Journal of Colloid and Interface Science 463 (2016) 8–12

Contents lists available at ScienceDirect

Journal of Colloid and Interface Science

journal homepage: www.elsevier.com/locate/jcis

Surface tension supported floating of heavy objects: Why elongated bodies float better?

Edward Bormashenko

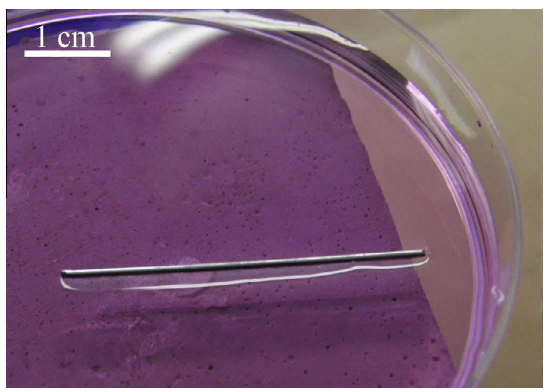
Ariel University, Physics Department, POB 3, Ariel 40700, Israel

HIGHLIGHTS

- Floating of bodies heavier than the supporting liquid is discussed.
- Floating of objects possessing lateral dimensions smaller than the capillary length is treated.
- Floating these bodies is prescribed by the surface tension related effects.
- Elongated bodies are better supported by capillarity due to the increase in the perimeter of the triple line.

GRAPHICAL ABSTRACT

Steel needle floating on the water surface.



ARTICLE INFO

Article history:
Received 18 August 2015
Revised 12 October 2015
Accepted 13 October 2015
Available online 23 October 2015

Keywords:
Floating
Surface tension
Heavy objects
Elongated bodies
Capillary length

ABSTRACT

Floating of bodies heavier than the supporting liquid is discussed. Floating of cylindrical, ellipsoidal bodies and rectangular plates possessing lateral dimensions smaller than the capillary length is treated. It is demonstrated that more elongated bodies of a fixed volume are better supported by capillary forces, due to the increase in the perimeter of the triple line. Thus, floating of metallic needles obtains reasonable explanation.

1. Introduction

Physics of floating as many other fundamental physical phenomena was first studied by Archimedes. For the details of the detective story of the revealing and restoring the original text of the Archimedes Palimpsest containing the treatise devoted to the floating of bodies see Refs. [1,2].

The famous Archimedes principle formulated in the Palimpsest states that: "any body wholly or partially immersed in a fluid experiences an upward force (buoyancy) equal to, but opposite to the weight of the fluid displaced". It seems that it follows from this principle that an object can float only if is less dense than the liquid in which it is placed. However, a sure-handed child may place a steel needle on a surface of water, and it will float, as shown in Fig. 1. The first explanation of this effect belongs to Galilei [3,4]. Consider heavy plate placed on a water surface, as shown in

E-mail address: edward@ariel.ac.il

http://dx.doi.org/10.1016/j.jcis.2015.10.031
0021-9797/© 2015 Elsevier Inc. All rights reserved.

Fig. 2. When the three-phase (triple line) is firmly pinned to the surface of the plate, it may displace a volume which is much larger than the total volume of the plate itself, as shown in Fig. 3. Hence the buoyancy will be essentially increased (it is noteworthy that the effect of pinning of the triple line is responsible on a broad diversity of wetting phenomena ([5–9]). It is seen that Galilei related floating of heavy bodies to the increase of the Archimedes force only, and this explanation is at least partially true.

The unbelievable physical intuition of Galilei is admirable, but actually floating of heavy objects arises as the interplay of the buoyancy and surface tension. The restoring force that counteracts the floating body weight mg, comprises a surface tension force and the buoyancy force arising from hydrostatic pressure, as shown in Fig. 3A. Following the Galilei idea, illustrated with Fig. 3A the buoyancy equals to the total weight of the liquid displaced by the body, shown with the dark-gray in Fig. 3A. Hand in hand with the buoyancy the surface tension supports floating as shown in Fig. 3A and B. Keller demonstrated [10] that the total force supporting the floating equals the weight of the entire volume of liquid displaced by the body, as depicted in Fig. 3B. The important problem of the maximal depth of sinking of a floating object is discussed in detail in Ref. [4].

The interest to the floating of bodies heavier than the supporting liquid was revived recently [11–14] due to a variety of effects, including the ability of water striders to walk on water [15–17] and self-assembly of floating particles [18,19]. An understanding of floating is crucial for a variety of biological and engineering problems, including the behavior of colloidal particles attached to a liquid surface, the formation of lipid droplets, liquid lenses, etc. [20–23].

Everybody who tried to place an object heavier than water on its surface knows that it is more convenient to do this with prolonged objects. It is much simpler to do this procedure with a steel needle than with a steel sphere of the same mass. Thus, we address the question: why elongated bodies float better? We restrict our treatment with small bodies possessing a characteristic lateral dimension smaller than the so-called capillary length, describing the interrelation between buoyancy and capillarity and is defined by the expression: $l_{ca} = \sqrt{\gamma/\rho_L g}$ (where γ and ρ_L are the surface tension and density of the liquid respectively) [24,25]. When the characteristic lateral dimension of floating bodies is much less than the capillary length, the buoyancy is negligible, and floating is totally prescribed by the surface tension [4]. It is noteworthy that the capillary length is on the same order of magnitude of several millimeters for all liquids [24]. The paper proposes a simple qualitative model clarifying the impact of the shape on the floating of heavy bodies.

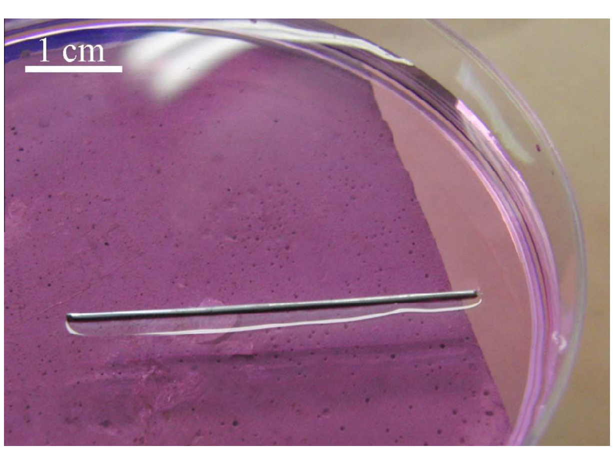


Fig. 1. Steel needle floating on the water surface.

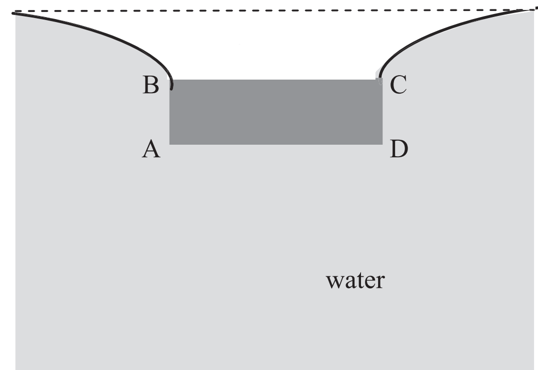


Fig. 2. Galileo intuitive reasoning explaining the floating of the heavy plate ABCD. When the triple line is pinned to the surface of the plate, it may displace the volume which is much larger than the total volume of the plate itself.

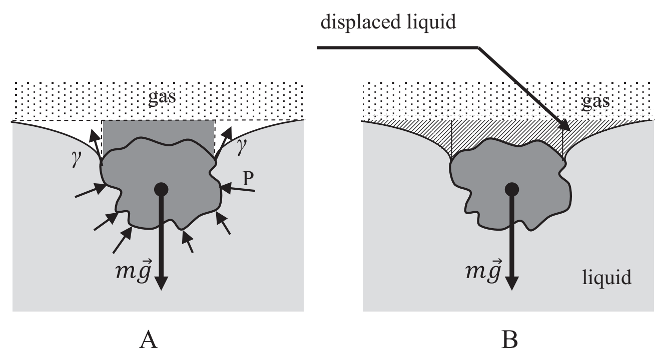


Fig. 3. A. The buoyancy of the floating heavy object equals to the total weight of the displaced water, shown shaded, dark-gray. The surface tension force which equals γ for the unit length of the triple line also supports floating. B. The total restoring force including the surface tension and buoyancy equals the total weight of the displaced liquid (the gray shaded area in (B)).

2. Discussion

2.1. Floating of heavy cylindrical needles

Consider floating of the cylindrical body which radius is smaller than the capillary length. Thus the effects due to the buoyancy may be neglected. The gravity effects f_{grav} are obviously given by:

$$f_{grav} = \rho g V = \frac{\pi}{4} g \rho d^2 l, \quad (1)$$

where ρ, V, l and d are the density, volume, length and diameter of the needle respectively (see Fig. 4). The capillary force withstanding gravity is estimated as: $f_{cap} \cong \gamma \xi f(\theta)$ where ξ is the perimeter of the triple (three-phase) line, and $f(\theta)$ is the function depending on the apparent contact angle θ [4,14]. The *maximal* capillary force f_{cap}^{max} withstanding gravity and supporting floating may be very roughly estimated as:

$$f_{cap}^{max} \cong \gamma \xi_{max} = 2\gamma(d + l), \quad (2)$$

where ξ_{max} is the maximal perimeter of the triple line, corresponding to the cross-section ABCD (see Fig. 4). This capillary force is maximal when it has only a vertical component (this is possible for hydrophobic surfaces, when the apparent contact angle characterizing the triad solid/liquid/vapor is larger than $\frac{\pi}{2}$, as shown in Ref. 4), and a liquid wets a cylindrical needle along a line dividing the floating body into equal parts (ABCD is the medial longitudinal cross-section of the needle, bounded by the triple line), as shown