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THE AIMS AND BOUNDARIES OF PHYSIOLOGY[1]

PHYSIOLOGY, as the passing generation has known it, took shape and established its boundaries in this country just fifty years ago, when, shaking off its long subordination to anatomy, it was brought to a new life of recognition and progress. The seventeenth century had seen England famous for her school of physiologists, leading the rest of the continent in experimental results and in new ideas. Working upon the foundations laid by Harvey, that brilliant group at Oxford—Boyle, Lower, Mayow, Willis—had brought new light to the study of the living body. Nor was their service only recognized by fellow-workers abroad or by those that came after. Their names and fame were on fashionable lips; like that of their predecessor Harvey himself, under Charles I, and of that other Cambridge philosopher Glisson, their immediate contemporary, their work was aided by the direct interest and favor of the sovereign. But, during the eighteenth century and the earlier part of the nineteenth, eclipse fell upon the light that had thus burned so brightly, though isolated gleams shone here and there. James Jurin, under George II, applied the Newtonian principles to calculating the work done by the heart and to other problems of the body, but his efforts to lay true and exact foundations for the study of disease were premature in the absence of experimental data. Stephen Hales, chaplain to the future George III, made the first measurements of blood pressure in his garden at Teddington, and made many far-reaching observations of the first importance; but, as he wrote, there was indeed "abundant room for many heads and hands to be employed in the work,

[1] From the address of the president of the Section of Physiology at the Edinburgh Meeting of the British Association for the Advancement of Science.

for the wonderful and secret operations of Nature are so involved and intricate, so far out of the reach of our senses . . ."; and it was not then or till much later that many heads and hands were ready to be employed. Neither of these men had effective influence upon the thought or practical affairs of their day, either within the universities or outside them.

Physiology, as we know it now in this country, took its shape in a new revival which may be reckoned as beginning half a century ago. All our chief schools may be said to derive their lineage from that new home of active and unshackled inquiry—I mean University College, in Gower Street, London—and from the influence there of an Edinburgh graduate, William Sharpey, who at the age of thirty-four was taken from the Edinburgh school to be professor of anatomy and physiology. Here, from 1836 to 1874, Sharpey was inspiring a group of younger minds with his eager outlook. Already in France the new experimental study of the living functions was being established by Claude Bernard—that true "father in our common science," as Foster later called him; already in Leipzig Ludwig, transmitting the impulse of Müller's earlier labors, had founded that school of physiology which moulded the development of the subject in Germany and other countries, and had very strong early influence upon several of those who were later to become leaders with us. England had lost the pre-eminence that Stuart kings at all events had valued and promoted. Learning had become identified in English society with the mimetic use of the dead languages, and progress at the two universities—even at the Cambridge of Newton, where mathematics kept independence of thought alive—was still impeded by the grip of ecclesiastical tradition and by sectarian privilege. But at University College learning had been unfettered. Here Sharpey and his colleagues were in touch with the best progress in France and Germany, and here the organized study of physiology as a true branch of university study may be said to have begun. Its formal separation from anatomy came later and irregularly; a separate chair of physiology was not created at University College until 1874, nor at Cambridge or at Oxford until 1883.

We ought in piety to recognize that this tardy reflection of continental progress in our own subject, like parallel movements in other subjects, had in its early stages received invaluable aid from the Prince Consort, who, familiar with the progress of other countries, had lent his influence and sympathy to many men of science in their struggle against the insularity and apathy of the wealthy and governing classes of the earlier Victorian days. The curious may take note that the first outward mark of recognition given by the official and influential world to the existence of physiology as such was given not, as in other and poorer countries much earlier, by the endowment of some chair or institute for research and teaching, but by an act of symbolic representation. For, when the expensive statuary of the Albert Memorial was completed in 1871, it was found that "Physiology," betokened by a female figure with a microscope, had been given its place among the primary divisions of learning and investigation acknowledged in that monument to the Prince.

From Sharpey himself and his personal influence we may trace directly onwards the development of all the chief British schools of physiology whose achievements have in the past half-century restored Britain to more than her old pride of place in this form of service to mankind. We here fittingly acknowledge first the close link with Sharpey which we find here to-day in Sir Edward Sharpey Schafer, who, after fruitful years in his old teacher's place at University College, brought that personal tradition back to this great school of Edinburgh from whence it originally came. At University College itself the line has been continued with undimmed lustre by Starling and Bayliss and their colleagues to the present day. From Sharpey's school again are derived the great branches which have sprung from it, both at Oxford and at Cambridge. Burdon Sanderson, Sharpey's immediate successor at University College, proceeded thence to Oxford and founded there, against many difficulties of prejudice and custom, the school of physiology which Gotch, Haldane, and Sherrington have nevertheless maintained so brilliantly in succeeding years. To Cambridge, Michael Foster, one of Sharpey's demonstrators, was invited in 1870 by Trinity College to be prælector in physiology and fellow of the college. This enlightened and then almost unprecedented act, no less than the personal qualities of Foster that so aboundingly justified it, I would, as in private duty bound, hold here in special remembrance. Under Foster's influence there came into being at Cambridge a strong and rapidly growing school of physiologists, from Langley, Gaskell, Sherrington, Hopkins, to numerous successors. There sprang from him, too, a new impetus to other subjects, through his pupils Francis Balfour and Adam Sedgwick to embryology and zoology, through Vines and Francis Darwin to botany, through Roy to pathology. From Foster again through Newell Martin, who, coming with him from London, had caught not only inspiration from him but some of his power of inspiring others, and who left Cambridge for a chair at Baltimore in 1876, we may derive a large part of the growth and direction of physiology since that time in the United States and in Canada. The rapid progress of all these biological sciences at Cambridge within a single generation, and the volume of original work poured forth depended, of course, upon two necessary conditions. The first is one which has never failed in this country—the existence of men fitted by temperament to advance knowledge by experiment. The second has been the supply of living necessities through the ancient endowments of the colleges, and these in the Cambridge of the last half-century have been freely and increasingly used in catholic spirit for the increase of any of the borders of knowledge.

If these have been the chief lines of descent along which our present heritage has come to us, as mind has influenced mind and the light has been passed from hand to hand, what has been the outcome as we look back over the half-century to those small beginnings?

Truly we can say that the workers in this country have in that short space of years laid the whole world under a heavy debt. In whatever direction we look we seem to see that in nearly all the great primary fields of psysiological knowledge the root ideas from which further growth is now springing are in great part British in origin, and based upon the work of British experimenters. If we consider the blood circulation we find that our essential ideas of the nature of the heart-beat were established by Gaskell, and that other first principles of its dynamics and of its regulation have been laid down by successors to him still with us; that the intricate nervous regulation of the arterial system has had its chief analyses here, and that here have been made more recently the first demonstrations of the part played by the minute capillary vessels in the regulation of the distribution and composition of the blood. Of the central nervous system the modern conceptions of function in terms of the purposive integration of diverse impulses along determined paths have sprung direct from British work, while the elementary analysis of the structure and functions of the sympathetic nervous system has been almost wholly British in idea and in detail. As with the nervous regulation of the body, so with the chemical regulation of function by traveling substances —the so-called "hormones," or stimulants from organ to organ—this, too, is a British conception enriched by numerous examples drawn from experimental work in this country. In the study of nutrition, of the primary "foodstuffs," proteins, carbohydrates, fats, salts and water, whose names in their supposedly secure sufficiency were written with his own hand by Foster upon the blackboard shown in his portrait by Mr. John Collier, to typify, as we may imagine, a basal physiological truth, we have come to learn that these alone are not sufficient for growth and life in the absence of minimal amounts of accessory unknown and unstable substances, the so-called "vitamins," which are derived from pre-existent living matter. This conception, undreamt of to the end of the nineteenth century, has fundamental value in medicine and in agriculture, and has already begun to bear a harvest of practical fruit of which the end can not be seen or the beneficence measured. This discovery stands to our national credit, and large parts of its development and application have been due to recent British work. If we turn to the regulation of respiration and its close adaptation to body needs, that also, as it is now known to the world, is known as British labors have revealed it, just as the finer analyses of the exchanges of gas between the air and the blood and between the blood and the body substance have been made with us. The actual modes by which oxygen is used by the tissues of the body, its special relations to muscular contraction, the chemical results of that contraction, the thermal laws which it obeys—all these fundamental problems of living matter have seen the most significant steps to their solution taken within the past generation in this country.

Work of this kind brings permanent enrichment to the intellectual life of mankind by giving new and fuller conceptions of the nature of the living organism. That we may think is its highest function; but it does more than this. Just as all gains in the knowledge of Nature bring increase of power, so these discoveries of the past fifty years have their place in the fixed foundations upon which alone the science and the arts of medicine now or in the future can be securely based. The special study of disease, its cure and prevention, has had notable triumphs here and elsewhere in the same half-century, and these as they come must make as a rule a more spectacular appeal to the onlooker. Yet it is the accumulating knowledge of the basal laws of life and of the living organism to which alone we can look for the sure establishment either of the study of disease or of the applied sciences of medicine. As we have seen, there are few indeed among the fields of inquiry in the whole range of physiology in which the British contributions to the common stock of ascertained knowledge or of fertile idea do not take a foremost place. It would be impiety not to honor, as it would be stupidity to ignore, these plain facts, which, indeed, are now perhaps more commonly admitted abroad than recognized at home. There is no occasion here for any spirit of national complacency—rather the reverse, indeed. British workers at no time earlier than the war have had the menial assistance or other resources which their colleagues in other countries have commonly commanded, and too often the secondary and relatively easy developments of pioneer work done in this country have fallen to well-equipped and well-served workers elsewhere. If in the past half-century better support had been available from public or private sources, or at the older universities from college endowments, it is impossible for any well-informed person to doubt that a more extended, if not a more diversified, harvest would have been won.

We stand too near to this remarkable epoch of progress to appraise it fairly. In the same span of years Nature has yielded many fresh secrets in the physical world under cross-examination by new devices which have themselves been lately won by patient waiting upon her. So great a revelation of physical truth has been lately made in this country, bringing conceptions of space and of matter so swiftly changing and extending, that our eyes are easily dimmed to the wonders of that other new world being unfolded to us in the exploration of the living organism. Only the lapse of time can resolve the true values of this or that direction of inquiry, if indeed there be any true calculus of "value" here at all. We seem to see in the progress of physiology, not at few but at many points, that we stand upon new paths just opening before us, which must certainly—as it seems—lead quickly to new light, to fuller vision, and to other paths beyond. The advances of the next half-century to come must far exceed and outshine those due to the efforts of the half-century just closing; that is probably the personal conviction of us all. Yet we may still believe that through all the history of mankind recognition will be given and honor be paid to the steps in knowledge which were made first and made securely in the period we now review. The men who have done this work will not take pride in it for themselves; they know that their strength has not been their own, but that of the beauty which attracted them, and of the discipline which they obeyed. They count themselves happy to have found their favored path. Other and more acute minds might have usurped their places and found greater happiness for themselves if, under a social ordering of another kind, they had been turned to the increase of knowledge instead of to the ephemeral, barren, or insoluble problems of convention and competition. By how much the realized progress towards truth and the power brought by truth might have been increased under a changed social organization we can never know, nor can we guess what acceleration the future may bring to it if more of the best minds are set free within the state for work of this highest kind, what riches may be added to intellectual life, or what fuller service may be given to the practical affairs of man and to the merciful work of medicine.

WALTER FLETCHER

TETRACHROMATIC VISION AND THE DEVELOPMENT THEORY OF COLOR

IT would seem to be time for the poor children in the kindergarten to be taught that the number of different "colors" in the spectrum (and in the whole world of natural objects as well) is not seven, nor six, but simply four —red, yellow, green and blue. We have been told lately by Dr. Jennings, in the *American Journal of Physiological Optics,* that the number is seven, and by U. S. Public Health Bulletin No. 92 (prepared by direction of the Surgeon General) that the number is six. The Milton Bradley Company, which furnishes countless delightful kindergarten objects for the children, follows the customary delusion that there are six. But every psychologist knows by this time, thanks to the life-long labors of Hering, that the number of different chromatic sensations (chromata) furnished by the spectrum, and by all of nature too, is four. No physicist, however, is as yet aware that there are more than three; I am in the habit of saying that the physicists are all psychically blind to both yellow and white, all save one, Professor Robert Wood, who in his *Physical Optics* explicity recognizes the existence of a "subjective" yellow. In course of time, no doubt, even the physicists will recognize the fact that *all* the color sensations are "subjective"—that there are no reds, greens, etc., in the extra-corporeal world, but that there are simply the erythrogenic, xanthogenic, chlorogenic and cyanogenic light rays—and that any ray-combination that looks white (as, for instance, a mixture of "yellow" and "blue" light) is a leucogenic combination and due to a "leuco-base."

The reason that led Newton to find seven colors in the spectrum was an æsthetic one—the spectrum is, counted in wave-lengths, about an octave long; in the music octave we recognize seven notes, so why not assign seven tones also to the color octave? In this way what was common knowledge in regard to the number of colors in the world from the time of Leonardo da Vinci became vitiated for a hundred and fifty years by an error which it is still hard to recover from. Hering, in opposition to Helmholtz, recognized that there are four chromatic sensations, but he too was led astray by a logico-aesthetic consideration; he thought it would be nice if, since red and green are, like blue and yellow, a "disappearing" color pair, they were also a white-constitutive color pair. So he said we will assume that they *are* a white-constitutive color pair, and to make the situation still more pleasing we will assume that black and white too are at least a disappearing color pair. But I have shown that when you take the exact red and green (or, in fact, anything near them) you get, on mixing, not white but yellow. My contention on this point has been accepted by Westphal, by v. Kries and others; the colors which are complementary, or white-constitutive, are, as Titchener, with a degree of honesty which is unusual in the followers of Hering, admits, not red and green, but crimson and verdigris,—in other words, white is here, as elsewhere, made out of red, green and *blue.*

Normal, mid-retinal, vision is tetrachromatic. It is to be hoped that we may sometime persuade the Milton Bradley people (whose red, green, yellow and blue papers are, as I have shown, very near to the exact, unitary, Red, Green, Yellow and Blue—I write these color-names with capitals when the colors are exact), and the United States government as well, that the *different* colors in the spectrum are four in number, and that if one adds to one's papers two of the dual color-blends, red-blue and red-yellow (the so-called purple and orange), one should add also the remaining dual color-blends, green-blue and green-yellow. (The fact that these last two color-blends have no misleading unitary names is so much to the good). At-