An oscillating Cartesian diver to study pressure in fluids

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Abstract. We suggest a modification to the classical Cartesian diver experiment, wherein the diver operates within a fluid with density stratification rather than uniform density. Unlike the conventional setup, under a given external pressure, the diver achieves a stable equilibrium at a specific depth where its density matches that of the surrounding fluid. By adjusting the applied pressure, its density changes and it moves towards a new stable equilibrium at a different depth. When subjected to a sudden pressure pulse, the diver density changes and it starts oscillating driven by a restoring force with a frequency dependent on the density gradient.

Introduction

It is well known that both high school and undergraduate students, encounter several difficulties in studying phenomena related to fluid pressure. The idea that a local action produces a pressure variation at all points in the liquid is challenging. Similarly, students struggle to attribute a role to pressure in the floating or sinking of an object, as well as recognizing the role of external pressure when studying pressure at different depths of a fluid (1).

We propose an experiment that can be easily conducted by students using readily available household items. It provides a hands-on opportunity to grasp various hydrostatics and hydrodynamic concepts and principles while introducing students to intriguing phenomena of broader scientific significance.

To familiarize students with these concepts, as well as to perform quantitative measurements, we have developed a variant of the famous Cartesian diver experiment, in which, unlike in the original version of the experiment, the diver is immersed in a liquid layered in density that can be easily created through the gradual dissolution of salt in water. The idea is an evolution of previous experiment (2), in which we studied the rise of a body slightly denser than water, which occurred during salt dissolution. At any instant of the process, the body is in stable equilibrium at a depth where the average density of the medium matches its own. Whenever the body is pushed outside its equilibrium position it starts oscillating at a frequency that depends on the density gradient.

Theoretical framework

In the previous experiment, we used a weighted cork which, at any instant, was in equilibrium in a stratified fluid. The experiment was thus able to track a fluid layer that gradually evolved over time as a consequence of salt dissolution, while the simultaneous exploration of oscillation frequencies at varying depths was hindered. Furthermore, the technique to push the body was intrusive, as the direct mechanical force exerted on the cork unavoidably disturbs its stratification and modifies concentration and density profiles. The new experiment allows for positioning the diver at different heights by varying the external pressure. It is then possible to put the diver in oscillation through the application of a sudden pressure pulse, without perturbing the system. It is then possible to characterize through the oscillations, different regions of the density profile at approximately the same time.

The oscillations that occur in a stratified fluid give rise to internal gravity waves similar to those observed in the atmosphere or beneath the surface of oceans (3). They are difficult to observe because they involve the displacement of fluid portions in regions with different densities and only give rise to variations in the refractive index.

Fig. 1. Experiment performed in a school. On the left typical objects used as divers; on the right the jar filled with coloured density-stratified liquid with a diver in equilibrium at a given height

The experiment we propose in this contribution, suggests also a simple and effective way to visualize gravity waves and measure their frequency. This can be done by following the oscillations of small fragments of a plastic slightly denser than water, previously dispersed in the fluid, which settle in a layer and oscillate with it.

Methods and findings

The experiments were included in an educational program funded by the National Recovery and Resilience Plan "Actions for the prevention and contrast of school dropout" of the Italian Ministry of Education. The experimentation involved a sample of third-year high school students from the Liceo Artistico di Brera (Milan, Italy) with previous experience in the traditional Cartesian diver experiment. The experimentation was conducted in an inquiry-based mode. To optimize the preparation time of stratified fluids, students prepared solutions of water and sugar with various concentrations (240g/l, 120/l, and 0 g/l), adding a different food color to each of them. The three solutions were slowly poured into a cylindrical jar, starting from the densest. This process allowed the rapid creation of density stratified fluids and highlighted the density variation with a color gradient. Using sugar in spite of salt allows obtaining more viscous liquids, which are less perturbed during the filling procedure. The students then inserted Cartesian divers into the containers and varied the applied pressure using rubber diaphragms sealed on top of the jars. They were then asked stimulating questions about the observed phenomenology, to which they attempted to respond both argumentatively and experimentally, proposing modifications to the original experiment. Subsequently, they answered questionnaires aimed at verifying the educational effectiveness of the laboratory course.

Conclusions

We propose a simple and engaging experiment, inspired by the famous Cartesian diver, effective in introducing many hydrostatics and hydrodynamic concepts. The experiment has been recently proposed in high school. It triggered many questions and interest and was much appreciated by students.

References

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