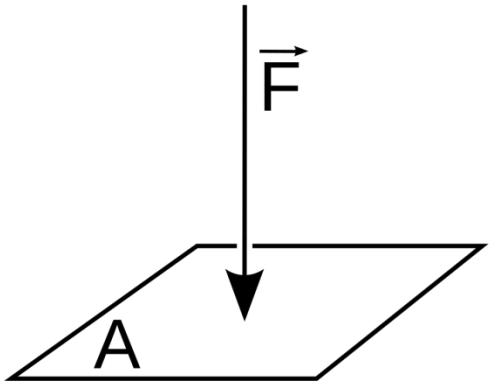
Three communities meet around a common theme:

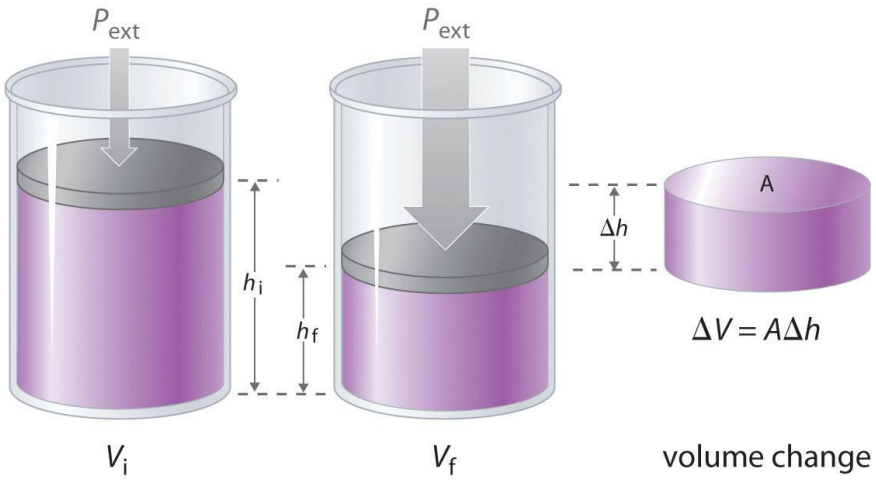
PRESSURE

What is pressure?



Pressure $P = \dfrac{F}{A}$ **Normal force** / **Area**

Pressure in thermodynamics



For a quasi-static process

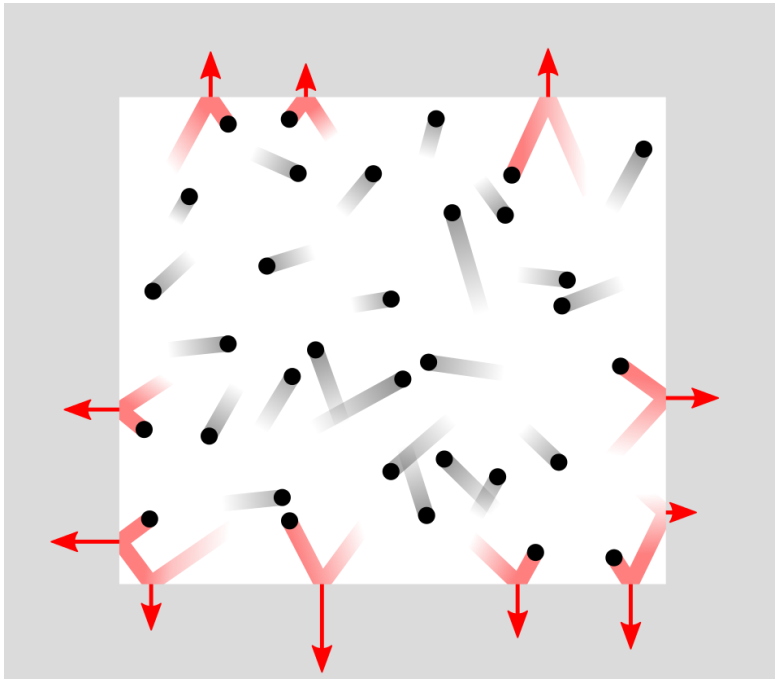
$$\mathrm{d}U = \delta Q - \delta W$$

Work done by the system

$$\delta W = F\mathrm{d}h = \frac{F}{A}A\mathrm{d}h = P\mathrm{d}V$$

$$\Rightarrow \quad P = -\left.\frac{\partial U}{\partial V}\right|_S$$

Pressure in ideal gas



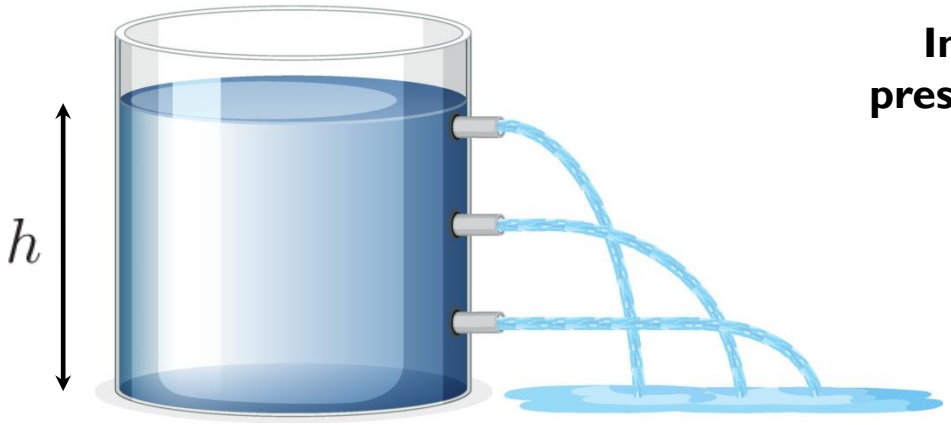
$$\vec{F}_{\text{part/wall}} = -\vec{F}_{\text{wall/part}} = -\frac{\mathrm{d}\vec{p}_{\text{part}}}{\mathrm{d}t}$$

Non-interacting point particles in a container at rest without gravitation

$$PV = nRT$$

Macroscopic pressure results from the averaging over a large number of bounces

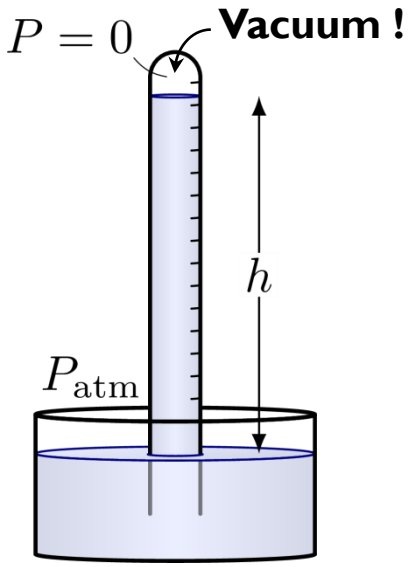
Hydrostatic pressure



In a gravitational field, pressure depends on height

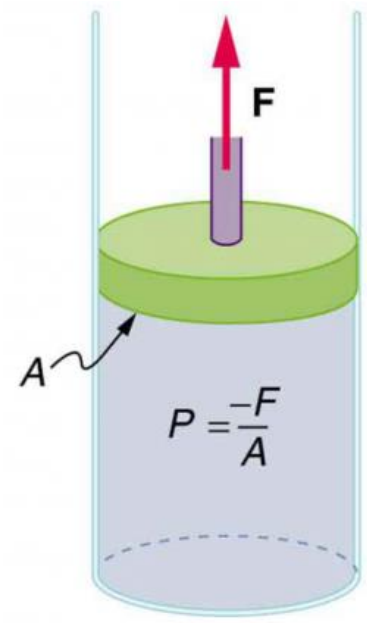
$$P = \rho g h$$

Torricelli experiment



air	800 km
water	10 m
mercury	760 mm
Hyperion (tallest tree on earth)	116 m **!!!**

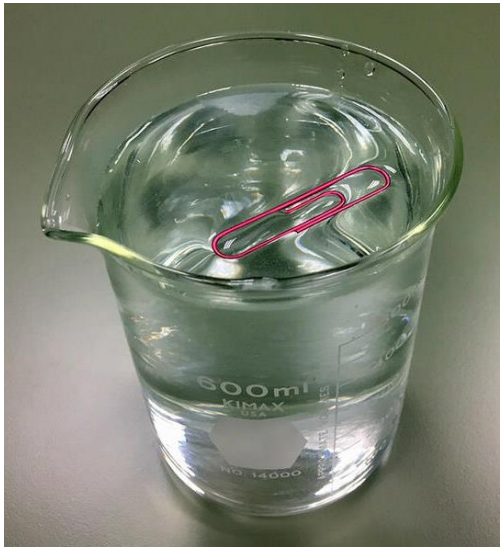
Negative pressure



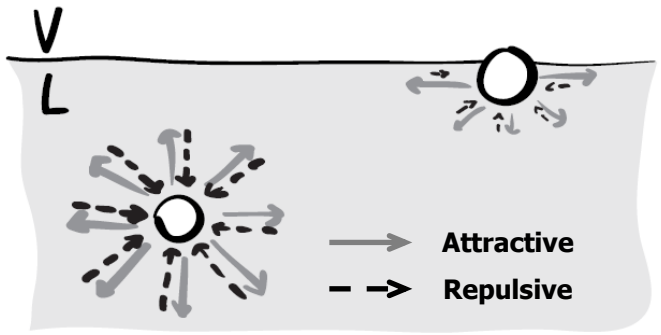
Negative pressure can be reached by pulling on a piston inside a cylinder filled with liquid

This is possible because there are attractive forces between the molecules

Surface tension is a 2D manifestation of these attractive forces



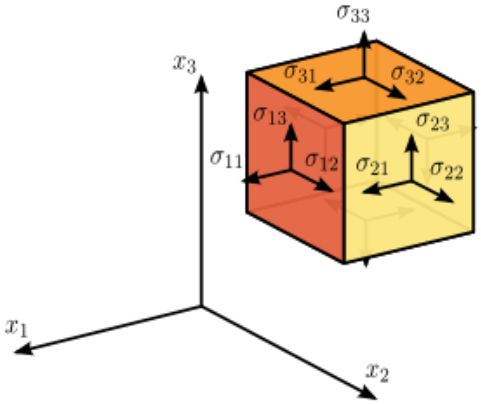
Anisotropic pressure



[Marchand *et al.*, Am. J. Phys. 79 (2011) 999]

Attractive forces are typically long range, while repulsive forces are short range

Pressure becomes anisotropic in regions where the density changes rapidly



Stress tensor

Force component

Cube side

$$\sigma_{ij} = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{pmatrix}$$

Normal stress

↕

pressure

Relativistic theory

The stress tensor is part of a larger object: the energy-momentum tensor

$$T^{\mu\nu} = \begin{bmatrix} T^{00} & T^{01} & T^{02} & T^{03} \\ T^{10} & T^{11} & T^{12} & T^{13} \\ T^{20} & T^{21} & T^{22} & T^{23} \\ T^{30} & T^{31} & T^{32} & T^{33} \end{bmatrix}$$

Energy density

Momentum density

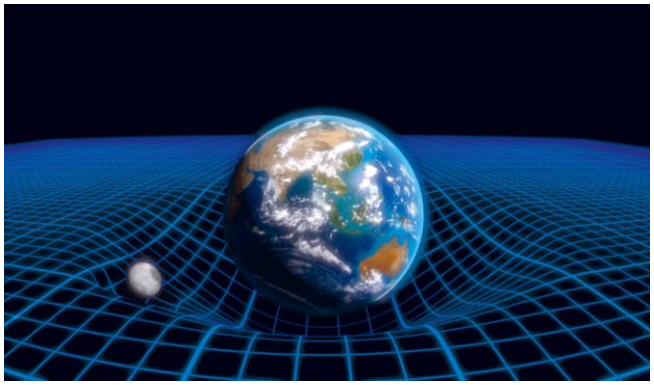
Shear stress

Normal stress (pressure)

Energy flux

Momentum flux

It plays the role of source for the gravitational field in General Relativity



$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} = \kappa\, T_{\mu\nu}$$

Spacetime curvature

$$\sim \partial_\rho \partial_\sigma g_{\alpha\beta}$$

Some figures …

	Density (kg/m^3)	Pressure (Pa or N/m^2)
Atmosphere at sea level	≈ 1.2	$\approx 10^5$
Center of sun	$\approx 1.6 \times 10^5$	$\approx 2.5 \times 10^{16}$
Center of neutron star	$\approx 8 \times 10^{17}$	$\approx 10^{35}$
Atomic nucleus	$\approx 2.3 \times 10^{17}$	$\approx 3.5 \times 10^{33}$
Center of nucleon	$\approx 3 \times 10^{18}$	$\approx 3.7 \times 10^{34}$
PhD student a month before graduation	$\approx 10^3$	$> 10^{42}$

… some big questions …

Hadronic physics

What is the sign of pressure anisotropy, and how do quarks and gluons contribute ?

What is the mechanical radius of nucleons ?

Nuclear physics

What is the role of pressure in equilibrium and non-equilibrium nuclear matter?

What is the incompressibility of nuclear matter ?

Astrophysics

What is the nature of matter at the core of a neutron star ?

What is the equation of state inside a neutron star ?

… and much more !

Degeneracy pressure

Virial theorem

Confinement

Radiation pressure

Thermal vs non-thermal pressure

Gravitational pressure

Stability

Phase transition

Sum rules

Dynamic pressure

Conservation laws

Sound speed

Alternative gravitational theories