scientific discoveries are made more by divergers than by convergers, the evidence does tend in this direction. Particularly if 'discovery' is to involve 're-orientation of mental attitudes and outlooks', the mental flexibility, even 'looseness', of the diverger would seem to be required. We can re-state the recruitment problem, then, by saying that science by selecting against divergers will reduce its own collective ability to 'come to terms with' reality in general. One particular problem is that science will otherwise impair its adequacy for self-government—the administration of science will be increasingly carried out by a new managerial class rather than by scientists. A recent article in *Nature*[4] stresses the need for concern with the mechanisms for decision-making with regard to scientific policy, and cites with approval Crossman's article "Scientists in Whitehall"[5]—obviously the personal qualities of the scientists in Whitehall must be of immense significance. Narrow and incomprehensible specialists can do great harm; while adaptable and versatile 'generalists', competent in evaluation and communication, can enhance the mutualism of science and society.

In the context of biology, Underwood[6] has spoken against acquiescence in the reductionist fallacy in teaching (that is, the thesis that biological phenomena can be understood and predicted solely in terms of their 'component' physico-chemical phenomena), and Beer[7] has powerfully elucidated the necessity for general and holistic thinking, from the standpoint of information theory. In biology, reductionism has been and continues to be useful. There are signs, however, of a revival in holistic thinking, particularly in the behavioural sciences. Teleology, for example, shorn of historical connotations under the name 'teleonomy'[8], seems likely to have a useful role in guiding research[9]. It can also add to the effectiveness of teaching, both in allowing greater breadth of insight and in giving increased psychological impact. To say: "An animal has a skeleton in order to keep its body in shape and to provide a firm basis for the muscles to work on", stimulates the interest of a class in proportion as it makes meaningful a number of hitherto discrete and amorphous items of knowledge. (Bones as levers, the identifiability of skull shapes, the lack of skeleton in *Amoeba*, coelom functions in earthworm locomotion, etc. . . .) Teleonomy can also help to unify the functional and evolutionary approaches whose seeming incompatibility, as Mayr[10] notes, has caused "most of the misunderstandings in biology".

It would be of interest and importance to know whether or not teleonomic holistic teaching really can attract relatively more 'divergers' than the conventional approach does, and research on this point would be of great value. Evidence at present is, of course, fragmentary and subjective. Hudson[2] has shown that, while secondary school pupils attracted to physics and chemistry are overwhelmingly of 'convergent' type, more 'divergers' are attracted to the biological sciences. Little of this attraction could be due to overtly teleonomic teaching—because little if any is done. But many good biologists are unconsciously teleonomic (as has been pointed out, for example, by Bernatowicz[11], who castigates them for it), and students undoubtedly respond to this. My own impressions, based on seven years as a student and eight years teaching in three different university institutions, are: that complex (rather than simple) subject-matter, presented in an organized fashion, tends to attract the more able students of both 'converging' and 'diverging' types; the more explicit and obvious the organization, the more attractive it is to 'convergers'; while the less obvious and more buried it is, within limits, the more attractive to 'divergers'. As a student in one department I saw implicitly teleonomic teaching draw able undergraduates, year after year, into the more advanced levels of the subject. Not all of them were 'divergers', but some were. In another and much larger department I have seen emphatically non-teleonomic teaching, teaching that has been intentionally 'objective', 'factual', 'mechanistic', etc., in the narrowest sense, result in numerically small and academically weak advanced classes.

I suggest that two propositions could, and should, be investigated by suitable research: that holistic and teleonomic teaching in biology does attract both the able and the 'diverger'; and that a 'diverging' tendency is often overborne, especially in the early postgraduate life of scientists, by subtle social pressures which force them into the 'converging' mould. One could adduce a multiplicity of such pressures. Some of them have achieved public discussion already, for example, by Barzun[12]. It is beyond the scope of this article, however, to attempt to do more than to point out the existence, and the importance, of some little-recognized relationships.

1 Appleton, E., *Nature*, **205**, 232 (1965).
2 Hudson, L., *Nature*, **196**, 601 (1962); **198**, 913 (1963).
3 Guilford, J. P., *Amer. Psychologist*, **5**, 444 (1950).
4 *Nature*, **205**, 215 (1965).
5 Crossman, R. H. S., *Encounter*, **23**, 3 (1964).
6 Underwood, G., *Nature*, **200**, 27 (1963).
7 Beer, S., *Nature*, **205**, 223 (1965).
8 Pittendrigh, C. S., in *Behaviour and Evolution*, edit. by Roe, Anne, and Simpson, G. G. (New Haven, Conn.: Yale University Press, 1958).
9 See, for example: Ewer, R. F., *Behaviour*, **17**, 247 (1961). Gregory, R. L., in *Current Problems in Animal Behaviour*, edit. by Thorpe, W. H., and Zangwill, O. L. (Camb. Univ. Press, 1961). Cf. Crombie, A. C., *Augustine to Galileo—Science in the Middle Ages*, 140 (London: Heinemann, 1952; Mercury Books, 1962).
10 Mayr, E., in ref. 8.
11 Bernatowicz, A. J., *Science*, **128**, 1402 (1958).
12 Barzun, J., *The House of Intellect* (Harper, New York, 1959).

JOHN WOODWARD, F.R.S. (1665–1728)

PHYSICIAN AND GEOLOGIST

By DR. V. A. EYLES

IN Westminster Abbey, not far from the tomb of Sir Isaac Newton, there lies the body of John Woodward, and a tablet commemorating his achievements was erected in the Abbey not long after his death on April 25, 1728. No one would compare Woodward's scientific attainments with those of his contemporary, Newton, yet, as a naturalist whose work attracted much attention not only in Britain but also in much of Europe, both during and after his lifetime, he deserves recognition by historians of science.

Woodward practised as a physician for more than thirty years, and as such gained notoriety, if not distinction. He made an important contribution to botanical science, and he was much interested in archaeology; but it was as a geologist that he is chiefly remembered. He can justly be regarded as the foremost British geologist of the period preceding Hutton, Smith and Lyell, and his name is perpetuated in the Woodwardian chair of geology in the University of Cambridge, for the foundation of which he left provision in his will.

Woodward was born in Derbyshire on May 1, 1665 (ref. 1). He was educated at a country school where he became proficient in both Latin and Greek. At the age of about sixteen he moved to London, and was there apprenticed to a linen draper. Finding this occupation uncongenial, he pursued a further course of study. Eventually he became acquainted with Dr. Peter Barwick (1619–1905), Physician in Ordinary to Charles II. Barwick was so impressed with Woodward's abilities that he took him into his household to study medicine. Under Barwick's tuition he must have made great progress in the physician's art for, in 1692, he was chosen to succeed Dr. Stillingfleet as "professor of physick" in Gresham College, although he had no academic qualification. Barwick's testimonial supporting his candidature states that Woodward had studied physic in his family almost four years, and that he had also "prosecuted his studies with so much industry and success, that he hath made the greatest advance not only in physick, anatomy, botany, and other parts of naturall philosophy; but likewise in history, geography, mathematicks, philologie, and all other usefull learning, of any man I ever knew of his age". This testimonial, supported by others from "many gentlemen of figure in the learned faculties", among whom was Robert Plot, formerly keeper of the Ashmolean Museum, was sufficient to secure his appointment. In the following year Woodward was elected Fellow of the Royal Society, and thereafter served on the Society's Council from time to time. On February 4, 1695, he obtained the degree of doctor of medicine by patent granted by the Archbishop of Canterbury. This 'Lambeth' degree was awarded relatively infrequently, usually as a reward for eminent service, to those who had not been able to conform with university regulations for internal degrees; and it then constituted a legal qualification for the holder to practise medicine[2]. A year later, apparently by virtue of his Lambeth degree, Woodward received an M.D. degree from Cambridge. In 1702 he was elected Fellow of the Royal College of Physicians.

Meantime, Woodward had taken up residence at Gresham College, where he delivered lectures on medicine and commenced to practise as a physician. In 1718 he published his only contribution to medical science, a book entitled: *The State of Physick: and of Diseases; with an inquiry into the Causes of the late increase of them; but more particularly of Smallpox. With some considerations upon the new practice of Purgeing in that Disease.* In this book he strongly attacked the new practice of purging used in the treatment of the secondary fever in smallpox by such well-known physicians as Richard Mead and John Freind, and advocated treatment by emetics. His book aroused the wrath of Mead, Freind and other physicians; and Woodward was immediately attacked in a series of pamphlets. These, mostly anonymous or pseudonymous, were mainly scurrilous rather than seriously critical, though Woodward had some defenders[3]. The quarrel might have been less bitter had Woodward been a more popular character; but contemporary evidence leaves no room for doubt that his character was not such as would have endeared him to his contemporaries. This quarrel led to the famous 'duel' between Mead and Woodward which took place on June 10, 1719, in the vicinity of Gresham College, when Mead disarmed Woodward. According to Woodward's own account of the incident[4], after onlookers had separated them, he said to Mead that "had he been to have given me any of his Physick, I would, rather than take it, have ask'd for my Life of him; but for his Sword, it was very harmless".

An account of some of Woodward's case-histories was published in 1757[5], but otherwise Woodward receives little or no mention in histories of medicine, and it must be concluded that he made no contribution of importance to medical science. It may be suggested, however, that a critical examination of the vigorous pamphleteering war in which he became involved might provide interesting material for a study of the medical ethics of the period.

Woodward mentions that he studied botany at an early stage in his career, but he made only one contribution to botanical science. Like others before him, he was curious about the subject of plant nutrition, and he was not convinced that the results obtained by van Helmont and Boyle, who inclined to the view that water alone was their source of nutrition, were based on satisfactory evidence. He therefore carried out a series of controlled experiments on the growth of plants in water, chiefly spearmint, over a period of months. He used weighed amounts of water from various sources, being well aware that some waters carried more dissolved or disseminated matter than others, and he used distilled water in one experiment. He weighed his plants at the beginning and end of the experiments. By this means he obtained one important result—proof that the greater part of the water drawn up by plants passes out through their pores and is exhaled into the atmosphere. He thus demonstrated for the first time the phenomenon of transpiration. He also believed that he had established that mineral substances and not water provided the plants with nutrition, water acting only as a vehicle from which the plant extracted nourishment; but in reaching this conclusion he was not, of course, aware of the part played by water in the formation of carbohydrates. The experiments were made in 1691 and 1692, while Woodward was still a pupil of Barwick, and for its time this was a careful piece of experimental work. The results were published in 1699 in the *Transactions of the Royal Society*[6].

Woodward's interest in geology was aroused by chance, as a result of a visit, in company with Dr. Barwick, to the home of the latter's father-in-law, Sir Ralph Dutton, at Sherbourne, Gloucestershire. Here, wandering about the Cotswold country botanizing, in an area studded with exposures of richly fossiliferous Jurassic rocks, he first became aware of the existence of fossil remains of marine organisms. The question of their origin, he relates: "was a Speculation new to me; and what I judg'd of so great moment, that I resolv'd to pursue it through the other remoter parts of the Kingdom; which I afterwards did . . .". The first fruit of Woodward's new interest was the publication, in 1695, of a book entitled *An Essay Toward a Natural History of the Earth.* This contained a theory of the origin of the rocks of the Earth's crust that, in the light of present knowledge, has little more to recommend it than Thomas Burnet's *Sacred Theory of the Earth,* published a few years earlier, and William Whiston's *New Theory of the Earth,* published in 1697. Woodward's views met with criticism, but the book was widely read. It was reprinted in 1702 and 1723, and translated into Latin, French, Italian and German. Woodward's 'theory' had, however, one merit, which was of considerable importance at that time. It advocated and emphasized that fossil remains were organic in origin, a view by no means universally accepted at the close of the seventeenth century, some still believing them to be sports of nature, formed within the rocks by some obscure process. At the same time the theory claimed that the distribution of the rocks and their fossil contents in successive beds or strata was a direct result of the universal deluge. Thus his theory was acceptable to most people, especially the clergy, who still believed in the universality of Noah's flood. Among those converted by Woodward to belief in the organic origin of fossils was the distinguished Swiss naturalist, J. J. Scheuchzer, who translated the *Essay* into Latin, and published it in Zurich in 1704.

In 1696 Woodward published anonymously a twenty-page pamphlet entitled: *Brief instructions for Making Observations in All Parts of the World: as also for Collecting, Preserving, and sending over Natural Things, Being an Attempt to settle an Universal Correspondence for the Advancement of Knowledg both Natural and Civil*; and a sub-title indicates it was intended for the *promotion of Natural History, in all parts of the World.* The instructions Woodward printed are so thorough and modern-sounding that it is worth summarizing them. Under the subhead ings "At Sea", "At Land" and "Upon the Sea-shores" he indicates the sort of meteorological, oceanographical, hydrological, geological, botanical and anthropological observations he considered worth making. Perhaps the most interesting part of the "Instructions" is the "List of Such Instruments as may be serviceable to those Persons who make Observations and Collections". Here we find mentioned the 'Weather-glass now lately contrived by Robert Hooke"; the common barometer and thermometer; the "Hygrobaroscope", for specific gravity observations; a "Dipping-needle" for observations on sea and land; a quadrant for astronomical observations and determining heights; a level for determining the dip of strata; hammers and a "Chissel" for examining rocks; crucibles and fluxes for trials of ores; and an "Eradicator" to take up the roots of herbs. Woodward then adds that "It would be of incredible *advantage* to this *Design*, were *all* the *Thermometers* and *Hygrobaroscopes* used in it adjusted nicely and exactly after some *one common standard*," and he recommended for this purpose "Mr. *Hunt*, *Operator* to the *Royal Society* at *Gresham College*", who would not only procure these instruments but instruct in their use. Nothing if not thorough, Woodward did not forget the necessity for quires of brown paper and nests of pill boxes in which to pack specimens; and for "the more tender Creatures, Insects, Lizards, Serpents, &c.", he recommended the use of bottles and jars, with spirits of wine, rum or brandy, and sublimate of mercury as preservatives. Finally, he suggested, the Custom-house officers should be warned, so that no inconvenience or damage resulted when the consignments were examined. This pamphlet, there is reason to suppose, was widely circulated, for it is known that Woodward corresponded with many naturalists, not only in Britain, but in Europe, America and Asia.

In succeeding years Woodward gathered together, at Gresham College, a very large collection of fossils, minerals and other 'curiosities', which he described carefully, noting information such as locality and mode of occurrence. Even by modern standards, the collection must have been a fine and very extensive one, for it included not only a large and representative suite of British minerals and fossils, but many specimens from Europe, and some from North America and Asia. It was probably accumulated largely from correspondents, and by exchange, though undoubtedly Woodward collected much British material himself. The fame of his museum must have travelled far, for among those who have left a record of visiting it were several foreigners.

Woodward's passion as a collector resulted in the appearance of two more books from his pen. One, bearing the misleading title *Fossils of all Kinds Digested into a Method*, was published in 1728, the year of his death. It contains much miscellaneous matter; but is essentially a text-book of mineralogy, with a systematic classification of minerals, and an indication of methods to be used in identifying them. Among those are determinations of hardness, specific gravity and the effects of heat, and other characters to be noted are form, colour, transparency and so on. At that time chemistry could provide relatively little help, and crystallography almost none for identification, and so Woodward's mineralogy bears little resemblance to modern text-books. It was, however, at least as good, and possibly better than others of its time, and, moreover, Woodward was the first British author to publish a work solely devoted to the subject, a fact that seems to have been completely overlooked by historians.

Woodward's last book, published posthumously in 1729, was a catalogue of his geological and mineralogical collections, entitled *An Attempt towards a Natural History of the Fossils of England: in a Catalogue of the English Fossils in the Collection of John Woodward, M.D.*, the term 'fossil' being used here to include both minerals and 'extraneous' or organic fossils. In fact, it also contains lists of the foreign minerals and fossils in the collection. The extent of the collection can be judged from the fact that the book contains nearly 600 pages in small type. Here again it is noteworthy that the lists of minerals occupy considerably more than half of the book, emphasizing the author's interest in mineralogy. The mineral lists give localities and notes on the types of ores and their mode of occurrence. Many specimens come from British mines long since abandoned, hence the book has some value, even to-day.

Little need be said of Woodward's activities as an antiquarian, though they were well known in his lifetime. He corresponded for many years with Thomas Hearne and others on the subject; and in 1712 published a book entitled *An Account of some Roman Arms and other Antiquities lately digged up near Bishopsgate; with brief Reflections of the Ancient and Present State of London*. It is perhaps worth noting, too, that he realized the nature and use of stone artefacts, which he figured and described in his book *Fossils of all Kinds Digested into a Method*.

Woodward was a typical virtuoso of a type common in the late seventeenth and eighteenth centuries, a man of intense intellectual curiosity, pursuing knowledge for its own sake. It is well known that he was ill-mannered, quarrelsome and easily offended, and that he had a great conceit of himself. His continued rudeness offended Sir Hans Sloane and led to his expulsion from the Council of the Royal Society. On this occasion, in reply to the plea that Woodward was a good natural philosopher, Sir Isaac Newton replied, "that in order to belong to the Council a man ought to be a good moral philosopher as well as a good natural one"[7]. Woodward's nature was such as to provide a natural target for the wits of the period, and many amusing examples of their shafts might be quoted; for example, he figured as 'Doctor Fossile' in a play, *Three Hours After Marriage*, performed at Drury Lane in January, 1717. One of his visitors, Sir John Clerk of Penicuik, Midlothian, after making the acquaintance of Woodward and his "vast collection of natural Curiosities", expressed the opinion that Woodward himself "was the greatest Curiosity on earth, being a vain, foolish affected Man. His *Natural History*, however, is a book that deserves to be read, as it treats very well on Minerals and fossils". Stukeley, the antiquarian, described him as an 'egregious coxcomb'.

Though Woodward made no contributions of outstanding and permanent value to natural science, his works were often quoted by eighteenth-century authors, and it can be said with truth that he greatly stimulated the study of geology and mineralogy both during and after his lifetime. In addition, he bequeathed his collection of English fossils to the University of Cambridge (which bought the foreign ones for £1,000 from his executors), and there they are still preserved in their original cabinets. He also left a sum of money to the University to found a lectureship in geology, the first of its kind in any university, and if the early occupants of the position made no serious effort to carry out Woodward's wishes, the fault was not his[8]. Woodward played a not unimportant part in forwarding the Scientific Revolution that commenced in the seventeenth century, and his labours deserve to be remembered.

1 The principal source of biographical material about Woodward is in J. Ward's *Lives of the Professors of Gresham College*, 283 (1740); but see also f.n.8.

2 Wall, C., *Brit. Med. J.*, 854 (1955).

3 See, especially, Beattie, L. M., *John Arbuthnot*, 190 (Cambridge, Mass., 1931).

4 *St. James's Evening Post*, No. 635, June 18, 1719, p. 3; and other newspapers.

5 *Select Cases and Consultations in Physick*, by the late eminent John Woodward, M.D., now first published by Dr. P. Templeman (1757).

6 *Phil. Trans. Roy. Soc.*, 21, 193 (1699).

7 See De Beer, G. R., *Sir Hans Sloane and the British Museum*, 87 (1953).

8 Clark, J. W., and T. McK. Hughes, *Life and Letters of Adam Sedgwick*, 1, Chap. 5 (1890).