# Michael Faraday's Recognition of Ruby Gold: the Birth of Modern Nanotechnology

## His 1857 Lecture to the Royal Society in London

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**Figure 1**
*Faraday's colloidal ruby gold. Reproduced by Courtesy of the Royal Institution of Great Britain*

From the paper in Philosophical Transactions entitled 'Experimental relations of gold (and other metals) to light' (1), based on his Bakerian lecture to the Royal Society in London on 5 February 1857, it is clear that Michael Faraday was fascinated by the ruby colour of colloidal gold. The objective of his investigations was to examine the interaction of light with metal particles, but much of this paper focused on various aspects of the formation, nature and properties of ruby gold, and these systematic studies and perceptive interpretations did in fact mark the birth of modern colloidal chemistry. This has now led to the strong emergence of the nanoscience of gold and nanotechnology (2), even although ruby glass was known to Faraday and had been used for centuries for stained glass windows, and 'Purple of Cassius', made from gold in the presence of tin, had been used for colouring glass and enamels since the seventeenth century (3).

The work described in Faraday's lecture fitted into his investigations into the relations between matter and electrical, magnetic, and optical phenomena (2). He was asking the question "to what extent experimental trials might be devised which, with their results and consequences, might contradict, confirm, enlarge, or modify... that wonderful production of the human mind, the undulatory theory of light...". The action of light on particles which are small compared with the wavelength of light should produce interesting results, and gold sprang to mind because "known phenomena appeared to indicate that a mere variation in the size of its particles gave rise to a variety of resultant colours."

Although Faraday described work with a number of metals, the ruby colour produced in 'solution' by fine particles of gold which are "very minute in their dimensions", and prepared via various practical approaches, was the main topic of his lecture. A typical preparation used an aqueous solution of a gold compound, e.g. $NaAuCl_4$, and treated this with a reducing solution such as phosphorus in carbon disulfide in a two phase system. The yellow colour of sodium chloroaurate ($NaAuCl_4$) changes within minutes to the deep ruby colour of colloidal gold. Faraday concluded that the ruby fluid was gold dispersed in the liquid in a very finely divided metallic form not visible in any of the microscopes available in his day. Nearly 100 years later Turkevich et al (2, 4) used electron microscopic investigations to reveal that the ruby-coloured colloids made by Faraday's preparative routes produce particles of gold with average sizes in the 6 ± 2 nm range. Faraday's original gold colloids were very stable and at least one example survived until the second World War, when it was accidentally destroyed by enemy action, and an example is pictured in Figure 1.

*Gold Bulletin* has monitored the development of uses for ruby gold via papers published by W.D. Mogerman (5), Leslie B. Hunt (3) and John Turkevich (4). Mogerman points out that the title for Faraday's 1857 paper does not do full justice to its contents, but as usual, Faraday had very broad objectives in mind and he was clearly fascinated with the ruby gold 'suspensions' and the various methods of obtaining them (the word 'colloid' was first coined only later by T.H.Graham in 1861 (2, 6). Yet the content of the lecture started from very small beginnings: in a strange statement written in a letter from Michael Faraday to his friend Prof C. F. Schönbein of Basle he wrote "I have been occupying myself with gold this summer; I did not feel headstrong 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" (5).

Hunt in his article entitled 'The true story of the Purple of Cassius', published in 1976 says "For the past 300 years the literature on gold, on glass and on ceramics has ascribed to Andrew Cassius the credit for discovering the purple preparation of colloidal gold and stannous hydroxide that bears his name

**Figure 2**

*Portrait of Michael Faraday. Reproduced by Courtesy of the Royal Institution of Great Britain*

and is still in use as the most effective means of producing enamel colours ranging from pink to maroon. But not only was it known and described more than 25 years before its publication by Cassius; it had been successfully used to produce a beautiful ruby glass (3), and the composition of the Lycurgus Cup of Roman times is described in an accompanying article (7). Egyptian manuscripts from the Greco-Roman era make reference to the red colour which gold can impart to glass. Paracelsus knew of it in the first half of the sixteenth century, and the Florentine priest Antonio Neri in his 'L'Arte Vetraria', the first treatise on glass making, published in 1612, made reference to "a wonderful red obtained from gold". These early workers seem to have used a gold powder and heated until the purple colour was produced sometimes with the help of 'liquor of flints' (potassium silicate). Glauber, in 1659 was probably the first to discover that by adding tin oxide to the gold a ruby colour could be produced and around 1679 it was used for the manufacture of ruby glass in a factory at Potsdam. However, it subsequently became known as 'Purple of Cassius' as described by Dr Cassius in a book entitled 'De Auro' and published in 1685. Dr Cassius had also realised the importance of the presence of tin, and was well aware that the gold-tin combination could be used for producing ruby glass and red enamels.

When John Turkevich (4) highlighted Faraday's achievements in preparing a ruby colloid of gold in two well-cited reviews on this topic published in *Gold Bulletin* in 1985, he summarized the developments which had taken place at that time in understanding the properties of ruby gold which had "intrigued the alchemists". He described the broadening interest in colloidal gold during the last quarter of the 19th and beginning of the 20th century as the development of Bredig's arc method for its preparation, the invention by Zsigmondy of the slit ultramicroscope, Mie providing a theoretical explanation for the colour of colloidal gold, Schulze and Hardy studying its stability in the presence of ions of different valencies, Einstein providing the theory for its Brownian motion and Smoluchowski formulating the theory of the coagulation process. The beautiful ruby-red colour is due to a rather narrow absorption band at 520 nm. Turkevich used a graded set of monodisperse gold sols of varying particle size to confirm experimentally the earlier calculations of Mie. Although Turkevich speculated that the size of gold nanoparticles would relate to their catalytic activity he missed the now well known high catalytic activity of gold nanoparticles on oxide supports – he said that "The material of choice for colloid studies with the electron microscope was colloidal gold. However it is a poor catalyst for the two standard reactions: decomposition of hydrogen peroxide in solution and the hydrogenation of ethylene in the gas phase. Platinum is however an outstanding catalyst for both of these reactions". Bulk and nanoparticle platinum show many similarities catalytically, but the nanoparticulate size of gold leads to it having very different catalytic properties from bulk gold (2, 8). If Faraday had lived in the 20th century his innovative thinking might have led him to be a pioneer in catalysis by gold!

Faraday was interested in a wide spectrum of scientific phenomena, and made significant innovative contributions to fields as wide apart as electromagnetic induction (1831) and the discovery of benzene (1825). His approach was that of a self-effacing skilled experimentalist who made epoch-making deductions, not involving equations of any sort. The full significance of ruby gold is only now being recognised in the proliferation of publications related to gold nanotechnology. It is therefore appropriate on *Gold Bulletin's* ruby anniversary, and the 150th anniversary of Faraday's lecture to give full recognition to his insight and foresight in performing the key pioneering steps towards the introduction to the field of gold nanotechnology which has already had a major influence on developments in colours, medical and catalysis applications.

## About the author

**David Thompson** has more than 45 years experience in precious metal catalysis, including almost 30 in ICI and Johnson Matthey, and for the last 12 he has been monitoring and encouraging participation in the exciting new developments in the nanotechnology of gold, especially its applications in catalysis. He is a consultant to Project AuTEK (Mintek, South Africa) and World Gold Council (London, UK) and a member of the Editorial Team of *Gold Bulletin*, having previously been Technical Editor (1996 -2002).

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