High-Energy Physics: Claims and Constraints

Constructing Quarks. A Sociological History of Particle Physics. ANDREW PICKERING. University of Chicago Press, Chicago, 1984. xii, 468 pp., illus. $30.

Thus science is much closer to myth than a scientific philosophy is prepared to admit. It is one of the many forms of thought that have been developed by man, and not necessarily the best.—PAUL FEYERABEND, Against Method *(1975)*

On the view advocated in this chapter, there is no obligation upon anyone framing a view of the world to take account of what twentieth-century science has to say. The particle physicists of the late 1970s were themselves quite happy to abandon most of the phenomenal world and much of the explanatory framework which they had constructed in the previous decade. There is no reason for outsiders to show the present HEP [high energy physics] world-view any more respect.—Constructing Quarks, *p. 413*

It may be unfair to begin a review of one book with a quotation from another, but it lets me admit right away that I accept neither Feyerabend's assertion that the scientific description of the world is close to myth nor the more extreme position taken by Pickering. Feyerabend advocates an "anarchist theory" of science; Pickering goes a step further, declaring that all this century's science, and not just contemporary high-energy physics, is ignorable. Outrageousness serves a purpose: it attracts attention. But note the qualifying phrase, "On the view advocated in this chapter," the chapter being the last 13 pages out of more than 400. Might that mean that the earlier pages, surveying two decades of high-energy physics, give the social and scientific data that imply the conclusions expressed in the final chapter? That would resemble what Pickering calls the "scientist's account," a thing he vigorously rejects. By his own standards, if the final chapter contains advocacy, that advocacy is already implicit in his selection of what is worth reporting. (In his words, he would have made an "unforced and irreducible choice" at the outset. By "irreducible," I take it he means unanalyzable or not rational.) On the other hand, in places the "scientist's account," predicated on the view that data constrain conclusions, may possibly seem more compelling than Pickering's view that science is merely a social compact (a "construction," as suggested by the book's title).

Constructing Quarks has really two parts. Introductory and final chapters make sociological and philosophical arguments. In between is a relatively straightforward historical account of the development of high-energy physics from 1960 to the present. As a "sociological history of particle physics" (as proclaimed in the subtitle) or as intellectual history, this is important, pioneering work, based on extensive study of the scientific literature and interviews with practitioners of high-energy physics, both theoretical and experimental. The book's bibliography is rich in what Pickering calls semipopular accounts (from, for example, *Nature* and *Physics Today*) and popular accounts (*Science*, *Scientific American*). With a fairly substantial investment in time, reading these may help to make the book more accessible to an audience broader than only physicists. Regrettably, the author's own attempts to describe the physics involved are often less than successful, being too hasty and lacking the simple examples and analogies that might be illuminating to the nonspecialist. Inaccuracies are few, but no one is perfect: "Brookhaven theorist Maurice Goldhaber" (p. 392) is actually a famous experimentalist, though he has been described as a crypto-theorist; M. Y. Han, of the Han-Nambu quarks, is Korean, not Japanese (p. 218).

Pickering's history deals only with particle physics; except for a few footnotes, it ignores the impact of the rest of contemporary physics. It puts little emphasis on the technological developments that have so greatly increased the power of the principal instruments of high-energy physics, accelerators and detectors, during the decades surveyed. Electronics, computers, superconductor magnets, and accelerator techniques like strong-focusing or the "cooling" of particle beams, which made possible the production of the heavy intermediate bosons of the weak interaction—these are taken for granted. Most of the themes of high-energy physics are mentioned somewhere in the book, but often entire subfields of study are merely listed in a footnote. These subfields are fairly numerous; Pickering calls them "research traditions," even though they may last for only a few years and are not especially word-of-mouth. As "traditions," I suppose they become automatic candidates for sociological treatment.

The book divides postwar high-energy physics into three periods: 1945–64, "old physics"; 1964–74, a period of transition; 1974 to the present, "new physics." The points of division are the observation in 1964 of "scaling behavior" in deep inelastic electron scattering at the Stanford Linear Accelerator Center, which suggested the presence of point-like constituents in hadrons (the quark-partons) and by the "November revolution" of 1974 caused by the discovery of the J-psi particle, the signal of "hidden charm," charm being the fourth quark that was needed to implement the Glashow-Weinberg-Salam electroweak gauge theory. The further significance of the charm discovery was that it emboldened theorists to pursue the color gauge theory of strong interactions, quantum chromodynamics. Current fundamental physics is dominated by these gauge theories, which are non-Abelian generalizations of quantum electrodynamics. Theorists are even making a run at "grand unified theories" (acronym: GUTS), intended to comprehend in one great non-Abelian group all electromagnetic, nuclear, and eventually gravitational forces. In this ambitious program, high-energy physicists combine their efforts with those of the cosmologists and discuss (without cracking a smile) what might have been happening 10^{-34} second after the big bang.

There are several major differences between the old and the new physics, and one that Pickering emphasizes is this (p. 353): "The old physics was common-sense physics. . . . The new physics was theory-loaded." The point here is that experimentalists using the first generation of high-energy accelerators looked mainly at scattering events that occurred with high probability (large cross section); these were "soft" scatterings, with small transfer of momentum. They tended to ignore the rare "hard" scatterings, with large transfer of momentum transverse to the beam (high p_T). One reason, of course, was the desire to accumulate large quantities of data in order to achieve high statistical precision, but more important was the consideration that the "soft" cross sections were "bumpy" as a function of energy whereas the "hard" cross sections were not only small but rather featureless. It was natural to concentrate attention on the bumps, which resembled the resonance structures found in atomic and nuclear cross sections, to use them to map out analogous structures, and to pursue what Victor Weisskopf called the "third spectroscopy." On the other hand, since the new physics concentrated on the pointlike constituents (the quarks) within the hadrons, its experiments were designed deliberately to screen out the large soft-scattering cross sections. It also turned out that color gauge theory is much easier to apply to hard than to soft scattering.

One of the most striking predictions of the electroweak theory is the "neutral current" of weak interactions, one example of which is the scattering of a muon neutrino from an electron. It is difficult to establish neutral currents experimentally because the neutrino is effectively invisible. The elimination of "background events," which might be confused with the desired signal, poses problems. If one is too stringent in admitting events as real, out goes the baby with the bath water. If one decides that an event counts, that may be self-delusion. This paradoxical situation with respect to neutral currents has been studied in detail elsewhere by Pickering (and by Peter Galison), and Pickering uses it to support his assertion that physics is constructed by making a series of such "irreducible" choices. However, even if the neutral-current example were typical of practice in high-energy physics (which it is not), the whole of physics made this way might still have more validity than the mere sum of its parts. In most scientific research, the requirement is to find a signal in a noisy environment. Though no one claims that this can be done without occasional error, it is not impossible ever to succeed.

Current high-energy physics is described by Pickering as a "satisfying symbiosis" of theory and experiment, characterized by an agreement not to study any problems that do not have a gauge-theory relevance—that is, by a kind of conspiracy. Pickering's arguments are clever but do not convince. Recall, as a historical parallel, Ernest Marsden's observation in 1909 of rare hard-scattering events in the bombardment of a gold foil with a beam of alpha particles. Ernest Rutherford, his professor, used those observations to deduce the structure of the nuclear atom. That marked the beginning of modern atomic *and* nuclear physics and taught physicists the lesson that hard-scattering events are most revealing of inner structure. Whenever that is your goal, it is appropriate to explore that possibility, provided it is technically feasible. That is the motivation for higher-energy particle accelerators and more sensitive detectors, and not an arbitrary agreement. (The model of high-energy physics that Pickering calls "opportunism in context" is on much safer ground, but it is not developed.)

By the same token, I reject Pickering's claim that modern experimental designs enforce an intellectual incommensurability between the old and the new physics. (But in comparing the scale of the tabletop experiments in Rutherford's Cavendish laboratory with the analogous experiments at Fermilab or CERN, we *may* approach incommensurability.) Were we to reject totally the claim of the "scientist's account," that nature itself constrains both experimental practice and its theoretical interpretation, as Pickering would have us do, then we should also be prepared to reject the actual existence not only of quarks but also of atoms and their nuclei (and of tables and chairs as well).

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Phenomena of Nuclear Physics

Treatise on Heavy-Ion Science. Volumes 1–4. D. ALLAN BROMLEY, Ed. Plenum, New York. Vol. 1, Elastic and Quasi-Elastic Phenomena, 1984. xxii, 753 pp., illus. $95. Vol. 2, Fusion and Quasi-Fusion Phenomena, 1984. xviii, 734 pp., illus. $95. Vol. 3, Compound System Phenomena, 1984. xx, 589 pp., illus. $89.50. Vol. 4, Extreme Nuclear States, 1985. xx, 701 pp., illus. $92.50.

Heavy-ion physics—the study of collisions with accelerated nuclei from atoms more massive than helium—has come to dominate nuclear physics research in recent years. In an attempt to provide a definitive treatment of the subject D. A. Bromley is compiling a seven-volume collection. The size of the project is not surprising considering the complexity of the field and the diversity of the phenomena involved. Unfortunately, there is no overall scientific editing of the independently written chapters. Nevertheless, the size (nearly 3000 pages so far) and scope of this work make it noteworthy in the literature of nuclear physics.

Bromley introduces the subject with a 130-page historical survey of heavy-ion physics. The initial impetus for the study of collisions between heavy nuclei came with the development of the hydrogen bomb around 1950. Scientists feared that a hydrogen bomb explosion might initiate a chain reaction in the atmosphere, fusing the nitrogen nuclei. Theoretical studies by G. Breit convinced the developers of the bomb that their fears were groundless, but it became apparent that they didn't understand enough about nuclear collisions and that they needed new accelerators to improve experimental knowledge of the subject. More recent motivations for the study of nuclear collisions have been the quest for superheavy atoms, which the military was also interested in, and most recently the search for new forms of matter.

Bromley records the development of laboratories at different institutions and the advances in the design of their accelerators that permitted the new machines to collide nuclei at ever higher energy. He dwells on the institutional aspects of the field's development more than on the scientific discoveries themselves. The introduction provides a view of a large-scale scientific enterprise by a protagonist in the field but not a coherent introduction for someone trying to learn about the physics.

Heavy-ion physicists divide the nuclear collisions they study into categories depending on how much energy is lost in the collision, and the division of chapters follows this scheme. The different categories are: elastic scattering, in which no energy is lost at all; quasi-elastic or direct reactions, in which little energy is lost and the target and projectile nuclei are left almost unchanged; strongly damped collisions, in which the nuclei lose most of their energy while still retaining their identity as separate nuclei; and fusion, in which the nuclei coalesce into one large nucleus.

The concepts of potential and of random motion are crucial to an understanding of the different types of collisions. A potential is a field that governs the deflection or absorption of particles. Potentials are used to analyze elastic scattering and direct reactions between nuclei. The idea of completely random behavior governed by the laws of statistics is applied to the strongly damped collisions.

The technical chapters on the different kinds of collisions are uneven in style and focus. For example, the chapter on elastic scattering makes only passing reference to the basic potentials and emphasizes instead a phenomenological approach. However, one of the chapters on direct reactions gives a broader perspective. A discussion of the elegant connection between quantum theory and classi-