FARADAY'S 1822 "CHEMICAL HINTS" NOTEBOOK AND THE SEMANTICS OF CHEMICAL DISCOURSE

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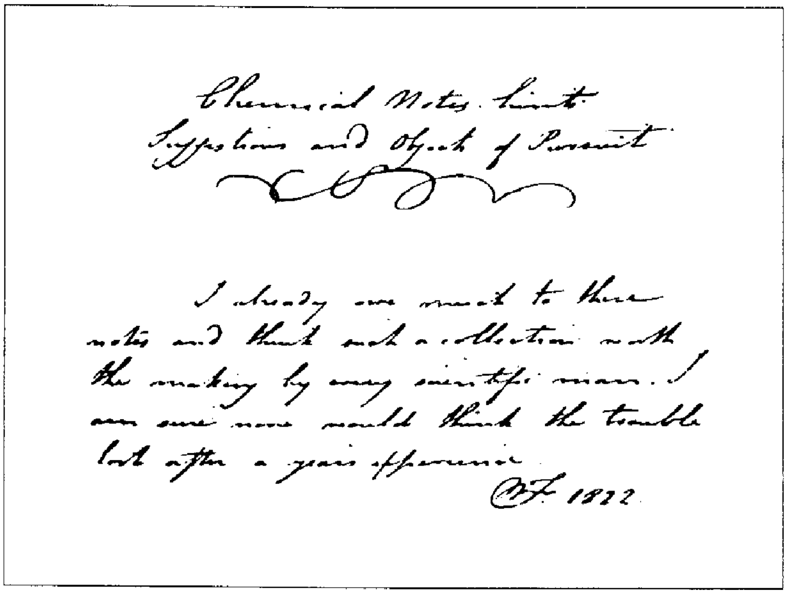
To examine the notebook of a famous scientist is a special experience. One feels privileged, blessed with a chance to see into the inner workings of genius. But coming to grips with that genius is a subtler and more difficult process than one might at first imagine, not least because, amid all of the awe and reverence appropriate to the occasion, one can't sometimes avoid a contrary feeling, that the notebook in hand is really a sparse thing, ephemeral stuff hardly worthy of serious attention except, perhaps, for reasons of sentiment.

Michael Faraday's 1822 notebook, which he titled *Chemical Notes, Hints, Suggestions, and Objects of Pursuit*, must have struck many of its examiners over the years in something of this fashion (1). A brief glance reveals only a modest volume, far shorter than the celebrated multi-volumed *Diary* (2). By contrast, the *Chemical Notes* seems a group of jottings, characterized by large runs of blank pages (especially at the end) and by seemingly disjointed lists of topics, substances, and unsolved problems. It lacks the chronological flow of the great *Diary* and does not reward the reader with detailed accounts of great discoveries. Many must, over the years, have glanced once or twice at it and returned to the safer, richer haven of the laboratory records, seemingly fitter tributes to one of the greatest scientists of the 19th century.


Chemical Notes, Hints
Suggestions and Objects of Pursuit

I already owe much to these notes and think such a collection worth the making by every scientific man. I am sure none would think the trouble lost after a years experience
MF 1822

Handwritten title page of the "Chemical Hints" notebook.

Yet Faraday himself felt differently. On the title page of the 1822 notebook, he placed the following initialed and dated (1822) note (1):

> I already owe much to these notes and think such a collection worth the making by every scientific man. I am sure none would think the trouble lost after a year's experience.

What led him to make such a strong claim, the like of which appears in none of his other notebooks? Why would he single out for praise a book which he clearly abandoned (as we know from the many blank spaces left unused)? The puzzle is even greater when one realizes that the notebook was of a type that played only a transient role in the long development of his active organization of records and notes, falling roughly halfway between his earliest efforts, the 1809-10 *Common-Place Book* (3), and the emergence of his full-blown, numbered *Diary*, after 1832 (4). What's so special about this transient, short effort?

To answer the question requires a closer look at the content of the notebook. I'd like to do this in two stages, describing first a relatively conventional view, one that singles out the 1822 notebook because it provides tantalizing anticipations of some of his famous later discoveries. Secondly, I'd like to take a deeper view, discussing some of the semantic principles that emerge when we look closely at the contextual meanings of the terms used by Faraday in the notebook. It's this second view that "opens" the notebook for a modern reader in a way which is more valid historically, more accurate cognitively, and more interesting. Along the way, there might be a lesson or two about the nature of scientific thought; insights into the mysterious workings of genius.

The notebook is a small volume, 6 1/2" by 8" and about 3/4" thick. It is bound in paper-covered boards with a sewn leather spine which is quite worn. Faraday was a skilled bookbinder by training and apparently bound the notebook himself (5) . The notebook is written on paper watermarked "H. Smith & Son 1821"; thus 1821 is the *earliest* date that Faraday could have written the notebook, especially since the clustering of watermarks suggests that the notebook was never disbound. Some of the entries could, of course, have been recopied from earlier notes, though this seems unlikely. The volume bears the marks of frequent use, showing that it was not a static repository, to be ignored after entries were made. Many leaves in the book are blank, indicating that Faraday bound and numbered the notebook pages expecting to make later entries under the topics listed in the contents.

The dated comment on the title page, and the watermarks, make it clear that he bound the book no later than 1822. It is also clear that he used it after 1822, because of the dated comments on some entries and the dated deletion of others. Exactly when Faraday composed and wrote the entries is important. If we can determine something of the chronology of the entries, then the notebook can serve as a clue to his working methods. For example, if we were to conclude that it was written primarily between 1821 and 1822, then we would have to conclude further that the notebook is a remarkable prevision of a lifetime's worth of research - that Faraday had anticipated himself in 1822. This is too extreme, however, since there is clear evidence that Faraday made entries after 1822. For example, Bradley has noted that the rotating copper plates sketched by Faraday on pages 72 and 73 are remarkably like those used by Arago in the 1825 discovery now known as "Arago's Effect", (the tendency of a copper plate mounted on an axis to turn along with a magnet which is rotating nearby) (6). If Faraday's sketch was inspired by Arago, then clearly he was still making entries in this notebook as late as 1825, by which date he was clearly keeping other notebooks as well. There is further evidence that Faraday was using the notebook after 1822. For example, there are a number of crossed out passages, some of which are dated, the latest of which is 3 November 1824. Such crossed out entries represent experiments or suggestions which he later conducted, updating his earlier entries in the 1822 book.

A quick browse through the notebook turns up many examples of the prescient character of the 1822 notebook. On page 73 is an entry and a sketch that suggests his later much-heralded discovery of electromagnetic induction in 1831. The description of "magnets in copper coils connected with other coils and galvanometer," and the accompanying sketch (figure 1), are uncannily like the apparatus used to first identify the occurrence of induction. In fact, this apparatus could have served for the discovery, provided that the magnet was moved. Why did Faraday not make the discovery in 1822, or, allowing for the possibility of a later entry, in 1825? The answer is complex and must rely on the fact that it was not until 1831 that he realized the importance of looking for a "transient" induction effect rather than a continuous one (7). What is clear is that he had most of the essential components of a successful experiment in the 1820s.

It is interesting to note that the entry occurs in the context of the section on "Heat & Light". This is not so puzzling as it may seem at first sight, since for Faraday, as for most other scientists at that time, heat and light were regarded as "imponderable matter", which, together with Davy's then-recent arguments for the centrality of electricity in the constitution of matter, made the topics of electricity, magnetism, heat, and light closely associated problems. In the 1820s there was no way to rule out (or rule in, of course) the possibility that electricity and magnetism were entities of a basically similar sort as heat and light.

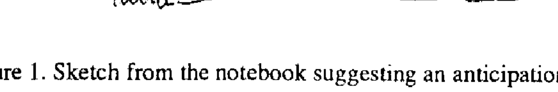


Figure 1. Sketch from the notebook suggesting an anticipation of Faraday's later work on electromagnetic induction.

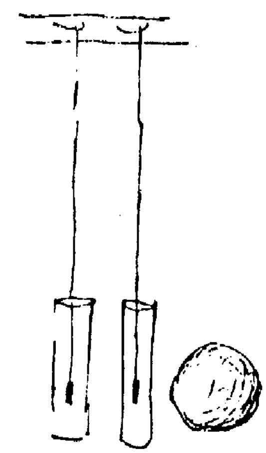


Figure 2. A sketch from the notebook outlining an experiment to detect a possible relationship between gravity and electromagnetism. This search for a unification of the various forces of nature was one of Faraday's life-long preoccupations.

Many of the other research programs that Faraday carried out in later years are foreshadowed in the 1822 notebook. His 1831 researches on vibrating plates, for example, are prefigured on page 93, where he devotes an entire page to the "Motions of fine particles on elastic plates" (8). Here we have what is apparently a late entry, done not too long in advance of the research itself (which is in the *Diary* for 1831), since he refers to issues that were only raised in Savart's 1827 research on such plates. Savart thought he had found a place of secondary vibration, in addition to the already-known places of nodal vibration familiar from Chladni's research. In 1831, Faraday showed that Savart was wrong, that some of the peculiarities of particle motion on the surface of vibrating plates could be attributed to air currents. In the notebook, we can see that this idea had already occurred, since he refers to "Currents of smoke on plates in still air" and to "Currents under water - shown by dropping coloured particles on to different parts of the plates".

Faraday's life-long preoccupation with the possible relation of gravity and electricity appears on page 10 (figure 2), where he also suggests that magnetism might be relevant. Faraday's predilection for a "unified force" view of the world is reflected here as well. He failed, of course, but not for want of trying. Over the years he repeatedly returned to the possible relation of gravity and electricity or magnetism, but, like Einstein, he never found his unified field theory!

Some discoveries show up after-the-fact, for example, his discovery of benzene ("Bi Carburet of Hydrogen") in 1825 appears in the section on "Sulphur", where he suggests "Bi car hydrogen & sulphur in bottom of a flask - heat" as a possible experiment, and, a few lines further on, to the possibility of a reaction with sulphurets of lead or antimony. Clearly this is a late entry (and it does occur at the end of a section, followed by a page and a half left blank), but it illustrates the fertility of his questioning approach - a newly discovered substance is no excuse for sitting back! Reacting benzene with sulphur or a sulphur compound makes sense here, since, in the original report, he paid special attention to the reaction of sulphuric acid and benzene (9).

Perhaps the most interesting aspect of the 1822 Notebook requires another level of reading. When, for example, Faraday heads a section "Heat & Light", we think we know what he means. The terms are familiar ones, and we find ourselves a bit surprised when he includes material on electricity and magnetism. As we have seen, the inclusion of these seemingly disparate topics is quite understandable once we have looked a bit deeper into the concepts of heat and of light as they were understood by Faraday. In fact, we must be careful to do this for all of his terminology - the language of chemistry has changed a great deal since 1822!

This problem was brought home to me in the course of editing the 1822 notebook for publication (10). My co-editor, David Gooding, and I wanted to include a glossary in the book, thinking particularly of those users who might find themselves puzzled by the many terms that are no longer in current use. "Iodide of zinc" should cause no problems, but what about "liquopodium" or "tutenage"? At first this seemed a straightforward editing task - just find some old dictionaries and look up the terms. This worked for "liquopodium" (a dry, powdered moss) and for "tutenage" (a zinc alloy). But then the problems began to mount. Should we state the modern equivalents and leave it at that? Such a strategy would work for the well-known "bi carburet of hydrogen" (now known as benzene), but it was going to be quite a task to correctly identify all of Faraday's terminology in this fashion! Furthermore, the strategy wouldn't work at all in those cases where the modern term and Faraday's term were the same, but had different meanings (as for "heat").

We ended up with a different sort of glossary than we had envisioned at the start. The best way out of the dilemma, it seemed to us, was to base all of the entries on sources as close to 1822 as we could find and to define all the terms, common and uncommon, familiar and unfamiliar, using quoted definitions appropriate to the times. This meant a very much longer glossary than first planned; in fact, the glossary is longer than the notebook itself. Since we couldn't always find definitions as such, we frequently had to quote passages from non-dictionary sources in the form of passages that revealed the meaning of the term. In effect, the glossary became almost entirely a list of quotations. As work progressed, the temptation to include interesting other bits of information (in the form, again, of contemporaneous quotes) was overwhelming. For example, the following entry for "hydriodic acid" includes information about its composition, its preparation, and its discovery (10):

Hydriodic Acid. "A gaseous compound of hydrogen and iodine, obtained by the mutual decomposition of iodide of phosphorous and water. It is composed of 126 iodine + 1 water" (Brande, 1845, p. 576). "First examined by Davy and Gay-Lussac ... 1814" (Brande, 1836, p. 367).

Much insight into the notebook is possible in this way. First, note that hydriodic acid was a "new" substance, having been discovered only eight years before Faraday began the notebook. Second, note that it was a "local" discovery - Faraday's mentor Humphry Davy shared in the discovery. Since Faraday and Davy were in Europe together in 1814, Faraday himself probably was a participant in the discovery. Note also that the composition is given in terms of the parts of water included.

Obviously, the choice of sources was important for this strategy to work. William Brande's two books (11, 12) were especially nice sources because Brande was Faraday's associate at the Royal Institution, having become Professor of Chemistry in 1813, the same year Faraday arrived as Davy's assistant. Another good source was the manuscript of Faraday's lectures on chemistry delivered before the City Philosophical Society from 1816 to 1818 (13). These were especially revealing for the basic terms (10):

Light. "Imponderable matter produces its most important effects and is best known to us when it is in a state of motion, or radient [sic]; hence it is called Radient [sic] Matter" (Faraday, 1816-18, p. 113).

Sometimes an entire program of research becomes meaningful when we see Faraday's starting point (10):

Gold. "... When beaten out and laid upon glass forms a screen of much transparency ... It has been said that this is occasioned by the existence of small holes in the leaves, which permit the light to pass ... supposing it to be true, the light which passes should be white, whereas it is coloured, and the colour is found to depend on the metal ... Pure gold appears by transmitted light of a purplish colour, gold with a little silver bluish with a little copper green ... and these changes of colour prove that light does not pass through such small accidental holes, but actually through the pores of the metal" (Faraday, 1816-18, pp. 118-119).

Here we get a sense of how certain topics and problems cluster together for Faraday. Consider, for example, Faraday's juxtaposition of queries about gold foil and electrical experiments on page 72 of the 1822 notebook. The topics move from the transparency and color of foil to the remarkably prescient "magnet in a good helix" comment. These seem unrelated, until one realizes that for Faraday a "unity of force" view of the world means that light and its interactions with material substances is a central topic. From the standpoint of the corpuscular theory of light, such interaction, in the absence of chemical change, is puzzling. But if the elementary forces of electricity and magnetism are indeed involved in the construction of matter, it is not so surprising. Gold foil is clearly a good place to look because gold foil changes color (from gold to green) when one changes from reflected light to transmitted light. Something is going on that could be relevant and so one naturally is lead to the possibility that a "Magnet behind gold leaves" will show something new. In later years, Faraday would spend a good deal of time on the investigation of gold by its optical effects on light (14). Thus, placed in its proper context, the juxtaposition is not so surprising and is certainly far from arbitrary!

Even such commonly used terms as "chlorine" reflect the very different context of Faraday's use of this term - for him it was a new word, reflecting its newly discovered elemental status - not a familiar element surrounded only by a technical definition. Similarly, the definitions given in the glossary are much closer to the everyday context of life in the early 19th century than the comparable terms would be today. Definitions are not given in terms of, say, atomic number (an unknown concept in 1822) but in terms of a substance's sensory attributes, its production, its use in commerce, its standing within someone's theory, etc. In general the definitions are closer to what Roberts calls the "sensuous" character of 18th century chemistry than to the 20th century abstractions of elements and compounds (15).

The notebook is a product of a specific context, a time and place which can be detected on every page. For example, it opens a window into one of the main centers of resistance to the new Daltonian atomic theory. Humphry Davy and W. T. Brande, and their protégé, Michael Faraday, did not believe Dalton's hypothesis that chemical phenomena could be explained by positing different, indivisible constituent atoms for each chemical element. To them, Dalton's views smacked of a static, mechanistic system that simply could not explain the active, dynamic universe. They saw this dynamism - not the mechanical interaction of inert corpuscles - as Newton's true legacy (16). Davy, in particular, was heavily influenced by Boscovich, for whom matter was constituted, not of hard material "stuff", but of active, immaterial, centers of force extending out to infinity. For Davy such views were closer to the nature of reality and the only ones capable of explaining his discoveries in electrochemistry. The elementary parts of a chemical substance had to be active, changeable things, capable of at least interacting with forces in a way that Dalton's "little circles" could not do (17, 18).

Faraday's 1822 notebook reflects similar concerns. Chemical questions appear to predominate, yet it includes queries and suggestions about electricity, heat, light, and many other topics that betray the force-centered chemistry of the anti-Dalton school. It should be remembered, too, that for Faraday (as for Davy), the electric current was a new and powerful research tool, to be used alongside more traditional analytical techniques (19). Although Faraday does use chemical equivalents, he avoids atomistic explanations and uses the more neutral term "particles" rather than the term "atom". Even as early as 1822, the notebook shows that Faraday was trying to link together the forces of nature as they were manifested to chemical philosophers through the chemical transformations familiar in the laboratory, in commerce, and in everyday life. In this sense, the notebook prefigures his 1832 discovery of "Faraday's Law of Electrolysis", perhaps the greatest triumph of this view (20).

Sometimes the most consequential evidence in historical study is derived from the smallest of details. This case is no exception. For the historian, it is perhaps an old lesson to say that one must understand the documents of the past in the terms that were relevant in that past - something akin to "translation" is central to all historical scholarship. But the point extends far beyond the literal meanings of terms for a very basic reason having to do with the organization of human memory. We do not construe meaning as simply a one-to-one identification of one term with its corresponding defining proposition. Instead, meaning arises out of networks of associated items. Until we penetrate the web of associations that constitute such networks, we cannot hope to penetrate the thoughts of those figures, like Faraday, that we hope to understand.

Glossaries of the type described help in this endeavor, but only to the extent that the user participates in them to a degree that allows an approximation to the original network. Simply looking up the term "Bi Carburet of Hydrogen" and translating it into "Benzene" does not help with such insight and can, to the extent that a modern network is invoked by the modern term, actually hinder a reading that approximates Faraday's understanding. Just as we learn more about his achievements by a close understanding of his laboratory apparatus, so too do we benefit by a close understanding of his linguistic tools. In this respect, each reader needs to be something of a cognitive scientist, constructing a model of Faraday's cognition that approximates as closely as possible the context of his own thought. To do that is to approach the mind of the master himself, to begin to appreciate the richness of Faraday's achievements and to feel a hint of the excitement that must have been his.

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FARADAY'S SEARCH FOR FLUORINE

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In a relatively concentrated and intense period of experimentation, from January 1834 to December 1835, Michael Faraday attempted to prepare elemental fluorine. He was not successful in those attempts. This article presents the background to Faraday's work, the status of fluorine in 1834, the details of Faraday's experimentation, and an assessment of the chemistry involved. It also speculates on Faraday's motivation in undertaking this endeavor.

In 1771 Carl Scheele, repeating and reinterpreting an experiment first reported by Marggraff in 1764, demonstrated that reaction between fluorspar (calcium fluoride) and sulfuric acid liberated a peculiar acid which was combined with lime in the fluorspar (1). This "flussaüre" was always accompanied by deposits of silica in the receiver, for Scheele used glass retorts for his experiments, and he opined that flussaüre might contain silica. In 1781 it was shown that the source of the silica in Scheele's experiments was the glass vessels (2). When Lavoisier advanced his new system in the *Traité élémentaire* in 1789, he described Scheele's acid as "l'acide fluorique" and, following his oxygen system of acids, asserted that it contained oxygen combined with an as yet unknown radical, "fluoricum" (3).

While Humphry Davy was engaged in clarifying the ele-

Carl Wilhelm Scheele