Development of a platform dedicated to the measurement of material properties at cryogenic temperatures : **CRYOMAT**

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CRYOMAT, contextualisation

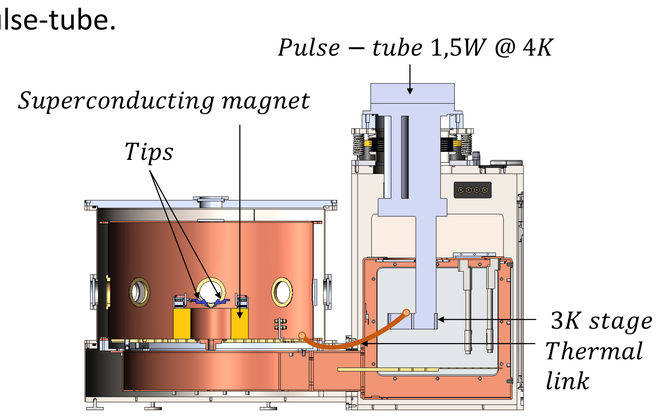
The **CryoMat** project aims to answer a demand in the field of astrophysics, where instruments need to work at cryogenic temperatures to get high sensitivity. A wealth of data on the properties of metallic and plastic materials is now available for temperatures down to 1K. However, there is still a significant lack of data on thermal, electrical and mechanical properties, particularly for anisotropic materials, and especially composites, across the 1K – 300K temperature range, and below 1K for metallic and plastic materials.

CryoMat aims to fill this gap by developing a **platform dedicated to the characterization of materials at cryogenic temperatures**, down to sub-Kelvin. This development, supported by IN2P3 and other institutions, is being carried out as part of the DIM Origines program, over a period of five years (2022-2027). This platform, based on the Grands Moulins campus of Paris Cité University (Paris, France), will be accessible to scientific laboratories and industries. The physical data of the measured properties will be shared via an open database. **CryoMat** will cover three families of physical properties installed in cryostats dedicated to electrical, thermal and mechanical properties.

Electrical measurements

The electrical resistances and impedances of the materials will be measured in the temperature range [3K; 40K], using a cryostat designed by **MyCryoFirm** and equipped with a pulse-tube.

Photograph of the closed cryostat



Preliminary 3D modelling of the electrical measurement cryostat

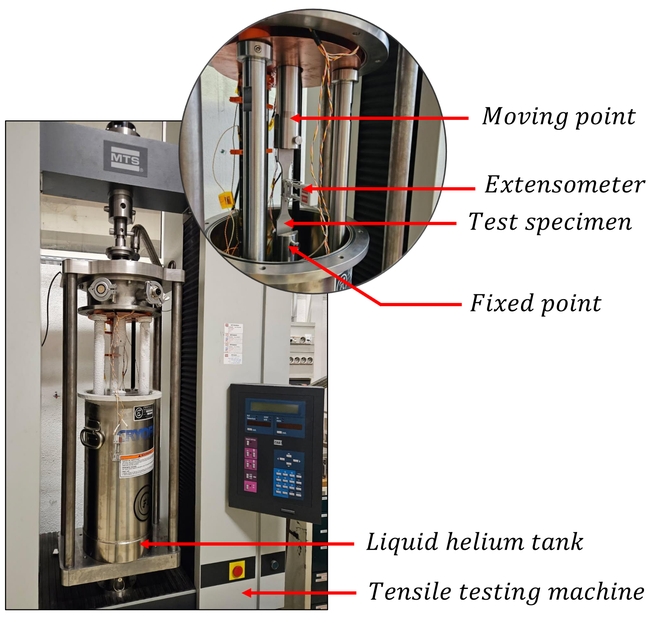
The measurements will be carried out using a 4-tips system operating at cryogenic temperatures. A superconducting magnet allows these measurements to be taken under a magnetic field. The probes will be aligned using a camera. The integration of a 4He/3He adsorption fridge will extend the measurement range down to 300 mK, and a dilution fridge will be integrated to reach 100 mK.

Mechanical measurements

Cryostats for mechanical characterization of materials will be designed by **APC** and **IJCLab**, in collaboration with **TOP-Industrie** and **ACS**.

Two measurement benches :

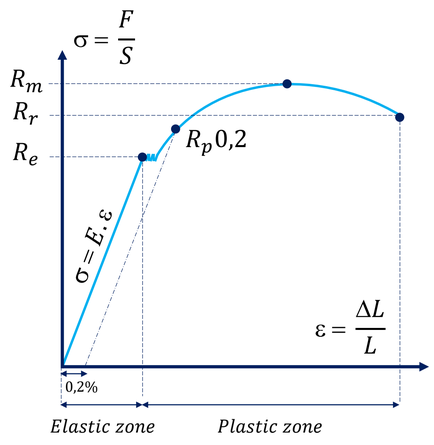
1. Tensile testing machine equipped with a cryostat to allow testing in cryogenic liquids [1]



Captioned photographs of the tensile testing device

Measured parameters :

- **Poisson's ratio** (ν)
- **Young's modulus** (E)
- **Yield strength** (R_e)
- **Ultimate tensile strength** (R_r)
- **Elongation at break** (A)



Stress-strain diagram : σ = f(ε)

2. Test machine for testing specimens under variable loads in a cryogenic environment : Fatigue testing (machine under development)

Thermal measurements

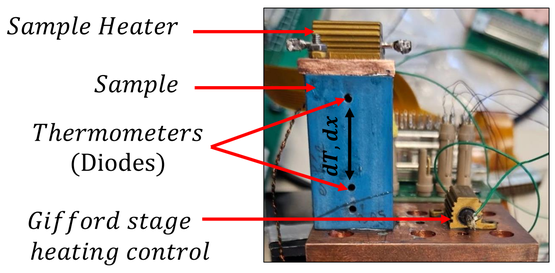
For the characterization of thermal properties, a cryostat equipped with a double-stage Gifford-McMahon, dedicated to stationary and non-stationary measurements in the temperature range [0.3K; 40K] thanks to the integration of a 4He/3He adsorption refrigerator, will be built at the **APC** and **IJCLab**, in collaboration with **Themacs Ingénierie, CNAM** and the **LNE**.

Photograph of the thermal measurements closed cryostat

Stationary measurements :

- **Thermal conductivity** is measured using the calorimetric method under adiabatic conditions, which involves applying thermal power to the sample and then measuring the temperature difference [2] :

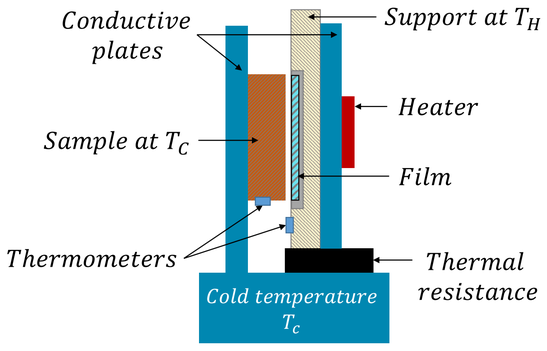
$$\lambda = -\frac{\Phi\, dx}{dT}$$



Thermal conductivity measurement bench (outside the cryostat)

- The **emissivity** measurement is performed using the calorimetric method [3] :

$$P = \sigma * S * \varepsilon\,(T_H^4 - T_C^4) = U * I$$

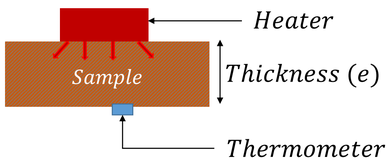


Principle of emissivity measurement

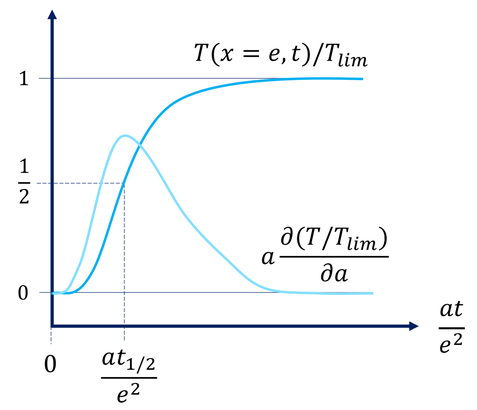
- **Thermal expansion** measurement (development in progress)

Instationary measurements :

- **Diffusivity** a is measured using the flash method, which allows the variation in temperature to be plotted as a function of time :



Principle of diffusivity measurement



Reduced sensitivity curve and half-rise time [4]

- By knowing the density and thermal conductivity of the sample, the diffusivity measurement allows us to deduce the **specific heat capacity**

$$\alpha = \frac{\lambda}{\rho\, C_p}$$

References :

[1] BAUDOUY, Bertrand, et al. "Propriétés des matériaux à basse température." (2014).
[2] MONCHAU, Jean-Pierre, et al. "Mesure de la conductivité thermique d'échantillons d'aluminium à basse température « . (2022).
[3] MONCHAU, Jean-Pierre, et al. "Comparative study of radiometric and calorimetric methods for total hemispherical emissivity measurements ". Heat Mass Transfer 54, 1415–1425 (2018)
[4] Hay, Bruno. Mesure de la diffusivité thermique par la méthode flash. Ed. Techniques Ingénieur, 2004.

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