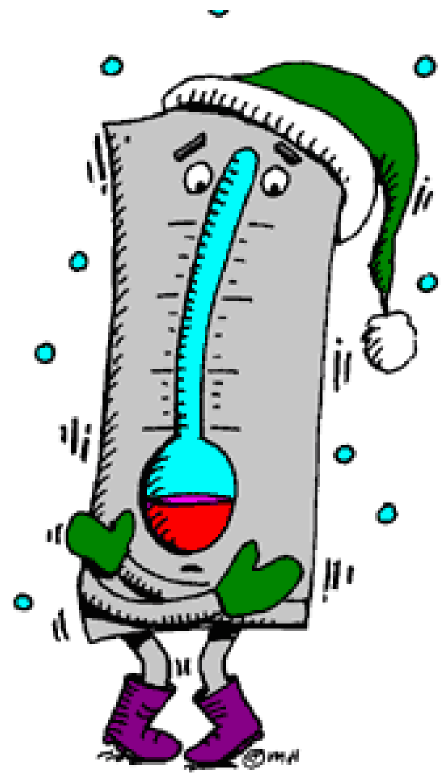
Cryo Symposium Topics

An	Wind Tunnel
Booher	Safety
Buvaev	Laser Cooling
Chadda	Helium Conservation
Cohen	Quantum Computing
Colbert	Preservation
Blank	LNG
Grange	Preservation
Jie	Quantum Measurement
Law	Surgery
Lewis	Laser Cooling
McLaughlin	Materials
Monaghan	Fermi Lab
Neff	Tuning Forks
Olmo	Cleaning
Ottens	Evanescent Heat Transfer
Paster	Strength of Materials
Radler	Laser Cooling
Sabri Dashti	Space Tanks
Teran	Cryonics
Vail	Machining
Wang	Processor
XI	Supersolid

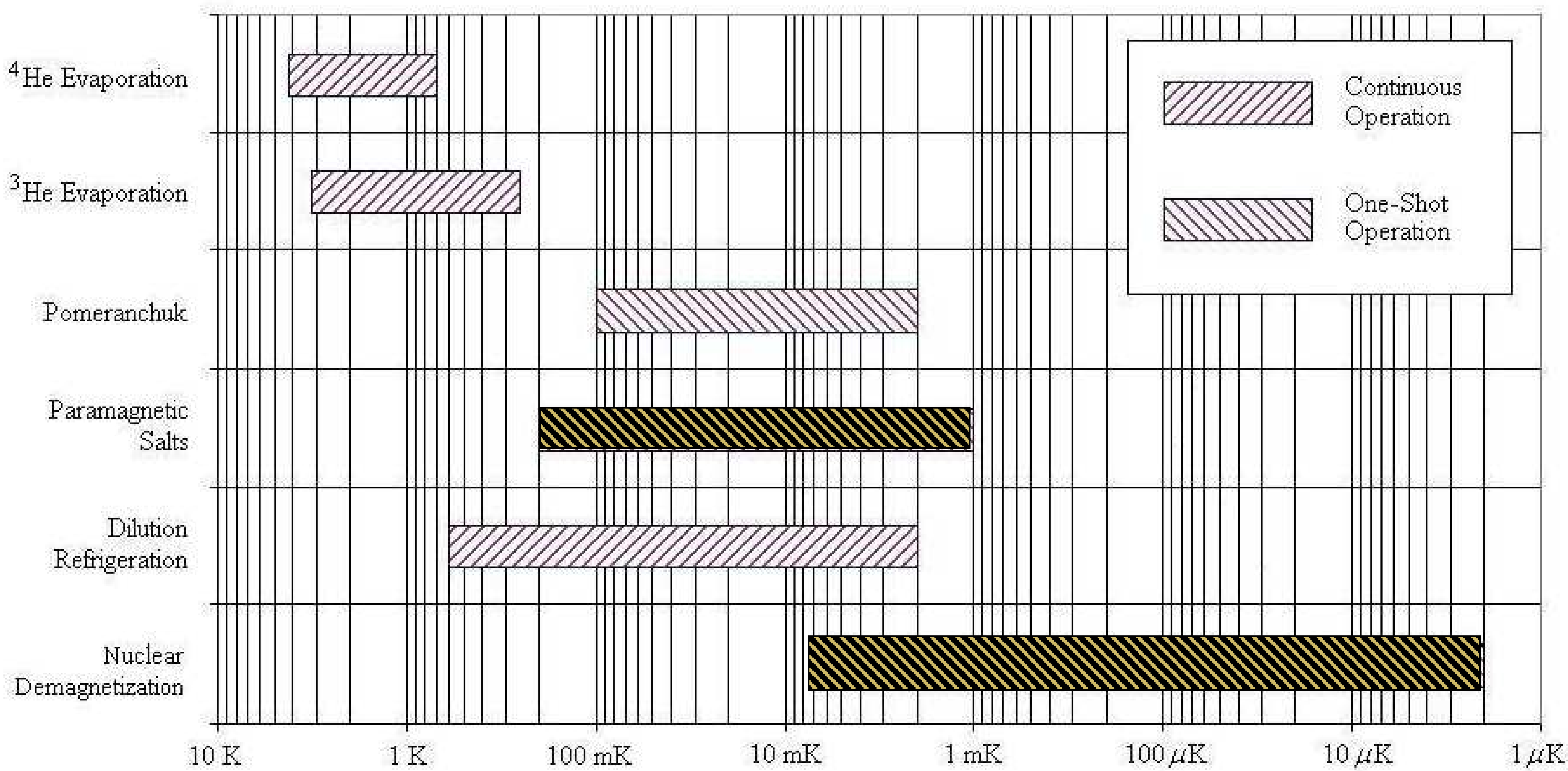
Huppert	Materials
Malin	Heat Xchangers
Prado	Presevation
Soergel	Fuels
Bosman	Telescopy
Bolin	Atom Laser

Cooling Below 4.2 K-Adiabatic Demag

1. Evaporative Cooling
2. Dilution Refrigeration
3. Adiabatic Demagnetization Refrigeration

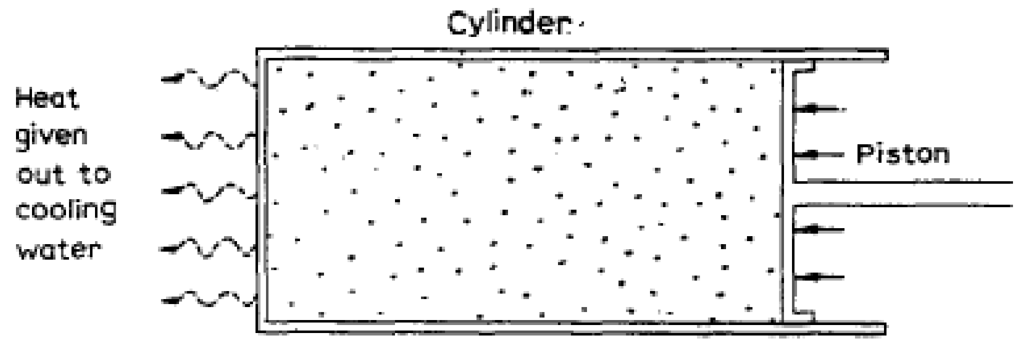


Refrigeration Methods for Very Low Temperatures

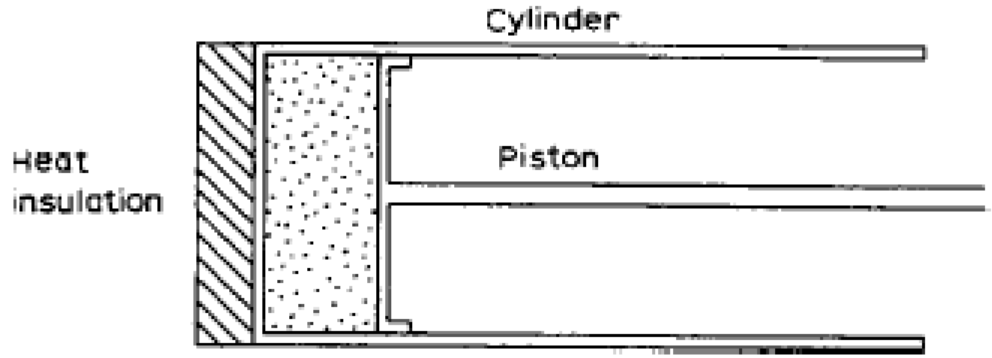


Adiabatic Decompression

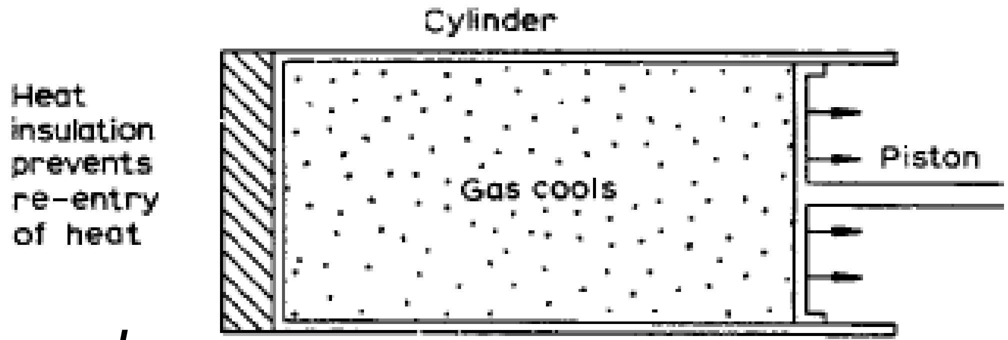
1. Compress gas isothermally



2. Insulate cylinder against the flow of heat

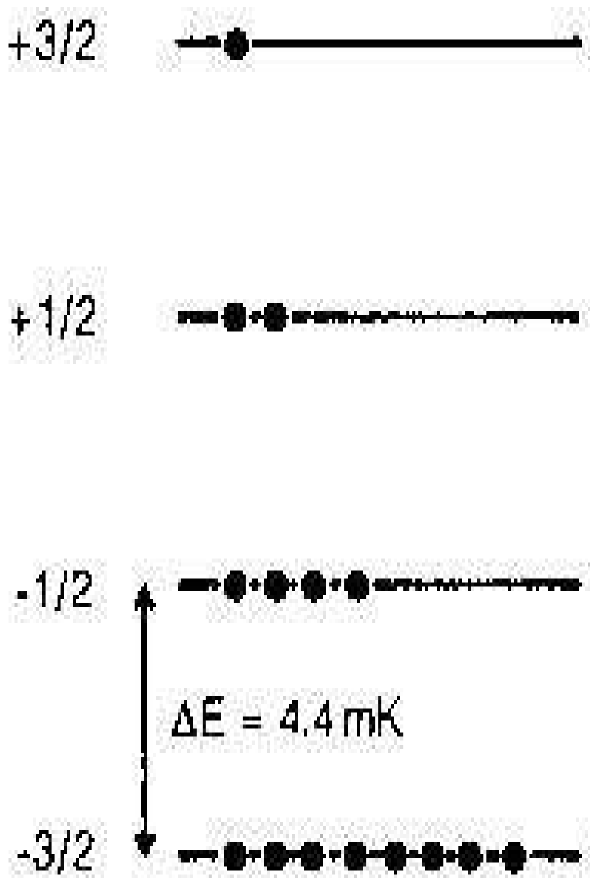


3. Allow gas to expand, mechanical work is done on piston at expense of the molecular energy, loss of energy cools gas to lower temperature



Experiment: Cooling a rubber band.

Changing the Boltzmann Distribution by deMagnetizing



$B_i = 8$ T
$T_i = 6$ mK

Adiabatic Demagnetization

The process of adiabatic demagnetization is similar to that of adiabatic decompression, except for the obvious change from decompression of a gas to demagnetization of a system of magnets.

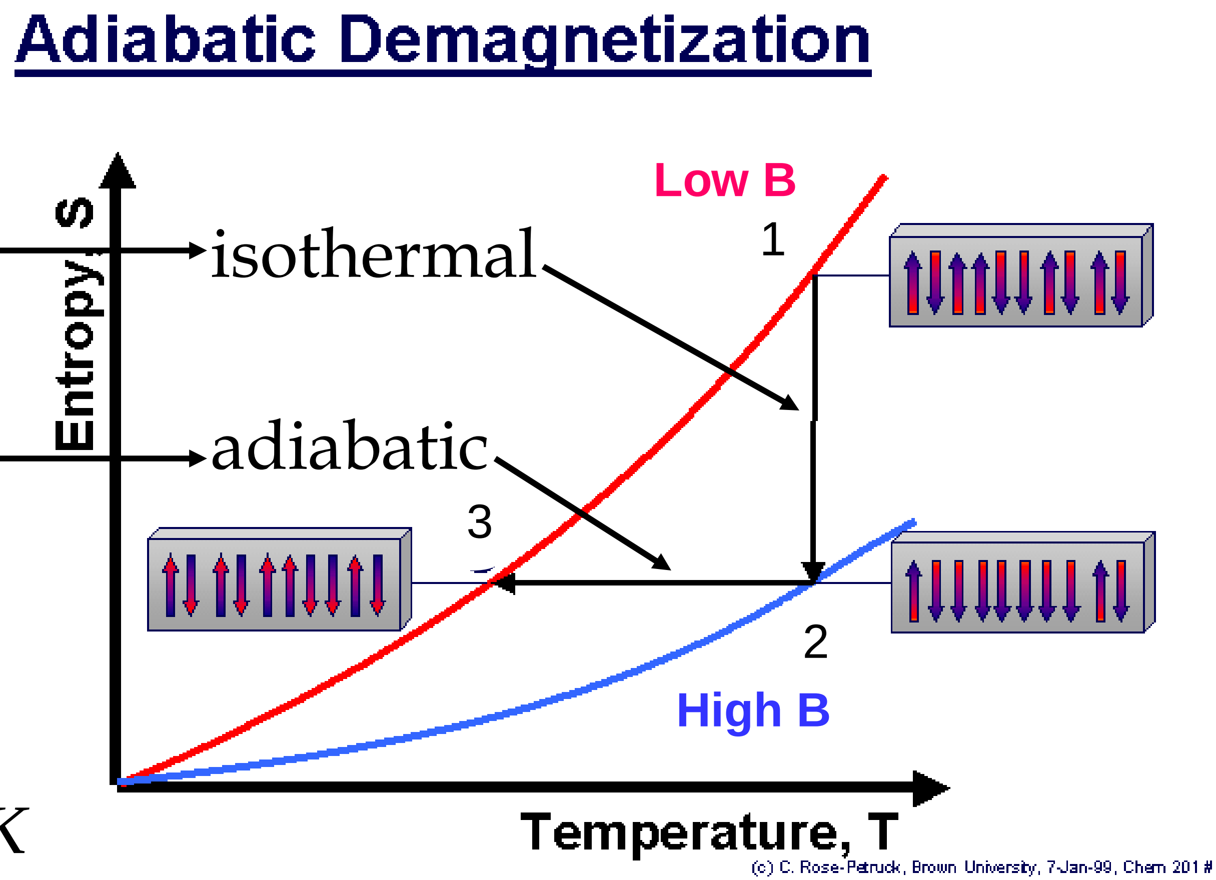
$$S = S_0 - S_B$$

$$S_1 = \frac{B^2}{T_1^2} \text{ and } S_2 = \frac{B^2}{T_1^2}$$

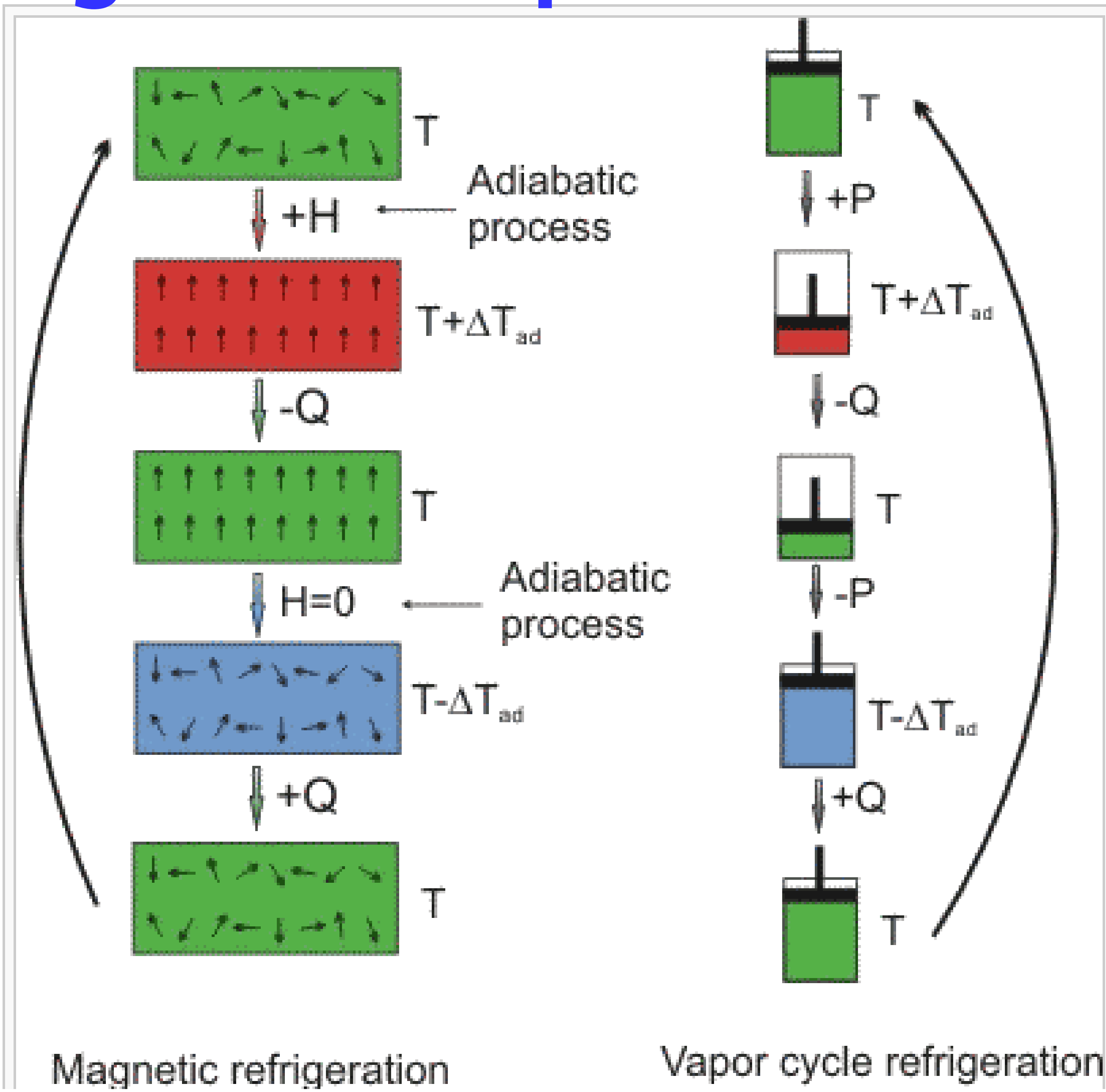
$$S_3 = \frac{B^2}{T_3^2} = \frac{B^2}{T_3^2} = S_2$$

$$\frac{B}{T_3} = \frac{B}{T_1} \text{ or } T_3 = T_1 \frac{B}{B}$$

$$T_3 = 0.01 \frac{.0001}{10} = 0.1 \mu K$$

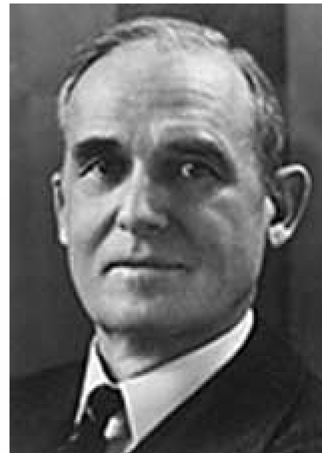


Demag and Evaporative Cooling

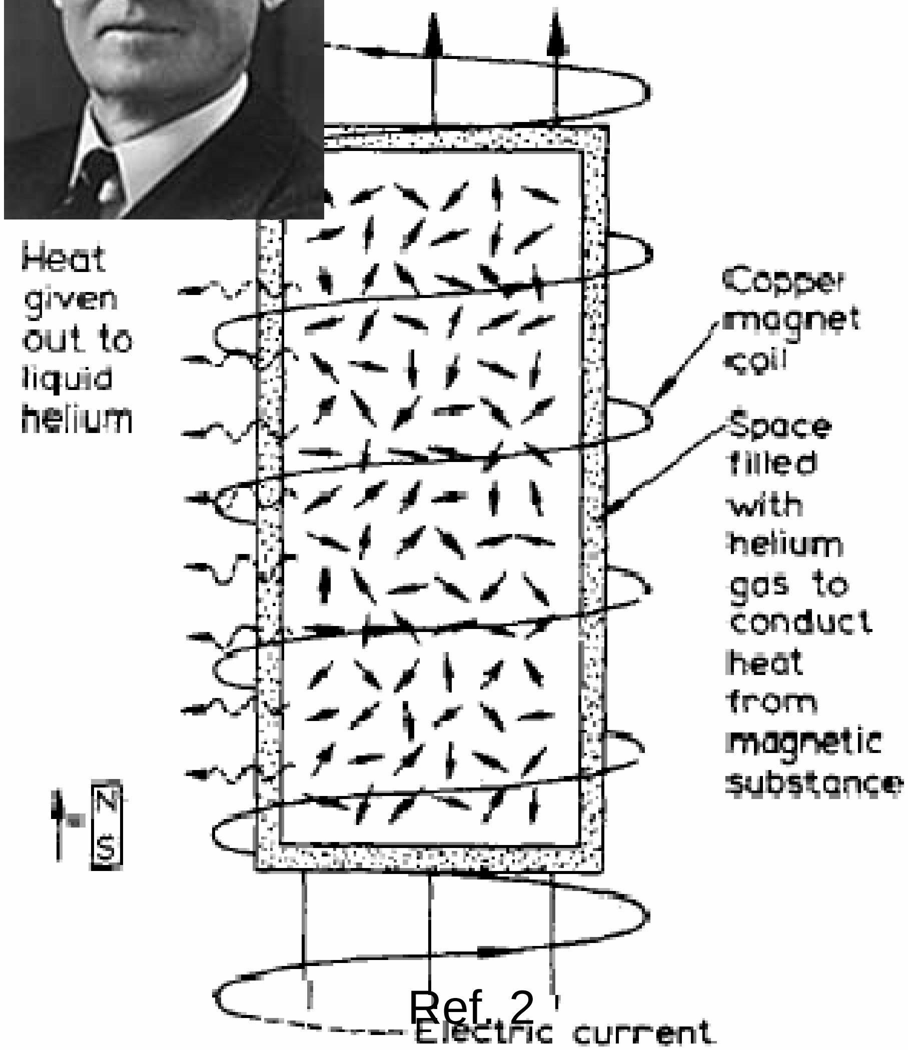


Giauque's Experiment Setup

- **Place paramagnetic salt:**
- 1. iron ammonium alum
  2. chromium potassium
- 3. Alum
- 4. cerium magnesium nitrate
- **in can filled with helium gas.**
- **Submerge case in liquid helium.**
- **Place this setup inside a solenoid magnet.**



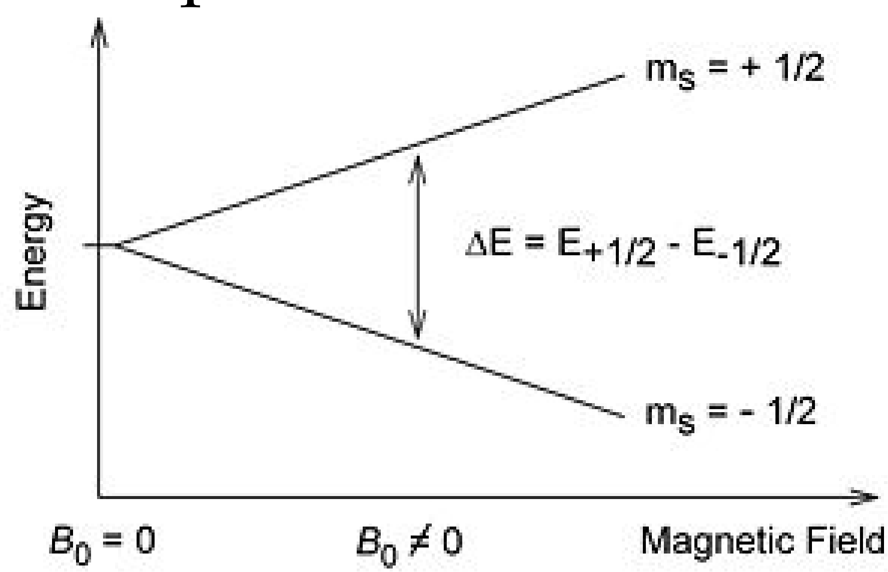
Giauque received the Nobel Prize for Chemistry in 1949

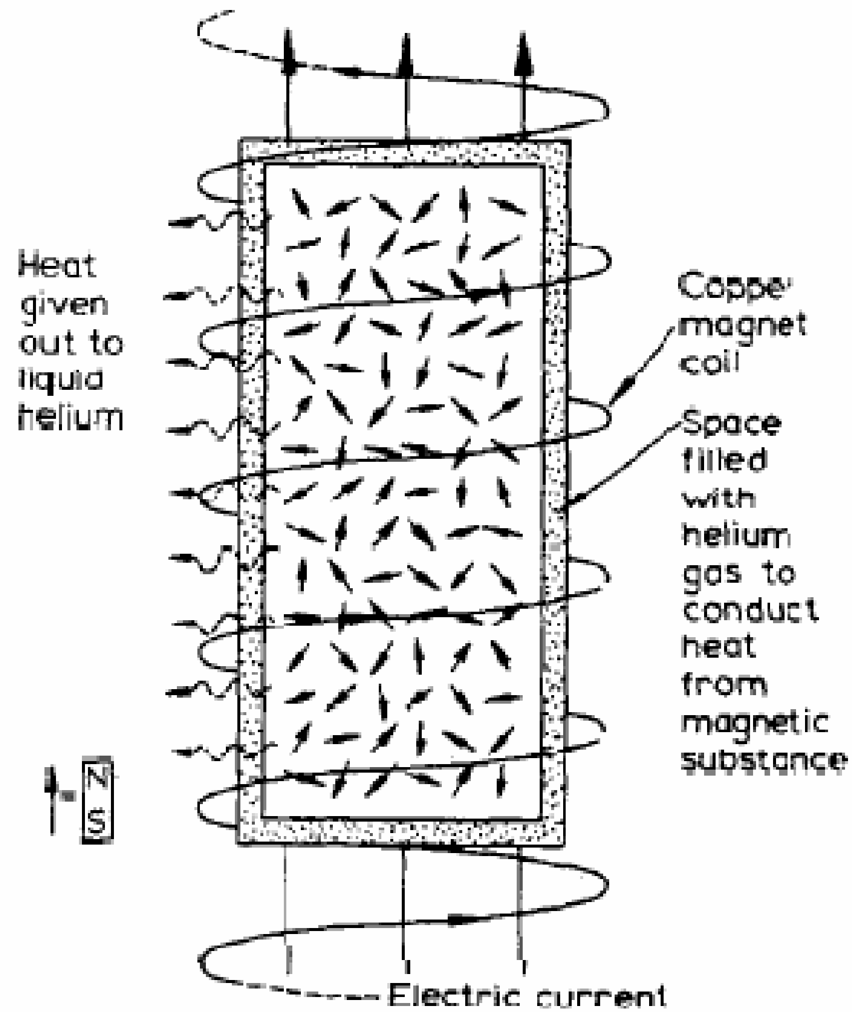


Ref. 2

Giauque's Process–Step #1

- **Increase magnetic field.**
- Entropy of spin states decreases as states align.
- Energy (heat) transferred through helium gas, keeps material at constant temperature.





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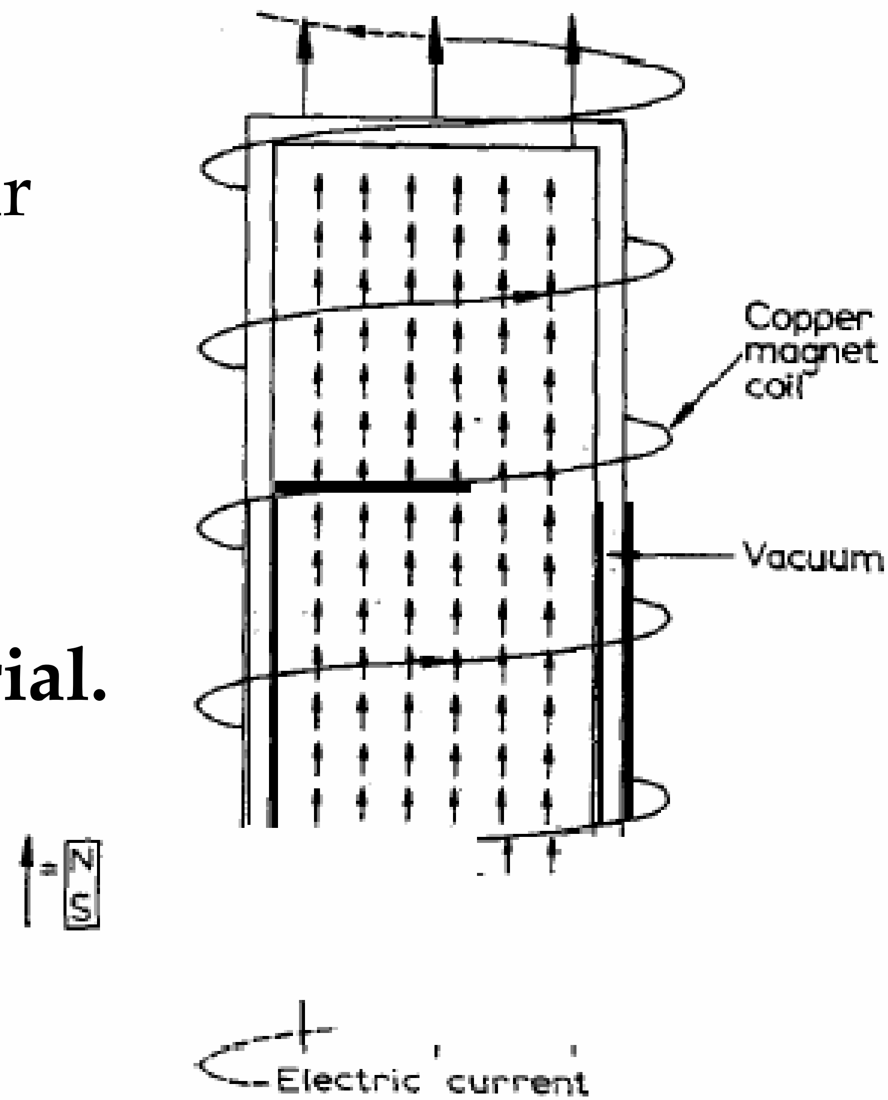
Step #2

- With magnetic field near maximum value and
- entropy near minimum value.
- **Remove helium gas to thermally isolate material.**



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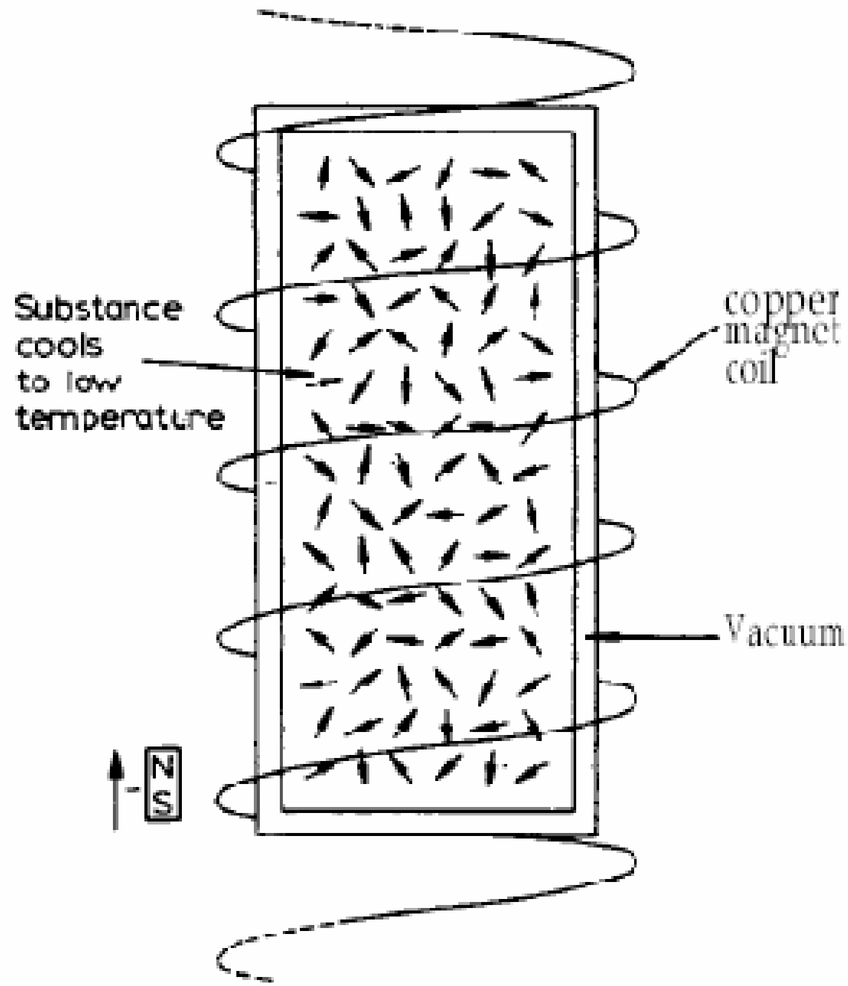
Step #3

- **Decrease magnetic field.**
- Adiabatic process
  - Entropy constant if system isolated and magnetic field slowly decreased.
- Entropy of lattice vibrations at this temperature negligible so entropy of spin states remains constant.
- However substance does magnetic work on coils of surrounding magnet.
- Work done at expense of molecular energy, thus system cools down.



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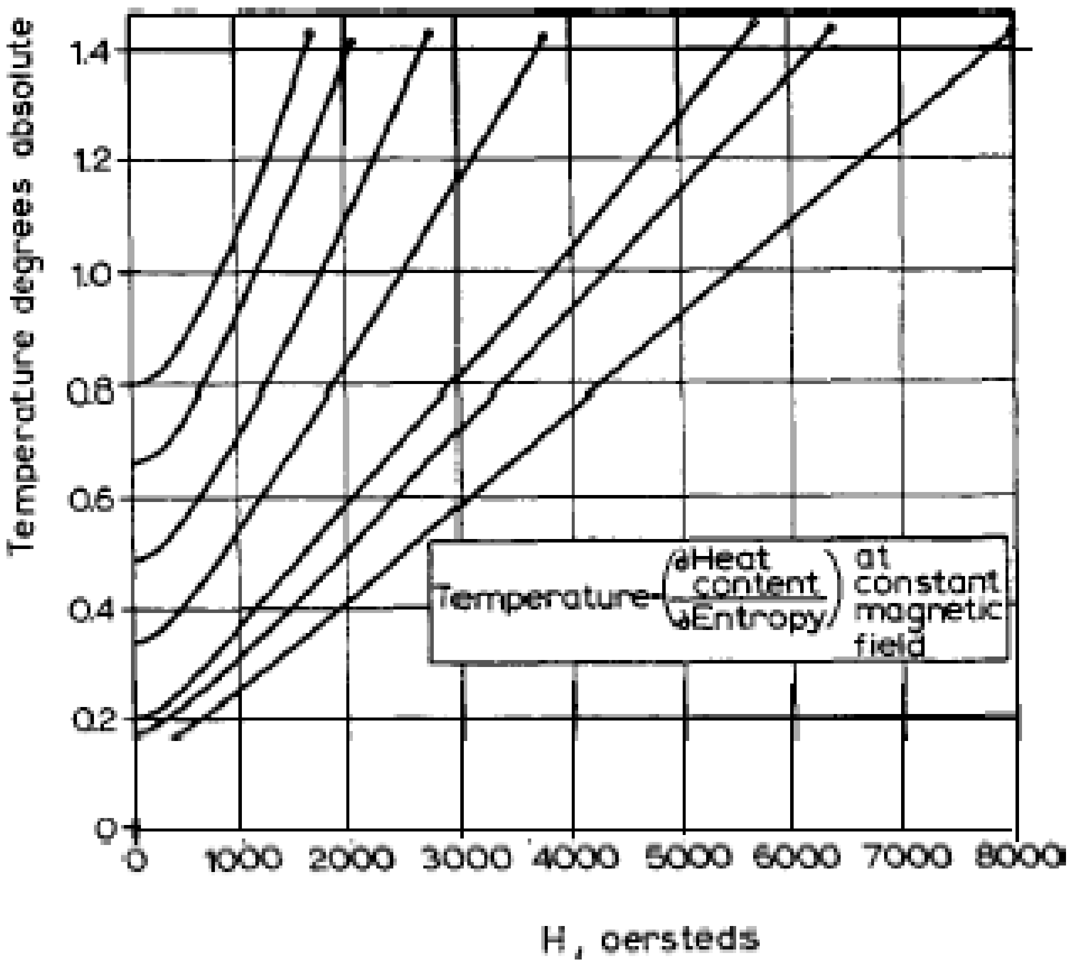
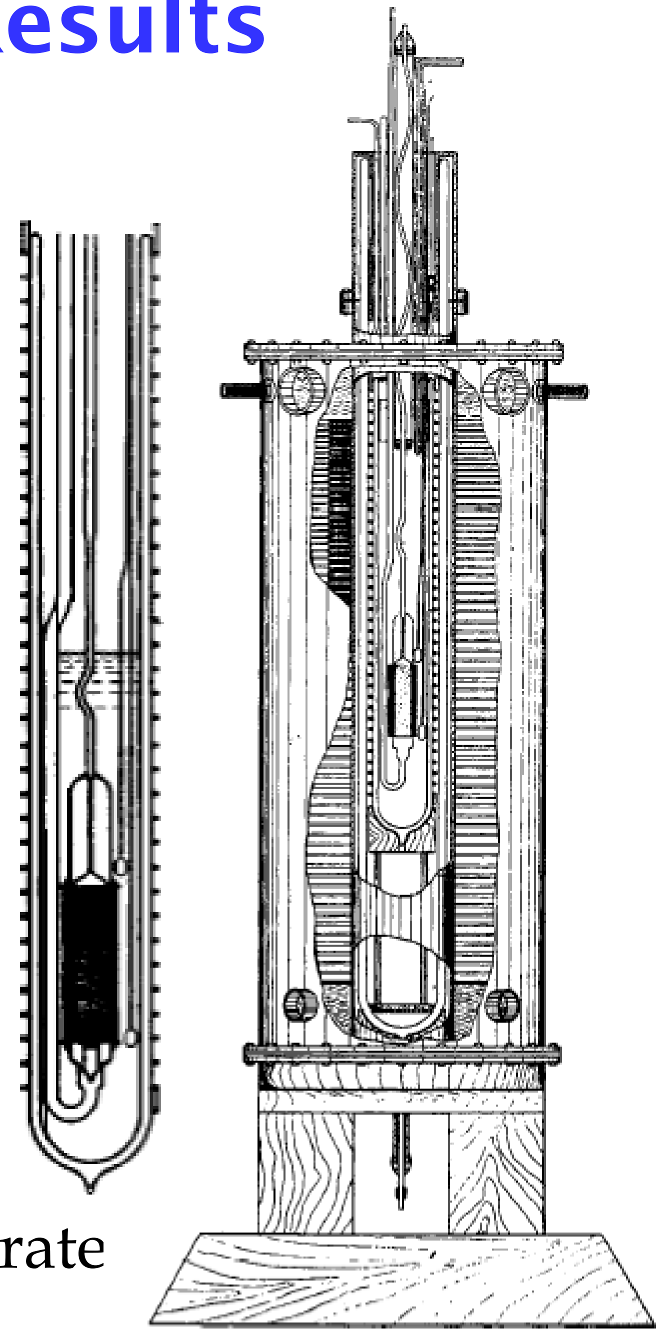
Giauque's Apparatus and Results





gadolinium phosphomolybdate tridecahydrate

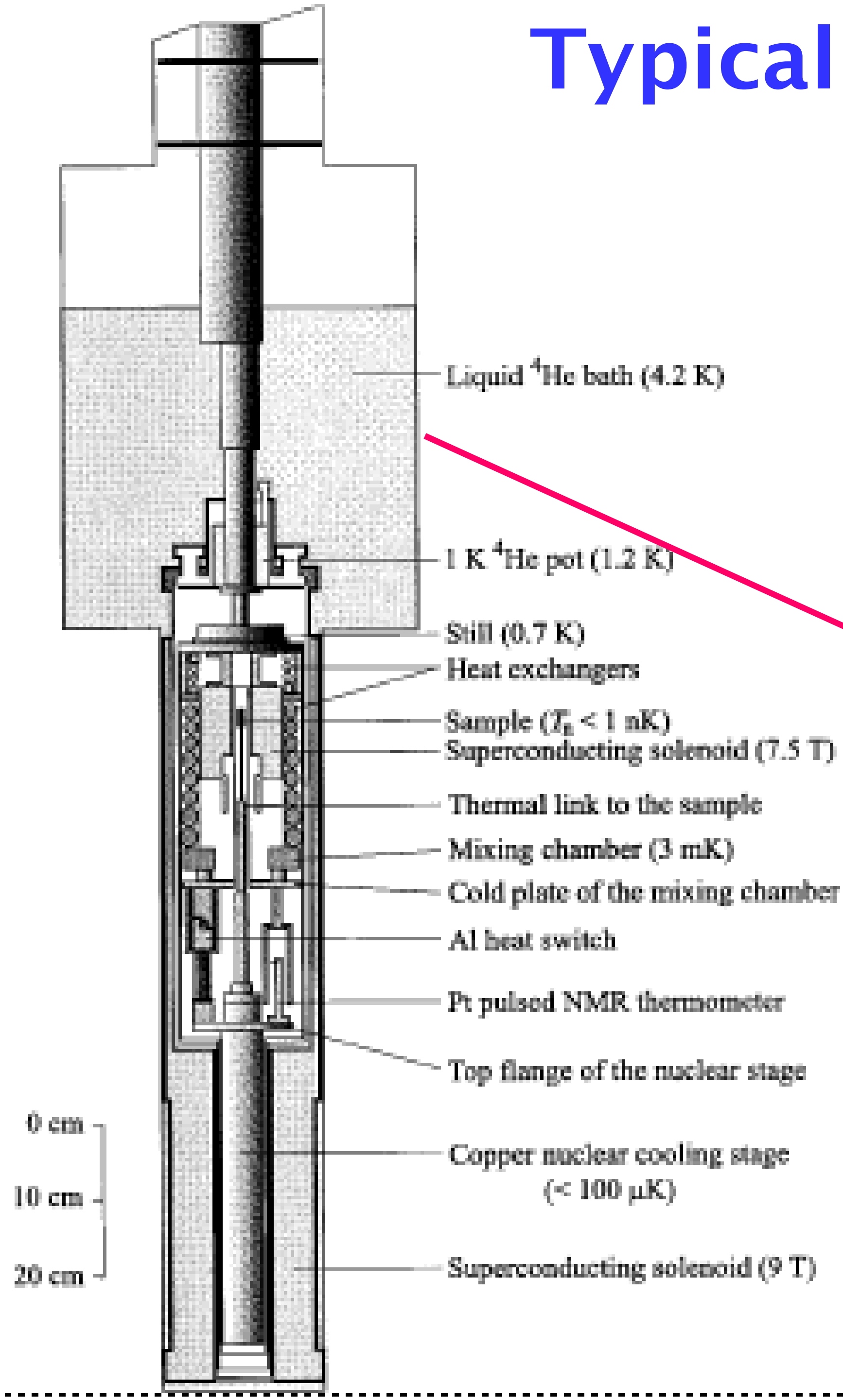
What is the magnetic entropy of a non-interacting spin system in a magnetic field B at temperature T?

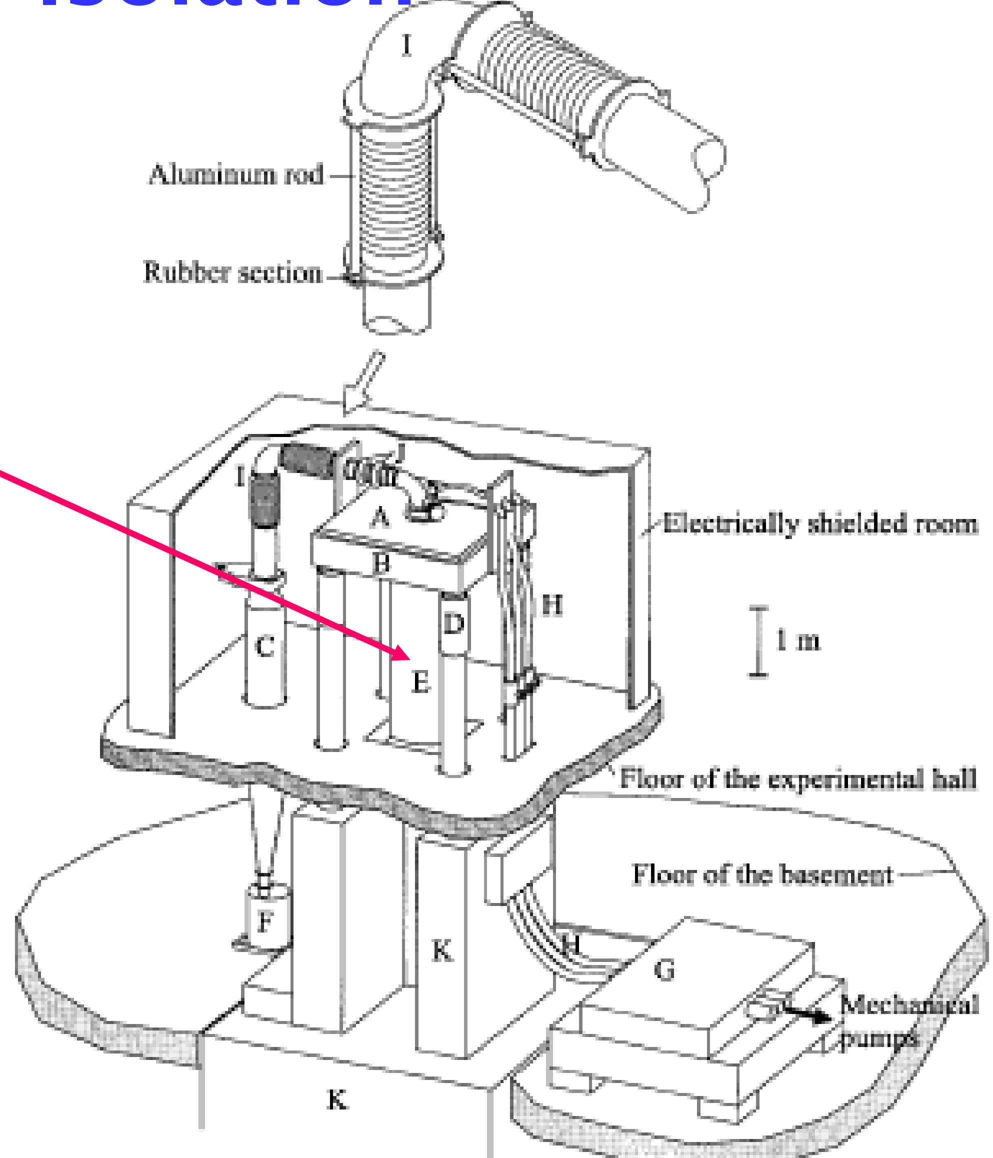
- A. $S \propto \frac{B}{T}$
- B. $S \propto \frac{T}{B}$
- C. $S \propto TB$
- D. $S \propto \ln(\frac{B}{T})$
- E. $S \propto \ln(\frac{T}{B})$

Nuclear demagnetization

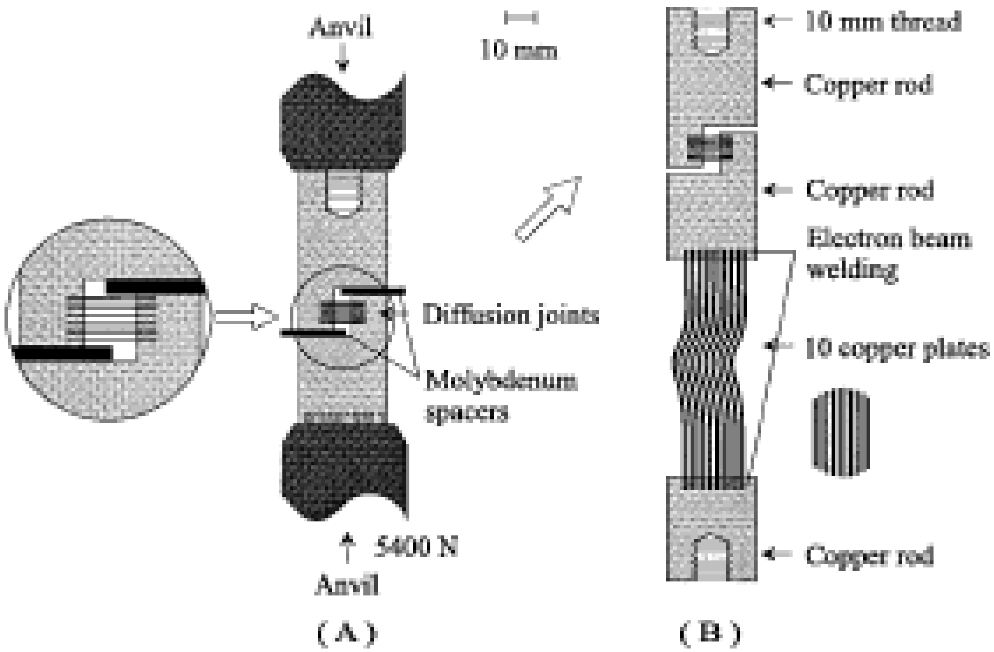
- Nuclear magnetic moments are smaller.
- Hence the nuclear magnetic interactions are much weaker than similar electronic interactions.
- First nuclear cooling experiment (1956) carried out on Cu nuclei:
- N. Kurti, F. N. Robinson, F. E. Simon, and D. A. Spohr, Nuclear cooling, Nature 178, 450 (1956).
  - Started at 0.02K-- reduced electron spin temperature to 1.2×10^{-6}K.

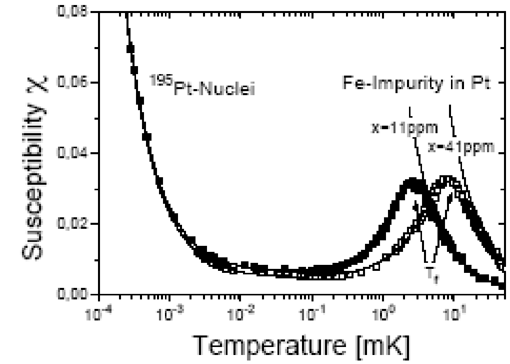
Typical Cryostat-Vibration Isolation

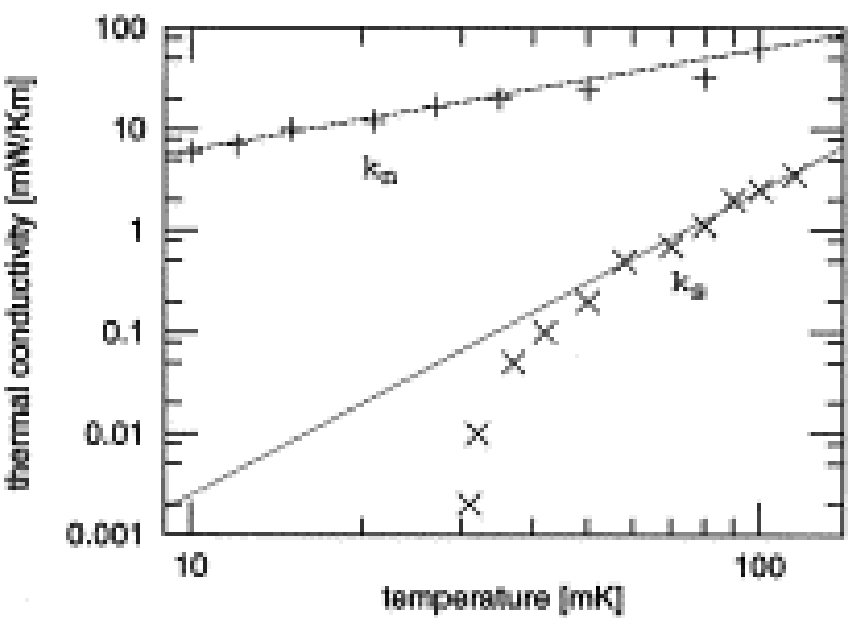


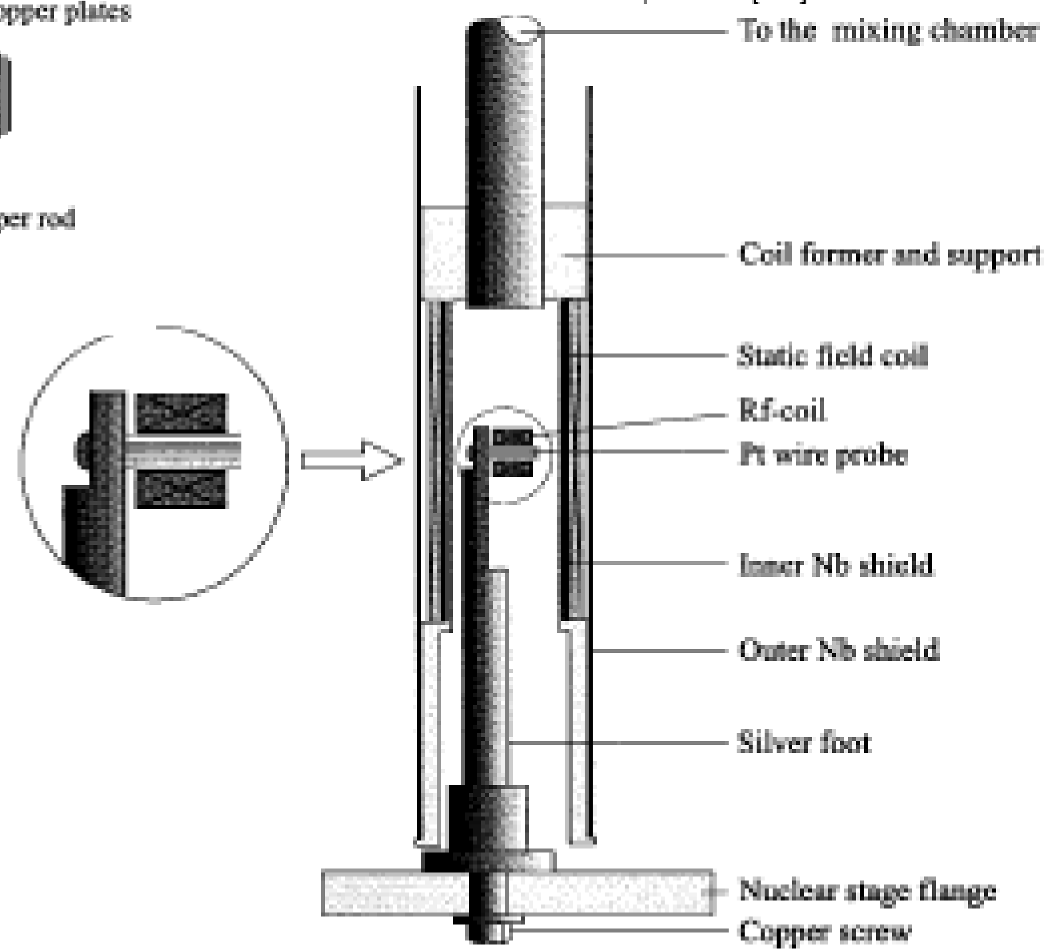


Heat Switch and Pt 195 Thermometry



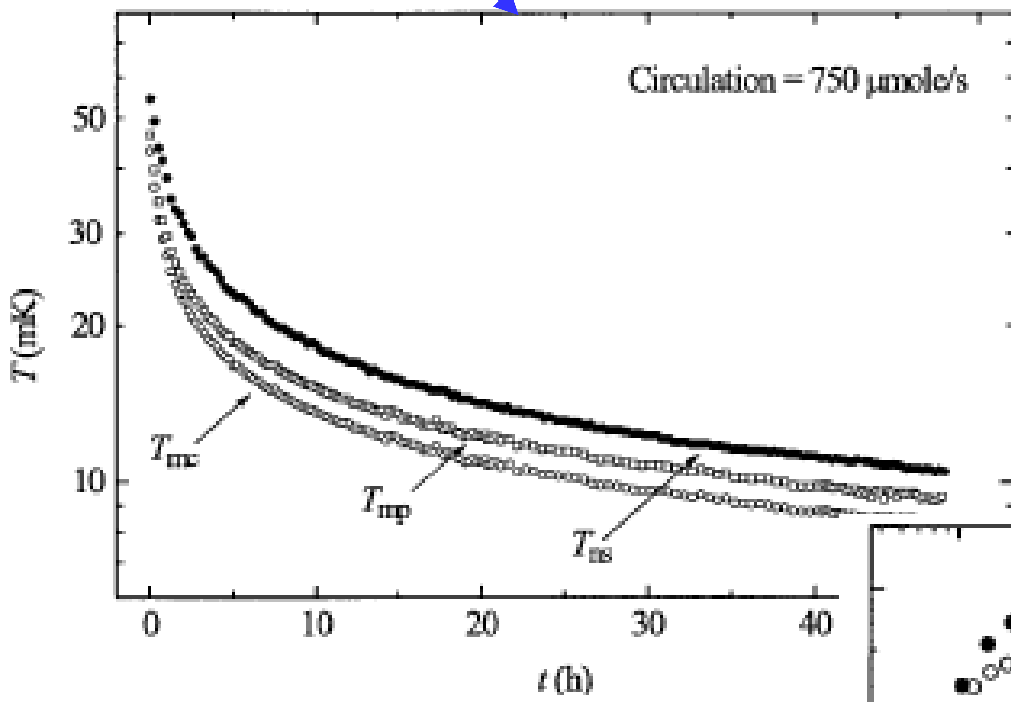


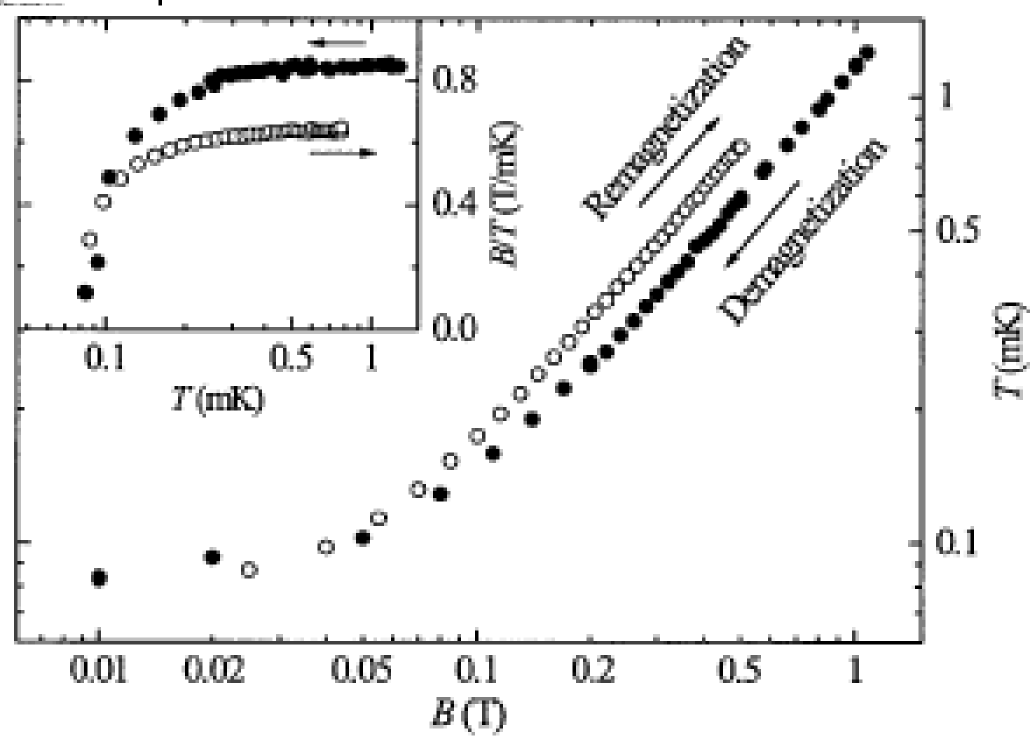




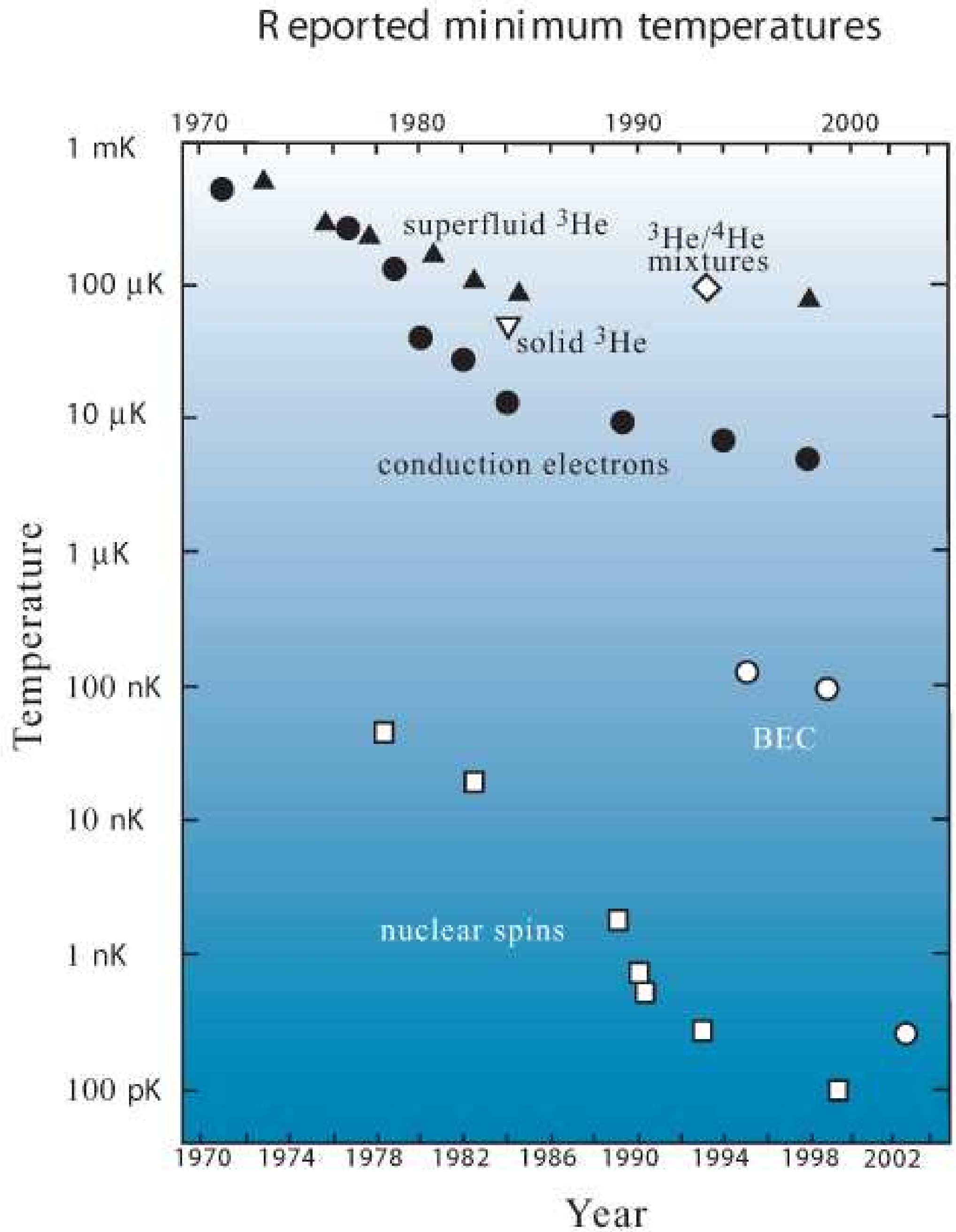
Pre-cool and

Demag and Remag





Minimum Temperatures Achieved Various Systems



References

1. William Giauque “Some consequences of low temperature research in chemical thermodynamics”. Nobel Lecture,
2. Dec. 12 1949 (work reported in 1935).

3. A Versatile Nuclear Demagnetization Cryostat for
4. Ultralow Temperature Research
5. W. Yao,1 T. A. Knuuttila, K. K. Nummila,2 J. E. Martikainen,
6. A. S. Oja,2 and O. V. Lounasmaa
7. Low Temperature Laboratory, Helsinki University of Technology, P.O. Box 2200,
8. FIN-02015 HUT, Finland
9. (e-mail: tauno.knuuttilahut.fi)

The Law

Amontons hypothesized a state devoid of heat in a paper published in 1703.

All systems in thermodynamic equilibrium at absolute zero have vanishing entropy. This principle is called the Nernst heat theorem, or. the third law of thermodynamics. Walther Hermann Nernst (1864-1941) Germany.

It is impossible reduce the temperature of any systems to absolute zero in a finite number of steps.

The Laws of Thermodynamics

There is a game.
You can't win.
You must lose.
You can't quit. (Alternate:
You can't cheat.)

What process would you use to cool a large experiment to 0.0005K?

A. Evaporatively cool ^4He
B. Evaporatively cool ^3He
C. Dilution refrigeration
D. Adiabatic demagnetize a paramagnetic salt
E. Adiabatic demagnetize nuclear spin system