(*Lebistes reticulatus*) is perhaps the most widely known representative. Nearly 30 years ago Hubbs and Hubbs (*1*) announced the discovery of a remarkable fish which has only one sex. This is the so-called Amazon molly (*Mollienesia formosa*), which inhabits coastal and inland waters of northeastern Mexico and adjacent Texas. These females are able to maintain themselves as natural populations by utilizing the males of *M. sphenops* in certain parts of their range and the males of *M. latipinna* in others. Fourteen years of experimental work has demonstrated that this species, evidently of hybrid origin, produces daughters only, and that these are invariably like their mothers despite the fact that the mothers were mated with the males of many related species, including even the guppy. Development is clearly induced by sperm, though no evidence of paternal inheritance has been found in resulting generations. These authors subsequently concluded (*2*) that "the most plausible explanation for the genetic behavior of *Mollienesia formosa* is that this unisexual species is a permanently fixed diploid," and that active sperm is essential to initiate embryonic development (gynogenesis).

Recently Hubbs, Drewry, and Warburton (*3*) reported the discovery of what they interpreted as a naturally occurring phenotypic male of *M. formosa* in a population of this species taken near Brownsville, Tex. We and others (*4*) feel, however, that it is quite possible that *M. sphenops* is occasionally liberated near Brownsville by aquarists or tropical-fish fanciers, or that it may occur there naturally on occasion. If so, the "male of *M. formosa*" may actually be a hybrid between *sphenops* and *latipinna,* which readily cross in aquaria and produce bisexual offspring. Only experimental evidence can reveal the correct explanation.

At this time we wish to announce the discovery of unisexual types in two other species belonging to the same family as *M. formosa.* These, members of the genus *Poeciliopsis,* inhabit coastal streams of northwestern Mexico. Unlike the Amazon molly, these two allopatric species each have two kinds of females —those which produce both sexes and those which, although mated to the same male as the former, produce daughters only. Four generations of these fishes have been reared in the laboratory, with consistent production of bisexual young from the "normal" females and of unisexual offspring from the "aberrant" females.

The "all-female" strains of the two species of *Poeciliopsis* (here referred to as *F* and *C*) were discovered by chance, since they are virtually indistinguishable from the normal females. A slight but consistent difference in dentition noted in preserved specimens first revealed the existence of two types of females in F and subsequently led to the studies now in progress (*5*). On similar grounds, the unisexual strain of C was later predicted and its occurrence has recently been verified.

Although the genetic explanation of these remarkable strains is not yet clear, sufficient data have accumulated to indicate that this all-female condition is not the result of (i) a sex-linked lethal, (ii) parthenogenesis, (iii) gynogenesis, (iv) cytoplasmic inheritance, or (v) sex reversal. We have established on the basis of genetical evidence that these fish have sex chromosomes and that, unlike most other viviparous fishes, the female is heterogametic and the male homogametic. Using marker genes, we have been able to show that paternal traits of the male of F are transmitted through the all-female of C to the F_1 hybrid (Fig. 1).

These unisexual strains are of interest as possibly representing a transitional stage in the development of an all-female form like that of *M. formosa.*

ROBERT RUSH MILLER
R. JACK SCHULTZ

Museum of Zoology,
University of Michigan, Ann Arbor

References and Notes

1. C. L. Hubbs and L. C. Hubbs, *Science* **76**, 628 (1932).
2. ———, *Records Genet. Soc. Am.* **14**, 48 (1946).
3. C. L. Hubbs, G. E. Drewry, B. Warburton, *Science* **129**, 1227 (1959).
4. C. Hubbs, personal communication, 1958; C. P. Haskins, personal communication, 1959.
5. Since 1955 these studies have been supported by grants from the Horace H. Rackham School of Graduate Studies, University of Michigan, and, since 1958, by a grant from the National Science Foundation (NSF G-4854).

6 August 1959

Wave-Riding Dolphins

I wish to take issue with P. F. Scholander (*1*) on the problem of how dolphins ride waves (*2*). The problem of wave-riding dolphins was posed by Woodcock (*3*) and by Woodcock and McBride (*4*), who estimated the hydrodynamics of a dolphin riding a wave propelled by its own weight times the angle (in radians) of the wave. Woodcock and McBride showed that with a reasonable estimate of the hydrodynamic drag, the submerged weight of the dolphin was insufficient to provide the necessary balancing thrust. I resolved the problem by showing that it is the total weight of the dolphin, rather than its submerged weight, which is significant in wave riding.

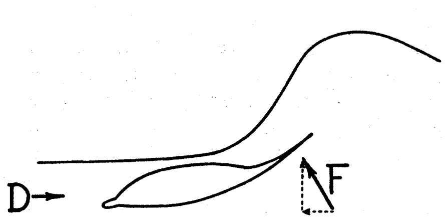

Fig. 1. Forces on the dolphin in Scholander's model.

Scholander has rejected my explanation and has substituted an explanation of his own for the phenomenon. In my opinion Scholander has discarded a satisfactory and rational explanation to substitute one which violates fundamental physical laws.

Scholander's criticism of my explanation (*5*) appears to involve some lack of understanding of this explanation. In the critical part of his discussion of it Scholander confuses the concepts of acceleration and velocity. Here I must admit that my earlier article was written in quite a terse style. Though the article states the argument completely, it includes little expositional detail and might be fully convincing only to a theoretical hydrodynamicist willing to supply this detail. The conclusions of the article are nonetheless sound: A streamlined body in a steady incompressible flow does experience a force very nearly equal to its volume times minus the average ambient pressure gradient in the flow field. This effect provides the dolphin with a net forward thrust approximately equal to its displaced weight times the wave angle. Scholander admits that his experiments testing this effect do not represent a fair evaluation, and he gives but little description of them.

The principle of a hydrodynamic force proportional to the ambient pressure gradient is an old one and plays a part in classical aerodynamics. [See, in particular, the work of Taylor (*6*).] Taylor's paper gives not only a thorough theoretical treatment but also a description of experimental verification of the basic effect. The additional induced mass over the displaced mass is small for a slender body, and was neglected in my earlier article (*5*).

Scholander's alternative explanation is based upon a model, in which the dolphin derives a large upward force F on its tail fluke (see Fig. 1). The tail fluke is in a part of the wave in which the water is rising, with the result that the upward force has an appreciable forward component which balances the drag on the dolphin. So far, Scholander's model is satisfactory. The difficulty lies in the fact that both horizontal and vertical components of the forces on the dolphin must balance, and so must the moments. These conditions are required by classical statics. In Scholander's model the horizontal force components balance, but the vertical components clearly do not balance. If we suppose that the dolphin also develops a large downward force on its flippers in the region in front of the wave, so that the vertical force components balance, the moments clearly do not balance. The inescapable conclusion is that Scholander's model is not a possible one. In this light it is also clear that the experiment described by Scholander is not a pertinent one, because of the vertical reaction at the pivot of the support arm.

WALLACE D. HAYES
Princeton University,
Princeton, New Jersey

References and Notes

1. P. F. Scholander, *Science* **129**, 1085 (1959).
2. I am indebted to Scholander for sending me, through W. H. Munk, a copy of his article in advance of publication. The criticisms of the present note were submitted (again through Munk) to Scholander in private correspondence, but they were insufficient to induce him to withdraw his article from publication.
3. A. H. Woodcock, *Nature* **161**, 602 (1948).
4. ——— and A. F. McBride, *J. Exptl. Biol.* **28**, 215 (1951).
5. W. D. Hayes, *Nature* **172**, 1060 (1953).
6. G. I. Taylor, *Proc. Roy. Soc. (London)* **A120**, 260 (1928).

13 May 1959

Eleven years ago Woodcock observed that a dolphin gets a free ride when in close proximity to the bow of a ship. In this situation the body of the dolphin rides in the horizontal water ahead of the bow—that is, it is not located within a wave. Only the tail fluke engages the disturbed water. This essential point was missed by both Woodcock and Hayes, who instead proceeded to explain an imaginary, unobserved situation where a dolphin supposedly gets a free ride in the front slope of a wind wave. With both dolphins and theories missing the boat, so to speak, it is no wonder that the observed bow-riding phenomenon remained unsolved.

Interesting, notwithstanding, is the thesis held by Hayes—namely, that a streamlined body of neutral bouyancy can be propelled within a wave at wave velocity. To most of my colleagues this seemed unrealistic, and with the authorities clearly split, the only way out was to test the idea experimentally. Standing on a dock one may easily observe that neutrally buoyant fish or pieces of seaweed in any orientation are not swept along with the waves passing by. The issue therefore narrows down to the question: Can the Hayes effect, if indeed it exists, maintain or assist a propulsion at wave velocity once such a propulsion has been started?

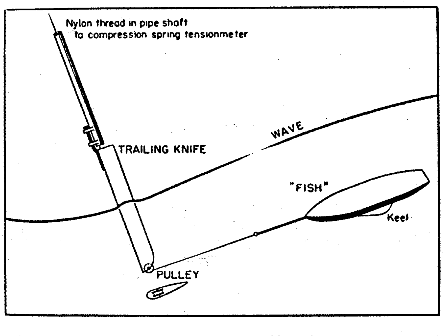

Fig. 1. Towing a neutrally buoyant and balanced model in the front slope of a steep wave.

The following experiments were designed to test this. A skiff at the end of a rope 20 m long was towed from the tip of the transversely secured boom of one of the Scripps Institution research ships. By careful steering it was possible to maintain the skiff in a fixed relation to the waves coming off the side of the ship. Streamlined and neutrally balanced models were towed at four positions within these smooth and relatively very steep waves (Fig. 1). With the wave angle some 30° and the model weighing 650 gm, the Hayes effect would amount to some 300 gm. It can be seen from Fig. 2 that the drag merely reflected the relative velocity between the water and the model, being least in the crest, largest in the trough, and intermediary in the slopes. There is no indication whatever of a 300-gm push in the front slope (or of an added 300-gm drag in the back slope).

As pointed out in my original article, better data can certainly be obtained, but even now it seems clear that if Hayes, like myself, caters to the judgment of the multitude, he must come down to an experimental defense of his thesis. If through a more refined technique he can demonstrate that my relatively crude results are misleading, then I shall gracefully bow out, happy all the while to have contributed to a better understanding of what goes on in a wave. At present, however, Hayes' basic thesis is challenged by many and stands contradicted by experimental evidence (*1*).

Now, to return to the main issue—namely, the relationship between the dolphin's tail and the curvaceous bow of the ship. Hayes is eminently right when he echoes my concern that the situation, as outlined in his Fig. 1, theoretically is not a stable one; for in tending to topple over, the dolphin will slide back and out of position. So much for the theory, but in the actual fact he remains right there. We ourselves can beautifully handle unstable conditions, like standing upright, and no doubt the porpoise is equally proficient in similar control functions. If the dolphin in Hayes' diagram slides forward relative to the bow wave, the front edge of the tail fluke will soon catch horizontal water. This will depress the fluke against the rising water behind, with consequent propulsive effect. Perhaps some such scheme can be made to balance out. I shall confess, however, that my feeble attempts to show this experimentally have met with failure, so again we must bow to the dolphin. How, also, can a dolphin swim several times faster than predicted from drag and muscle power? This is another problem which has long amused physiologists but has rather worried students of theoretical fluid mechanics.

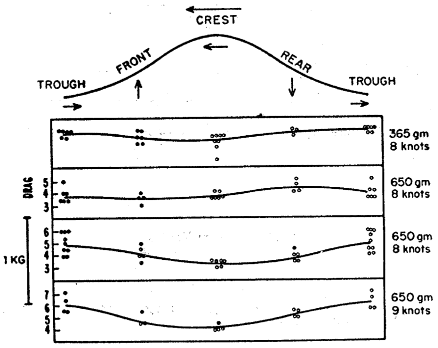

Fig. 2. Drag measurements in the trough, front, crest, and rear slope of a wave. Each point is a single reading. The short arrows in the wave profile indicate the direction of movement of the water particles. The large horizontal arrow indicates the direction of wave propagation.

When playing around in the ocean, dolphins are pleasing to the eye no end, but let it only add to your thrill that these rascals are a graveyard to our wits. For is not finding out infinitely more exciting than knowing the answer?

P. F. SCHOLANDER
Scripps Institution of Oceanography,
La Jolla, California

Note

1. For bibliography see the preceding report by Hayes.

4 September 1959

Carbon Isotope Fractionation in Bacterial Production of Methane

Abstract. Anaerobic bacteria from a Pacific Ocean mud cause unusually large carbon isotope fractionations during fermentation of methanol. The methane produced is about 8 percent enriched in C^{12}, relative to the original methanol. Fractionation factors determined at 30°C and 23°C were 1.081 and 1.094, respectively, which indicates that this process is dependent on temperature.

Bacterial fractionation of stable isotopes has been reported for sulfur (*1*) and hydrogen (*2*). Recent studies at this laboratory have revealed that an unusually large carbon isotope frac-