Michael Faraday—putting perception in its place

Michael Faraday (22 September 1791–25 August 1867), the greatest experimental scientist of the nineteenth century, was born two hundred years ago. Born humbly, the son of a blacksmith, he learned to see and question with a fascination for science, by reading customers' books while he was apprenticed from the age of fourteen to a kind and generous bookbinder, Mr Riebau, in London. He also became interested in art, at this time learning perspective drawing, and later contributing to the new art-science of photography. Faraday attended Sir Humphry Davy’s lectures on chemistry at the Royal Institution. He made such neat notes that they so impressed Davy that he took the unknown apprentice on as his assistant—later to become Davy's successor as Professor of Chemistry and Director of the Royal Institution, where Faraday spent his incredibly creative working life. His laboratory with much of its original apparatus is still to be seen at the Royal Institution, in Albermarle Street (Gregory 1986).

Faraday is famous for an astonishing range and number of electrical and chemical discoveries, including magnetic rotation, and the first current electric motor (1821), production of electricity by moving a magnet in a coil, electric induction (1831), the relation of electricity to magnetism, and that all forms of electricity are essentially the same (1833), electrochemical decomposition (1834), Faraday’s cage for isolating electricity (1837), rotating polarization of light by magnetism, and diamagnetism (1846) and more—including field concepts that led away from other theories and towards Einstein's conception of space. His experimental work is meticulously recorded in his Diary (Martin 1932) which is a uniquely detailed account of methods of discovery of an experimental genius. These are most interestingly discussed in Faraday Rediscovered (Gooding and James 1985).

Much less well known is Faraday’s interest in perception and illusion. He wrote, in the same year he discovered that electricity could be produced by moving a magnet in a coil of wire (Faraday 1831):

“The pre-eminent importance of the eye as an organ of perception confers an interest upon the various modes in which it performs its office, the circumstances of which modify its indications, and the deceptions to which it is liable, far beyond what they otherwise would possess.”

Faraday goes on to describe an illusion of motion, which is a physical effect, in that it is explained quite apart from the particular optics of the eye or neurology or functions of the brain. This would now be called a 'stroboscope', used for making moving machinery appear stationary. It is the basis of cinema and television. Faraday described the observation:

“Mr Brunel, jun. described to me two small similar wheels at the Thames Tunnel: an endless rope, which passed over and was carried by one of them, immediately returned and passed over in the opposite direction over the other, and consequently moved the two wheels in opposite directions with great but equal velocities. When looked at from a particular position, they presented the appearance of a wheel with immovable radii.”

The Thames Tunnel was bored by Sir Mark Brunel (1769–1849) and his son Isambard Kingdom (1806–1859) under the Thames (Clements 1970; Rolt 1970). The first successful underwater tunnel, it took nearly twenty years to complete. It was
bored with a new kind of shield, invented by Mark Brunel—based on the tunnelling ship-worm teredo navalis—which sank more ships than gun fire achieved. There were numerous serious mishaps before the Thames Tunnel opened in 1843. The work was costly in lives, and it nearly killed Isambard Brunel when he was trapped as the foul water of the Thames poured in. Although he died young, he became one of the greatest engineers of the nineteenth century, building bridges, railways, and ships including the enormous Great Eastern, which was the only ship in the world able to carry the entire transatlantic telegraph cable, weighing 21000 tons, which she laid in 1866.

It is interesting that Faraday and Brunel, the greatest scientist and engineer of their day, and outstanding for all time, shared this curious observation of stilling seen motion. It is interesting that the engineer saw it in his machinery, and Michael Faraday took it further as a phenomenon worthy of experimental investigation. He had an apparatus built for seeing how illusory stationary, forwards or backwards, motion could be produced—and why strange and beautiful phenomena (moving moiré patterns) occurred with rotating spokes placed in front of parallel lines or bars, that reminded him of his observations of magnetic fields with iron filings. This was a technique for making invisible visible, which Humphry Davy first used (in ‘Davy’s disk’). Now the use of iron filings for showing magnetic fields is a favourite demonstration for every child at school.

Faraday wrote (1831):

“If the wheels revolve in opposite directions, then the spectral lines, originating at each axis as a pole, have another disposition, and instead of running the one set in to the other, are disposed generally like filings about similar magnetic poles, as if a repulsion existed: not that the curves or the causes are the same, but the appearances are similar.”

It could be argued that the lined-up filings produce the lines in a continuous magnetic field—so these lines are misleading fictions suggesting lines of force which do not exist apart from the filings. Was Faraday misled here by appearances? Was his notion of magnetic lines of force based on an artefact? However this may be, the notion was useful as a thinking tool and for describing extremely puzzling phenomena.

Faraday used the stroboscopic principle to observe structures of electric discharge sparks. At first he waved his hands with open fingers; then used a rotating mirror system, developed by Charles Wheatstone, to measure the speed of electricity. Faraday and Wheatstone used this illusion to make entirely new observations. Now the electronic stroboscope is an important instrument for apparently stopping moving machinery, so dynamic performance and faults can be observed in repetitive movement faster than eyes can follow. This has its dangers: fingers have been lost by freezing motion.

Faraday saw that though stroboscopic effects are essentially physical there is also a physiological component—persistence of vision. He observed its effects as transparent surfaces produced by waving white rods in front of a dark background, or dark rods upon a light background. Pairs of moving rods at different distances gave “two or more distinct impressions, or sets of impressions, being made upon the eye, but appearing to the perception as one”.

Most ingeniously, and as it turned out this was important, he looked through a spinning spoked wheel at a mirror—when the wheel appeared perfectly stationary for any speed of rotation:

“A very striking deception may be obtained in this way, by revolving a single cog-wheel between the fingers before the glass, when from twelve to fifteen feet from it. It is easy to revolve the wheel before the face so that the eyes may see the glass through or between the cogs, and then the reflected image appears as if it were the image of a cog-wheel having the same number of cogs, but perfectly still, and every cog distinct ..."
This is the basis of the first device giving illusory continuous motion from a sequence of pictures—and so the first cinema. The Phenakistoscope (as it came to be called) was described a year later (1832) by Professor J A F Plateau of Brussels and independently by Professor S Stampfer of Vienna. Dr P M Roget is also significant as he added to Michael Faraday’s experiments with the cogs and spokes. By stopping motion with an illusion Faraday made a major contribution to the invention of the cinema.

Have illusions of stroboscopic appearances misled scientific observation? Yes—Faraday himself gives an example. An *animalcule* was described by several early microscopists as having two rotating wheels, one on each side of the head, having some fourteen teeth or spokes. These are never seen as wheels except when in motion. Faraday says:

“So striking are the appearances of these animalculae, that men of much practice in microscopical observation are at this day convinced that they do possess wheels which actually revolve continuously in one direction.”

He quotes the well known microscopist Henry Baker (1698–1774), Fellow of the Royal Society (in *Baker on the Microscope*, vol. II, page 266; the first edition appeared in 1742):

“As I call these parts wheels, I also term the motion of them rotation, because it has exactly the appearance of such. But some gentlemen imagined there may be a deception in the case, and that they do not really turn round, though indeed they seem to do so. The doubt of these gentlemen arises from the difficulty they find in conceiving how or in what manner a wheel or any other form, as part of a living animal, can possibly turn upon an axis supposed to be another part of the same living animal, since the wheel must be a part absolutely distinct and separate from the axis whereon it turns; and then say they, how can this living wheel be nourished, as there cannot be any vessels of communication between that and the part it goes round upon, and which it must be separate and distinct from? To this I can only answer, that place the object in whatever light or manner you please, when the wheels are fully protruded they never fail to show all the visible marks imaginable of a regular turning round ... Nay, in some positions you may, with your eye, follow the same cogs or teeth, whilst they seem to make a complete revolution; for the other parts of the insect [!] being very transparent, they are easily distinguished through it ... as a man can move his arms or legs circularly as long and as often as he pleases by the articulation of the ball and socket, may there not possibly be some sort of articulation in this creature whereby its wheels or funnels are enabled to turn themselves quite round.

It is certain all appearances are so much on the side of the question, that I never met with any who did not, on seeing it, call it a rotation; though, from a difficulty concerning how it can be effected, some have imagined they might be deceived.”

Drawings of wheel-animalculae (including Baker’s Branchionus) are given by Jabez Hogg in his *The Microscope* (1854), on page 143. These are reproduced in the figure (with a magnification 200) together with the original caption. Jabez Hogg writes (page 142):

“The Rotifer, Rotating or Wheel-Animalculae
This higher grade of the Infusoria derives its name from the appearance presented by the motion of its circles of cilia on the superior part of its body, which resembles the turning round of a wheel, as they rapidly vibrate. Many have been the speculations as to the mechanism of this beautiful movement: some have considered it as a magnetic or electrical force; and as one passes out of sight and while the next appears, adding to the optical illusion, a philosopher of considerable note was led to look upon the whole as a deception of the sight, and affirmed they had no existence.”

Jabez Hogg does appear to accept that these are rotating wheels, as he then says (page 142): “On the food being drawn by the currents to the cup part of the wheels, it passes down canals in the neck to the mouth...”
Unlike these distinguished naturalists and microscopists, Michael Faraday understood the principle and was familiar with the appearances of stroboscopic illusions, so he could reject the observation. He was sure the animalculae do not have rotating wheels. He was, of course, also sure that the appearances he described of rotating spokes over parallel lines are not really like iron filings in magnetic fields, though these appearances are similar. Throughout his work Faraday used active exploratory experiments to separate illusions of perception from phenomena of nature, then presented the phenomena in such a way that anyone could see the truth of the matter. This he did in his many lectures at the Royal Institution; so his private thoughts and discoveries became public knowledge (Gooding and James 1985). The stroboscope experiments are unusual because these are phenomena of perception itself that are being investigated with, as it turned out, an illusion having practical uses for physical discovery.

For a very different kind of illusion, he described (Faraday 1826): “a curious aerial phenomenon”, observed on 19 August 1826 on the Isle of White just above Puckaster Cove:

“The sky was clear, the sun had just set, when several enormous rays of light and shade were remarked towards the E., N.E., and S.E., all radiating in straight lines from a spot rather south of east, and just upon the horizon.”

Faraday continues:

“The phenomenon seemed inexplicable, but after a little consideration was referred (and as it appeared from after observations correctly) to an effect of aerial perspective. The rays which seemed to originate from a common centre on the east, were really only the intervals between long shadows caused by the occurrence of clouds far to the west, and were in fact passing to the place from which they seemed to originate .... All these phenomena, with their variations, were easily referable to their causes, and may be observed at almost any sun-set in fine weather ...”

Fig. 88.

1. The common Wheel-Animalcule, with its cilia or rotators pointed. 2. The same in a contracted state and at rest; at g is seen the development of the eyes in the young. 3. The Pitcher-shaped Branchionus: a the jaws; b the shell; c the cilia, or rotators; d the tail. 4. Baker's Branchionus: a the jaws and teeth; b the shell; c the rotators; e the stomach.
He concludes,

"It is with a view to guarding persons who may observe the same effect, against any mistake as to its origin, that the appearance, with its nature, has been thus particularly described."

So far we have not considered intentional delusion or delusions of the supernatural. Faraday considers both in experiments he conducted on Table moving (Faraday 1853). His methods were "precisely of the same nature as those I should adopt in any other physical investigation". He stressed that table-turners he investigated were honourable, and truly believed "the table draws their hands; that it moves first, and they have to follow it—that sometimes it even moves from under their hands". He made plates of a great variety of materials, having very different physical and electrical properties, and placing them under the table-turner's hands found that the table still moved. He then tried low-friction plates, marked their position on the table, and found that the plates moved though the table did not.

He found no evidence of "any peculiar natural force ... nor anything which could be referred to any other than the mere mechanical pressure exerted inadvertently by the turner". So he investigated these pressures from the hands, and found that it is exceedingly difficult to press purely downward for any length of time, without some sideways pressure. This may not be known to the turners, especially as their fingers become numb with the constant pressure. So he arranged for indicators of sideways movement to be visible to the turners. Then the movements no longer occurred. With a mechanical lever arrangement to see whether the table or the hand moved first, he found that hand movements always preceded table movements. He suggested that "the apparatus I have described may be useful to many who really wish to know the truth of nature, and would prefer that truth to a mistaken conclusion; desired, perhaps only because it seems to be new or strange".

Although relatively simple and even trivial, these studies of illusion illustrate how, with his subtle use of experimental methods and his extraordinarily powerful imagination, Michael Faraday could see beneath appearances sometimes to very different realities—putting perception in its place.

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