Physics 451 Spring 2014: Introduction to Experiments

- Sonoluminescence
- Cavendish Balance—a study of gravity

- Nuclear Physics: Gamma Ray Spectroscopy & Muon Lifetime

- Photoelectric Effect and Determination of Plank's Constant
- Pulsed Nuclear Magnetic Resonance
- Optical Pumping
- Diode Laser Spectroscopy (Doppler-free Spectroscopy)

- Superfluidity of Liquid Helium-4
- Superconductivity and Superconducting Tunnel Junctions

Sonoluminescence

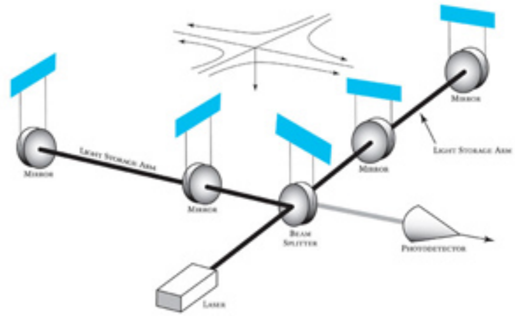
- Sonoluminescent bubble lighted with laser

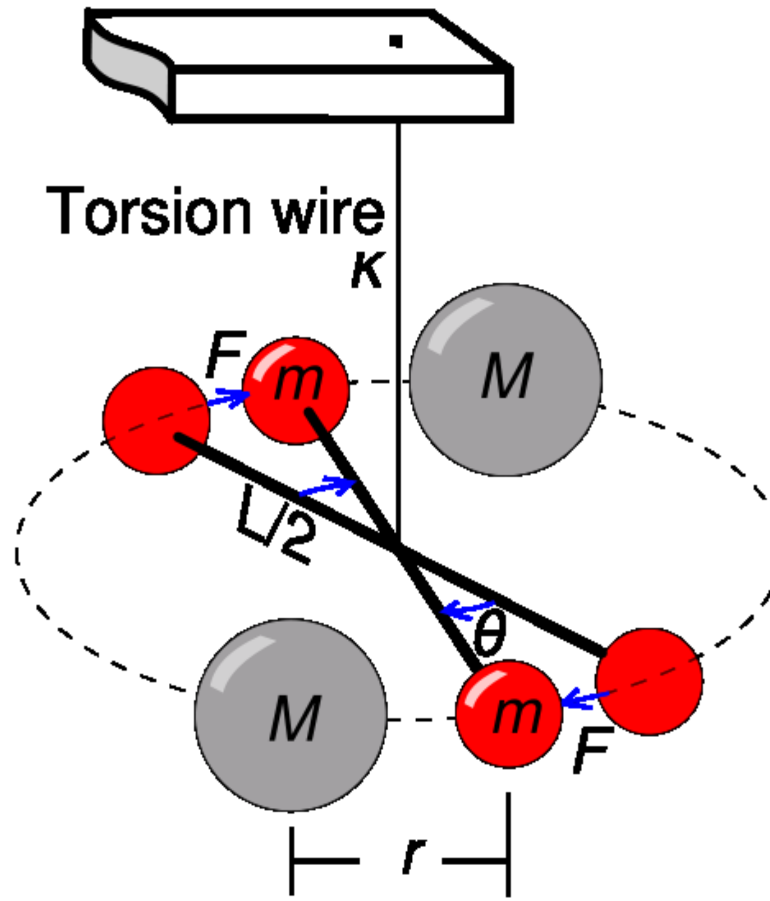
http://www.youtube.com/watch?v=3bfJploSBgM

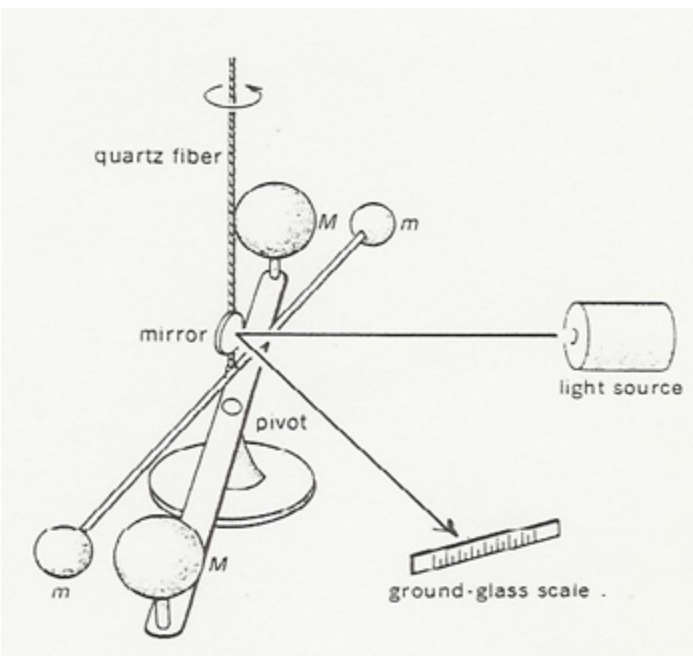
Ultrasonic levitation

http://www.youtube.com/watch?v=S4exO4CuoSU&feature=related

Cavendish Balance



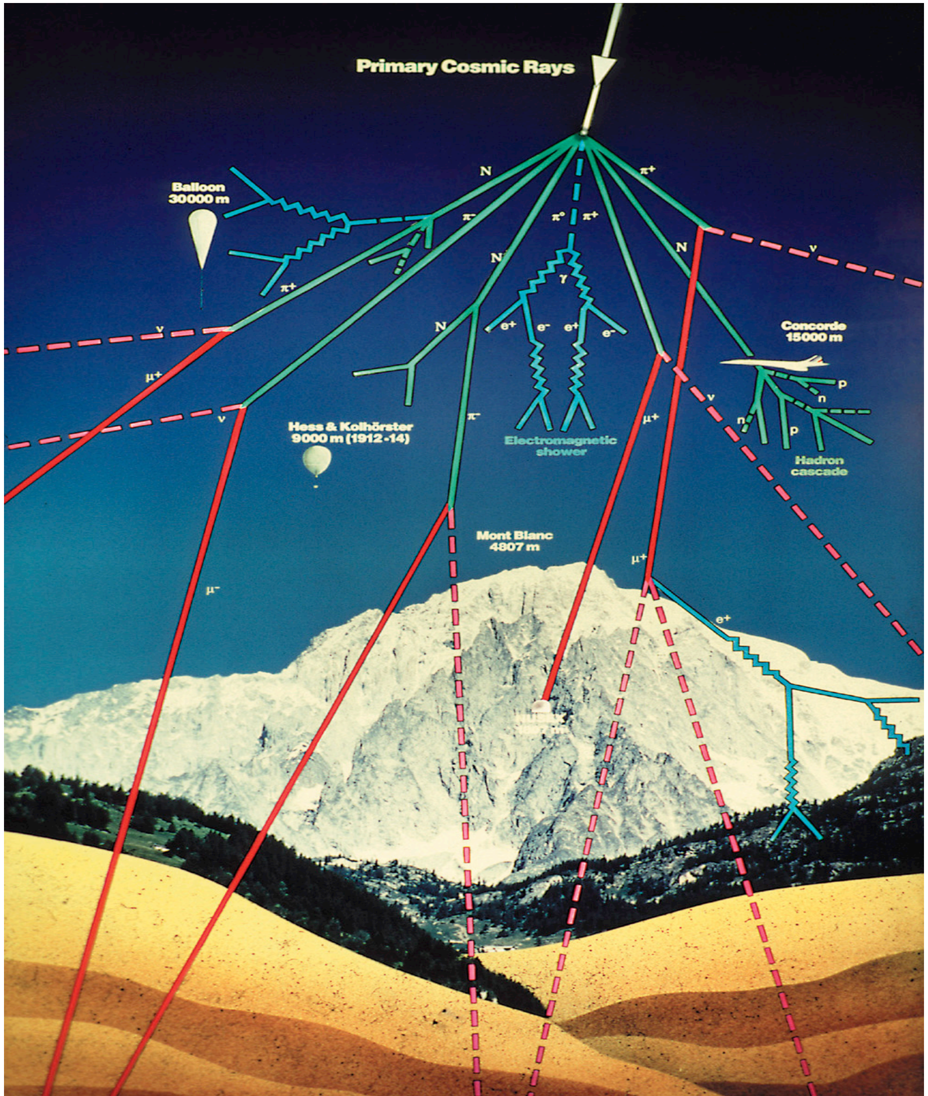




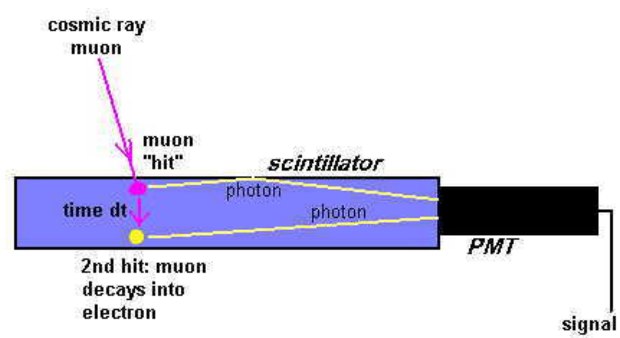
SYMMETRIC DIFFERENTIAL CAPACITIVE SENSORS (transducers)

Nuclear Physics

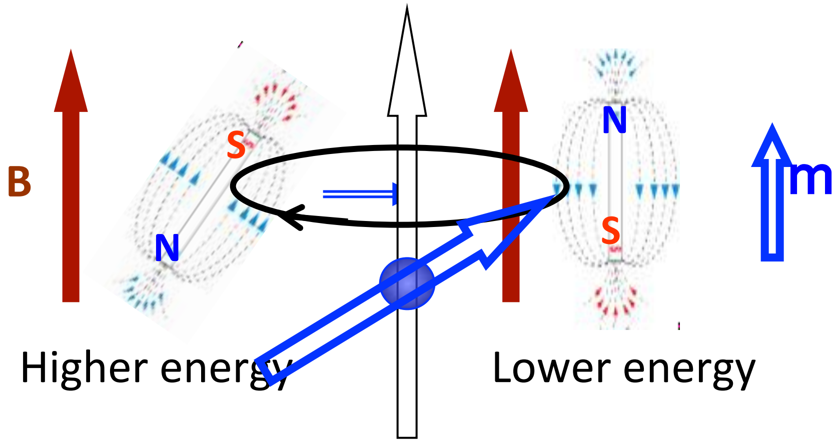
$$\mu^- \rightarrow e^- + \nu_e + \nu_\mu$$



Primary cosmic rays are particles such as protons and neutrons moving at high energies through the intersteallar medium. Locally, many of these are ejecta from the sun. When these primary cosmic rays come toward earth they encounter atmospheric nuclei at around 30,000 m above the surface. The imapacts cause nuclear reactions which produce pions. The pions decay into muons; this generally occurs at around 9000 m altitude. The muons rain down upon the surface of the earth, travelling at about 0.998c. Many decay on the way down while others reach the surface. A few of those will encounter Jeff and Ed's muon detector. These muons constitute "secondary cosmic rays" and have paths which are indicated by the red arrows on the diragram. Note that this diagram shows a "muon shower" on the Alps...such an event on the Rockies would look much the same!



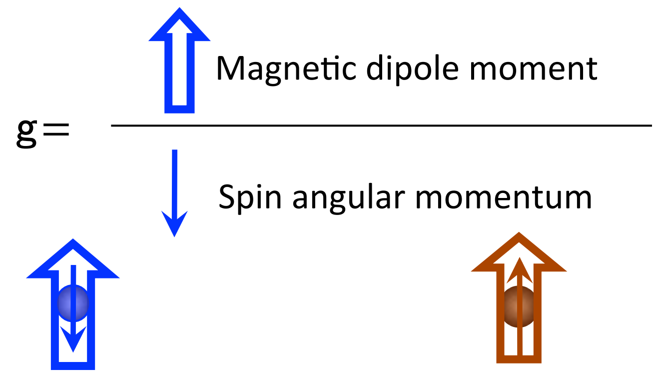
Nuclear Magnetic Resoance



$E_{mag} = -\mathbf{m} \cdot B$

$\tau = m \times B$

$w = -g B$



electron

$g_e < 0$

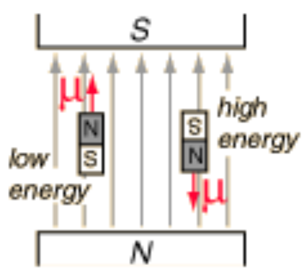
$\mathbf{m}_e = g_e S \sim 58\ meV/T$

proton

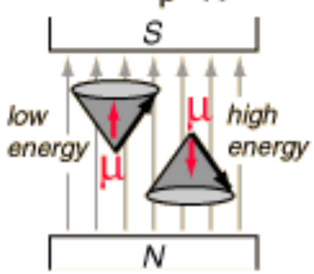
$g_p > 0$

$\mathbf{m}_p = g_p \mathbf{I} \sim 32\ neV/T$

$\mu = g_p \mu_N$



Bar magnet magnetic moment

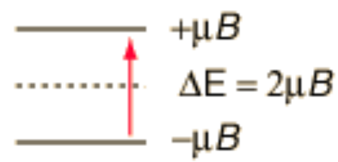


Proton spin magnetic moment

$g = 2.79$

$\mu_N = 3.15x10^{-8} eV/T$

B=1Tesla



$$\Delta E = 2\mu B = 2 g_p \mu_N B$$

$$\Delta E = 2 \cdot 2.79 \cdot 3.15x10^{-8} eV/T \cdot 1T$$

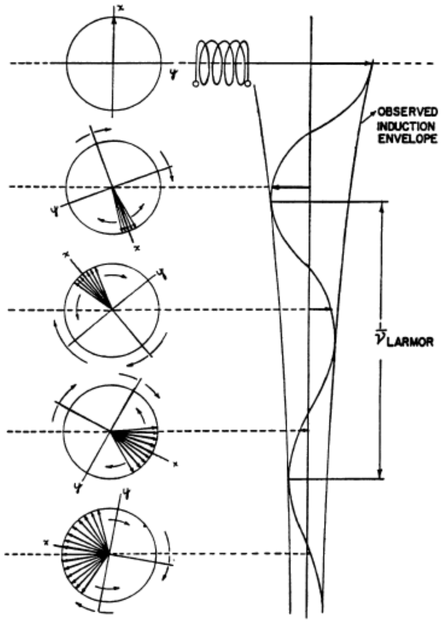
$$\Delta E = 1.76x10^{-7} eV$$

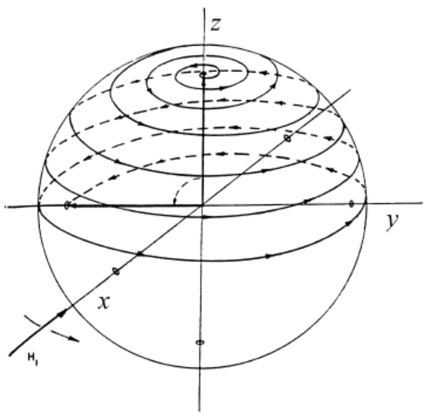
kT~25meV@300K

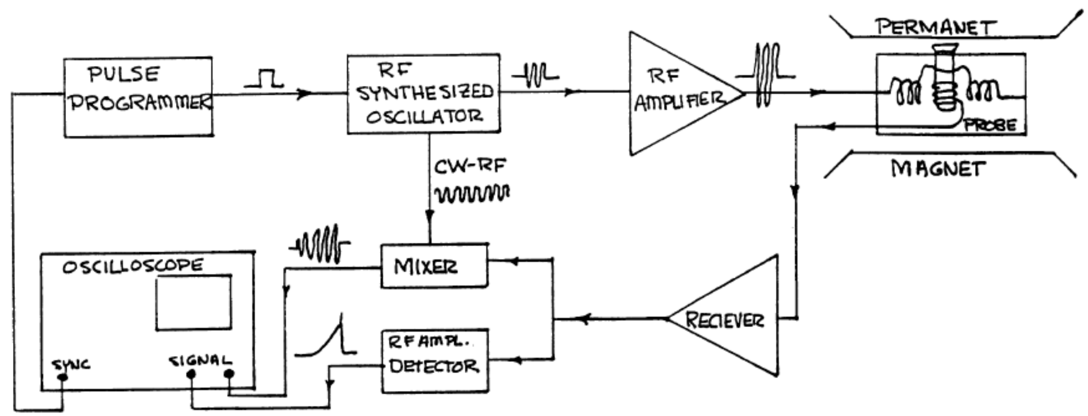
$$e^{\frac{-\Delta E}{kT}} \cong 1 - \frac{\Delta E}{kT} = 1 - \frac{1.76x10^{-7}}{0.04} = 1 - 4.4x10^{-6}$$

High filed
Low temperature
Paramagnetic ions

Pulse NMR Experiments

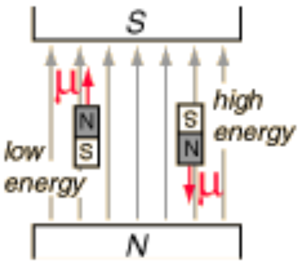




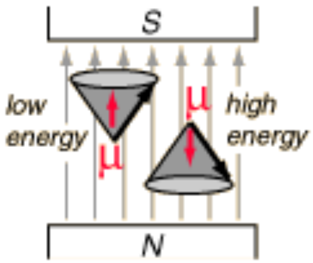


Nuclear spin and Hyperfine interaction

$\mu = g_p \mu_N$



Bar magnet magnetic moment



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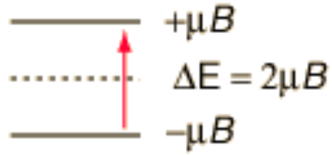

$$\Delta E = 2\mu B = 2 g_p \mu_N B$$

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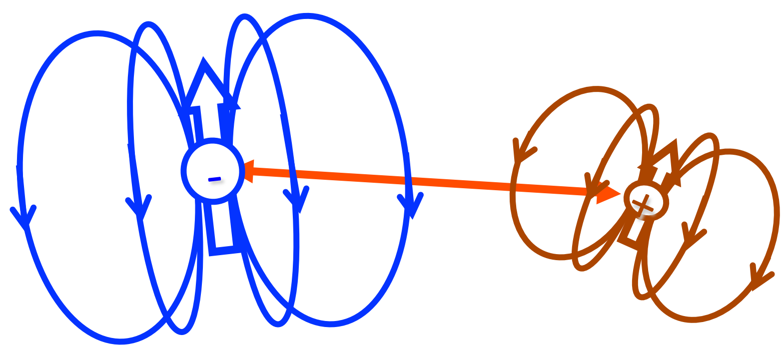
kT~25meV@300K

$$e^{\frac{-\Delta E}{kT}} \cong 1 - \frac{\Delta E}{kT} = 1 - \frac{1.76x10^{-7}}{0.04} = 1 - 4.4x10^{-6}$$

High filed
Low temperature
Paramagnetic ions

Isotope/Atom	^{85}Rb	^{87}Rb	^{23}Na
Natural abundance	**72.2%**	**27.8**	**100**
Nuclear spin	$I = {}^{5}/_{2}$	${}^{3}/_{2}$	${}^{3}/_{2}$
Magnetic moment	$m_n = +1.35 m_p$	**+2.75**	**+2.22**

$m_e/m_p \sim g_p/g_e \sim m_e/m_p \sim 10^3$



Hyperfine interaction

What is optical pumping?

$$\frac{n_1}{n_2} = exp^{\left(\frac{E_2 - E_1}{kT}\right)}$$

$$k = 8.62 \times 10^{-5} \text{ eV K}^{-1}$$

kT~0.03eV@300K
First excited state ~ 2eV

The Boltzmann factor is therefore
which implies that only about one a
is in an excited state at any given m

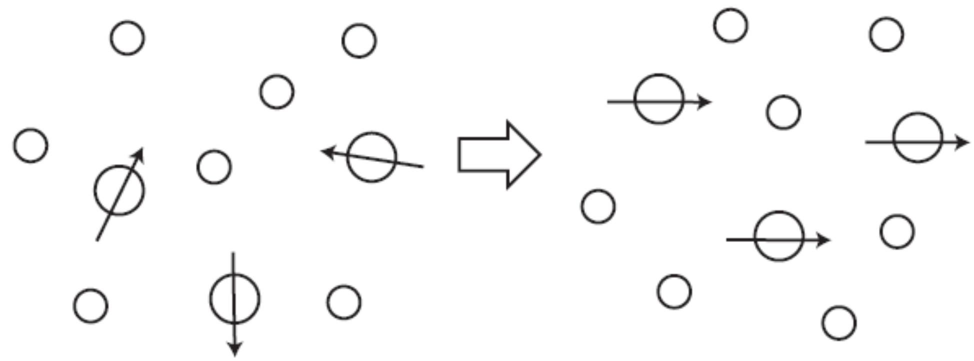


Figure 1: Optical pumping can be used to polarize a gas of atoms that have magnetic dipole moments. In practice, these atoms are often mixed with a nonpolar *buffer gas*, which helps keep the polarized atoms from touching with the walls of the container and losing their polarization.

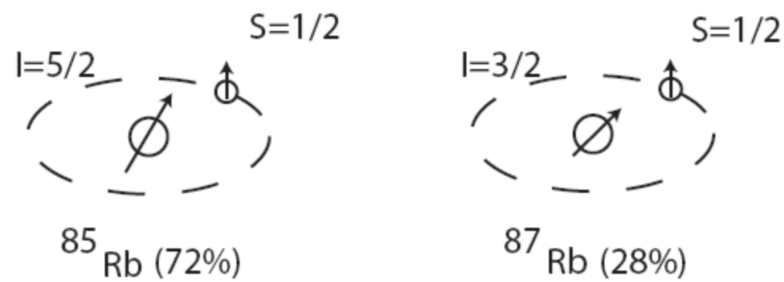
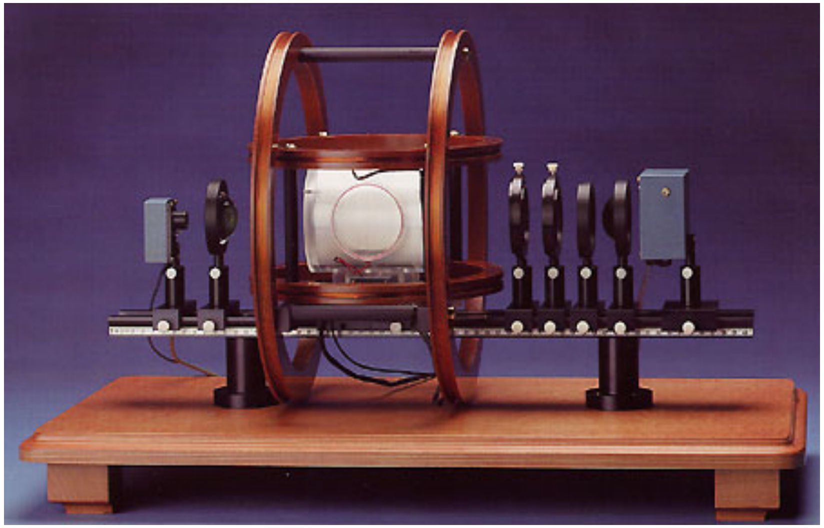
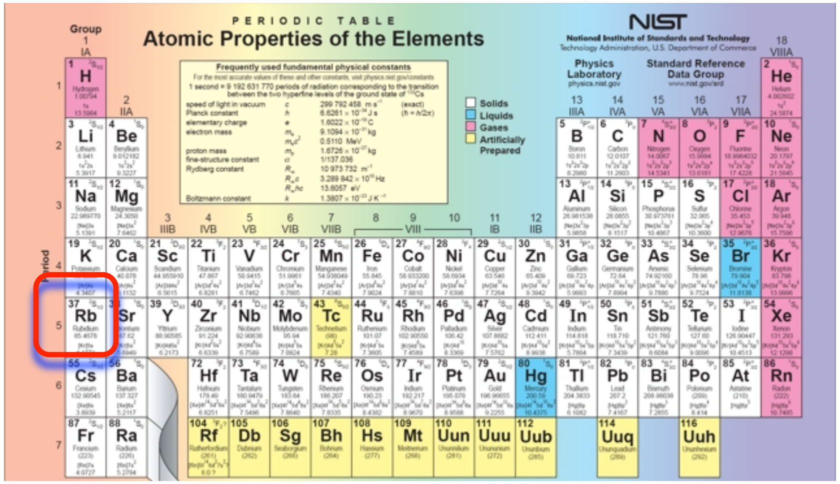
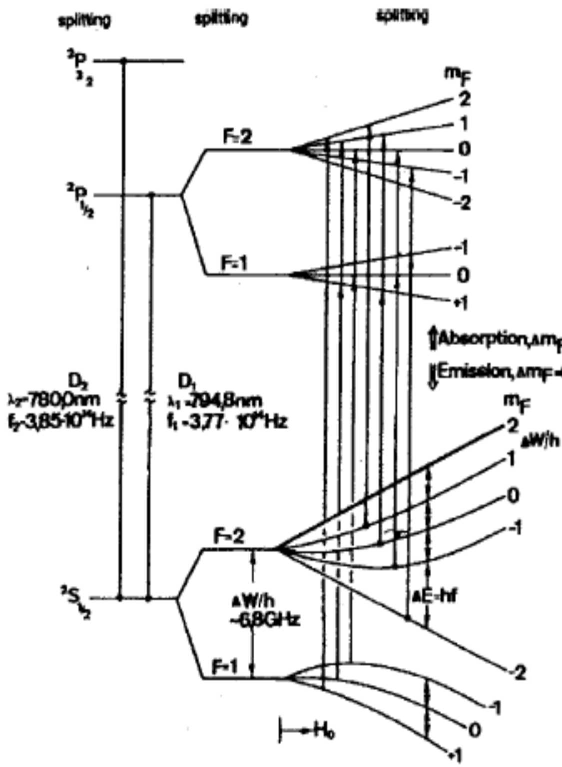


Figure 2: There are two commonly-occurring isotopes of Rubidium found in nature, ^{85}Rb and ^{87}Rb. Both have only one valence electron and can be approximated as one-electron atoms. The major difference between the isotopes is in the nuclear spin I.

Optical Pumping Instruments



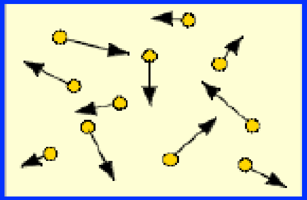




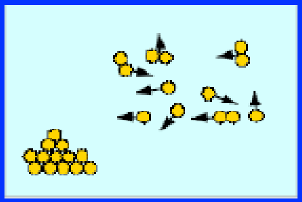
Properties of some liquids

subst.	T_b (K)	T_m (K)	T_{tr} (K)	P_{tr} (bar)	T_c (K)	P_c (bar)	lat. heat, L ($kJ\,l^{-1}$)	vol% in air
H_2O	373.15	273.15	273.16	0.06*	647.3	220	2,252	–
Xe	165.1	161.3	161.4	0.82	289.8	58.9	303	0.1×10^{-4}
Kr	119.9	115.8	114.9	0.73	209.4	54.9	279	1.1×10^{-4}
O_2	90.1	54.4	54.36	0.015	154.6	50.4	243	20.9
Ar	87.2	83.8	83.81	0.69	150.7	48.6	224	0.93
N_2	77.2	63.3	63.15	0.13	126.2	34.0	161	78.1
Ne	27.1	24.5	24.56	0.43	44.5	26.8	103	18×10^{-4}
n-D_2	23.7	18.7	18.69	0.17	38.3	16.6	50	–
n-H_2	20.3	14.0	13.95	0.07	33.2	13.2	31.8	0.5×10^{-4}
^4He	4.21	–	–	–	5.20	2.28	2.56	5.2×10^{-4}
^3He	3.19	–	–	–	3.32	1.15	0.48	–

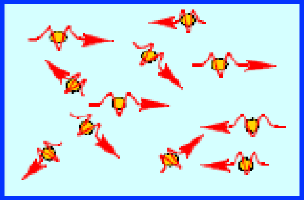
What's cool about "cold" and "absolute zero"?
Quantum fluid and many-body effects



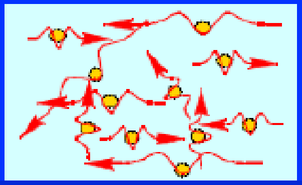
Cooling @ high density



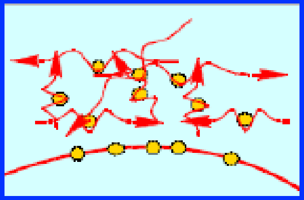
Cooling @ low density



$$\lambda_{dB} = \frac{h}{p} = \frac{h}{\sqrt{2\pi m^{*} k_B T}}$$



$T_{three\text{-}body} > t_{therm}$

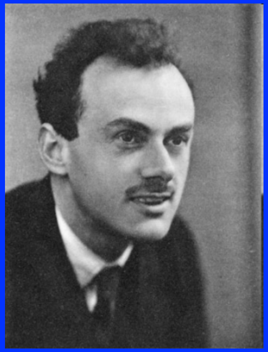


Single free particle
➔
Many-body collective effects

Interaction + Statistics + ?

L. V. de Broglie 1922

S. N. Bose, A. Einstein 1924-25

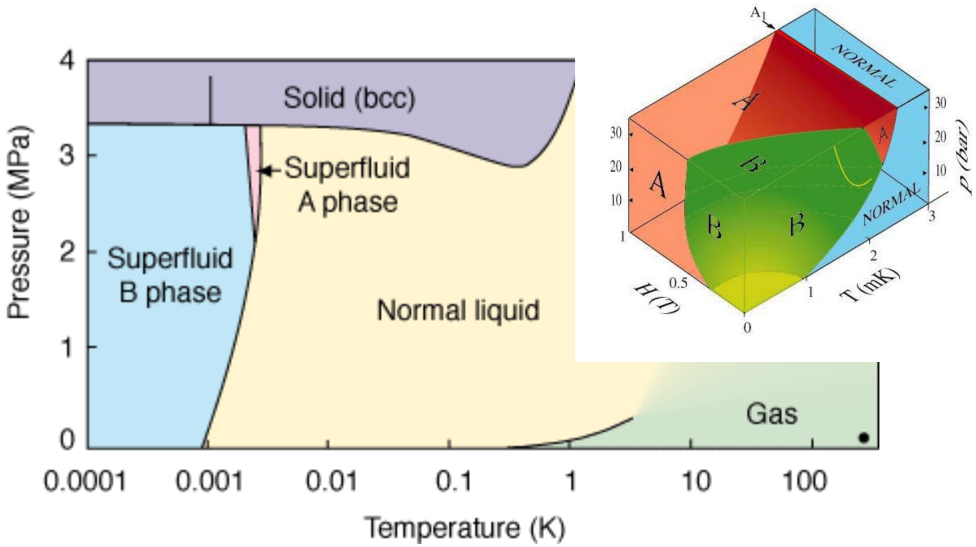


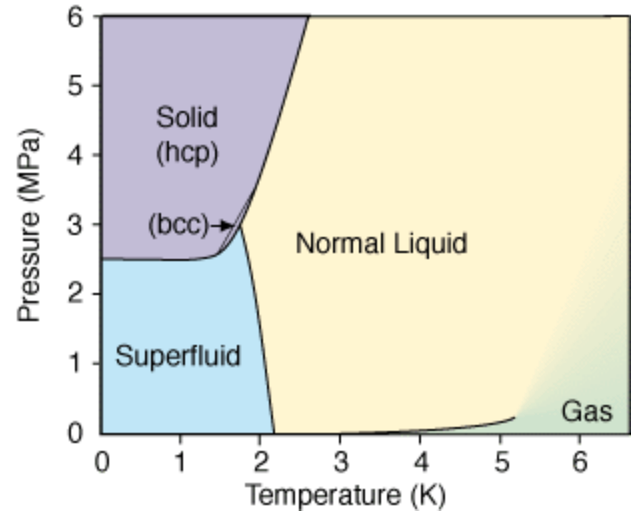
E. Fermi, P. Dirac 1926

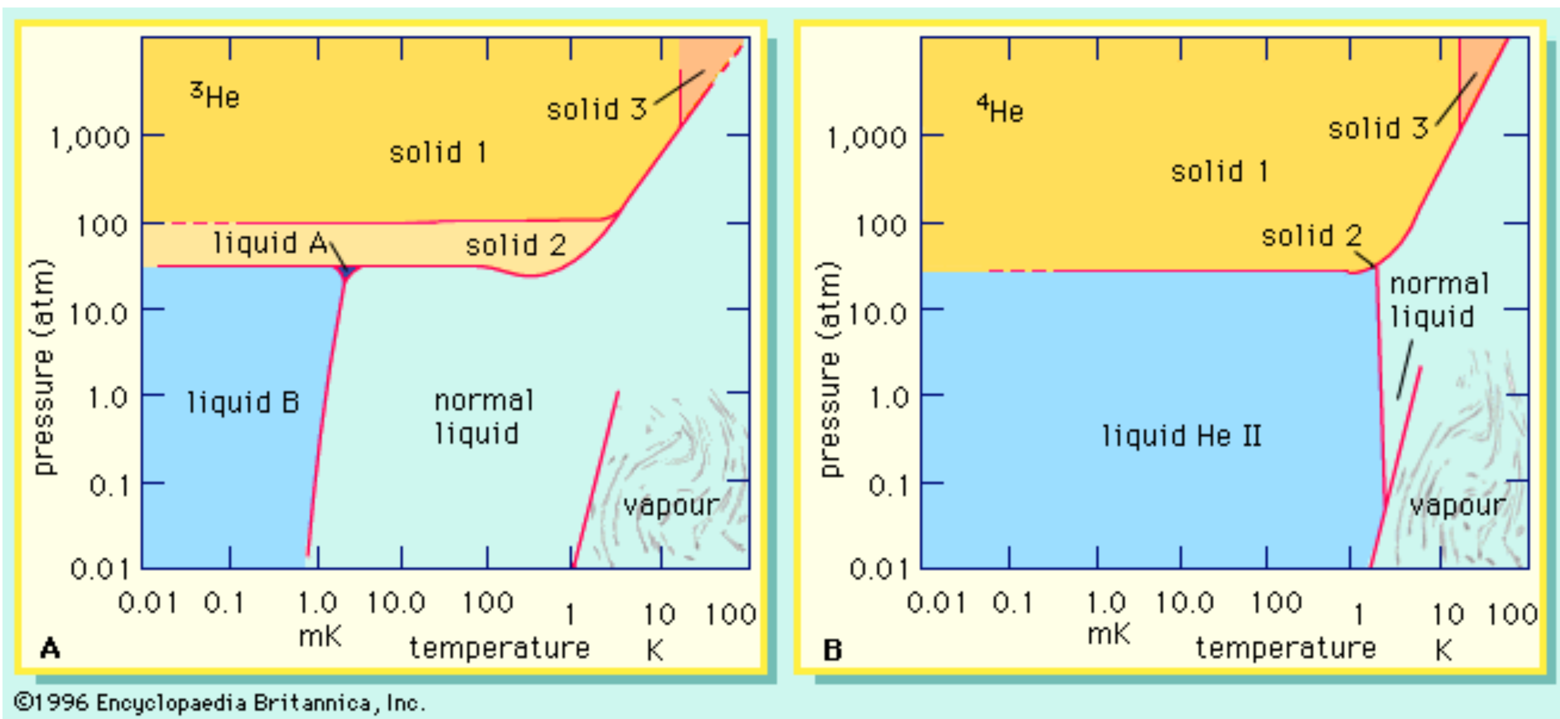
Helium as a Quantum Fluid

The behavior of liquid helium-4's two fluid phases, helium I and helium II, is important to researchers studying quantum mechanics (in particular the phenomenon of superfluidity) and to those looking at the effects that temperatures near absolute zero have on matter (such as superconductivity).

Phase Diagram of ^{3}He and ^{4}He







Superfluid Helium II

Phase transition and viscousless flow

http://www.youtube.com/watch?v=TBi908sct_U

Superfluid fountain

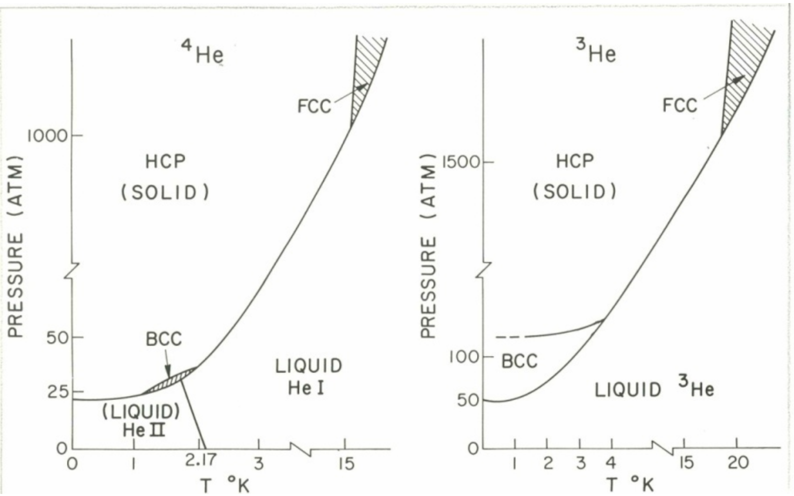
http://www.youtube.com/watch?v=kCJ24176enM

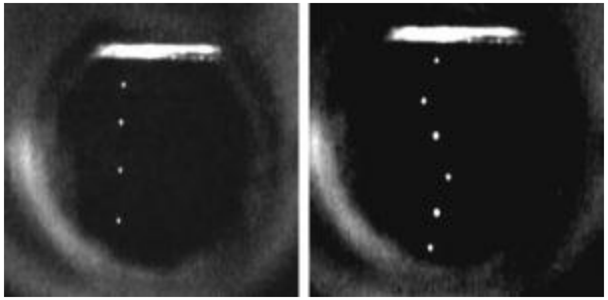
Liquid Helium II: The Superfluid (Physics demonstation by Alfred Leitner, 1963)

http://www.youtube.com/watch?v=uw6h4K6begA

Movement of single electron in helium

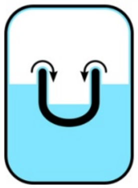
http://www.youtube.com/watch?v=04KaWCXkSC0

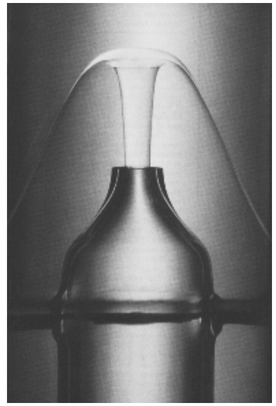


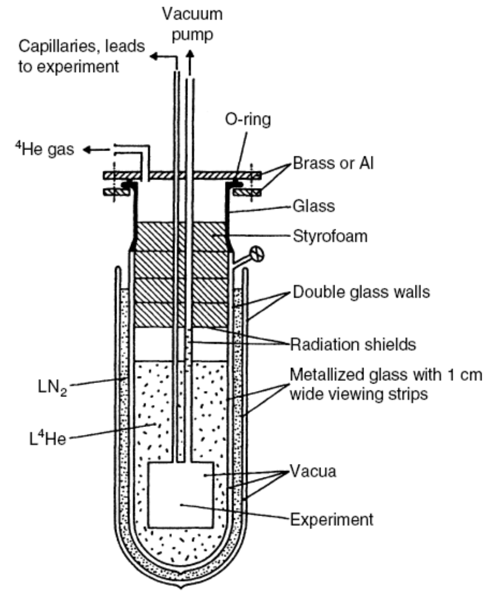


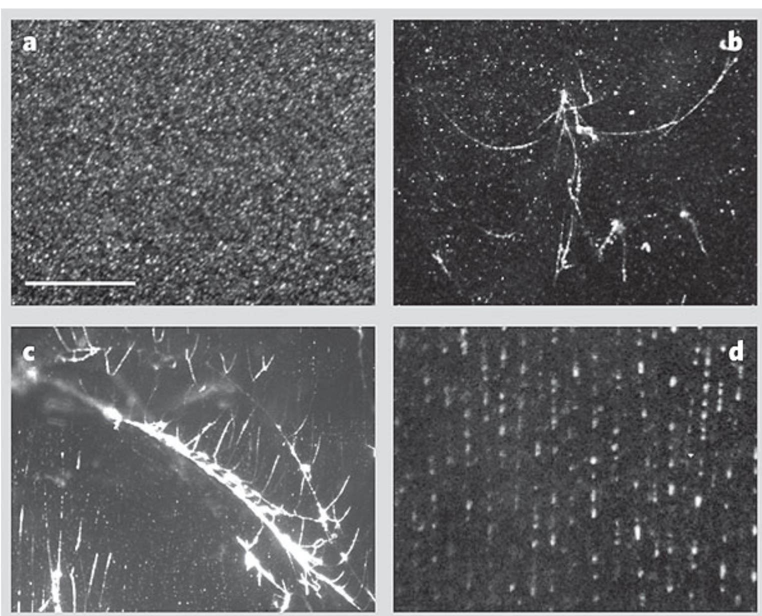
Captured on a home video camera, some electrons follow a straight path through superfluid helium (far left). Those entrained in a superfluid vortex follow a snakelike path. (Credit: Humphrey Maris and Wei Guo)

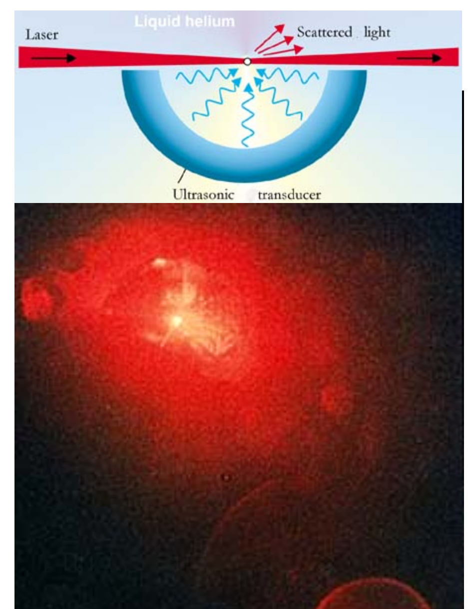
Select Amazing Phenomena of Helium as “Superfluid”



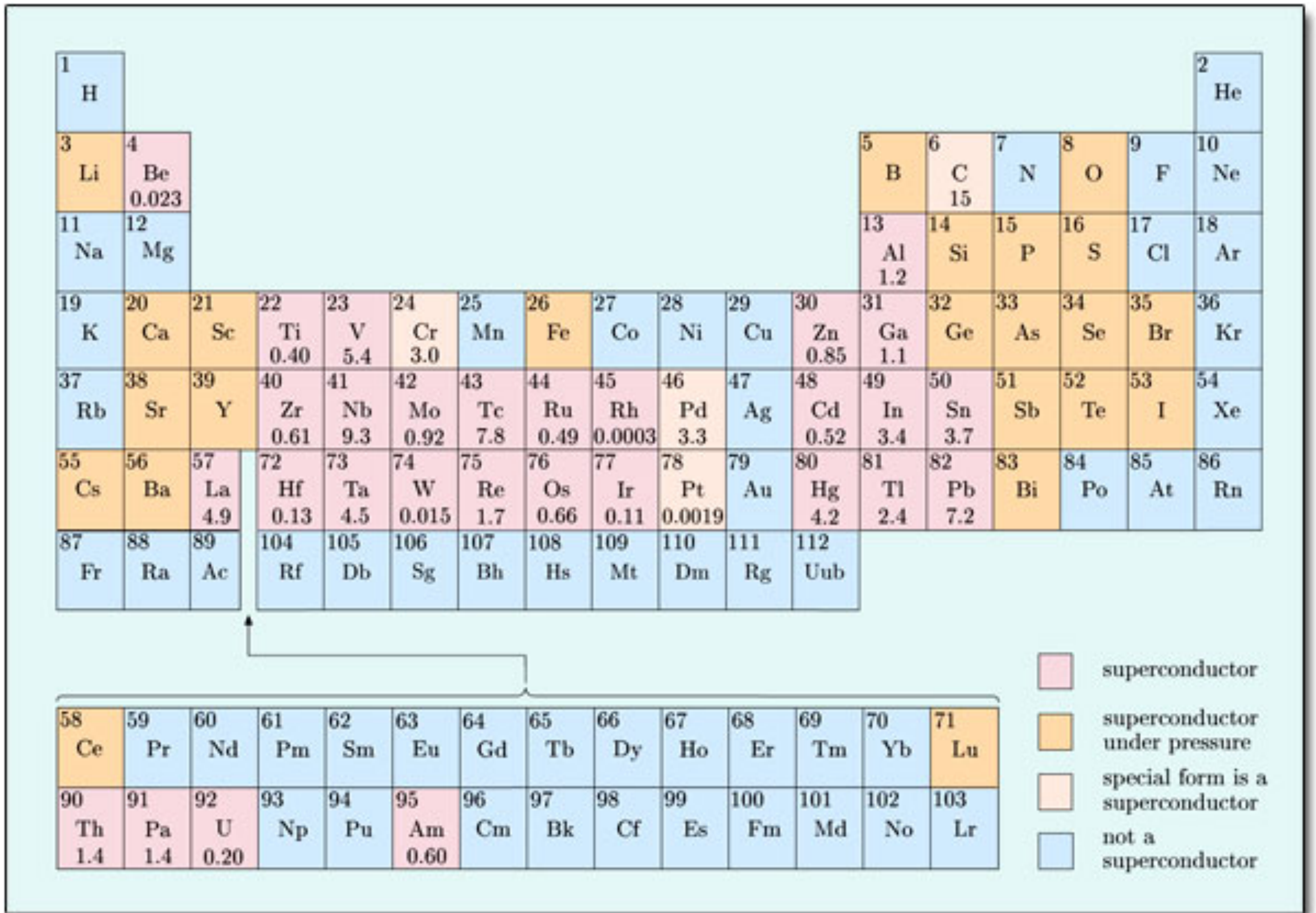


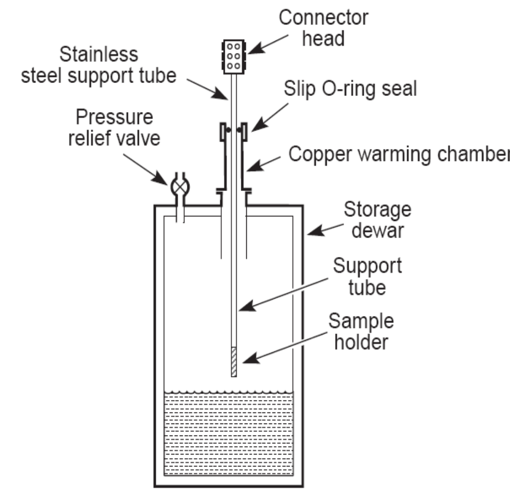






Periodic Table of Superconductors





Dipper Cryostat

Superconductor

- Meisner effects (levitation)

http://www.youtube.com/watch?v=4VGACLNfZ8s

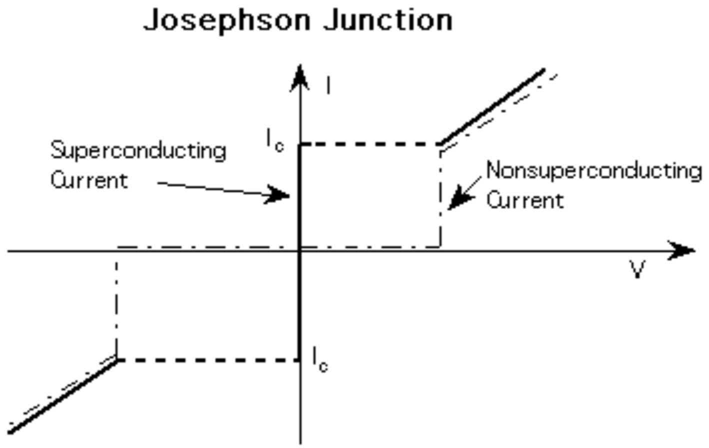
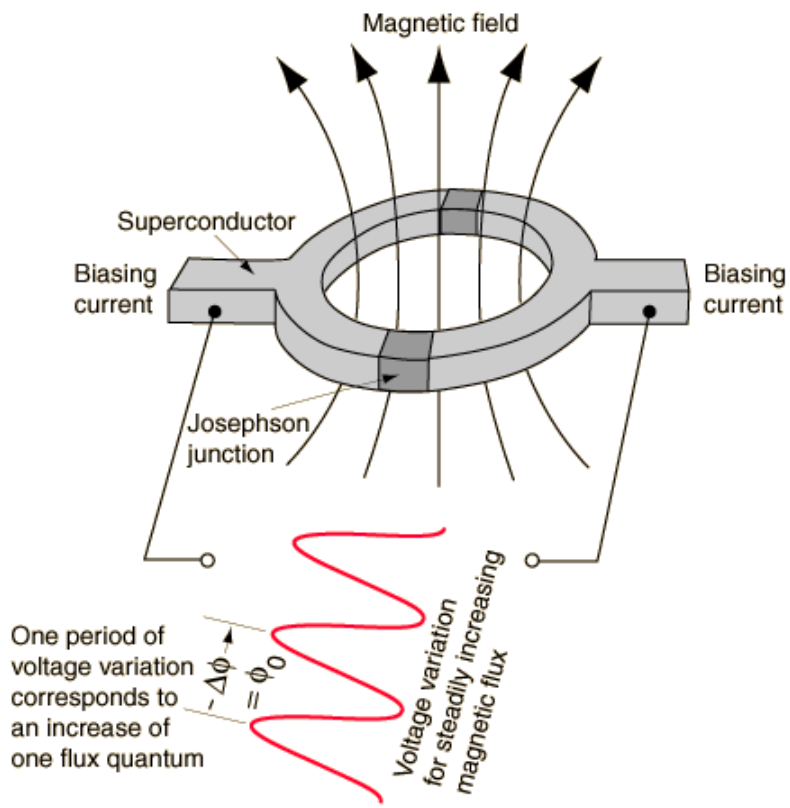


Fig. 14



Superconductor

- Meisner effects (levitation)

http://www.youtube.com/watch?v=4VGACLNfZ8s

Physical realization of quantum computation

Condensed Matter

Liquid-state NMR
NMR spin lattices

Impurities in semiconductors & fullerines
Nitrogen vacancies in diamond
Spins in quantum dots

Electrons on liquid He
2DEG in the quantum hall regime

Josephson junctions (superconductor-based)

- **charge, flux, and phase qubits**

AMO

Linear ion traps

Neutral-atom optical lattices

Cavity QED + atoms

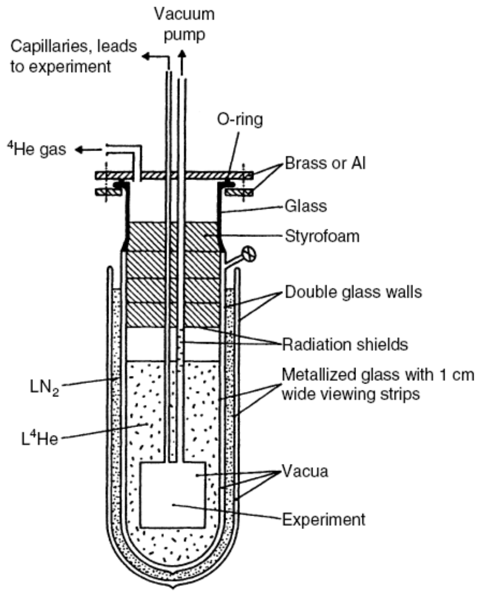
Linear optics/single photons

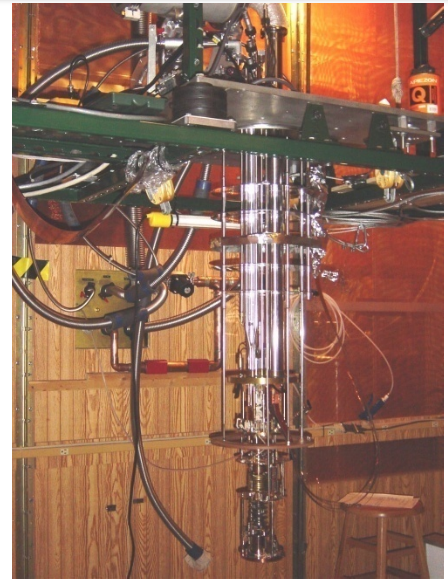
Preparation – Manipulation/Control – Detection

How to accomplish these before the coherence (entanglement) is lost!

Storage of cryoliquids: cryogenic dewars (cryostats)

Cryostats



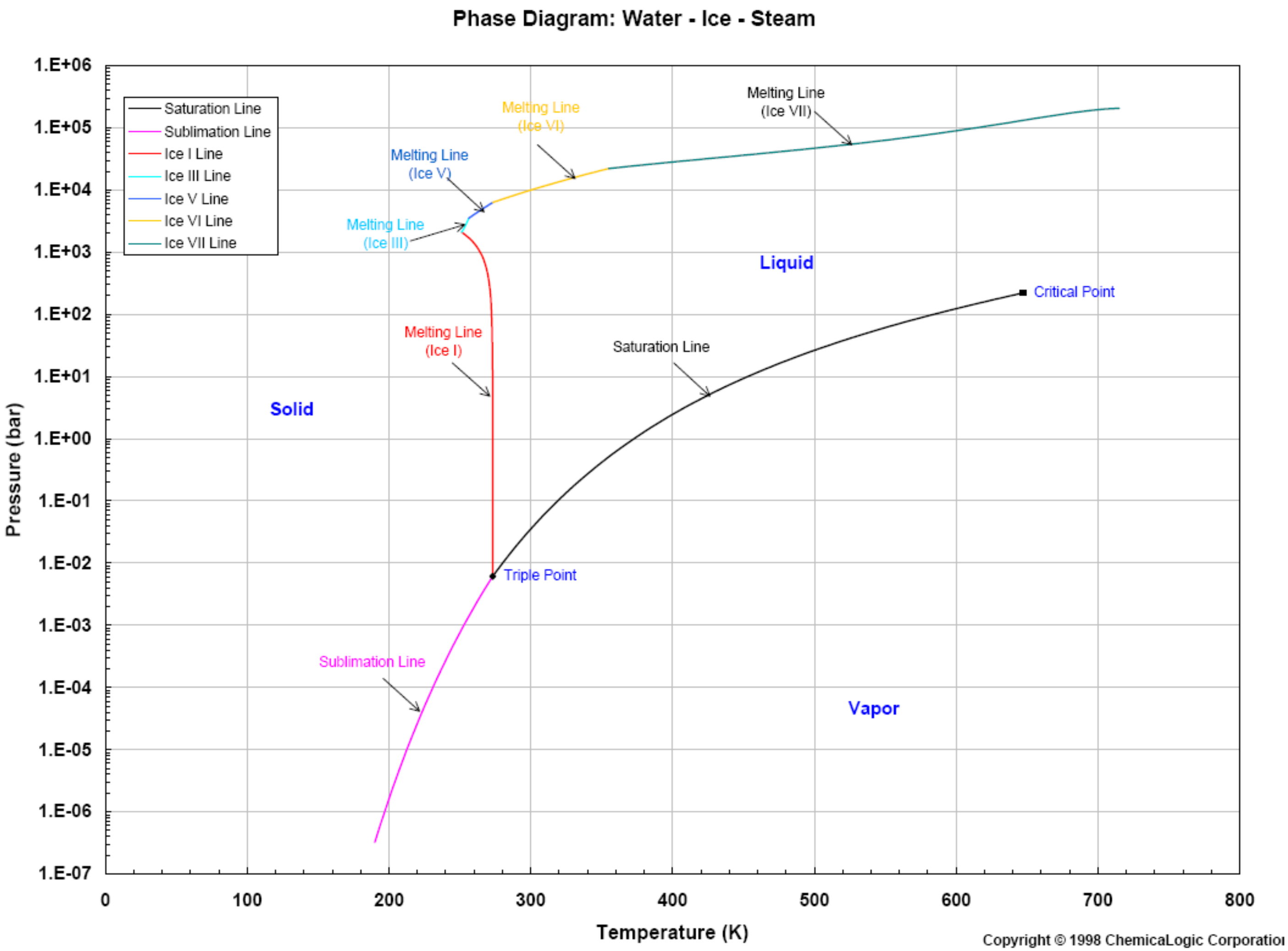


Flow cryostat

Magnetic optical cryostat

Closed cycle

Water Phase Diagram



CO_2 Phase Diagram