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TEACHING EXPERIMENTAL CHEMISTRY IN ENGLISH SCHOOLS*

NAUCZANIE CHEMII DOŚWIADCZALNEJ W ANGIELSKICH SZKOŁACH

Abstract: An historical background to the teaching of chemistry is presented, together with examples of great teachers from the past. Some aspects of the modern English school chemistry syllabus are discussed, both from the point of view of its theoretical content and its aim in helping children to develop practical skills. Chemistry Clubs, Open days and popular science lectures are also mentioned as a means of stimulating interest in chemistry as taught in schools.

Keywords: chemistry, experiment, demonstration, teacher, pupil

Historical background

The teaching of experimental chemistry in English schools stems from a tradition of which we can be proud. This tradition can readily be traced back to the middle of the 17th century which witnessed rapid developments in the science of chemistry. This was largely due to the work of Robert Boyle (1627-1691) and his colleagues at Oxford University; for it was Robert Boyle who recognised the importance of the experimental method in the chemical sciences. This method can be summarized in the logical sequence of events accompanying every experiment: method, observations and conclusion. Furthermore, it was Robert Boyle who, through several decades of experimental research, established the quintessential idea in modern chemistry: the **element**. It was this concept to which he devoted his *Sceptical Chymist* which was first published in 1661. With the publication of this work, modern chemistry was born: the age of chemical reason had begun. With this came the development of the chemical demonstration as a teaching tool, and also the introduction of chemical experiments for children.

The painting (Fig. 1) of a typical chemical demonstration of the late 17th century shows what happens when a bird is placed in a glass sphere which is subsequently evacuated. The bird dies, showing that air is necessary for respiration. The subdued expression on the children's faces clearly reflects the effectiveness of the demonstration.

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* Note: unless stated, all photographs were taken at Highgate School

Fig. 1. “An experiment on a bird in an Air Pump” by Joseph Wright (1734-1797)

Chemistry was, a European science, and accordingly there were many brilliant chemists who were outstanding teachers. These included Hermann Boerhaave (1668-1738) - Dutch, professor of chemistry at Leyden University, Joseph Black (1728-1799) - Scottish, professor of chemistry at Edinburgh University, Jedrzej Sniadecki (1768-1838) - Polish, professor of chemistry at Wilno (Vilnius) University, Humphry Davy (1778-1829) - English, president of the Royal Society (1820-1827) (Fig. 2), Michael Faraday (1791-1867) - English, director of The Royal Institution for over 30 years, Justus von Liebig (1803-1873) - German, professor of chemistry at the University of Giessen, and George Porter (1920-2002), English, Nobel Prize winner for chemistry in 1967, director of the Royal Institution (1966-1986).

Each of the above-mentioned scientists played a significant role, not only in chemical discoveries but also in disseminating chemical knowledge to vast numbers of young people.

Two noteworthy teachers of chemistry had a huge impact on chemistry education in England: Jane Haldimand Marcet (1769-1858) in the 19th century, through her book entitled: *Conversations in Chemistry* (1805), and George Fowles (1882-1969) in the 20th century, through his outstandingly long (1904-1953) teaching career at Latymer Upper School in London, and also his renowned book: *Lecture Experiments in Chemistry* (1937).

Jane Haldimand (who was of Swiss parentage), was born in London, and as a child had attended Joseph Black’s chemical lectures and also Humphry Davy’s spectacular Royal Institution performances. In 1799 she married the eminent Swiss physician and chemist (who also lived in London): Alexander Marcet. Although she had no formal education in the chemical sciences, she was inspired by the lectures which she had attended, and thus developed her knowledge and understanding of chemistry to a remarkable level. She was also able to make the acquaintance of many important scientists of the day. As a result of her firm belief in equal educational opportunities for both boys and girls, she produced her celebrated text in 1805. It is written in the form of a dialogue between Mrs Bryan (a teacher) and two young ladies - Caroline and Emily. Descriptions and interpretations of experiments form the basis of the text, which is lucid and most interesting. It reflects Jane Marcet’s supreme understanding of the psychology of teenage girls. The work went through 16 editions (the last one being in 1837) and was translated into French and German, and was also published anonymously (and illegally) in several editions in America.

Fig. 2. The famous cartoon by James Gillray (a prolific early 19th century cartoonist) depicts Humphry Davy demonstrating laughing gas to an audience at the Royal Institution in London

Michael Faraday, who was also not formally trained in chemistry, had the opportunity to become acquainted with this book during his 8 years’ work at a bookbinder’s in London. It was this book which provided him with his chemical background. Soon after Jane Marcet’s death in 1858, Faraday wrote: “Mrs Marcet was a good friend to me, as she must have been to many of the human race… When I questioned Mrs Marcet’s book by such little experiments as I could find means to perform, and found it true to the facts as I could understand them, I felt that I had got hold of an anchor in chemical knowledge, and clung fast to it. Thence my deep veneration for Mrs. Marcet.”

The 19th century witnessed a truly remarkable growth in the chemical sciences - both in terms of concepts *eg* Dalton’s Atomic Theory and the development of electrical theories based on electrolysis experiments, and in terms of factual knowledge *eg* discovery of new elements and the growth of organic chemistry. Anyone born into this age could not fail to be inspired by all that chemistry had to offer - such a person was George Fowles.

Like Michael Faraday, George Fowles was an outstanding experimenter. As a young teacher he became convinced of the enormous value of lecture demonstrations as an aid in the teaching of chemistry in schools. He firmly believed that every chemistry teacher should, within his own capabilities, strive to teach chemistry through practical demonstrations. A good demonstration in addition to being a profound learning experience can also be a polished theatrical performance - it teaches and entertains. To this end he wrote his book on lecture experiments in chemistry, in which he described a vast array of experiments from the past 150 years, together with references. The publication of this book stimulated the design of lecture rooms and demonstration benches in many English schools - every child could thus have access to the ultimate teaching medium of chemistry: the lecture/demonstration. His book went through 5 editions, and was continuously in print from 1937 until 1965.

Experimental chemistry in schools today

Chemistry is taught to two age groups: 13-16 years (GCSE) and 16-18 years (A level). Two types of experiment are used: demonstration (shown by the teacher), and class practicals (carried out by pupils).

The demonstration experiment has three aims:

1. To show a particularly interesting reaction or series of reactions *eg* redox reactions involving halogens/halide ions, and their colours in organic solvents
2. To illustrate techniques for manipulating apparatus and chemicals *eg* titration
3. Demonstrate a process which requires considerable manual dexterity and/or experience *eg* the quantitative reduction of metal oxides with hydrogen

Some common examples of important demonstration experiments include:

GCSE
1. Distillation - simple and fractional
2. Hofmann Voltameter - electrolysis of water
3. Typical reactions of dilute acids (with alkali, base, metal and carbonate)

A level
1. Use of pH meter to construct titration curves
2. Reflux distillation - esterification

The diagram shows (Fig. 3) an apparatus for steam distillation, which is used to extract limonene from oranges, for example. It is taken from *Practical Organic Chemistry*, by Mann and Saunders, London (1961).

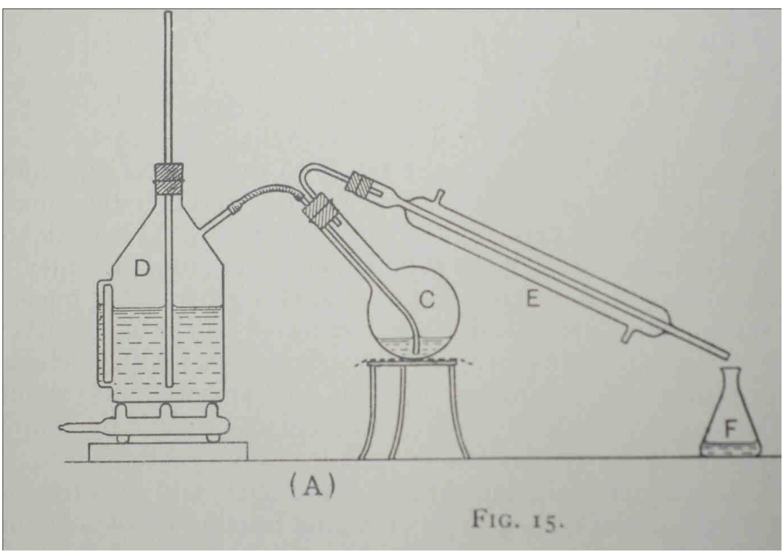

Fig. 3. An apparatus for steam distillation

The 4 photographs (Figs. 4-7) were taken during consecutive lessons whose theme was “synthesis” and “decomposition”.

Fig. 4. A demonstration experiment showing the synthesis of carbon dioxide and its effect on lime water

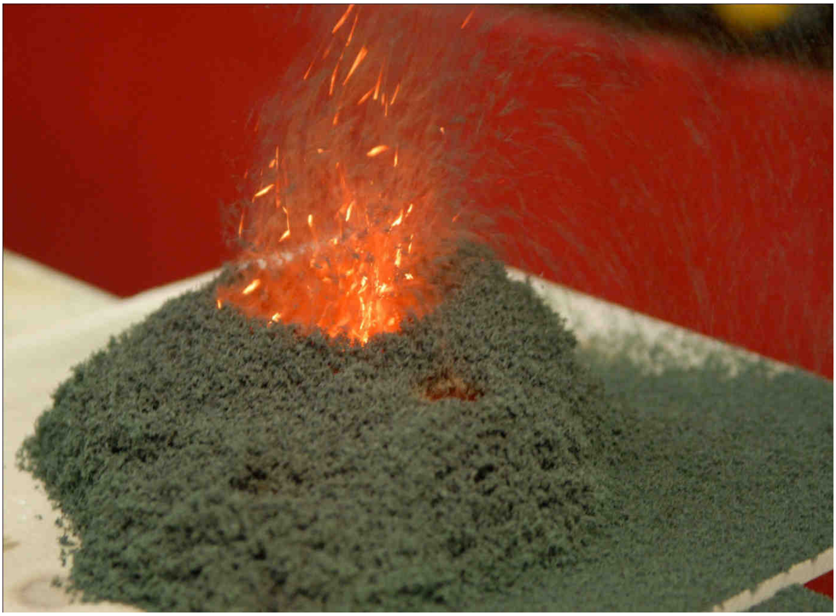

Fig. 5. The ammonium dichromate volcano is spectacular for its colour change and also the huge increase in volume of solid

Fig. 6. The photolytic decomposition of silver bromide illustrates the reaction which underlies “traditional” photography. In this reaction we burn magnesium ribbon over a metal object which covers freshly precipitated silver bromide - the result is an impressive photogram of the metal object

Fig. 7. The Hofmann Voltameter (1866) shows one of the most significant experiments of the 19th century - this is the decomposition of water (which for centuries had been considered to be an element) into hydrogen and oxygen

The celebrated “iodine clock” reaction (Fig. 8) lends itself to theatrical performances - here we see a violin duet accompanying a series of colour changes, as part of a lecture for students at Durham University in February 2009.

Fig. 8. “Iodine clock”

The aims of class experiments can be broadly summarized as follows:

(a) Develop practical skills
(b) Enhance understanding of chemical principles
(c) Broaden factual knowledge
(d) Add an element of enjoyable diversity to the lesson

Some examples of class practicals include:

GCSE: (1) Measuring the boiling point of brine, (2) synthesis of iron sulphide, (3) separation of mixtures *eg* chromatography, (4) rates of reaction (chemical kinetics)

A level: (1) Preparation and purification of 2,4 dinitrophenylhydrazine derivatives of carbonyl compounds, and their melting point determination, (2) formation of transition metal complex ions.

Many surprisingly interesting issues can arise from even the simplest experiments: the girls shown in Figure 9 are determining the boiling point of brine, and comparing it to the boiling point of pure water.

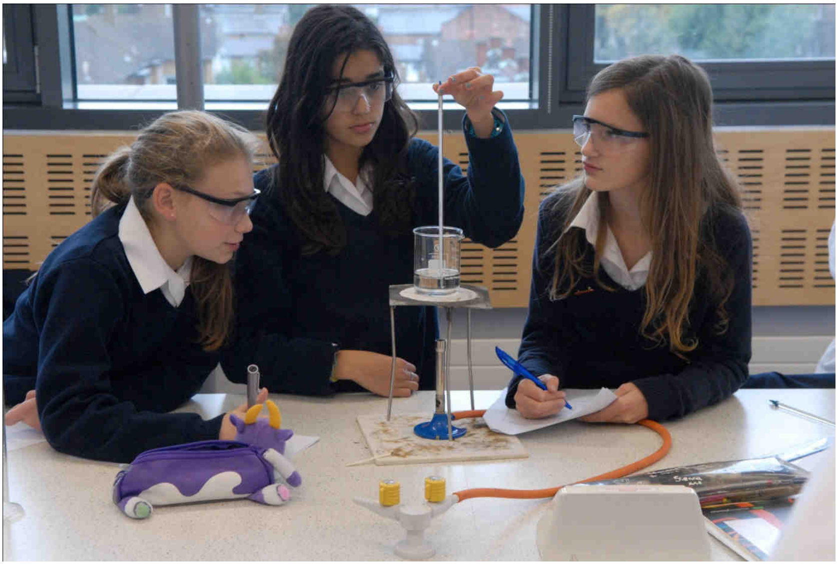

Fig. 9. Determining the boiling point of brine

Competitions can greatly enhance the interest in a practical session. The next 3 images show a "traditional" competition for year 9 pupils (13 years old), in which they separate a mixture of salt, sand and iron. The results are judged on two criteria: yield and purity of products. Small prizes are awarded to the winning team (Figs. 10-12).

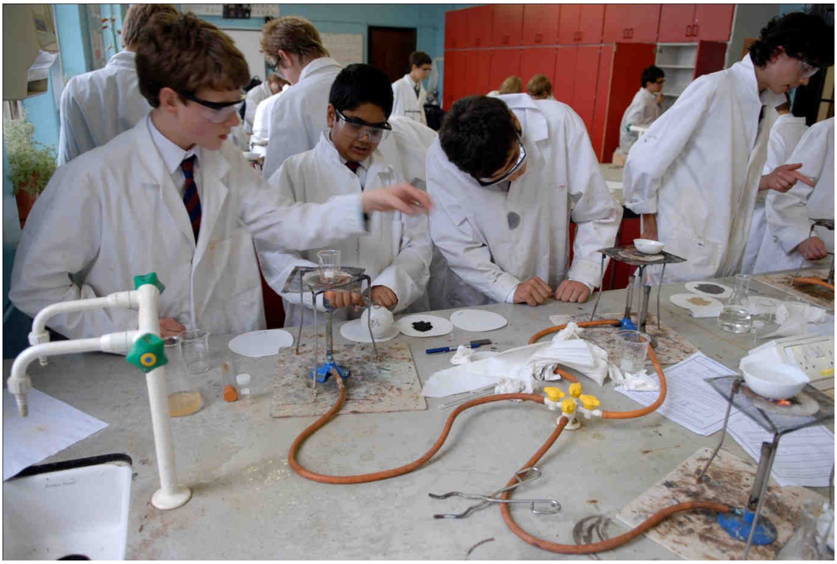

Fig. 10. Separation of a mixture of salt, sand and iron filings

Fig. 11. The final products

Fig. 12. Judging the products

Flame tests (Fig. 13), shown here at an open day, are always popular.

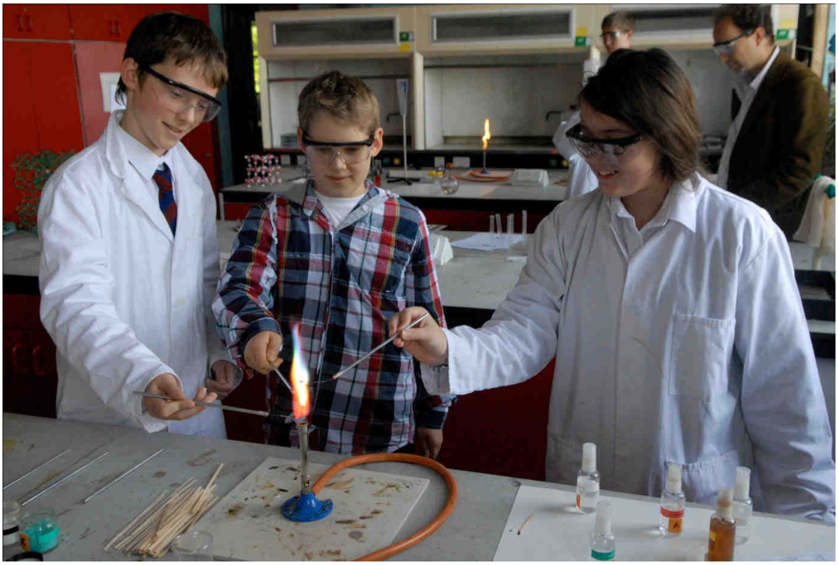

Fig. 13. Flame tests

The synthesis of metal sulphides is always spectacular: in the experiment shown on Figures 14 and 15, students heat a small piece of preweighed copper foil in sulphur vapour. They observe the reaction and weigh the product. They also note its different physical properties, and are taught a simple equation for the reaction.

Fig. 14. Synthesis of copper sulphide

Fig. 15. Synthesis of copper sulphide (closeup)

Changes in the teaching of experimental chemistry during the past century

Chemistry is much more accessible today, than it was 100 years ago. This is partly through simple and effective experiments which have been ingeniously devised with modern technology *eg* with the use of plastics for containers, pipettes and laboratory furniture. This greater accessibility to children from various backgrounds has been achieved through the training of greater numbers of teachers, through the active involvement of the Royal Society of Chemistry and the Association for Science Education. Facilities for experimental chemistry have also become more widespread (*eg* school laboratories). A greater proportion of children can now participate in practical chemistry assignments.

However in order to reduce costs, many experiments (eg organic preparations) have been downsized. Smaller experiments are less spectacular than large ones. The popular image of chemistry has been damaged through unsympathetic and sensation seeking reports in the media and press, over dramatization of accidents, and an obsession with “health and safety”. This has resulted in a significantly reduced number of experiments and demonstrations being carried out in schools.

There is currently an increased awareness of hazards associated with chemistry experiments. Emphasis has been placed on safety training for teachers, and their responsibilities for the well being of pupils during experiments. Today’s chemical laboratory is a safe, healthy and inspiring environment for both pupils and teachers.

The modern school laboratory, with teaching facilities for 24 pupils, is shown here (Fig. 16). Cupboards on the left house chemicals and apparatus. Pupils sit at the tables in the foreground, and there are 3 laboratory benches at the back of the room, together with 3 fume cupboards. Demonstrations can be performed on the rear bench, and also in the fume cupboards.

Fig. 16. The modern school laboratory

Fig. 17. Chemistry preparation room

Most schools in England employ laboratory technicians who prepare/make apparatus and chemicals, and models, in specially allocated “preparation” rooms (Fig. 17). These technicians cooperate closely with teaching staff to ensure that experiments are prepared and put away at the right time. Typically, there is one full time technician for four full time chemistry teachers. Many technicians are also skilled glass workers, competent IT users and also deal with the ordering of equipment and chemicals.

Chemistry Clubs

It is possible to foster an interest in experimental chemistry through “after school” or lunchtime activities such as chemistry clubs (Figs. 18-23). These require dedicated teachers who understand their significance and are willing to take on the huge responsibility of running them. Such teachers exist in many schools. Two posters advertising the activities of such a club are illustrated in Figures 18 and 19, the latter one showing the celebrated zinc/sulphur fusion. During meetings of such clubs, pupils are able to conduct any experiment of their choice - a wide range of literature and worksheets is available - under the guidance of a teacher.

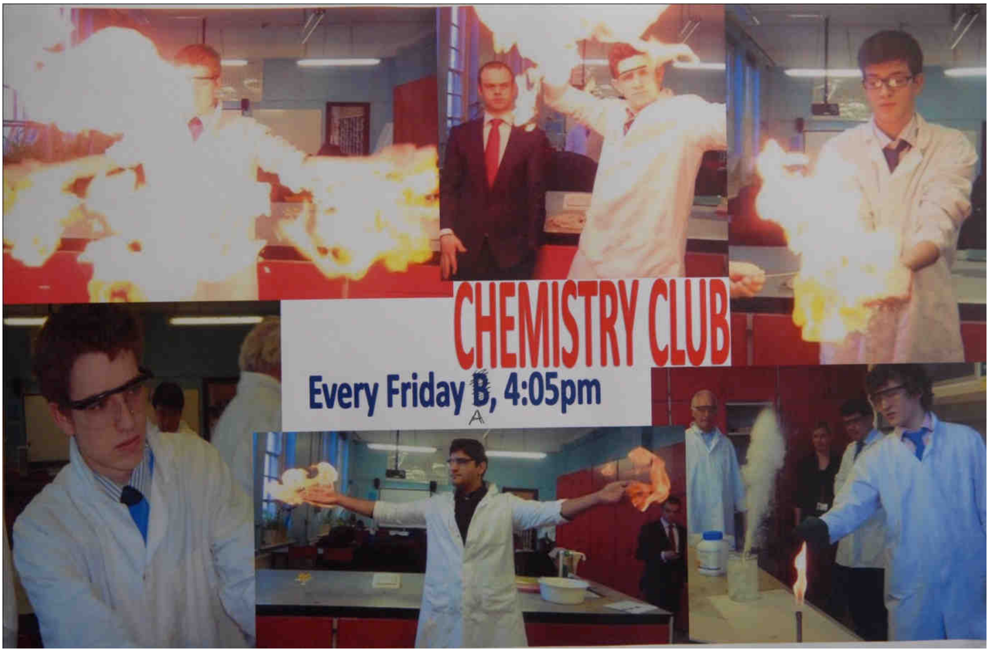

Fig. 18. Chemistry Club poster

Fig. 19. Chemistry Club in action - the celebrated zinc/sulphur fusion

The girls shown here (Fig. 20) are making glass beads by fusing together a mixture of lead oxide, sodium borate and sodium carbonate. Tiny amounts of manganese dioxide/copper oxide are added to impart colour to the glass. The finished products are shown in Figure 21.

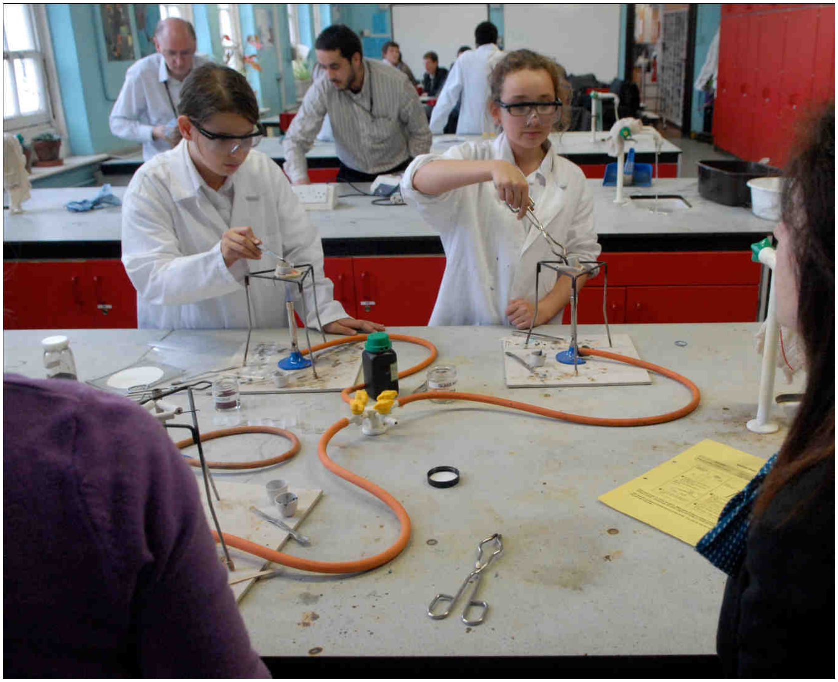

Fig. 20. Chemistry Club in action

Fig. 21. The finished product: glass beads

Pyrotechnic reactions involving thermite mixtures and fuse powders are popular at club meetings. Figures 22 and 23 show a group of A level students who are experimenting successfully with different coloured flares.

Fig. 22. Experimenting A level students

Fig. 23. Experimenting A level students

Open Days

The purpose of school open days (Figs. 24-28) is to show invited members of the public, especially children, the fabric of a school and its programme.

Fig. 24. School open day

Every department participates, and chemistry experiments are naturally popular with parents and children alike. Guests are shown around the laboratory, where current pupils and teachers outline the programme of chemistry teaching. This is accompanied by experiments in which children take part.

Fig. 25. Flame tests

Fig. 26. Observing with interest

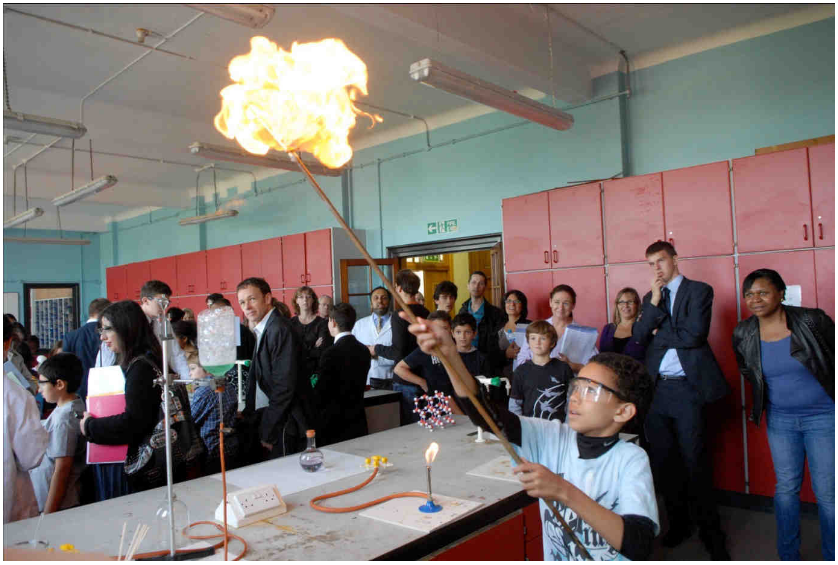

Fig. 27. Methane soap bubble combustion

Fig. 28. Scene from the lecture at Durham University in 2009: Flame colours (lithium, sodium, copper) and cold steam from liquid nitrogen in a pot of tea

There is no doubt that such events stimulate a huge interest in the chemical sciences. For the forseeable future, chemistry experiments will have an important role in our education. They have intrinsic interest, fascinating manipulative procedures, and above all, allow us the sheer pleasure of watching one substance change into another. This is the magic of chemistry.

NAUCZANIE CHEMII DOŚWIADCZALNEJ W ANGIELSKICH SZKOŁACH

Abstrakt: W artykule przedstawiono tło historyczne nauczania chemii; podano także przykłady wybitnych nauczycieli z przeszłości. Omówiono wybrane elementy programu nauczania chemii w szkołach angielskich z punktu widzenia zawartości teoretycznej, jak również przydatności w rozwijaniu przez uczniów umiejętności praktycznych. Jako dodatkowe sposoby wzbudzania zainteresowania chemią szkolną przedstawiono także działalność kółek chemicznych, organizowanie dni otwartych oraz wykładów popularnonaukowych.

Słowa kluczowe: chemia, eksperyment, demonstracja, nauczyciel, uczeń