The wood ash is alkaline

La ceniza de madera es alcalina

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Resumen

Se organiza un novedoso experimento de lectura, que podría utilizarse como demostración de la quema de madera con identificación química de los principales productos de la oxidación. En realidad, se quemaron pedazos de palillos chinos estándar en oxígeno puro. Se ofrecen formas de probar los productos obtenidos. El producto sólido muestra una reacción fuertemente alcalina (pH > 11). Para un efecto máximo, se recomienda utilizar una cámara de flujo (Petruševski y Najdoski, 2005). Este experimento se puede aplicar para enseñar procesos de oxidación (combustión), ácidos, bases y/o indicadores. El experimento es adecuado para el salón de clases, brindando una oportunidad para que los estudiantes participen activamente en el examen de las propiedades de los productos resultantes.

Palabras clave

Aprendizaje activo, álcali, educación química, experimentos de conferencias, ceniza de madera.

Abstract

A novel lecture experiment is arranged, that could be used as a demonstration of burning wood with chemical identification of the main products of the oxidation. Pieces of standard Chinese chopsticks were burned in pure oxygen. Ways of proving the obtained products are offered. The solid product shows strongly alkaline reaction (pH > 11). For a maximum effect it is advisable to use a flow chamber (Petruševski and Najdoski, 2005). This experiment can be applied to teach processes of oxidation (burning), acids, bases and/or indicators. The experiment is suitable for classroom setting, providing an opportunity for active involvement of students in examining the properties of the resulting products.

Keywords

Active learning, alkali, chemistry education, lecture experiments, wood ash.

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Introduction

Let's start with a question: when was soap discovered? In 20th century? 19th century? Earlier than that?

The history of soap dates 5 millennia back, some 2800 BC in Babylon (Shan, 2019). There are also mentions of a somewhat newer date: "The legend says that soap was first discovered on Sappo Hill in Rome when a group of Roman women were washing their clothes in the river Tiber at the base of a hill, below which animal fats from the sacrifices ran down into the river and created soapy clay mixture. They soon found that using this same cleansing substance the clothes were coming clear easier" (Perri, 2016). Mentions are made of Egyptians (1550 BC), Phoenicians, who according to Pliny the Elder (Shan, 2019; Ridner, 2020), made soap from goat's tallow and wood ashes in 600 BC, ancient Greeks, Celts, and Arabs…

Classical soaps are salts of the fatty acids (palmitic, stearic, or oleic acid and sodium or potassium hydroxide). Soap is usually mildly alkaline (as a salt of weak acid(s) and a strong base). The very word alkali/alkaline is derived from Arabic *al qalīy* (or *alkali*) (Mandal, 2014; Wasserman, 2021) meaning *the calcined ashes* (cf. calcination (Hatashita-Lee, 2017)), referring to the original source of alkaline substances. "A water-extract of burned plant ashes, called potash and composed mostly of potassium carbonate, was mildly basic. After heating this substance with calcium hydroxide (*slaked lime*), a far more strongly basic substance known as *caustic potash* (potassium hydroxide) was produced. Caustic potash was traditionally used in conjunction with animal fats to produce soft soaps, one of the caustic processes that rendered soaps from fats in the process of saponification, and is known since ancient times. Plant potash lent the name to the element potassium, which was first derived from caustic potash, and also gave potassium its chemical symbol **K** (from the German name Kalium), which ultimately derived from alkali (Hatashita-Lee, 2017). It is well known that wood ash (but also ash from various plants) have been used in pure form instead of soap. This is possible due to the alkalinity of the ash(es). Let's elaborate on its origin in few more details…

As for the wood ash, it seems that its major ingredient is calcium carbonate, providing the temperature at which the wood burns is up to 750 °C, or calcium oxide – if the temperature is higher (Abdullahi, 2006; Pitman, 2006). There is no doubt that, providing the temperature is high enough, the calcined ash contains oxides of calcium and carbonates of alkali metals. As such, in contact with water, it will give a strongly alkaline reaction. The principal purpose of the presently offered lecture experiment is to enable a simple but efficient way to demonstrate this fact, while at the same time using equipment developed by us, as done earlier (Stojanovska et al., 2012; Bukleski and Petruševski, 2019).

Experimental section

The experimental setup

To the best of our knowledge, there is no decent demonstration of the fact mentioned in the title of this paper, that is why we offer it. To make the demonstration as effective (yet attractive) as possible, a flow chamber was used (Figure 1) introduced some time ago

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(Petruševski and Najdoski, 2005). The advantage of using the flow chamber is the continuous combustion of substances in a gas flow (in this case, oxygen) with the possibility of collecting the gaseous product in other vessels, followed by identification of the nature or properties of the product. It is worth mentioning that the simple variant where air is used instead of oxygen does not give satisfactory results, probably due to the lower temperature that is attained with air.

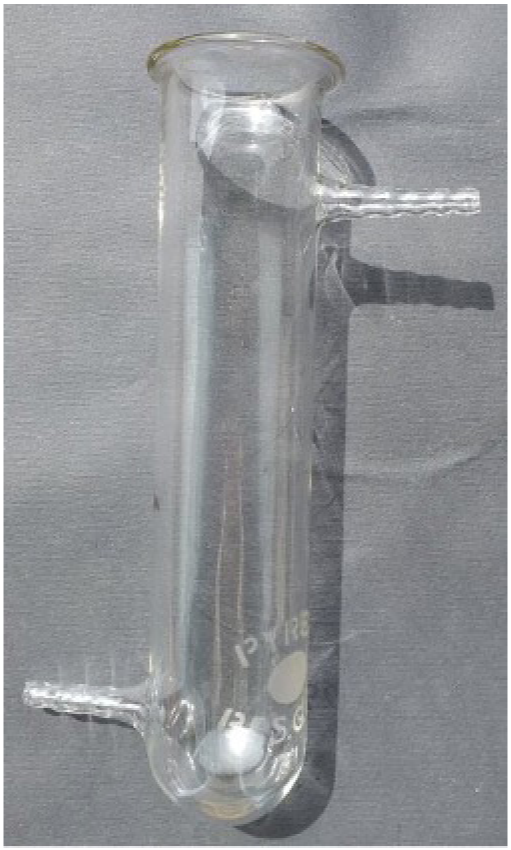

Figure 1. The typical flow chamber.

The lower left tube of the chamber is the inlet tube, from where (as a rule) the gas enters in the chamber. The upper right tube is the outlet one from which the gaseous products come out. The large opening from above is usually reserved for a cork with a deflagration spoon passing through it. Effective demonstrations were offered for burning substances in pure oxygen, for catalytic oxidation of ammonia (or, methanol) giving nitrogen oxides (or formaldehyde (Petruševski and Najdoski, 2005)) as products. The exact setup for the demonstration is shown in Figure 2.

The central part of the setup shows the flow chamber. It was filled by ¼ with pieces of marble and a suitable porcelain crucible was placed on the top of the marble. The crucible contained several small pieces of a chap-stick. The balloon was filled with pure oxygen from a container, that could circulate without difficulty through the pieces of marble. Of course, stones of appropriate size could be used instead of marble.

The upper opening is closed with a rubber cork. Two micro-wash-bottles are connected to the outlet tube: one is filled by ⅓ with aqueous methyl orange solution, the other one with lime-water (Figure 2).

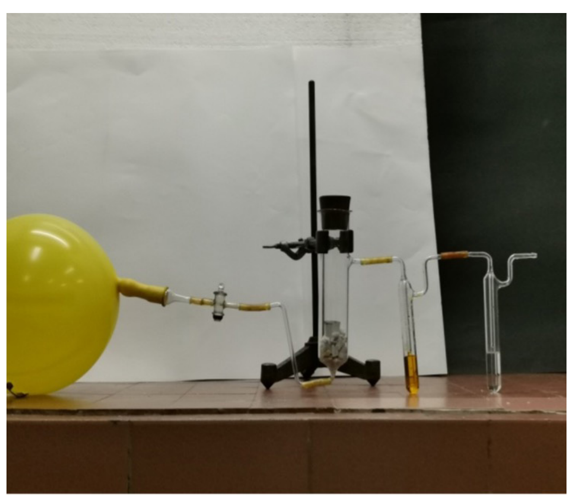

Figure 2. The experimental setup.

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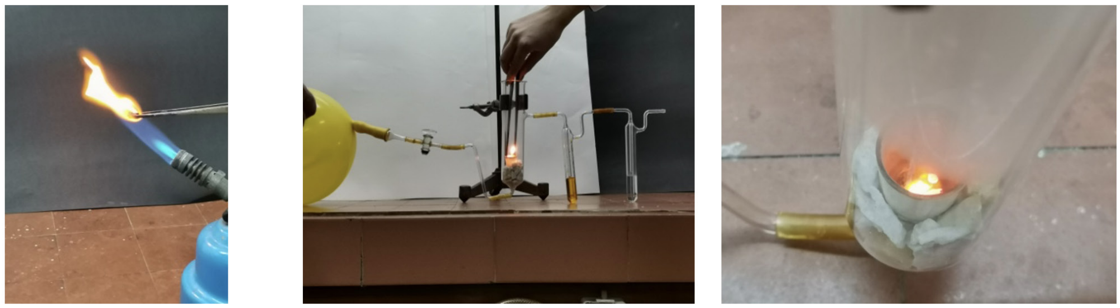
The experiment

A small piece of a chap-stick was placed in the flame of a Bunsen burner, the stream of oxygen was directed through the chamber, and the burning piece was placed in the crucible filled with pieces of a chop-stick (Figure 3). In that way, the other wooden pieces start burning intensely. The chamber was immediately corked.



a b c

FIGURE 3. Held with tweezers the piece of a chap-stick is lighted (a) and is placed in the crucible inside a flow-chamber (b) where it burns in pure oxygen very intensely (c).

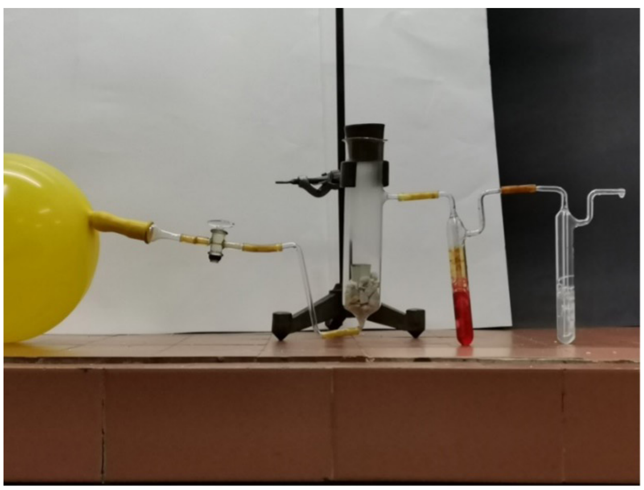


FIGURE 4. Bubbling of the excess oxygen with the gaseous products through the wash-bottles induces noticeable changes of the optical properties of the solutions.

As the wood burns, the stream of oxygen together with the other gaseous products passes through the wash-bottles. Dramatic changes are seen immediately: the light orange color of the methyl orange changed into intense red one, while the clear and transparent solution of lime-water turned foggy (Figure 4). Upon longer bubbling the liquid may or may not turn clear again, as will be discussed in what follows.

After the pieces of wood burned completely to ash, the stopcock joined to the balloon was closed. After few minutes, when the chamber and the crucible were cold enough, the content of the crucible was checked. The bottom of the crucible was covered with some white substance, but soot impurities (due to incomplete burning of the wood) were also present (Figure 5).

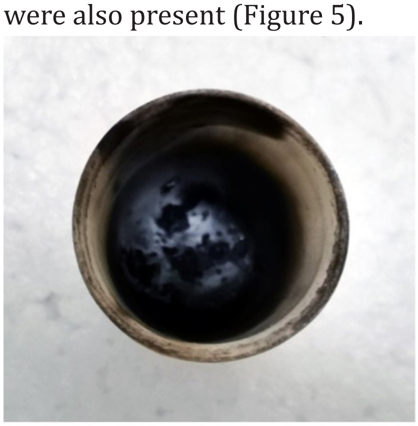


FIGURE 5. Ash (white) and soot (black).

After that, the crucible was placed in a beaker with ≈ 20 mL of distilled water where a dropper of phenolphthalein indicator has been added previously. The color of the liquid turns raspberry red (Figure 6a). This is a proof that the solution is alkaline. One more sample of chap-stick ash was prepared. A large part of it was treated with water containing thymolphthalein indicator and the liquid turned blue (Figure 6b). The minor part of the ash sample was used with a wet piece of universal indicator paper, to better estimate the final pH value of the solution (Figure 6c), which appeared to be between 11 and 12.

a b c

FIGURE 6. Color change of indicators: phenolphthalein (a), thymolphthalein (b), and universal indicator paper (c).

Discussion

The ash obtained by burning the chap-stick in oxygen is a mixture of carbonates and/or oxides of K, Ca and/or Na (Serafimova et al., 2011; Füzesi et al., 2015,). When the wood is burned in pure oxygen, the temperature is high enough to induce pyrolysis of at least a part of the $CaCO_3$ obtained in the ash. At high temperatures even potash (i.e., K_2CO_3) could be pyrolysed. The more ash is obtained the more basic reaction is expected in the end. However, with more chap-stick pieces, more oxygen will be necessary to burn it completely and the longer the demonstration will last. The latter may turn to be undesirable, as there is always an optimum timing of the school experiments. Few grams of chap-sticks give quite satisfactory results, while keeping the total timing acceptable.

Several indicators were used in the end, exclusively depending on the experimenter's preference. Phenolphthalein is sort of standard indicator in the chemistry lab. However, in a very strongly basic solution phenolphthalein is again colorless (Petruševski and Risteska, 2007), so as a second option thymolphthalein was used as an indicator that changes the color in a more basic solution. The universal indicator paper was used for a better estimate of the pH value in the end of the experiment. The pH value depends on the presence of $(OH^-)aq$ in the aqueous solution. If the composition of the ash is mainly K_2CO_3 (the latter is expected to show basic reaction, due to hydrolysis) and CaO (as major components), and some K_2O as a minor one, after dissolution in water chemical reactions will proceed as described with the following chemical equations:

$$CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(s, aq) \qquad (1a)$$

$$K_2O(s) + H_2O(l) \rightarrow 2KOH(aq) \qquad (1b)$$

Most of the calcium hydroxide will be present as a solid, for it is only slightly soluble in water. However, due to formation of very sparsely soluble $CaCO_3$ (upon addition of water to the product), another reaction is expected to occur, upon addition of water into the crucible, described by:

$$K_2CO_3(aq) + Ca(OH)_2(aq) \rightarrow 2KOH(aq) + CaCO_3(s) \qquad (2a)$$

or better, in net ionic form:

$$CO_3^{2-}(aq) + Ca^{2+}(aq) \rightarrow CaCO_3(s) \qquad (2b)$$

In effect, the elimination of calcium cations from the system enables an increase of the concentration of the OH^- anions (originally from calcium hydroxide), at the expense of the CO_3^{2-} ones (originally from potassium carbonate, potash).

Upon wood burning, gaseous CO_2 is generated in large quantities. Therefore, when the gas mixture bubbles through the micro-wash-bottles the carbon dioxide dissolves in the water and forms a weak acid. Usually, equations of the chemical reaction are offered like this:

$$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq) \qquad (3)$$

although there is some doubt about the very existence of $O{=}C(OH)_2$ molecules [Füzesi et al., 2015]. It is possible that most of the dissolved carbon dioxide is physically dissolved as $CO_2(aq)$, and that only a tiny part reacts with water giving $H^+(aq)$ and $HCO_3^-(aq)$. The unequivocal assertions about its existence seemed to us to be rather peremptory, till Wang & Bürgi (Wang and Bürgi, 2021) offered direct spectroscopic evidence for carbonic acid formation. There is still a lack of a crystallographic proof for its existence as a pure substance, but the structure of $H_2CO_3{\cdot}H_2O$ is known (Abramson, 2018).

In the second micro-wash-bottle containing lime-water, the CO_2 reacts with the lime:

$$CO_2(g) + Ca(OH)_2(aq) \rightarrow CaCO_3(s) + H_2O(l) \qquad (4)$$

giving $CaCO_3$ as a white precipitate. In case of prolonged bubbling of CO_2 through this solution it is possible that the precipitate is dissolved, due to formation of a soluble calcium hydrogencarbonate (in fact, the latter is an aqueous solution of Ca^{2+} and HCO_3^- ions):

$$CaCO_3(s) + CO_2(g) + H_2O(l) \rightleftharpoons Ca(HCO_3)_2(aq) \qquad (5)$$

but the latter reaction is possible only with an excess of carbon dioxide (which means enough wood, i.e., chap-stick pieces, present in the crucible).

Conclusion

The offered demonstration fills-in the blank of suitable demonstrations for the alkaline properties of the ash. These experiments are rather simple and do not require complicated or expensive laboratory equipment. Teachers believe that demonstration experiments should be more extensively applied because they are effective, and the students like them. Students remember performed demonstration experiments and knowledge acquired with use of demonstration experiments is more permanent than theoretical facts.

This experiment can be applied to teach processes of oxidation (burning), acids, bases and/or indicators. The experiment is suitable for classroom setting, and offers the opportunity for active involvement of students in examining the properties of the resulting products. If micro-wash-bottles are not available, standard test tubes may be used instead. The usage of a rubber balloon is also optional. However, it is not always possible to have the oxygen container in the same room where the lecture experiment is performed, hence the offered option to simplify the experiment.

In addition, the experimental work can maximize the learning of the abstract concepts and theories of science, especially chemistry (Ibrahim et al., 2004) as it enables students to master these concepts in a different way. The authentic and practical learning environment provided in the laboratory work is a totally different than the actual classroom learning environment and therefore it helps motivating students to develop interest in learning science, especially chemistry because through the experimental work, the students can develop the scientific skills (Hofstein, 2004). Essentially experimental work is a basic component of any science courses and especially in chemistry courses (Reid and Shah, 2007).

Hazards and Safety

Burning in pure oxygen includes a minor to moderate safety risk. One possible hazard is if a spark is caught by the oxygen stream and is stuck at the (rubber) cork which in pure oxygen could easily burn. In such case, one should first stop the oxygen supply (close the stop-cock) at the balloon. This, alone, will soon prevent further burning of the cork.

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