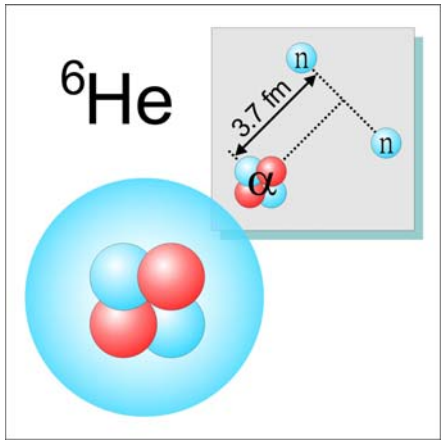
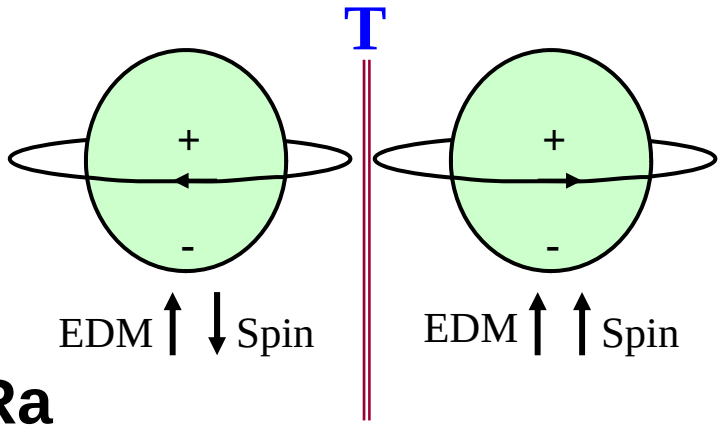
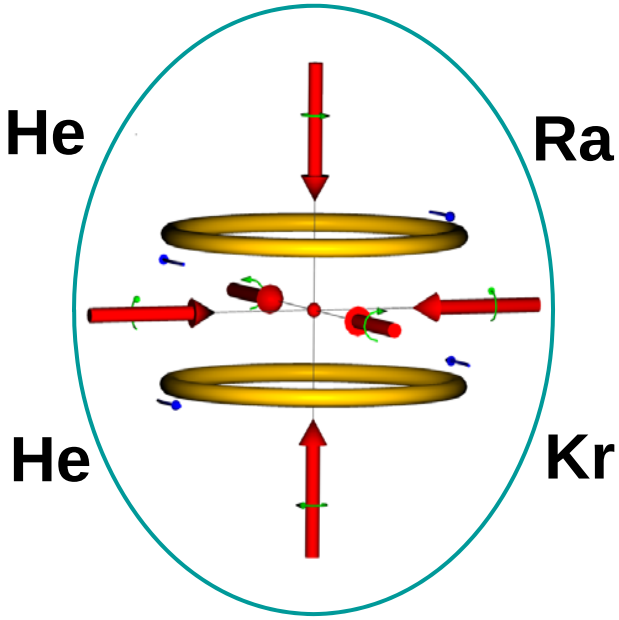
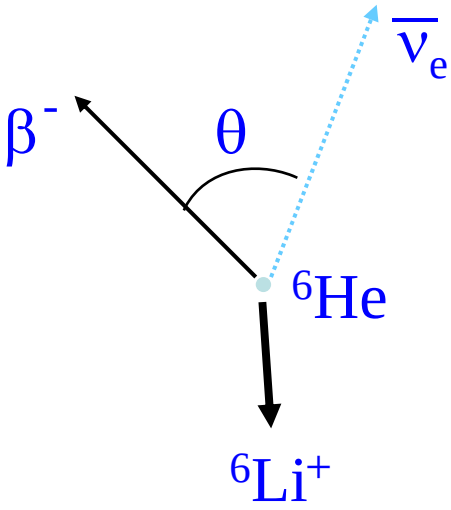
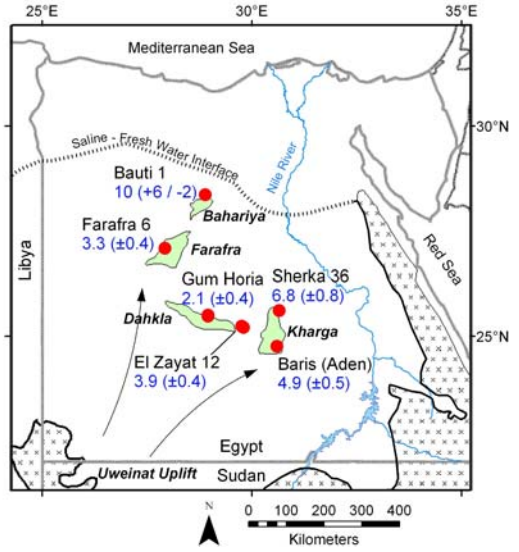




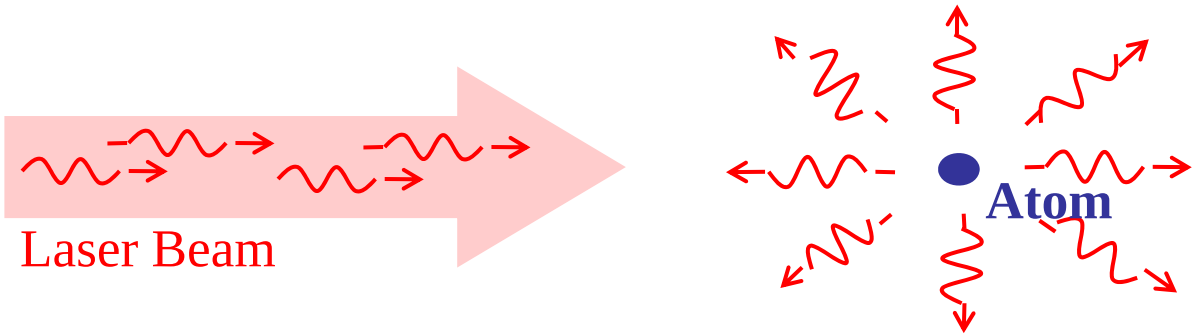






Supported by
DOE, Office of Nuclear Physics

Spontaneous Scattering Light Force
Resonance & Repetition



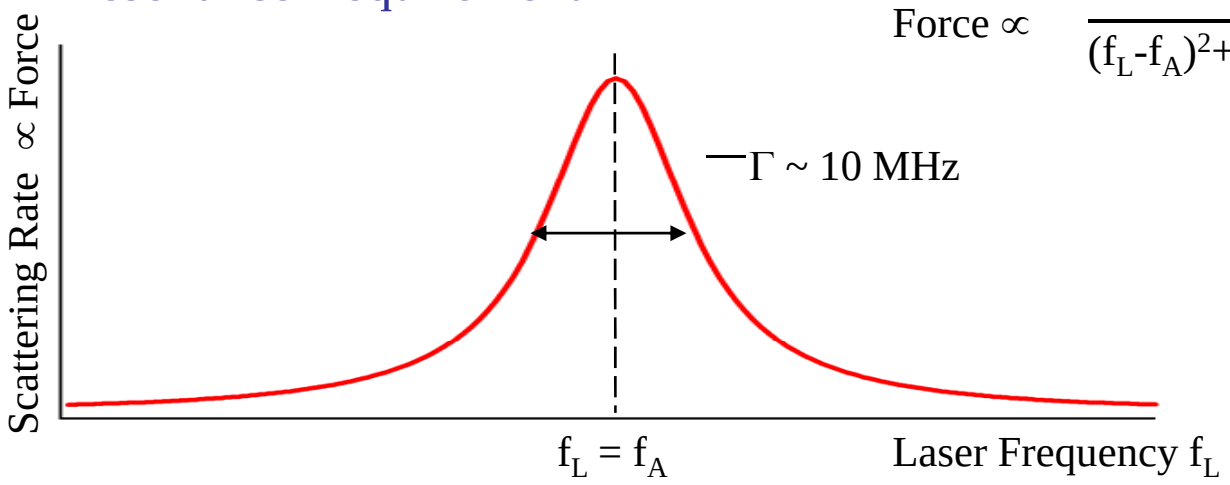
Krypton Atom:

$1s_5$ -- $2p_9$ wavelength = 811 nm Single photon kick δv = 6 mm/sec

Transition rate ~ 1×10^7 /sec Acceleration ~ 6×10^4 m/sec^2

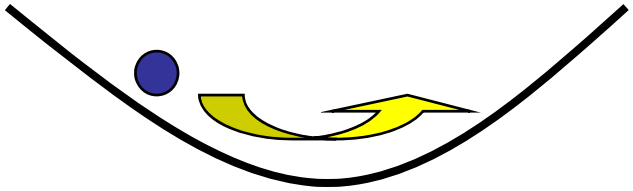
Resonance Requirement

$$\text{Force} \propto \frac{1}{(f_L - f_A)^2 + (\Gamma/2)^2}$$



Trapping

F = -kx



Magnetic Field B(x)

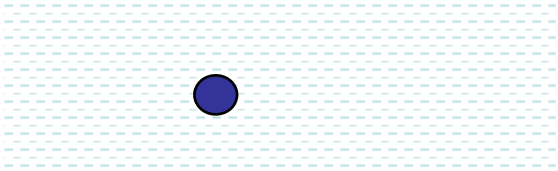
↓

$f_A(x)$

Zeeman Shift

Cooling

F = -av



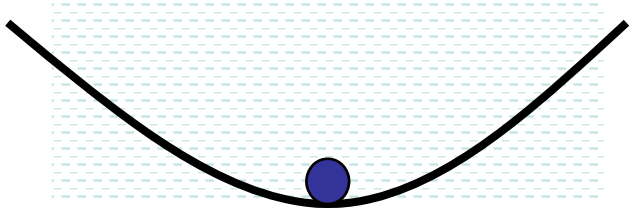
Atom Velocity

↓

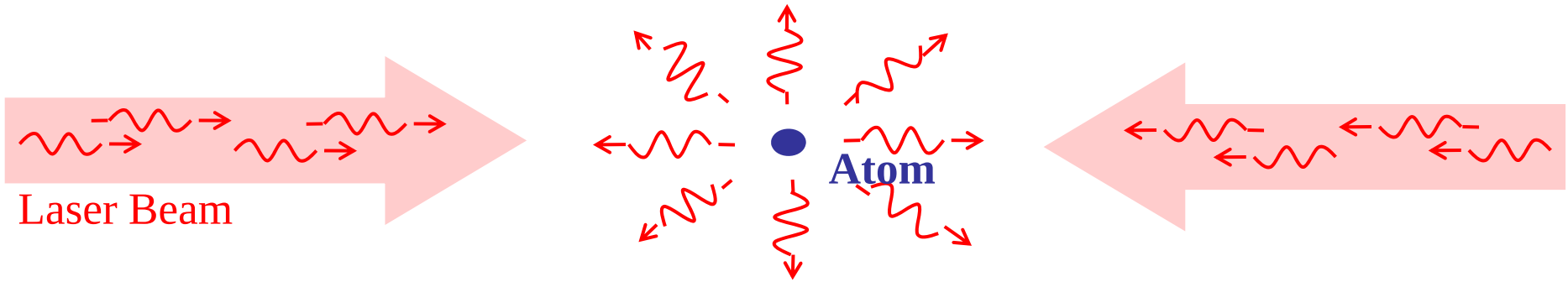
$f_L(v)$

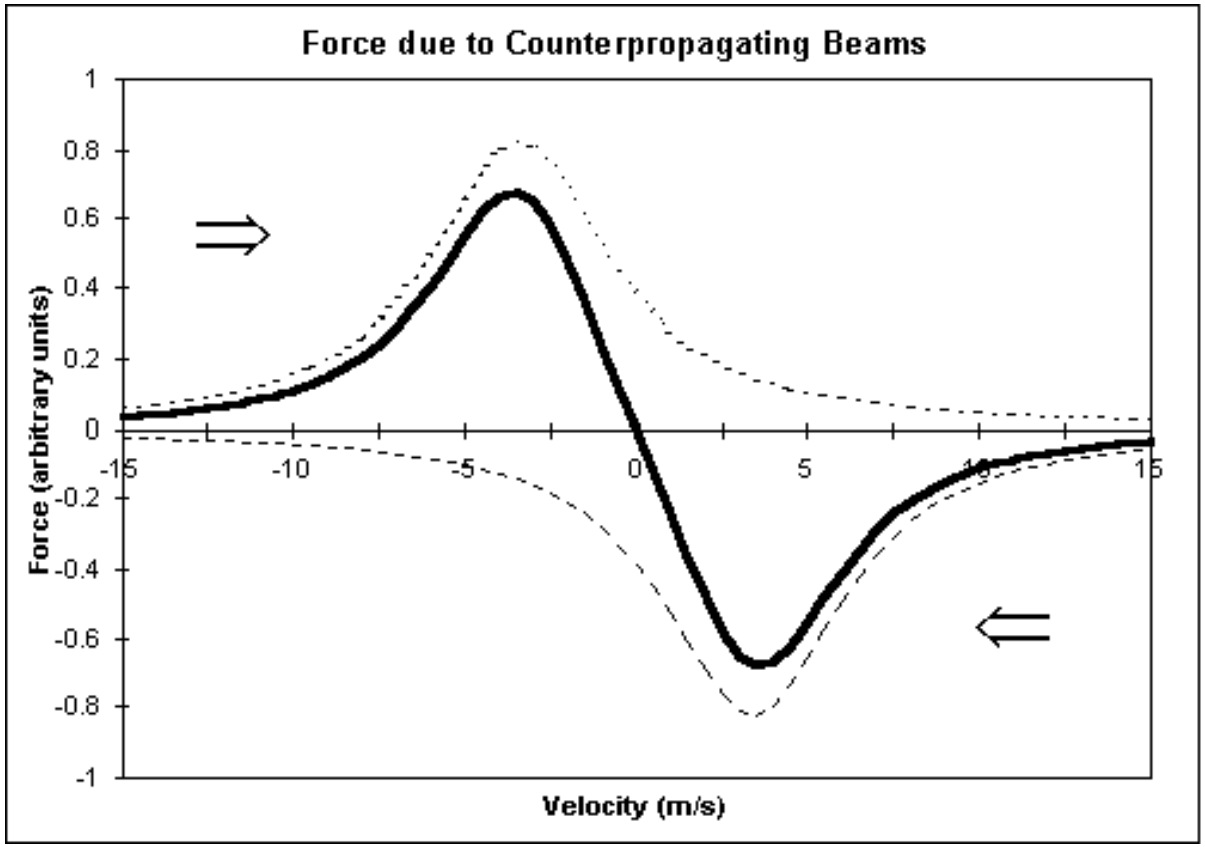
Doppler Shift

A Trap with Cooling



Doppler Cooling





Laser frequency red detuned

$$F = -\alpha \cdot V$$

$$k_B T_D = \frac{1}{2} h\Gamma$$

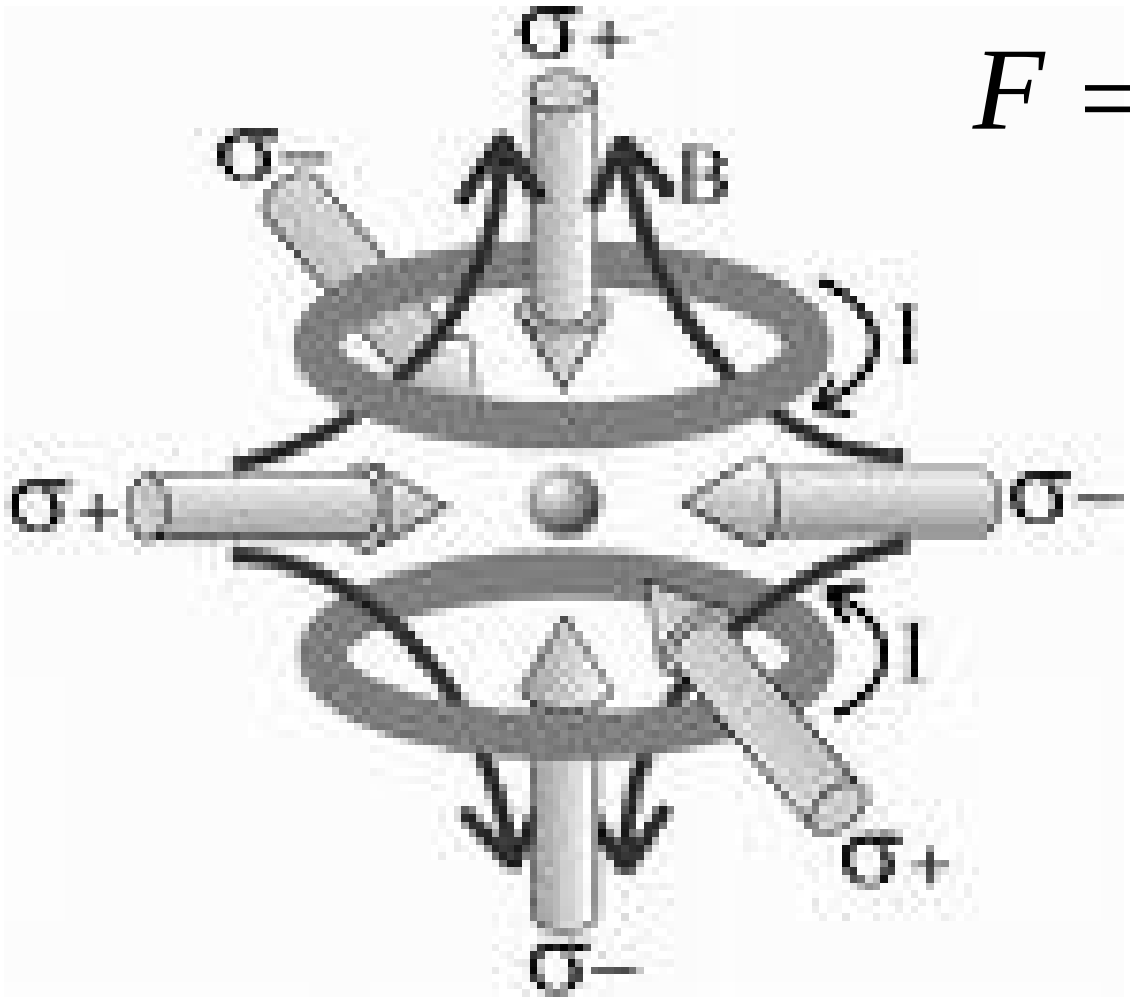
Kr:

Γ= 6 MHz

T_D = 0.1 mK

Magneto-Optical Trap

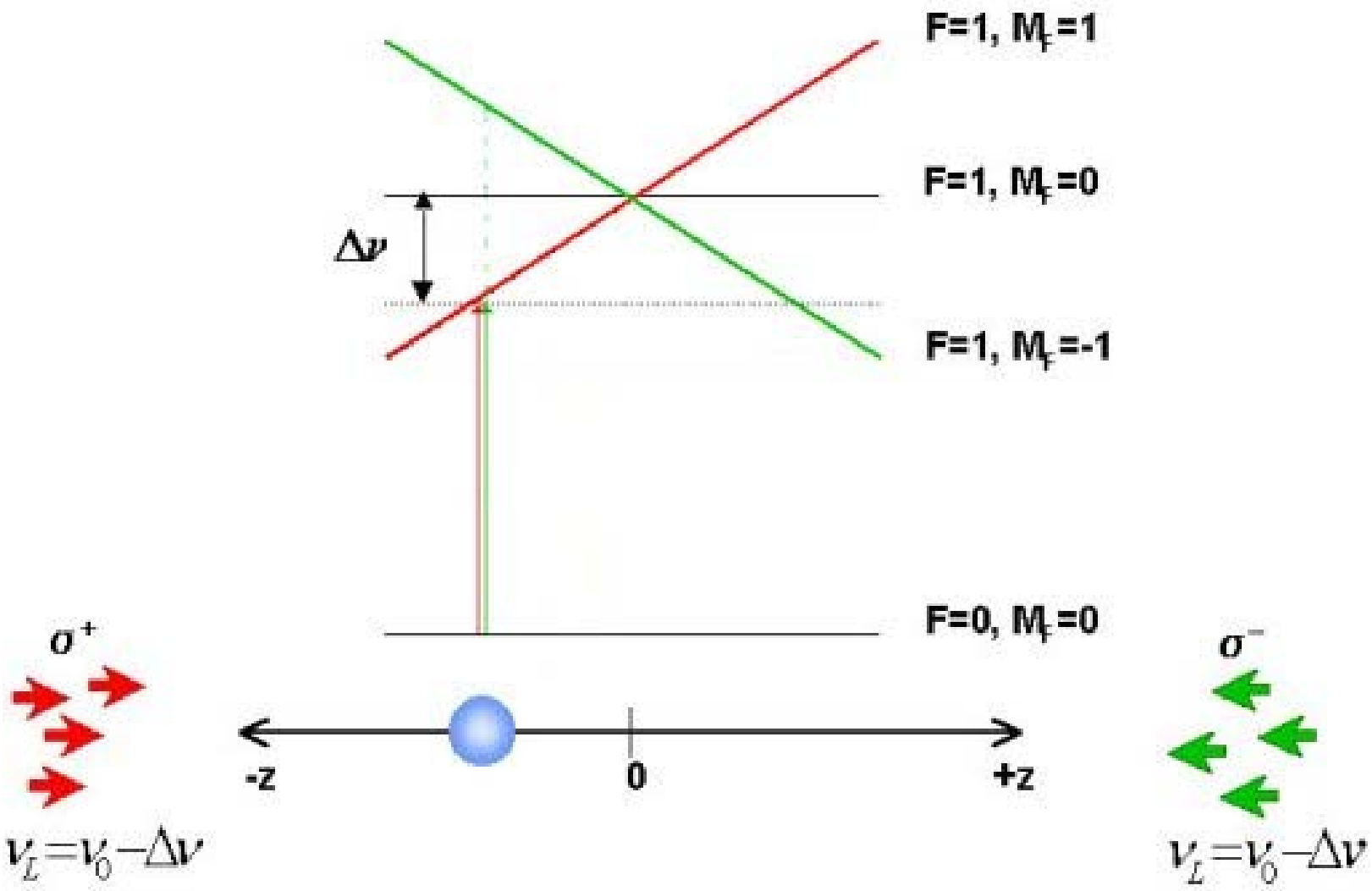
Raab et al., Bell Lab & MIT, 1987



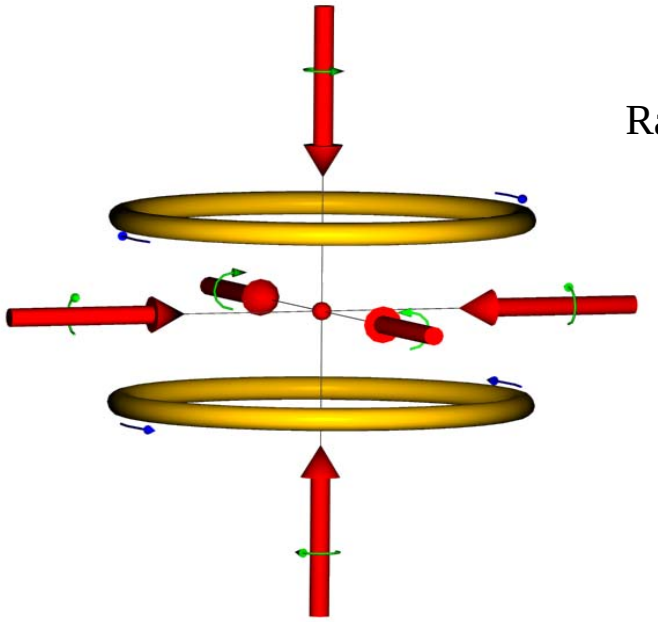
$$F = -k \cdot z$$

Magneto-Optical Trap

Raab et al., Bell Lab & MIT, 1987



Magneto-Optical Trap (MOT)



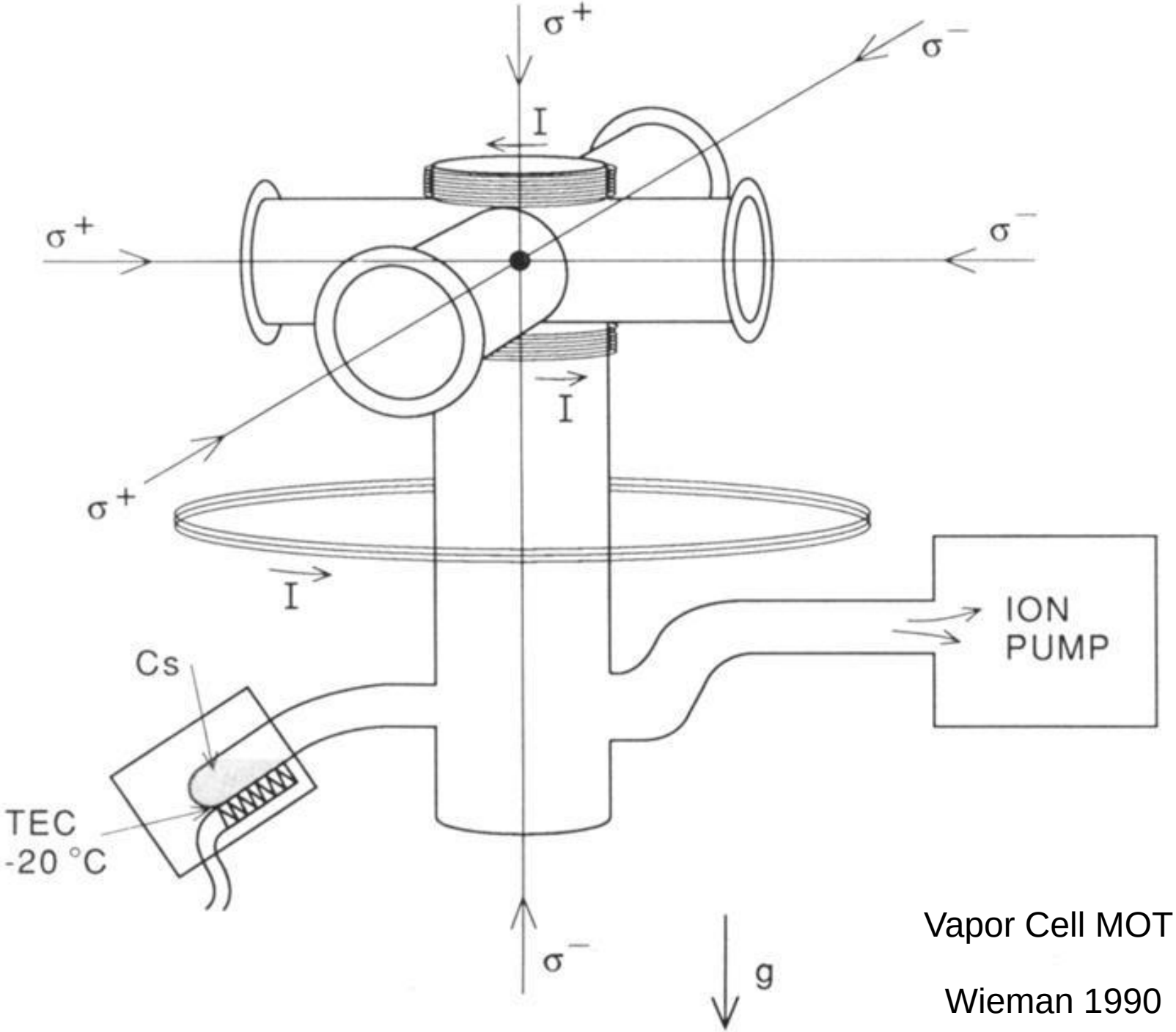
Raab et al., Bell Lab & MIT, 1987

Ingredients:

Laser beams --- alignment, frequency, polarization;
Quadrupole B-field --- 20 G/cm, anti-Helmholtz;
Ultra-high vacuum --- τ_{trap} ~ 1 sec @ 1×10^{-8} Torr.

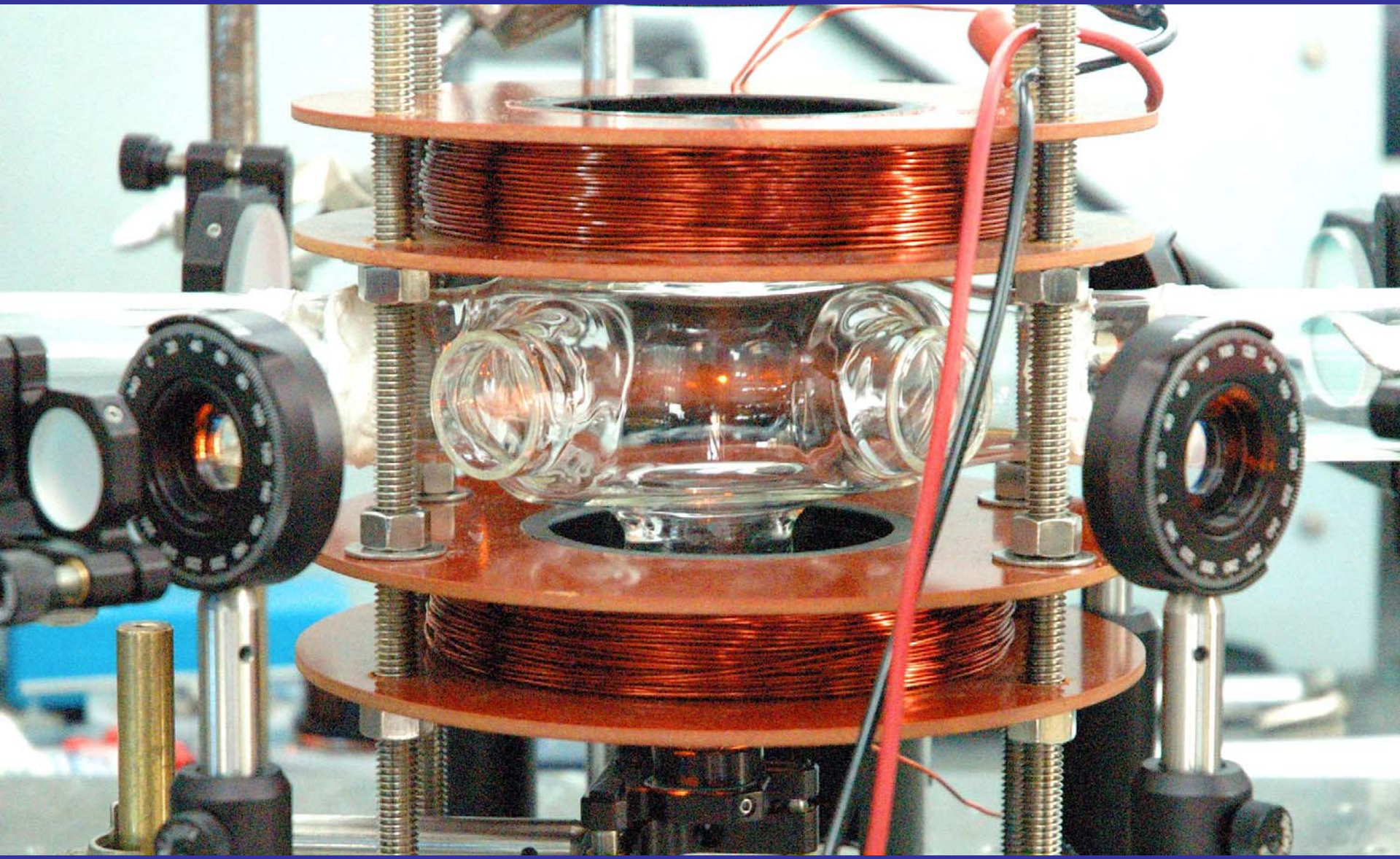
Typical Parameters:

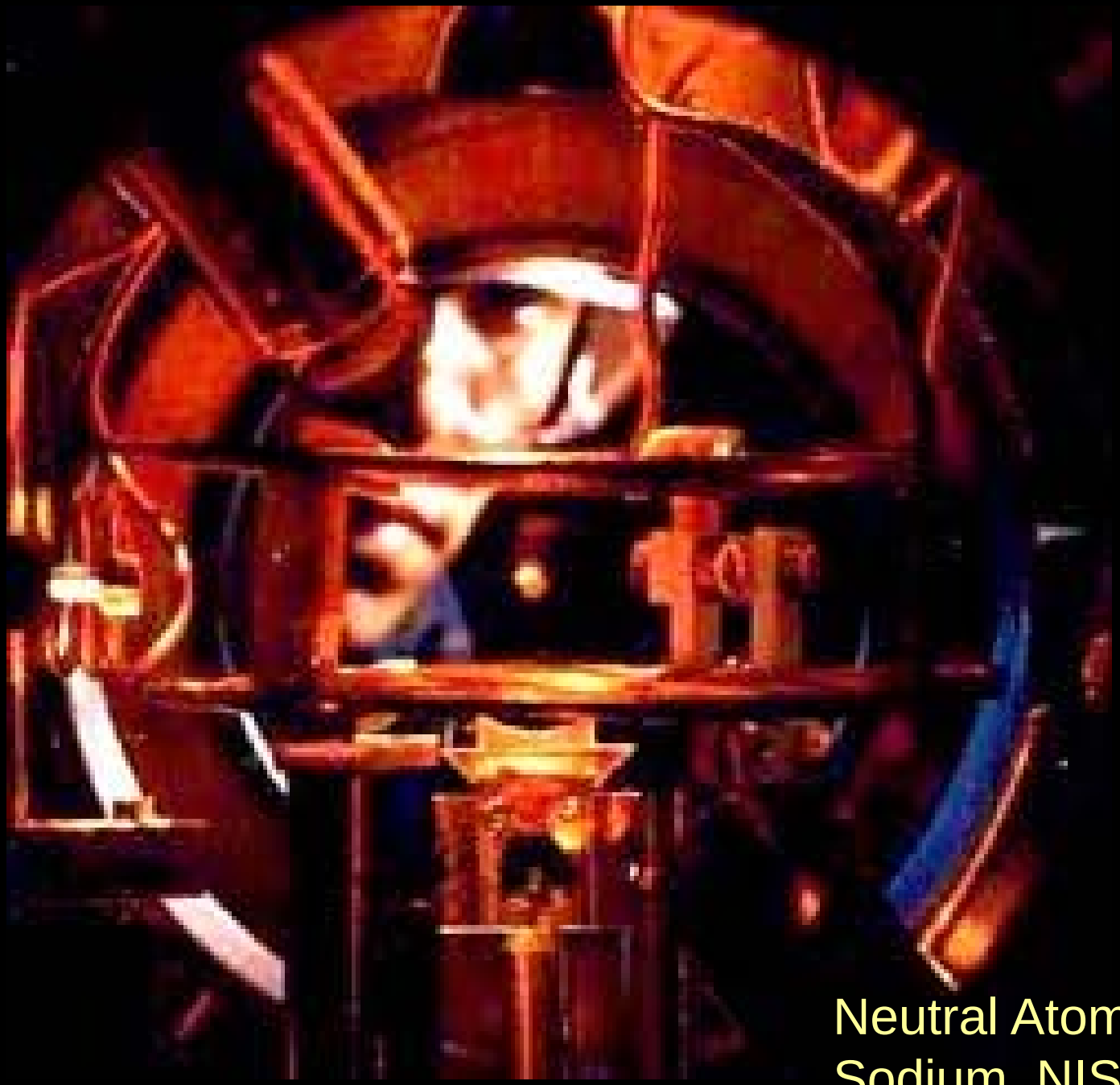
Number --- 10^{10};
Density --- 10^{8} mm^{-3} (optically thick);
Temperature --- ~ 0.1 mK, ~ 0.1 m/sec;
Capture speed --- ~ 10 m/sec.



Vapor Cell MOT

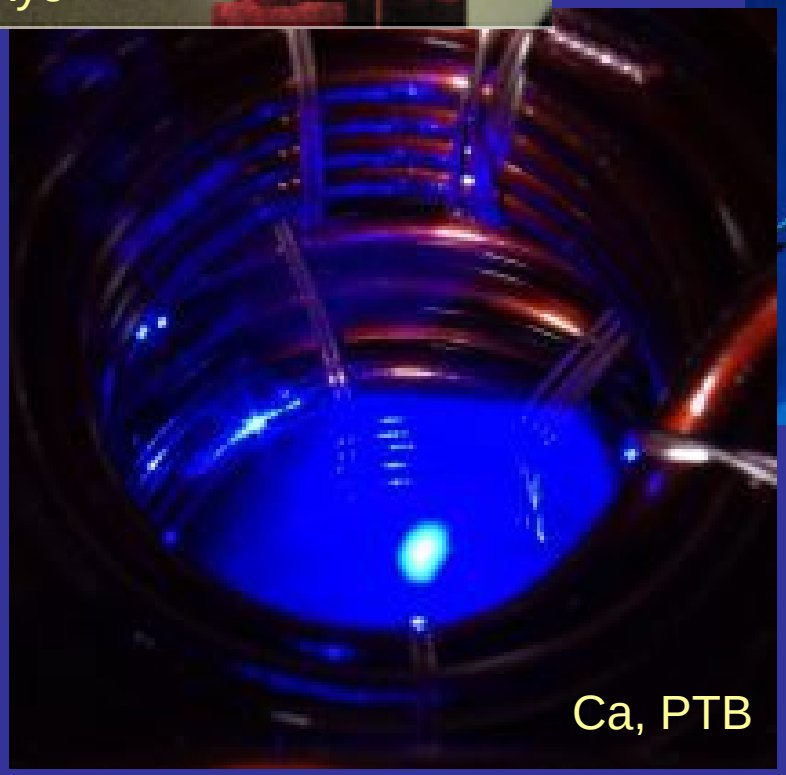
Wieman 1990

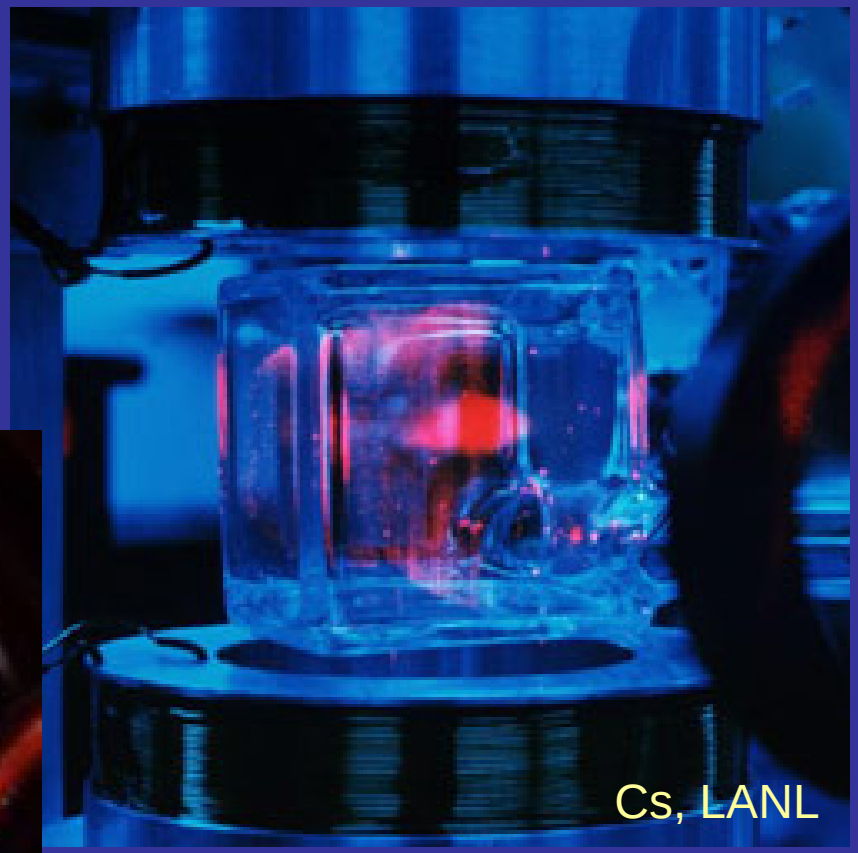




Neutral Atom Trap
Sodium, NIST


Neon, Tokyo

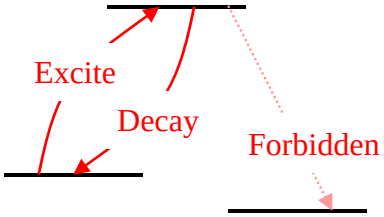

Ca, PTB

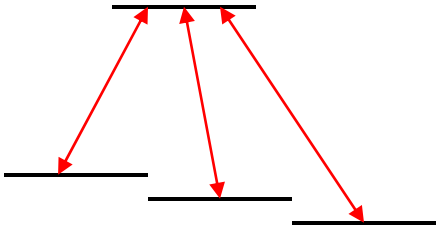

Cs, LANL

Trappable Atoms

Transition Requirements:

- Cycling transition
- High transition rate (10^7 sec^{-1}, allowed E1)
- Practical wavelength ($\lambda > 200$ nm)

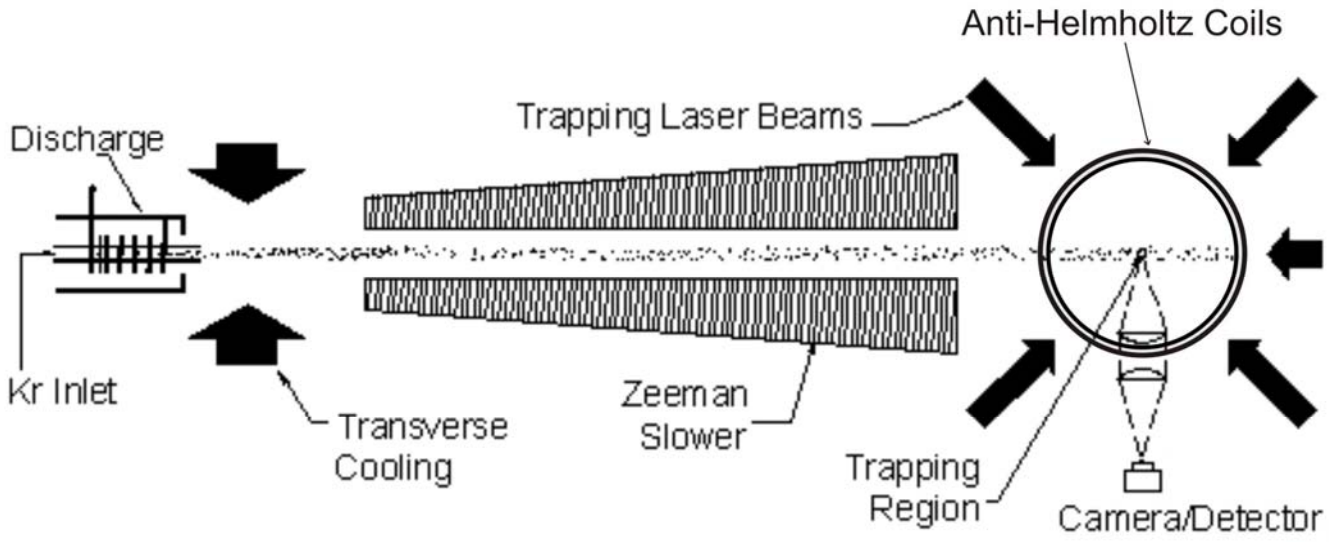


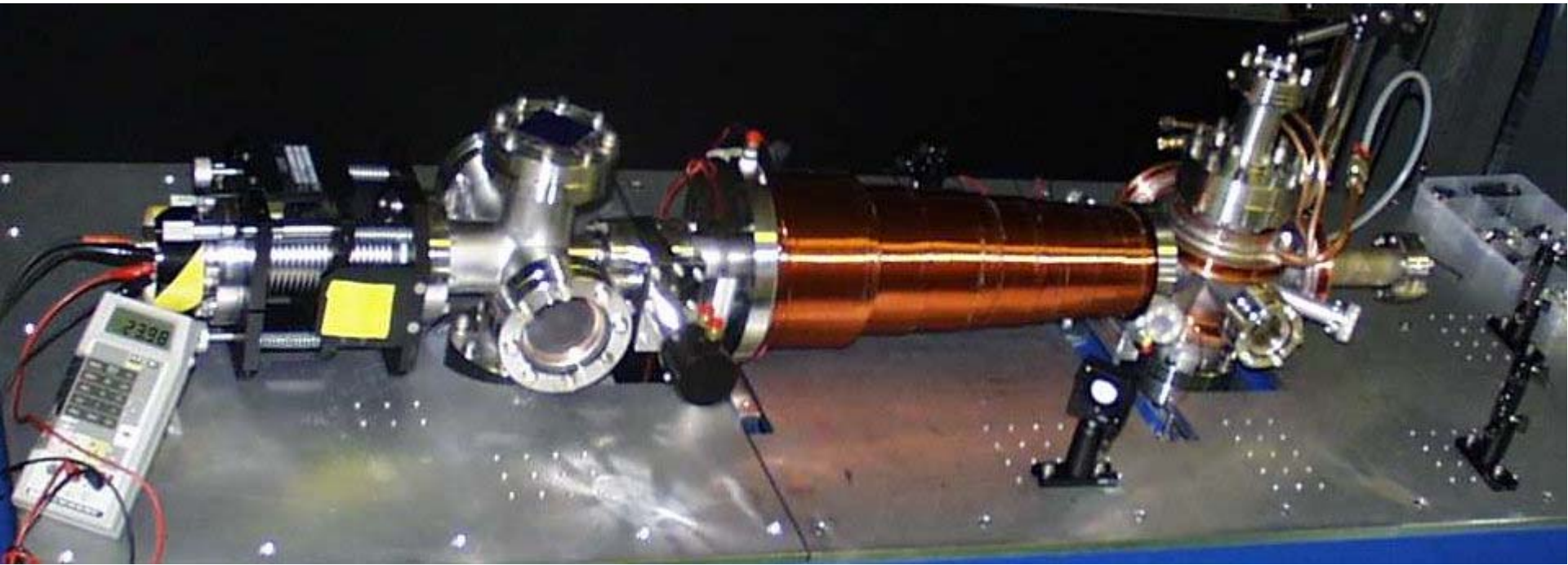


1 H																2 He
3 Li	4 Be				36 Kr	Trap demonstrated					5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg										13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub		114 Uuq		116 Uuh		118 Uuo

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Transverse Cooling - Zeeman Slower - MOT





Optical Dipole Trap

$$H = -\tilde{d}E = -\frac{1}{4}\alpha E_0^2$$

Excitation rate $\sim \dfrac{Intensity}{(f_{laser} - f_{atom})^2}$

Trap potential $\sim \dfrac{Intensity}{(f_{laser} - f_{atom})}$

- CO_2 laser: $\lambda = 10\ \mu m$, Power = 100 Watts
- Focused to 200 μm diameter → trap depth 100 μK
- Excitation rate ~ $10^{-5}\ s^{-1}$
- Spin relaxation rate < Excitation rate

Steven Chu **Claude Cohen-Tannoudji** **William Phillips**

The Nobel Prize in Physics 1997
"for development of methods to cool and trap atoms with laser light"