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Education of natural science in schools with help of experiments of food investigations

1. Summary

Experiments play a particularly important role in the teaching of science subjects. Students are very fond of experiments performed with substances well-known to them, in our case, foods. In this article, ten simple physical, chemical and biological experiments are described in the following topics: microwave heating for mass and water content determination, discoloring a tea beverage, unscrewing the top of a jam bottle, changes in the texture of biscuits and bread during storage, dissolution and chemical reactions of cooking oil, thermal instability of margarine, determination of the acid degree value of milk, hydrolysis of egg protein, and protein denaturation.

Foods used in the tests and experiments are: ascorbic acid, lemons, citric acid, jam, cooking oil, fruit juice, fruit syrup, traditional tea, fruit tea, biscuits, bread, margarine, baking soda, milk and egg protein.

The experiments were designed at Congregatio Jesu Ward Mária Elementary School, High School and Music Vocational School of Budapest, where the scientific, ethical and human education are on equaled level.

2. Introduction

As was already described in our two previous articles **[1]**, **[2]**, we are convinced that the presentation of experiments plays a particularly important role in the teaching of science subjects. If science experiments are incorporated in teaching, i.e., theoretical topics are illustrated, hopefully our educational work will be more effective and successful.

Both in our previous articles, 10 experiments each were described, some of them being more of physical nature, while others of chemical or biological nature. Obviously, there is no sharp boundary between these disciplines, and we think that presenting the overlaps and relationships between these subjects and, furthermore, emphasizing the links between them form an important part of the modern approach to science education. In the following section, 10 simple experiments, related to food testing, are described again, that can be performed without much difficulty in a moderately equipped school laboratory for physical, biological and chemical experiments. As additional information to the presentations, the scientific literature comprehensively dealing with the subject of food testing, food analysis **[3]**, **[4]**,**[5]**, **[6]** can be brought to the students' attention as well.

3. Description of scientific experiments

3.1. Application of a microwave oven for the determination of water content by temperature measurement

In the past decade or two, the application of microwave ovens became widespread in households, and they are mainly used for heating in everyday life. It is a heating technique which is fast, easy and inexpensive – while also requiring less dishwashing. Its principle is that, by turning on the device, a high energy magnetic field is created by the application of electromagnetic vibrations in the microwave range (oscillation rate ca. 2×10^9 Hz). A substantial part of foods is made up by water, and since water

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has a high permittivity, energy transfer occurs by creating resonance, as an interaction between water molecules with a dipole character and the microwave radiation. Thus, by forcing the water molecules in the food placed in the device to perform spinning and rotational movement, the friction that occurs between the molecules results in the generation of heat by the microwave energy. Of course, the electric power delivered by the microwave oven is a function of the set heating degree (intensity) and the heating time.

Since the efficiency of the energy transfer, due to the resonance generated by the microwave field, mainly depends on the water content of the sample to be analyzed, measuring the temperature can be used to estimate the water content of the sample.

In theory, this measurement method can be suitable for the determination of the water content of the sample (the food tested) under any circumstances and in the case of any sample. However, in practice, because of the complexity of the correction factors, the measurement can only be performed with acceptable accuracy, if the measurement conditions and sample weights are the same. Based on this, in the case of liquid foods of the same weight, but with water contents of 40%, 60% and 80% – for example, fruit juices or fruit syrups – samples of different water content can be easily separated by a simple temperature measurement.

The calculation is based on the following formula:

$Q = c \times m \times T$, where:

Q – is the thermal energy absorbed

c – is the specific heat

m – is the heated mass

T – is the measured temperature difference

It should be noted that, in the case of foods, samples have several components, so, in addition to water, other ingredients (e.g., sugar) are also present, for which the value of specific heat is significantly lower than for water. During microwave treatment, these components do not warm up themselves, or only slightly, however, they receive energy (heat) from the gradually warming water, so the energy transmitted by the microwave oven is not used exclusively for the heating of the water content.

Additional losses are caused by the heat absorption of the structural materials of the oven, such as the rotating glass tray holding the sample, or the glass or plate used for containing or accommodating the sample. Because of the uncertainty of these characteristic parameters, an accurate calculation of the water content cannot be performed, based on the temperature measurement, but, under identical conditions, significant differences in water content can be demonstrated and verified clearly.

3.2. Mass and volume determination by temperature measurement by heating in a microwave oven

According to the principles described above, heating in a microwave oven can be used easily for mass determination. Or, to be more accurate, to estimate mass and volume. Once again, in theory, the method can be used under any circumstances and for any sample, but because of the complexity of the calculations already described, in practice, the accuracy of the result will only be satisfactory, if samples of identical chemical composition (i.e., of the same water content) are compared. For example, if two samples of fruit juice with a water content of 80% are analyzed, with volumes of 150 ml and 200 ml, respectively, then, under identical circumstances (glass material and size, intensity, heating time) the two samples can be definitely distinguished by temperature measurement. In this case, with a given setting, the temperature of the sample with a volume of 150 ml increased from 23 °C to 78 °C, while that of the sample with a volume of 200 ml increased from 23 °C to only 73 °C.

3.3. Brewing tea and adding lemon

It is a well-known fact that, depending on the type of tea and the method of brewing (real tea or fruit tea, black, yellow or green tea), and also on the amount used, the temperature and the brewing time, the color of the tea beverage can be significantly different. Let's brew for a few minutes in a 200 ml beaker real, so-called Sri Lanka, Indian or Georgian black tea (one filter bag), and a brown to dark brown tea solution with a color markedly different from that of water is obtained. Put roughly identical amounts of the brew obtained – for example, 50 ml each – into two Erlenmeyer flasks, and to one of them add a few drops of freshly squeezed lemon juice, and significantly more to the other one. It will be clearly visible that the tea will be discolored by the lemon juice, causing a reduction in brown color in the first case, while resulting in an almost colorless, slightly yellowish solution in the second case. Of course, the experiment can also be performed using orange juice.

When evaluating the experiment, we should point out the close relationship between oxidation and reduction – the substance that oxidizes, is itself reduced – and draw attention to the ascorbic acid in lemon juice, which is easily oxidized and, during this, it interacts with the pigments giving tea brew its color. In this context, we can ask students, who already have some knowledge of organic chemistry, what will become of ascorbic acid as a result of oxidation.

Be sure to point out that it is not only color materials and flavor and fragrance substances providing the pleasant tea aroma that dissolve from the tea during brewing, but several other components as well: tannin (tannic acid causing tartness), theine (the alkaloid responsible for the stimulating effect) and also minerals. Of the latter, fluorine and manganese should be mentioned, both of which are essential micronutrients, and they are present in tea in high concentrations. Therefore, in the case of people drinking plenty of tea, manganese and fluorine deficiency can definitely be ruled out. However, it can also be stated that, because of the chemical similarity of manganese and iron, these two metallic elements are each other's antagonists, and so an excess of manganese intake can reduce iron utilization, and can be a cause of relative iron deficiency.

It should be noted that the explanation of the effect of lemon or orange juice altering the color of tea is quite complex. This complexity can be clearly verified by a comparative experiment, during which to the tea brews are added lemon juice, ascorbic acid and citric acid separately. The most intense discoloration can be experienced in the case of squeezed lemon juice, the effect of ascorbic acid is less pronounced, and the least effect occurs in the case of citric acid. This can be explained also by the fact that tea - similarly to many other plants – contains natural acid-base indicators, the colors of which changes when an acid or an alkali is added. Therefore, when adding acidic lemon or orange juice, the color of tea becomes lighter **[7]**. The importance of acidity (i.e., of decreasing the pH) regarding color development can also be verified by the fact that the color once again turns darker if an alkaline substance, baking soda is added to the system. Furthermore, it is also a relevant aspect that the structure of polyphenols found in tea – partially responsible for the color of tea because of their conjugated and aromatic systems – can also be modified as a result of the acid, so that the wavelength of the light absorbed changes, and so the the color of the tea beverage changes as well. Tea color intensity is also reduced if a vitamin C pill, that can be purchased in a pharmacy, is added to the beverage.

To demonstrate the dominant role of the pH, the tea brewing experiment can be performed by using with products with characteristic infusion colors, for example, sour cherry flavored fruit teas. When adding lemon juice, the purplish-red color changes to intense, bright red, indicating the characteristic color of anthocyanins in a medium with an acidic pH **[8]**. When adding an alkali – $NaHCO_3$ solution – , the red color fo the brew disappears.

3.4. Unscrewing the top of a jam bottle

It is our everyday experience that sometimes it is very hard to unscrew the top of jam bottles. We also know what methods can be used to achieve success: we have to introduce air under the lid or put the bottle in a pot with warm water, and then it is easy to unscrew the top that was sucked onto the bottle.

Perform a simple experiment with two jam bottles of different sizes – with diameters of 6 and 8 cm – , to explain the cause of the phenomenon described above.

Compotes and jams are filled into the bottles when hot, mainly to limit the life conditions of microorganisms causing spoilage. In the simplified experiment, the filling material is simulated by water. When closing the bottle, a small amount of hot air remains in the vessel above the liquid, which later – together with the content of the bottle – cools down. According to Gay-Lussac'-s law, the decrease in pressure of a constant volume of gas in a sealed container is proportional to the decrease in temperature, measured in Kelvin.

This way, in our experiment, a pressure drop develops in the bottle, compared to the external atmospheric pressure. Because the external atmospheric pressure is higher than the internal one, the external air "weighs on" the screw cap, pressing it against the rim of the bottle opening. This is the reason why it is hard to move and twist the lid. We know that the physical interpretation of pressure is the ratio of the force and the area of cross-section. Therefore, the force necessary for opening can be defined as the product of the pressure differential and the area.

When opening the bottle, we increase the internal pressure by either introducing air particles from the external space, or by heating the air above the filling material. It is noticeable that, to open the larger bottle, a larger force is required, since, in the case of the bottle with a diameter of 8 cm, the area of the lid is almost twice as large as that of the lid used for closing the bottle with a diameter of 6 cm. From an educational point of view, 2 or 3 replicate experiment should be performed, so that several students can experience the difference in forces necessary to unscrew the tops.

3.5. Drying of bread and softening of biscuits

It is also well-known that if biscuits are left in the open air without packaging, even for only one night, by morning the biscuits become soft. At the same time, if a slice of bread is left outside, the bread becomes hard, it dries out. Although the compositions of these two foods can be considered similar, they still behave in different ways, even when the temperatures (e.g., 20 °C) and the relative humidities (e.g., 70%) are the same. After one day of storage, the textures of the samples (a slice of bread and a few biscuits) are investigated in a simple storage experiment.

After storage, the change in the texture of the samples (hardness, softness) can be clearly felt by sensory analysis – touching, chewing – compared to the previous day. The difference in behavior can be explained by the different structures of the foods. While there are small holes in the dough of the biscuits, bread contains significantly larger ones. The small holes of the biscuits function as tiny capillaries, transporting air and its moisture content into the biscuits and, therefore, the biscuits become soft. However, the larger holes in the bread do not function as capillaries. Therefore, bread quickly dries out in open air, its water content decreases, it becomes hard, and its enjoyment value decreases significantly during storage.

3.6. Experiments with cooking oil – like dissolves like

Oils and fats can be used in connection with the chemistry subject in elementary and high schools to demonstrate physical and chemical phenomena, and they also offer an opportunity, in addition to chemical experiments, to discuss healthy eating habits and to show several properties characteristic of oils and fats.

Using cooking oil-water and cooking oil-benzine two-component systems, the "*like dissolves like*" principle can be clearly demonstrated in the seventh grade of elementary school, when discussing the topic of solutions and dissolution.

Experiments performed in test tubes are suitable for the observation of phases developing due to density difference and of interfaces. In the case of water, by using a small amount of food coloring, the experiment can be made even more spectacular. It should emphasized for the students that the dissolution of cooking oil in benzine is not accompanied by chemical changes, so it cannot be considered a chemical process. Incidentally, understanding the formation of the two-phase system experienced in the case of water and oil can be helped by the demonstration of the stick models of polar and apolar molecules.

With the help of experiments performed using the same materials in the ninth grade, the concept of emulsions can be introduced. After shaking the oil-water mixture, the temporarily formed system once again separates into two phases, indicating that such colloidal systems are unstable. Although this is not strictly part of the ninth grade curriculum, but in connection with this, the manufacture of margarines, or the significance of emulsifiers and soaps can be mentioned to interested students. It is also worth taking the test tube containing cooking oil into our hands – when discussing the characteristic reactions, addition and oxidation, of unsaturated fatty acids also present in cooking oil. Namely, if bromine water is added to the cooking oil in the test tube, and the mixture is then shaken, the color of bromine disappears. The color of the potassium permanganate solution, acidified with sulfuric acid, also disappears when added to the oil. The disappearance of the color of bromine is caused by the addition reaction of unsaturated fatty acids and bromine, while the disappearance of the color of potassium permanganate is the result of the oxidation reaction between the oil and potassium permanganate. In advanced placement groups, the concept of iodine or iodine-bromine number, used for the determination of the degree of unsaturation of fats and oils, can also be mentioned, and we can also briefly touch upon the chemical processes of fat rancidification.

3.7. Measuring the thermal instability of margarine

The examination of margarines can be incorporated into student experiments either in the ninth or the tenth grade. In the ninth grade, it can be viewed as a typical example of emulsions, studied in the topic of colloidal systems, and in the tenth grade, in the context of organic chemistry, we can experiment with them when discussing fats and oils.

The water contents of margarines produced using different technologies (classical margarine, margarine spread, light margarine) can be very different. To demonstrate this, measure the same amount of margarine and light margarine into a graduated cylinder, and then place the graduated cylinders in a hot water bath. Within a few minutes, the margarines will melt, and separate into two clearly discernible phases, indicating the thermal instability of the emulsion system. In the case of the light margarine, the volume of the lower, aqueous phase is greater, and that of the organic phase is smaller, than the values that can be measured for the high fat content margarine. Cream and sour cream generally can be considered „oil in water", while margarine is a „water in oil" emulsion. It is also worth taking the additional time in the class to discuss the nutritional values of butter and margarine **[9]**.

3.8. Determination of the acid degree value of milk

When determining the acid degree value of milk using the definitive standard method (Soxhlet-Henkel degree, Sh°), it is examined how many cm^3 of 0.25 mol/dm^3 sodium hydroxide solution is necessary for the neutralization of 100 cm^3 milk **[10]**. According to our current practice, the acid degree value was determined by measuring the volume (cm^3) of 0.10 mol/ dm^3 sodium hydroxide solution used for the neutralization of 40 cm^3 of milk (*the two methods are equivalent from a stoichiometric point of view – Ed.*).

Fresh cow's milk is usually a slightly acidic liquid, with its pH value between 6.5 and 6.8. However, the acid degree value is generally between 5 and 7 SH°. During the test, 40 cm^3 of milk was pipetted into an Erlenmeyer flask, and 3-4 drops of phenolphthalein indicator was added. The burette was filled to mark with the 0.1 mol/dm^3 sodium hydroxide solution. Subsequently, we started a slow titration, taking care to shake the flask containing the milk continuously, in order to dispense the NaOH solution added. Titration was continued until the entire solution became pale pink. When the color became permanent, the stopcock of the burette was turned off, and the amount of the NaOH solution consumed was recorded in cm^3. The operation was repeated until three similar results were obtained, i.e., the difference between the measured values was less than 0.5 cm^3. The three reading were averaged, giving the acid degree value of the milk.

3.9. Experiment with egg protein to detect ammonia gas

The following experiment is well suited to prove biochemical theories and to deepen knowledge during high school chemistry and biology education. The task is to detect ammonia that forms during the hydrolysis of egg protein. As a theoretical background, one needs to know that, as a result of the addition of an alkali solution and heating, proteins hydrolyze, i.e., they decompose to their building blocks, amino acids. Amino acids that contain a carboxamide functional group, lose ammonia as a result of the alkali.

Let's review the reaction of glutamine with NaOH:

$HOOC\text{-}CH\text{-}CH_2\text{-}CH_2\text{-}CONH_2 + NaOH$

|

NH_2

↓

$NaOOC\text{-}CH\text{-}CH_2\text{-}CH_2\text{-}COONa + NH_3 + H_2O$

|

NH_2

When carrying out the experiment, a small piece of cooked egg white is placed in a test tube. 4-5 cm^3 concentrated – at least 30-40 m/m% - sodium hydroxide solution is added, and then the test tube is gently heated. During the heating, a moistened litmus paper is held to the mouth of the test tube, and it turns blue, indicating the alkalinity, caused by the ammonia that forms. The ammonia gas, lighter than air, exiting the test tube can also be recognized by its characteristic pungent smell.

3.10. Reaction of egg protein with metal ions

During the experiment, raw egg protein is diluted with distilled water, shaken, and filtered through a cotton plug placed in a funnel. Roughly the same amounts of protein solution are poured into three test tubes. In one of the test tubes, a small spoonful of sodium chloride is placed, in the second, copper sulfate, and in the third, silver nitrate. It can be observed that the protein precipitates in all three test tubes. However, in the test tube containing sodium chloride, the protein dissolves again as a result of dilution, while in the other test tubes it does not.

The observed phenomenon can be explained by the fact that proteins can be precipitated from their solutions by metal ions, they coagulate. The effect of light metal ions (sodium chloride) is reversible, i.e., after removing the salt, or strongly diluting the solution, the protein can be dissolved again. However, precipitation due to heavy metal ions is irreversible, and the resulting protein is called denatured protein. This phenomenon explains the toxic effect of heavy metal salts.

4. Designing experiments

We believe that it is also worth drawing students' attention to the topic of designing experiments and the evaluation of the data obtained **[11]**, naturally, at an introductory level. Following Genichi Taguchi Japanese expert **[12]**, point out that the design of experiments has become a routine tool of technical development and quality management in food production as well, and the appropriate biometric (mathematical-statistical) methods are now also available for this. In addition, computerized data processing also makes the application of more complex statistical methods possible, since there are several modern programs that provide substantial help to researchers.

In their work, a number of experiments are carried out by researchers by keeping certain parameters constant and changing others. This so-called "one parameter at a time" approach is not efficient enough. However, the DOE (Design Of Experiments) protocol established by Taguchi is a powerful procedure for designing a series of experiments, executing it and interpreting the results objectively, while changing several parameters simultaneously. Its advantage is that it maximizes the obtainable amount of information that can be acquired from a given number of experiments, and so it ensures efficient data analysis. Application of the DOE principle helps us to obtain as much information as possible by optimizing experimental parameters and minimizing the cost and time required **[13], [14].**

5. Conclusions

We believe that performing in the class the ten simple physical, biological and chemical experiments using foods, is an efficient tool in helping students prepare better in science subjects.

Their logical skills are also improved by discussing and evaluating experimental data, and by drawing the conclusions. The fact that the experiments are performed using foods, i.e., substances that are well-known to students from everyday life, strengthens our hope that we convey useful knowledge about foods to students, which can also raise their interest in agriculture and the food industry.

6. References

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