tall vessel that is put on a tray. Then washing up liquid is added to it and the content is mixed. A little food colouring is made to flow down on the inner wall of the vessel and then suddenly concentrated potassium iodide solution is poured in it. The product is examined by a burning splint.

**Observations:** ………………………………………………………………………………………………………………………………………………………

…………………………………………………………………………………………………………………………………………………………………………….**Explanations:** The hydrogen peroxide decomposed according to the following reaction equation (to be completed): …. H2O2 → …. H2O + …. O2

What did blow up the foam?..................................................................................

What product of the reaction was detected by the burning splint? .........................................................................

The hydrogen peroxide also decomposes when it is left alone in its container, but the potassium iodide hugely

accelerated, i.e. **catalysed** that process. In what context had you heard the word “**catalyst**”? ……………………………

What does it accelerate there? ………………………………………….....................................................................................

**Experiment 2:** Put 2 drops of the following colourless solutions on the dark surface of the tile that you find on your tray. Make sure that the solutions are placed only on one half of the tile, but far apart from one another.

* 0.1 mol/dm3 concentration sodium thiosulphate solution (Na2S2O3 solution);
* 1.0 mol/dm3 concentration sodium thiosulphate solution.

Then add to both patch of liquids 2 drops of 1.0 mol/dm3 concentration hydrochloric acid solution and measure (e.g. by using the stop watch application of your mobile phone) how much time (how many seconds) is needed to see the first noticeable change in the case of both patches.

**Observations**: After a while the sodium thiosulphate solution became ………………………………………. colour and

later it changed to ………………………………….. colour.

The time that was needed to see the first noticeable change:

* in the case of 0.1 mol/dm3 concentration Na2S2O3 solution ………….. second,
* in the case of 1.0 mol/dm3 concentration Na2S2O3 solution ………….. second.

To see the first noticeable change less time was needed in the case of ……… mol/dm3 concentration sodium

thiosulphate solution and more time was needed in the case of ……… mol/dm3 concentration sodium thiosulphate solution.

**Explanations:** A reaction has taken place between the sodium thiosulphate solution and the hydrochloric acid solution, according to the following equation that **has to be completed**:

…. Na2S2O3 + …. HCl → …. NaCl + …. SO2 + …. S + …. H2O

The colour was caused by the …………………….…………..

**Conclusion:** The **lower/higher** was the **concentration** of the sodium thiosulphate solution, **the faster the change took place**.

**Experiment 3:** Put 2 drops of the following colourless solutions on the dark surface of the tile. Make sure that the solutions are placed on the other (not yet used) half of the tile, but far apart from one another.

* 0.1 mol/dm3 concentration hydrochloric acid solution;
* 1.0 mol/dm3 concentration hydrochloric acid solution.

Then add to both patch of liquids 2 drops of 1.0 mol/dm3 concentration sodium thiosulphate solution and measure how much time is needed to see the first noticeable change in the case of both patches.

**Observations**: The time that was needed to see the first noticeable change:

* in the case of 0.1 mol/dm3 concentration hydrochloric acid solution ………….. second,
* in the case of 1.0 mol/dm3 concentration hydrochloric acid solution ………….. second.

To see the first noticeable change less time was needed in the case of ……… mol/dm3 concentration

hydrochloric acid solution and more time was needed in the case of ……… mol/dm3 concentration hydrochloric acid solution.

**Conclusion:** The **lower/higher** was the **concentration** of the hydrochloric acid solution, **the faster the change took place**.

The **lower/higher** **is the concentration of the starting materials**, **the higher is the rate of reaction**, because the **less/more frequently** the particles collide.

**Experiment 4:** Put 2 drops of the hydrochloric acid solutions with unknown concentration on the dark surface of the tile that has not been used yet and add 2 drops of 1.0 mol/dm3 concentration sodium thiosulphate solution to it. Measure how much time is needed to see the first noticeable change. Knowing the time that was needed, decide what the concentration of the hydrochloric acid solutions could be. You can choose among the following concentrations:

* 0.01 mol/dm3 concentration hydrochloric acid solution;
* 0.05 mol/dm3 concentration hydrochloric acid solution;
* 2.0 mol/dm3 concentration hydrochloric acid solution.

Then add to both patch of liquids 2 drops of 1.0 mol/dm3 concentration sodium thiosulphate solution and measure how much time is needed to see the first noticeable change in the case of both patches.

**Observations**: To see the first noticeable change ………………… seconds were needed.

**Conclusion:** Considering the times measured in the Experiment 3, the concentration of the unknown solution is

probably ………….. mol/dm3, because …………………………………………………………………………………………………………………

**Experiment 5:** Put 2 drops of the 0.1 mol/dm3 concentration sodium thiosulphate solution in the corner of the tile you have on your tray, that has got dark surface and the word “WARM” is written on it. Then warm the tile from below with an alcohol burner. After cca. 15 seconds add 2 drops of 1.0 mol/dm3 concentration hydrochloric acid solution to the warmed up solution and measure how much time is needed to see the first noticeable change.

**Observations**: To see the first noticeable change ………………… seconds were needed.

**Explanations:** At a higher temperature the particles move **more slowly/faster**, therefore they collide **more rarely/more often** and **less/more** particles have got the activation energy needed for the reaction too. At higher temperature the rate of reaction is **lower/higher**.

**Conclusion:** The reactions can be **slowed down/accelerated** by heating.

So, the **rate of reaction depends** on thefollowing 3 factors: 1. …………………………………………………………………………

2. ………………………………………………………………………………… 3. ……………………………………………………………..………………….

**Homework:**

1. What can be the reason that the teams did not measure the same time in the same experiments?

……………………………………………………………………………………………………………………………………………………………………………

2. How could you slow down a reaction?

……………………………………………………………………………………………………………………………………………………………………………

3. You can often read the „*clock reaction*” expression on websites dealing with the reaction rate. Why do you think those processes were given this unusual name?

………………………………………………………………………………………………………………………………………………………………………......

**16. Student sheet: Speedometer at the chemistry lesson**

(type 2: ‘step-by-step’ version + explanation of experiment-design for Group 2 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), but after the Experiment 5 and before the homework the worksheet also contains the text below that the students have to read and discuss with their teacher.*

While designing the experiments, we applied the “**how to vary one thing at a time**” principle:

* during Experiment 2 only the concentration of the sodium thiosulphate solutions was changed;
* during Experiment 3 only the concentration of the hydrogen chloride solutions was changed;
* during Experiment 5 the only different variable was the temperature.

During Experiment 3 you learnt that the reaction rate increases with the concentration of the hydrogen chloride solutions. Based on this knowledge, you compared the reaction rate experienced during the Experiment 4 to the results of Experiment 3 and then you could work out the constitution of the unknown solution. Using suitable instruments and solutions with exact concentration you can even get a very precise result considering the reaction rate.

**16. Student sheet: Speedometer at the chemistry lesson**

(type 3: experiment-designing version for Group 3 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), except the Experiment 4 and Experiment 5 that goes as follows.*

**Experiment 4:** Now determine the concentration of the hydrochloric acid solution that you find in the beaker labelled as “UNKNOWN”. You can choose among the following concentrations:

* 0.01 mol/dm3 concentration hydrochloric acid solution;
* 0.05 mol/dm3 concentration hydrochloric acid solution;
* 2.0 mol/dm3 concentration hydrochloric acid solution.

Think of the “**how to vary one thing at a time**” principle that was applied during the previous experiments, everything else (equipment, materials, procedure) were the same. The changing things (variables) were the followings:

* during Experiment 2 the concentration of the sodium thiosulphate solutions;
* during Experiment 3 the concentration of the hydrogen chloride solutions.

To the data of which experiment should the time to be measured in the case of the hydrochloric acid solution with unknown concentration should be compared?

To the data measured during Experiment …….

How do you think the time to be measured in the case of the hydrochloric acid solution with unknown concentration would be related to the times measured earlier in the cases of hydrochloric acid solutions with different concentrations? Design the experiment. (Use the tile that you have used earlier.)

**Plan of the experiment**:………………………………………………………….…………………………….…………………..……………………..

…………………………………………………………………………………………………………………………………………………………………………….

**Observations**:……………………………………………………………………………………….……………………………………………………………..

**Conclusion:** unknown solution is ………….. mol/dm3, because ………………………………………………………………………………

…………………………………………………………………………………………………………………………………………………………………………….

**Experiment 5:** Put 2 drops of the 0.1 mol/dm3 concentration sodium thiosulphate solution in the corner of the tile you have on your tray, that has got dark surface and the word “WARM” is written on it. Then warm the tile from below with an alcohol burner. After cca. 15 seconds add 2 drops of 1.0 mol/dm3 concentration hydrochloric acid solution to the warmed up solution and measure how much time is needed to see the first noticeable change.

**Observations**: To see the first noticeable change ………………… seconds were needed.

**Explanations:** At a higher temperature the particles move **more slowly/faster**, therefore they collide **more rarely/more often** and **less/more** particles have got the activation energy needed for the reaction too. At higher temperature the rate of reaction is **lower/higher**.

What was the thing (variable) that changed during this experiment? ………………………………………………………………….

**16. Student sheet: Speedometer at the chemistry lesson**

(teacher notes)

A speedometer measures the speed of the vehicles on the road, so that nobody endanger the life of the other people by driving too fast. In the aspect of the chemical reactions, you also want to avoid any danger, e.g. the explosion of a chemical factory or plant. Sometimes it is better, if a process goes faster (e.g. at the time of cooking), but at other times you want to slow it down (e.g. to avoid the going off of any food). The speed of the vehicles (the distance that they take in a certain time unit) can easily be regulated by using the accelerator or the brake pedals. But **how could the rate of reaction be regulated**, so that **a given amount of starting material would react in a time unit**? To be able to do that, you have to learn about the **factors** that can be used to accelerate or slow down the chemical reactions.

While completing the worksheet, **underline or frame the correct or cross the not correct parts of the text.**

**Experiment 1 (teacher demonstration):** First concentrated hydrogen peroxide is poured into the tall vessel that is put on a tray. Then washing up liquid is added to it and the content is mixed. A little food colouring is made to flow down on the inner wall of the vessel and then suddenly concentrated potassium iodide solution is poured in it. The product is examined by a burning splint.

**Observations: *Suddenly a huge amount of foam forms. Pushing a burning splint into foam formed from the aqueous solution it does not go out, but it burns.***

**Explanations:** The hydrogen peroxide decomposed according to the following reaction equation (to be

completed): **2** H2O2 → **2** H2O + O2

What did blow up the foam? ***The gas produced blew up the foam.***

What product of the reaction was detected by the burning splint? ***The oxygen gas.***

The hydrogen peroxide also decomposes when it is left alone in its container, but the potassium iodide hugely

accelerated, i.e. **catalysed** that process. In what context had you heard the word “**catalyst**”? ***E.g. the catalyst of vehicles.***

What does it accelerate there? ***Possible answers:***

* ***The catalyst accelerates the transformation of nitrogen oxides, the not yet burnt hydrocarbons and the carbon monoxide to substances that are less dangerous to the environment.***
* ***The further transformation of the products.***
* ***Further reactions.***

**Experiment 2:** Put 2 drops of the following colourless solutions on the dark surface of the tile that you find on your tray. Make sure that the solutions are placed only on one half of the tile, but far apart from one another.

* 0.1 mol/dm3 concentration sodium thiosulphate solution (Na2S2O3 solution);
* 1.0 mol/dm3 concentration sodium thiosulphate solution.

Then add to both patch of liquids 2 drops of 1.0 mol/dm3 concentration hydrochloric acid solution and measure (e.g. by using the stop watch application of your mobile phone) how much time (how many seconds) is needed to see the first noticeable change in the case of both patches.

**Observations**: After a while the sodium thiosulphate solution became ***white (opaque)*** colour and later it changed to ***yellow*** colour.

The time that was needed to see the first noticeable change:

* in the case of 0.1 mol/dm3 concentration Na2S2O3 solution ***e.g. 78*** second,
* in the case of 1.0 mol/dm3 concentration Na2S2O3 solution ***e.g. 17*** second.

To see the first noticeable change less time was needed in the case of ***1.0*** mol/dm3 concentration sodium

thiosulphate solution and more time was needed in the case of ***0.1*** mol/dm3 concentration sodium thiosulphate solution.

**Explanations:** A reaction has taken place between the sodium thiosulphate solution and the hydrochloric acid solution, according to the following equation that **has to be completed**:

Na2S2O3 + **2** HCl → **2** NaCl + SO2 + S + H2O

The colour was caused by the ***sulphur***.

**Conclusion:** The **lower/higher** was the **concentration** of the sodium thiosulphate solution, **the faster the change took place**.

**Experiment 3:** Put 2 drops of the following colourless solutions on the dark surface of the tile. Make sure that the solutions are placed on the other (not yet used) half of the tile, but far apart from one another.

* 0.1 mol/dm3 concentration hydrochloric acid solution;
* 1.0 mol/dm3 concentration hydrochloric acid solution.

Then add to both patch of liquids 2 drops of 1.0 mol/dm3 concentration sodium thiosulphate solution and measure how much time is needed to see the first noticeable change in the case of both patches.

**Observations**: The time that was needed to see the first noticeable change:

* in the case of 0.1 mol/dm3 concentration hydrochloric acid solution ***e.g. 25*** second,
* in the case of 1.0 mol/dm3 concentration hydrochloric acid solution ***e.g. 12*** second.

To see the first noticeable change less time was needed in the case of ***1.0*** mol/dm3 concentration

hydrochloric acid solution and more time was needed in the case of ***0.1*** mol/dm3 concentration hydrochloric acid solution.

**Conclusion:** The **lower/higher** was the **concentration** of the hydrochloric acid solution, **the faster the change took place**.

The **lower/higher is the concentration of the starting materials**, **the higher is the rate of reaction**, because the **less/more frequently** the particles collide.

[Only for type 1 and type 2 student sheets.]

**Experiment 4:** Put 2 drops of the hydrochloric acid solutions with unknown concentration on the dark surface of the tile that has not been used yet and add 2 drops of 1.0 mol/dm3 concentration sodium thiosulphate solution to it. Measure how much time is needed to see the first noticeable change. Knowing the time that was needed, decide what the concentration of the hydrochloric acid solutions could be. You can choose among the following concentrations:

* 0.01 mol/dm3 concentration hydrochloric acid solution;
* 0.05 mol/dm3 concentration hydrochloric acid solution;
* 2.0 mol/dm3 concentration hydrochloric acid solution.

Then add to both patch of liquids 2 drops of 1.0 mol/dm3 concentration sodium thiosulphate solution and measure how much time is needed to see the first noticeable change in the case of both patches.

**Observations**: (possible answers)

a) 0.01 mol/dm3 concentration hydrochloric acid solution: To see the first noticeable change ***e.g. 732*** seconds were needed.

b) 0.05 mol/dm3 concentration hydrochloric acid solution: To see the first noticeable change ***e.g. 21*** seconds were needed.

c) 2.0 mol/dm3 concentration hydrochloric acid solution: To see the first noticeable change ***e.g. 5*** seconds were needed.

**Conclusion:** (possible answers) Considering the times measured in the Experiment 3, the concentration of the unknown solution is probably

***a) 0.01 mol/dm3,***

***b) 0.05 mol/dm3,***

***c) 2.0 mol/dm3,***

because

a) ***more time was needed than in the case of the 0.1 mol/dm3 concentration hydrochloric acid solution and the necessary time decreases by the increase of the concentration of the hydrochloric acid solution.***

b) ***the change happened in a shorter period of time than in the case of the 0.1 mol/dm3 concentration hydrochloric acid solution, but more time was needed than in the case of the 1.0 mol/dm3 concentration hydrochloric acid solution and the necessary time decreases by the increase of the concentration of the hydrochloric acid solution.***

c) ***less time was needed than in the case of the 1.0 mol/dm3 concentration hydrochloric acid solution and the necessary time decreases by the increase of the concentration of the hydrochloric acid solution.***

[Only for type 3 student sheets.]

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), except the Experiment 4 that goes as follows.*

**Experiment 4:** Now determine the concentration of the hydrochloric acid solution that you find in the beaker labelled as “UNKNOWN”. You can choose among the following concentrations:

* 0.01 mol/dm3 concentration hydrochloric acid solution;
* 0.05 mol/dm3 concentration hydrochloric acid solution;
* 2.0 mol/dm3 concentration hydrochloric acid solution.

Think of the “**how to vary one thing at a time**” principle that was applied during the previous experiments, everything else (equipment, materials, procedure) were the same. The changing things (variables) were the followings:

* during Experiment 2 the concentration of the sodium thiosulphate solutions;
* during Experiment 3 the concentration of the hydrogen chloride solutions.

To the data of which experiment should the time to be measured in the case of the hydrochloric acid solution with unknown concentration should be compared?

To the data measured during Experiment ***3.***

How do you think the time to be measured in the case of the hydrochloric acid solution with unknown concentration would be related to the times measured earlier in the cases of hydrochloric acid solutions with different concentrations? Design the experiment. (Use the tile that you have used earlier.)

**Plan of the experiment**: ***E.g.*** ***2 drops of the hydrochloric acid solutions with unknown concentration should be put on the tile and 2 drops of 1.0 mol/dm3 concentration sodium thiosulphate solution has to be added to it. (It also could be done in reverse order.) If the time that is needed to see the first noticeable change is measured, and the results of the Experiment 3 are known, the conclusion could be drown considering the unknown concentration of the solution*.**

**Observations**: (possible answers)

a) 0.01 mol/dm3 concentration hydrochloric acid solution: To see the first noticeable change ***e.g. 732*** seconds were needed.

b) 0.05 mol/dm3 concentration hydrochloric acid solution: To see the first noticeable change ***e.g. 21*** seconds were needed.

c) 2.0 mol/dm3 concentration hydrochloric acid solution: To see the first noticeable change ***e.g. 5*** seconds were needed.

**Conclusion:** (possible answers) Considering the times measured in the Experiment 3, the concentration of the unknown solution is probably

***a) 0.01 mol/dm3,***

***b) 0.05 mol/dm3,***

***c) 2.0 mol/dm3,***

because

a) ***more time was needed than in the case of the 0.1 mol/dm3 concentration hydrochloric acid solution and the necessary time decreases by the increase of the concentration of the hydrochloric acid solution.***

b) ***the change happened in a shorter period of time than in the case of the 0.1 mol/dm3 concentration hydrochloric acid solution, but more time was needed than in the case of the 1.0 mol/dm3 concentration hydrochloric acid solution and the necessary time decreases by the increase of the concentration of the hydrochloric acid solution.***

c) ***less time was needed than in the case of the 1.0 mol/dm3 concentration hydrochloric acid solution and the necessary time decreases by the increase of the concentration of the hydrochloric acid solution.***

[For all the three type student sheets.]

**Experiment 5:** Put 2 drops of the 0.1 mol/dm3 concentration sodium thiosulphate solution in the corner of the tile you have on your tray, that has got dark surface and the word “WARM” is written on it. Then warm the tile from below with an alcohol burner. After cca. 15 seconds add 2 drops of 1.0 mol/dm3 concentration hydrochloric acid solution to the warmed up solution and measure how much time is needed to see the first noticeable change.

**Observations**: To see the first noticeable change ***e.g. 35*** seconds were needed.

**Explanations:** At a higher temperature the particles move **more slowly/faster**, therefore they collide **more rarely/more often**, and **less/more** particles have got the activation energy needed for the reaction too. At higher temperature the rate of reaction is **lower/higher**.

[Only for type 3 student sheets.]

What was the thing (variable) that changed during this experiment? **The temperature.**

[Only for type 2 student sheets.]

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), but after the Experiment 5 the worksheet also contains the text below that the students have to read and discuss with their teacher.*

While designing the experiments, we applied the “**how to vary one thing at a time**” principle:

* during Experiment 2 only the concentration of the sodium thiosulphate solutions was changed;
* during Experiment 3 only the concentration of the hydrogen chloride solutions was changed;
* during Experiment 5 the only different variable was the temperature.

During Experiment 3 you learnt that the reaction rate increases with the concentration of the hydrogen chloride solutions. Based on this knowledge, you compared the reaction rate experienced during the Experiment 4 to the results of Experiment 3 and then you could work out the constitution of the unknown solution. Using suitable instruments and solutions with exact concentration you can even get a very precise result considering the reaction rate.

[For all the three type student sheets.]

**Conclusion:** The reactions can be **slowed down/accelerated** by heating.

So, the **rate of reaction depends** on thefollowing 3 factors: 1. ***the catalyst used***; 2. ***the concentrations of the starting materials***; 3. ***the temperature*.**

**Homework:**

1. What can be the reason that the teams did not measure the same time in the same experiments?

***Possible answers:***

* ***Different teams measured the time needed to the appearance of the different shade of white/opaque colour.***
* ***If the 2 + 2 drops are not the same size, that can also cause a difference.***

2. How could you slow down a reaction?

***Possible answers:***

* ***The reaction mixture has to be cooled down.***
* ***By adding substances that adsorb the intermediates.***

3. You can often read the „*clock reaction*” expression on websites dealing with the reaction rate. Why do you think those processes were given this unusual name?

* ***In the case of these reactions the time needed for the change can be predicted very precisely (provided the concentrations are known), therefore they could be used as clocks.***

END OF THE 16. STUDENT SHEETS AND TEACHER NOTES

**17. Student sheet: From the indicators to a country flag**

(type 1: ‘step-by-step’ version for Group 1 students)

Everybody can paint pictures by using colourful paints. However, how much more exciting is to make colourful paintings by changing the colour of colourless solutions! This can be done, because the colour of the acid-base indicators change according to the pH of the added colourless solutions. For instance, red cabbage juice is a natural indicator, and you have already worked with that. Dyes that make some flowers colourful can also behave as indicators. However, many silly things can be read on the internet, e.g. on a website that is about changing the colours of the hydrangea[[5]](#footnote-5). **Find the mistakes** in the quotes below.

„*It is good to know that the pH (*pondus Hidrogenii*) in gardening characterises the acidity or alkalinity of the soil. The higher the concentration of the hydrogen ions, the more alkaline is the soil.*

What is the mistake?..................................................................................................................................................

„*The smashed eggshell also increases the acidity of the soil*.”

What is the mistake?..................................................................................................................................................

People who follow the incorrect advice certainly will not understand, what causes the different colours. So, **it is worth knowing chemistry**, **if** **we want to change our environment according to our own will**. You have already find out the colours of four, well known indicators that are needed for the following experiments. Fill in the table below according to your knowledge about them.

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of the indicator** |
| in acidic solutions | in neutral solutions | in alkaline solutions |
| phenolphthalein |  |  |  |
| methyl orange |  |  |  |
| red cabbage juice |  |  |  |
| universal indicator |  |  |  |

Fill in the tables according to your observations after doing the experiments. Give your explanations completing the sentences below them and **underline or frame the correct or cross the not correct parts of the text.**

**Experiment 1**: There are the **same volume** with the same **0.1 mol/dm3** concentration of the following solutions in 4 test tubes on your tray: hydrogen chloride, acetic acid, sodium hydroxide and ammonia. Add 3 drops of red cabbage juice to each solution. What are your observations? Fill in the table. How can be the pH of the various solutions related to one another? Arrange them in increasing order. What are the reasons that despite their same concentration there are differences?

**Observations and conclusions:**

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of indicator** |
| HCl solution | acetic acid solution | NaOH solution | NH3 solution |
| red cabbage juice |  |  |  |  |
| acidity/alkalinity |  |  |  |  |

**Conclusions:** In spite of the same concentration, the pH of the hydrogen chloride (HCl) solution **higher/lower** than the pH of the acetic acid. The sodium hydroxide (NaOH) solution has a **higher/lower** pH than the ammonia (NH3) solution of same concentration.

The order of the solutions according to the increasing pH:

1………………………. 2……………………… 3…………………….. 4……………………..

**Explanations**:

The HCl is a **stronger/weaker** acid than the acetic acid, therefore it donates **more/less** hydrogen ions in the solution at the time of dissociation, if their concentrations are the same.

The NaOH is a **stronger/weaker** base than the ammonia, therefore it donates **more/less** hydrogen ions in the solution at the time of dissociation, if their concentrations are the same.

**Experiment 2:** For the next experiment, you will find the following solutions of the **same volume and concentration** in 3 test tubes on your tray: sodium bicarbonate (NaHCO3), kitchen salt (sodium chloride, NaCl) and sal-ammoniac (ammonium chloride, NH4Cl). Add 3 drops of universal indicator to each solution. Fill in the table thinking of your observations. What are the explanations?

**Observations and conclusions:**

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of indicator** |
| NaHCO3 solution | NaCl solution | NH4Cl solution |
| universal indicator |  |  |  |
| acidity/alkalinity |  |  |  |

**Explanations**: Salts dissociate in aqueous solution, forming ions. The cation and the anion may react with water in an acid-base reaction. These reactions are called **hydrolysis**. An anion that comes from a strong acid behaves as a **strong/weak** base, **does not react with water**. On the other hand, an anion that comes from a weak acid behaves as a **strong/weak** base, does react with water and **gains hydrogen ion from it**. Meanwhile **hydroxide ion/oxonium ion** is formed of the water, and therefore the solution becomes **alkaline/acidic**. In the case of bases all of this is in the opposite way. A cation that comes from a strong base behaves as a **strong/weak** acid, therefore it does not react with water. On the other hand, a cation that comes from a weak base reacts with water as a **strong/weak** acid. As a consequence of that, the concentration of the **hydroxide ion/oxonium ion** increases, i.e. the solution becomes **alkaline/acidic**. The reactions taking place in the solutions of the following salts:

NaHCO3 solution: …………………………………………………………………………………………………………………………………………….…..

NaCl solution: ………………………………………………………………………………………………………………………………………………………

NH4Cl solution: …………………………………………………………………………………………………………………………………………………….

**Experiment 3**: There are the same volume of the following solutions in three test tubes in unknown order: KOH solution, Na2CO3 solution and HNO3 solution. All of them have got 0.1 mol/dm3 concentration. Determine what is in each test tube. Add 3 drops of one of the indicators that you have already used. Fill in the table with your observations and draw a conclusion.

**Observations and conclusions:**

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of indicator** |
| Test tube 1 | Test tube 2 | Test tube 3 |
| universal indicator |  |  |  |
| acidity/alkalinity |  |  |  |

**Answers:**

Test tube 1 contains: …………………………………………….,…………………………………………………………………………………………….

Test tube 2 contains: …………………………………………….,…………………………………………………………………………………………….

Test tube 3 contains: …………………………………………….,…………………………………………………………………………………………….

In the order of increasing pH: ……………………………………………………………………………………………………………………………….

**Explanations**:

The KOH solution was in the number ….. test tube, because it is **strongly/weakly acidic/alkaline**.

The Na2CO3 solution was in the number ….. test tube, because it is **strongly/weakly acidic/alkaline**.

The HNO3 solution was in the number ….. test tube, because it is **strongly/weakly acidic/alkaline**.

**Experiment 4:** Now comes the art! With the help of the solutions and indicators that you have already used, draw and colour a Hungarian flag on the white tile that you find on your tray. You will need red, white and green colours for that. The table below helps you to mix the right colours. The white can be simply left empty.

|  |  |  |  |
| --- | --- | --- | --- |
| the colour of the flag | red | white | green |
| solution | hydrochloric acid | acetic acid | Na2CO3 solution |
| indicator | methyl orange | phenolphthalein | red cabbage juice |

If you managed to paint a Hungarian flag, take a photograph of it!

**17. Student sheet: From the indicators to a country flag**

(type 2: ‘step-by-step’ version + explanation of experiment-design for Group 2 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), but after Experiment 4 the worksheet also contains the text below that the students have to read and discuss with their teacher.*

Testing the acidity or alkalinity of the solutions by acid-base indicators is a type of the **qualitative analysis**. First you must get know which colour the given indicators show in acidic, neutral and alkaline solutions. When you worked out what colours had to be written in the first table, you modelled the data collection from the literature. This **literature search** is an important step of the planning of the scientific investigations. After that it can easily be determined whether a solution is acidic, neutral or alkaline, since **an indicator always shows the same colour at a given pH**. During the experiments you applied the “**how to vary one thing at a time**” principle again. The changing thing (variable) could be the **indicator** or the **solute**. The **concentration and the volume of the solutions** and the **amount of the indicators** added were the same in each case. This was important, because otherwise you could not be easily differentiate between the pink colour of the red cabbage juice in the mildly acidic solution and its red colour in the highly acidic solution.

**17. Student sheet: From the indicators to a country flag**

(type 3: experiment-designing version for Group 3 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), except the following parts (the table that has to be filled in based on the homework, the Experiment 3 and Experiment 4) that goes as follows.*

Testing the acidity or alkalinity of the solutions by acid-base indicators is a type of the **qualitative analysis**. First you must get know which colour the given indicators show in acidic, neutral and alkaline solutions. After that it can easily be determined whether a solution is acidic, neutral or alkaline, since **an indicator always shows the same colour at a given pH**. For the following experiments you have already worked out the colours of four, well known indicators. By doing this, you have modelled the **literature search** that is an important step of the planning of the scientific investigations. Fill in the table below according to your findings.

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of the indicator** |
| in acidic solutions | in neutral solutions | in alkaline solutions |
| phenolphthalein |  |  |  |
| methyl orange |  |  |  |
| red cabbage juice |  |  |  |
| universal indicator |  |  |  |

During the experiments you will apply the “**how to vary one thing at a time**” principle again. The changing thing (variable) could be the **indicator** or the **solute**. The **concentration and the volume of the solutions** and the **amount of the indicators** added have to be the same in each case. This is important, when the indicator shows the acidity or alkalinity only with different **shades of a certain colour** (e.g. pink and red). Fill in the tables according to your observations after doing the experiments. Give your explanations completing the sentences below them and **underline or frame the correct or cross the not correct parts of the text.**

**Experiment 3:** There are the same volume of the following solutions in three test tubes in unknown order: KOH solution, Na2CO3 solution and HNO3 solution. All of them have got 0.1 mol/dm3 concentration. Design an experiment to identify the content of each test tube. Put the solutions in the order of their increasing pH values.

**Plan of the experiment**:………………………………………………………….…………………………….…………………..……………………..

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**Observations**:……………………………………………………………………………………….……………………………………………………………..

…………………………………………………………………………………………………………………………………………………………………………….

…………………………………………………………………………………………………………………………………………………………………………….

**Answers:**

Test tube 1 contains: ……………………………………………..…………………………………………………………………………………………….

Test tube 2 contains: ……………………………………………..…………………………………………………………………………………………….

Test tube 3 contains: ……………………………………………..…………………………………………………………………………………………….

In the order of increasing pH: ……………………………………………………………………………………………………………………………….

**Explanations**: …………………………………………..………………………………………………………………………………………………………….

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**Experiment 4:** Now comes the art! Design an experiment, how you could make a Hungarian flag on the white tile that you find on your tray, with the help of the solutions and indicators that you have already used. Then do the planned experiment.

**Plan of the experiment**:………………………………………………………….…………………………….…………………..……………………..

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If you managed to paint a Hungarian flag, take a photograph of it!

**17. Student sheet: From the indicators to a country flag**

(teacher notes)

Everybody can paint pictures by using colourful paints. However, how much more exciting is to make colourful paintings by changing the colour of colourless solutions! This can be done, because the colour of the acid-base indicators change according to the pH of the added colourless solutions. For instance, red cabbage juice is a natural indicator, and you have already worked with that. Dyes that make some flowers colourful can also behave as indicators. However, many silly things can be read on the internet, e.g. on a website that is about changing the colours of the hydrangea[[6]](#footnote-6). **Find the mistakes** in the quotes below.

„*It is good to know that the pH (*pondus Hidrogenii*) in gardening characterises the acidity or alkalinity of the soil. The higher the concentration of the hydrogen ions, the more alkaline is the soil.*

What is the mistake? ***The higher concentration of hydrogen ions means more acidic soil, rather than more alkaline one.***

„*The smashed eggshell also increases the acidity of the soil*.”

What is the mistake? ***The calcium carbonate content of the eggshell does not dissolve in water, so it does not influence its acidity. What is more, if it reacts with the acids in the soil, then it decreases the acidity of the soil.***

[Only for type 1 and 2 student sheets.]

People who follow the incorrect advice certainly will not understand, what causes the different colours. So, **it is worth knowing chemistry**, **if** **we want to change our environment according to our own will**. You have already find out the colours of four, well known indicators that are needed for the following experiments. Fill in the table below according to your knowledge about them.

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of the indicator** |
| in acidic solutions | in neutral solutions | in alkaline solutions |
| phenolphthalein | ***colourless*** | ***colourless*** | ***purple*** |
| methyl orange | ***red*** | ***yellow*** | ***yellow*** |
| red cabbage juice | ***red/pink*** | ***lilac*** | ***green/yellow*** |
| universal indicator | ***red/yellow*** | ***green*** | ***blue*** |

Fill in the tables according to your observations after doing the experiments. Give your explanations completing the sentences below them and **underline or frame the correct or cross the not correct parts of the text.**

[Only for type 3 student sheets.]

Testing the acidity or alkalinity of the solutions by acid-base indicators is a type of the **qualitative analysis**. First you must get know which colour the given indicators show in acidic, neutral and alkaline solutions. After that it can easily be determined whether a solution is acidic, neutral or alkaline, since **an indicator always shows the same colour at a given pH**. For the following experiments you have already worked out the colours of four, well known indicators. By doing this, you have modelled the **literature search** that is an important step of the planning of the scientific investigations. Fill in the table below according to your findings.

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of the indicator** |
| in acidic solutions | in neutral solutions | in alkaline solutions |
| phenolphthalein | ***colourless*** | ***colourless*** | ***purple*** |
| methyl orange | ***red*** | ***yellow*** | ***yellow*** |
| red cabbage juice | ***red/pink*** | ***lilac*** | ***green/yellow*** |
| universal indicator | ***red/yellow*** | ***green*** | ***blue*** |

During the experiments you will apply the “**how to vary one thing at a time**” principle again. The changing thing (variable) could be the **indicator** or the **solute**. The **concentration and the volume of the solutions** and the **amount of the indicators** added have to be the same in each case. This is important, when the indicator shows the acidity or alkalinity only with different **shades of a certain colour** (e.g. pink and red). Fill in the tables according to your observations after doing the experiments. Give your explanations completing the sentences below them and **underline or frame the correct or cross the not correct parts of the text.**

[For all the three type student sheets.]

**Experiment** **1**: There are the **same volume** with the same **0.1 mol/dm3** concentration of the following solutions in 4 test tubes on your tray: hydrogen chloride, acetic acid, sodium hydroxide and ammonia. Add 3 drops of red cabbage juice to each solution. What are your observations? Fill in the table. How can be the pH of the various solutions related to one another? Arrange them in increasing order. What are the reasons that despite their same concentration there are differences?

**Observations and conclusions:**

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of indicator** |
| HCl solution | acetic acid solution | NaOH solution | NH3 solution |
| red cabbage juice | ***red*** | ***pink*** | ***yellow*** | ***green*** |
| acidity/alkalinity | ***highly acidic*** | ***mildly acidic*** | ***highly alkaline*** | ***mildly alkaline*** |

**Conclusions:** In spite of the same concentration, the pH of the hydrogen chloride (HCl) solution **higher/lower** than the pH of the acetic acid. The sodium hydroxide (NaOH) solution has a **higher/lower** pH than the ammonia (NH3) solution of same concentration.

The order of the solutions according to the increasing pH:

1. ***HCl solution*** 2. ***acetic acid solution*** 3. ***NH3 solution*** 4. ***NaOH solution***

**Explanations**:

The HCl is a **stronger/weaker** acid than the acetic acid, therefore it donates **more/less** hydrogen ions in the solution at the time of dissociation, if their concentrations are the same.

The NaOH is a **stronger/weaker** base than the ammonia, therefore it donates **more/less** hydrogen ions in the solution at the time of dissociation, if their concentrations are the same.

**Experiment 2:** For the next experiment, you will find the following solutions of the **same volume and concentration** in 3 test tubes on your tray: sodium bicarbonate (NaHCO3), kitchen salt (sodium chloride, NaCl) and sal-ammoniac (ammonium chloride, NH4Cl). Add 3 drops of universal indicator to each solution. Fill in the table thinking of your observations. What are the explanations?

**Observations and conclusions:**

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of indicator** |
| NaHCO3 solution | NaCl solution | NH4Cl solution |
| universal indicator | ***blue*** | ***green*** | ***yellow*** |
| acidity/alkalinity | ***alkaline (basic)*** | ***neutral*** | ***acidic*** |

**Explanations**: Salts dissociate in aqueous solution, forming ions. The cation and the anion may react with water in an acid-base reaction. These reactions are called **hydrolysis**. An anion that comes from a strong acid behaves as a **strong/weak** base, **does not react with water**. On the other hand, an anion that comes from a weak acid behaves as a **strong/weak** base, does react with water and **gains hydrogen ion from it**. Meanwhile **hydroxide ion/oxonium ion** is formed of the water, and therefore the solution becomes **alkaline/acidic**. In the case of bases all of this is in the opposite way. A cation that comes from a strong base behaves as a **strong/weak** acid, therefore it does not react with water. On the other hand, a cation that comes from a weak base reacts with water as a **strong/weak** acid. As a consequence of that, the concentration of the **hydroxide ion/oxonium ion** increases, i.e. the solution becomes **alkaline/acidic**. The reactions taking place in the solutions of the following salts:

NaHCO3 solution: ***HCO3- + H2O ⇌ H2CO3 + OH-***

NaCl solution: ***No reaction with water.***

NH4Cl solution: ***NH4+ + H2O ⇌ NH3 + H3O+***

[Only for type 1 and type 2 student sheets.]

**Experiment 3**: There are the same volume of the following solutions in three test tubes in unknown order: KOH solution, Na2CO3 solution and HNO3 solution. All of them have got 0.1 mol/dm3 concentration. Determine what is in each test tube. Add 3 drops of one of the indicators that you have already used. Fill in the table with your observations and draw a conclusion.

**Observations and conclusions:**

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of indicator** |
| Test tube 1 | Test tube 2 | Test tube 3 |
| ***e.g. red cabbage juice*** | ***yellow*** | ***red*** | ***green*** |
| acidity/alkalinity | ***highly alkaline*** | ***acidic*** | ***mildly alkaline*** |

**Answers:**

Test tube 1 contains: ***KOH solution***

Test tube 2 contains: ***HNO3 solution***

Test tube 3 contains: ***Na2CO3 solution***

In the order of increasing pH: ***HNO3 solution, Na2CO3 solution, KOH solution***

**Explanations**:

The KOH solution was in the number ***1***. test tube, because it is **strongly/weakly** **acidic/ alkaline**.

The Na2CO3 solution was in the number ***3***. test tube, because it is **strongly/weakly acidic/ alkaline**.

The HNO3 solution was in the number ***2***. test tube, because it is **strongly/weakly** **acidic/alkaline**.

**Experiment 4:** Now comes the art! With the help of the solutions and indicators that you have already used, draw and colour a Hungarian flag on the white tile that you find on your tray. You will need red, white and green colours for that. The table below helps you to mix the right colours. The white can simply be left empty.

|  |  |  |  |
| --- | --- | --- | --- |
| the colour of the flag | red | white | green |
| solution | hydrochloric acid | acetic acid | Na2CO3 solution |
| indicator | methyl orange | phenolphthalein | red cabbage juice |

If you managed to paint a Hungarian flag, take a photograph of it!

[Only for type 2 student sheets.]

Testing the acidity or alkalinity of the solutions by acid-base indicators is a type of the **qualitative analysis**. First you must get know which colour the given indicators show in acidic, neutral and alkaline solutions. When you worked out what colours had to be written in the first table, you modelled the data collection from the literature. This **literature search** is an important step of the planning of the scientific investigations. After that it can easily be determined whether a solution is acidic, neutral or alkaline, since **an indicator always shows the same colour at a given pH**. During the experiments you applied the “**how to vary one thing at a time**” principle again. The changing thing (variable) could be the **indicator** or the **solute**. The **concentration and the volume of the solutions** and the **amount of the indicators** added were the same in each case. This was important, because otherwise you could not be easily differentiate between the pink colour of the red cabbage juice in the mildly acidic solution and its red colour in the highly acidic solution.

[Only for type 3 student sheets.]

**Experiment 3:** There are the same volume of the following solutions in three test tubes in unknown order: KOH solution, Na2CO3 solution and HNO3 solution. All of them have got 0.1 mol/dm3 concentration. Design an experiment to identify the content of each test tube. Put the solutions in the order of their increasing pH values.

**Plan of the experiment**: ***E.g. red cabbage juice could be used as an indicator, because it will show different colours in the different solutions. 3 drops of indicator should be added to the content of each test tubes.***

**Observations and conclusions: *(e.g. summarised in a table)***

|  |  |
| --- | --- |
| **Name of indicator** | **Colour of indicator** |
| Test tube 1 | Test tube 2 | Test tube 3 |
| ***e.g. red cabbage juice*** | ***yellow*** | ***red*** | ***green*** |
| acidity/alkalinity | ***highly alkaline*** | ***acidic*** | ***mildly alkaline*** |

**Answers:**

Test tube 1 contains: ***KOH solution***

Test tube 2 contains: ***HNO3 solution***

Test tube 3 contains: ***Na2CO3 solution***

In the order of increasing pH: ***HNO3 solution, Na2CO3 solution, KOH solution***

**Explanations**:

***The KOH solution was in the number 1. test tube, because it is strongly alkaline.***

***The Na2CO3 solution was in the number 3. test tube, because it is weakly alkaline.***

***The HNO3 solution was in the number 2. test tube, because it is strongly acidic.***

**Experiment 4:** Now comes the art! Design an experiment, how you could make a Hungarian flag on the white tile that you find on your tray, with the help of the solutions and indicators that you have already used. Then do the planned experiment.

**Plan of the experiment**: ***Red, white and green colours are need. The table below shows what solutions and indicators have to be used to get the right colours. The white can simply be left empty.***

|  |  |  |  |
| --- | --- | --- | --- |
| ***the colour of the flag*** | ***red*** | ***white*** | ***green*** |
| ***solution*** | ***hydrochloric acid*** | ***acetic acid*** | ***Na2CO3 solution*** |
| ***indicator*** | ***methyl orange*** | ***phenolphthalein*** | ***red cabbage juice*** |

If you managed to paint a Hungarian flag, take a photograph of it!

END OF THE 17. STUDENT SHEETS AND TEACHER NOTES

**18. Student sheet: The Janus-faced hydrogen peroxide**

(type 1: ‘step-by-step’ version for Group 1 students)

In ancient Roman religion and myth, Janus is the god of beginnings and endings. He is usually depicted as having two faces. Therefore, the expression “Janus-faced” means duality.[[7]](#footnote-7) Hydrogen peroxide (H2O2) is “Janus-faced” in the sense that it can behave both as an **oxidizing** and a **reducing** agent. (In a similar way than the water can behave as either an acid or a base in acid-base reactions.) Whether a reaction takes place or not and if yes, then which substance plays which role, it all depends on the reaction partners and the conditions. Now, in the apropos of the hydrogen peroxide, you will study the **redox reactions**.

The term “**oxidizing agent**” comes from the name of oxygen. The “oxidation” often really means gaining oxygen. The oxygen atom has the highest **electronegativity (*EN*)** value among all the chemical elements that can be found in an elemental state on the Earth. If it forms an oxide with a metal, then the oxygen attracts the electrons of the metal atoms closer to itself. It is said that the metal “gives up electrons” while it is oxidized. This **giving up electrons, i.e. oxidation** can also happen when oxygen does not even participate in the reaction. For instance, chlorine is also a strong oxidizing agent, because its atoms have got a high *EN* value, therefore it usually makes its reaction partners give up electrons (i.e. oxidation).

While completing the worksheet, **underline or frame the correct or cross the not correct parts of the text.**

How do you think it could be determined whether the **hydrogen peroxide played the role of oxidizing or reducing agent in a reaction**? Let us have a look at the following reactions. (The meaning of → is: „it follows”.)

A) H2O2 + H2SO3 = H2O + H2SO4 Sulphur forms 2 more bonds with oxygen atom. Oxygen has a higher *EN* than sulphur, so it attracts 2 electrons of the sulphur closer to itself → sulphur gives up 2 electrons, it is oxidized → the H2O2 is **an oxidizing agent**.

B) 4 H2O2 + PbS = 4 H2O + PbSO4 Sulphur has got higher *EN* than the lead, but lower than the oxygen → 8 electrons get further away from the sulphur at the time of the reaction → giving up electrons, oxidation → the H2O2 isa(n)……………………………**agent**.

C) H2O2 + Mn2+ = Mn4+ + 2 OH- The positive charge of the manganese ion increases by two, therefore the

manganese ……………………………………. …………….. negatively charged electrons → it is **oxidized** → the H2O2 is **an oxidizing agent**.

D) H2O2 + 2 Fe3+ + 2 OH- = **O2** + 2 Fe2+ + 2 H2O The positive charge of the iron (III) ion is reduced by 1

………………………………………… charged electron (i.e. by a reduction), therefore the iron (III) ion is reduced → the H2O2 is **a reducing agent**.

E) H2O2 + Cl2 +2 OH- = **O2** + 2 Cl- + 2 H2O Negatively charged chloride ions form of the neutral elemental chlorine molecule by gaining two electrons (i.e. by reduction) → the H2O2 isa(n) …………………………. **agent** and

the elemental chlorine isa(n) …………………..………. **agent**.

F) H2O2 + 2 HCl = Cl2 + 2 H2O The chlorine attracts the electron of the hydrogen closer to itself in the hydrogen chloride, but giving up the hydrogen, this electron is “lost” by the chlorine → giving up electrons, oxidation → the H2O2 isa(n)……………………………**agent**.

You may notice that whenever the **hydrogen peroxide is a reducing agent**, the **elemental oxygen** appears among the products.

How can you detect the production of the oxygen gas? .............................................................................................

Let us investigate, whether it is true that if we detect the production of **O2 gas, then the H2O2 is a reducing agent indeed in the reaction.**

**Experiment 1:** Pour starch solution into one of the test tubes to about 1-2 cm height. Add potassium iodide solution (KI solution) to it to about 1-2 cm height. Light the splint and let it burn for about half a minute. Meanwhile add hydrogen peroxide solution (H2O2 solution) to about 1-2 cm height to the potassium iodide solution that already contains starch. Blow out the burning splint and while it is still glowing hold it into the test tube in a way that it does not touch the liquid. Observe each change and write down your observations.

**Observations:**………………………………………………….………………………………………………………………………………………..…………

…………………………………………………………………………………………………………………………………………………………………………….

**Explanations:** The glowing splint **was relit/went out**, which shows that oxygen gas **formed/did not form** in the

reaction. → Assuming H2O2  is a(n) ………………………….**agent**, the iodide ions were **oxidized/reduced** → the

iodide ions **gave up/gained** electrons→ the neutral …………………………………………… formed of the negative

iodide ions → and that was detected by the starch …………………………………………………. colour indeed.

The reaction equation to be completed: H2O2 + …… KI = …… KOH + ……

**Experiment 2:** Pour sulphuric acid solution (H2SO4 solution) into the other test tube to about 1-2 cm height. Add potassium permanganate solution (KMnO4 solution) to it to about 1-2 cm height. Light the splint and let it burn for about half a minute. Meanwhile add hydrogen peroxide solution (H2O2 solution) to about 1-2 cm height to the potassium permanganate solution that already contains sulphuric acid. Blow out the burning splint and while it is still glowing hold it into the test tube in a way that it does not touch the liquid. Observe each change and write down your observations.

**Observations:**………………………………………………….………………………………………………………………………………………..…………

…………………………………………………………………………………………………………………………………………………………………………….

**Explanations:** The glowing splint **was relit/went out** which shows that oxygen gas **formed/did not form** in the

reaction. → Assuming H2O2  is a(n) ………………………….**agent**, the permanganate ions (MnO4-) were **oxidized/reduced** → the permanganate ions **gave up/gained** electrons → manganese (II) ions (Mn2+) formed of the MnO4- by giving up oxygens (by reduction) → and that was shown by the disappearance of the

……………………………. colour of the KMnO4.

The oxygen atoms that were given up by the permanganate ions formed water with the hydrogen atoms. The sulphate ions and the potassium ions did not change (those are “counter ions” that balance the charges of the other ions). There are 2 potassium on the right hand side of the equation, so there must be the same number on the left hand side. Starting with that, balance the equation:

5 H2O2 + …… KMnO4 + …… H2SO4= ………… + …… MnSO4 + …… K2SO4 + …… H2O

In general: When H2O2 **reduces**, then it is oxidized → **gives up/gains** **electron**. This can only happen, if the oxygen of the H2O2 passes an electron to the hydrogen that has got a **lower/higher** electronegativity than itself and forms **elemental oxygen**. Why cannot the elemental oxygen give up electrons?

…………………………………………………………………………………………………………………………………………………………………………….Notice that as many electrons get further away from a given atom in the redox reaction, **the same number of electrons** get closer to the other atoms, because **they are the same electrons**! Based on this fact, even the **equations** of the most complicated redox reactions **can be balanced**.

**Homework:**

1.During the so called “elephant toothpaste” experiment[[8]](#footnote-8), potassium iodide (KI) catalyses the decomposition of hydrogen peroxide to water and oxygen gas. How do you know that during the experiment that you made with KI and H2O2 this was not the (only) reaction that took place?

……………………………………………………………………………………………………………………………………………………………………………

2. Which agents are the hydrogen peroxide and the potassium periodate (KIO4) in the reaction below?

Which atom of which compound gives up/gains electrons and how many of them?

H2O2 +KIO4 = O2 + KIO3 + H2O

…………………………………………………………………………………………………………………………………………………………………………….

**18. Student sheet: The Janus-faced hydrogen peroxide**

(type 2: ‘step-by-step’ version + explanation of experiment-design for Group 2 students)

*It is the same as the type 1 student sheet (‘step-by-step’ version for Group 1 students), but after the Experiment 2 and before the homework the worksheet also contains the text below that the students have to read and discuss with their teacher.*

You got to the **general rule** concerning the role of the hydrogen peroxide **by the application of the following steps of the scientific investigations**:

Step 1: **Observations, systemization, composing the problem**: You had known from other people experiments that the oxidation is either gaining oxygen and/or giving up electron(s) and that the hydrogen peroxide could be an oxidizing agent and a reducing agent too. The problem-solving task was to answer the following question: How can it be decided, which role the H2O2 plays in the different reactions?

2. **Collecting information, making a model, forming a hypothesis:** After the examination of several reaction equations, it seemed that whenever the H2O2 is a reducing agent, then elemental oxygen forms. We assumed that this might be a general rule.

3. **Planning an experiment:** Making the hydrogen peroxide react with different substances, you tested by a glowing splint whether oxygen gas was produced or not.

4. **Doing the experiment and writing down the observations:** You made notes of each observation after doing the experiment.

5. **Explanations, drawing a conclusion, argumentation**: The results of the experiments showed that when oxygen was produced, the hydrogen peroxide really reduced its partner (the permanganate ions to Mn2+ ions that could be noticed, because the lilac solution became colourless). When oxygen was not produced, then the H2O2 has oxidized its partner (the iodide ions to elemental iodine that was detected by the dark blue colour of the starch). Thinking of the movements of the electrons you reasoned why is it that oxygen is only produced when the H2O2 is a reducing agent. Therefore, you could state that it is a **general rule**.

**18. Student sheet: The Janus-faced hydrogen peroxide**

(type 3: experiment-designing version for Group 3 students)

*It is the same as on the type 1 student sheet (‘step-by-step’ version for Group 1 students) until the end of the equation F), but after that it goes as follows until the Homework starts.*

Now you will work out the **general rule** concerning the role of the hydrogen peroxide **by the application of the following steps of the scientific investigations**:

Step 1: **Observations, systemization, composing the problem**: You know from other people experiments that the oxidation is either gaining oxygen and/or giving up electron(s) and that the hydrogen peroxide could be an oxidizing agent and a reducing agent too. The problem-solving task is to answer the following question: How can it be decided, which role the H2O2 plays in the different reactions?

2. **Collecting information, making a model, forming a hypothesis:** After the examination of several reaction equations, it is noticeable that there is a product that only forms when H2O2 is a reducing agent. What is this

product? ………….…………..…… Assumption: It might be a general rule that when ……………………………….. is produced, then H2O2 is a reducing agent.

3. **Planning an experiment:** Making the hydrogen peroxide react with different substances, you can see whether the product named in the previous paragraph formed or not. How can you test if that was produced?

...................................................................................................................................................................................

4. **Doing the experiment and writing down the observations:** You have to make notes of each observation after doing the experiment.

5. **Explanations, drawing a conclusion, argumentation**: You have to examine if the results of the experiments do not contradict your assumption and whether they seem to justify it. Then you can try to compose a logical theoretical explanation. If you manage, you could state the **general rule**.

**Experiment 1:** You have to make the hydrogen peroxide react withpotassium iodide solution containing starch. (The added amount of each solution should raise the level of liquid by about 1-2 cm in the test tube.)

**Plan of the experiment**: ………………………………………………………….…………………………….…………………..……………………..

…………………………………………………………………………………………………………………………………………………………………………….

**Observations**: ……………………………………………………………………………………….…………………………………………………………….

…………………………………………………………………………………………………………………………………………………………………………….

**Explanations:** The glowing splint **was relit/went out** which shows that oxygen gas **formed/did not form** in the reaction. → Assuming H2O2  is a(n) ………………………….**agent**, the iodide ions were **oxidized/reduced** → the

iodide ions **gave up/gained** electrons→ the neutral ………………………………………….………… formed of the negative

iodide ions → and that was detected by the starch …………………………………………………. colour indeed.

The reaction equation to be completed: H2O2 + …… KI = …… KOH + ……

**Experiment 2:** You have to make the hydrogen peroxide react withpotassium permanganate solution (KMnO4 solution) containing sulphuric acid. (The added amount of each solution should raise the level of liquid by about 1-2 cm in the test tube.)

**Plan of the experiment**: ………………………………………………………….…………………………….……………….…..……………………..

…………………………………………………………………………………………………………………………………………………………………………….

**Observations**: ……………………………………………………………………………………….…………………………………………………………….

…………………………………………………………………………………………………………………………………………………………………………….

**Explanations:** The glowing splint **was relit/went out** which shows that oxygen gas **formed/did not form** in the

reaction. → Assuming H2O2 is a(n) ………………………….**agent**, the permanganate ions (MnO4-) were **oxidized/reduced** → the permanganate ions **gave up/gained** electrons → manganese (II) ions (Mn2+)

…………………………………………… formed of the MnO4- by giving up oxygens (by reduction) → and that was shown

by the disappearance of the …………………………..……. colour of the KMnO4.

The oxygen atoms that were given up by the permanganate ions formed water with the hydrogen atoms. The sulphate ions and the potassium ions did not change (those are “counter ions” that balance the charges of the other ions). There are 2 potassium on the right hand side of the equation, so there must be the same number on the left hand side. Starting with that, balance the equation:

5 H2O2 + …… KMnO4 + …… H2SO4= ………… + …… MnSO4 + …… K2SO4 + …… H2O

In general: When H2O2 **reduces**, then it is oxidized → **gives up/gains** **electron**. This can only happen, if the oxygen of the H2O2 passes an electron to the hydrogen that has got a **lower/higher** electronegativity than itself and forms **elemental oxygen**. Why cannot the elemental oxygen give up electrons?

…………………………………………………………………………………………………………………………………………………………………………….Notice that as many electrons get further away from a given atom in the redox reaction, **the same number of electrons** get closer to the other atoms, because **they are the same electrons**! Based on this fact, even the **equations** of the most complicated redox reactions **can be balanced**.

**18. Student sheet: The Janus-faced hydrogen peroxide**

(teacher notes)

In ancient Roman religion and myth, Janus is the god of beginnings and endings. He is usually depicted as having two faces. Therefore, the expression “Janus-faced” means duality.[[9]](#footnote-9) Hydrogen peroxide (H2O2) is “Janus-faced” in the sense that it can behave both as an **oxidizing** and a **reducing** agent. (In a similar way than the water can behave as either an acid or a base in acid-base reactions.) Whether a reaction takes place or not and if yes, then which substance plays which role, it all depends on the reaction partners and the conditions. Now, in the apropos of the hydrogen peroxide, you will study the **redox reactions**.

The term “**oxidizing agent**” comes from the name of oxygen. The “oxidation” often really means gaining oxygen. The oxygen atom has the highest **electronegativity (*EN*)** value among all the chemical elements that can be found in an elemental state on the Earth. If it forms an oxide with a metal, then the oxygen attracts the electrons of the metal atoms closer to itself. It is said that the metal “gives up electrons” while it is oxidized. This **giving up electrons, i.e. oxidation** can also happen when oxygen does not even participate in the reaction. For instance, chlorine is also a strong oxidizing agent, because its atoms have got a high *EN* value, therefore it usually makes its reaction partners give up electrons (i.e. oxidation).

While completing the worksheet, **underline or frame the correct or cross the not correct parts of the text.**

How do you think it could be determined whether the **hydrogen peroxide played the role of oxidizing or reducing agent in a reaction**? Let us have a look at the following reactions. (The meaning of → is: „it follows”.)

A) H2O2 + H2SO3 = H2O + H2SO4 Sulphur forms 2 more bonds with oxygen atom. Oxygen has a higher *EN* than sulphur, so it attracts 2 electrons of the sulphur closer to itself → sulphur gives up 2 electrons, it is oxidized → the H2O2 is **an oxidizing agent**.

B) 4 H2O2 + PbS = 4 H2O + PbSO4 Sulphur has got higher *EN* than the lead, but lower than the oxygen → 8 electrons get further away from the sulphur at the time of the reaction → giving up electrons, oxidation → the H2O2 isa(n) ***oxidizing* agent**.

C) H2O2 + Mn2+ = Mn4+ + 2 OH- The positive charge of the manganese ion increases by two, therefore the

manganese ***gives up*** ***2*** negatively charged electrons → it is **oxidized** → the H2O2 is **an oxidizing agent**.

D) H2O2 + 2 Fe3+ + 2 OH- = **O2** + 2 Fe2+ + 2 H2O The positive charge of the iron (III) ion is reduced by 1

***negatively*** charged electron (i.e. by a reduction), therefore the iron (III) ion is reduced → the H2O2 is **a reducing agent**.

E) H2O2 + Cl2 +2 OH- = **O2** + 2 Cl- + 2 H2O Negatively charged chloride ions form of the neutral elemental chlorine molecule by gaining two electrons (i.e. by reduction) → the H2O2 isa(n) …………………………. **agent** and

the elemental chlorine isa(n) ***reducing* agent**.

F) H2O2 + 2 HCl = Cl2 + 2 H2O The chlorine attracts the electron of the hydrogen closer to itself in the hydrogen chloride, but giving up the hydrogen, this electron is “lost” by the chlorine → giving up electrons, oxidation → the H2O2 isa(n) ***oxidising*** **agent**.

[Only for type 1 and 2 student sheets.]

You may notice that whenever the **hydrogen peroxide is a reducing agent**, the **elemental oxygen** appears among the products.

How can you detect the production of the oxygen gas? ***It relights the glowing splint.***

Let us investigate, whether it is true that if we detect the production of **O2 gas, then the H2O2 is a reducing agent indeed in the reaction.**

**Experiment 1:** Pour starch solution into one of the test tubes to about 1-2 cm height. Add potassium iodide solution (KI solution) to it to about 1-2 cm height. Light the splint and let it burn for about half a minute. Meanwhile add hydrogen peroxide solution (H2O2 solution) to about 1-2 cm height to the potassium iodide solution that already contains starch. Blow out the burning splint and while it is still glowing hold it into the test tube in a way that it does not touch the liquid. Observe each change and write down your observations.

**Observations: *The solution became dark blue. The glowing splint has gone out.***

**Explanations:** The glowing splint **was relit/went out**, which shows that oxygen gas **formed/did not form** in the reaction. → Assuming H2O2 is a(n) ***oxidising* agent**, the iodide ions were **oxidized/reduced** → the iodide ions **gave up/gained** electrons→ the neutral ***iodine molecules*** formed of the negative iodide ions → and that was detected by the starch ***dark blue*** colour indeed.

The reaction equation to be completed: H2O2 + ***2*** KI = ***2***KOH +***I2***

**Experiment 2:** Pour sulphuric acid solution (H2SO4 solution) into the other test tube to about 1-2 cm height. Add potassium permanganate solution (KMnO4 solution) to it to about 1-2 cm height. Light the splint and let it burn for about half a minute. Meanwhile add hydrogen peroxide solution (H2O2 solution) to about 1-2 cm height to the potassium permanganate solution that already contains sulphuric acid. Blow out the burning splint and while it is still glowing hold it into the test tube in a way that it does not touch the liquid. Observe each change and write down your observations.

**Observations: *There was a very intense fizzing. The solution became colourless. The glowing splint was relit.***

**Explanations:** The glowing splint **was relit/went out** which shows that oxygen gas **formed/did not form** in the reaction. → Assuming H2O2  is a(n) ***reducing* agent**, the permanganate ions (MnO4-) were **oxidized/reduced** → the permanganate ions **gave up/gained** electrons → manganese (II) ions (Mn2+) formed of the MnO4- by giving up oxygens (by reduction) → and that was shown by the disappearance of the ***lilac*** colour of the KMnO4.

The oxygen atoms that were given up by the permanganate ions formed water with the hydrogen atoms. The sulphate ions and the potassium ions did not change (those are “counter ions” that balance the charges of the other ions). There are 2 potassium on the right hand side of the equation, so there must be the same number on the left hand side. Starting with that, balance the equation:

5 H2O2 +***2*** KMnO4 +***3***H2SO4= ***5 O2*** + ***2*** MnSO4 + ***1*** K2SO4 + ***8***H2O

In general: When H2O2 **reduces**, then it is oxidized → **gives up/gains** **electron**. This can only happen, if the oxygen of the H2O2 passes an electron to the hydrogen that has got a **lower/higher** electronegativity than itself and forms **elemental oxygen**. Why cannot the elemental oxygen give up electrons?

***Because it has got a very high electronegativity. (Positively charged oxygen ion does not exist.)***

Notice that as many electrons get further away from a given atom in the redox reaction, **the same number of electrons** get closer to the other atoms, because **they are the same electrons**! Based on this fact, even the **equations** of the most complicated redox reactions **can be balanced**.

[Only for type 2 student sheets.]

You got to the **general rule** concerning the role of the hydrogen peroxide **by the application of the following steps of the scientific investigations**:

Step 1: **Observations, systemization, composing the problem**: You had known from other people experiments that the oxidation is either gaining oxygen and/or giving up electron(s) and that the hydrogen peroxide could be an oxidizing agent and a reducing agent too. The problem-solving task was to answer the following question: How can it be decided, which role the H2O2 plays in the different reactions?

2. **Collecting information, making a model, forming a hypothesis:** After the examination of several reaction equations, it seemed that whenever the H2O2 is a reducing agent, then elemental oxygen forms. We assumed that this might be a general rule.

3. **Planning an experiment:** Making the hydrogen peroxide react with different substances, you tested by a glowing splint whether oxygen gas was produced or not.

4. **Doing the experiment and writing down the observations:** You made notes of each observation after doing the experiment.

5. **Explanations, drawing a conclusion, argumentation**: The results of the experiments showed that when oxygen was produced, the hydrogen peroxide really reduced its partner (the permanganate ions to Mn2+ ions that could be noticed, because the lilac solution became colourless). When oxygen was not produced, then the H2O2 has oxidized its partner (the iodide ions to elemental iodine that was detected by the dark blue colour of the starch). Thinking of the movements of the electrons you reasoned why is it that oxygen is only produced when the H2O2 is a reducing agent. Therefore, you could state that it is a **general rule**.

[Only for type 3 student sheets.]

Now you will work out the **general rule** concerning the role of the hydrogen peroxide **by the application of the following steps of the scientific investigations**:

Step 1: **Observations, systemization, composing the problem**: You know from other people experiments that the oxidation is either gaining oxygen and/or giving up electron(s) and that the hydrogen peroxide could be an oxidizing agent and a reducing agent too. The problem-solving task is to answer the following question: How can it be decided, which role the H2O2 plays in the different reactions?

2. **Collecting information, making a model, forming a hypothesis:** After the examination of several reaction equations, it is noticeable that there is a product that only forms when H2O2 is a reducing agent. What is this product? ***Oxygen (gas).*** Assumption: It might be a general rule that when ***oxygen (gas)*** is produced, then H2O2 is a reducing agent.

3. **Planning an experiment:** Making the hydrogen peroxide react with different substances, you can see whether the product named in the previous paragraph formed or not. How can you test if that was produced? ***It relights the glowing splint.***

4. **Doing the experiment and writing down the observations:** You have to make notes of each observation after doing the experiment.

5. **Explanations, drawing a conclusion, argumentation**: You have to examine if the results of the experiments do not contradict your assumption and whether they seem to justify it. Then you can try to compose a logical theoretical explanation. If you manage, you could state the **general rule**.

**Experiment 1:** You have to make the hydrogen peroxide react withpotassium iodide solution containing starch. (The added amount of each solution should raise the level of liquid by about 1-2 cm in the test tube.)

**Plan of the experiment**: ***Starch solution, potassium iodide solution and hydrogen peroxide solution should be poured into a test tube. Meanwhile a glowing splint has to be prepared and held into the test tube, above the level of the liquid.***

**Observations: *The solution became dark blue. The glowing splint has gone out.***

**Explanations:** The glowing splint **was relit/went out** which shows that oxygen gas **formed/did not form** in the reaction. → Assuming H2O2 is a(n) ***oxidising* agent**, the iodide ions were **oxidized/reduced** → the iodide ions **gave up/gained** electrons→ the neutral ***iodine molecules*** formed of the negative iodide ions → and that was detected by the starch ***dark blue*** colour indeed.

The reaction equation to be completed: H2O2 + ***2*** KI = ***2***KOH +***I2***

**Experiment 2:** You have to make the hydrogen peroxide react withpotassium permanganate solution (KMnO4 solution) containing sulphuric acid. (The added amount of each solution should raise the level of liquid by about 1-2 cm in the test tube.)

**Plan of the experiment**: ***Sulphuric acid, potassium permanganate solution and hydrogen peroxide have to be poured into the other test tube. Meanwhile a glowing splint has to be prepared and held into the test tube, above the level of the liquid.***

**Observations: *There was a very intense fizzing. The solution became colourless. The glowing splint was relit.***

**Explanations:** The glowing splint **was relit/went out** which shows that oxygen gas **formed/did not form** in the reaction. → Assuming H2O2  is a(n) ***reducing* agent**, the permanganate ions (MnO4-) were **oxidized/reduced** → the permanganate ions **gave up/gained** electrons → manganese (II) ions (Mn2+) formed of the MnO4- by giving up oxygens (by reduction) → and that was shown by the disappearance of the ***lilac*** colour of the KMnO4.

The oxygen atoms that were given up by the permanganate ions formed water with the hydrogen atoms. The sulphate ions and the potassium ions did not change (those are “counter ions” that balance the charges of the other ions). There are 2 potassium on the right hand side of the equation, so there must be the same number on the left hand side. Starting with that, balance the equation:

5 H2O2 +***2*** KMnO4 +***3***H2SO4= ***5 O2*** + ***2*** MnSO4 + ***1*** K2SO4 + ***8***H2O

In general: When H2O2 **reduces**, then it is oxidized → **gives up/gains** **electron**. This can only happen, if the oxygen of the H2O2 passes an electron to the hydrogen that has got a **lower/higher** electronegativity than itself and forms **elemental oxygen**. Why cannot the elemental oxygen give up electrons?

***Because it has got a very high electronegativity. (Positively charged oxygen ion does not exist.)***

Notice that as many electrons get further away from a given atom in the redox reaction, **the same number of electrons** get closer to the other atoms, because **they are the same electrons**! Based on this fact, even the **equations** of the most complicated redox reactions **can be balanced**.

 [For all the three type student sheets.]

**Homework:**

1.During the so called “elephant toothpaste” experiment[[10]](#footnote-10), potassium iodide (KI) catalyses the decomposition of hydrogen peroxide to water and oxygen gas. How do you know that during the experiment that you made with KI and H2O2 this was not the (only) reaction that took place?

***The blue colour of the solution containing starch indicate the forming of the iodine. (This could only form by oxidation from the iodide ions.) There was not a significant fizzing. The presence of the oxygen could not be proved.***

2. Which agents are the hydrogen peroxide and the potassium periodate (KIO4) in the reaction below?

Which atom of which compound gives up/gains electrons and how many of them?

H2O2 +KIO4 = O2 + KIO3 + H2O

***The hydrogen peroxide is a reducing agent (oxygen gas forms) and the potassium periodate is an oxidizing agent. The oxygens of the hydrogen peroxide give up altogether 2 electrons that are gained by the iodine of the KIO4 (since there is one oxygen less in the KIO3).***

END OF THE 18. STUDENT SHEETS AND TEACHER NOTES

1. <https://en.wikipedia.org/wiki/Light> (last visited: 22.07.2020.) [↑](#footnote-ref-1)
2. <https://en.wikipedia.org/wiki/Light> (last visited: 22.07.2020.) [↑](#footnote-ref-2)
3. <http://storeinsider.hu/gazdasag/cikk/onhuto_italos_dobozok_a_7_elevennel> (Last visited: 26.07.2020.) [↑](#footnote-ref-3)
4. <http://storeinsider.hu/gazdasag/cikk/onhuto_italos_dobozok_a_7_elevennel> (Last visited: 26.07.2020.) [↑](#footnote-ref-4)
5. https://hobbikert.hu/magazin/buveszmutatvany-hobbikerteszeknek-valtoztasd-meg-a-hortenzia-szinet.html (in Hungarian, last visited: 25.07.2020.) [↑](#footnote-ref-5)
6. https://hobbikert.hu/magazin/buveszmutatvany-hobbikerteszeknek-valtoztasd-meg-a-hortenzia-szinet.html (in Hungarian, last visited: 25.07.2020.) [↑](#footnote-ref-6)
7. <https://en.wikipedia.org/wiki/Janus> (last visited 25.07.2020.) [↑](#footnote-ref-7)
8. You can watch several videos about the experiment ont he internet, e.g. here: <https://www.youtube.com/watch?v=90nthtCG-1Y> (las visited? 25.07.2020.) [↑](#footnote-ref-8)
9. <https://en.wikipedia.org/wiki/Janus> (last visited 25.07.2020.) [↑](#footnote-ref-9)
10. You can watch several videos about the experiment ont he internet, e.g. here: <https://www.youtube.com/watch?v=90nthtCG-1Y> (las visited? 25.07.2020.) [↑](#footnote-ref-10)