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## To buoy or not to buoy?

The article about buoyancy in the September issue of *Physics Education* caught my eye [1]. The authors consider a scale at the bottom of a beaker of water with no water between the scale and beaker. A block rests on top of the scale with no water between the block and scale either. The authors state that the scale will read the weight of the block plus that of the column of water above it. I submit that this is not the way an ordinary scale behaves. By way of analogy, a scale in air does not read the weight of a block placed on its pan plus the weight of the column of air above it, for two reasons:

(i) The scale is normally zeroed ('tared') before the block is placed on it. In this case, the scale will read only the block's apparent weight, $(\rho_{block}-\rho_{air})Vg$, regardless of the extent to which air penetrates between the block and pan. (Here $\rho_{block}$ and $\rho_{air}$ are the densities of the block and air, respectively, $V$ is the volume of the block and $g$ is the magnitude of Earth's gravitational field.) This can be proved by drawing free-body diagrams of the pan before the addition of the block, and of the pan and block after its addition, and finding the change in the supporting force on the pan, which is what the scale reads.

(ii) An electronic scale consists of a pan supported by a thin post. Air gets under the pan and pushes upwards on the bottom of the pan, even if air does not penetrate between the top of the pan and the block to push up on the bottom of the block. The scale effectively measures the apparent weight of the combined block-pan system (minus a taring constant); sealing the block to the pan increases the net fluid force down on the block, but it also increases the net fluid force up on the pan by exactly the same amount.

In any event, a key question is: to what extent will fluid seep into an interface between two solid surfaces? For two ordinary surfaces in contact, fluid penetration will be partial and time dependent. This has practical implications, such as in predicting whether a low-density object that is glued to a surface will break loose when immersed in a high-density fluid [2]. Asking whether the object will float off if no fluid penetrates into the glue joint is trivial because the question assumes a negative answer.

One *should* ask: when and why will fluid seep into an interface? Since water firmly presses down on the top of a paraffin box at the bottom of an aquarium [1], a student might incorrectly conclude that water would never be able to seep underneath it. But, sooner or later, the box always floats away. The box is in unstable equilibrium, which suggests that there is a competition between upwards ('buoyant') and downwards ('suction') fluid forces. If buoyant force is instead defined as being due to the net 'difference between the pressure exerted by a fluid' on the surfaces of an object [1], then one must conclude that 'buoyant' forces can be 'non-buoyant' in direction.

**References**

[1] Valiyov B M and Yegorenkov V D 2007 Some simple observations on buoyancy *Phys. Educ.* **42** 481
[2] Mungan C E 2004 Reprise of a 'Dense and tense story' *Phys. Teach.* **42** 15

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*Reply to the above letter from the authors of 'Some simple observations on buoyancy'*

We thank Prof. Mungan for his attention to our paper and agree with him that the scale that we described is not an ordinary one. It constitutes a part of the Gedanken experiment (or thought experiment) outlined by E H Graf [1] and is not a device on its own with its own special type and properties. The only property of this scale that we used was to indicate the pressure exerted by the mass in water and the column of water over it on the part of the bottom under it. Thus Prof. Mungan's argument is irrelevant. If we consider the notion of a buoyant force:

(i) In Serway and Jewett [2] we read: 'The upward force exerted by a fluid on any immersed object is called a buoyant force… The buoyant force is the resultant force due to all forces applied by the fluid surrounding the parcel.' In other words, the fluid in this case is present on all sides of the object.

(ii) Prof. Mungan claims: 'If buoyant force is instead *defined as* being due to the net "difference between the pressure exerted by a fluid" on the surfaces of an object, then one must conclude that "buoyant" forces can be "non-buoyant" in direction.' What we actually said was: 'The buoyant force is essentially *caused by* the difference between the pressure (exerted by a fluid) at the top of the object, which pushes it downwards, and the pressure (exerted by a fluid) at the bottom, which pushes it upwards. Since the pressure at the bottom (of a fluid) is always greater than at the top (of a fluid), every object submerged in a fluid necessarily feels an upwards buoyant force. [This statement refers to the case of a floating object.] But the case of a body firmly standing on the bottom of a vessel without any fluid between it and the bottom is quite different.' Here we have no water under the object, so the treatment given by Serway and Jewett [2], for example, is not valid, and a separate consideration is required and presented in our paper.

(iii) Prof. Mungan also states: 'The box is in unstable equilibrium, which suggests that there is a competition between upwards ("buoyant") and downwards ("suction") fluid forces.' Unstable equilibrium means that a negligibly small disturbance will cause a cessation of the equilibrium. We observed this 'unstable equilibrium' for hours or even days. Moreover, so-called suction cups became everyday devices for fixing items onto even surfaces.

**References**

[1] Graf E H 2004 Just what did Archimedes say about buoyancy? *Phys. Teach.* **42** 296
[2] Serway R A and Jewett J W 2004 *Physics for Scientists and Engineers* 6th edn (Thomson Brooks/Cole)

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