Bajas Temperaturas:

Investigación Aplicada:

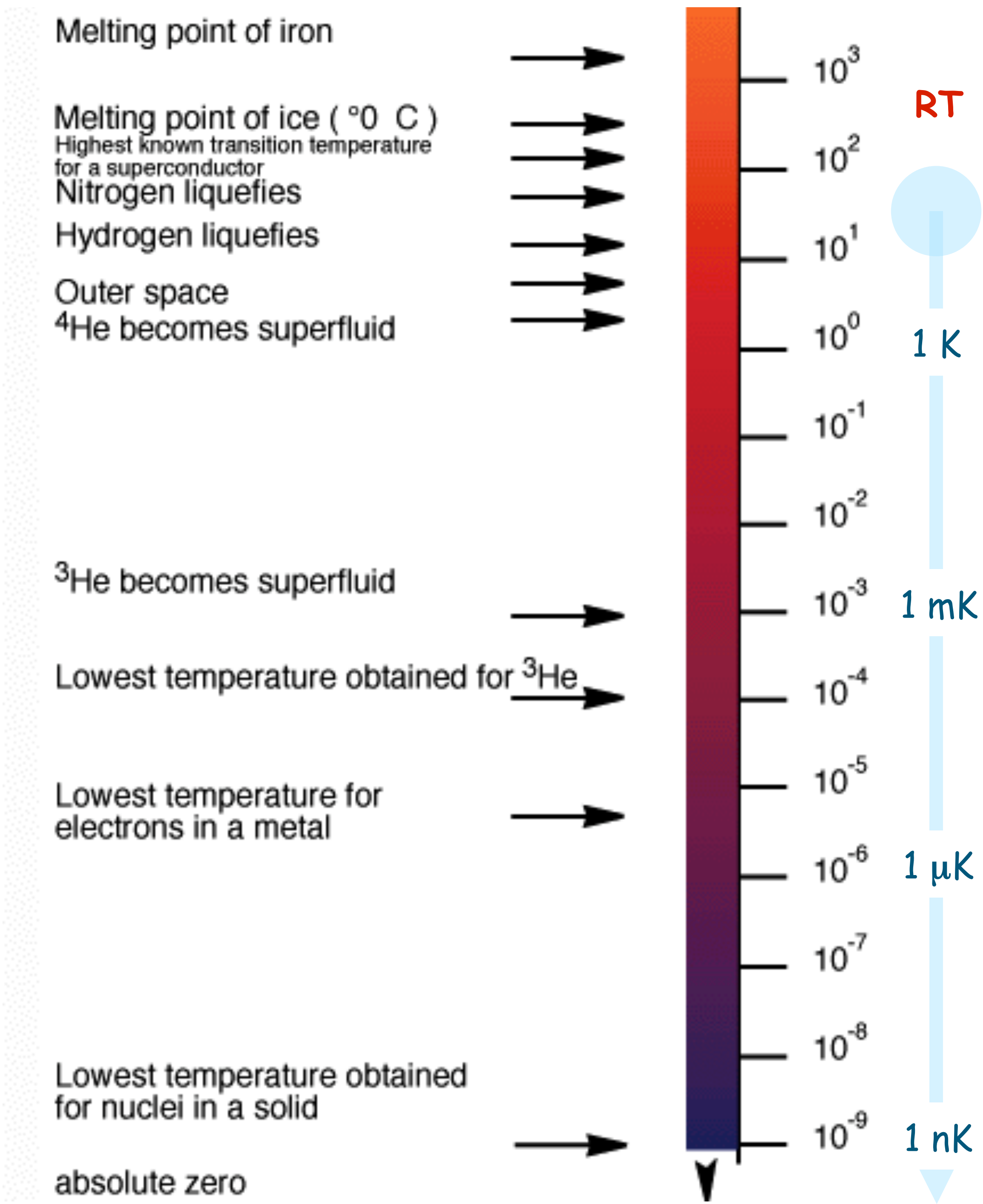
Industria
Biología
Medicina

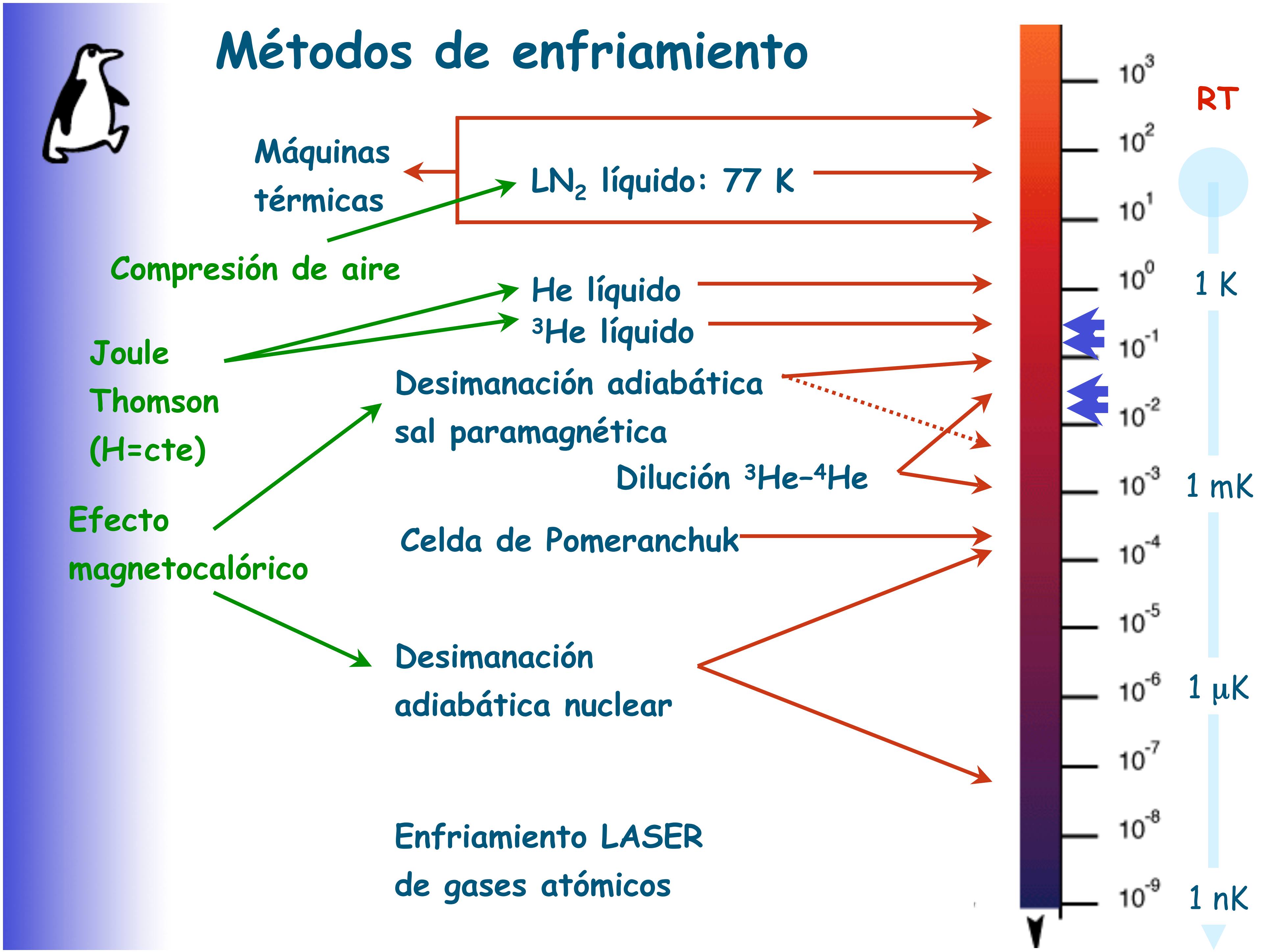
Investigación Fundamental:

Estado sólido
Materia Condensada

Física de partículas
Física atómica
Astrofísica
Teoría General

Óptica
Computación Cuántica

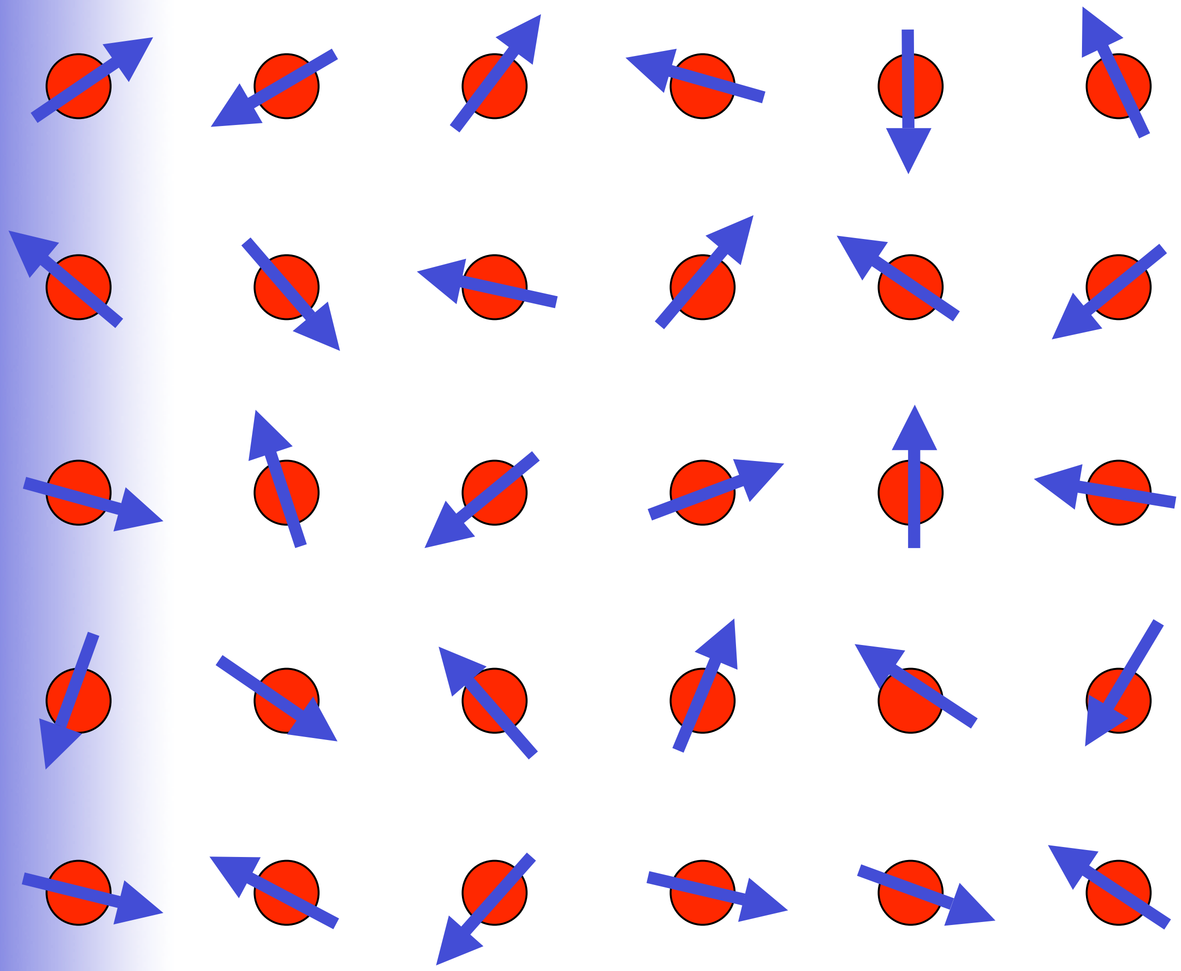




Métodos de enfriamiento
Máquinas térmicas
LN$_2$ líquido: 77 K
Compresión de aire
He líquido
^{3}He líquido
Joule Thomson (H=cte)
Desimanación adiabática sal paramagnética
Dilución ^{3}He-^{4}He
Efecto magnetocalórico
Celda de Pomeranchuk
Desimanación adiabática nuclear
Enfriamiento LASER de gases atómicos
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
RT
1 K
1 mK
1 μK
1 nK

Métodos de enfriamiento: Desimanación adiabática

Paramagneto: gas de espines



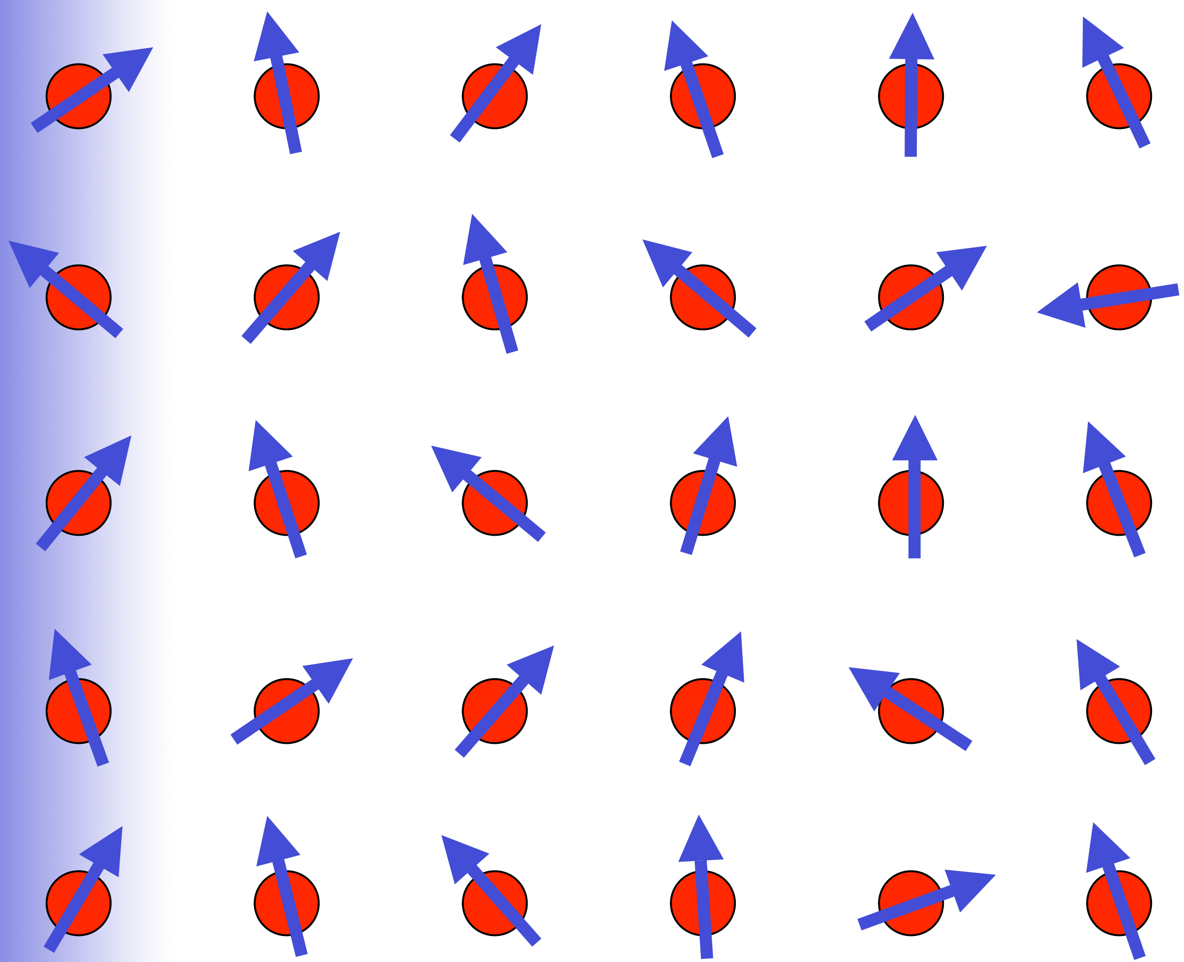
H=0

T>0

M=0

Métodos de enfriamiento: Desimanación adiabática

Paramagneto: gas de espines



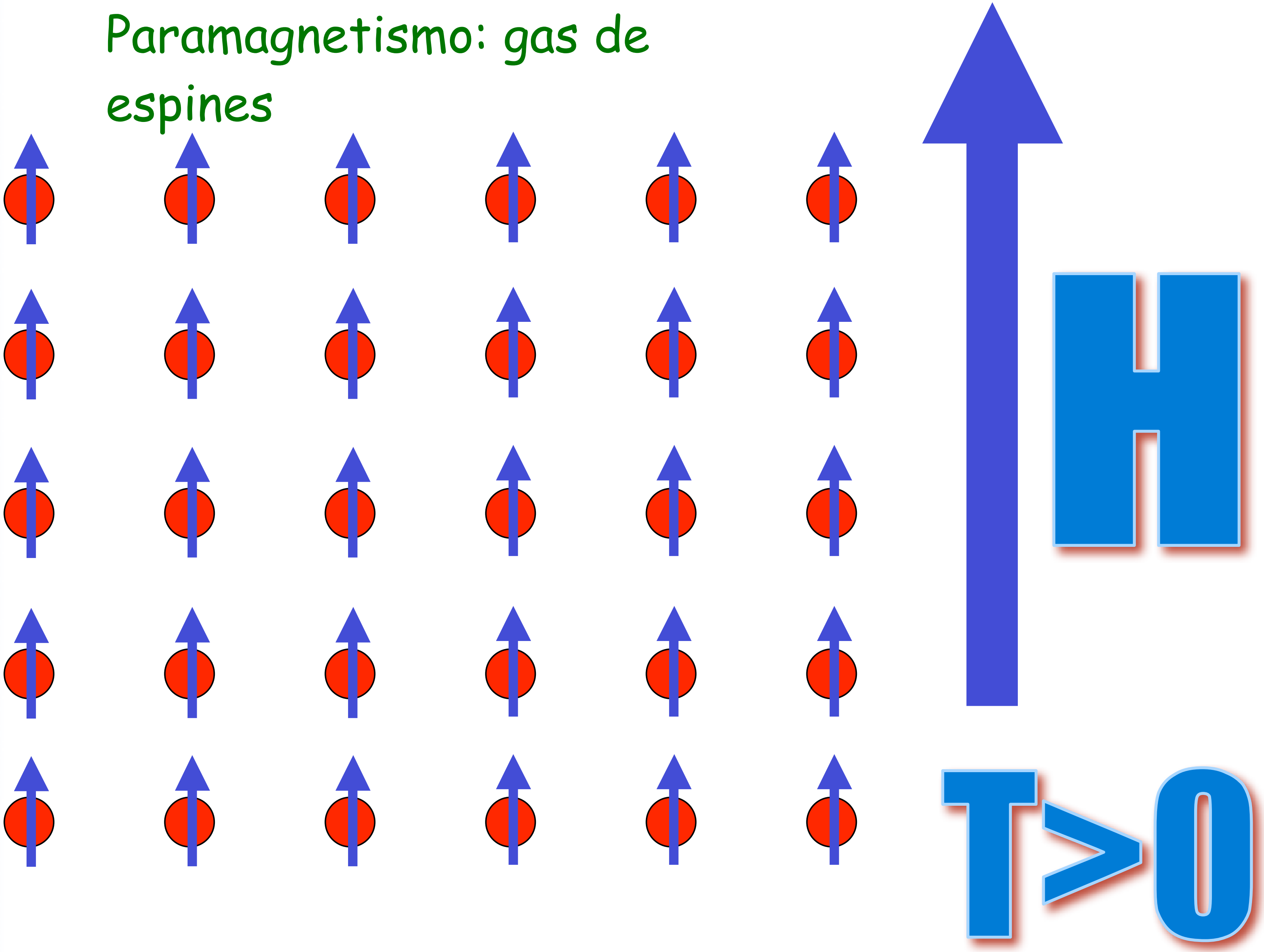
H>0

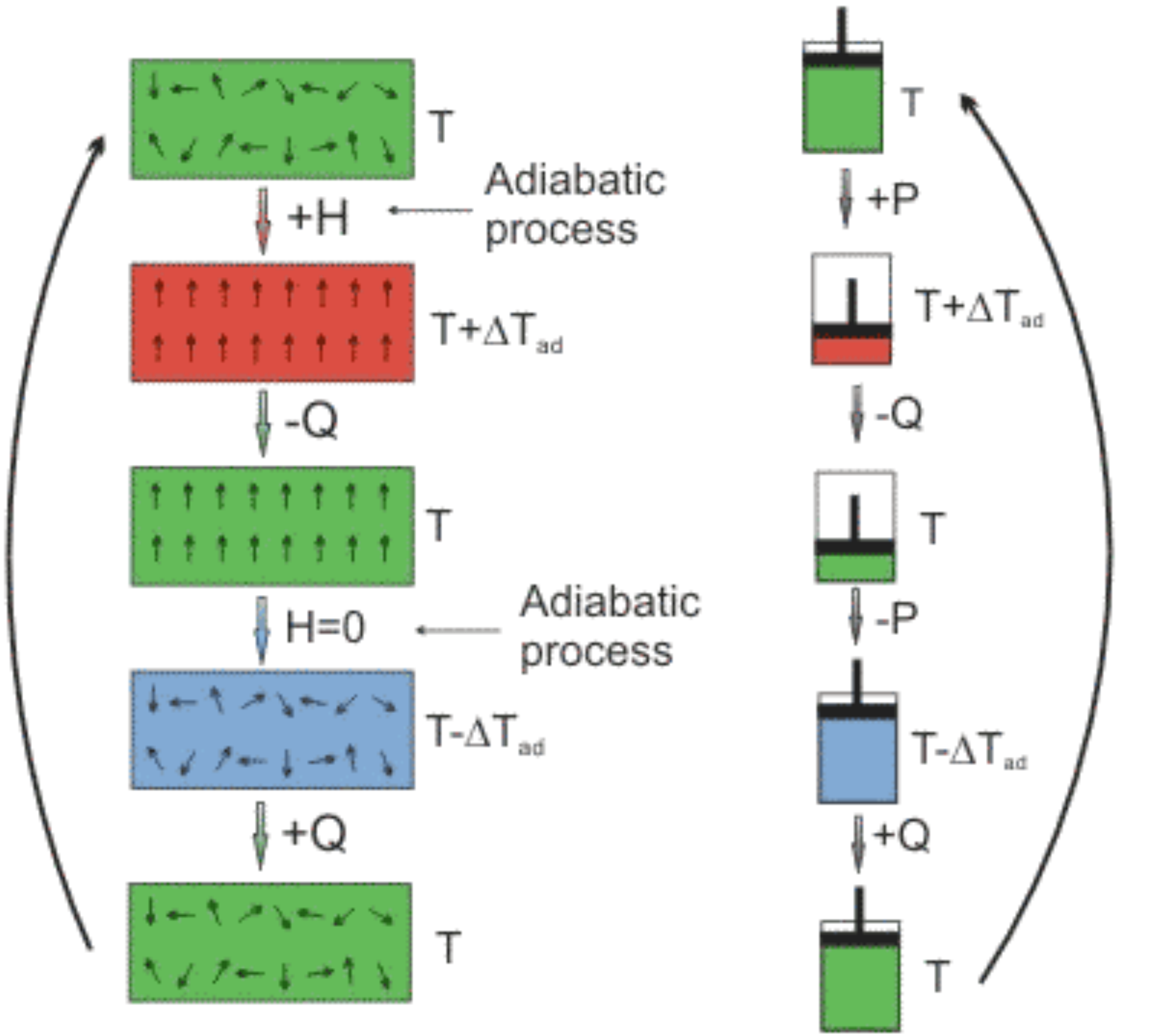
T>0

M>0

Métodos de enfriamiento: Desimanación adiabática

Paramagnetismo: gas de espines





Magnetic refrigeration

Vapor cycle refrigeration

Paramagneto cuántico

H=0   T>0   M=0

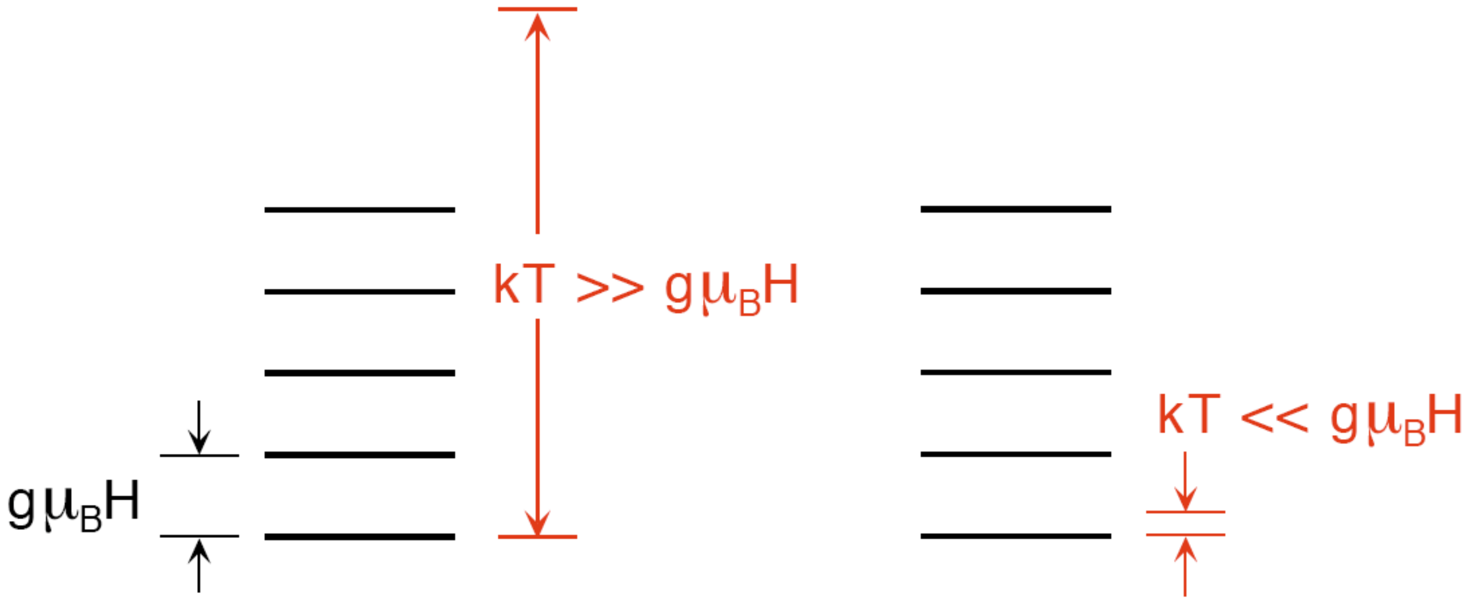
$J = 5/2$ .... 5/2 3/2 1/2 / −1/2 −3/2 −5/2 J_z

Entropía: degeneración

Población de cada $J_z = 1/6$

Paramagneto cuántico bajo campo

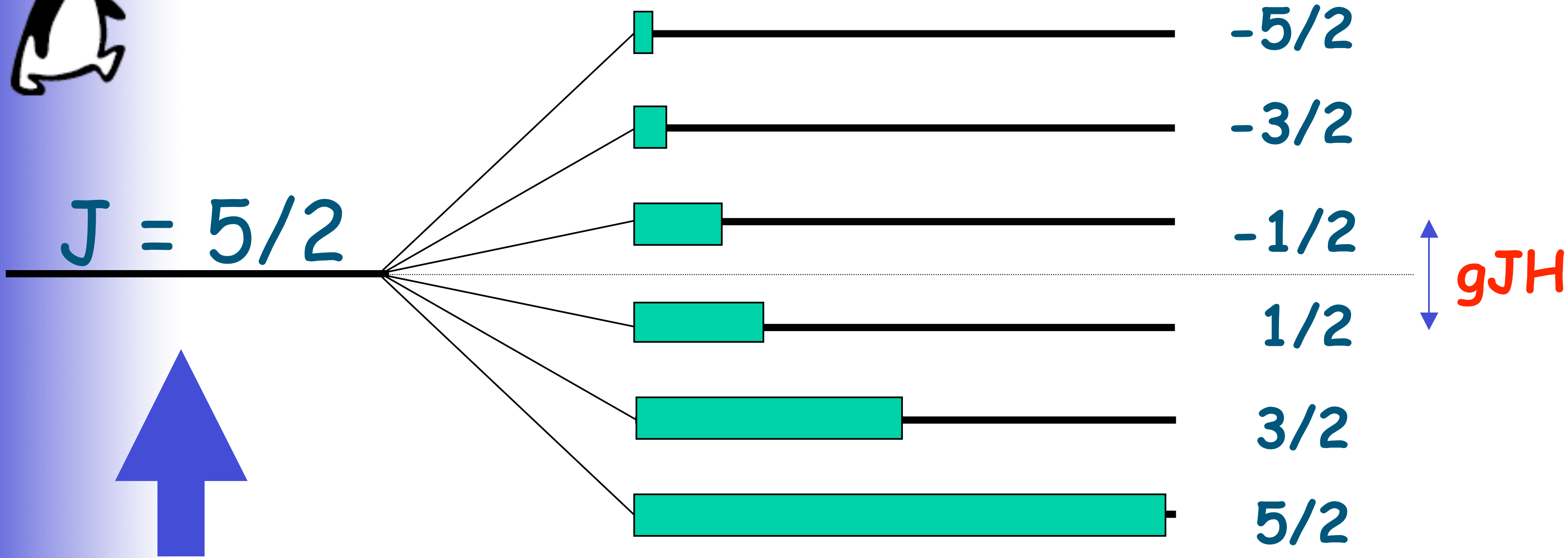
HIGH AND LOW TEMPERATURE BEHAVIOR OF A QUANTUM PARAMAGNET



ENERGY LEVELS ALMOST EQUALLY POPULATED, CURIE LAW BEHAVIOR

MOMENT ALMOST SATURATED, ENERGY GAP BEHAVIOR

Paramagneto cuántico



H>0

M>0

$$\text{Población} \propto e^{-gJH/k_BT}$$

Entropía de un paramagneto

$$\frac{S}{R} = \frac{x}{2J} \coth\left(\frac{x}{2J}\right) - \frac{(2J+1)\,x}{2J} \coth\left(\frac{(2J+1)\,x}{2J}\right) + \ln\left[\frac{\operatorname{senh}\left(\frac{(2J+1)\,x}{2J}\right)}{\operatorname{senh}\left(\frac{x}{2J}\right)}\right]$$

donde $x = \mu_B\, g_J\, B \,/\, (k_B\, T)$. (2.1)

Una inspección de la ecuación (2.1) revela que la entropía sólo es función de B/T. Tras un proceso adiabático desde un estado inicial (B_i, T_i) hasta uno final (B_f, T_f) la temperatura final viene dada por:

$$S = cte \;\Rightarrow\; \frac{B}{T} = cte \;\Rightarrow\; T_f = T_i \,\frac{B_{int}}{B_{ext} + B_{int}}$$

Métodos de enfriamiento: Desimanación adiabática

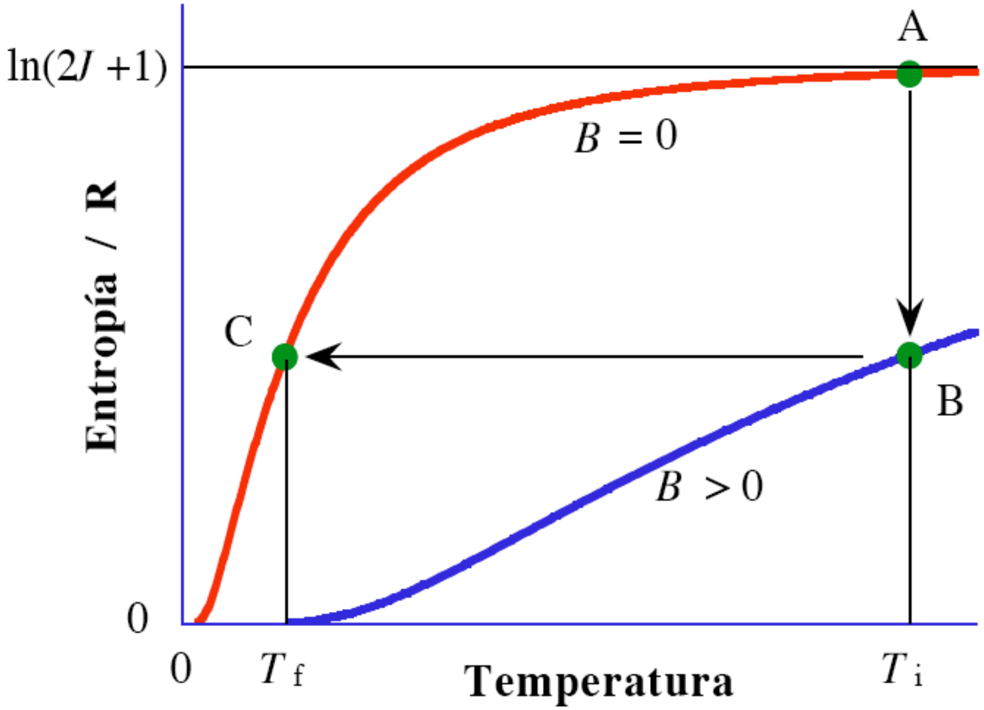
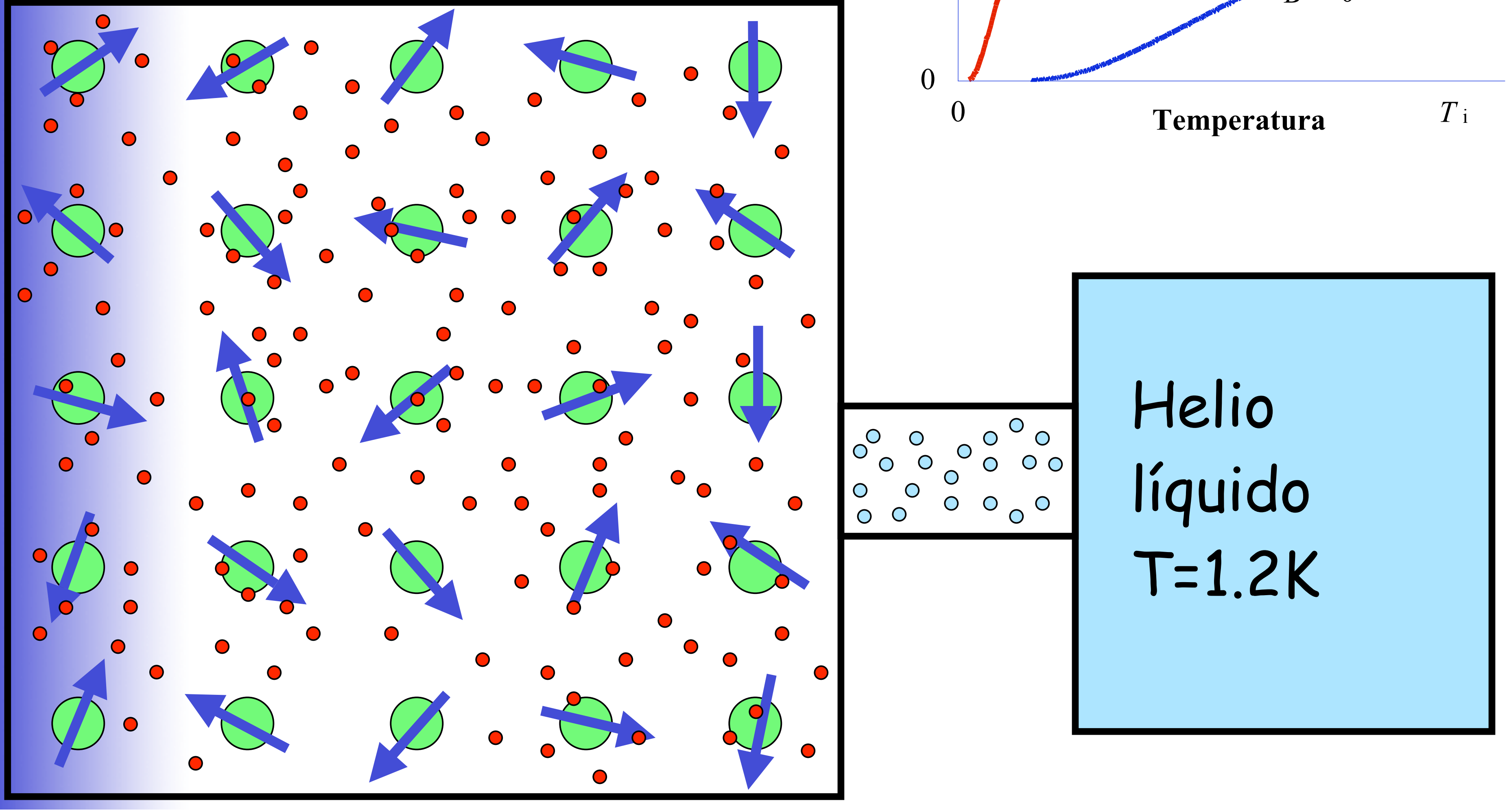
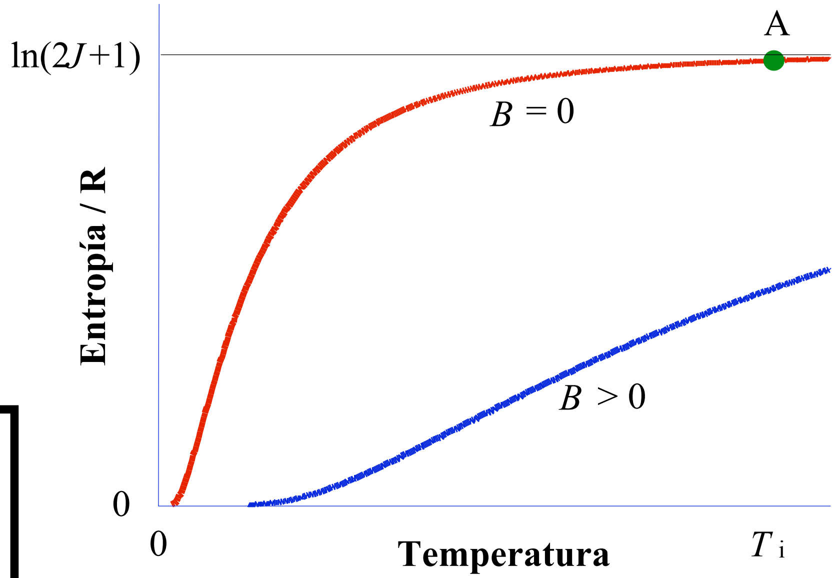


Figura 2.1. Diagrama esquemático de la variación de la entropía con la temperatura con y sin campo magnético aplicado. En nuestra instalación T_i es cercana a 1.4 K y T_f es aproximadamente 0.15 K, algo superior a lo que se acepta como alcanzable en este tipo de sistemas.

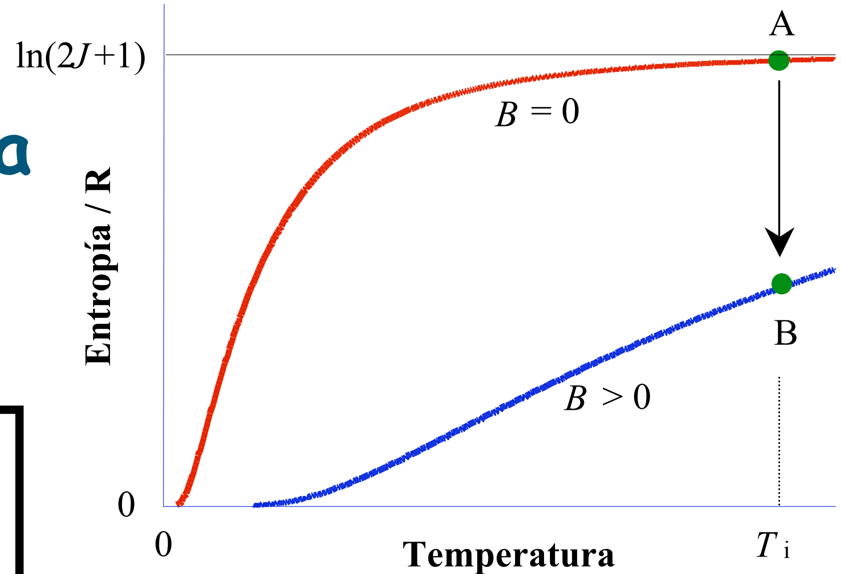
Diagrama S(T,H) de un paramagneto

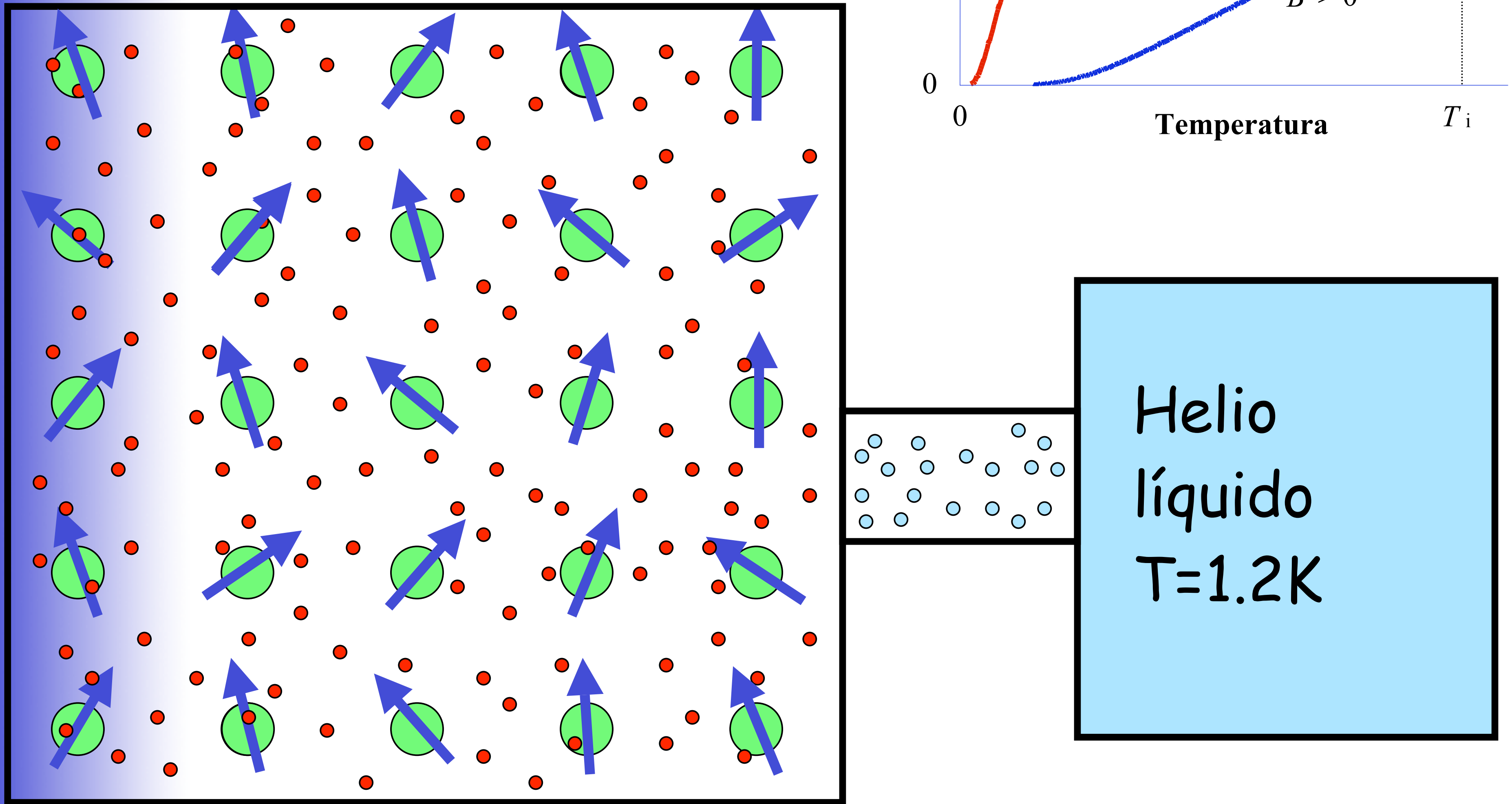
Desimanación adiabática 1



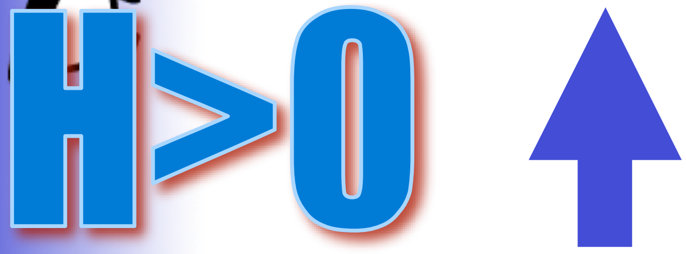


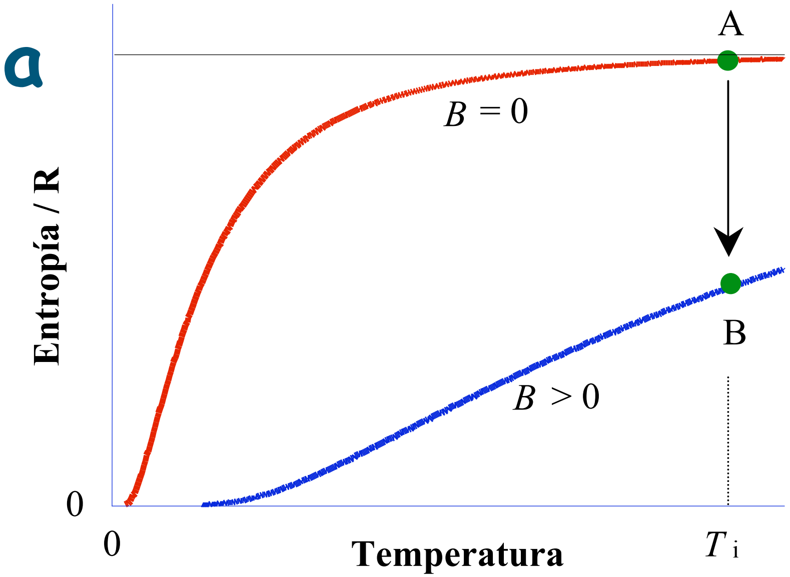
DA 2: Imanación isoterma

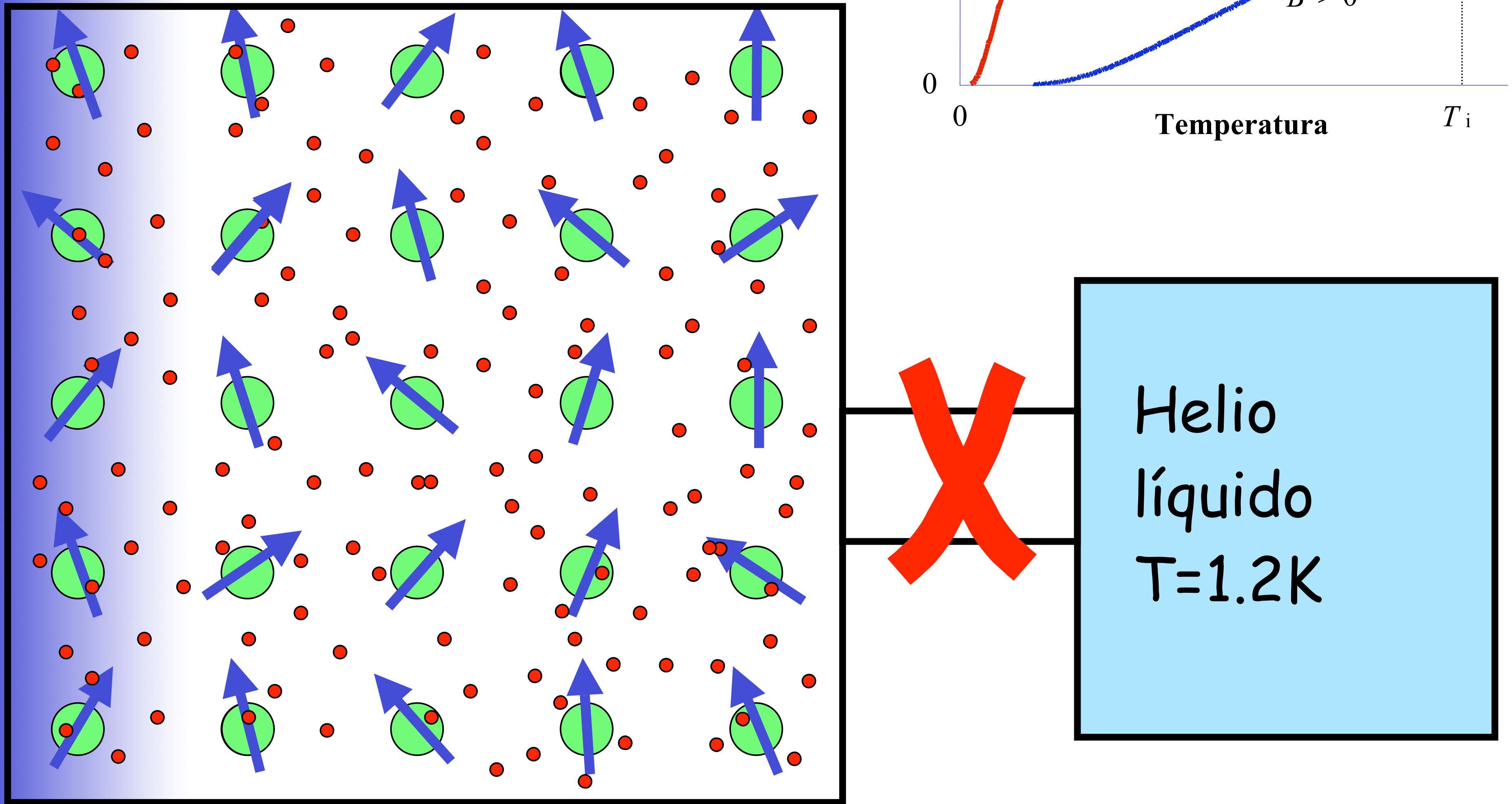




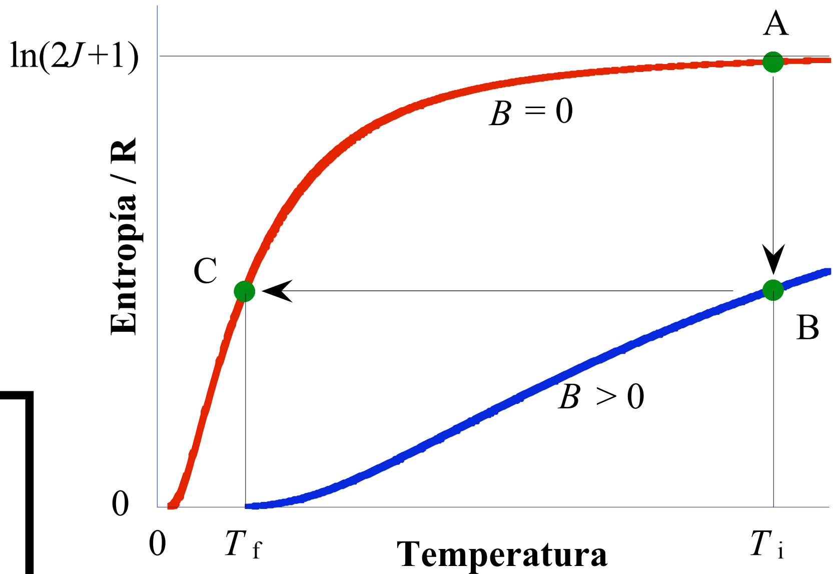
DA 3: Pared adiabática



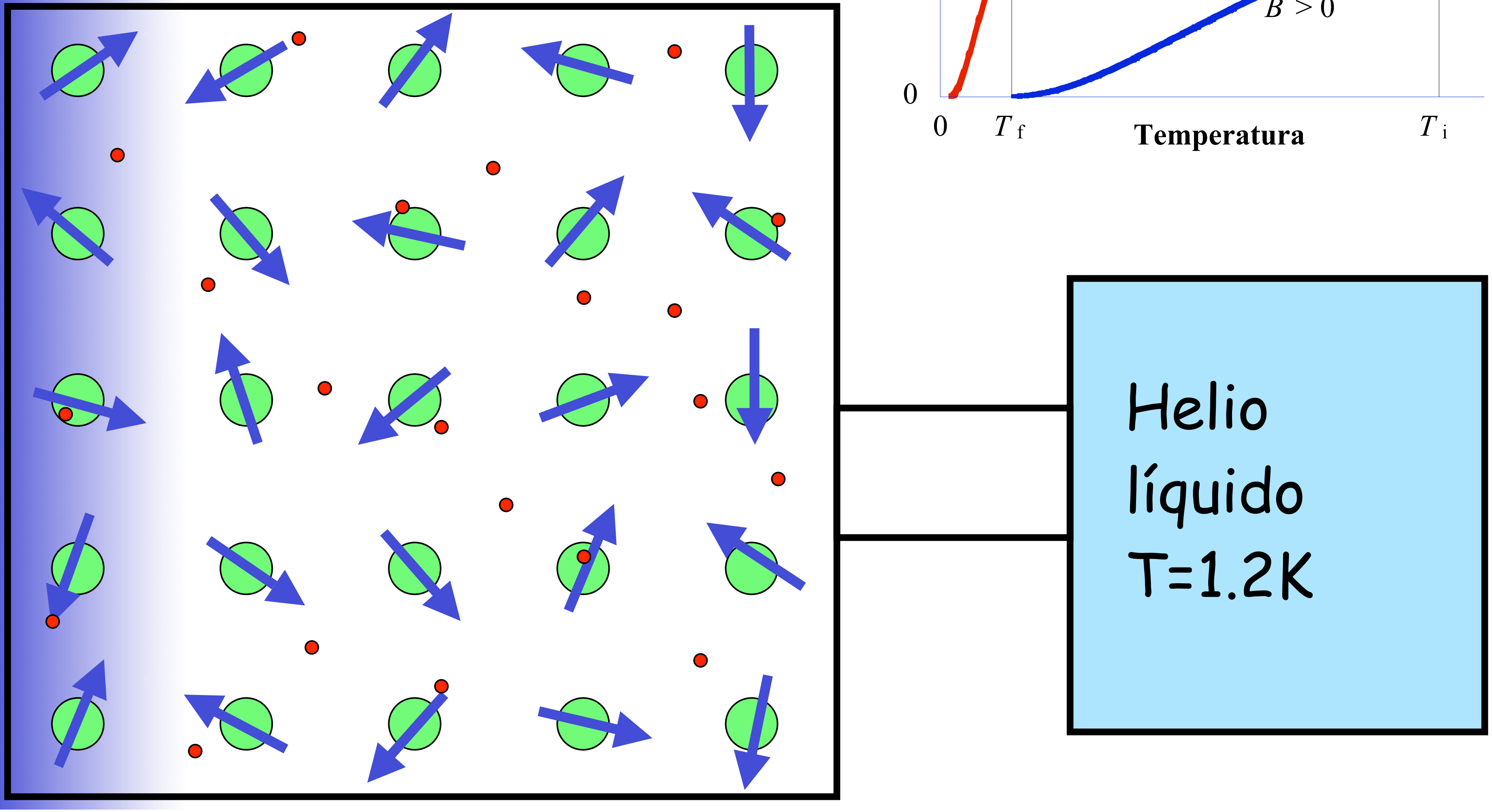


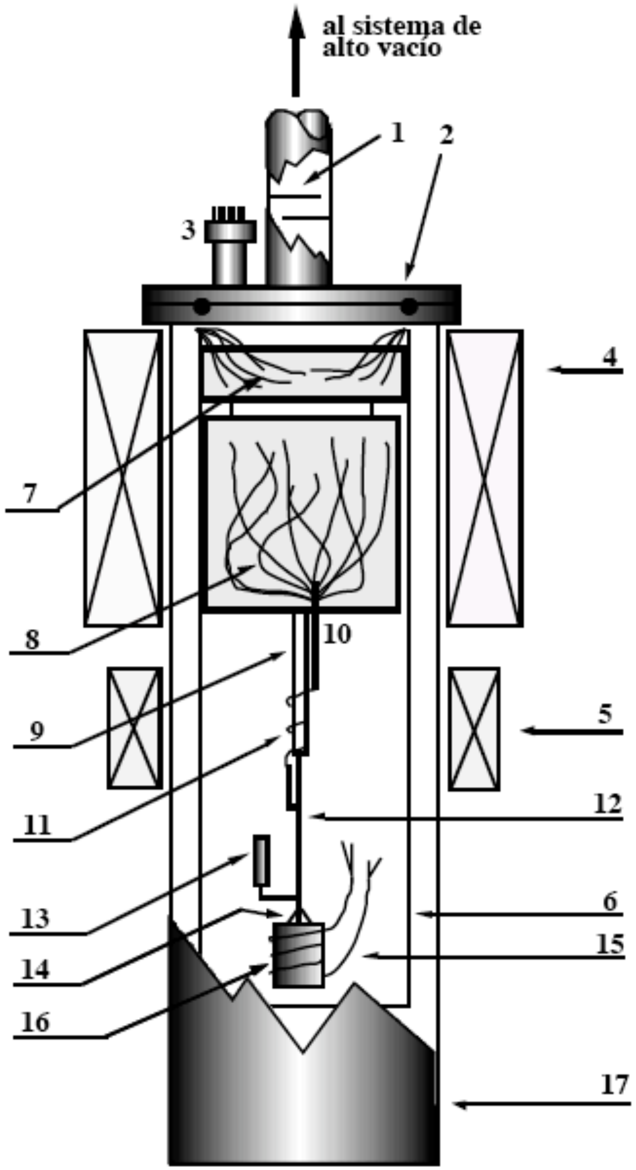


DA 4: desimanación adiabática



T = 50 mK





Leyenda:

1 : Pantalla de radiación a 1.2 K.

2 : Cierre con junta de indio.

3 : Pasamuros

4 : Bobina superconductora para las sales paramagnéticas.

5 : Bobina superconductora para el interruptor térmico.

6 : Pantalla de radiación a 0.15 K.

7 : Depósito de sales para apantallamiento térmico.

8 : Depósito principal de sales para enfriamiento.

9 : Barra aislante térmica.

10 : Barra de cobre de la brocha en contacto con las sales.

11 : Hilo de estaño (interruptor térmico)

12 : Soporte mecánico del conjunto calorimétrico (Cu).

13 : Termómetro resistivo de Ge.

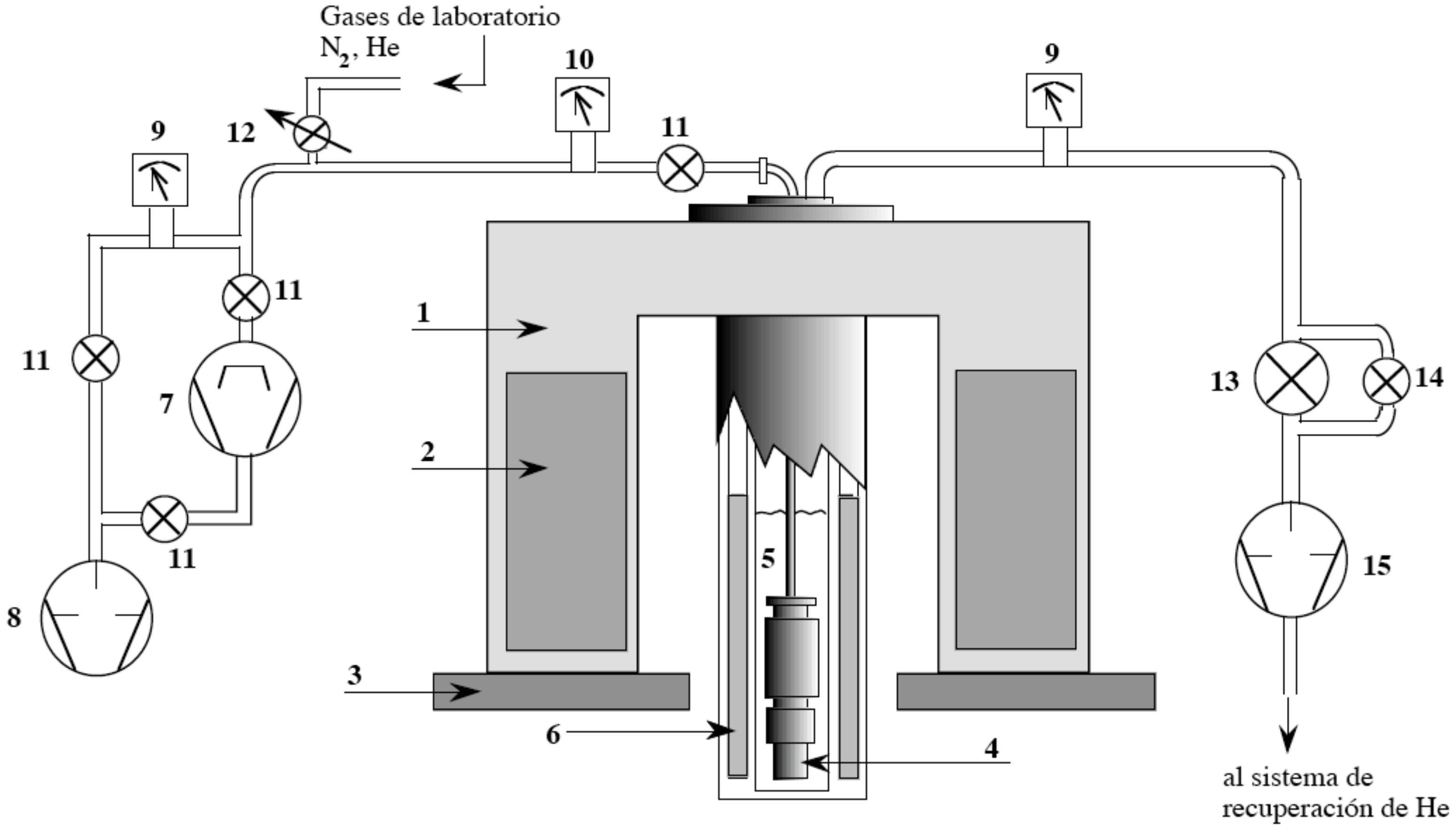
14 : Brocha para contacto térmico de la muestra y termómetro.

15 : Calentador.

16 : Portamuestras.

17 : Camisa de alto vacío.

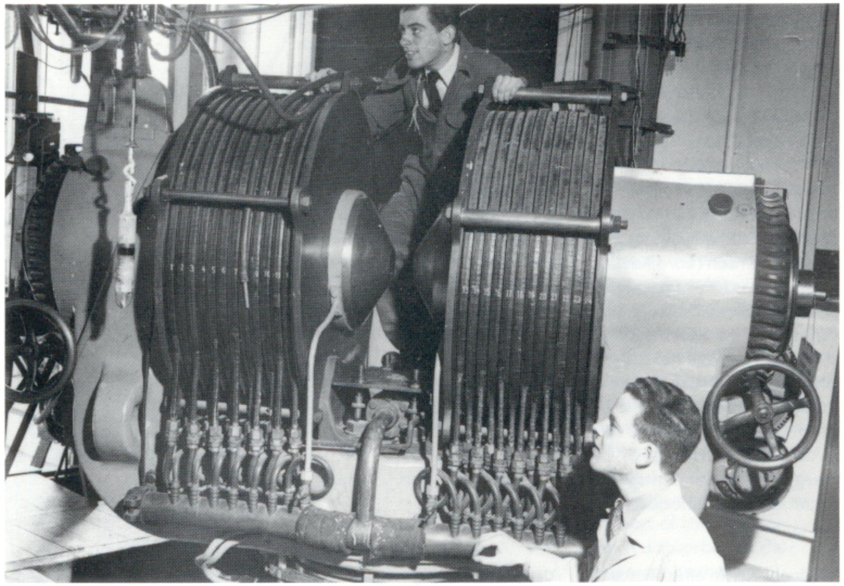
Figura 2.3. Diagrama esquemático del criostato del calorímetro refrigerado por desimanación adiabática.

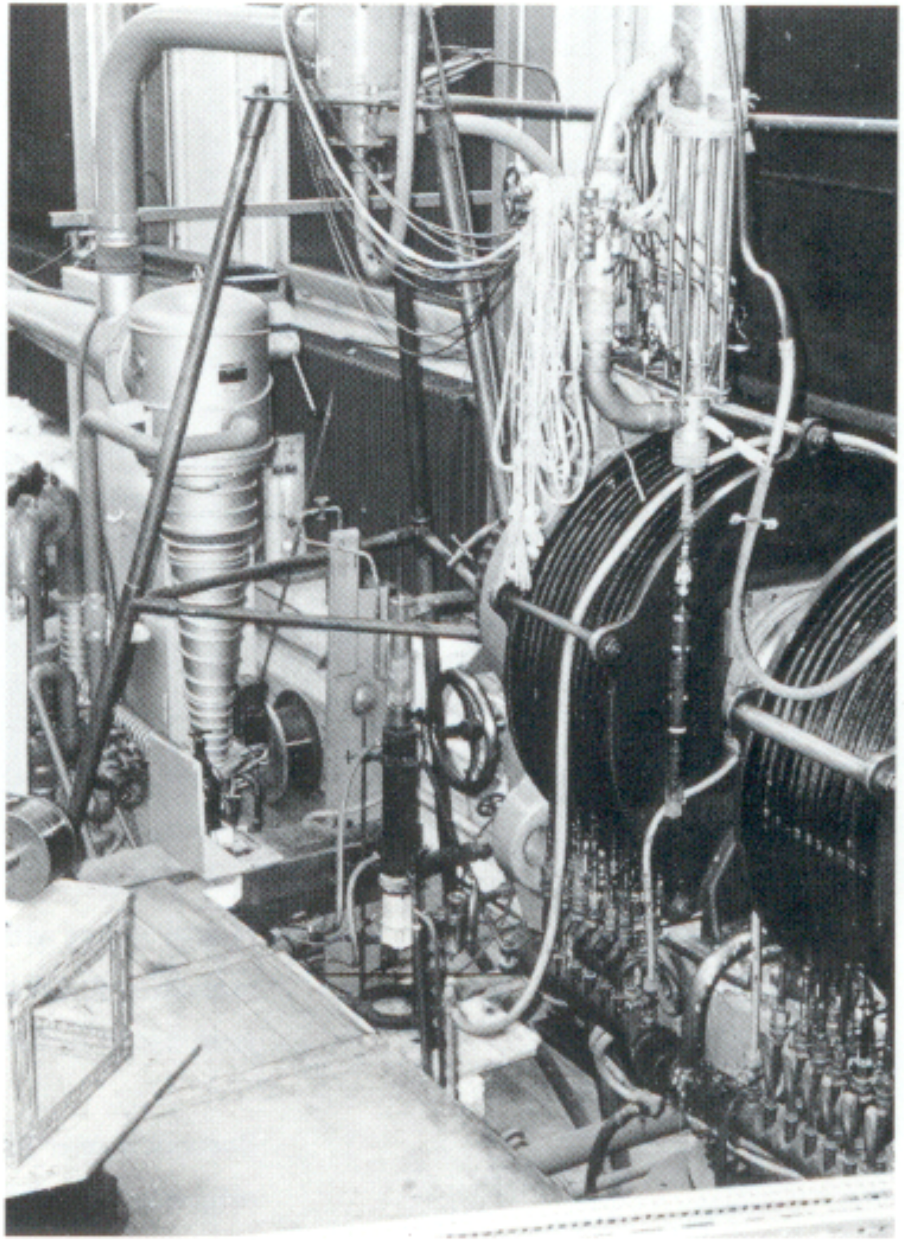


1. Soporte de madera.
2. Pesos de arena.
3. Base de corcho.
4. Criostato (ver Fig 2.2).
5. Baño de helio líquido.
6. Baño de nitrógeno líquido.
7. Bomba difusora.
8. Bomba rotatoria.
9. Vacuómetros Pirani.
10. Vacuómetro Penning
11. Válvulas.
12. Válvula milimétrica.
13. Válvula de gran calibre.
14. Válvula de tirada fina.
15. Rotatoria de gran tirada.

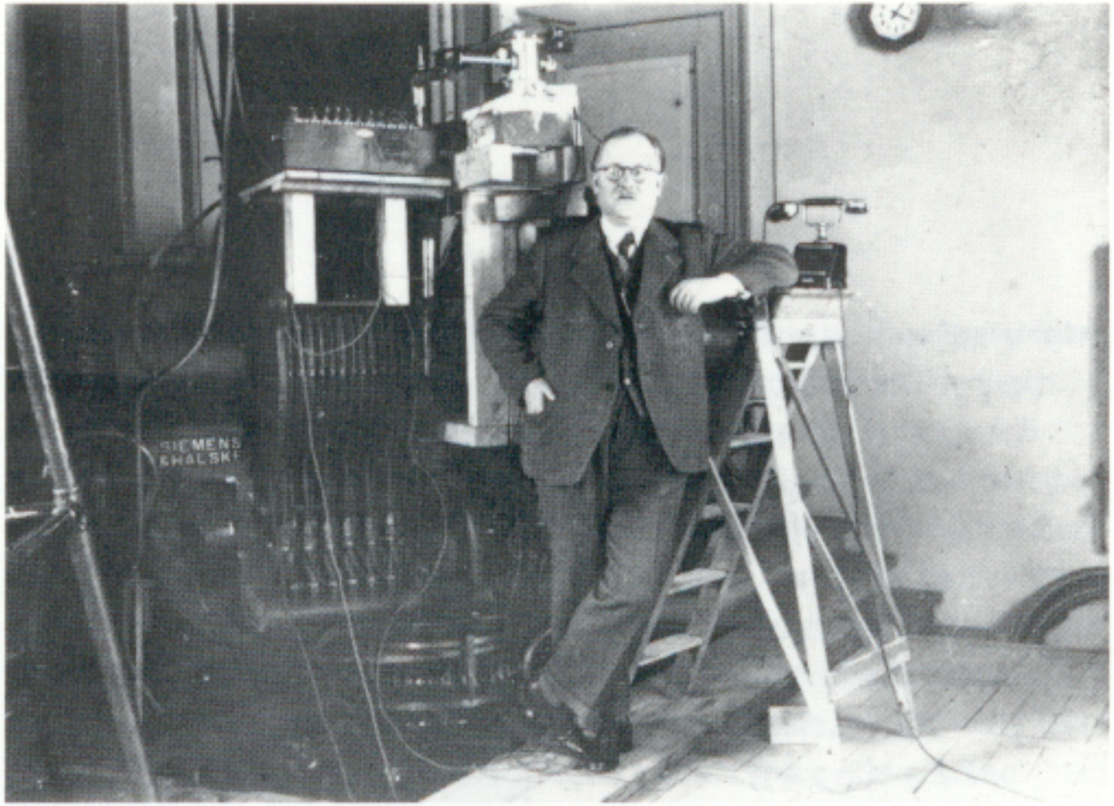
Figura 2.2. Diagrama esquemático de los sistemas auxiliares de la instalación calorimétrica.

desimanación adiabática histórica





W.J. de Haas…



W.J. de Haas with the large electromagnet

… en el
Kamerlingh
Onnes
Laboratorium

(RUL)

PHYSICAL REVIEW LETTERS

VOLUME 21 | 21 OCTOBER 1968 | NUMBER 17

OBSERVATION OF HYPERFINE-ENHANCED NUCLEAR MAGNETIC COOLING

K. Andres and E. Bucher

Bell Telephone Laboratories, Murray Hill, New Jersey

(Received 11 September 1968)

We point out the suitability of rare-earth ions in singlet ground states for the production of very low temperatures by means of nuclear adiabatic demagnetization. We have observed nuclear cooling in PrBi from an initial temperature of 0.026°K to a final temperature of 0.01°K.

Design, Manufacture, and Test of an Adiabatic Demagnetization Refrigerator Magnet for Use in Space

Steve Milward, Stephen Harrison, Robin Stafford Allen, Ian D. Hepburn, and Christine Brockley-Blatt

***Abstract*—The proposed European Space Agency (ESA) XEUS mission will use an adiabatic demagnetization refrigeration (ADR) system to cool X-ray detectors to a temperature of less than 0.1 K. The superconducting magnet for the flight standard prototype is currently under construction by Space Cryomagnetics Ltd of Culham, England. The magnet is subject to tight constraints on its mass, stray field, and power consumption. This paper describes the design, manufacture and test of the magnet.**

***Index Terms*—Cooling, cryogenics, space technology, superconducting magnets.**

I. Introduction

XEUS or X-ray Evolving Universe Spectrometer is being studied by ESA as a possible permanent space-borne X-ray observatory [1]. Grazing incidence X-ray mirrors, with

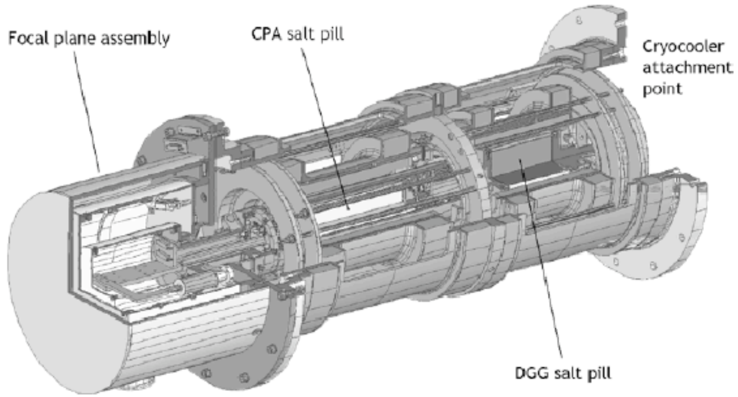


Fig. 1. Cut-away view of the ADR assembly.

TABLE I
ADR Magnet Coils Design Requirements

TABLE I
ADR MAGNET COILS DESIGN REQUIREMENTS

Requirement	Value
DGG and CPA magnets will operate independently	
CPA pill length	148 mm
DGG pill length	97 mm
Minimum field at the centre of each pill	3.0 T
Minimum field at the pill ends	2.4 T
Operating current	less than 2.5 A
Pill centre on-axis separation	222.5 mm
Minimum free bore diameter of the coil formers	62.25 mm
CPA coil to focal plane assembly (FPA) separation	167 mm
Maximum field at FPA	5 μT
Maximum field at DGG centre from CPA coils	20 mT
FPA Helmholtz pair	30 mT at 15 mT/A
Homogeneity of FPA Helmholtz pair	1 in 1000 in a 2 mm DSV[a]
Maximum stray field at a radial and axial distance of 500 mm from the coils	50 μT

[a]Diameter Spherical Volume.

A Continuously Operating Adiabatic Demagnetization Refrigerator for Cooling to 10 mK and Below

Peter J. Shirron[a] and Michael J. DiPirro[b]

[a]NASA/GSFC Code 552, Greenbelt, MD 20771, USA
[b]NASA/GSFC Code 552, Greenbelt, MD 20771, USA

Over the last few years we have developed a multi-stage adiabatic demagnetization refrigerator (ADR) that can produce continuous cooling at temperatures as low as 30 mK, and have recently begun developing additional stages that will enable operation below 10 mK. The ADR is small and compact, and expandable in terms of operating temperature and cooling power. Our prototype device uses a 4.2 K heat sink, but it can easily work with mechanical cryocoolers. Within NASA, this development supports a growing number of x-ray, far-IR and sub-millimeter astronomy missions that use cooled microcalorimeter and bolometer arrays. But the cooling technology and detectors have application in other fields such as non-destructive evaluation, quantum computing, and biomolecular mass spectrometry. Consequently, we are also designing more generic systems that provide such capabilities as cryogen-free operation, large experimental working space, and rapid turnaround, which combined with fully automated operation, make them very attractive for general laboratory use. Details of the design and operation will be presented.

Figure 2. PrCu6 sample at left; integrated with a thermal interface at right

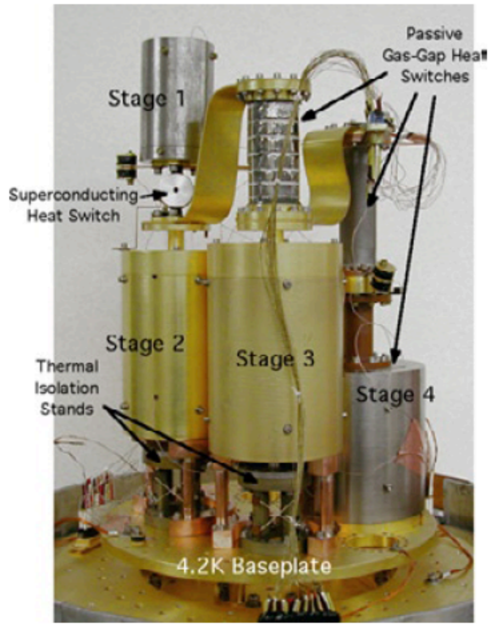


Figure 1. 4-stage CADR used as a testbed for 10 mK stages

MULTI-STAGE ADR

DESCRIPTION

Goddard has developed a new process for the formation of crystalline, hydrated magnetic salts that are used as refrigerants in our very low temperature Continuous Duty Multi-stage Adiabatic Demagnetization Refrigerator (ADR). This multi-stage ADR provides continuous cooling over a wide operating temperature range (less than ~0.1 K to above 10 K). The ADR requires these salts because they have low magnetic ordering temperatures. Traditional methods of growing these "salt pills" for ADRs involves precipitating salt out of a solution that, when cooled, becomes supersaturated. This works well for salts that have high solubility at room temperature, but the ADR uses salts with very low solubility. The process developed at Goddard uses a continuous circulation system that works with any type of salt, achieves near perfect fill fractions, and because it is automated, results in faster growth rates. Salt pills can now be manufactured in a fraction of the time previously required and at lower cost.

NASA APPLICATIONS

Multi-stage ADR:
- cooling detectors and amplifiers which operate at temperatures of 0.05 K or lower and require large cooling power
- Small, high efficiency, continuously-operating, vibration-free cooler

Crystal Growth Process:
- formation of magnetic salts for ADR

BENEFITS

Multi-stage ADR:
- Provides a greater temperature range
- No limit on its cooling life
- Continuous cooling
- Lower weight than a one-stage ADR
- Increased efficiency - requires less power and resources

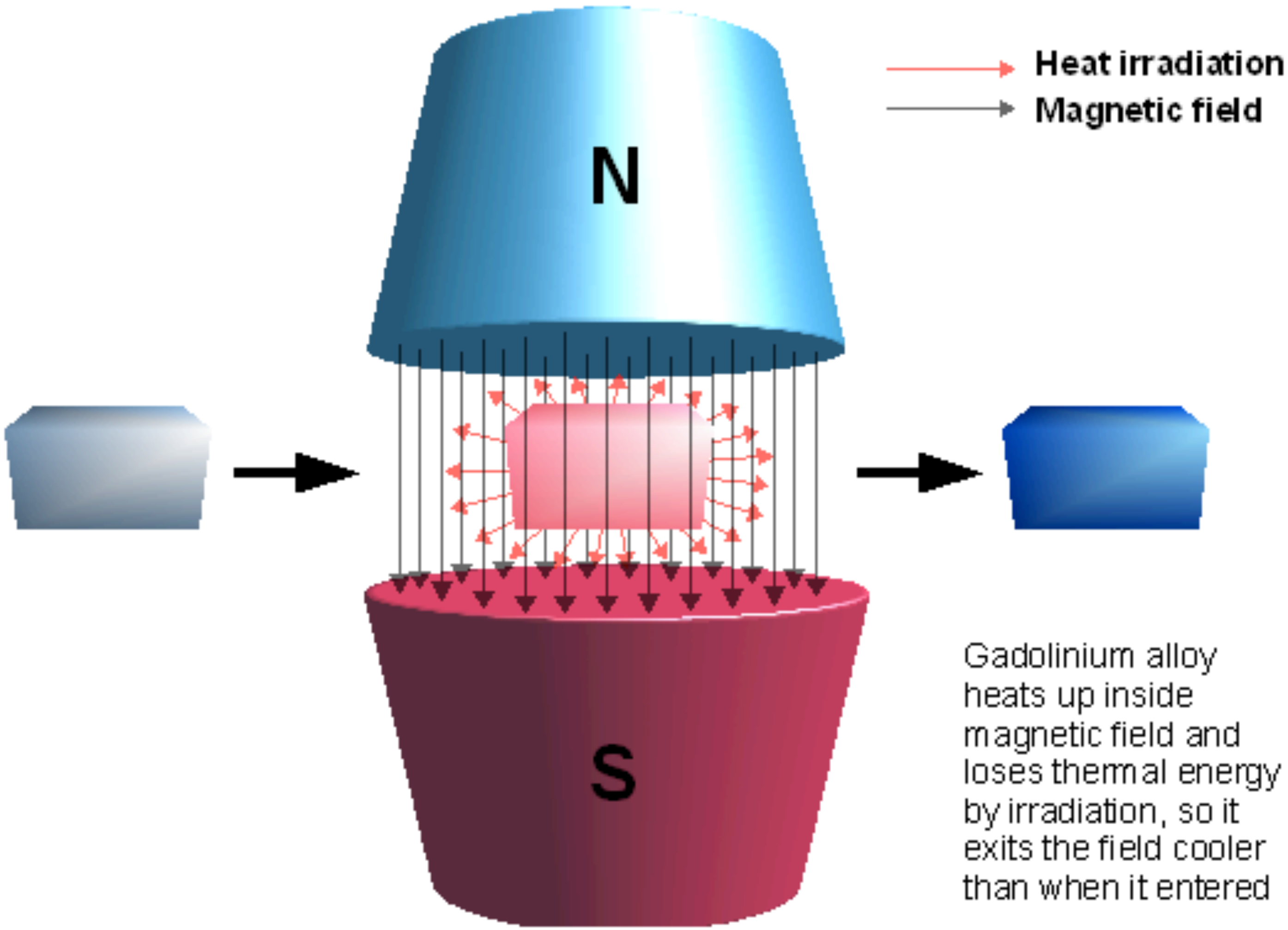
Crystal Growth Process:
- Produces large crystal grain structure
- Increases yield (relative to solid density) to near 100%
- Automated process reduces time required for growth

PARTNERING OPPORTUNITIES

This technology is part of NASA's Technology Transfer Program, the goal of which is to transfer technologies both into and out of NASA to benefit both the NASA space missions and the American public. NASA invites companies to consider opportunites for licensing, partnering or collaboration.

Email: hottechnologies@nttc.edu

Robert C. Byrd National Technology Transfer Center at Wheeling Jesuit University


Heat irradiation
Magnetic field
N
S
Gadolinium alloy heats up inside magnetic field and loses thermal energy by irradiation, so it exits the field cooler than when it entered

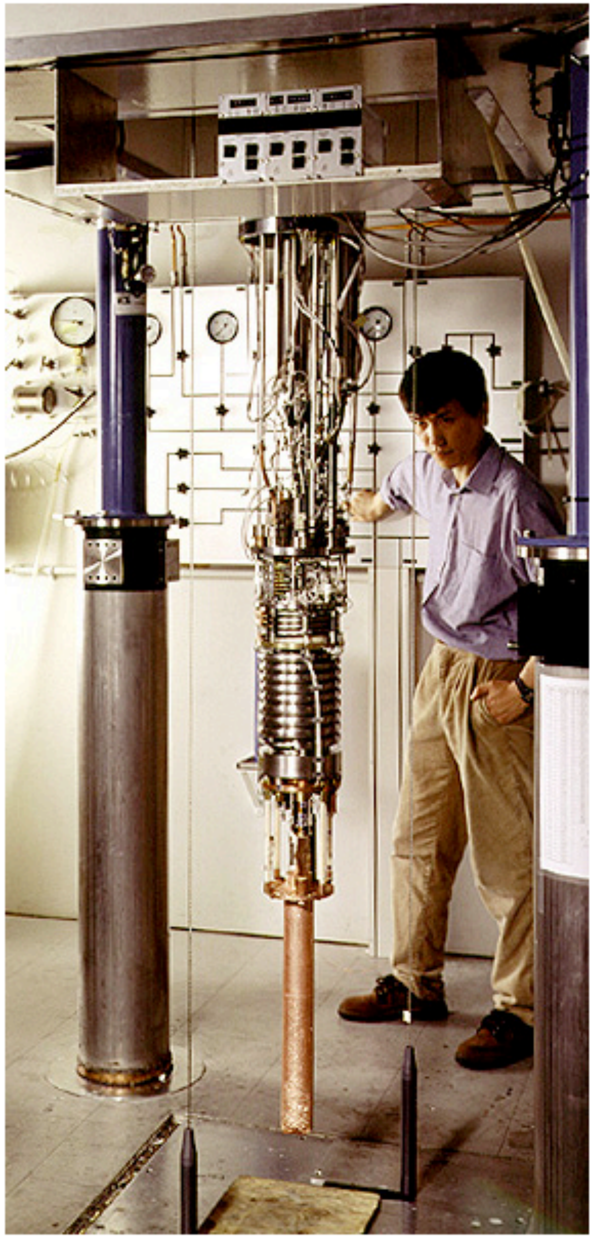
Magnetic cooling more efficient and cheaper - Astronautics Corporation of America and Ames Laboratory have successfully tested a magnetic refrigerator that operates at near room temperature - Brief Article

USA Today (Society for the Advancement of Education), June, 1997

Astronautics Corporation of America, Ames, Iowa, and the U.S. Department of Energy's Ames Laboratory have constructed and tested a fully instrumented magnetic refrigerator operating in the near-room temperature region typical of air conditioners and refrigerators for food storage. Magnetic refrigerators exploit the magnetocaloric effect -- the ability of some metals to become hot when magnetized and cool when demagnetized. Some of the major losses present in conventional gas-compression refrigerators are absent in magnetic refrigerators. Thus, it is expected that cooling systems based on this new technology can attain substantially higher efficiency than conventional gas-compression coolers.

In addition to higher efficiency and cost savings, another advantage that magnetic refrigeration systems have over conventional vapor cycle machines is the elimination, in many cases, of the hazardous materials used for heat transfer, such as chlorofluorocarbons (CFCs) and ammonia. The magnetic technology uses water as a heat transfer medium for the refrigeration temperature range and a water-antifreeze mix to reach below freezing.

Potential areas of commercial applications of magnetic cooling could include large-scale refrigeration, food processing, and heating and air conditioning; liquor distilling; grain drying; and waste separation and treatment systems. Further development of magnetic refrigeration could lead to the production of cheap liquid hydrogen, an environmentally safe and endless alternative fuel source. Magnetic refrigeration efficiently can span the large temperature difference needed to produce liquid hydrogen. Because of this great temperature difference, even a small improvement in efficiency would result in huge energy savings.



The new microkelvin refrigerator became operational in 1998. It provides a plaform for ultralow temperature experiments below 100 microkelvin in high magnetic fields up to 7 T. In 1999, the nuclei of a single crystal rhodium sample were cooled in this apparatus to the record breaking temperature of 250 picokelvin.

An adiabatic demagnetization refrigerator (ADR)is used to cool NASA-built monolithic silicon bolometers to 100mK.

The low noise optics produce a 20' beam on the sky giving us sensitivity to previously unmeasured regions of the power spectrum of the radiation.