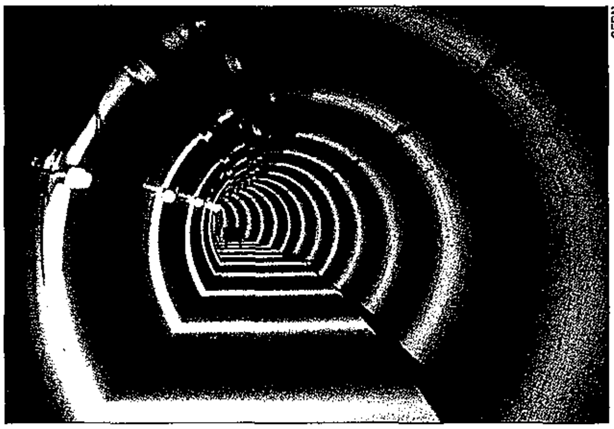
Unlike Pais, Fraser has chosen to write in a way that makes particle theory and technical explanations accessible to the layman. This means that analogies have to be used to explain physical phenomena. Fraser shows unusual skill in finding vivid analogies that capture physical pictures without distorting them. To explain virtual photons, for example, he uses the analogy of a bank loan: "Each virtual photon has a quantum-mechanical mortgage which governs how long and how far it can roam around its parent charge before it has to repay its energy debt. These quantum-mechanical mortgages carry no interest. Simply, the larger the loan, the faster it has to be repaid. The energy loan multiplied by the repayment time cannot exceed a fixed amount, Planck's constant." Or to explain why antiprotons need to be cooled, he writes: "Filling a synchrotron that way [without cooling] would be like trying to feed a hose-pipe from a shower attachment."



Success route – inside the CERN tunnel

The principal characters of *The Quark Machines* come to life through the use of anecdotes and personal characterizations. Of Julian Schwinger, Fraser writes: "Ambidextrous, he could write two different equations at the same time, an obstacle which the less gifted found difficult to overcome, especially when just one Schwinger equation could be more than a handful." And in comparing the styles of Schwinger and Richard Feynman, he concludes, "If Schwinger were a concert soloist, Feynman would have been rock and roll."

After an introductory chapter, *The Quark Machines* then discusses the pre-war period, with emphasis on the work of Rutherford, the birth of quantum mechanics and the development of the cyclotron by Ernest Lawrence. Fraser also covers the invention of the klystron by the Varian brothers and the discovery of fusion by Otto Hahn and Fritz Strassman. The last two events went on to become the basis of the most important military technology of the Second World War.

The end of the war brought a renaissance in particle physics, particularly in the US, with the development of quantum-field theory and the construction of the first accelerators in the 1950s, which took over the forefront of research from cosmic-ray experiments. The fifth chapter, entitled "All We Want Is the World's Biggest Machine", traces the story of how CERN was founded. Subsequent chapters discuss the development of the quark–parton model and its experimental verification, the evolution of quantum chromodynamics (the theory of the strong force), the construction of higher-energy accelerators and colliders, and the theoretical and experimental exploration of the electroweak force – including the discovery of weak neutral currents, and the W and Z bosons at CERN in the 1980s.

I was particularly interested in the chapter on the Superconducting Supercollider, "Armageddon in Texas". Given that we learn more from our failures than our successes, this subject is worth a book in itself, and I hope that one will be written someday. Fraser correctly characterizes the cancellation of the SSC as an act of political assassination. He discusses all of the ingredients of the SSC demise: the incompetent oversight by the Department of Energy; the (at least apparent) lack of cost control; the mishandling of foreign contributions; the changing political climate, including the waning influence of Texas politicians; and the effect of the end of the Cold War. Fraser has been perhaps overly kind in not criticizing the SSC management in its failure to deal effectively with these problems. But that issue awaits for a more complete analysis in the future.

Fraser concludes the final chapter on the LHC with the sentence: "Managed correctly, Europe works." A historian rather than a soothsayer, Fraser stops there. But the question we would really like answered is: "Managed correctly, does the world work?" In other words, can the nations of the world cooperate to build the quark machines that will take us beyond the LHC? The historical record, which shows a duplication or attempted duplication of almost every electron–positron and hadron collider on both sides of the Atlantic, does not appear promising. Fraser criticizes the US for not involving the International Committee for Future Accelerators in the planning of the SSC. Although there is no question that, at the governmental level, foreign participation in the SSC could not have been handled more poorly, major European co-operation in the building of the SSC was never a realistic possibility. Let us hope that we can learn from this history.

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Michael Berry

Slippery as an eel

The Fire Within the Eye: A Historical Essay on the Nature and Meaning of Light
David Park
1997 Princeton University Press 378pp £25.00hb

With passion and poetry, David Park sets out to get behind the optical science we are familiar with as physicists. He tells us how attempts to understand light have been at the heart of people's efforts to make sense of the world ever since they began to reflect on it (note how the natural choice of metaphor reflects this). It is a fascinating story, beginning with the "immense fact [that] we can see", and ending...well, it has not ended yet, as we will "see".

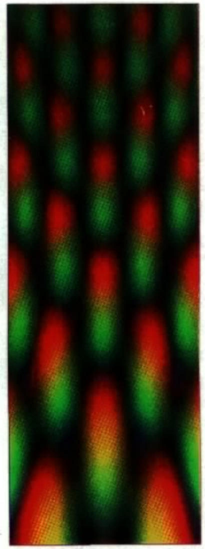
Early theories are discussed in detail. Empedocles' "visual ray" is "like a long finger projecting from the eye, and sight is a kind of touch". It was believed that the ray can occasionally be seen, for example in the gleam of an animal's eye from the darkness near a campfire, and that it can have powerful effects, as in the "evil eye". Then there was the "eidolon", conceived by Leucippus: "...under the influence of light the surface of any visible object continually produces thin veils of matter, perhaps only one atom thick, which peel off and retain their shape as they fly with immense speed in every direction". These notions persisted for centuries, and much ingenuity was expended in overcoming the problems they raised, such as "How does the eidolon get into the little hole in my eye?".

We learn how Euclid was the first to try "to catch Nature in the web of mathematically exact reasoning" with his studies of the optics of mirrors based on the laws of specular reflection. Much later, Islamic scientists pursued the mathematical study of light, in constructing the beginnings of optics as we recognize it today. Apparently, Ibn Sahl in 984 knew the law of refraction, soon forgotten and rediscovered half a millennium later by Harriot, Snel and Descartes. At about the same time, the Egyptian scientist Alhazen began to understand how the eye works, and (following Ptolemy) appreciated that proposed explanations can be tested by experiment.

Inevitably, many pages are devoted to Newton, and here I read two sentences that knocked me flat. As everyone knows, Newton imagined light as a stream of particles travelling along rays, but pondered intensely on effects that seemed discordant with this picture and were convincingly explained much later in terms of light waves. One of these was Grimaldi's observation in 1665 of the fringes in light diffracted from an edge. In one of the famous "queries" in his *Opticks*, Newton asked: "Are not the rays of Light in passing by the edges and sides of Bodies, bent several times backwards and forwards, with a motion like that of an Eel? And do not the three Fringes of colour'd Light above-mention'd arise from three such bendings?" Park thinks that "science still awaits a mathematical theory of the eel". He is wrong, and in an interesting way.

One way of writing wave equations, discovered in the context of quantum mechanics by Madelung and emphasized by Bohm and his followers, is in terms of the local current vector rather than the function describing the wavefield. The lines of current can be regarded as analogous to the rays of geometrical optics, but survive into wave optics. Where propagating waves interfere, these rays indeed wriggle like an eel, as the result of non-Newtonian forces acting from edges etc. Although (perhaps for reasons of historical contingency) this is not the interpretation of wave physics that most of us use, all wave phenomena can be regarded as the effect of these generalized rays. So, Newton was right after all!

Any study of light must include colour, and Park gives an excellent account of the familiar story leading from Newton's prism through Fraunhofer's spectroscopy to the quantum mechanics of today. I was, however, astonished by Euler's "clairvoyant insight" that coloured light originates in internal vibrations of atoms in the emitting body. *Seeing* colours is very different, of course. Eyes are not spectroscopes, but respond to the excitation of three colour receptors – that is, colour space is three- (rather than infinite-) dimensional. Young's pioneering understanding of this fact is well described, as is Goethe's impassioned dissidence from this developing consensus. Although Goethe's unscientific modes of expression made his view unpopular, modern studies – particularly by Edwin Land – have rehabilitated his emphasis on the importance of the surroundings. This can be restated in a way that resonates with our contemporary thinking: while Newton, Young and Maxwell pioneered the local theory of colour, Goethe pioneered the non-local theory.



Rainbow skittles – the interference of three waves of white light

Relativity is introduced in terms of the rise and demise of the ether, as the medium in which light was supposed to wave. Here is Park on the Michelson–Morley experiment. "It is a rare thing when the Lord bends down and speaks to his children, but on this occasion he did. Clothing his word in the language of Nature, he told those two men that they had blown the ether away; but they didn't hear him."

I was disappointed by two omissions. There is no explicit mention of the development of caustics, that is generalized focal curves and surfaces. Interference near caustics produces the largest and brightest wave effects; their most dramatic manifestations are supernumerary rainbows. There is no evidence that Newton noticed these; if he had, the development of physics might have been very different. But Young knew about them, and pointed out that here was a natural phenomenon that Newton's theory (without the eels) was unable to explain, but his could. And I would have liked to have read something about Hamilton's theory of conical refraction, which, as well as getting right to the heart of light's transversality, also laid the groundwork for the mathematical unification of particle and wave motion that was so important in the construction of quantum mechanics.

That is where we are now. Light is waves. Light is particles. Interactions are non-local. Is this the end? Park thinks not. As he says: "Some scientific questions are interesting and some uninteresting, where the words are defined as follows. After an uninteresting question has been settled, it is settled. After an interesting question has been settled, it keeps popping up again. The question of non-locality, in the opinion of many physicists, is interesting." I could not agree more.

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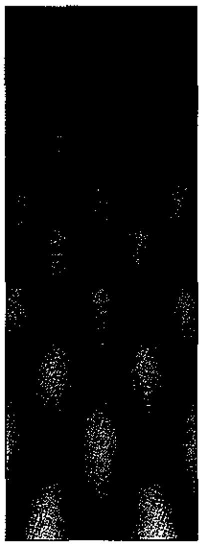

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Robert Hanbury Brown

Radar tale picks up US bias

The Invention That Changed the World: The Story of Radar From War to Peace
Robert Buderi
1997 Little, Brown 352pp £20.00hb

"I wonder", Sir Henry Tizard wrote in his diary as Magdelen College, Oxford, celebrated the end of the Second World War in Europe, "if the part that scientists have played will be faithfully and fairly recorded. Probably not." Sir Henry would, I guess, have appreciated the real effort that Robert Buderi has made to get things right in this book about radar, although he might well have preferred it to have been written from a British, rather than an American point of view.

The aim of the book, so it says in the preface, is to present the story of radar not as an account of technological advances, but as a "story of people bringing out their escapades, from the silly to the serious, and flushing out their thoughts, motivations and fears". While this undoubtedly sugars the technological pill, widens the readership and makes the book more lively, it does narrow the choice of the cast. Some of the principal characters, such as Arnold Wilkins, have been given rather brief supporting parts or kept out of sight in the wings.

Understandably the book starts in August 1940 telling us how, with Taffy Bowen in the lead, the Tizard mission laid the foundations of centimetre-wave radar in the US. This was achieved in three main ways – by insisting on the value of radar in military operations, by giving the precious gift of the cavity magnetron, and by advising the Americans to copy something particularly wise that had already been done in Britain. Britain had created a special *civilian*, not military, laboratory with the sole purpose of developing radar; after all, good scientists did not like being bossed about by people in uniform. In 1936 the Bawdsey Research Station was set up under the direction of a respected scientist, Robert Watson Watt, who was capable of attracting other good scientists.

In November 1940 the Americans established the Radiation Lab at the Massachusetts Institute of Technology as a *civilian* laboratory under the direction of the well known physicist Lee Du Bridge who, together with Isidor Rabi, rapidly assembled a distinguished staff. Five years later, with a staff of about 4000, this remarkably successful laboratory had been involved in