The Mid-Victorian Physicists and the Founding of the Cavendish Laboratory[1]

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The opening of the Cavendish Laboratory at Cambridge University in 1874 marked the arrival of professional science in the British university system. The establishment of the Cavendish was an achievement of a group which included Maxwell, Kelvin, Faraday, Joule, Stokes, Rankine and Rayleigh—as well as men of lesser scientific reputation who nonetheless played significant roles in the development of physics: i.e., men such as John Tyndall, Peter Guthrie Tait, William Grove, Balfour Stewart and Fleeming Jenkin. These mid-Victorian physicists were responsible for the development of the modern idea of energy and for the creation of physics as an intellectual discipline (14). They were also leaders in popularizing physics; they were instrumental in developing visible applications of physical theory and persuasive about the intrinsic value of scientific work.

Above all these men firmly established professional science in the British universities and thereby laid the groundwork for academic careers for scientists in Britain. As they brought physics into the British academic world, they developed a new synthesis of theory and experiment and gave the discipline a particular cast, one which, to a certain extent, it retains today.

What I should like to do in this paper is first to recount the events that led to the founding of the Cavendish Laboratory, second to briefly describe the group that was most responsible for these events, third to examine some of the actions the members of this group took to bring physics into Cambridge University, and finally to focus on Clerk Maxwell's presentation of physics as a 'liberal' discipline.

The Founding of the Cavendish Laboratory

Despite increased respect among laymen in mid-19th century Britain, the prestige of science and the status of scientists remained low. The increased popularity of science was to some extent grounded in its appeal to practical interests, and it was seen as "a tool for trade" rather than an intellectual activity of high importance— ". . . suitable for the lower ranks of the hierarchy, but not for gentlemen . . ." (3). The low reputation of science at mid-century was reflected in the exclusion of scientific pursuits from the British universities.

During the 1850s, however, there was strong pressure on Oxford and Cambridge Universities to open their doors to new students and their curricula to new subjects. This pressure grew out of the industrial revolution and was focused on the universities from three directions.

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First, business and professional people, newly rich and powerful, were clamoring for the admission of their children and for curricula relevant to the vocations these new entrants would pursue. Second, other groups, including scientists, were calling for curricular reform, along the lines of the German university model, as a way of meeting the threat of foreign economic and technological competition. Third, there was broad interest in opening up the universities to diverse religious groups through the removal of statutory restrictions.

Eventually the "Old Universities" responded to this pressure. Oxford moved first in 1866 with the election of R. B. Clifton to a chair. Clifton had begun to organize experimental physics at Owen's College a few years earlier. He immediately set out to do the same at Oxford, insisting that for the first time laboratory training be a required part of the science curriculum. In 1868 construction was begun on the Clarendon Laboratory, in 1870 classes were held there, and in 1872 it was completed.

While Clifton's appointment and the opening of the Clarendon did represent a gain for physical science, jubilation would have been premature. Clifton was never more than a minor figure in physics. He did no significant research, he taught only undergraduates, and his idea of experimental work was the controlled repetition of standard exercises illustrating theoretical precepts. Clifton, a 20th century British physicists commented, "lived to a great age and for just fifty years he was successful in forbidding all physical experiment in the Clarendon Laboratory." (7).

Meanwhile a much more significant development was brewing at Cambridge (2, 5, 15, 18, 19). There a faculty syndicate was appointed in 1868 to consider the best ways of meeting new demands for the teaching of physics that resulted from the earlier inclusion of topics on heat, electricity and magnetism in the mathematical tripos. In their February 1869 report, this committee argued for an experimental course of lectures, the founding of a new professorship, and the construction of a "well-appointed" laboratory—all at an estimated cost of £6300 in initial outlay and £660 p. a. for stipends. The university Senate accepted these recommendations and appointed a second syndicate in May 1869 to consider the ways and means of providing the necessary funds.

The task of the second syndicate was more difficult. Over the next year this committee developed and had rejected a number of plans. The most nearly acceptable of these was one which would have made capital outlays from University surpluses and would have covered the stipends through a small, temporary increase (from 17 to 19 shillings) in the Capitation Tax paid by the Colleges each year to the University to meet the levies of the Town of Cambridge. Even this modest proposal was beaten back because of the 2 shilling tax increase, and the matter lay in limbo through the summer of 1870. During the summer, however, something happened.

In October 1870 the Duke of Devonshire, a wealthy and influential aristocrat and industrialist, a mathematics graduate of Cambridge and an amateur scientist, offered the University funds to meet the capital requirements for a laboratory (£6300). Resistance evaporated, and the colleges now committed themselves to a permanent levy of 17 shillings per capita, far greater support for science than they had been willing to consider earlier in the year. In due course, after Sir William Thomson (later Lord Kelvin) and Hermann von Helmholtz declined to stand, Clerk Maxwell was elected as the first Cavendish Professor (23). In March of 1871 he arrived in Cambridge to supervise the planning and construction of the laboratory. He gave his inaugural lecture the following autumn. The laboratory was partly completed in October 1873 and used for lectures that term and for laboratory instruction the following spring. The Cavendish Laboratory was formally inaugurated on June 16, 1874, and experimental physics was thereby officially introduced into the curriculum of Cambridge University. As the course of the history of science since then has proven, this was a very significant moment for British scientists and their work.

The Mid-Victorian Physicists and Their Actions

Behind the important event of June 16, 1874 were a group of men whose actions made the founding of the Cavendish Laboratory an achievement rather than a happenstance. This group was intially defined through its promulgation of the idea of energy. Energy, its conservation and degradation—especially after these ideas were succinctly expressed in the first two laws of thermodynamics—provided a new and fruitful way of seeing the world (6, 8, 9, 12). Physical scientists increasingly adopted these ideas after 1850 and oriented their investigations in accord with them. By 1855 a definable scientific group emerged, a group I call the mid-Victorian physicists.

Collectively the 145 or so members of this group between 1855 and 1875 have some interesting characteristics. They are overwhelmingly of high social standing—both with regard to their social origins (more than 90% from the upper or upper middle classes) and in terms of their educational backgrounds (e.g., 40% were Oxford or Cambridge University graduates). This was a privileged group of men, not only in comparison to British society generally but also in comparison to other scientists, for example, the British chemists of the same period. The mid-Victorian physicists were also far more likely to pursue professional academic careers than other scientists of their era, even though this was a time before professional science had been established in the universities. Finally, in comparison both to earlier scientists and to their scientific contemporaries, the British physicists of the third quarter of the 19th century tended to be religious and religiously orthodox. In the eyes of those at Oxford and Cambridge, who were under increasing attack for their religious restrictiveness, and who were just beginning to confront the implications of the "Darwinian Revolution" as these were being developed by Thomas Huxley and others, the religious tendency of the physicists was an important feature of the group.

The mid-Victorian physicists were then a group of scientists who had an inherent interest in bringing science into the British universities and whose social backgrounds and orientations signaled a natural affinity between themselves and the universities, particularly Oxford and Cambridge. Both individually and collectively, the physicists undertook a number of actions to pursue these interests and affinities, actions which led directly to the founding of the Cavendish Laboratory. In this paper I am concerned with examing those actions which presented physics as a field that was appropriate for inclusion in the established curricula of Oxford and Cambridge Universities.

The presentation of physics to lay audiences from 1855 to the founding of the Cavendish had two phases. During the first phase, the physicists worked within the tradition of popular science that had been established at the Royal Institution of London, modified for wider audiences at the Mechanics' Institutes, and amplified through the plethora of popular scientific journals published between 1830 and 1870 (10, 15, 16). During the second phase, the presentation of physics became 'elementary' rather than 'popular' science, and the audience became the universities and prospective physicists rather than the public at large.

Between 1855 and 1867 British physicists published nearly 50 popular scientific books expounding their views; and almost half of the "Friday Evening Discourses" at the Royal Institution, plus uncounted articles in popular journals, dealt with important issues in mid-Victorian physics. John Tyndall was an important figure during this phase. He lectured often, wrote many articles and published several books (24, 26). In his lecture "On the Study of Physics" (1854), for example, he argued for the value of the then new physical knowledge and of its pursuit. Physics "has given us glimpses of the methods of Nature which were quite hidden from the ancients. . . ." The "earnest prosecutor" of this science has, moreover, discovered "an indirect means of the highest moral culture." "The strictest precision of thought is everywhere enforced, and prudence, foresight, and sagacity are demanded." And with this discipline also come "treasures of power of which antiquity never dreamed," in the form of "mastery over Nature." Although these ends are not central, "this gradual conquest of the external world, and the consciousness of augmented strength which accompanies it, render the study of Physics as delightful as it is important." The utility of physics was, for Tyndall, connected with its intrinsic worth.

> But while the scientific investigator, [he argued] standing upon the frontiers of human knowledge, and aiming at the conquest of fresh soil from the surrounding region of the unknown, makes the discovery of truth his exclusive object for the time, he cannot but feel the deepest interest in the practical application of the truth discovered. There is something ennobling in the triumph of Mind over Matter. Apart even from its uses to society, there is something elevating in the idea of Man having tamed that wild force which flashes through the telegraphic wire, and made it the minister of his will.

He closed his lecture by drawing upon his earlier experience as a schoolmaster. He described how he would "withdraw the boys from the routine of the book" so as to permit them to struggle unaided with challenging questions. The results confirmed all he had claimed for the pursuit of science: "I have seen his eyes brighten, and, at length, with a pleasure of which the ecstacy of Archimedes was but a simple expansion, heard him exclaim, 'I have it, sir.'"

The works of Tyndall, as well as those of other mid-Victorian physicists, were widely circulated and well-reviewed in both serious and popular media. Such statements, coupled with numerous visible applications of physics, led to a general approbation for the work of these men. Queen Victoria spoke for a large segment of the British public in the praiseful dedication with which she knighted William Thomson in 1866 (23):

> In testimony of their high appreciation of his successful efforts to increase our knowledge of the natural laws of heat, magnetism, and electricity, the means of rendering their powers practically useful, and especially of his valuable services in connection with submarine telegraphy, and the now successful completion of the laying of the Atlantic Cable.

It was on this congratulatory note that the mid-Victorian physicists reoriented their public statements of and about their work.

This reorientation (and the second phase of the presentation of physics) began with Kelvin's and Tait's textbook, *Treatise on Natural Philosophy* (22). The publication of this book by the Cambridge University Press in 1867 marked a shift in the public presentation of physics toward the recruiting and training of professional practitioners. The *Treatise* reflected the recognition of the need for a regular cadre of recruits whose training requires special attention, and it was a first step in reshaping physics into educationally appropriate terms. Such a shift was evident in the didactic cast which increasingly characterized the public statements of the mid-Victorian physicists after 1867. From the *Treatise* onward for a decade the public expositions of physics are better called "elementary" than "popular" science. This is true, for example, of even such apparently popular material as Balfour Stewart's articles entitled "What is Energy?" in *Nature* during 1870 (17). Even Tyndall modified his style of popularization, realizing that the educational aims of the physicists entailed certain restraints on their public statements (25). There was, in fact, a decline of purely popular physics, and there were explicit efforts to disparge that which was produced (1, 11). Tait summed up the physicists' position during this phase (20, 21). Popular science must be distinguished from science teaching, he said. The former is too often mere amusement which gives an erroneous impression of the intrinsic difficulty of the subject and, at the same time, "spoils the taste for the simple facts of science."

> There is but one way to be scientific: but the number of ways of being unscientific is infinite. . . . For, though science is in itself essentially simple . . . it is my duty to warn you in the most

> formal manner that the study of it is beset with difficulties, many of which cannot but constitute real obstacles in the way even of the beginner. . . . there is as yet absolutely no known road to science except through or over these obstacles, and a certain amount of maturity of mind is required to overcome them.

Tait was articulating the claims of the mid-Victorian physicists about the character of their field as they sought to establish physics as a university science: physics is not "word painting" and rhetoric but a serious and disciplined activity which requires a substantial investment on the part of its practitioners, and which can be a worthy part of higher education.

Physics in the Universities

By the late 1860s it was possible to see a potential place for professional science at Oxford and Cambridge, though certain constraints were entailed. Only that science could enter these universities which was willing to stress teaching over research and eschew specialization, which was nonexclusive and commensurate with other fields, and which could claim a tradition that fell within the established liberal arts.

By the late 1860s the mid-Victorian physicists were willing and able to conform to these conditions, and to undertake the necessary compromises. T. G. Bonney, for example, expressed this willingness when he answered a critic who had accused him of too modest claims for science at Cambridge (4). "I have done all that was in my power," he said, "to help the cause of University Reform, and especially of Natural Science. But much as I delight in the latter I decline to regard it as the only culture, the only training worthy of respect." Literature and classics, the physicists argued more generally, were essential parts of one's course of study at a university; physics was simply part of culture, pedagogically neither the most nor the least important.

The educational program for physics—shaped to fit the curricula of Oxford and Cambridge while still upholding the thrust of science toward original research—was the work of Clerk Maxwell. The vision of science in Cambridge that Maxwell publicly offered to the University authorities just before and just after his election to his chair blended mathematics and experiment, as well as liberal and professional studies, in a unique way (13). I want to conclude this paper with some of the details of Maxwell's presentation and leave you with the question of whether science today bears the legacy of this stamp.

The aim of the working physicists, Maxwell said, is "to acquire and develop clear ideas of the things he deals with." Yet clear ideas, both the products and the tools of scientific work, are not easily come by, partly because "physical research is continually revealing to us new features of natural processes, and we are compelled to search for new forms of thought appropriate to these features." "Every science must have its [own] fundamental ideas—the modes of thought by which the process of our minds is brought into the most complete harmony with the process of nature. . . ." The physicist may approach his task of gaining clear, fundamental ideas either mathematically or experimentally.

The former involves learning and using abstract forms so as to bring regions of physical phenomena "in succession under the power of the calculus;" the latter, observing and measuring the details of these phenomena, is trying "to deduce the laws of their relations." Each of these modes is useful to the other, yet neither by itself is sufficient to do the work of genuine physics. Some synthesis is obviously required, one in which each region of natural phenomena "in turn is regarded, not merely as a collection of facts to be coordinated by means of the formulae laid up in store by the pure mathematicians, but as itself a new mathesis by which new ideas may be developed." The design of an educational program which could impart this combination of mathematics and experiment to students of physics was not a trivial challenge.

Maxwell saw the initial step in meeting this challenge as that of bringing experimental physics into the blend of mathematics and natural philosophy which was already established in the Cambridge curriculum. To do so he would emphasize "Experiments of Research" as distinguished from "Experiments of Illustration." The former expose students to measurement of physical phenomena and encourage them to cooperate as potential scientific colleagues in the exploration of new regions; the latter, even when engaging students in manipulations, seek only to reinforce the memory of previously known, abstract ideas. In adopting this emphasis, Maxwell was banking upon "the unsearchable riches of creation" and "the untried fertility of those fresh minds into which these riches will continue to be poured;" and he knew that "the labour of careful measurement has been rewarded by the discovery of new fields of research, and by the development of new scientific ideas." He also knew that, if 'experiments of research' were linked to thorough mathematical training, he would be able to expose his students to physical phenomena as a "mathesis by which new ideas may be developed." If he could have his students "wrenching [their minds] away from symbols to the objects, and from the objects back to the symbols," they would acquire "not a mere piece of knowledge . . . [but] the rudiment of a permanent mental endowment . . . the scientific faculty."

So far Maxwell had done no more than provide an articulate justification, appropriate for Cambridge, for what chemists like Roscoe at Owens College had already established in Britain (albeit in non-mathematical form)—namely, Liebig's model of original research as professional training. Maxwell was, however, less interested than his contemporaries in chemistry in simply establishing a new professional program. He was not content merely to develop 'the scientific faculty' in his students, and he would not abide the "narrow professional spirit which may grow up among men of science, just as it does among men who practice any other special business." Furthermore, he insisted on a more active role for the professor *qua* teacher than just that of exemplar to and master of apprentices. His vision was of a liberal education appropriate to the cultivation of British gentlemen, some of whom might want to become physicists. To realize this vision, education in physics had to do more than just be tied up with the mathematical tripos. If the Cavendish was to be successful, Maxwell argued, "we must endeavor to maintain it in living union with the other organs and faculties of our learned body." Moreover, "it must be one of our most constant aims to maintain a living connection between our work and the *other* liberal studies of Cambridge, whether literary, philological, historical or philosophical. . . . [for] surely a University is the very place where we should be able to overcome [the] tendency of men to become, as it were, granulated into small worlds, which are all the more worldly for their very smallness."

In order to ensure such links and their vitality, Maxwell made two radical proposals for the conduct of activities within the Cavendish. First, he proposed that the physicists develop and work within "a spirit of sound criticism."

> Our principal work . . . in the Laboratory must be to acquaint ourselves with all kinds of scientific methods, to compare them, and to estimate their value. It will, I think, be a result worthy of our University, and more likely to be accomplished here than in any private laboratory, if, by the free and full discussion of the relative value of different scientific procedures, we succeed in forming a school of scientific criticism, and in assisting the development of the doctrine of method.

Second, he would teach the history of science. We must recognize, Maxwell argued, that those people

> whose names are found in the history of science are . . . men like ourselves, and their actions and thoughts, being more free from the influence of passion, and recorded more accurately than those of other men are all the better materials for the study of the calmer parts of human nature.
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> But this history of science is not restricted to the enumeration of successful investigations. It has to tell of unsuccessful inquiries, and to explain why some of the ablest men have failed to find the key of knowledge, and how the reputation of others has only given firmer footing to the errors into which they fell.
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> The history of the development, whether normal or abnormal, of ideas is of all subjects that in which we, as thinking men, take the deepest interest.

The implications of these novel proposals were manifold. They meant, for example, a genuine role for the teacher. A spirit of criticism, and the philosophical study Maxwell would promote thereby, cannot arise automatically from the evaluation of alternative methods to be used on a single concrete research problem; and the understanding of the course, and the fits and starts, of the development of scientific ideas is a feat beyond the grasp of any unaided apprentice. Scientific criticism, philosophy and history taught at the Cavendish would also mean that non-scientific students would be attracted there to extend their studies, and that there would be a general broadening of intelleuctual life in Cambridge University. Most importantly, however, and perhaps most welcome to the critics of science within the University, was the fact that, to the extent that these proposals were acted upon, physics would be looked at as human activity (the activities of human beings) and therefore taught as one of the liberal studies.

Conclusion

Maxwell's presentation of physics to Cambridge University is the culmination of an achievement by a group of scientists, the mid-Victorian physicists, as they brought professional science into the British universities through the establishment of the Cavendish Laboratory. This was an achievement with very significant consequences for the fate of the scientific enterprise. It was made possible, in part, through the persuasive presentation of physics as a humanistic discipline. Now, more than 100 years later, one might ask to what extent the field still bears this stamp.

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