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# Various experiments involving fluids statics

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*These examples focus on no-cost/low-cost materials or every-day objects to facilitate the reproduction of the proposed experiments, to cope with low resources contexts, to have them assigned as home-work. Materials from school laboratory equipment are of course appropriate.*

*The structure of their presentation echoes the goals of this site:*

- to go beyond excitement by helping students to get more understanding from simple experiments;
- to propose teachers some approaches and means to be used in class practice thus enlarging the range of their choices.

*Educational added value is aimed at through:*

- comments on possible ways of fostering students' understanding;
- discussion of naive ideas and reasoning strategies conflicting with physics knowledge;
- spotlighting various viewpoints of the same phenomenon that may favour its links with contents not often presented in current teaching materials.

*Each teacher is invited to make the best possible use of these suggestions in the frame of his/her own teaching strategy, given the particular conditions of his/her teaching and the stresses he/she has to face.*
*It is very often recommended*
*-to ask a prediction about the outcome of an experiment along with a justification;*
*- or to assign the experiment as home-work and request to return a short note (about 1 page) on how the experiment has been done, the collected data and their interpretation;*
*-in any case, to perform the experiment with the class and discuss its facets according to the wanted level of depth.*

# Archimedes’ down-thrust (AD)

**Why this experiment?**

This very simple experiment aims to stress that Archimedes’ interaction involves two reciprocal forces (Newton’s third law). Very commonly, what is evidenced in simple experiments about Archimedes’ theorem is the upward force (“up-thrust”) acting on the immersed body. Here, the downward force acting on the water is needed to interpreting what happens to the scale supporting the vessel.

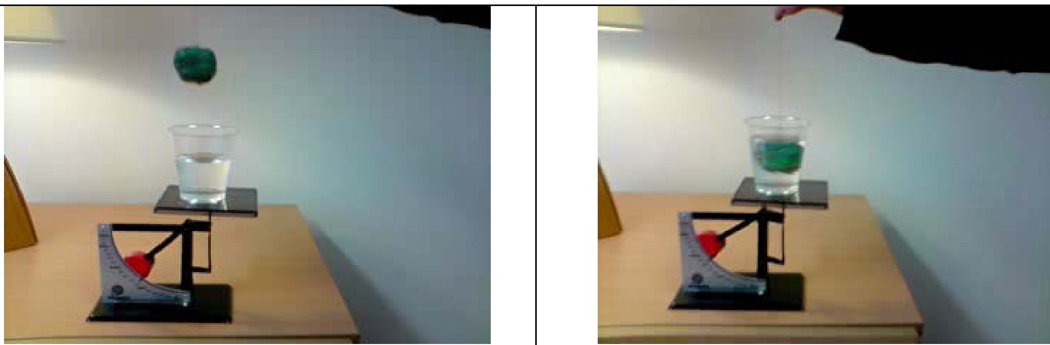
**Experiment**

***Description***

A vessel filled with water is put on a scale, the red sign then indicates the weight of the <vessel+ water> system (fig. 1a).

Then, a ball of plasticine hanging down from a thread is completely immersed without touching the bottom of the vessel.

The new position of the red indicator shows that the plate of the scale is now in a lower position (fig. 1b), which means a larger value of the “weight” indicated by the scale.



| | |
|---|---|
| *a-* The reading of the scale indicates the weight of the system <water+vessel> | *b-* Once the ball is immersed, the reading of the scale is larger than the weight of the system <water+vessel> |

Figure 1. Archimedes' interaction and Newton's third law

***Added value with respect to more common variants:***

This variant aims to avoid a series of limitations that may affect other ways of presenting Archimedes’ interaction.

-The label itself - “Archimedes’ up-thrust” – calls attention on one of the partner forces of the interaction, letting the students ignore the reciprocal downward force that is acting on the fluid.

-When asked to predict the outcome of the ball’s immersion, the most frequent answer in various groups of students (including doctoral students in physics), is by far that the scale will not move at all, and that it will read the same weight as before.

Several factors may cause or reinforce this belief:

- The label commonly used for this interaction (“Archimedes’ *up*-thrust”)
- The (wrong) belief that “a body exerts its weight on its support”, whatever the situation.

- A more general tendency to ignore Newton’s third law, which itself may stem from a focus on an “Agent/Patient” scheme: the water would then be “active”, and the ball “passive”: It is often said that an immersed body “receives” a force.

***Some elements to clarify the physical analysis of the situation***

- In order to analyse the situation, it might be said simply that, , when the ball is immersed, there is an additional downward force acting on the water due to Newton’s third law, therefore a force acting on the system <water + vessel + scale>. The force is equal to the weight water equal in volume to that of the ball. Hence the increased scale reading. Note that the value of the scale reading is not “the weight” of any object, or group of objects, that would be present in the experimental setting.
- For a slightly more formal and detailed analysis, a diagram with a dislocated display of the involved objects may be shown. For more clarity, the forces are just referred to the objects involved in each interaction, with no particular reference to the point on which these forces are supposed to be acting. Note that the Newtonian balance of forces on <vessel +water> clearly goes with a force on the scale that is larger than before immersion. Avoiding to separate water and vessel in this analysis permits not to mention the various forces due to the atmosphere – that cancel out (neglecting the Archimedes’ interaction between the vessel and the atmosphere) - nor the interaction between the bottom of the vessel and the water.

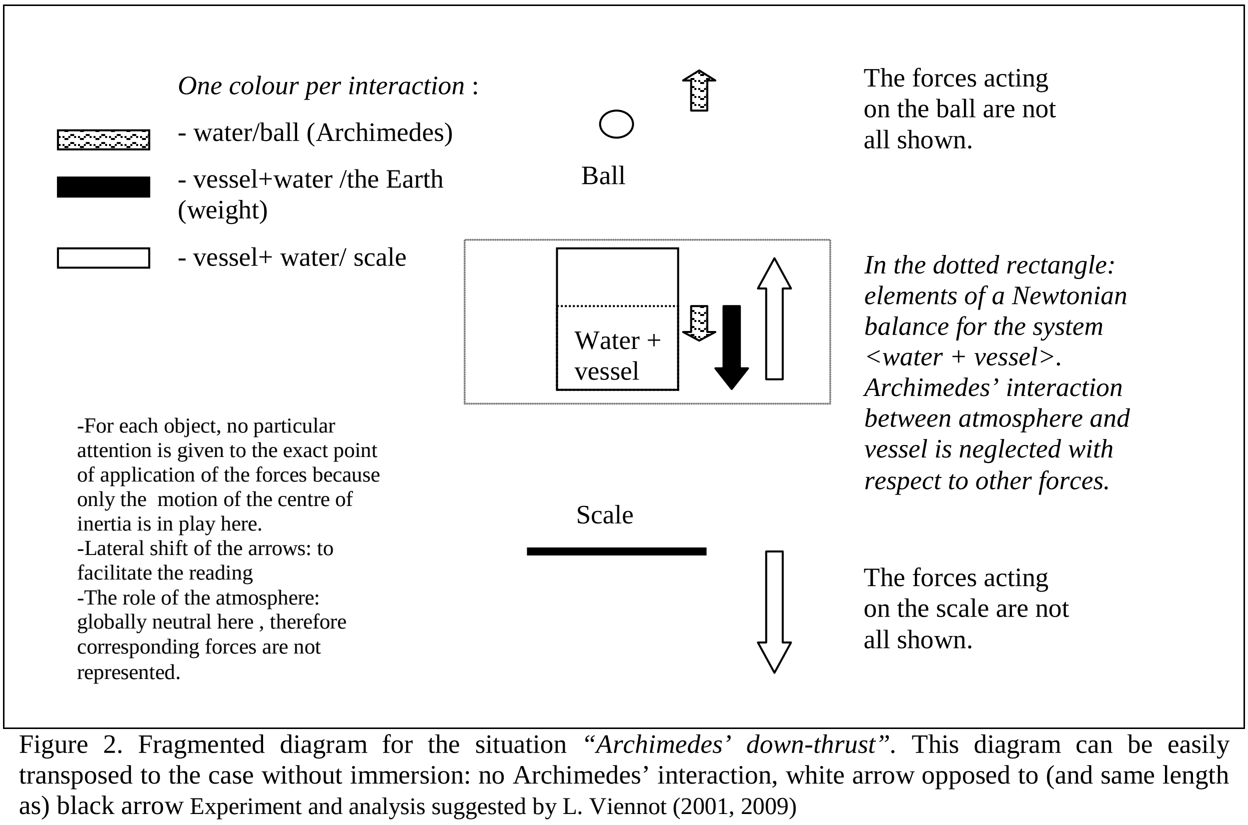



Figure 2. Fragmented diagram for the situation “*Archimedes’ down-thrust*”. This diagram can be easily transposed to the case without immersion: no Archimedes’ interaction, white arrow opposed to (and same length as) black arrow Experiment and analysis suggested by L. Viennot (2001, 2009)

***Practical aspects***

On the practical level, different types of scales can be used (see fig. 1, and, below, fig. 3 and fig. 4). The one presented on Figure 1 has the inconvenience to make the reading more difficult, but the advantage of explicitly showing the mechanical link between an action on the scale and the scale reading.

*Materials for the experiments:*

- tap water (another liquid could be used)
- a transparent container (e.g. a cut plastic bottle of mineral water)
- any scale weighing up to about 1 kg, with 5 -10 g marks
- any body denser than water that can be immersed in water without affecting its transparency and be suspended to any sort of stand
- any kind of string for the suspension
- wooden tongues or a strong ribbon to squeeze the container in its middle (see below fig. 4)

**Links, variants and further possible developments**

***More quantitative evidence for Newton's third law***

For a more complete and quantitative treatment relating Archimedes' *interaction* and third law, Figure 3 shows how to proceed.

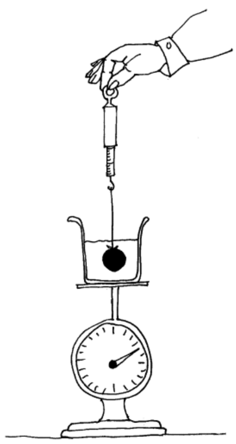


Figure 3. Quantitative evidence for the *two* forces involved in Archimedes' interaction and Newton's third law (fig. G. Planinsic)

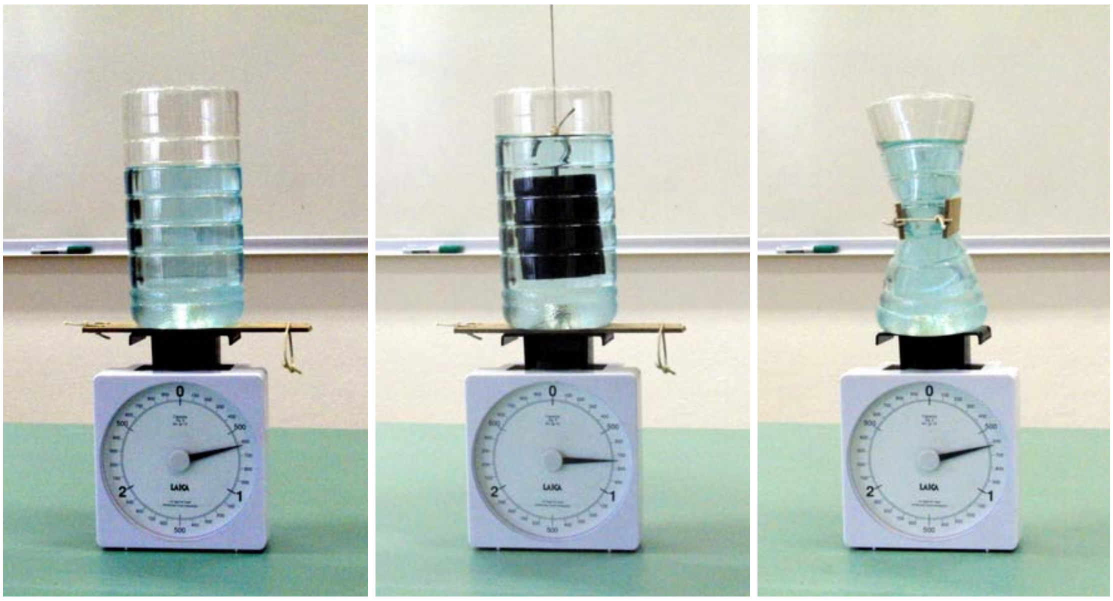
***Pressure at the bottom of a container and force exerted by this container on a scale***

Among the reasons that can be given to explain the larger reading of the scale after immersion of the ball, it can be argued that this immersion results in a higher level of water, therefore (see the law of fluids statics: $\Delta p = -\rho g \Delta z$, $\overrightarrow{Oz}$ axis oriented upwards) in a higher pressure ($p$) at the bottom of the vessel.

The experiment shown in Figure 4

- evidences this phenomenon with a cylindrical tank (fig. 4*a* and *b*). According to Archimedes' theorem, the value of the additional force on the scale is the weight of a volume of water (here: a "ring") equal to that of the immersed body. The following reasoning may be applied: when the body (the weight) has been immersed, the water level has risen for one ring. Subsequent increase in pressure at the bottom of the vessel caused the increase in scale reading.

- Figure 4c introduces a caveat: the level of water, alone, does not suffice to predict the action of the vessel on the scale. The pressure at the bottom is, indeed, higher if this level is higher, but the wall(s) of the vessel also matter. A vertical wall does not contribute to the vertical component of the total force exerted by water on the vessel. But with a tilted wall, as in Figure 4c, the higher pressure near the bottom results in an upward force on the wall. Note that the upward force on the lower part is not cancelled out by the downward force acting on the higher part of the wall. The net result is that, despite the higher pressure at the bottom level of the squeezed bottle, the water (+ vessel) "weighs", in terms of the scale reading, the same as in Figure 4a.



a b c

Figure 4. Introducing a discussion about the links between the height of water in a vessel and the action of this vessel on a scale.

a) water + container + wooden tongues: scale reading of about 620 g, water level at 4th ring
b) water + container + wooden tongues + immersed weight: scale reading of about 750 g, water level at 5th ring
c) water + container (squeezed) + wooden tongues: scale reading about 620 g, water level at 5th ring.

Experiment and analysis suggested by G. Planinsic.

Note that it is far from obvious, for many students – even in first year at university -, that the pressure at the bottom of a container only depends on the height of the fluid. It is often argued (Kariotoglou and Psillos 1993, Besson and Viennot 2004) that the pressure at two points at same depth cannot be equal if "there is more water above" one of them, as in the situations shown in Figure 5 (in particular, Figure 5 b shows a vessel similar to the lower half of the bottle in Figure 4*c*).

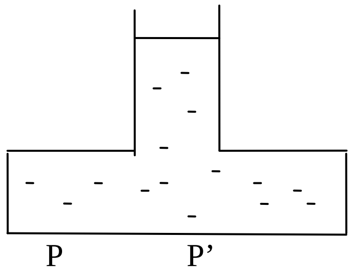
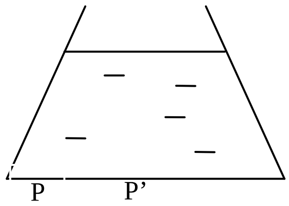
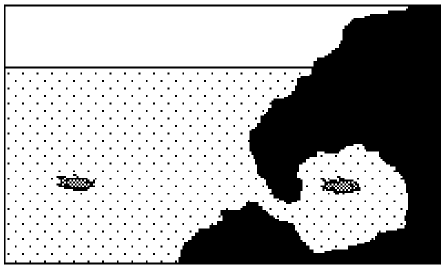
| | | |
|---|---|---|
| a)   | b)   | c)  |
| Two points at the bottom of a tank full of water with “upside down T” shape. | Two points at the bottom of a tank full of water with tilted walls | Two fish, one in the open sea, the other in an underwater cave, at the same depth. |

Figure 5. Examples of situations where it is not obvious that pressure is the same for the two considered points, because “there is more water above” one of them. (see ref. in the text, c: first proposed by Pugliese-Jona, S. 1984. *Fisica e Laboratorio*,vol. 1, Turin: Loescher)

***Other links***

This experiment (and variants) can be considered in relation to

-the glass of water upside down (GW) and variants , which also put in play the same possible reasons to explain students’ common difficulties.

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*References for related topics in progress*

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# Glass of water upside down (GW)

## Why this experiment?

In order to stress the role of the atmospheric pressure, it is very common to turn upside down a small vessel filled with water and covered with a cardboard, and to show that the water remains in the glass (for instance: video http://www.youtube.com/watch?v=cZgkc9MT2L8, http://www.youtube.com/watch?v=frkSCwroYuM, http://www.youtube.com/watch?v=ezwyHNs_W_A).

But some misunderstandings may occur.

## Experiment

### *Description*

As just explained, it is common to use the setting shown in Figure 1*a*.

| *a* | *b* | *c* |
|---|---|---|
|  | Elements often found in common explanations :<br>-the water exerts on the cardboard a force equal to its weight.<br>-The force due to atmospheric pressure supports the carboard which (therefore) does not fall down. | A diagram that suggests the disproportion (in fact about x100) between the values of the forces mentioned in (*b*):<br>Red: force due to atmospheric pressure on the cardboard<br>Blue: weight of water<br> |

Figure 1. A simple experiment (*a*) that is often « explained» with problematic arguments (*b, c)*
ldsp.diderot.googlepages.com/viennot_geneve08.pdf

But it is worth noting that there is a risk of misunderstanding in this situation. It is often argued that the water exerts on the cardboard a force equal to its weight, which is leading more or less directly to the conclusion that the force due to atmospheric pressure supports the cardboard, thus preventing it from falling down. Note that the order of magnitude of the force exerted by the external air on the cardboard is about hundred times that of the weight of the water (the weight of the carboard is often neglected with respect to that of the water). A Newtonian balance between only these two forces is then to be excluded.

What is proposed here is to start the experiment as usual then to tilt the glass only by 90°, putting it horizontally as in Figure 2 (video http://www.youtube.com/watch?v=Ua6eq6Yyk9c).

Figure 2. In an horizontal position, the water does not either flow out of the glass

***Added value with respect to more common variants***

-The vertical orientation of the glass, commonly chosen for this experiment, may suggest that the weight of the water is balanced out by a force exerted by a support. This is dangerously resonant with students' common ideas:

--any object«exert its weight» on the support,

--the third law is disregarded (students are not concerned with the force exerted by the cardboard on the outer air, which in fact is equal in magnitude to that exerted by the outer air on the cardboard),

--it is enough to focus on one end of a system, there where something is likely to happen (in this case the carboard).

It is of course possible to provide a more correct view of the forces in play (fig. 3). But with the «horizontal» version of this experiment, there is no need to analyse the vertical components of forces acting on the water (including its weight).

--The analysis of the horizontal component of forces is sufficient to stress the role of the atmospheric pressure.

--This analysis is therefore significantly simplified, and it is focused on the main phenomenon: a compression at both ends of the system, by the forces due to atmospheric pressure.

-- This analysis is symmetrical: both ends of the system are taken into account.

### *Some elements to clarify the physical analysis of the situation*

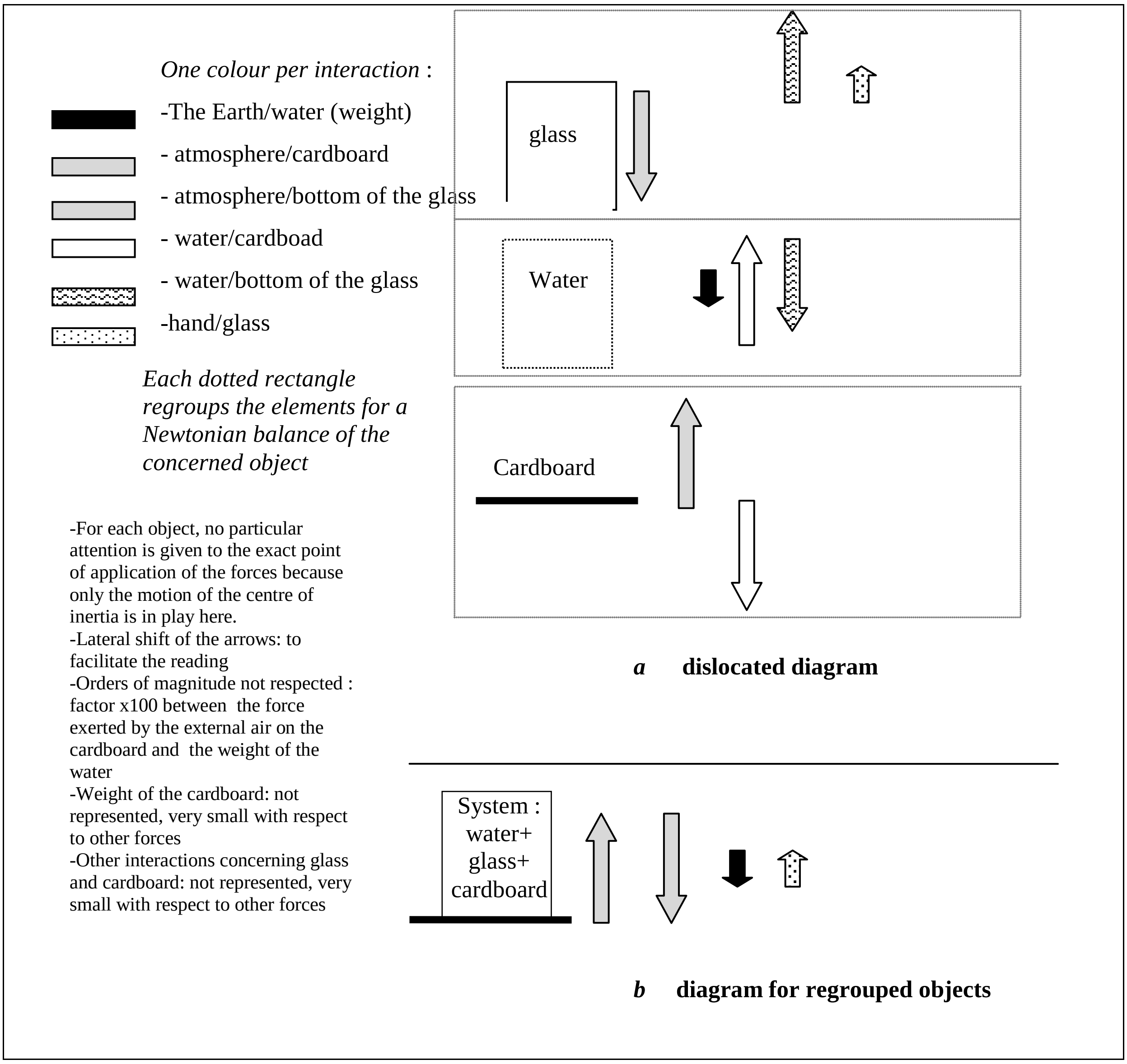



Figure 3. Main forces (vertical components) in the situation of the glass full of water and upside down

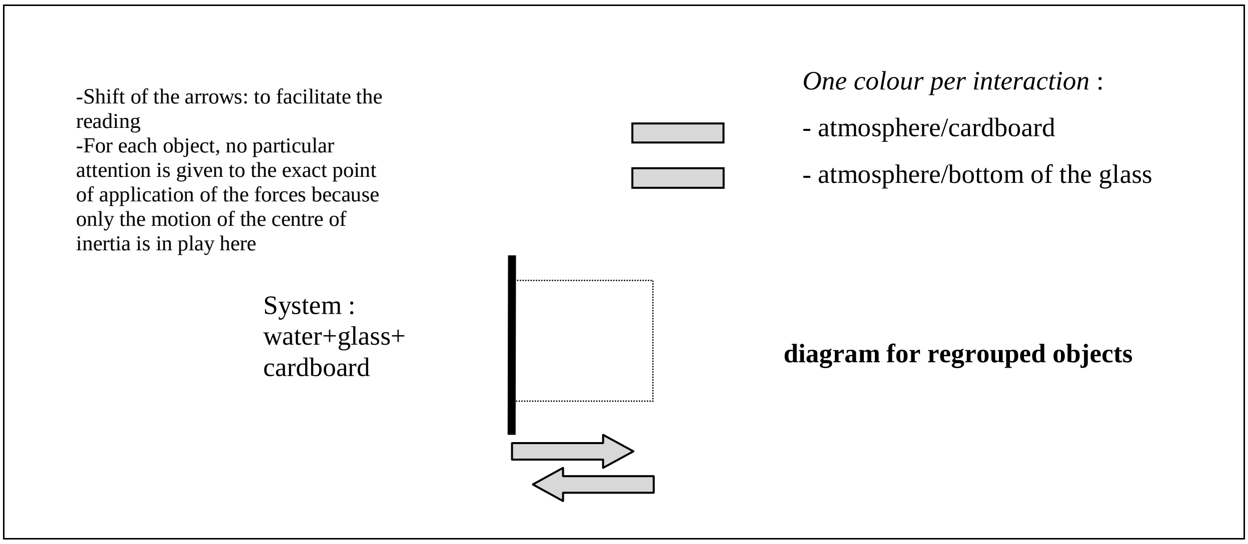



Figure 4. Main forces (horizontal components) acting on the glass of water in an horizontal position.

***Practical aspects***

This experiment is very easy to perform. Various containers and "cardboards" (or even sheets of paper) can be used.

## Links, variants and further possible developments

***The students' common difficulties are, to a large extent, the same as for Archimedes' "down-thrust".***

1- It is often thought that the water in the glass (as any object *whatever the situation*) "exerts its weight" on its support. This situation is an example where the contact force between an object and its "support" is not equal to its weight.
2- Newton's third law is not taken into account: the question of how the cardboard can exert on the atmosphere a reciprocal force of same value as that exerted by the atmosphere on the cardboard is not commonly posed.
3- Commonly, the suggested analysis is focused on the cardboard only, that is on *one end* of the system <glass + water + cardboard>. This is the part where something visibly can occur. The bottom of the glass, where a contact interaction should be taken into account, is not considered.
   This common "one- end approach" appears more clearly in this experiment (GW) than in "Archimedes' down-thrust" experiment (AD), although the "weight-exerted-on-the-support" syndrome can also be seen as the outcome of a *reduced* analysis, that disregards some of the forces acting on the water.

***This situation may serve as an introduction of more complex cases.***

The glass may be filled with different fluids.

1 If these fluids are all liquids, we may use the same analysis as before; replacing "water" by "fluids". The pressure at the interfaces between fluids, and in every parts of these fluids, is determined by applying the relationship of hydrostatics $\Delta p=\rho g\Delta h$ to each fluid.

2 The most common variant met in practise is when there is some air in the glass. We then have to seriously reconsider the statement that the pressure at the lower surface of the fluid is (very close to) atmospheric pressure $p_0$. Indeed, according to the way the glass has been partly filled and turned upside-down, the values of pressure inside the glass may be very different from $p_0$, in particular the pressure $p_b$ at the bottom of the inverted glass. Thus, with a glass partly filled with water (height of water: $h$) under atmospheric pressure $p_0$, subsequently hermetically and rigidly closed and inverted, the pressure at the lower level would result to be $p_b = p_0 + \rho gh$ . In order to compensate such a difference between $p_b$, and the pressure outside the glass $p_0$, it seems at first sight, it is necessary to maintain a rigid mechanical connection between the cardboard and the glass.

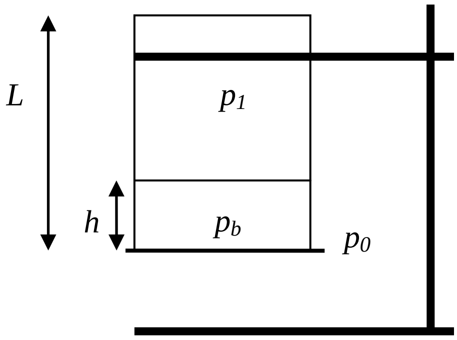



Figure 5. An inverted glass parly filled with water

More precisely, as discussed by Weltin (1961, different notations), to ensure a value of $p_b$ - at the cardboard's level - that would be close to $p_0$, there should be a small expansion of volume of the air enclosed in the glass, that results in a slight downward displacement $l$ of the liquid.

In equilibrium the pressure in the internal air, $p_1$ , should be such that

$p_1 + \rho gh = p_0$ or equivalently

$p_1 = p_0 - \rho gh$

To achieve this situation at constant temperature, given the law of perfect gas ($pV=nRT$, in usual notations), the increase $\Delta V$ of the gas volume, $V$, should be such that

$(V + \Delta V)/ V = p_0 /(p_0 - \rho gh)$

Or, $L$ being the total height of the glass, here supposed to be cylindrical:

$(L-h+l) / (L-h) = p_0 / (p_0 - \rho gh)$ or equivalently

$$l=[(L\text{-}h)\,\rho gh]\;/\;(p_0-\rho gh)$$

For a few centimetres of water in the glass, the needed slip $l$ is about as little as thousandth of the length $L$-$h$ of the part of the glass that is filled with air. For instance, if $L$-$h$ is 10cm a slip of $l \approx 0{,}1$ mm is required to hold one centimetre of water,. Given the capillary forces, this can be achieved easily.

But for a long tube half filled with water, it will not be possible to have the tube inverted without spilling the water.

***From a test tube above a tank of water to a barometer.***

The “vertical version” of this experiment (GW) and its simplified analysis (fig. 3) is transferable to the situation of a test tube filled with water and turned upside down above a tank of water (fig.6), which itself is a good preparation for the understanding of a barometer.

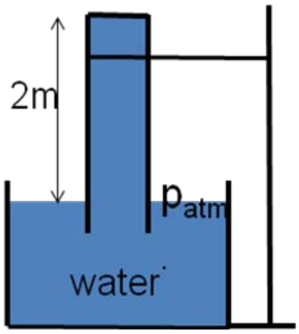
| **a) A test tube filled with water, above a tank of water.** | **b) A questionable explanation** | **c) Considering orders of magnitude** |
| --- | --- | --- |
|  | « What is lifting this column of water up by 2m ? It's atmospheric pressure that is pushing on the water in the tank. In the tube, there is no air, and no pressure is exerted on the water*. »<br><br>*Translated from: Leçons de Marie Curie, recueillies par Isabelle Chavannes en 1907. *Physique élémentaire pour les enfants de nos amis*. Dir. B. Leclercq, Paris : EDP Sciences, 2003, p. 46. | Comparing orders of magnitude of the forces acting on the column of water that are mentionned in the explanation (col. b).<br> |

Figure 6. A situation that can be analysed like the glass of water turned upside down (GW, fig. 3): a test-tube full of water and turned upside down over the tank filled with water (with atmospheric pressure at its lower end). The quoted explanation has the same features as the common comments concerning the glass of water (see preceding section).

In the case of a barometer, the force on the bottom of the tube (which is now at the top) exerted by the content of this tube is nearly zero (its value is determined by the vapour pressure of the liquid at the temperature of the experiment). Then, the weight of the column is balanced out by the force exerted by the liquid in the tank (at atmospheric pressure) on the lower end of this column.

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