Gergely Levente Szabo[1], Andras S. Szabo[2], Margit Izsak[2], Janos Bozi[2], Eszter Imola Tisza-Kosa[2]

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Experiments of food investigations in the education of high school students

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1. Summary

Experiments have a dominant role in the education of natural science subjects. It has been our experience that students have been very satisfied, if the materials used in the experiments were well known substances to them, in this case foodstuffs. Again, 10 simple experiments of physical, chemical and biological type are described, concerning the following topics: measurement of the temperature of black coffee and milk exposed to natural light, study of capillarity in a sugar cube dipped into coffee or red wine, measuring honey viscosity, determination of the acid content of vinegar, the change of cooking oil viscosity as a function of temperature, measurement of concentration on the basis of the law of Archimedes, acidity measurement of fruits, measurement of the alcohol content of alcoholic beverages, microscopic examination of yeast, study alcoholic fermentation produced by yeast.

Foodstuffs used during the investigations and measurements: apples, black coffee, brandy, fruit juice, honey, milk, oranges, red wine, rum, sucrose, sunflower oil, vinegar, wine, yeast.

2. Introduction

As it was mentioned in our earlier papers **[1], [2], [3], [4],** the presentation of experiments has a dominant role in the education of natural sciences. If the experiments are part of the teaching materials, the education will be hopefully more successful and effective.

In the previous articles, 10 experiments each were described, some of them belonging to the field of physics, the others were of the chemical or biological type. Of course there is no sharp boundary between these disciplines, and the presentation of the overlappings and relationships – chemistry is based on physics, and biology is based on chemistry – and the stressing of the interconnections play an important role in the modern education of natural sciences. In this final part of the series, again 10 simple experiments are described, related to food investigations. These measurements can be performed without difficulties in the average school laboratory equipped for physical, chemical and biological tests.

If we need a classification, of the 10 measurements 6 can be classified as physical, 2 as chemical and 2 as biological tests. This ratio shows rather well that today in food analysis, food qualification and the methods of food investigations the major role is played by measurement techniques based on physics **[5], [6], [7]**, as was predicted by Ernő Pungor **[8]**, academician, outstanding specialist of instrumental analytical techniques decades ago. It is surprising, but true – mentioned Pungor, concerning developments in the future – that the importance of chemistry in analytical techniques was going to decrease, and physical methods will have the dominant role. Let us say that today – not to mention the relatively new, but already widely applied instrumental measuring techniques,

[1] Budapest Technical Vocational Center, Lajos Petrik Bilingual Chemical, Environmental and Information Technology Vocational School
[2] Ward Mária Elementary School, High School and Music Vocational School of Budapest

such as DSC, NIR-NIT, ESR-EPR, NMR, INAA, XRF, PAS – some very recent methods and techniques, e.g., FTIR, Fourier Transform Infrared Spectroscopy, PLM, Polarized Light Microscopy, SEM, Scanning Electron Microscopy, XPS, X-ray Photoelectron Spectroscopy – are in use, as well **[9]**.

3. Description of the proposed scientific experiments

3.1. Measurement of the temperature of black coffee and milk exposed to natural light

Pour into identical cups approximately 50 ml of each of black coffee and milk, and put the cups in places where they are directly illuminated by natural sunshine. Pay attention that the original temperature of the fluids at the beginning is the same (e.g., room temperature, that is, 293 K). After 15-20 minutes with a simple stick thermometer we can detect a significant difference, the temperature of the coffee being much higher, than that of milk.

The reason is rather simple, dark materials (in this case, black coffee) absorb the majority of thermal radiation – infrared light with longer wavelength than that of visible light – and the temperature increases as a consequence of this absorbtion. On the other hand, white materials (in this case, milk) reflect the majority of the radiation and only a small fraction is absorbed. Therefore, the increase in temperature will be much less in the case of milk, although the energy of sunshine, having an influence on the liquids in the cups, was approximately the same for both cups.

3.2. Study of capillarity in a sugar cube dipped into coffee or red wine

Pour into a cup a little coffee and dip a sugar cube into the liquid. You can recognize easily that the black liquid is absorbed into the sugar cube to the top of the cube, even if the level of coffee is below the top of the sugar. Why?

The answer is simple: because of capillarity. In communicating vessels with larger cross sections the level of liquids can be considered the same, but in very thin pipes, because of capillarity, the level of wetting liquids is higher than in pipes with large cross-sections. The crystalline sugar cube - chemically beet sugar, i.e., sucrose - has a spongy structure, it can be considered a network of capillaries, so the water, as the solvent of coffee - which is a wetting liquid - rises higher than the level of coffee in the cup **[10]**.

Of course, the spectacular experiment can be performed with other liquids as well. For example, with red wine, where there is also a clear increase of the fluid level. However, the duration of the experiments is very limited, since the sugar is a highly water soluble substance, and in coffee and wine the sugar cubes disintegrate and dissolve within a short time.

3.3. Investigation of the viscosity of honey

It is a commonly known fact that honey flows less easily than, for example, water. This is so, because honey is more viscous, that is, its viscosity is higher than that of water. In other words, it has a greater internal friction, so due to the differences in the rheological properties, its flowability is lower. Honey consists mainly (about 80%) of a variety of sugars, the remaining part being water and other useful substances, hence honey is considered to be a concentrated sugar solution. The viscosity of honey is influenced by a number of parameters, of which the temperature and the water content are of primary importance. Here we should mention that there is often a very close correlation between the physical and chemical characteristics of honey **[11]**.

Whoever uses honey to bake is aware that if you put the honey in a microwave oven for a short time, it will flow much more easily and can be mixed more easily with the dough of the cake. Thus, by increasing the temperature, the viscosity decreases considerably. While in the market, looking at different honey types in stores and moving the bottles, we can see that one type of honey may flow more easily than another type. This is mainly due to the different composition (e.g., glucose-fructose ratio) and partly the water content. Honey that contains more water is generally flows more easily, with less viscosity. In order to compare the viscosity of honey of 2 different temperatures or 2 different water contents, we only need a capillary, that is, a small cross-section glass tube. Of course, there are many advanced viscosimeters (e.g., rotary viscometer), but such devices are usually not available in school labs.

A stopwatch is used to measure the time during which a given amount of honey can flow through the capillary or the time over which a small ball hits the bottom of the honey-filled capillary, and then released. For both measurements, that sample with the shorter time measured will have the lower viscosity. Compare several honeys from different origins (e.g., acacia, linden, mixed flowers, chestnuts), and if there is still time, perform the measurements at different temperatures!

3.4. Examination of the acetic acid content of vinegar

Household vinegar products generally have a concentration of 10 or 20%. This means that a 1 liter bottle contains approximately 100 ml or 200 ml of acetic acid. Since the density of acetic acid, a liquid at room temperature, is almost the same as that of water (only slightly higher: 1.05 g / cm^3), the percentage can also be expressed in weight: 1 kg of vinegar contains about 100 g or 200 g of acetic acid. The vinegar is used in the kitchen for the preparation of a wide variety of foods, and it is important to know what quantity and concentration we add to our food.

The question arises as to how we could establish the acid content of the vinegar in case there is no label on the bottle? How can you decide with the help of simple kitchen tools and materials if the vinegar involved is of 10 or 20% concentration?

The simple solution is acid-base titration. When alkali is added to an acid of unknown concentration in the presence of an indicator, the reaction of the neutralization between the acid and the alkali is indicated by the change in color of the indicator. If we measure the amount of alkaline solution used to affect the color change, then the acetic acid content can be calculated. The principle of measurement is shown in the reaction equation:

$$CH_3COOH + NaHCO_3 = CH_3COONa + H_2O + CO_2$$

1 mole, i.e., 60 g of acetic acid reacts with 1 mole, i.e., 84 g of baking soda. Put into a graduated cylinder (or a home scaled glass) 100 ml (100 g) of vinegar, containing 10 g or 20 g of acetic acid. Take 28 g of baking soda and dissolve it in 300 ml of water. (At 25 ° C its solubility is about 100 g / liter, i.e., for dissolution about 10 times more water is necessary). Pour 100 ml of the vinegar in a half liter glass, add a few drops of red beet juice (this is the indicator) and start adding the baking soda solution with stirring. If, for the color change, approximately half of the alkali solution is necessary, the concentration of the measured vinegar sample was 10% (since 10 g of acetic acid reacts with 14 grams of baking soda), but if we see color change only when adding the whole alkaline solution, then we have a 20% vinegar. So we identified the acetic acid concentration of the tested vinegar sample.

3.5. Measuring the viscosity of sunflower oil as a function of temperature

It's a well known fact that if you put a teaspoon into a glass with honey, which stands on the table, and stir it quickly, the glass will start to rotate even if the spoon does not come into contact with the glass. The force is transmitted to the glass by the viscous material, which means that the internal friction of the honey results in the rotation of the glass. In the moving liquid, tangential forces, forces of friction appear among the fluid layers of non-zero relative velocity. The size of the friction force depends on the internal friction or the coefficient of viscosity, characteristic of the fluid.

The viscosity of fluids varies widely, the viscosity of vegetable oils being considerably larger than that of the water, but the viscosity of honey is much larger than that of oils. The internal friction depends significantly on the temperature as well: with increasing temperature the viscosity decreases significantly. This fact can be demonstrated easily with 3 consecutive series of measurements. Add the same amount (e.g., 50 ml) of sunflower oil to a glass cylinder ending in a thin capillary! Measure the outflow time of the oil at three different temperature values (e.g., 20 °C, 50 °C and 80 °C)! The flow time is directly proportional to the viscosity, so the viscosities in these three cases can be compared. Of course, the measurement is merely a comparative analysis, the instrument is not calibrated, and the actual viscosity of the oil is not determined. We only demonstrate with this measurement that the viscosity of the oil changes when its temperature changes significantly.

Of course, we can also point out that temperature also affects the energy consumption of certain food technologies. The energy required for mixing also depends on viscosity. And the fact is also well known that, for example, it is easier to work with butter at room temperature than it is with butter just taken out from the fridge. The reason here is that viscosity is a temperature-dependent physico-chemical property, and we can distinguish between dynamic and kinematic viscosity **[12]**. The importance of the measurement of rheological parameters in food testing is clearly demonstrated by the fact that in the scientific program of international conferences on food physics, food rheology is usually a separate section **[13], [14]**. Moreover, the viscosity measurement can be used – rather theoretically - to determine the temperature of a given system as well.

3.6. Concentration measurement, based on Archimedes' law

Previously, it was pointed out that by simple densitometry the concentration of binary mixtures can be determined without chemical analysis **[2], [15]**. In addition to the well known and widely used pycnometric method, here the density measurement procedure is carried out based on Archimedes' law for the analysis of a beet sugar (sucrose) solution. Based on the result of the density measurement, the concentration can be concluded using concentration vs. density data from the literature, or a self-made calibration curve can be used. The task is to determine the density of a sugar solution of unknown concentration.

The weight of the solid, water-insoluble object of known density and volume (in our case, an iron or aluminum prism) is determined with a spring dynamometer. Then the object is immersed in the fluid of unknown density, and the weight of the object is measured again! The density of the liquid can then be calculated from the difference between the two measurements. For example, if the mass of the 100 cm^3 aluminum prism was 270 g, and after the immersion it was 158 g, the difference is 112 g, and since the 100 cm^3 prism is equal to 100 cm^3 of sugar solution, based on the Archimedes' principle, the density of the liquid : 112: 100 = 1.12 g/cm^3. Based on the tabulated data **[16]**, this density corresponds to an approximate beet sugar concentration of 30%.

We think that this measurement is especially suitable for students to combine chemistry and physics knowledge, and to use the relationships during a measurement. Because when Archimedes' law is taught, students also study the weight loss of a solid body immersed in a liquid (water), so it helps to deepen the knowledge of the law if it is used in practice to determine the density of a solution of unknown density and concentration. (Of course, other procedures, based on simple physical principles, are also known for the determination of sugar concentrations. For example, refractometric or polarimetric measurement methods can be mentioned here, since the refractive index and polarized light are also discussed when the topic in the classroom is optical phenomena!)

3.7. Acidity measurement of sour foodstuffs

Already in the 7th grade, students get acquainted with the phenomenon of acidity and alkalinity. With the example of lemon and vinegar, it is easy for children to experience the taste of sour (aqueous) solutions comes from the acids (or more precisely, their dissociation), and these solutions are acidic. Of course, in addition to vinegar and lemon, there are many foods that are acidic. Children often mention sour flavored fruits (lemons, oranges, tangerines, apples, sour cherries) and fruit juices and, in addition, sour cabbage and foods made from it. However, they rarely know that, for example, must, wines, beers and soft drinks are definitely acidic, as well.

The acidic character of sour foods can be studied even by students in the 7th grade, without explaining the concept of pH in depth (and resorting to mathematical formulas).

Although acidic-neutral-alkaline aqueous solutions can be distinguished by using universal indicator paper, for the testing of acidic foods, fine-scale pH paper in the acidic pH range or a digital pH meter is recommended. With the help of the latter, different fruits, acidic foods and beverages can easily be sorted according to their acidities (or their relatively accurate pH values). From acidic fruits, you can choose, from practical point of view, fruits that are rich in juice, so that the preparation of the samples can be done easily and quickly (e.g., by using a manual fruit juicer). When examining, for example, the pH of oranges and apples, we found that it was about 3.0 in the case of oranges and 3.5 in the case of apples. Of course, attention should be drawn to the fact that the measured values are merely indicative, as varieties of the same species and the maturity status may also be the reason for significant differences. It should be noted here, that due to the complex composition of certain agricultural products and foods, there are many components with buffer effects, so the mathematical correlation between the measured pH value and the titrated real acid content is not perfect **[17]**.

When examining the fruits, we can briefly point out that the acidic taste of the fruits and the recognition of the intensity of the taste are influenced by a number of factors, so that by only tasting the acidic nature of the fruits cannot be determined accurately. On the other hand, in lemons, it is worth mentioning in the lower classes that citric acid and ascorbic acid (vitamin C) are not the same. Otherwise, detailed information on organic acids is provided in the 10th grade chemistry curriculum (organic chemistry). By examining various acidic beverages, we can conclude that their pH values have a rather wide range. Comparing the pH values of the carbonated mineral water, beer, wine, fruit juice and cola, it can be concluded carbonated mineral water had the value (around pH 5) closest to neutral, then came beer (pH range 4.3 to 5.0), wine (pH 3-4), fruit juice (pH 2.5-3.0) and cola (pH 2.5-2.8), in the order of increasing acidic character.

The pH also depends on the concentration of the solutions. To illustrate this, the pH of a pure fruit juice (100% fruit content), a nectar (at least 25% fruit content), a fruit juice (at least 12% fruit content) and a soft drink with some fruit juice (1-12% fruit content) of the same fruit may be suitable if the product is produced without added acid (e.g., citric acid). For students in the ninth and tenth grades, it is advisable to prepare 10-fold and 100-fold dilutions of cola (or 10% vinegar) and compare the pH of the three solutions. Thus, the children will experience that a tenfold acid content means one unit change in the pH value.

3.8. Alcohol content determination by measurement of density

For students in the 10th grade, one of the most popular organic chemistry topics - perhaps not by accident - is the subject of alcohols. Of course, among these, ethanol gets the most attention, mainly because of its importance in alcoholic drinks. Utilizing that ethanol is highly miscible with water and has a lower density than water (0.789 g/cm^3 at 20 ° C), the alcohol content of the various alcoholic beverages can be determined by measuring the density of the samples when the system is considered to be practically a binary liquid. This can be most easily accomplished by direct measurement of the mass and volume of the samples in a graduated cylinder or by an areometer (floating density tester). If you want to get more accurate results, measurements using a pycnometer are recommended.

Of course, in order to be able to calculate the alcohol content of the samples analyzed, knowledge of the density data of different water-ethanol mixtures or preparation of a calibration series is required before the samples are measured.

To determine the alcohol content, it is worth testing three different alcoholic beverages - one wine, one brandy and one rum with high alcohol content – and the density data obtained should be compared with the tabular or calibration data available. The results will show that the higher the alcohol content of alcoholic beverages is, the lower their density will be.

3.9. Investigation of yeast propagation with a light microscope

The word yeast means several varieties of yeasts belonging to the Saccharomyces genus, most notably Saccharomyces cerevisiae, and a number of spontaneously formed or cultured strains of it, and more specifically the food products produced from yeast. Regarding yeast composition, it contains 73-75% of water, 12-14% of protein, and there are also minor amounts of minerals, fats, carbohydrates, vitamins and enzymes (mainly zymase). This is the microorganism that is used most often in different fermentation processes. The role and importance of yeast in bread baking, brewing, and wine-making is clear probably to everyone. Regular consumption of yeast mitigates the adverse effects of stress as well, plays a major role in the process of degradation of carbohydrates and stimulates pancreatic function and is therefore extremely beneficial for diabetics. In addition, it beautifies the skin, and has been applied in home cosmetics and the cosmetics industry for a long time because of its skin regenerating effect.

Yeast, which is used for the production of bread and other baked goods made from dough, belongs to the species Saccharomyces cerevisiae, which is a single-cell fungus. Yeasts carry out their metabolism on a carbohydrate-rich matrix with alcoholic fermentation and reproduce asexually. This type of reproduction is called sprouting (and also budding) with an optimum temperature of 25 ° C. Under favorable conditions, this process is very fast, and the amount of yeast is doubled within 1-2 hours. During dough leavening, yeast fermentation is the most important factor. In the experiment, small pieces of store-bought yeast are placed in a glass, 20-30 ml of lukewarm water with a 2-3% sugar content is added, and it is mixed with a mixing stick. After a few minutes, we put a drop of the solution on a microscope slide, cover it with a covering plate and it is examined by light microscopy using gradually increasing magnification. By increasing the magnification gradually, we can observe the sprouting process better and the characteristic shape of yeast can be observed as well. Saccharomyces cerevisiae cells may be oval, spherical or pear shaped, and because the cells are 5 to 10 micrometers in diameter, the observation can be performed easily with an ordinary light microscope (100x magnification). It should be noted that the resolution of the light microscope (about 10^{-6} m) is much smaller than that of the electron microscope (about 10^{-9} m), because the electron beam wavelength is much smaller than that of light.

3.10. Study of alcoholic fermentation produced by yeast

The alcoholic fermentation typical of yeasts produces ethyl alcohol (ethanol) and carbon dioxide. For example, if the yeast is used for baking purposes, the carbon dioxide produced by the fermentation makes the dough spongy and light.

In the experiment, 150-200 ml of lukewarm water (2-3% sugar content) and 20 grams of yeast in small pieces are mixed well **[18]**. The solution is transferred to a long, thin-necked Erlenmeyer flask. Pull a balloon over the mouth of the flask and tighten it around the neck of the flask. The flask is placed in a lukewarm water bath, and the change is observed, during which the volume of the balloon increases gradually. After 20-30 minutes, remove the balloon from the flask and let its gas content into a small glass container with a burning candle placed on the bottom. The fact that the balloon contained CO_2 is indicated by the immediate extinguishing of the candle.

4. Conclusion, summary

We are convinced that the presentation, during classes, of the 10 simple experiments of the physical, chemical and biological type, based on the study of the given phenomena using foodstuffs, will help students to prepare better for natural science subjects. We believe that discussion of the data of the measurements, interpretation of the results and of course the drawing of the conclusions also improves their logic skills. The fact that the experiments are carried out using agricultural products and foods well known to our students reinforces our hope that useful information is provided to students about foods and nutrition, thus also raising their interest in the food sector.

This paper concludes our series, consisting of 5 articles. We sincerely hope that by writing these articles, we have helped some of our colleagues, who are interested in examining and qualifying food, to perform experiments that make the teaching of natural science more interesting and more illustrative. We also hope that these measurements and tests will be incorporated into the teaching material, helping the education of students in natural science subjects.

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