Faraday's Lecture on Gold

THE OPTICAL EFFECTS OF FINE PARTICLES

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"I have been occupying myself with gold this summer; I did not feel head-strong enough for stronger things. This work has been of the Mountain and Mouse fashion; and if I ever publish it and it comes to your sight I dare say you will think so."

The work referred to in this strange statement—in a letter from Michael Faraday to his old friend Professor C. F. Schönbein of Basle in the autumn of 1856—was published as the Bakerian Lecture for 1857 with the title "Experimental Relations of Gold (and other Metals) to Light". According to Faraday's diary he laboured on this project through eleven months, from February 2nd to December 20th, 1856, and found it hard to relinquish. In fact he kept at the work long after the manuscript was submitted to the Royal Society; the paper was received by *Philosophical Transactions* on November 19th, 1856, read by Faraday on February 5th, 1857, and published in Volume 147 for that year.

The original objective of this lengthy investigation was the devising of experiments to further our understanding of the phenomena of light and colour and in particular to confirm or modify the undulatory theory. Believing that valuable evidence might be obtained by introducing into a ray particles having a great influence on light, the particles to be very small by comparison with its wave lengths, he cast about among the metals for the one most suitable to his purposes and considered that

> "gold seemed especially fitted for experiments of this nature because of its comparative opacity amongst bodies, and yet possession of a real transparency; because of its development of colour both in the reflected and transmitted ray; because of the state of tenuity and division which it permitted with the preservation of its integrity as a metallic body; because of its supposed simplicity of character; and because known phenomena appeared to indicate that a mere variation in the size of its particles gave rise to a variety of resultant colours. Besides, the waves of light are so large compared to the dimensions of the particles of gold which in various conditions can be subjected to a ray, that it seemed probable the particles might come into effective relations to the much smaller vibrations of the ether particles; in which case, if reflection, refraction, absorption, etc., depended upon such relations, there was reason to expect that these functions would change sensibly by the substitution of different-sized particles of this metal for each other".

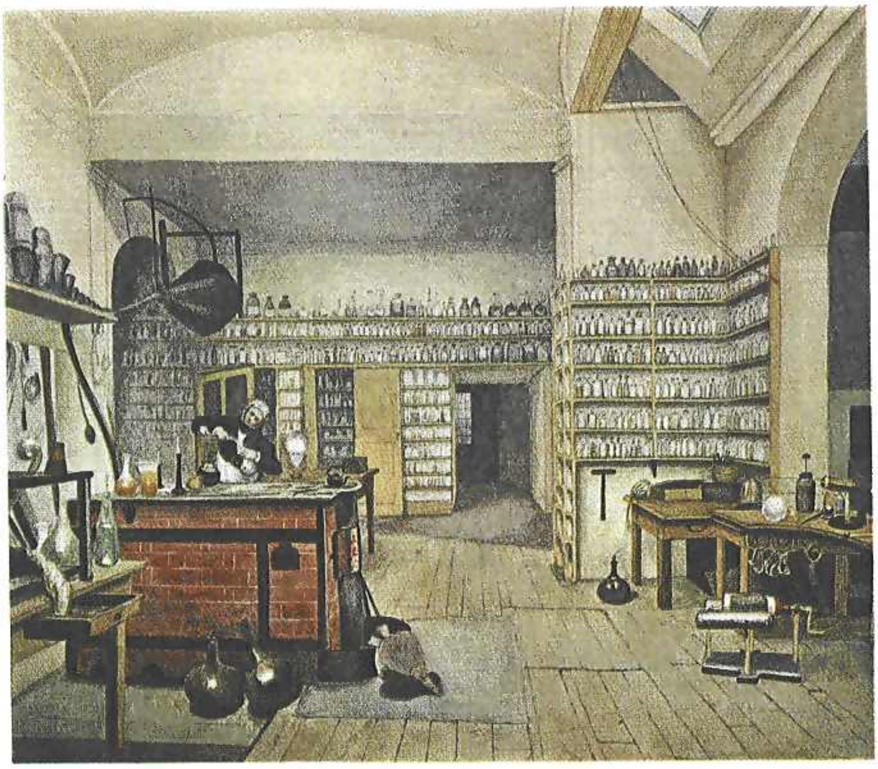
One can tell from the letter to Schönbein and from certain apologetic statements in the paper itself that Faraday was not completely satisfied with the work himself, although it would certainly be unfair to say that the Mountain had brought forth a Mouse. While the product evidently did not come up to his own high expectations, no one else has accomplished some of the goals he had in mind. It turned out to be his last published work, which was not his design either; he kept on working as steadily as his waning strength would permit, and it must have been a severe blow to this sensitive man when in the following year, 1858, his completed paper on "Transformation of Gravity into other Forces, particularly Electricity" was rejected by the Royal Society. This was done kindly enough by the physicist G. G. Stokes (afterwards Sir George), who felt forced to inform Faraday that his paper was unsuitable for the *Philosophical Transactions* since it contained only negative results. (Some critics thought that it also contained too much mysticism.) Faraday then promptly turned to a study of the effect of magnetism on spectral lines, but again he had only negative results to report and was unable to get them published. However, many of his flashes of insight were correct and were later confirmed by Zeeman and others, using modern instrumentation.

It is plain that Faraday's great mental powers were slowly failing during those last years. With pathetic frankness he spoke and wrote to many people about his loss of memory and general exhaustion. But one may question the wisdom of rejecting negative results from such a weakened lion. As John Bernoulli remarked when some unsigned solutions to difficult problems he had posed were sent to him from England, "I can recognise the lion by his claws". He was speaking of Sir Isaac Newton, and that was long after the great man had undergone his dreadful period of "phrenitis". Reasoned results of any kind offered by such men are often of great potential value to other workers. This was surely in Faraday's mind when he spoke of his negative findings in the Bakerian Lecture:

> "At one time I hoped that I had altered one coloured ray into another by means of gold, which would have been equivalent to a change in the number of undulations; and though I have not confirmed that result as yet, still those I have

Faraday at work in his laboratory at the Royal Institution. Here he produced the many types of films and colloidal suspensions of gold that so fascinated him in his work on light. Although his investigations did not succeed in the way he had hoped, they have since been recognised as fundamental contributions to colloid chemistry

From the water-colour by Harriet Moore in the possession of the Royal Institution.



obtained seem to me to present a useful experimental entrance into certain physical investigations respecting the nature and action of a ray of light. I do not pretend that they are of great value in their present state, but they are very suggestive, and they may save much trouble to any experimentalists inclined to pursue and extend this investigation."

This statement must rank high among the most modest ever uttered by a major discoverer.

It may be presumed that thoughtful editors of the day—especially very able men like Stokes—understood these matters. But other offences were also being alleged against Faraday. It was charged that his lack of positive results was sometimes abetted by a fund of occult thinking which suffered from an absence of mathematical treatment—as when lines of physical force, ether, fields and other difficult conceptions were vaguely used to link gravitation with other forces. One anonymous critic in *The Athenaeum*—evidently much better trained in mathematical physics than in manners—went so far as to advise Faraday to study sixth-form mathematics before he again aired his basic physical theories. This was a mean stroke in a vulnerable spot.

All his life this self-trained blacksmith's son had stood in awe of good mathematical linguists, much more than he should have. It was this excessive awe that probably accounts for such statements as one finds in the Bakerian Lecture—"it seems to me, who am only an experimentalist". The word "only" is surely misused here by a great theoretician who happened also to be one of the most gifted experimenters the world has ever seen and allowed to work himself to complete exhaustion. Despite his modest protestations, imaginative hypotheses streamed from his mind into his papers, where they were always expressed in verbal form with the occasional help of a few simple diagrams. The marked dearth of familiar mathematical discussion caused some people who had learned this language to howl in pain about Faraday's vagueness. But it was probably his daring new ideas that would have anguished these people in any form. We must remember that even Newton was accused of occultism in his day, and who was a better mathematician? In due time, James Clerk Maxwell came forward to build a clear and lasting mathematical structure on Faraday's lines of force and field theories, and it would have taken a very bold man to tell that canny Scot to go back to the sixth form and study a little more.

The famous scientist Hermann von Helmholtz finally clarified the whole matter gracefully in 1881:

"Now that the mathematical interpretation of Faraday's conceptions regarding the nature of electric and magnetic forces has been given by Clerk Maxwell, we see how great a degree of exactness and precision was really hidden behind the words, which to Faraday's contemporaries appeared either vague or obscure. . . . I have no intention of blaming his contemporaries, for I confess that many times I have myself sat hopelessly looking upon some paragraph of Faraday's descriptions of lines of force, or of the galvanic current being an axis of power."

Faraday was 65 when he delivered to the Royal Society his lecture describing his experiments on the relations of gold to light, and it is apparent that his great powers had begun to diminish by this time. While little of value emerged, as he had hoped, concerning the nature of light, his conclusions on the metallic nature of the many and various preparations of gold and their effects upon reflected and transmitted light still hold considerable interest and value and deserve quotation.

"With regard to *gold-leaf* no question respecting its metallic nature can arise, but it offers evidence reaching to the other preparations. The green colour conferred by pressure, and the removal of this colour by heat, evidently belong to it as a metal; these effects are very striking and important as regards the action of light, and where they recur with other forms of gold, may be accepted as proof that the gold is in the metallic state. Although I do not attach equal importance to the fact already described, that gold-leaf frequently presents fine parts that appear to be ruby in colour, I am not as yet satisfied that they are not in themselves ruby; and if they should be so, it will be another proof by analogy of the metallic nature of other kinds of preparations eminently ruby.

"The *deflagrations* of gold wire by the Leyden discharge can be nothing but divided gold. They are the same whatever the atmosphere surrounding them at the time, or whatever the substance on which they are deposited. They have all the chemical reactions of gold, being so finely divided, insoluble in the fluids that refuse to act on the massive metal, and soluble in those that dissolve it, producing the same result. Heat makes these divided particles assume a ruby tint, yet such heat is not likely to take away their metallic character, and when heated they still act with chemical agents as gold. Pressure then confers the green colour, which heat takes away, and pressure reconfers. All these changes occur with particles attached to the substances which support them by the slightest possible mechanical force, just enough indeed to prevent their coalescence and to keep them apart and in place, and yet offering no resistance to any chemical action of test agents, as the acids, &c., not allowing any supposition of chemical action between them and the body supporting them. Still this gold, unexceptionable as to metallic state, presents different colours when viewed by transmitted light. Ruby, green, violet, blue, &c., occur, and the mere degree of division appears to be the determining cause of many of these colours. The deflagrations by the voltaic battery lead to the same conclusion.

"The *gold films* produced by phosphorus have every character belonging to the metallic state. When thick, they are in colour, lustre, weight, &c., equal to gold-leaf, but in the unpressed state, their transmitted colour is generally grey, or violet-grey. The progression of their lustre and colour is gradual from the thickest to the thinnest, and the same is generally true, if thick films are gradually thinned and dissolved whilst floating on solvents; the thick and the thin films must both be accepted as having the same amount of evidence for their metallic nature. When subjected to chemical agents, both the thick and the thin films have the same relations as pure metallic gold.

"It may be thought that the *fluid preparations* present more difficulty to the admission, that they are simply cases for pure gold in a divided state; yet I have come to that conclusion, and believe that the differently-coloured fluids and particles are quite analogous to those that occur in the deflagrations and the films. In the first place they are produced as the films are, except that the particles are separated under the surface and out of the contact of the air; still, when produced in sufficient quantity against the side of the containing vessel to form an adhering film, that film has every character of lustre, colour, &c., in the parts differing in thickness, that a film formed at the surface has."

However, one minor fault may be fairly charged against "Experimental Relations of Gold (and other Metals) to Light". This title does not describe the contents of the paper, although it probably does indicate what Faraday set out to do. People are now led to expect a study in physical optics and the like—the kind of information that has led to the remarkable use of gold surfaces on solar cells, heat shields for jet engines, satellites and space vehicles with all their reflective gear, and in layers on glass or metal for the purposes of heating and of cryogenic engineering. But as usual Faraday had very broad aims in mind. Among his original objectives was a kind of crucial experiment on the existence of the luminiferous ether by means of reflections from very small gold particles. As it turned out the investigation became a very comprehensive study of the properties of gold in many forms—as gold leaf, thin coatings, the kind of dispersions now called colloids, and others. The effects of deflagration and of polarised light were also examined.

Clearly the nature of the gold suspensions must have fascinated Faraday, and a substantial part of the lecture was given to the various methods of obtaining them. According to colloid specialists, especially in Germany where the paper is honoured in translation as "Ostwald's Klassik Nr. 214", many fundamental observations of great value to their science are casually stated here for the first time. Practical details for producing, analysing and destroying colloids with many agents are lavishly spread over thirty-six pages, along with acute theoretical comments of basic importance. It would be useless for a non-specialist to attempt to pass these on to other non-specialists, but as Dryden remarked when he looked into the new world of Chaucer's *Canterbury Tales*: "'Tis sufficient to say, according to the proverb, Here is God's plenty!"