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MICHAEL FARADAY THE EDUCATOR - AN ESSAY TO COMMEMORATE THE 150TH ANNIVERSARY OF FARADAY'S DEATH

MICHAŁ FARADAY JAKO PEDAGOG - ESEJ W 150. ROCZNICĘ JEGO ŚMIERCI

Abstract: Michael Faraday (1791-1867) is renowned for his outstanding contribution to science and technology during the first half of the nineteenth century. However, he is less well known for his contribution to education. In the present paper, an outline of Faraday's own education is presented, and how this experience inspired him to pass on his knowledge to others. This was mainly achieved through his popular science lectures - Chemical History of a Candle, delivered at the Royal Institution of Great Britain, in London on 19 occasions between 1825 and 1860, and through his popular textbook for students: *Chemical Manipulation* (London, 1828). The author examines Faraday's methodology of teaching chemistry by analysing a fragment of one of his lectures, and also by summarizing the content of *Chemical Manipulation,* and commenting on some excerpts from it. Using Faraday's approach to chemistry education as a model, the author challenges today's chemistry teaching programme for schools, and makes a suggestion for its improvement.

Keywords: Michael Faraday, chemistry education, learning by experiment, demonstration in chemistry, Faraday's lectures, explanation of the burning process

Introduction

Michael Faraday (1791-1867) came from a poor background, had little formal education and yet became an outstanding natural philosopher and scientist. He grew up at a time when two invisible and intangible phenomena were dominating the minds of scientists: **gases** - as material substances, and **electricity** - as a form of energy. Through a set of remarkable circumstances, he became an employee of the Royal Institution of Great Britain in London. This Institution, which had been founded in 1799 by a group of leading intellectuals and entrepreneurs, led by Count Rumford (otherwise known as Benjamin Thompson (1753-1814)) and Sir Joseph Banks (1743-1820), had as its aims: conducting original scientific research in order to serve "King and Country", and educating the public in science. As a result of the evolution of experimental techniques, huge advances had been made since the beginning of the 18th century, and they were continuing with great impetus. The consequences were enormous and they instigated the Industrial Revolution. This in turn resulted in a rapid population growth in Europe.

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It was during the first two thirds of the nineteenth century that Michael Faraday grew and flourished. His greatest discovery, made on August 29^{th} 1831, was the principle of electromagnetic induction. This gave birth to the electrical engineering industry which has resulted in global electrification. Faraday also made several other notable discoveries in physics and chemistry. In addition to his great achievements in science, he further distinguished himself in the field of humanities, as an educator.

Faraday's scientific education

Michael Faraday became a bookbinder's apprentice at the age of 13, at Monsieur Riebau's shop in Blandford Street, central London. Bookbinding was a complex and skilled trade, requiring a thorough knowledge of different kinds of paper and card, adhesives, twines, leathers, inks and dyes. Furthermore, several manipulative procedures, involving a wide variety of tools, had to be mastered - folding, marking, stitching, embossing and pressing. In all, it was a trade which took several years to perfect, but which provided a reliable and sound income.

While Faraday was undergoing his apprenticeship, he read some of the books which he was binding. It was at this stage that his passion for science began. Two events in this respect were to determine Faraday's future: (i) reading Mrs Marcet's book [1], and (ii) attending lectures at the Royal Institution (RI) in Albemarle Street, where the flamboyant and brilliant, recently appointed (in 1802) Professor of Chemistry, Humphry Davy (1778-1829), was giving popular science demonstrations for adults and children.

Mrs Jane Marcet (1769-1858) had only received a basic education, but as a child had mingled with scientists and doctors and, crucially, had attended and been inspired by Davy's early lectures at the RI. She had conducted chemical experiments at home, and feeling the need for sciences to be taught and made more widely available to girls, she wrote books with this aim in mind. *Conversations on Chemistry*, "more especially intended to the female sex" [1], was read by the adolescent Faraday. It was first published anonymously in 1805, but went through 16 editions, and was translated into French and German. The dialogue took place between Mrs Bryant, a friendly chemistry teacher and two inquisitive students - Caroline and Emily. Mrs Bryant answered their many questions, and illustrated her answers with experiments.

With the limited financial resources at his disposal, Faraday was able to successfully recreate some of Mrs Bryant's experiments. One of these was the electrolysis of Epsom Salts (magnesium sulphate solution) using a battery constructed from 7 zinc plates, 7 half penny copper coins, 6 pieces of blotting paper, salt solution (muriate of soda) and pieces of copper wire. This experiment clearly delighted the young Faraday: bubbles of gas were evolved at both electrodes and after two hours the colourless solution had become turbid. This result gave him the confidence and inspiration to conduct further experiments.

In March 1812, Michael was given a ticket to attend one of Davy's lectures (The Elements of Chemical Philosophy) at the Royal Institution. He was so inspired by the lecture that he attended three more in order to complete the series. During these lectures he took detailed notes, transcribed them "in best", with diagrams, and bound them. As a mark of his enthusiasm and gratitude, he sent the bound copy to Davy in late December 1812. By now, Faraday had decided that he wanted to pursue a career in science and thus became very keen to gain a post, no matter how humble, at the Royal Institution. He arranged to meet Davy in January 1813, with this aim in mind. Davy was impressed with Faraday but was unable to offer him any employment at that time. A few months later however, after a brawl at the RI involving Davy's assistant, a vacancy was created, and so Davy recommended the RI to appoint Faraday as a Chemical Assistant from 1st March 1813. Under Davy's supervision and guidance, Faraday quickly established himself not only as an outstanding experimenter, but also as a brilliant observer and logician.

His education was augmented during the 19 month European Tour (from 13th October 1813 until 23rd April 1815), on which Faraday was invited to serve as Davy's philosophical assistant. During the voyage, he was not well treated by Davy's pompous and domineering wife - Jane Apreece, a wealthy widow whom Davy had married on 11th April 1812. Nevertheless, he managed to maintain minimum contact with her, and developed his own programme of activities. He learnt French and had many opportunities to devise and carry out his own experiments. All the observations (geological, sociological, gastronomical, meteorological, physical and chemical) which he made during the journey were carefully recorded in a diary.

Extended tours of Europe were fashionable among the aristocracy at that time, but the fact that such a trip occurred at all was quite remarkable, considering that England was at war with France. Nevertheless, Napoleon 1 (1769-1821) (Emperor of France) was an avid supporter and enthusiast of science, and had personally invited Davy in order to present him with the Napoleon Prize. This had been awarded by the Institut de France in 1807, for his work: On some chemical agencies of Electricity. Davy's itinerary included many towns and cities - Rennes, Paris, Geneva, Zurich, Montpellier, Genoa, Florence, Rome, Naples, Rimini, Munich, Heidelberg, Brussels, Turin and Florence. The mode of transport was stage coach. The French school of chemistry was foremost in Europe at that time, and scientists were keen to meet one another and to discuss their findings. Faraday thus had a unique opportunity to meet distinguished scientists. These included: Joseph Gay Lussac (1778-1850) (chemist/physicist), François Arago (1786-1853) (astronomer/physicist), George Cuvier (1769-1832) (naturalist/zoologist), André Marie Ampère (1775-1836) (physicist/mathematician), Alessandro Volta (1745-1827) (physicist, chemist, pioneer of electrical sciences), Alexander von Humboldt (1786-1853) (geographer/naturalist/explorer) and Gustave de la Rive (1770-1873) (physicist) and his son Auguste (1801-1873). Auguste was later to become a distinguished physicist with whom Faraday maintained a close friendship for many years.

On his return to London in 1815, at the age of 24, Faraday was well equipped, both intellectually and psychologically, to embark on a career in science.

His contribution to Education

Why did he become a lecturer in the first place? Partly out of his sense of duty towards the Royal Institution, of which he was an employee, and partly through his appreciation of the great importance of passing on scientific knowledge to others, at a time when discoveries were being made at a rapid pace. Additionally, he had a great liking for children, playing hide and seek with his nieces and nephews in the grand rooms of the Royal Institution, and clearly thriving in their company: his warm relationship with children has been well documented [2]. Through his reading, experiences in the laboratory and those gained while travelling, he had developed a profound understanding of natural phenomena and was thus ideally qualified to teach.

At the age of 25 (in 1816) Faraday commenced his career as an educator, when he delivered lectures on chemistry to members of the City Philosophical Society. Aware of his shortcomings in the use of English, he took lessons in writing, over a period of 7 years, from Edward Magrath. In 1824 he began lecturing at the Royal Institution, giving a series of 19 lectures on metals to medical students. He was appointed Director of the Laboratory of the RI in 1825, and gave lectures on a variety of scientific topics, to different audiences. Of these lectures, the series on the chemical history of a candle, became the most widely known. Faraday's career encompassed a wide variety of activities associated with science, but his contribution to education can be broadly classified under four headings:

1. The lecture series (consisting of 6 lectures, illustrated with experiments) entitled *The Chemical History of the Candle* which was delivered around the Christmas period on 19 occasions between 1827 and 1860.
2. His book entitled: *Chemical Manipulation* [3] - this was written for students, and was reprinted twice.
3. His involvement in policy on science education at a national level.
4. The debunking of scientific myths such as table turning, spiritualism and the apparent phenomenon of spontaneous generation by electrolysis.

In the present essay I shall focus on the first two of these four fields.

The Chemical History of the Candle

Faraday gave his first series of lectures "suited to a juvenile auditory" in 1827-1828. He was by no means the first natural philosopher to give popular (suitable for members of the public and children) lectures. Notable lecturers from the past include: Jean Beguin (1550-1620) [4], Nicholas Lemery (1645-1715) [5], Herman Boerhaave (1668-1738) [5], Joseph Black[2] (1728-1799) [5] and Jędrzej Śniadecki[3] (1768-1799) [6]. Due to the supreme quality of the lecture hall at the RI, the rapid developments in science at that time, and the central location, Faraday was in an excellent position to capture the imagination of his public. His natural talents included an outstanding capacity for observation and deduction, designing simple experiments to illustrate/prove an idea, a supremely logical mind, which he used to connect phenomena that were not obviously related, and a great facility in his use of language. He was humble, yet he had an enormous stage presence. This was the result of his profound knowledge of the subject matter and his deep religious belief - he was a devout Christian. This gave him the confidence and reassurance to know that by explaining the truth about the natural world and thus enlightening his audience, he was fulfilling an important vocation. Furthermore, on 18th June 1821 he had married Sarah Barnard. The marriage, although childless, was a very happy one and Sarah provided Michael with advice and loving support throughout his life.

In his short monograph on Faraday, Sir William Bragg, who had had the rare opportunity to interview an ageing attendee (Sir Alfred Yarrow (1842-1932)) of Faraday's lectures, stated that they were delivered with "clearness…, power…, simplicity… and charm…" [7]. The purpose of the lectures was to use the well-known phenomenon

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[2] It is of interest to note that Thomson had good reason for his appraisal of Black: "I can speak of them (lectures) from experience, for I was fortunate enough to hear the last course of lectures (winter 1796-1797 - Z.S.) which he ever delivered."

[3] Śniadecki (Professor of Chemistry at the Universirty of Vilno (Vilnius) was the first in Europe to teach the new Lavoisierian Chemistry. His funeral in May 1838, was attended by 20,000 people.

of a burning candle in order to develop, in an easily digestible form, an understanding of the main tenets of chemistry.

At that time, the state of scientific knowledge was different from that of today. Although flames had been utilized (for a wide variety of applications - e.g. domestic heating, cooking, illumination, smelting of metals) for millennia, and although they had instilled awe, wonder and amazement, an experimentally verifiable explanation of the process of burning had only been given by Lavoisier (1743-1794) a few decades earlier [8]. This explanation was thus a very novel idea in Faraday's time - **burning is a process in which oxygen from the air combines chemically with the fuel to form new substances (products), called oxides**. Furthermore, the states of matter: gas, liquid, and solid, had only recently been recognised as a particularly useful way of interpreting many phenomena, and the idea of particles, especially atoms (as exemplified by Dalton's Atomic Theory of 1808) was still in its infancy.

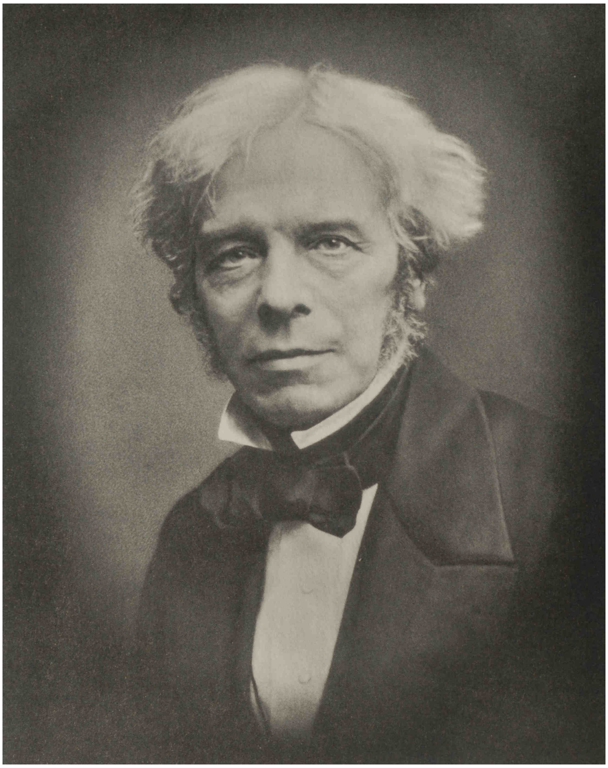


Photo 1. Photograph of Michael Faraday by John Watkins, c. April 1861 [9]

Analysis and discussion

I am going to analyse a short section from lecture no. 5 [9]. It consists of 6 experiments, nos. 132-137, and is entitled: **carbonic acid**. In today's parlance, carbonic acid is an aqueous solution of carbon dioxide in water - H_2CO_3(aq), whereas in Faraday's time it was the term for **gaseous carbon dioxide.**

Faraday has already at this stage demonstrated that when a candle burns in air, it produces soot (a form of carbon) and water. The water, he reaffirms, is “produced from the candle by the action of the air upon its hydrogen”. He then states that in addition to these two products, there is a third product of combustion to which he will now turn his attention.

It might seem obvious that this gaseous invisible product of burning does not itself burn, and neither does it support combustion. But in his simple experiment, Faraday experimentally proves precisely this point: the vapour which arises from a burning candle puts out a burning splint.

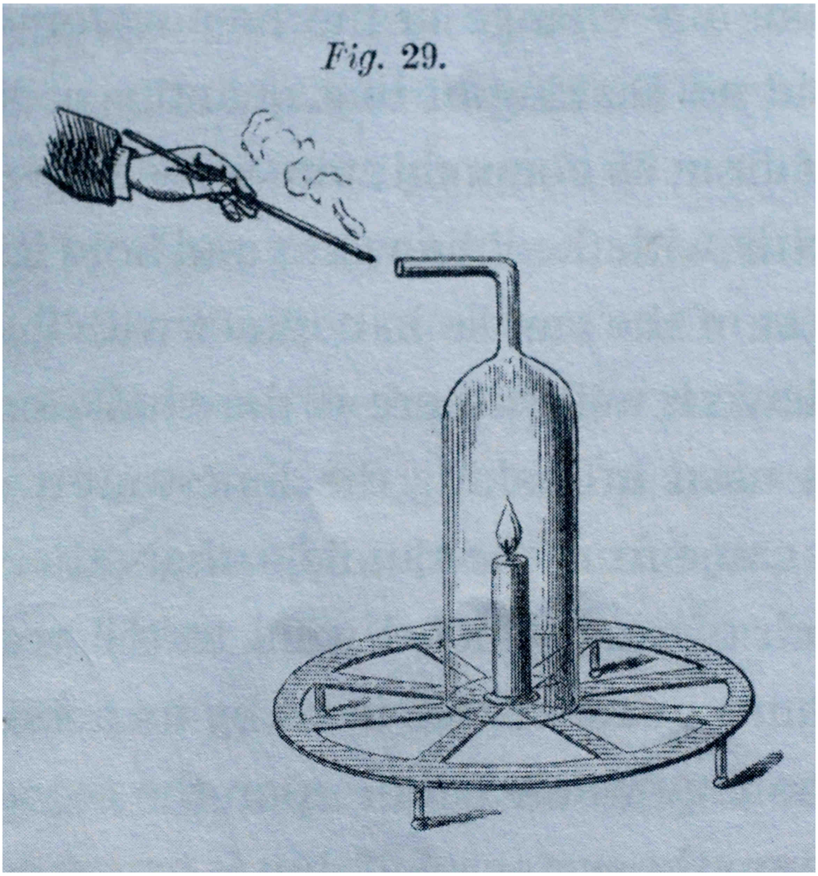


Photo 2. Figure 29 from the first (1861) edition of *Chemical History of a Candle* [9]

So what does it contain, and how is it different from air? Furthermore, argues Faraday, can it be shown that it is similar to a gas which he had previously demonstrated? Faraday had already explained that air is primarily a mixture of oxygen and nitrogen (a very difficult concept to accept at that time), and that oxygen is “consumed” during combustion. So does this mean that only the “carcass” of the air, or nitrogen, is left? He then goes on to demonstrate the presence of another gas, carbonic acid. He begins by taking some quicklime (calcium oxide, CaO), adding it to water and filtering it. Noting that the filtrate is perfectly clear, like pure water, he calls it lime water. (This term is still used today and is, in fact, a saturated solution of calcium hydroxide in water, which is formed by the calcium oxide reacting with water in accordance with the equation - $CaO(s) + H_2O(l) \rightarrow Ca(OH)_2(aq)$). He shakes some lime water in a test tube with air and shows that air has no effect on it - an important control experiment. He then pours some of this lime water into a jar which contains "air from the candle". The lime water immediately turns milky. Faraday then states that since neither oxygen nor nitrogen in the air can achieve this effect, then clearly there is a gaseous product of combustion which is not normally present in air but which is formed as the candle burns. This, using his own words, is: "that other product which we are in search of, and which I want to tell you about today".

Using the simplest of experiments, the simplest of substances and procedures, Faraday has thus **proven** to his audience, that during the combustion of a candle, an invisible gaseous product is formed, which turns lime water milky. He then further deduces that the white substance, which causes the milkiness has been formed from the lime water reacting with the gaseous exhalation from the candle. He then informs his audience, that the white powder (suspended in the water to give it its milkiness, which we recognise today as calcium carbonate, $CaCO_3$), "produced by the lime-water and the vapour from the candle" is exactly the same as whitening, or chalk, which is used for painting the walls of barns, houses etc. He states that if this chalk is strongly heated, it emits the same gaseous exhalation as a burning candle. This reaction can be represented by means of the equation: $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$. It is interesting to note that occasionally, when time or circumstances did not allow, Faraday did **not** prove a fact by experiment. Today we know that the carbon constituent of the hydrocarbon mixture wax is oxidized to carbon dioxide. We can represent this by the equation: $[C] + O_2 \rightarrow CO_2$. The train of thought can be summarized in Figure 1.

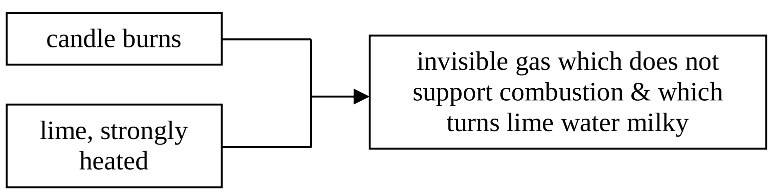


Fig. 1. A simple representation of Faraday's logic, which shows that the same invisible gas is produced when a candle burns, as when lime is strongly heated

Faraday then explains that there are many natural substances which contain this "curious air" in the fixed state and that they are very abundant and common e.g. limestone, chalk, marble, coral, shells. He then adds that Dr Black[4], had called it "fixed air". This was because in these solids, this air had "lost its quality of air, and assumed the condition of a solid body". The idea of a gaseous substance forming part of a solid body is difficult to understand - for it is counter-intuitive. Indeed the word "fixed" had been used for some time to express the idea of a gaseous (or spirituous) substance forming part of a solid body [10].

[4] Joseph Black (1728-1799) (Professor of Edinburgh and Glasgow Universities) discovered this "curious air" as the product of the thermal decomposition of carbonates, and had also noted the milkiness produced by bubbling it through lime water

For his next experiment, Faraday asserts that “we can easily get this air from marble”. He always uses **control experiments**, even to illustrate the obvious, which are **most important tools** in the teaching of science. In this case, he lowers a burning taper into an “empty” jar: it continues to burn, since air is present. He next pours muriatic (hydrochloric) acid into the jar and lowers another burning splint into it, which also continues to burn. He then adds “a very beautiful and superior marble” - note the use of unnecessary embellishments to emphasize his own enthusiasm - to the acid, whereupon “a great boiling apparently goes on”. The audience would not have experienced the phenomenon of bubbling (or effervescence) in a chemical reaction, hence the use of the word “apparently”. A burning taper, when lowered into this “steam”, is extinguished however, just as was the case with the “air which issued from the end of the chimney over the burning candle.” These 3 simple experiments are illustrated diagrammatically in Figure 2.

a) b) c)

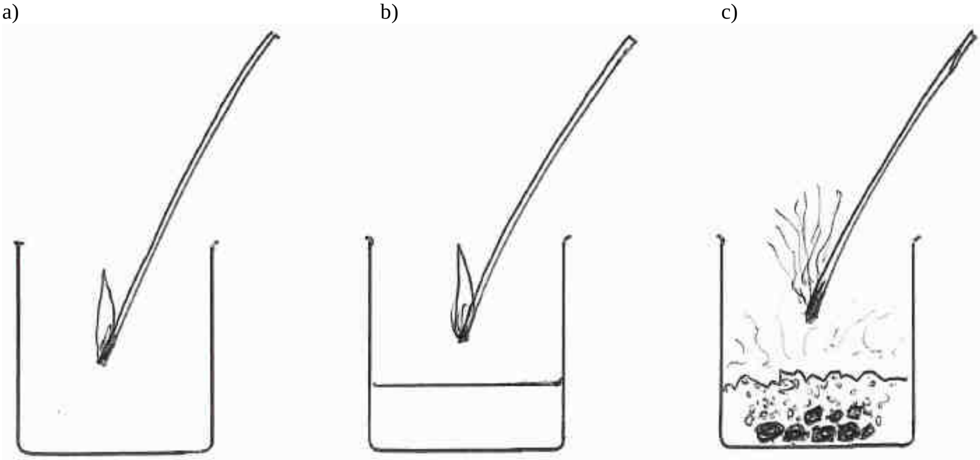


Fig. 2. a) Burning splint in empty jar, b) burning splint in jar with muriatic acid, c) burning splint in jar with muriatic acid and marble, is extinguished

At this point it would have made sense to show that this gas is *identical* to the one produced by the burning candle, by bubbling it through lime water - which would turn milky. However, on this occasion, Faraday merely asserts that the two gases are identical.

In his next experiment however, Faraday does show that both marble and chalk give exactly the same gas when treated with an acid: this implies that they both have the same chemical composition. On this occasion, he uses sulphuric acid, and reacts it with whitening (a suspension of calcium carbonate in water). Faraday’s observation that both muriatic and sulphuric acids give similar reactions is entirely consistent with known facts. In the case of sulphuric acid however, the product leaves an insoluble substance (calcium sulphate), whereas in the case of muriatic acid, the calcium compound produced (calcium chloride) is soluble in water.

$$CaCO_3(s) + H_2SO_4(aq) \rightarrow CaSO_4(s) + CO_2(g) + H_2O(l)$$

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

He concludes this section with the assertion that regardless of the way in which carbonic acid is formed, it will always behave in the same way i.e. it will have identical chemical and physical properties.

Faraday commences the next section by repeating experiments, which demonstrate that carbonic acid is neither combustible, nor does it support combustion. This is done to re-emphasize what he has already taught. He adds that clearly it does not dissolve readily, since it can be collected over water. However, he then notes that although carbonic acid *appears* to be insoluble in water, when bubbled through water "all night long", it causes two effects: (i) the water tastes "a little acid to the mouth", and (ii) it turns lime water milky. (He demonstrates this by pouring some of the acidified water into lime water, which turns milky.) These observations **prove** that carbonic acid is slightly soluble in water and is thus "one of the constituents to make carbonate of lime or lime-stone".

Summary

The analysis of the passage which we have examined shows the great effort which Faraday makes, to carefully analyse a few simple observations: he is not concerned about the experiments being spectacular, but about explaining every observation in detail, thus enabling the listener not only to **learn** the processes, but also to **understand** them. His philosophy is simple enough - you can only learn and understand what you see.

We can represent his train of thought by means of Table 1.

Table 1

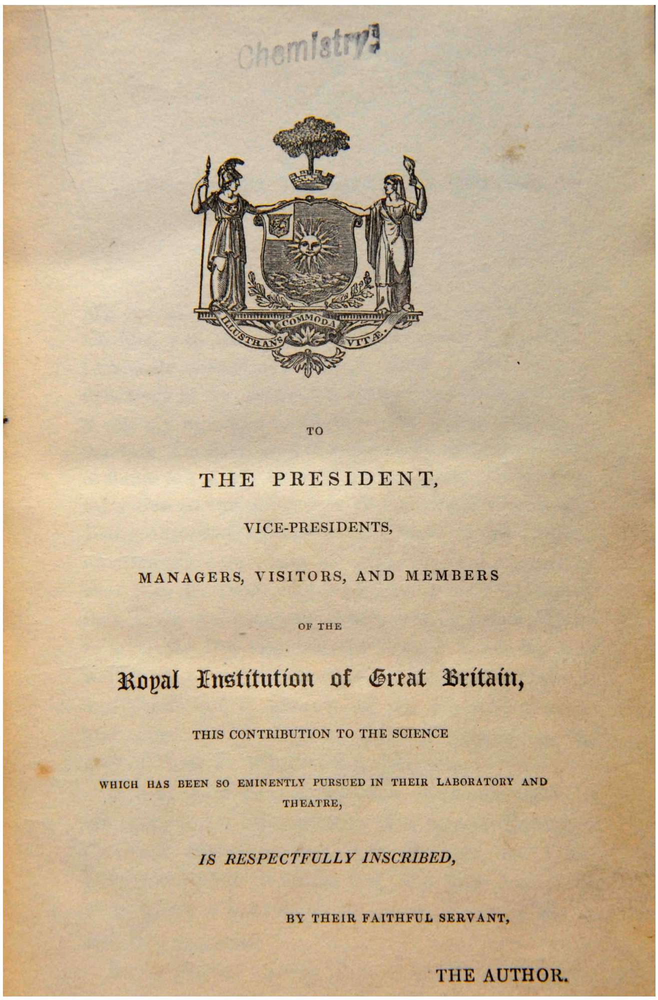
A summary of Faraday's experiments, which prove, by experiment, that carbonic acid is formed during the combustion of a candle

Experiment	Observation	Inference
Burn candle and test exhaled air with burning splint	Splint extinguished	Exhaled air does not support combustion
Add lime to water, filter, and shake filtrate in air	No reaction	Air does not affect lime water
Shake lime water with exhaled air	Lime water turns milky	The exhaled air contains a new gas, which is a product of burning of the candle
Add marble to muriatic acid and test gaseous product with lime water	Lime water turns milky	Marble contains, chemically fixed, the same gas that is formed when a candle burns
React powdered marble with sulphuric acid and test gaseous product with lime water	Lime water turns milky	The gas released from marble is independent of the acid which is used
Put burning splint into gas	Flame is extinguished	Revision/reminder of the fact that carbonic acid does not support combustion and that it does not burn
Bubble carbonic acid through water overnight, taste the product, and test it with lime water	Tastes sour, lime water turns milky	Carbonic acid is soluble in water

A very simple scheme of experiments, yet logical and profound teaching.

Chemical Manipulation [3] - for the present discussion I shall use the Third (revised) Edition, published in 1842

In addition to the several hundred scientific/research papers, which Faraday published, he wrote one book with a specifically educational aim: *Chemical Manipulation* [3]. This was based on the course of 12 lectures (on Chemical Manipulation) which he had delivered at The London Institution in 1816. The Preface to the second edition opens with his raison d'être: "My reason for venturing to add a new work on Chemistry to the many excellent productions which previously existed, was because there seemed to be a deficiency in the particular kind of instruction which it was my intention to convey… Being intended especially as a book of instruction, no attempts were made to render it pleasing, otherwise than by rendering it effectual; for I concluded that, if the work taught clearly what it was intended to inculcate, the high interest always belonging to a well made or successful experiment would be abundantly sufficient to give it all the requisite charms, and more than enough to make it valuable in the eyes of those for whom it was designed." Faraday is thus emphasizing the importance of chemistry as an **experimental** science, and that it should be taught **primarily** by experiment.



TO

THE PRESIDENT,

VICE-PRESIDENTS,

MANAGERS, VISITORS, AND MEMBERS

OF THE

Royal Institution of Great Britain,

THIS CONTRIBUTION TO THE SCIENCE

WHICH HAS BEEN SO EMINENTLY PURSUED IN THEIR LABORATORY AND THEATRE,

IS RESPECTFULLY INSCRIBED,

BY THEIR FAITHFUL SERVANT,

THE AUTHOR.

Photo 3. Faraday's dedication page from *Chemical Manipulation* [3]. Note the beautiful coat of arms, with the inscription: Illustrans commoda vitae (illustrating the benefits to life), and the 11 different font types/sizes!

Chemical Manipulation [3] is a substantial work: it is 664 pages long, and contains in its main body 1388 manipulations (23 sections, pp. 11-598), to which are added a further 326 manipulations (24th section entitled: *A Course of Inductive and Instructive Practices* which is divided into 23 topics, pp. 598-648). These further 326 experiments consist of short practical exercises involving specific substances. The total number of experimental procedures is 1714. There are 127 line drawings of modest quality, and four tables of data. Some of the important sub sections include the following techniques: (1) Separation - filtration, crystallization, sublimation, distillation, decantation, evaporation, (2) Manipulation - furnaces, blowlamps, crucibles, pneumatic trough - handling of gases, corks, paper, glass tubing/apparatus, electric cells/batteries, (3) Quantitative - use of chemical balance, (gravimetric), thermometers, measuring cylinders (volumetric).

In reading this book, we can look into the mind of a great scientist - what transpires is the considerable attention to detail - cleanliness, orderliness, safety. At the same time we can discern the enormous body of factual knowledge which Faraday possessed. He was very widely read, as is shown by numerous references to other scientists and to articles in philosophical journals. Furthermore, his extraordinary level of organisation is shown by the multitude of cross references to all his procedures.

Six examples have been chosen to illustrate the nature and content of this work.

1. The first example relates to the use of a vegetable based indicator: red cabbage. Its extract displays a remarkable range of colours - yellow, green, blue, mauve, red - which are dependent on the relative acidity/alkalinity of its environment: it had therefore served effectively as an indicator for some time. Its disadvantage however, is that on standing at ambient temperatures the red cabbage rapidly degrades, and a foul odour is produced. On page 275, Manipulation [618], Faraday gives instructions for preparing an improved red cabbage extract: "The only substance of the kind perhaps worth keeping in solution is an acid infusion of red cabbage. For its preparation, one or more red cabbages should be cut into strips, and boiling water poured upon the pieces; a little dilute sulphuric acid is to be added, and the whole well stirred: it is then to be covered and kept hot as long as possible, or, if convenient, should be heated nearly to boiling for an hour or two in a copper or earthen vessel. The quantity of water to be added at first should be sufficient to cover the cabbage, and the sulphuric acid should be in the proportion of about half an ounce of strong oil of vitriol by measure to each good sized plant. This being done, the fluid should be separated and drained off, and as much more hot water poured on as will cover the solid residue, adding a very little sulphuric acid. The whole is to be closed up, and suffered to stand until cold, and then the liquid poured off and added to the former infusion. The cabbage may now be thrown away. The infusion is to be evaporated to one-half or one-third of its first bulk, poured into a jar, allowed to settle, and the clear red fluid decanted and preserved in bottles. The residue may have water added to it, the solid part be allowed to subside; the clear liquor drawn off, evaporated and added to the former, or it may be dismissed altogether. This solution will keep for a year".

2. Second example

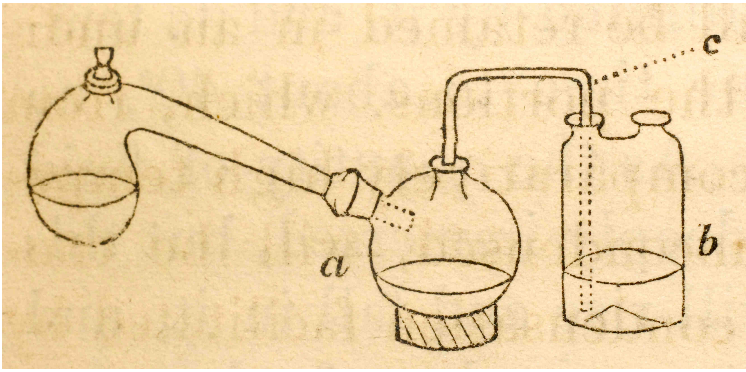


Photo 4. A diagram on page 220, showing an experimental arrangement with a retort flask, gives an example of the illustrations in this book. Manipulation [475] *The accompanying figure… may be supposed to be a distillation of nitric acid from nitre and sulphuric acid* [3]

3. Third example

154. The following are useful estimates and comparisons of certain measures, both linear and cubic, with the weights of the cubic measures in grains of distilled water added.

	Inches.
Yard	36
Metre	39.37079
Decimetre	3.93708
Centimetre	0.39370
Millimetre	0.03937

The seconds pendulum vibrating at London, 39,13929 inches.

	Cubic Inches.		Grains of distilled Water.
Imperial gallon . .	277.274	....	70000
Imperial pint . . .	34.65925	....	8750
Imperial fluid ounce .	1.7329625	....	437.5
The old wine pint .	28.8827	....	7291.666
Old fluid ounce . .	1.805169	....	455.73
Cubic inch . . .	1.	....	252.458
Litre	61.02525	....	15406.312
Decilitre	6.10252	....	1540.631
Centilitre . . .	0.61025	....	154.063
Millilitre	0.06102	....	15.406

Photo 5. An example of a data table (conversion of units) on page 83 serves to show varying numbers of significant figures, some of which were experimentally unrealistic! [5]

4. Section XXI beginning on page 558, is especially written for children: "*General Rules for Young Experimenters*". Experiment [1292] is concerned with analysis: "On commencing the examination of a substance of unknown nature, the experimenter should proceed to the most general and instructive experiments, and then to those which are more particular. He should therefore apply heat to the substance contained in a tube and remark whether it fuse or volatilize; he should then heat it in the open air upon platina foil, observing whether it will burn or not. Whether it will evolve fumes, &c. Afterwards it should be heated in water in a tube, and observed whether it be soluble; and then trials should be made to ascertain if it be sapid, if it be soluble in alcohol, &c. These general examinations will soon indicate to what class of bodies the substance belongs, and will point out the particular train of investigation it may require; after which the substance may be dissolved by acids or alkalies, or any other proper solvent, and its properties more minutely ascertained."
   Using today's language we could summarize this sequence as follows: Effect of heat, does it burn in air, solubility in water and/or alcohol (hence organic/inorganic), reaction with acids/alkalis.
5. Section XXIV on page 598, is entitled: "A COURSE OF INDUCTIVE AND INSTRUCTIVE PRACTICES" It begins thus: "The chemical student must not expect that, by reading this book, he will find himself ready and expert in the application of the various methods and contrivances which it describes. No valuable experimental knowledge can be obtained at so cheap a rate. Practice is essential to that facility, without which nothing dependant on the hands can be done well."
   More simply put: "practice makes perfect!"
6. Expt. [205] (page 628) describes the preparation of olefiant gas (ethene): "Mix one volume of good alcohol with two volumes of oil of vitriol carefully (436), because of the heat liberated. Distil the mixture in a glass retort (386) applying the heat of an oil lamp (212, 386), and receive the gas into jars over water (749); it will be olefiant gas, and should burn with a brilliant flame….." Expt [319] (page 648) describes a simple method for making ice: "Freeze a little water in a cup made of tin foil (1349), by a mixture of ice and salt".

Summary

Chemical Manipulation not only gives an excellent insight into Faraday's brilliant mind but it also serves to remind us of the vast body of chemical knowledge and laboratory techniques which were in use during the first half of the 19th century.

Conclusions

Faraday had a no-nonsense approach in his assessment of the popular culture of his times. In a private letter to his friend Christian Schönbein (1799-1868) (Professor of Chemistry at Basel University) he wrote: "What a weak, credulous, incredulous, unbelieving, superstitious, bold, frightened, what a ridiculous world ours is, as far as concerns the mind of man. How full of inconsistencies, contradictions and absurdities it is. I declare that taking the average of many minds that have recently come before me (and apart from that spirit which God has placed in each) and accepting for a moment that average as a standard, I should prefer the obedience, affections and instinct of a dog before it” [11]. Being acutely aware of the disharmony which such a statement might cause, he added: “Do not whisper this however to others.”

Is today’s world any different? To what extent are we succeeding in chemical education for young people? Faraday the Educator would, I have little doubt, not have approved of today’s school system. His approach to chemical education was adopted by brilliant scholars, authors and teachers. These included James Riddick Partington (1886-1965) (Professor of Chemistry at QMC, London) and John Read (1884-1963) (Professor of Chemistry at the University of St Andrew’s). Both of these outstanding and popular (at all levels) authors and teachers had a profound understanding of chemistry, its history and its place and ramifications in society. Their written works and lectures enabled generations of young people to gain respect, understanding and admiration for the achievements of chemistry.

In today’s school syllabuses, where chemistry forms a compulsory part of the education curriculum, there is no historical content and only a superficial treatment of facts and concepts. By contrast, the History of Art A level syllabus is taught in many schools. An History of Science, or History of Science & Technology syllabus does not exist. The History of Chemistry is today not taught in any university course. As a postgraduate student I attended the last year of Dr. Bill Smeaton’s (1925-2002) excellent and popular History of Chemistry course for undergraduates at UCL, in 1983-1984.

It is no surprise therefore that Faraday‘s damning statement of 1853 is today truer than ever before. The quality of the public understanding of science, and an informed respect and understanding of its achievements can only be improved by restructuring the education curriculum.

The History of Science & Technology should be taught as a core subject for all children from the ages of 7-16. It would be experiment based with a focus on the development of scientific concepts and inventions. It would include a study of the *dramatis personae* involved - and who better than Michael Faraday as one example? The separate sciences: chemistry, biology and physics, would be taught as optional subjects for children from the ages of 13 to 18. This programme would have had the approval of Faraday the educator.

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MICHAŁ FARADAY JAKO PEDAGOG - ESEJ W 150. ROCZNICĘ JEGO ŚMIERCI

Abstrakt: Michał Faraday (1791-1867) jest powszechnie znany i poważany ze względu na jego wielki wkład w rozwój nauki i technologii w pierwszej połowie dziewiętnastego wieku. Natomiast jest On mniej znany z działalności pedagogicznej. W tym eseju autor opisuje proces kształcenia młodego Faradaya oraz sposób, w jaki doświadczenie życiowe inspirowało go do przekazywania wiedzy innym. Jego popularny podręcznik dla studentów pt. *Chemical Manipulation* (London, 1828) oraz seria popularno-naukowych wykładów nosząca tytuł *Chemiczna Historia Świecy*, wygłaszana (w latach 1825-1860) 19 razy w brytyjskim Królewskim Instytucie (Royal Institution) w Londynie, świadczą o wybitnym talencie i pasji dydaktycznej Michała Faradaya. Autor rozpatruje metodologię Faradaya nauczania chemii przez dokonywanie analizy części jednego z wykładów oraz przez streszczenie zawartości *Chemical Manipulation* i krótką dyskusję na temat kilku fragmentów z tego podręcznika. Biorąc podejście Faradaya do nauczania chemii jako wzór, autor stawia pod znakiem zapytania dzisiejszy program nauczania chemii w szkołach i sugeruje sposób jego udoskonalenia.

Słowa kluczowe: Michał Faraday, nauczanie chemii, nauczanie poprzez pokaz chemiczny, pokaz chemiczny, wykłady Faradaya, wyjaśnienie procesu spalania