A Demonstration Apparatus for the Cartesian Diver

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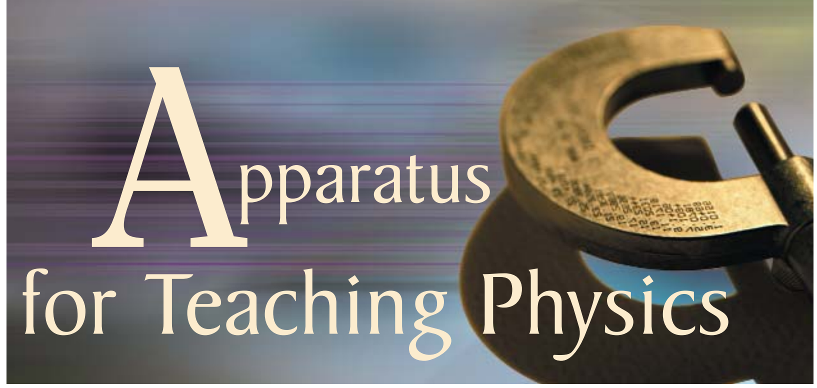

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A Demonstration Apparatus for the Cartesian Diver

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The Cartesian diver is a nice toy and an intriguing physics instrument.[1-6] Recently we reported an experimental study on the statics and dynamics of the Cartesian diver,[7] using a specially designed apparatus that is much larger than the usual models. The Cartesian diver is an interesting example of the so-called "fold catastrophe," the pressure being the control parameter,[7] and this behavior is well observed in our apparatus.

Our Cartesian diver apparatus is made of the following parts (Fig. 1):

(i) A transparent cylindrical tube 1 m high and 10 cm in diameter almost filled with water. Its upper part was reinforced with a circular rim where a lid is fixed with six screws. We glued a ruler onto the external surface of the cylinder.

(ii) A lid with two narrow hollow tubes (Fig. 2). One tube is connected to a syringe, a one-way stopcock (to control and maintain the pressure), and a three-way stopcock (to control the air admittance). The other is connected to a digital manometer. (A two-arm mercury manometer is also appropriate, but to prevent hazards, a medical digital manometer is recommended.) The lid has six screw holes symmetrically located around its edge, and in its bottom surface a narrow circular channel, 2 mm deep and 4 mm broad, to fit an O-ring.

(iii) Six screws and an O-ring (4-mm diameter) to secure the lid tightly to the upper part of the tub.

(iv) A set of test tubes (the divers) with two iron or steel strips attached to them (using Scotch tape if necessary). See Table I of Ref. 7 for the dimensions of a typical set of tubes.

(v) A magnet.

A test tube is partially filled with water, then closed with a cork and inverted into the water that almost fills up the open cylinder. The cork is removed and the test tube, with an air bubble trapped inside, floats at the liquid surface. For a typical demonstration with our apparatus, five or six test tubes prepared with air bubbles of different sizes may be used simultaneously. The water level in the cylinder is then adjusted to a reference (zero) level using a plastic suction bottle. Next, the lip with the O-ring is mounted on the mouth of the cylinder and tightly attached to it with the screws (Fig. 2).

The three-way stopcock allows us to control the air volume in the syringe. After this adjustment, its tap should be closed to keep the system isolated from the outside. The

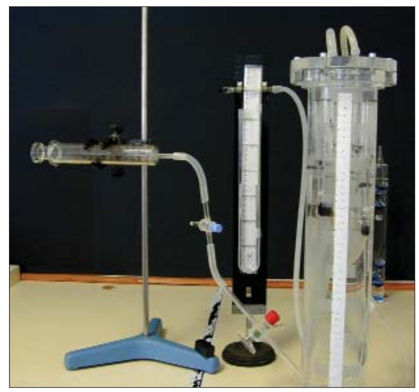

Fig. 1. The Cartesian diver is an inverted test tube with an air bubble trapped inside. The tube is placed in a closed 1-m long acrylic cylinder containing water. The pressure on the liquid surface in the cylinder is controlled with a syringe (on the left) and measured with a manometer (in the center).

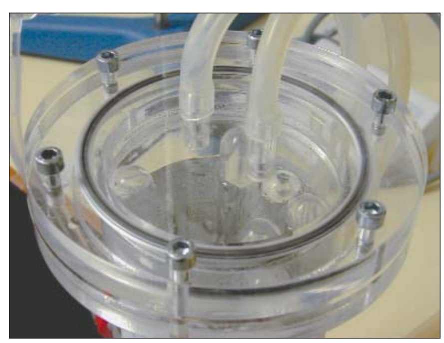

Fig. 2. The top of the cylinder with a removable lid tightly fixed with screws and an O-ring to ensure good closure.

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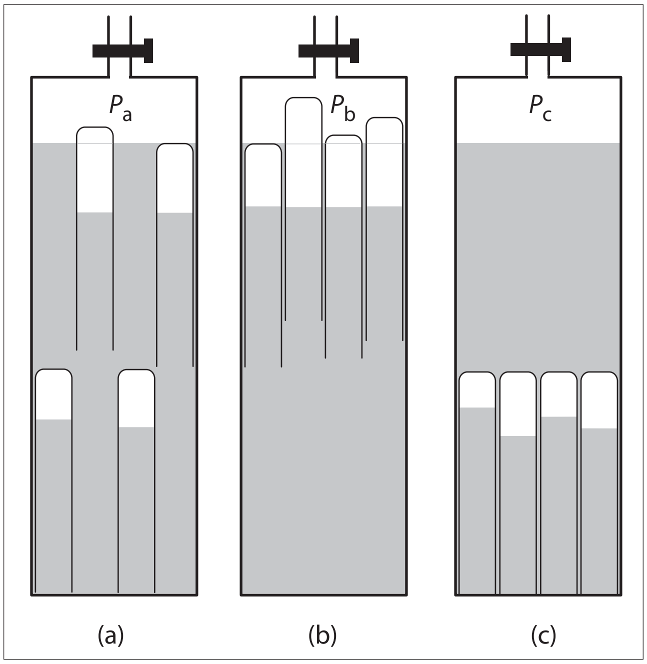

Fig. 3. Scheme of Cartesian divers (test tubes) for various pressures. In the first situation, two tubes are floating and two tubes sink. Decreasing the pressure ($P_b < P_a$), all tubes float, and increasing the pressure ($P_c > P_a$), all tubes sink.

syringe allows us to control the pressure on the liquid surface, which may be measured with the manometer. When this pressure is different from the atmospheric pressure, the one-way stopcock should be closed to prevent the syringe piston from moving.

The equilibrium position of a floating test tube with an air bubble inside can be varied by changing the pressure on the water. Figure 3 shows four *identical* tubes with different amounts of air.

Archimedes' principle, Pascal's principle, Boyle's law, and Newton's law are topics that can be addressed in quantitative demonstrations carried out with the apparatus. We list some studies that may be performed:[7]

- The part of the air bubble below the zero level of the water in the cylinder has approximately the same size for all floating divers, provided we use identical test tubes (Archimedes' principle), as shown in Fig. 3(b). In practice, the bottoms of the trapped bubbles differ slightly in height with respect to the zero level of the water due to buoyancy effects on the glass of the test tubes.

- A floating diver sinks, as in Fig. 3(c), by increasing the pressure (reducing the volume of air in the syringe), and a sunken diver rises up by reducing the pressure (increasing the volume of air in the syringe). This demonstrates Pascal's principle and Boyle's law. The pressure at which a certain floating diver sinks is slightly different from the pressure at which the sunken diver starts to rise (the "constraint catastrophe"[7]).

- The diver, initially in static equilibrium at pressure P_0, sinks if the pressure increases by ΔP. At atmospheric pressure P_0, there is a position at distance $x_{nr} = \Delta P/(\rho g)$ (ρ = 1.0 g/cm^3 is the water density and g = 9.8 m/s^2) from the water surface, below which the diver does not return to the surface. If the diver oscillates around the stable equilibrium position and reaches this *no return* point, it sinks and remains at the bottom. A tall cylindrical tube (1 to 1.5 m high) is required for a good observation of this behavior at relatively low pressures.

- The no return point is an unstable equilibrium point, in contrast with the stable equilibrium at the surface (Newton's laws). At fixed pressure one may find experimentally the no return point (for a given diver, bubble size, and pressure), noting that the tube does not move when located exactly at this point, but it emerges or sinks when located above or below that point, respectively. The metal strips taped to the outside of the test tube allow a strong magnet to move the test tube up and down. In this way the no return point can be found experimentally.

In conclusion, the described Cartesian diver apparatus may be used to perform quantitative experiments in high schools or in undergraduate laboratory. Both the statics and the dynamics of the apparatus present some interesting and not so well-known aspects of the system.

Acknowledgment

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