Pentameral Symmetry in Echinoderms

Nichols, in his recent restatements[1,2] of the suture-line theory, has made out a strong case for the adaptive significance of pentameral symmetry in the newly metamorphosed echinoderm. Its admittedly transient advantages at this stage, however, do not seem to account for a pentamerous form persisting to determine the symmetry of the adult body. There are exceptions—Nichols[1] quotes *Promachocrinus*—but why are they not the rule ?

Nichols has looked for a reason for pentamerism in the life of modern echinoderms, but the evolution of echinoderms is a continuous process which has gone on since Pre-Cambrian times[3]. Once the pentameral condition had been established at some time in the past, in many members of the phylum it was likely to persist tenaciously in a variety of ways of life because any disadvantages of pentamerism are likely to be less than the disadvantages of changing it. Conversion of pentameral symmetry to a higher symmetry could not be done gradually because there is no intermediate between five-fold and six-fold radial symmetry. If it occurred as one mutation, the whole body-plan of the animal would be altered. In groups in which parts of the skeleton fit together to form a rigid box, such as the theca of blastoids or the corona of echinoids, the disruption caused by this mutation would certainly be disadvantageous. In echinoids, with a corona of elaborate architecture and, in most groups, a complex jaw assembly also, the angular relationships and so the shapes of most parts of the skeleton would have to be altered to fit. This is presumably why the only echinoids without five rays are occasional teratological individuals. Where the constraint of a rigid test has been reduced, pentameral symmetry has been less persistent. In the asteroids, the basic skeletal structure is in the flexible arms. In consequence, the asteroids have both species (for example, *Oreaster reticulatus*[4]) and genera (for example, *Luidia*[5]) with pentameral and other symmetries. The adaptability of the asteroid skeleton to this sort of disruption is illustrated in the growth of *Pycnopodia helianthoides*[6] where the extra arms "wedge apart" the adambulacral and interbrachial ossicles as they develop.

Bather's theory[7] is an account of how the pentamerous condition may have arisen, and it is still favoured today[8]. It may be possible to explain how the original trimerous condition arose in terms of the demands of bilateral symmetry, but, as Nichols[1,2] points out, it is not clear why only the lateral rays divided, and those only once. Unless there is some constant, but unknown, ecological or anatomical factor involved, the failure of the anterior ray to divide must be explained by applying the suture-line theory to this stage in evolution. This would eliminate forms with an even number of rays produced by division of the anterior ray or only one lateral ray. Seven or nine rays, produced by a further division of the lateral rays, seem to have been unnecessary. It may be that five ambulacra carried sufficient podia for the early echinoderms, which tend to be smaller than their later relations. (This is better demonstrated from a collection of specimens than a collection of references.) Also, under the suture-line theory, seven or nine rays would make the animal more vulnerable. An echinoderm, which had evolved pentameral symmetry like this, might be capable of changing gradually in such ways as to give rise to all the major groups of echinoderms, without being able to attain a higher symmetry for the reason given in the second paragraph. Nevertheless, there seems to have been a need in many of the later groups for an increased number of podia, which has been met without losing the pentameral symmetry. In Palaeozoic echinoids, the number of ambulacral columns has been increased[9]; in later echinoids, compound ambulacral plates have been developed[10]; in edrioasteroids, the ambulacra have become longer and curved[11]; in crinoids the arms have frequently branched extensively[12].

It would seem that a complete theory of echinoderm pentamerism should consider the history of these animals, especially in Cambrian and Pre-Cambrian times. Such a theory can be more firmly based as recently discovered fossils[2,3] are further interpreted.

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PHYSICS

Drag of Spheres in Dilute High Polymer Solutions

White[1] showed that the drag on spheres in water, at Reynolds numbers exceeding the critical value ($vd/\nu >$ about 2×10^5), could be increased by dissolving a very small quantity of polyethylene oxide (Union Carbide 'Polyox *WSR*301') in the water, and suggested that this effect resulted from suppression of turbulence in the boundary layer by the additive, which caused earlier separation and a corresponding increase in the wake size.

Experiments carried out below the critical Reynolds number, where the boundary layer is laminar, have shown that the drag on a sphere is considerably reduced by adding 'Polyox'[2-4], although drag reduction in pipe flow occurs only in the turbulent regime. Flow visualization studies[3] showed delayed boundary layer separation and a smaller wake size with the polymer solutions, which is consistent with the reduction of drag.

Tests have now been carried out for a wider range of Reynolds number to span the critical region ; the technique of measurement was similar to that of the previous investigators. Steel spheres were dropped down through cylinders containing the test liquid ; the spheres were

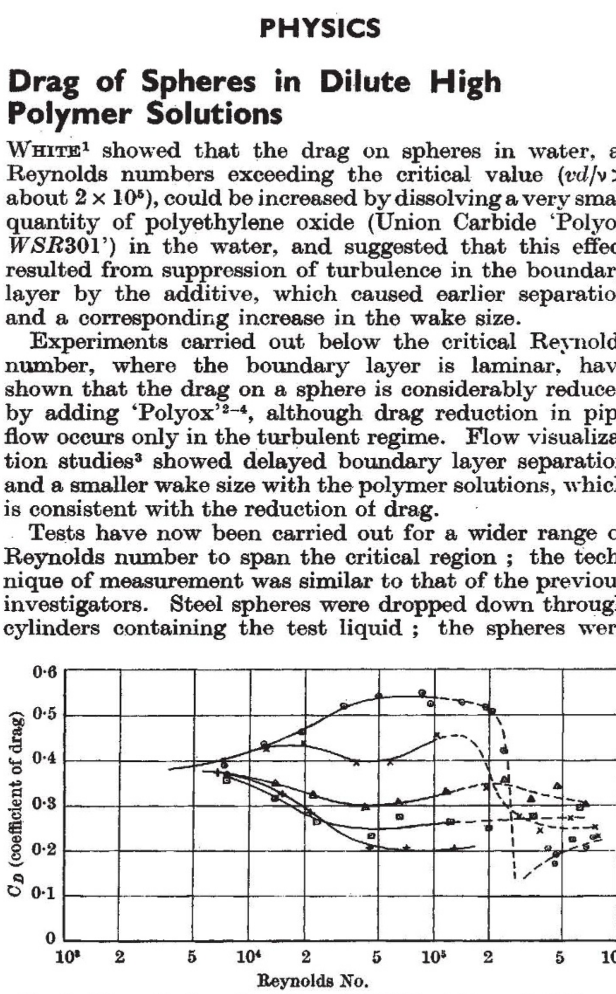

Fig. 1. Drag of spheres in 'Polyox *WSR*301' solution. ⊙, Water; ×, 10 p.p.m. 'Polyox' solution; △, 30 p.p.m. 'Polyox' solution; ⊡, 60 p.p.m. 'Polyox' solution; +, 120 p.p.m. 'Polyox' solution.