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10. We thank P. H. Winston for his important role in inspiring our experiments, and M. G. Ruddy for computer programming and data collection. We also thank K. Ainslie, V. Blaisdell, A. S. Coriell, B. Gates, G. Ozog, and R. Szoc for assistance with these experiments or related pilot studies, and M. Allyn and D. E. Meyer for extensive comments on the manuscript. This work was carried out while N.W. was on sabbatical leave from Loyola University of Chicago. It was supported in part by PHS grant R01EY00143 to N.W.
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Development of Mollusk Shells

We wish to contribute perspective to Clark's (*1*) report on the growth and shape development of bivalve shells. Our examination of representative species among the various pelecypod (bivalve) families indicates that, as a general case, the periostracum forms a topologically continuous sheath completely enclosing each growing shell. On the outer surface it becomes a tough cuticle (*2*). The Pectenidae (scallops) and Cardiidae (cockles) seem atypical in the apparent absence of this continuous periostracum.

It is not clear from the text or the electron micrographs in (*1*) whether the periostracum in *Pecten diegensis* forms a similar enclosing sheath, but it does appear that the periostracum is present, although extremely thin, and continuous over at least the margin of the advancing shell. Shell growth is probably not by extension of the advancing shell margin into the aqueous medium, but is more like the picture of a man in a sheet who extends his arms. All the sequential biochemical events are thus contained within this protective membrane, which is continuous and maintains a controlled environment. It would be valuable to follow the periostracum with the scanning electron microscope over the entire outer surface to the hinge to establish its continuity. If continuity were established, the shell development of *Pecten diegensis* would be consistent with that of many animals in other pelecypod families.

The layering observed by Clark in the deposition of new shell material suggests a biological rhythm, possibly the same rhythm which is responsible for the concentric lines normal to the direction of growth which are common to all of the pelecypods. If the periostracum were continuous over the tops of the growth ridges described by Clark, the interspaces might be due to loss of matrix during handling and treatment of the sections or perhaps partial delamination of the layers. The shells of the scallops and cockles are convoluted, and this may be related to the invisible (or missing) periostracum on the outer shell surface.

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References and Notes

1. G. R. Clark, *Science* **183**, 968 (1974).
2. In freshwater mussels of northern California this cuticle has a protective function, so that injury to this covering allows leaching and perforation of the shell matrix. Shell integrity seems essential, as all healthy individuals had intact shells, while all individuals found with perforations were dead and in many instances filled with mud.

26 March 1974

I appreciate the interest of Gainey and Morris in my recent report (*1*), and welcome the opportunity to broaden the perspective of the discussion.

Gainey and Morris devote most of their comment to a discussion of the function and limited distribution of the periostracum in bivalves. They correctly note two functions of the periostracum, the first being as a protective covering for the entire shell and the second being as a mechanism for isolating the calcification of the shell margin from the sea. They also note that in some groups of bivalves the periostracum is not obvious as a covering on the entire shell and suggest that scanning electron microscopy should be used to see whether it is, in fact, present in areas other than the shell margin. Here they seem to be arguing that the protective function is the original function of the periostracum, whereas current theory and the very evidence they cite suggest strongly that the periostracum evolved to satisfy the needs of calcification and the protective function evolved later in certain groups. These concepts are scattered throughout the literature of the past 25 years (*2*), and will be discussed at some length in a paper now in press (*3*).

Gainey and Morris also present some speculations on layering and delamination, but further discussion might best await at least one supportive fact.

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9 September 1974

Niobium for Superconducting Alternating-Current Power Transmission

Suenaga and Garber (*1*) have reported low a-c losses for samples of Nb_3Sn conductor tested at 4.2 K and 60 hertz. Their results are significant because they demonstrate that the a-c losses of this material are not high enough to preclude its consideration for use as a commercial superconducting cable. However, their concluding sentence, "Such cables would have marked advantages with respect to higher operating temperature and fault current capability than cables employing a niobium conductor, and with the same or lower a-c loss," is not fully supported by the data in their report, nor is it supported by experimental work carried out and reported elsewhere (*2–7*).

Suenaga and Garber compare the a-c losses at 4.2 K of "composite" and "tin dipped" Nb_3Sn with the niobium a-c losses at 4.2 K reported by the Linde Division of Union Carbide Corporation in 1969 (*2*). Earlier in 1969 (*3*), and more recently in 1973 (*4*), niobium a-c losses have been reported by investigators at Linde and Siemens that are significantly lower than the results Suenaga and Garber have chosen to compare against. Bogner *et al.* (*4*) have reported niobium a-c losses at a peak surface field of 1000 oersteds [corresponding to a root-mean-square (r.m.s.) surface current of 563 amp/cm] that are less by about a factor of 10 than the losses given by the best Nb_3Sn conductor discussed by Suenaga and Garber. It is to be expected that such low losses can be obtained with niobium, Nb_3Sn, and other superconducting materials that have been prepared expressly for the purpose of exhibiting low a-c losses. However, the incentive to do so is diminishing since the technology has now reached the point where the conductor's a-c losses can be made smaller than the other heat loads on the system (*5*).

There is no question that Nb_3Sn, by virtue of its higher transition temperature, will exhibit a-c losses lower than niobium at some operating temperature higher than 4.2 K. But Suenaga and Garber do not provide any loss data at temperatures higher than 4.2 K. The reader must infer that the a-c losses of Nb_3Sn at a peak surface field of 1000 oersteds do not increase with increasing temperature so rapidly as to remove any economic incentive for higher temperature operation.

Suenaga and Garber claim that Nb_3Sn possesses a marked fault current advantage by virtue of its higher critical currents. But fault capability is not a function of critical current alone. Necessary and sufficient fault recovery capability can be designed into niobium conductors if adequate cooling and coolant mass are provided. It would be more relevant to compare the costs of niobium and Nb_3Sn cables designed for the same service.

The fault recovery capability of niobium conductors was discussed by Meyerhoff at the 1973 Cryogenic Engineering Conference (*6*) and in a progress report (*7*) for a project on superconducting cable R & D sponsored by the Electric Power Research Institute–U.S. Department of the Interior. In one test reported, a niobium conductor operating at a steady-state a-c surface current of 686 amp/cm r.m.s. was pulsed to 2747 amp/cm r.m.s. (sufficient to drive the conductor to the normal state) for 18 cycles and then brought back to its steady-state current of 686 amp/cm. Within eight cycles, the conductor returned to the superconducting state.

In summary, both niobium and Nb_3Sn conductors can be made to exhibit adequately low losses and adequate fault current capability. And, in fact, better experimental confirmation exists concerning the ability of niobium cables to recover from fault currents than of Nb_3Sn cables.

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21 March 1974; revised 12 June 1974

We appreciate Haid's acknowledgment that Nb_3Sn can be considered for use in a commercial superconducting cable. But, contrary to the impression given by his remarks, it has not been generally expected that low a-c losses could be obtained with Nb_3Sn. We cite a few of the many references in which it is explicitly stated that Nb_3Sn is not suitable for a-c power transmission because of large anticipated hysteretic loss (*1*, *2*). In fact, the starting point for the use of niobium in a-c transmission line projects has been the presumed uniqueness of this material with respect to losses. The purpose of our report (*3*) was to contribute to the overthrow of this dogma, and this we believe we have done.

We did not discuss the effect of temperature on loss in our original report, but standard theoretical estimates indicated there should be no serious rise in the loss level with temperature up to ~ 8 K (*4*). Recent measurements (*5*) on commercial Nb_3Sn tapes confirm this expectation: in the best such tape the loss was 10 $\mu w/cm^2$ at 8 K for a [root-mean-square (r.m.s.)] current of 550 amp/cm at a frequency of 60 hertz. It is true that this loss level is higher than that of the very best niobium. However, as Haid and others (*2*) agree, discussions of losses that are significantly lower than the above value are of purely academic interest since the refrigerator load is then dominated by other sources of heat.

We measured critical currents in many commercial tapes. Values as high as 5200 amp/cm r.m.s. were observed at 4.2 K. The temperature dependence (*5*) was measured on a limited number of tapes, and, in general, there was a 20 percent reduction in the critical current at 8 K. With Nb_3Sn, then, quite large fault currents can be carried as supercurrents. During any fault condition the total heat input to the coolant will be less and the return to normal operation faster for a Nb_3Sn cable than for a niobium one.

Thus, operation of Nb_3Sn cable at ~ 8 K is very feasible. Instead of comparing the cost of niobium and Nb_3Sn cable, as Haid suggests, it is far more relevant to compare total system costs. The higher operating temperature of Nb_3Sn cable affords significant economies in cooling system design (*4*, *6*).

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30 August 1974