Properties of liquids and gasses

Hydrostatic pressure, Archimedes' principle, Pascal's principle, fluids in motion, equation of continuity, Bernoulli's equation. Surface tension, viscosity.

Fluid (liquid or gas)

Different from solid state, no permanent shape, shaping according to the space (e.g. bottle), no long-range arrangement of molecules

Ideal fluid – no internal friction, no viscosity

Viscous fluids – honey, asphalt, dispersion of various particles (milk, starch), …

Liquid crystals – substances with combined properties of liquids and solids (LCD displays)

Forces in fluids - pressure

Density of fluid $\rho = \frac{m}{V}$

Body inside the fluid under the force ΔF on its surface ΔS is subjected to the pressure

$$p = \frac{\Delta F}{\Delta S} \quad [Pa]$$

Gasses are easily compressible, liquids might be almost incompressible (e.g. water)

Pascal's principle

If an external pressure is applied to a confined fluid, the pressure at every point within the fluid increases by that amount.

Pressure in incompressible and non-viscous fluid is the same in all directions.

1652 - Blaise Pascal

Pressure is always perpendicular to the surface of submerged body.

Hydraulic lift

Vessel of variable cross-section – pressure transfer by Pascal's principle

Force ratio

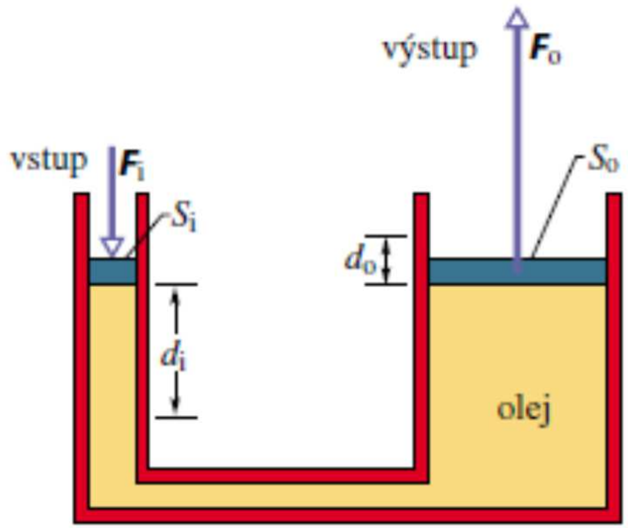
$$F_o = F_i \frac{S_o}{S_i}$$

Displacement ratio

$$d_o = d_i \frac{S_i}{S_o}$$

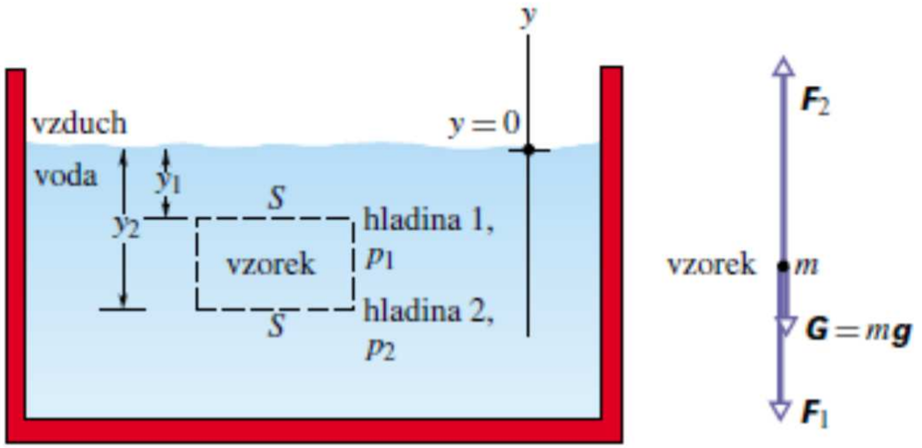
Work is the same

$$W = F_o d_o = \left(F_i \frac{S_o}{S_i}\right)\left(d_i \frac{S_i}{S_o}\right) = F_i d_i$$



Hydrostatic pressure

Fluid in static equilibrium

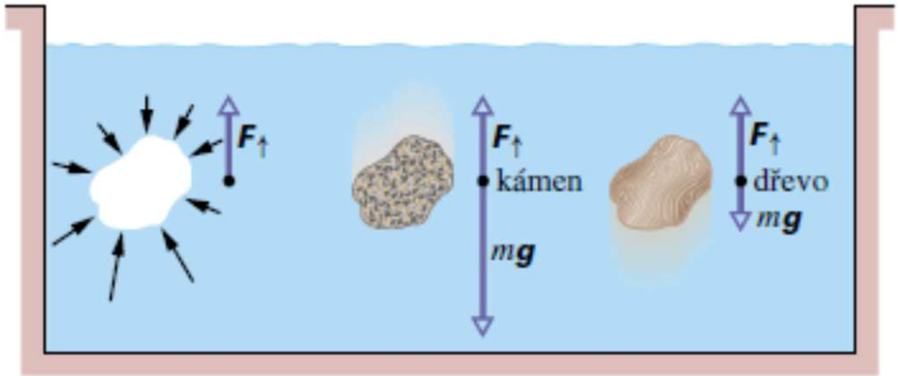


Hydrostatic pressure

$$p_2 = p_1 + \varrho g (y_1 - y_2).$$

Archimedes' principle

Buyoancy force on submerged body – floating of bodies



The buyoant force on an object immersed in a fluid is equal to the weight of the fluid displaced by that object.

Fluids in motion

- Incompressible fluid – equal density
- Compressible fluid – density varies in space and time

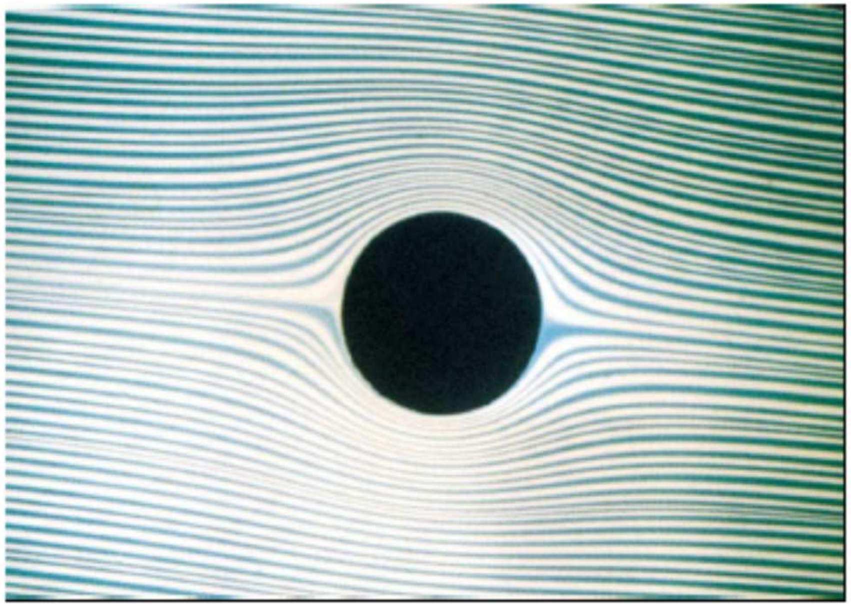
Types of fluid motion

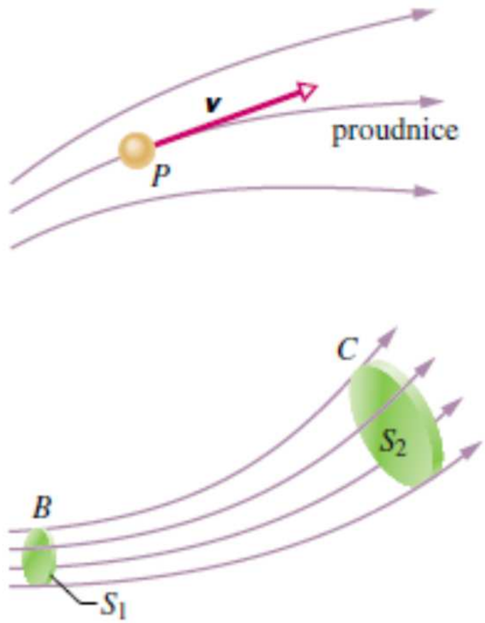
- Laminar (or streamline) – no eddy currents, stacionary
- Turbulent – eddy currents, nonstacionary

Laminar (streamline) flow

Streamlines – coloration for visualisation

Streamline pipe – set of streamlines



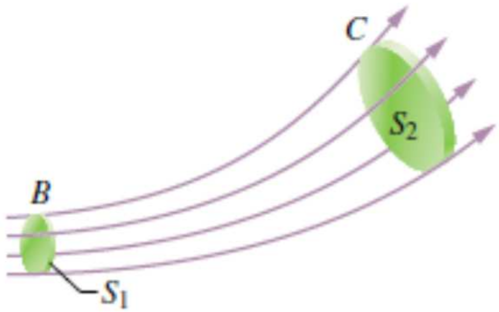


Equation of flow continuity

Incompressible fluid is continuous along streamline pipe, volume rate is conserved

$$\Delta V = S_1 v_1 \Delta t = S_2 v_2 \Delta t$$

$$\boxed{S_1 v_1 = S_2 v_2}$$



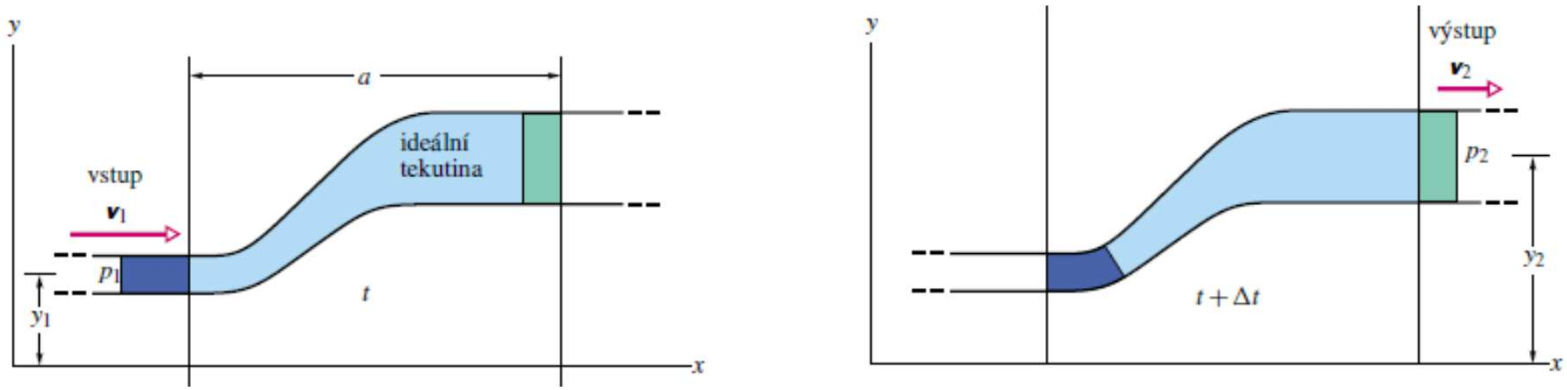
Volume rate $R = Sv = \text{konst.}$

Mass rate is conserved in case of compressible fluid

$$Sv\rho = konst.$$

Bernoulli’s principle

Daniel Bernoulli, 18th century – energy conservation law for the fluid particle



$$p + \frac{1}{2}\varrho v^2 + \varrho g y = \text{konst.}$$

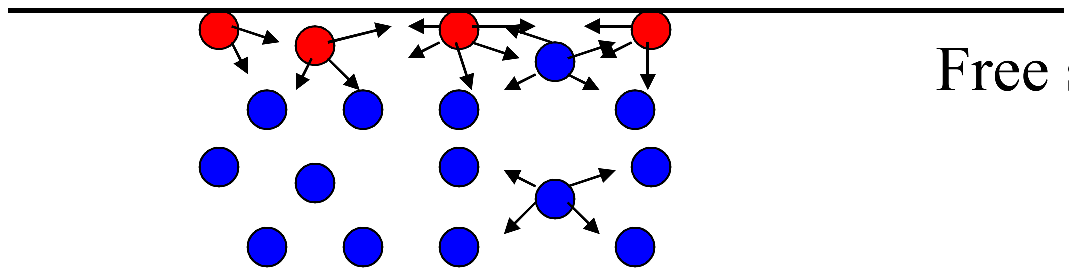
Where the velocity of a fluid is high, the pressure is low, and where the velocity is low, the pressure is high.

Surface phenomena

- Drops and bubbles
- Capillarity
- Laplace formula
- Wetting of surfaces
- Ultrasound atomization of liquids
- Surface tension experiments

Surface layer

Cohesive forces between molecules



Surface energy

Surface tension

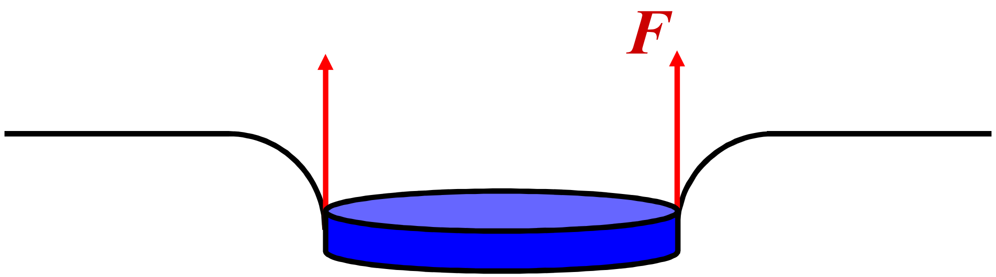
Surface energy per 1m^2

$$\sigma = \frac{\Delta W}{\Delta S} \quad [Jm^{-2}, Nm^{-1}]$$

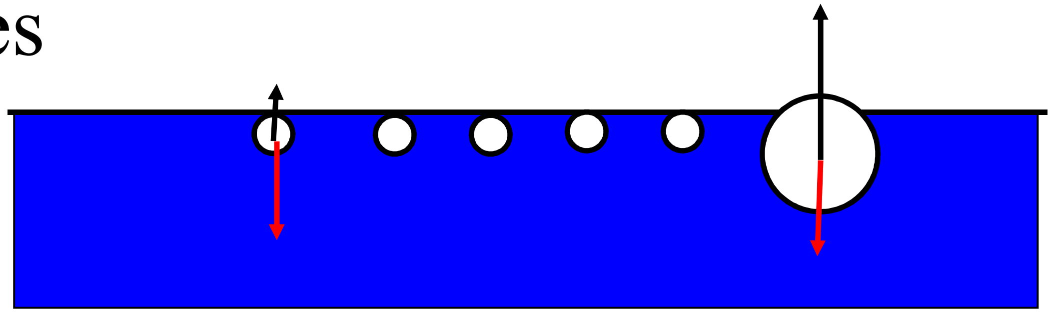
$\sigma\ [10^{-3}\, Nm^{-1}]\quad at\quad 20^{o}C$			
Water	73.0	Oil	20-40
Ethanol	22.0	Mercury	491
glycerol	62.5		

Surface forces

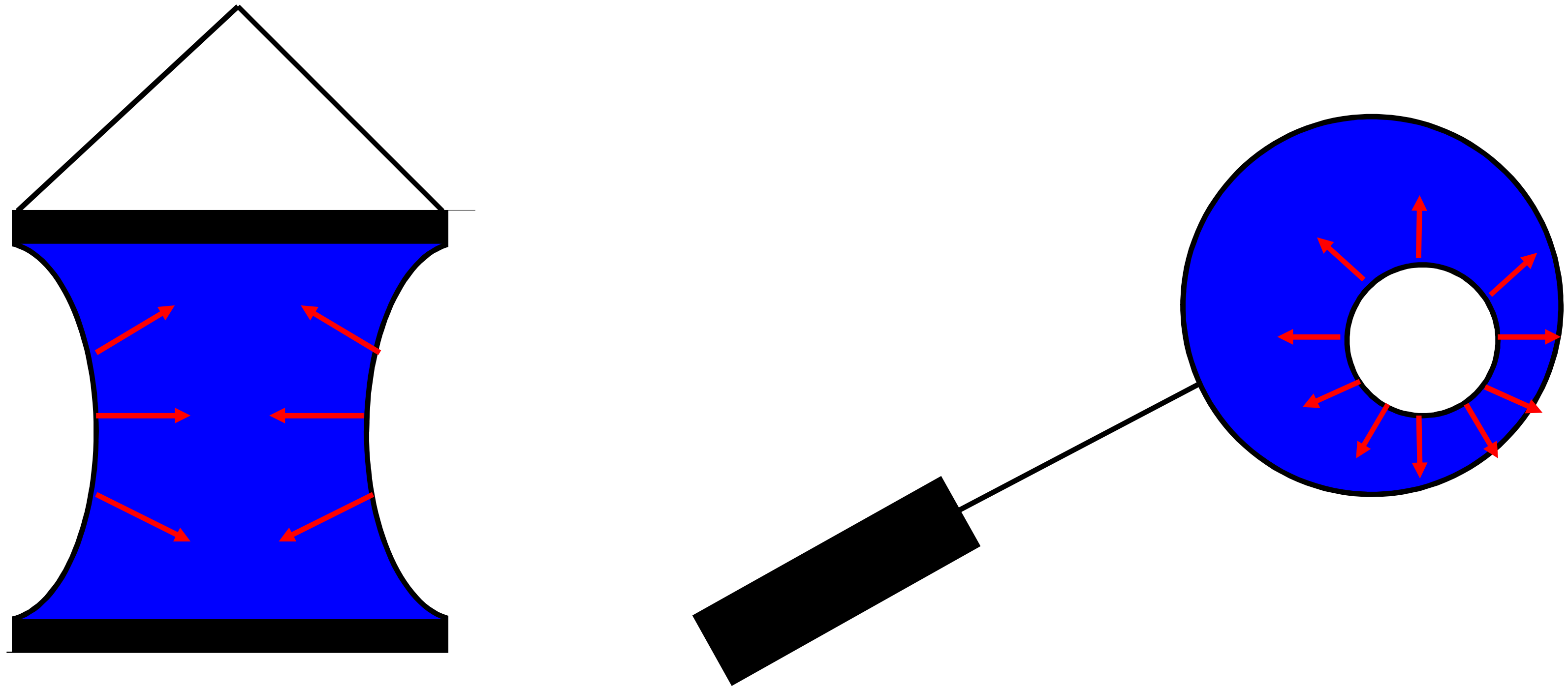
- Flotation of objects heavier than water



- Flotation under the surface – e.g. wine bubbles



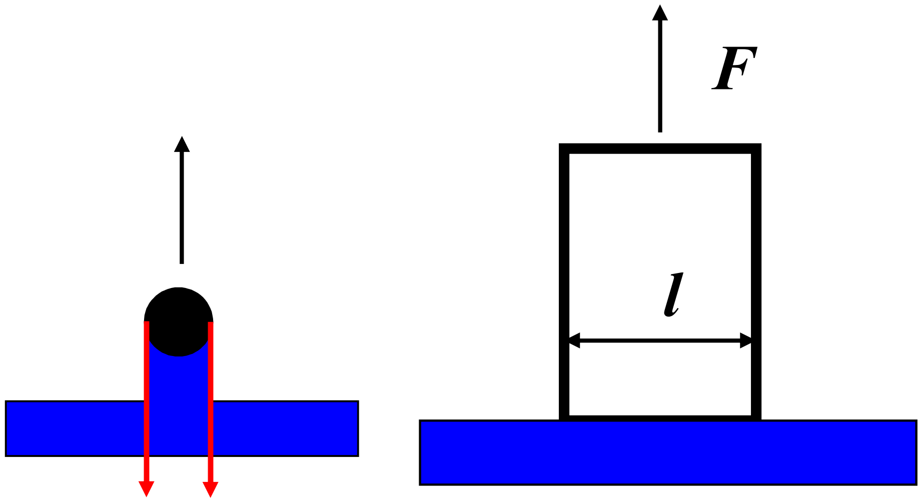
Experiments with surface tension



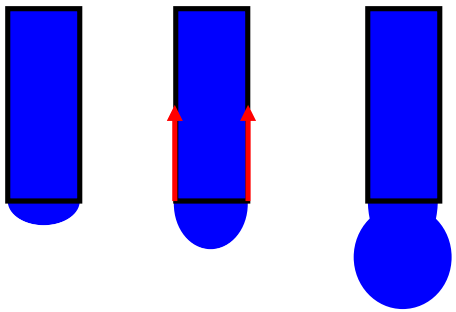
Measurement of surface tension

- Frame method

$$F = 2\sigma l$$



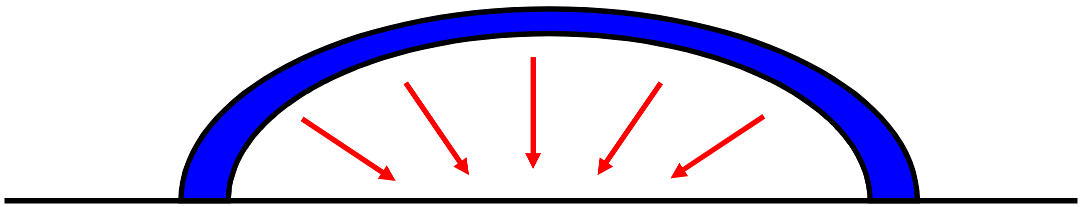
- Drop method



Laplace's formula

Surface curvature → additional capillary pressure

$$p = \sigma\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$



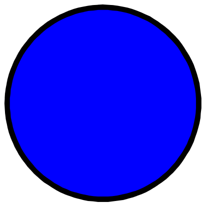
Shape of liquid body = optimum (minimum) of surface energy

Curvature radii might be positive as well as negative!

Drops and bubbles

Drop

$$p = \frac{2\sigma}{r}$$

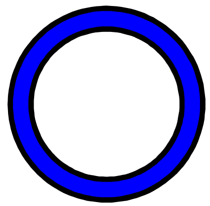


$$\sigma = 73 \cdot 10^{-3}\,Nm^{-1}$$

$$p \approx 150\,Pa, \quad 2r = 1\,mm$$

Bubble

$$p = \frac{4\sigma}{r}$$

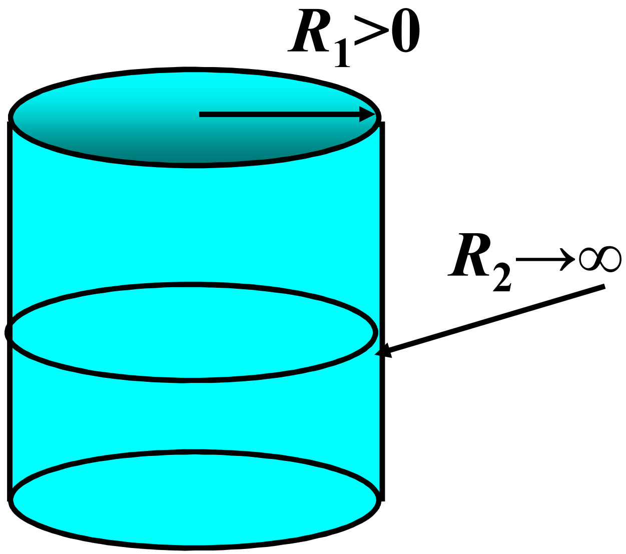


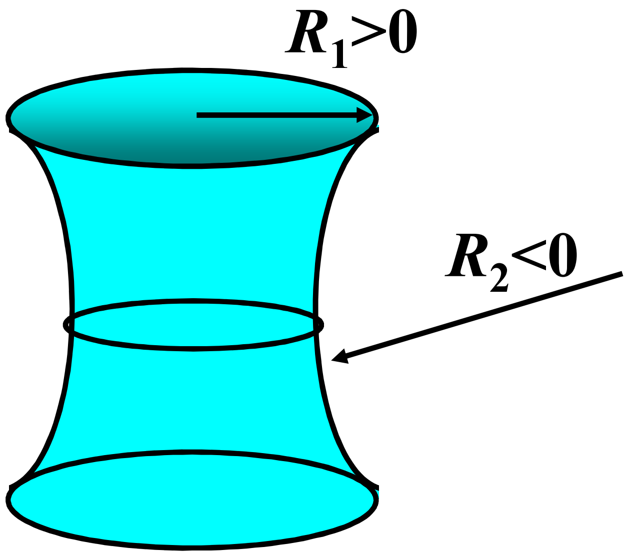
$$\sigma = 73 \cdot 10^{-3}\,Nm^{-1}$$

$$p \approx 300\,Pa, \quad 2r = 1\,mm$$

Pressure under saddle surface

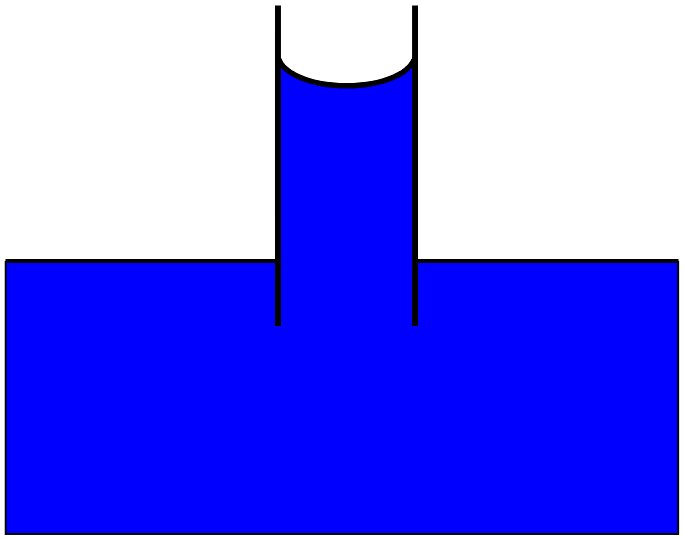
$$p = \sigma\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = 0$$



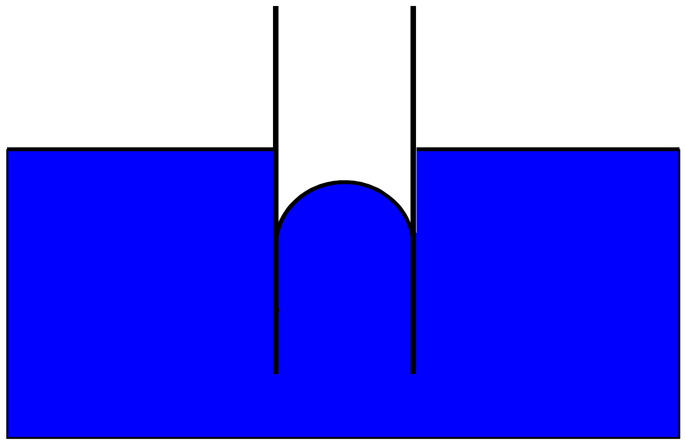


Capillary pressure

Elevation



Depression

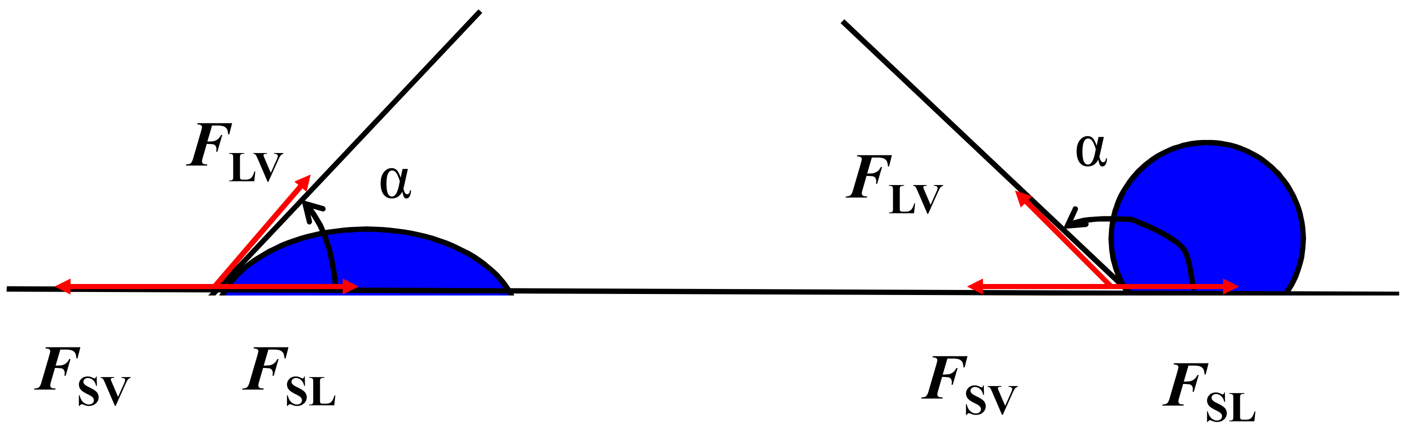


Attractive forces - cohesive (same particles) and adhesive (different particles)

Wetting

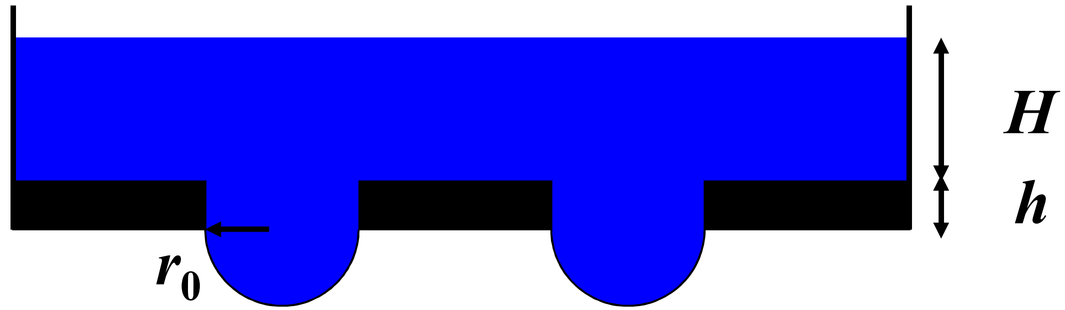
Equilibrium of surface forces – contact angle

$$\sigma_{SV} - \sigma_{SL} - \sigma_{LV} \cos\alpha = 0$$



Physics of strainer

Surface tension is responsible for holding liquid above strainer



Maximum height of liquid layer

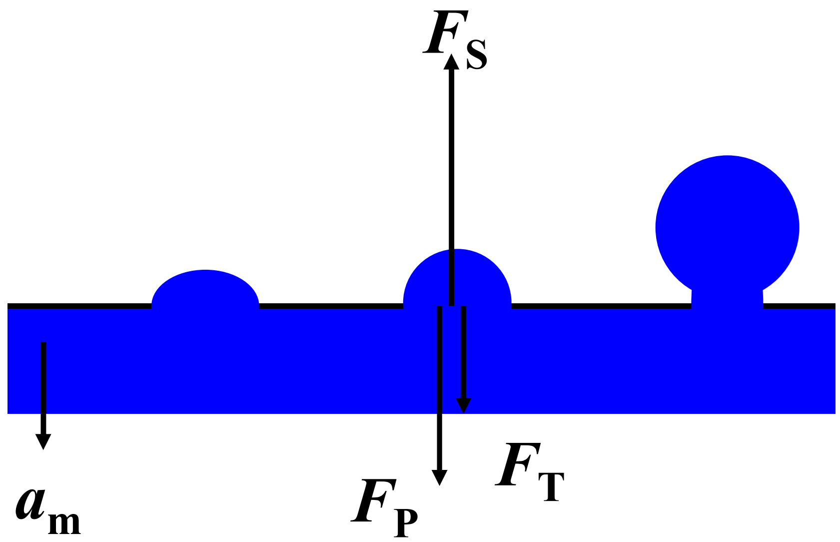
$$H_{\max} = \frac{2\sigma}{r_0 \rho g} - h$$

Ultrasonic atomization

Ultrasound wave oscillates the surface of liquid

Mean droplet radius

$$r = 0.365\sqrt[3]{\frac{\sigma}{\rho f_r^{2}}}$$



Narrow droplet size distribution

Rate and size of droplets is electronically controllable

Viscosity

Internal friction

Dynamic viscosity $[\eta] = Pa \cdot s$

$$\tau = \frac{F_{tř}}{S} = \eta \frac{\Delta v}{\Delta y}$$

Highly viscous liquids – honey, glycerine,…

Low viscosity liquids – water, ethanol, …

Internal friction force on sphere moving in viscous liquid –

Stokes' formula $$F = 6\pi r\eta v$$

Dynamic viscosity

Highly temperature dependent – exponencial

Higher temperature – lower viscosity

Smaller temperature – higher viscosity

Dynamic viscosity [10^{-3} *Pa·s*]				
acetone	**benzene**	**ethanol**	**glycerine**	**water**
0.33	**0.65**	**1.20**	**1480**	**1.00**

Literature

Material data used from tables:

BROŽ, J., ROSKOVEC, V., VALOUCH, M.:
Fyzikální a matematické tabulky, SNTL Praha 1980

and pictures from the book

HALLIDAY, D., R. RESNICK, J. WALKER
Fyzika. Brno: VUTIUM, 2000. díl 2 Mechanika - Termodynamika