THE AMATEUR SCIENTIST

How to build and maintain aquariums for organisms that live in the ocean

Conducted by C. L. Stong

Sea water, like fertile soil, is a remarkably complex mixture—a broth of reactive chemicals in dynamic equilibrium with the life it supports. Maintaining that balance in a small marine aquarium can present a challenge to any one who enjoys the exotic organisms of the sea, particularly if he has a flair for chemistry. The essential supplies are not inexpensive if the experimenter lives some distance from the coast: no adequate substitute for sea water has been compounded, and the transportation of live specimens runs into money. With the development of relatively inert materials such as plastics and glass fiber, however, methods of conserving sea water have been perfected. In recent years even beginners have succeeded in minimizing the cost of specimens by breeding at home some species of marine fishes and a number of fascinating invertebrates. A small salt-water system that is well adapted for amateur operation has been constructed by Lars H. Carpelan, assistant professor of biology at the Riverside campus of the University of California. In this system the water is pumped through a battery of aquariums from a relatively large reservoir that serves as a settling basin and oxidation pond. The reservoir minimizes the accumulation of organic wastes in the aquariums and tends to concentrate bacterial action at a point remote from the specimens.

"According to theory," writes Carpelan, "it should be possible to achieve chemical stability in a stagnant, isolated aquarium. In practice, however, it is extremely difficult to establish a precise balance between the nutritional requirements and the metabolic products of plants, bacteria and herbivorous, carnivorous and scavenging animals. An arrangement that allows water to flow through the aquarium from a comparatively large reservoir simplifies the problem greatly by removing wastes, aerating automatically and diluting local contamination. In addition, it is fairly easy to maintain a large tank of water at the uniform temperature required by many marine animals, whereas small aquariums tend to follow fluctuations in the temperature of the surrounding air.

"The system I constructed occupies a space two feet wide and eight feet long in a vivarium at the university. It was built of wood, glass fiber, plastic pipes and a pump at a total cost, exclusive of labor and the aquariums, of about $250. Aquariums can be constructed at a cost of about $12 each for materials. A considerable saving could be made by using a second-hand bathtub for the reservoir. Care would have to be taken to coat all exposed metal parts of the tub with an inert material such as paraffin. Don't worry too much about ferrous metals, but keep brass or bronze away from the water; they will react to form copper ion, which is highly toxic to most marine organisms. Be sure that the stoppers used for closing the drain and overflow holes of the tub are leakproof and coated with paraffin.

"An arbitrary rule of thumb calls for a reservoir with twice the total capacity for storing the water when the aquariums are empty and a minimal ratio of aquariums-to-reservoir volume for the dilution of contaminants when the system is in operation. A reservoir of adequate proportions provides a favorable surface-to-volume ratio for the diffusion of atmospheric oxygen into the water. When the surface is small in relation to the volume, animals consume dissolved oxygen faster than it can be replaced by diffusion.

"My system serves 12 10-gallon aquariums. The reservoir has a capacity of 240 gallons. In practice the containers are kept three-quarters full, so that there are 90 gallons in the aquariums and 90 gallons in the reservoir when all the aquariums are in use. The reservoir is then filled to a depth of only nine inches, a surface-to-volume ratio adequate for maintaining equilibrium between dissolved oxygen, dissolved carbon dioxide and the atmosphere.

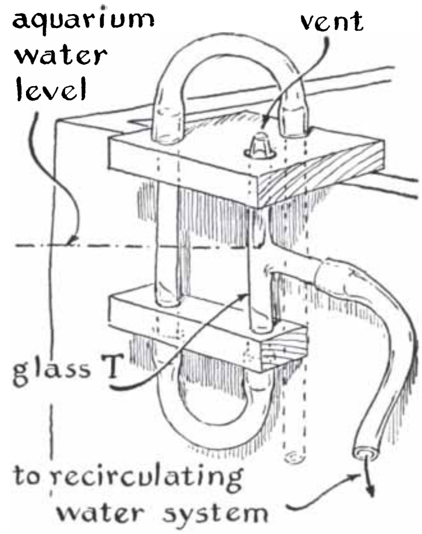
"To maintain the water at a constant level in the aquariums one must balance the inflow and the outflow. This could be accomplished by installing a drain tube at the desired height in one wall of each aquarium, but such an arrangement has the disadvantage of permanency: the hole can't be shifted when one wants to change the water level. Moreover, in the case of glass aquariums holes are difficult to drill and they weaken the glass. An alternative but equally permanent solution is a vertical overflow pipe penetrating the bottom of the tank, in which case the height of the open end of the pipe determines the water level.

"The usual aquarium outflow is a siphon. I use automatic siphons assembled from simple glass T's and straight glass tubes coupled by short lengths of flexible plastic tubing [*see illustration on next page*]. Conventional siphons are not satisfactory because they must be restarted when the level of the water drops low enough to admit air. The vented branch of the automatic siphon prevents water in the aquarium from falling below the level of water trapped in the external U of the siphon. Once installed, the device requires no attention other than periodic cleaning. To prime it one stoppers the discharge tube and applies suction to the vent. If the vent is closed, the device functions as a conventional siphon. A flexible tube leads from each siphon to an open trough or to a 3/4-inch plastic pipe fitted with open T joints, either of which returns the outflow water to the filter.

"A filter must be placed somewhere in the circuit to serve as a 'kidney' for ridding the circulating water of wastes. The required amount of filtration will vary according to use. If only animals that take food in large particles are to be kept, the water should be sparkling clear, and this calls for maximum filtering. Thorough filtering is ill-advised, however, for invertebrates. The food cycle in a closed system can be made almost self-regulating when the system includes adequate populations of filter-feeding animals, such as bivalve mollusks, and grazers, such as gastropod mollusks. Once a properly filtered recirculating system for invertebrates is in operation, the accumulation of organic matter supports a natural cycle of bacterial action that liberates nutrients for the growth of algae. The algae, in turn, support the growth of encrusting algae and other phytoplankton—if enough light reaches the aquarium to maintain photosynthesis. The consumption of phytoplankton and encrusting algae by filter-feeding and grazing animals then completes the food cycle. A deposit of organic matter on the bottom of an aquarium will simultaneously provide a substrate of nutrients for protozoa and other organisms to support bottom-feeders. Excessive filtering breaks the cycle. When a variety of invertebrates are kept in the aquarium, the filter-feeders can do the filtering and the bottom-feeders can do the cleaning.

"Minimal filtering can be accomplished by returning the overflow from an aquarium to the reservoir through an inch or so of replaceable glass wool on top of a few inches of calcareous gravel (beach gravel that contains a substantial amount of broken mollusk shell). The loose materials can be packed in an inert container equipped with the necessary tubing [*see illustration on page 172*]. The filtering action can be increased substantially by adding a layer of fine sand above the calcareous gravel and still more by placing a layer of activated charcoal on top of the sand. Both the charcoal and the glass wool must be replaced when they become loaded with waste. The calcareous gravel plays only an incidental role in the removal of wastes but maintains the hydrogen-ion concentration within the slightly alkaline range of the sea.

"Maintaining the temperature of the water within a range favorable to specimens may or may not be a problem, depending on the tolerance of the organisms and the room temperature. The temperature of the vivarium at the university is held at 75 degrees Fahrenheit, which is high for many marine organisms but which can be tolerated by tide-pool forms, particularly those native to tropical waters. A temperature of 64 degrees F., which is about right for many species, could be maintained either by lowering the temperature of the room or by circulating the water through a coil of plastic garden hose kept in a small refrigerator of the type used for cooling bottled drinks. The

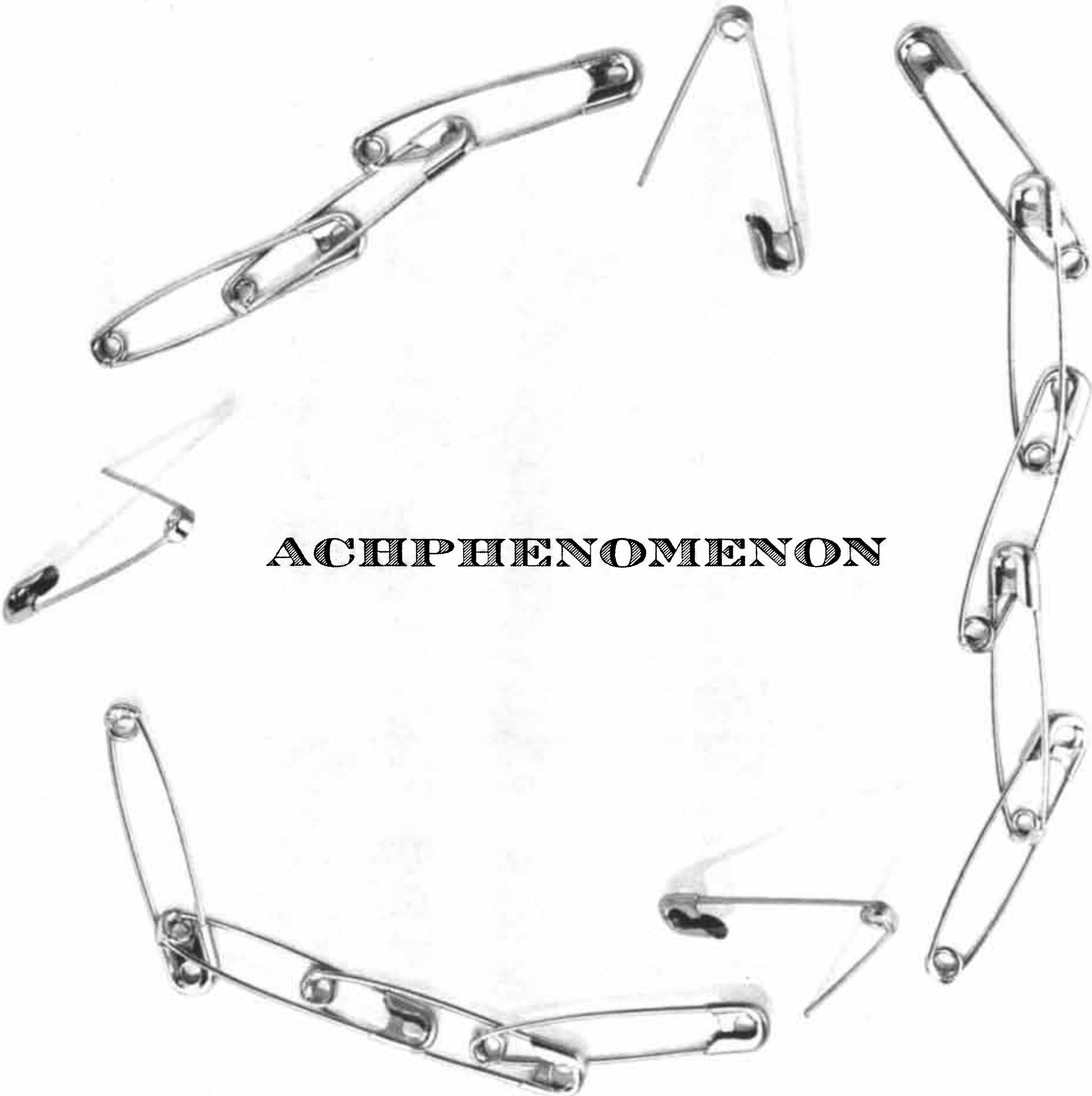


Automatic siphon

amount of cooling would depend on the length of the coil, the speed of flow and the temperature of the refrigerator and would have to be determined by trial and error.

"The salinity of deep-sea water ranges between 33 and 38 parts per thousand by weight, but water near the shore is frequently more dilute. Many tide-pool organisms can survive fluctuations in salinity ranging from 25 to 45 parts per thousand. Even so, a conscientious effort to maintain salinity in the range of 33 to 38 parts per thousand will be repaid in terms of more vigorous specimens. This range corresponds to a specific gravity of 1.025 to 1.029 at the temperature of 64 degrees. The specific gravity at 25 parts per thousand is approximately 1.02 and at 45 parts per thousand about 1.035. Hydrometers of adequate sensitivity for determining density are available from dealers in scientific supplies for about $2. Under normal conditions density can be expected to increase gradually as the system loses water by evaporation. Salinity should be checked weekly and lowered by adding distilled water when the specific gravity increases to 1.03. If the available sea water for stocking the system is too dilute, either allow water to evaporate at room temperature or add one of the preparations compounded to simulate sea water. A number of these are on the market and can be ordered from manufacturers through dealers in tropical fish.

"In the normal course of cleaning aquariums, inserting or removing specimens from the water and otherwise maintaining the system, and in the event of a clogged outflow pipe, some water is inevitably spilled over the sides. For



ACHPHENOMENON

A cursory analysis leads some to say that five breaks and rejoins are required to make a fifteen-link chain out of five chains of 1, 2, 3, 4, and 5 links. If you say four, you show imagination and perception. The optimal solution, three, requires the ingenuity, acumen—Achphenomenon, if you will—that is welcome at Litton Systems.

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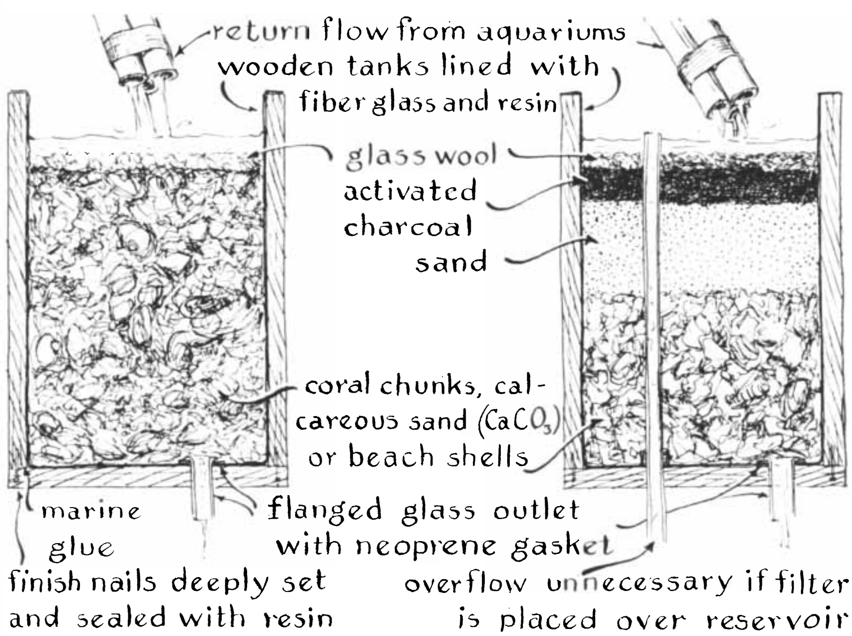
this reason I place my aquariums on shelves made in the form of shallow trays equipped with drains that lead to a plastic catch bucket. The trays are made of marine plywood 3/4 inch thick, which can be bought from lumberyards that cater to boatbuilders. (Ordinary plywood comes apart when it is soaked.) In my arrangement the lowest shelf, or tray, is a foot above the reservoir, with succeeding shelves spaced at 18-inch intervals above the first [*see illustration on page 174*].

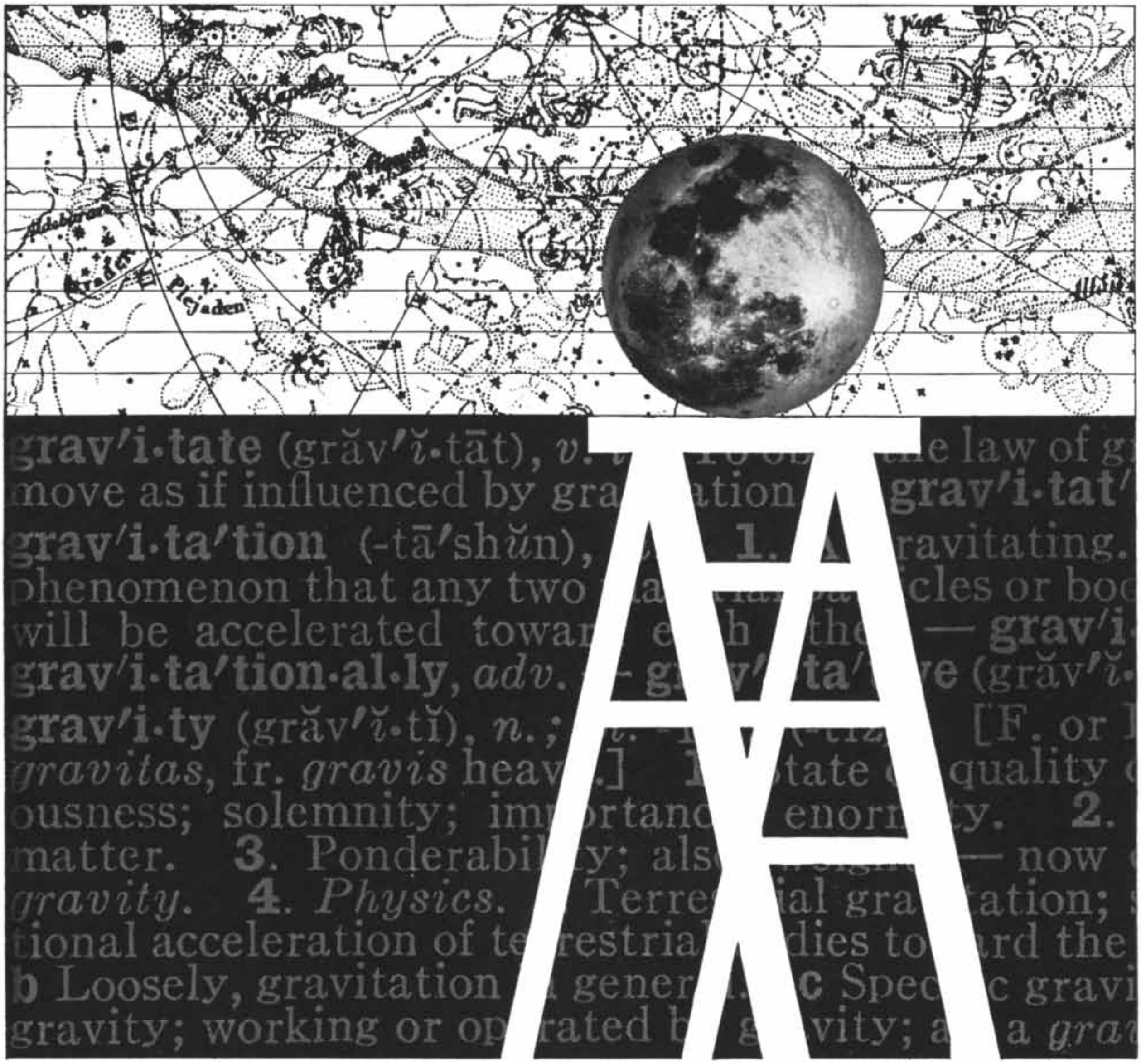
"The construction of the trays and reservoir is not difficult if care is taken to make straight cuts and to keep the ends square. The job is easy if one has access to a power saw. Marine plywood of the necessary thickness comes in sheets four feet wide and eight feet long priced at about $5 a sheet. My construction required four sheets and about 100 feet of two-by-four stock for the base and supporting structure. The shelves and reservoir were assembled with nails and waterproof glue. The nails were countersunk and the holes were calked to prevent corrosion. The interior surfaces of all shelves and the reservoir were coated with glass fiber, a material that provides a smooth, inert, waterproof finish. It can be obtained from boat-supply dealers, along with excellent advice on the technique of applying it to wood. The material, which consists of glass filaments woven into a clothlike fabric, comes in various widths. I used the 50-inch width at $1.60 a yard. When split down the middle, it fitted the two-foot width of my shelves and reservoir with a 1/2-inch overlap at the sides. Glass fiber is applied to wood with a fluid resin priced at about $7 a gallon, enough for three coats over an area of 45 square feet. One simply paints the wood with resin and applies the fabric like wallpaper. For a watertight seal the material must overlap at the corners and edges. When the first coat of resin has hardened, two more coats are applied directly over the fabric to seal the spaces between filaments. Drainpipes can be installed after the layers have hardened by drilling slightly oversized holes through the walls and cementing the pipes in place with a filler made of scraps of fabric mixed with resin.

"All the plumbing is of glass, Tygon, polyethylene or rubber, with no metal parts coming in contact with the water. Various flexible and rigid tubes together with a wide selection of fittings for lawn-sprinkler systems are available from most hardware stores and mail-order houses. Flexible transparent tubing smaller than 1/2 inch in diameter, together with plastic and glass stopcocks, are stocked by dealers in scientific supplies. The stopcocks range in price from $3 to $5 each. A substantial saving can be made by substituting flexible tubing and pinchcocks for stopcocks, although at some cost in terms of convenience.

"The pump, mounted on a wooden support, is suspended from a wooden slat across the top of the reservoir by nylon cords, as shown in the illustration. The suspension reduces noise and makes vertical adjustment easy. Incidentally, be sure to set aquariums with exposed



Minimal filter (left) *and a more thorough one* (right)



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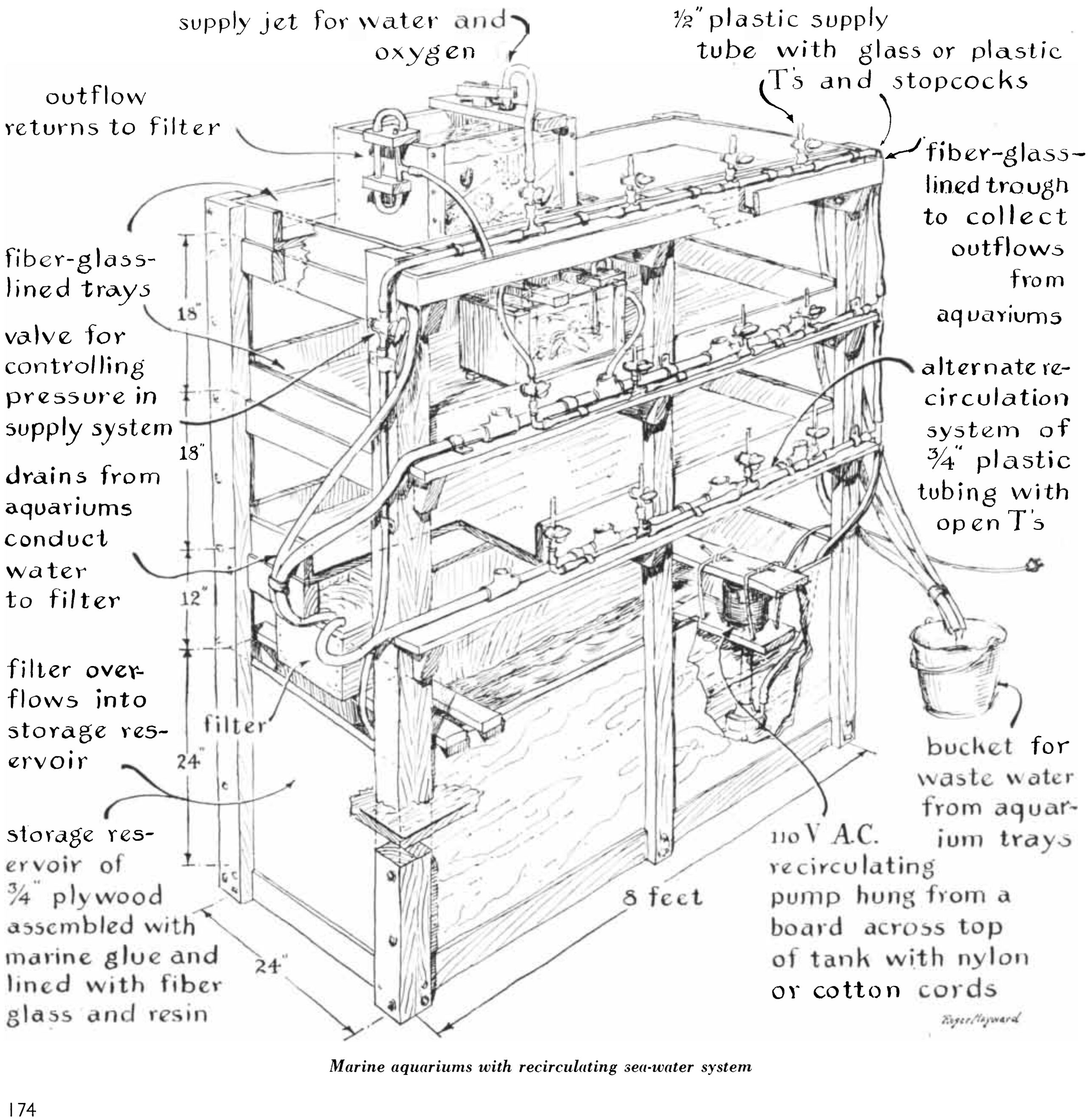
wooden bottoms on small 1/2-inch sticks to provide air circulation. Wood should be kept either all wet or all dry. It goes to pieces if it is allowed to become alternately wet and dry. The plumbing system must also include a device at some point for regulating the water pressure. A standpipe can be used or, as in my system, a valve in the return line. The system should be operated at the lowest pressure consistent with adequate recirculation, which will vary with the number of aquariums in use.

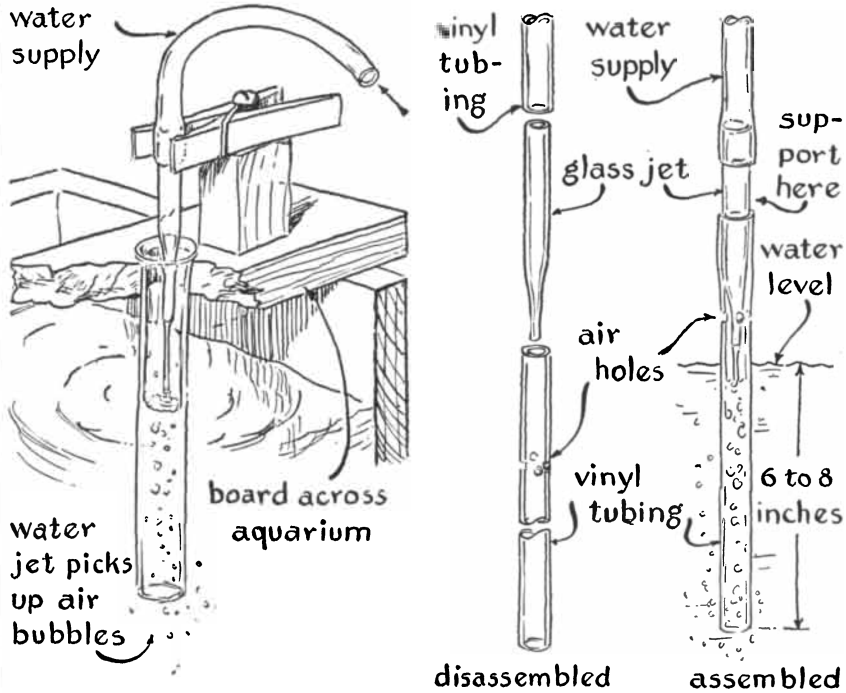
"Supplementary aeration can be supplied as required by discharging water into aquariums through bubbler jets. These can be improvised from the glass part of a medicine dropper and either glass tubing of somewhat larger diameter or close-fitting plastic tubing [*see illustration on page 176*]. In each version air is drawn into the stream by the force of the jet. The dimensions of the bubbler jets are not critical.

"The plumbing should be cleaned periodically to prevent debris or growths of organisms from clogging the siphons or other parts of the system and causing the aquariums to overflow. Float valves that shut off the inflow when water in an aquarium rises above a predetermined level are effective. Equipping the siphon inlet with glass or plastic strainers keeps the siphons from clogging and causing an overflow. In my opinion trays fitted with drains that empty into a plastic catch bucket are adequate to cope with the few emergencies that may arise.

"Aquariums can be of wood and glass fiber construction, but most amateurs will surely prefer to make at least one side of glass so that the specimens can be observed. A sheet of 1/4-inch plate glass can be sealed into a wooden tank successfully by the use of either vinyl tubing or vacuum tape [*see illustration on page 178*]. The seams could also be calked with a remarkable new compound called Silastic RTV 731, a product of the Dow Corning Corporation. Although I have had no experience with this preparation, I understand that it comes in collapsible tubes and has the



Marine aquariums with recirculating sea-water system



Bubble-jets for aerating marine aquariums

consistency of tooth paste. When it is exposed to humid air, the material sets in the form of a tough, inert rubber that adheres to clean glass so firmly that it will tear before separating from the glass. It should be possible to assemble an effective all-glass aquarium with this preparation, particularly if the glass structure is supported in part by an external framework. Within recent years seamless aquariums made of acrylic plastics have been marketed, some perforated for inlet and outlet tubing. Prices appear to average about $2 a gallon in the 10-gallon to 40-gallon sizes.

"In operating the system under suboptimal conditions—at about 75 degrees F. without supplementary aeration or special nutritional supplements for individual species—we found that about two-thirds of the specimens readily available in the coastal waters of California could be kept from two weeks to two months. About a third lived indefinitely. Tide-pool fishes such as the blenny, kelp greenling and the opaleye are particularly easy to maintain. Other interesting specimens from these waters include the topsmelt, sargo, mudskipper and killifish. Large sea horses of the kind that abound in the Gulf of Mexico and along the coast of Florida have also done well in small aquariums and will mate occasionally if they are kept apart from other specimens. Incidentally, young sea horses develop in a pouch on the tail of the male and occasionally, with luck, a shipment may include a 'pregnant' male. The 'herd' that ultimately emerges from the pouch may number as many as 400 baby sea horses! Other Florida vertebrates that do well in small marine aquariums include the clownfish, cowfish, batfish, boxfish and the fearsome toadfish. Still other species, including some of nature's most beautifully colored animals, will survive for long periods with proper care, including the queen angelfish, the rock beauty, the neon goby and the spectacular (but poisonous) lionfish.

"The great diversity of invertebrate animals that thrive in small aquariums opens the hobby to amateur biologists whose interests go beyond fishes. Without an aquarium it is not easy to observe the mussel *Mytilus* in the act of spinning byssus threads for anchoring, to catch a starfish dining on a mussel, to watch the hermit crab's erratic search for a larger shell in which to take up residence or to feed an anemone by dropping bits of shrimp on its tentacles. West Coast invertebrates that do well in small aquariums include the mussel, starfish, sea anemone and crab. Of these the easiest to keep are the California and horse mussels; the hermit and hairy hermit crabs; the Southern California starfish, sand star, sea bat and common purple starfish.

"I have not tried any of the Gulf and Florida organisms, but collectors report that the spider crab, the 'daddy longlegs of the sea,' survives well on ordinary care. Other semitropical invertebrates recommended by Florida collectors in-

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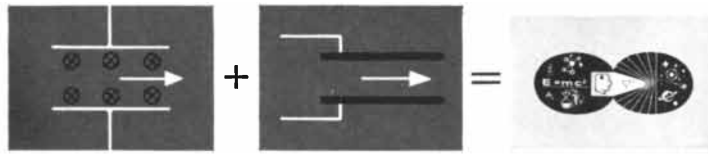

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ALLISON DIVISION, GENERAL MOTORS CORPORATION clude banded coral shrimp, colorful but predatory sea anemones, corals, flame scallops and the amusing mantis crab.

"The cost of specimens and sea water depends on the distance to the aquarium from the coast. Sea water is normally transported in sealed polyethylene bags. Glass containers are better but less convenient. Water near the beach usually contains too much suspended matter for satisfactory use; the water shipped by most collectors is taken from the open sea, which requires the use of a boat and increases the cost.

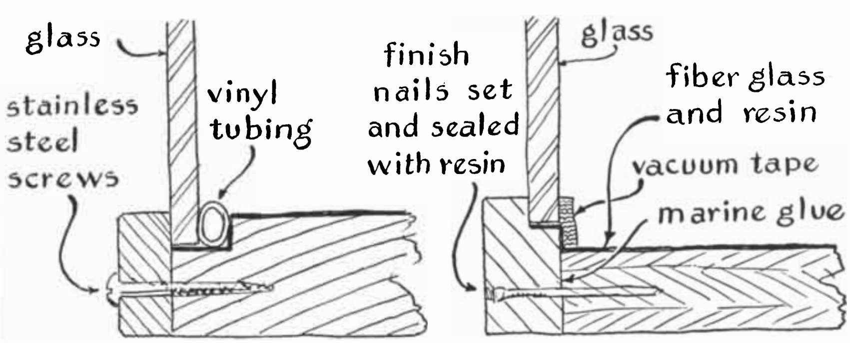
"The collection of specimens is an art in itself. Professional collectors make use of all the techniques and gear familiar to skin divers as well as the services of commercial fishermen. Small organisms are usually shipped in polyethylene bags that contain about two gallons of sea water along with an equal volume of pure oxygen injected just before the bags are sealed and crated. Minimum transportation charges for air express shipments average about $20.

"The price of sea water varies with individual collectors and is determined by the cost of collecting and packaging. Specimens are priced from $2, with rare species commanding as much as $100 each. Prices, which tend to vary with the season, are quoted on request by commercial suppliers such as Aron Enterprises, Haywood, Calif.; The Gulf Specimen Company, Carrabelle, Florida; The Aquarium Stock Company, Inc., 31 Warren Street, New York 7, N.Y.; and the General Biological Supply House, 8200 South Hoyne Avenue, Chicago, Ill.

"Extreme care must be taken to equalize the temperature and salinity of the water when one is transferring specimens from shipping containers to the aquariums. If the differences are great, the specimens may not survive the shock of transfer. The temperature can be adjusted by immersing the shipping bag in the aquarium for several hours. The specific gravity of the water inside and outside the shipping bag is then measured. If a difference in specific gravity of more than two parts per thousand is observed, transfer about two ounces of shipping water to the aquarium and two ounces of aquarium water to the shipping container once every 15 minutes until the difference in specific gravity is reduced to two parts per thousand. Use a glass or plastic dipper.

"Nutritional requirements vary with the nature of the specimen and its age. In general it can be said that the venerable cliché still holds: 'The best food for fish is fish.' Hardy species such as clownfish do well on dry food, chopped shrimp, brine shrimp and bits of worm. The more exotic types, such as lionfish, require small live minnows, fed one or two at a time and supplemented with bits of earthworm and fresh shrimp. Starfish need live clams. Sea urchins and other invertebrates prefer finely chopped shrimp, green algae, fish roe and decayed plant matter.

"In theory the cultivation of the sea in miniature should pose no more technical difficulty than the operation of a farm. But the agricultural revolution that generated solutions for so many of the farmer's problems stopped at the beach; the marine aquariist finds himself some 8,000 years behind the tiller of the soil, his problems not only unsolved but in substantial measure awaiting identification. It should be possible to condition sea water for the optimum growth of specific organisms, much as the farmer encourages good crops by proper fertilization or as the specialist in hydroponics compounds ideal mediums for cultivating lettuce and tomatoes. Sea water, however, evidently contains one or more elusive substances essential for the long-term support of its population that have so far escaped detection. Numerous attempts have been made to duplicate sea water by dissolving various combinations of salts in distilled water, but no effective long-term substitute has been developed. The task of finding one poses a real challenge."



Details of watertight seals between glass and wood