23. IYPT, Problem No. 9: Sticky water

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The problem

9. Sticky water

When a horizontal cylinder is placed in a vertical stream of water, the stream can follow the cylinder's circumference along the bottom and continue up the other side before it detaches. Explain this phenomenon and investigate the relevant parameters.

Photo courtesy of János Hegedüs, http://picasaweb.google.hu/jancsika80/Kiserletek

Possibly relevant effects

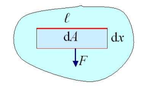
- Surface tension
- Gravity
- Fluid dynamics

Surface tension

Cause

Surface tension is caused by the attraction between the liquid's molecules by various intermolecular forces.

Description



$$\gamma = \frac{dw}{dA} = \frac{Fdx}{ldx}, \frac{J}{m^2} = \frac{N}{m}.$$

Temperature dependence

Eötvös rule:

$$\gamma V_m^{2/3} = k(T_c - T),$$

where V_m is the molar volume, k and T_c art the Eötvös-constant and critical temperature (material characteristics).

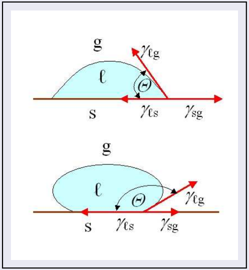
source of figures: http://hu.wikipedia.org/wiki/FelületiFeszültség

Surface tension

Wetting: three surfaces

Young's equation:

$$\gamma_{sg} - \gamma_{ls} - \gamma_{lg} \cos\Theta = 0$$



Effects related to surface tension

http://web.mit.edu/1.63/www/Lec-notes/Surfacetension/Lecture6.pdf

Fluid sheets:  Fluid bells: 

Fluid dynamics

Description of a moving liquid

velocity field: $\mathbf{v}(\mathbf{r})$

streamlines: their tangent gives the velocity

thermodynamical quantities : density $\varrho(\mathbf{r})$, pressure $p(\mathbf{r})$

Ideal liquids

- no friction,
- relatively simple to describe by the Euler equation:

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}\,\mathrm{grad})\mathbf{v} = -\frac{1}{\varrho}\,\mathrm{grad}\,p,$$

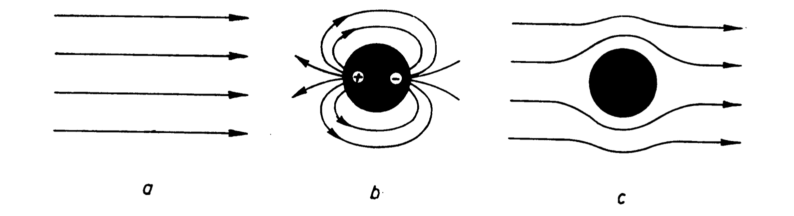
- assumption: incompressible.

Ideal liquids: the Bernoulli-equation

Along a streamline $p + \frac{1}{2}\varrho v^2 + \varrho g h = \text{const.}$

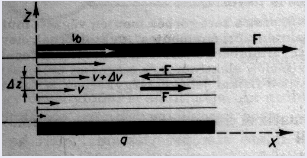
Ideal liquids: an interesting fact

A ball in an ideal incompressible liquid:



a vectorial sum of two flows.
Á. Budó: Kísérleti fizika 1., Budapest, 1986.

Internal friction: viscosity



$$F = \eta q \frac{dv}{dz}$$

Laminar and turbulent flows

laminar: the liquid can be divided into non-mixing *layers*

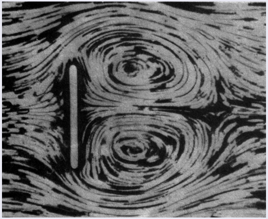
turbulent: no layers, abrubptly altering velocity field

Reynolds:

$$R = \frac{\varrho r v}{\eta} > 1160$$

Fluid dynamics

Eddies behind a solid obstacle

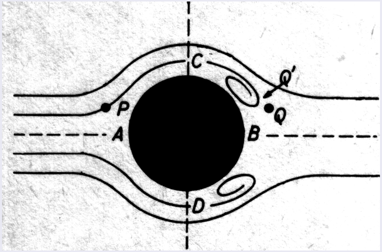


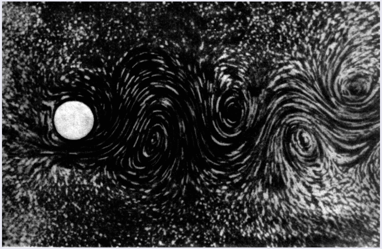
Theory of the laminar boundary layer (L. Prandtl, 1904)

- For low viscosity liquids such as water the internal friction is only relevant in a thin layer close to the surface.
- On the surface the velocity is zero, thus in the layer there is a large velocity gradient.
- Outside the layer the theory of ideal liquids applies.

Fluid dynamics

Explanation of the eddies





Further details:
L. D. Landau & E. M. Lifschitz:
Fluid mechanics,
2nd. ed., Pergamon 1987.

Conclusion?

- Surface tension?
- Gravity?
- Fluid dynamics?

What's your opinion, Watson?