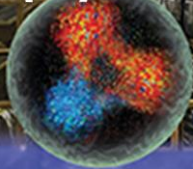




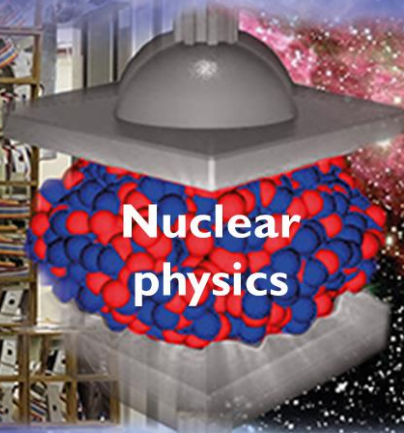
NUCLEAR MATTER UNDER PRESSURE

SEPTEMBER 4-9, 2022
SAINT-PIERRE D'OLERON, FRANCE

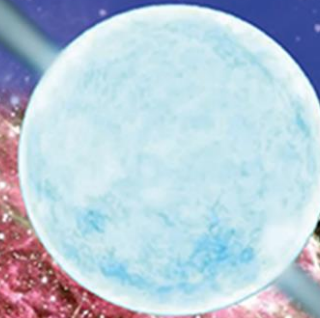
**Hadronic
physics**



**Nuclear
physics**



Astrophysics



SPEAKERS

Nicole d'Hose (CEA-Saclay, France)
Bruno Giacomazzo (Univ. of Milano-Bicocca, Italy)
Julien Gabelin (LPC, France)
Olivier Lopez (LPC, France)
Hervé Moutarde (CEA-Saclay, France)
Xavier Roca-Maza (Univ. of Milano, Italy)
Anna Watts (Univ. of Amsterdam, Netherlands)

ejc2022.sciencesconf.org
ejc2022@sciencconf.org



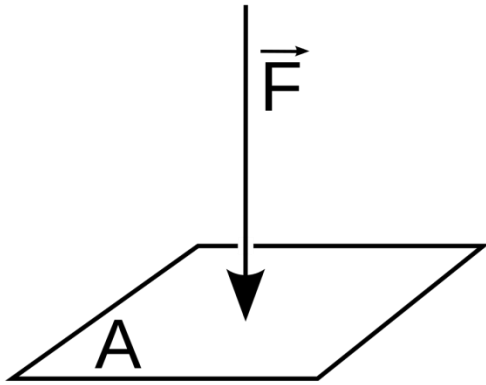
ORGANIZING COMMITTEE

Nicolas Chamel
Aurélie Gontier (secretary)
Elias Khan
Cédric Lorcé
Jérôme Margueron
Miguel Marqués (chair)
Soizic Milhoud (communication)
Carlos Muñoz Camacho

Crédits photos de gauche à droite : © LPC, © Tom Ruch, © INSA-CFIS-CNRS-Photographie, © Uniphys - Brest, © Science Museum/CCO/Sciencconf

**Three communities meet around a common theme:
PRESSURE**

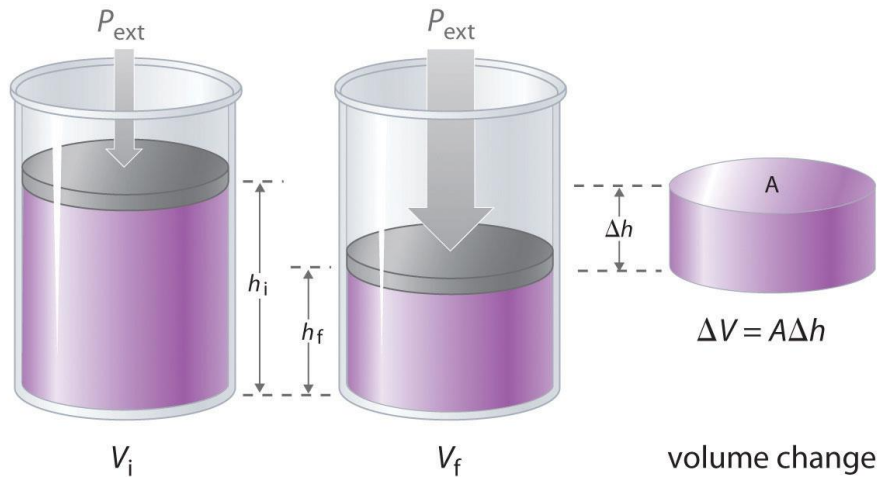
What is pressure?



Pressure $P = \frac{F}{A}$ Normal force
Area



Pressure in thermodynamics



For a quasi-static process

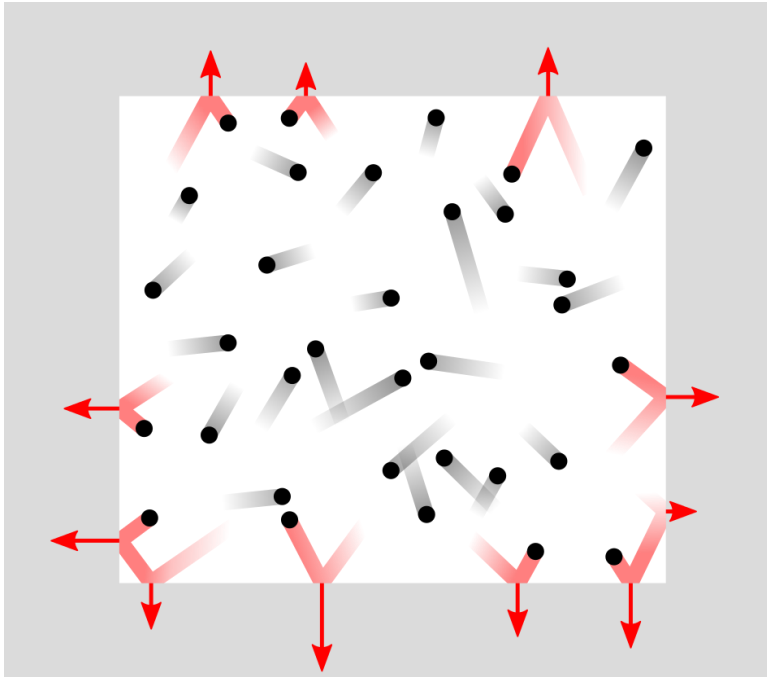
$$dU = \delta Q - \delta W$$

**Work done
by the system**

$$\delta W = F dh = \frac{F}{A} A dh = P dV$$

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

Pressure in ideal gas



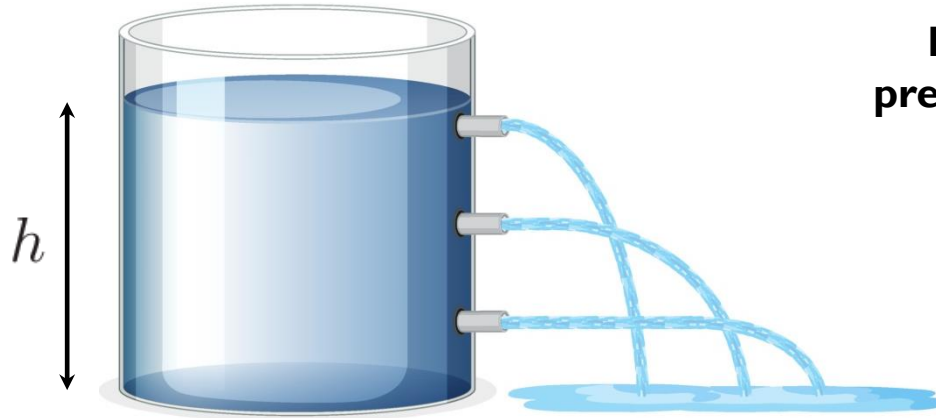
**Non-interacting point particles
in a container at rest
without gravitation**

$$PV = nRT$$

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

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

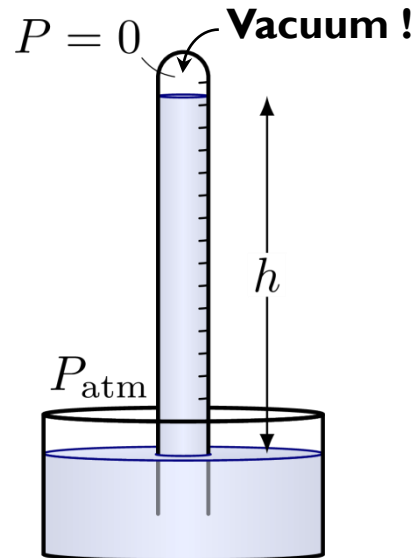
Hydrostatic pressure



In a gravitational field,
pressure depends on **height**

$$P = \rho gh$$

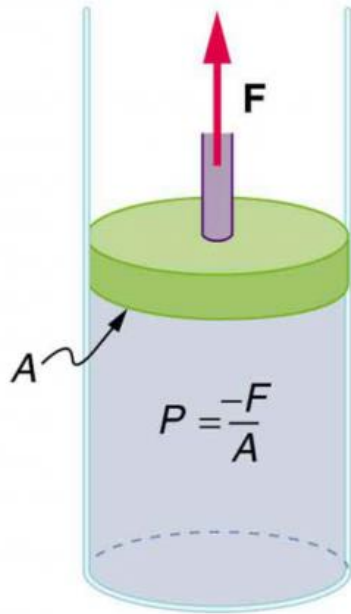
**Torricelli
experiment**



air	800 km
water	10 m
mercury	760 mm

Hyperion 116 m !!!
(tallest tree on earth)

Negative pressure



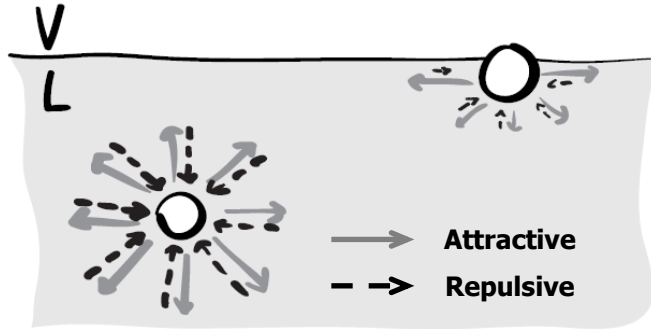
Negative pressure can be reached by **pulling** on a piston inside a cylinder filled with liquid

This is possible because there are **attractive** forces between the molecules

Surface tension is a 2D manifestation of these attractive forces



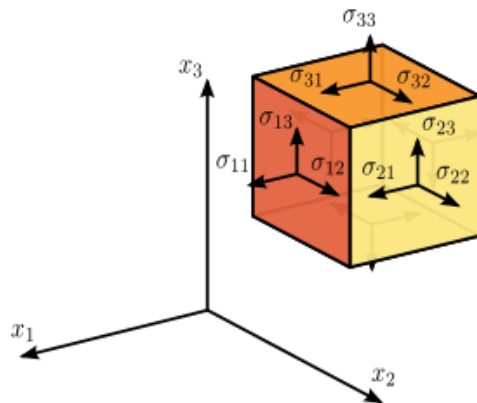
Anisotropic pressure



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

Pressure becomes anisotropic in regions where the density changes rapidly

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



Stress tensor

$$\sigma_{ij} = \begin{matrix} & \text{Force component} \\ & \begin{matrix} \rightarrow \\ \rightarrow \\ \rightarrow \end{matrix} \\ \begin{matrix} \downarrow \\ \downarrow \\ \downarrow \end{matrix} \text{Cube side} & \begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{pmatrix} \end{matrix}$$

Normal stress

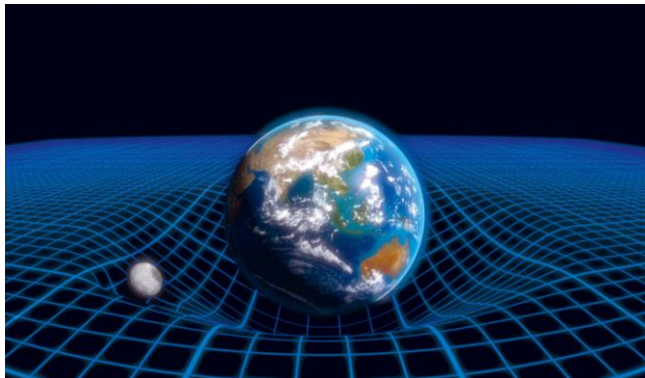
↕
pressure

Relativistic theory

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

$$T^{\mu\nu} = \begin{bmatrix} \text{Energy density} & \text{Momentum density} & & \\ T^{00} & T^{01} & T^{02} & T^{03} \\ \text{Energy flux} & \text{Momentum flux} & \text{Shear stress} & \\ T^{10} & T^{11} & T^{12} & T^{13} \\ T^{20} & T^{21} & T^{22} & T^{23} \\ T^{30} & T^{31} & T^{32} & \text{Normal stress (pressure)} \\ & & & T^{33} \end{bmatrix}$$

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