



Should it be 'picoscopy'? ☆

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ABSTRACT

Here are a few books for John Spence to read (or avoid) in the aftermath of his birthday festivities, preceded by some partially coherent reflections.

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1. Introduction

Near this spot are deposited the remains of one who possessed Beauty without Vanity, Strength without Insolence, Courage without Ferocity, and all the Virtues of Man without his Vices. This praise, which would be unmeaning Flattery, if inscribed over human ashes, is but a just Tribute to the Memory of BOATSWAIN, a Dog.

J.C. Hobhouse

By a happy coincidence, the name 'microscope' accords well with the resolution of the (light) microscope, which is of the order of micrometres. The word 'microscope' was of course coined long before the metre came into fashion and the prefix 'micro' acquired its current SI meaning but it is the association of 'micro' with resolution that has generated the neologism 'nanoscope', which appears in two of the titles mentioned below. Incidentally, the first appearance of the word in English (Hobbes, 1656 says the OED) is surprisingly late; a friend of Galileo, Giovanni Faber, used *microscopio* in 1625 and Demisianus, a learned Greek living in Rome, introduced *Mikroskop* in the early years of the 17th century, as an improvement on Goethe's *Kleinsehglas* (and certainly an improvement on *Engyoskop*, which was also in use). But why did the editors of the nanoscopy books stop at 'nano'? The resolution of the modern electron microscope is often better than an ångström (100 pm) so the natural unit is now the picometre (as it is for the electron wavelength, 3.7 pm at 100 kV). The new generation of electron microscopes are not nanoscopes but picoscopes! John

Spence has spent much of his professional life striving for high resolution and, with three editions of a book on HREM published, he undoubtedly deserves to be known as a picoscopist. However that is not the only Spence neologism awaiting consecration, for the last few years of Spence's research have been concerned with forming high-resolution images with no lenses at all (downstream from the specimen at least). Having spent some 50 years wrestling with the properties of electron lenses and their aberrations, I am bound to deplore this dismissal of lenses and the increasingly more sophisticated aberration correctors that enable microscopes to reach resolutions measured in tens of picometres. As a rearguard action, therefore, I ask whether lensless imaging really is lensless? However difficult to put into practice, the various methods can be described very simply. In one described by Spence [1], for example, one or more far-field diffraction patterns are recorded and, after numerous ingenious digital manoeuvres, a high-resolution image is reconstituted. A particularly dramatic form of lensless imaging is described by Rodenburg et al. [2] and again, a set of far-field diffraction patterns is collected; these are created by illuminating (sampling) overlapping patches of the specimen with the same illuminating beam after which the resulting samples are combined appropriately. The results are spectacular and the computing is not excessive. These are only two among the many techniques, all with ancestry in the work of Gerchberg and Saxton [3,4] and Hoppe [5] (see [6] for a recent survey) and more continue to appear. Wolf [7,8] has described a method of solving the phase problem (with X-rays in mind) based on measurement of mutual coherence. But the question remains, must we burn our copies of Hawkes and Kasper [9] and Rose [10] and concede that the battle for high-resolution imaging has been won by a stretch of empty space and a computer? Is the sun setting on Nion, CEOS, SPOC and MEBS? Close examination of the various proposals suggests that there is some hope for us. Certainly, no lenses are employed in image space (unless the camera-length is too long) but what about the illumination? John Spence argues that the better the resolution, the less severe are the requirements on (spatial) coherence. In other words, if the aim is to obtain high-resolution information about a

☆ Cordially offered to John Spence (for whom the epigraphs have been chosen) on his 65th birthday. As a bonus: A raw north-easterly wind swept gustily across the Weald of Kent, tearing the sagging nimbus clouds into shreds of dripping vapour and tugging at the camouflaged bough-shelters which housed the aircraft of Number 666 Fighter Squadron, until the fabric flapped heavily, like wet sails, in protest. Quietly, almost furtively, three Spitfires in vee formation dropped out of the murk above the rain-soaked turf; with engines throttled back they circled once, losing height, and then, still in formation, came to rest near the farm-house that served both as an Officers' Mess and the Squadron Office. Mechanics ran out to take charge of the machines while the pilots, after an appraising glance round the landing-ground, walked towards the building.

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small region of the specimen, the angular spread of the incident beam (and hence the spatial coherence) does not limit the performance of the technique: “We note that the drive for higher resolution, for a fixed number of object pixels, reduces the demand on coherence” [1]. Much more ambitious claims are made for the lensless mode described by Rodenburg et al. [2], inspired by the intellectually satisfying procedure known as ptychography [5,11]. Rodenburg tells us that there is no serious limitation on the form of the wave incident on the specimen; this wave may be a spherical wave distorted by aberrations, as in an (uncorrected) STEM, for example. But what about the spatial and temporal coherence of the incident wave? This is not discussed and the mathematical model assumes that the incident illumination is perfectly coherent. (We recall that in electron optics, the illumination is always quasi-monochromatic, $\Delta\lambda/\lambda \sim 10^{-6}$, whereas the spatial coherence needs careful thought.) Coherence is not affected by the properties of the condenser lenses and we must therefore return to the source, which is a form of cathode lens. A Ph.D. subject for a budding lensless microscopist.

2. Spenceana

“Old people like looking at the sea. It brings back their memories, their lives. It is like looking at a fire. It is a sort of dream. ...But old people cannot afford very much money. And nor can young people. That is all right. Life has been good to me. You must have a room in my pensione, if you wish, and dream about your poeta inglese”. Her pensione was next door but one to the Casa Magni. The room was on the first floor, looking directly over the sea, with a big stone balcony carved with fleur-de-lys. It was the best room I ever had in Italy, and also the strangest.

The windows were hung with old brocade curtains, the floor was tiled with patterned marble, smooth and warm to my naked feet. In one corner was a huge old mahogany armoire, with pier-glass mirrors; in the other an enormous double-bed with spiral-carved bedposts and the tattered remnants of a canopy. In the middle of the floor was a white tin table, and a beautiful high-backed cane chair with curving arms. Strangest of all, against the far wall, were not one but two cradles, also made of cane, on wooden rockers with small, embroidered tent-like lace veils over each head. Their design was certainly nineteenth century. I felt I was moving in with a whole family.

For this enchanted room I was asked to pay the equivalent of one pound ten shillings a week, in advance. I moved the table out on to the balcony and unpacked my books. Overhead was a canvas awning with a loop of washing-line clipped with wooden pegs. Out in the bay the lighthouse on Palmaria had begun to wink. I craned over the balustrade and looked across to the balcony of Casa Magni. Then I sat down and began to write my daily notes, the long continuous imaginary conversation I had with my subject.

Richard Holmes, *Footsteps*

I have no book by John Spence to dissect but he is present in a *Compendium of Quantum Physics* edited by D. Greenberger, K. Hentschel and F. Weinert [12]. The editors' aim was to provide guidance on the “concepts, experiments, history and philosophy” of quantum physics and for this, they have attracted about 90 authors to write the 185 entries, which are arranged alphabetically from Aharonov–Bohm effect to Zero-point energy. The contributors are physicists, historians of science and philosophers of science and the entries range from a few lines (L. Ballentine on Density matrix) to several pages (D. Dürr, S. Goldstein, R. Tumulba and N. Zanghi on Bohmian mechanics, for example). Under the letter E, we find T. Arabatzis on Electrons (he is also present under C, on Cathode rays), an excellent choice as he is also the author of *Representing Electrons* (see *Ultramicroscopy* 108 (2008) 1623–1635). Just before Electrons are seven pages on Electron interferometry, in which John

Spence manages to compress an excellent account of the contributions of Möllenstedt and Düker, the growth of holography, the Aharonov–Bohm effect, Hasselbach's work on the Sagnac effect and the Hanbury–Brown and Twiss experiment for electrons. I would have liked to see Marton, Simpson, Faget and Fert mentioned (they too were examining electron interference in the 1950s), but no doubt the space allotted did not allow this; and someone in Heidelberg should have corrected the mis-spellings of German words and names in the references (and removed numerous stray inverted commas). But otherwise, Spence's essay could not be bettered. The first entry, on the Aharonov–Bohm effect, is written by H. Lyre, who has a degree in physics and a PhD in philosophy (he is interested in “philosophy of mind (in particular, mental externalism)”). In view of recent letters in *Physics Today*, arguing that the Effect should (or should not) be re-named after its true discoverers (Ehrenberg and Siday, ten years before the first Aharonov and Bohm paper, whose authors gave credit to Ehrenberg and Siday as soon as they became aware of their observation), Lyre's account of the “theoretical debate” around the effect is timely, though he fails to mention the many attempts by P. Bocchieri (Pavia) and A. Loinger (Milan) to undermine its reality. Unfortunately, it is too short and technical to be comprehensible to all but specialists—he should have been told to write at greater length and address himself to a wider readership. One last complaint: unbelievable as it may seem, the book has no index. The publishers may retort that dictionaries and encyclopædies never do have indexes but here, an index is really badly needed.

Several books of direct interest to a picoscopist have been announced but, at the time of writing, most of these are still virtual. One that has materialized is *4D Electron Microscopy* by A.H. Zewail and J.M. Thomas [13]; John Spence is present here too for he “reviewed the book in its entirety and made constructive suggestions and detailed comments on an early draft of the manuscript”. It is not until Chapter 5 that the acquisition of time-resolved images is considered, though it is mentioned sporadically in the preceding chapters, which contain a potted history of microscopy (Chapter 1), an introduction to coherence (Chapter 2), 2D and 3D structural imaging and some applications (Chapters 3 and 4). It is for the ‘ultrafast’ chapters that the book will be read for these contain new and very unfamiliar material. The book is handsomely produced with all the illustrations on a Cambridge blue background (J.M. Thomas was Master of Peterhouse, my own Cambridge college); they are in colour throughout, except for the portraits of the authors which are in black-and-white in the book (but in colour on the dust-jacket). The style is discursive: one figure shows the “Tablet erected on the Stanford University campus in 1929, commemorating ‘motion picture research’ of Eadweard Muybridge at the Palo Alto farm of Leland Stanford in 1878 and 1879” and A.H. Zewail recalls the Faraday Discourse in which he demonstrated “the concept of freezing motion by displaying ‘horses in motion’ using Muybridge's device, which was in the archives of the Royal Institution, and then compared its time scale (20 frames/s; slowing down the motion by 50 times) with the vastly different femtosecond time resolution (slowing down the motion by nearly 10^{14}) needed to record ‘atoms in motion’, the subject of the Discourse”. This makes the early chapters entertaining reading but unsuits them for learning the subjects they deal with: better learn about electron image formation and coherence elsewhere before reading about its relevance to ultrafast electron microscopy here—you cannot learn about the latter anywhere else and could scarcely hope for a better account. What you could hope for is an index; like [12], this book too has no index! I found this so incredible that I wondered whether I had a defective copy. But no, here is a scholarly book by two eminent scientists with no index. Publisher, please rectify if there is a second printing.

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