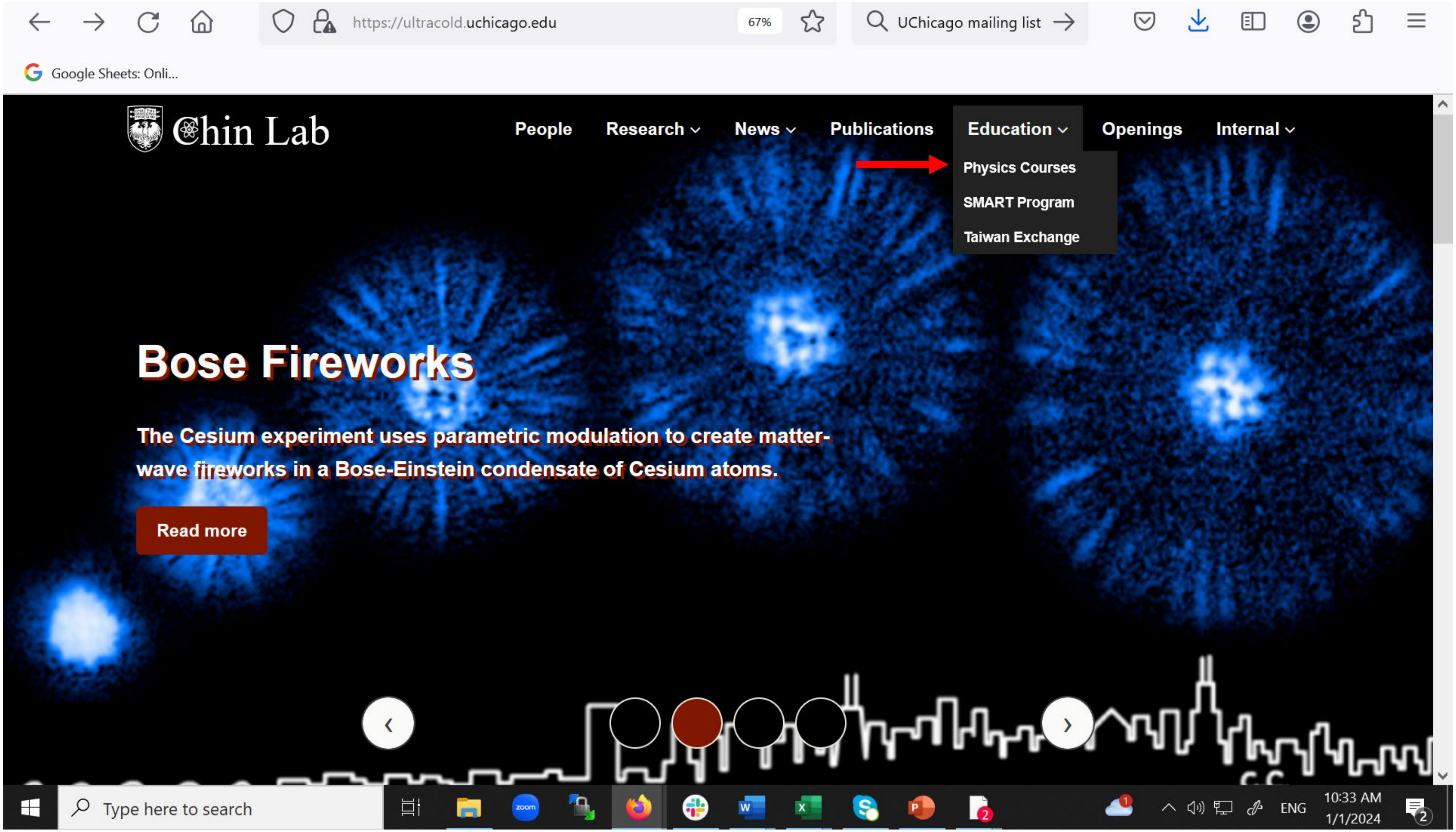
Physics 471 - Introduction to Modern Atomic Physics

Time: MW 9:00 AM - 10:20 AM
Location: KPTC 105

Lecturer: Cheng Chin
Office: GCIS E107
Office hour: TuTh 11am to noon
Email: cchin@uchicago.edu

Online discussion on Piazza
Sign up: https://piazza.com/uchicago/winter2024/physics47100
Access code: 47100

Where do I find class information?



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https://ultracold.uchicago.edu/node/230

Google Sheets: Onli...

Winter 2024 P471

Physics 47100 Introduction to Atomic Physics

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Class outline: 17 Lectures, 2 presentation sessions

Single Atom

Wk1 01/03 W 9:00~10:20 Atomic structure

Wk2 01/08 M 9:00~10:20 Atom-field interaction HW1

Wk2 01/10 W 9:00~10:20 Application 1: Laser cooling and trapping

Wk3 01/15 M 9:00~10:20 Application 2: Atomic interferometry HW2

Wk3 01/17 W 9:00~10:20 Application 3: Single qubit rotation

Two Atoms

Wk4 01/21 M 9:00~10:20 Atom-atom interactions HW3

Wk4 01/23 W 9:00~10:20 Low energy scattering

Wk5 01/29 M 9:00~10:20 Feshbach resonance HW4

Wk5 01/31 W 9:00~10:20 Application 1: Ultracold molecules

Wk6 02/05 M 9:00~10:20 Application 2: Quantum logic gates HW5

Many Atoms

Wk6 02/07 W 9:00~10:20 Second quantization

Wk7 02/12 M 9:00~10:20 Bose-Einstein condensation HW6

Wk7 02/14 W 9:00~10:20 Degenerate Fermi gas

Wk8 02/19 M 9:00~10:20 Application 1: Hubbard model HW7

Wk8 02/21 W 9:00~10:20 Application 2: Dynamical instability

Special topics

Wk9 02/26 M 9:00~10:20 Topic 1: HW8

Wk9 02/28 W 9:00~10:20 Topic 2:

Evaluation Problem sets and presentation/term paper

Recommended Textbooks

Atomic Physics, D. Budker, D. F. Kimball and D. P. DeMille

Bose-Einstein Condensation in Dilute Gases, C.J. Pethick and H. Smith

Evaluation and Textbooks

Evaluation

Problem sets
Presentation or term paper

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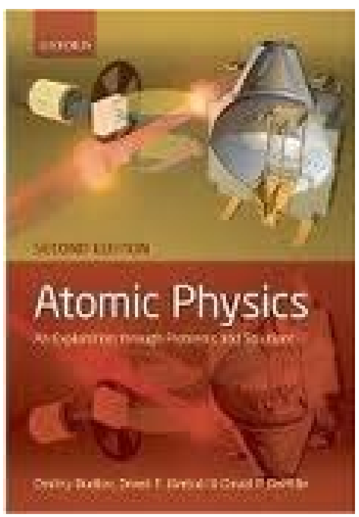

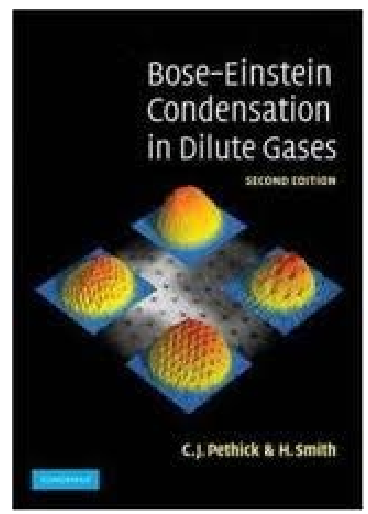

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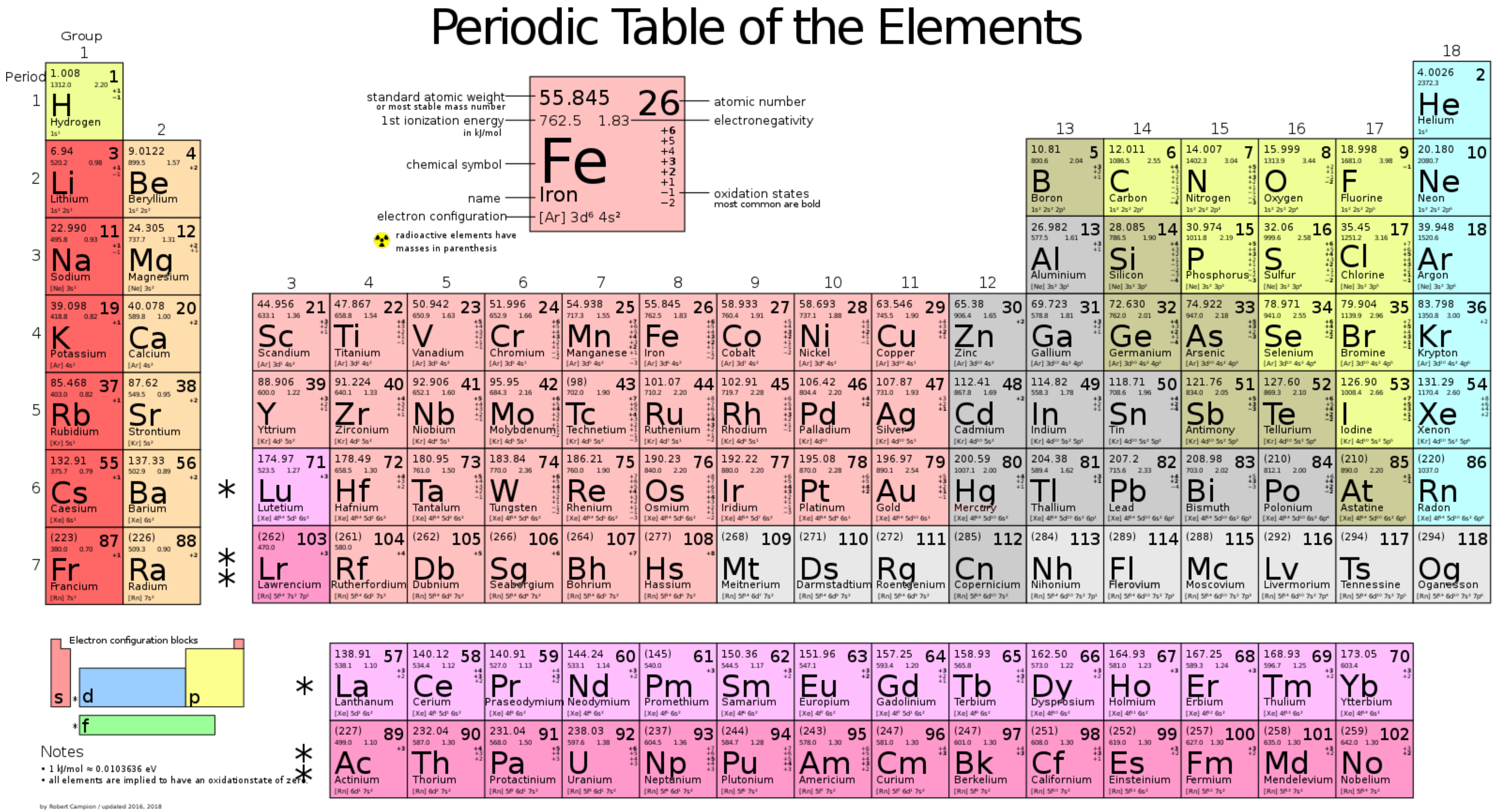
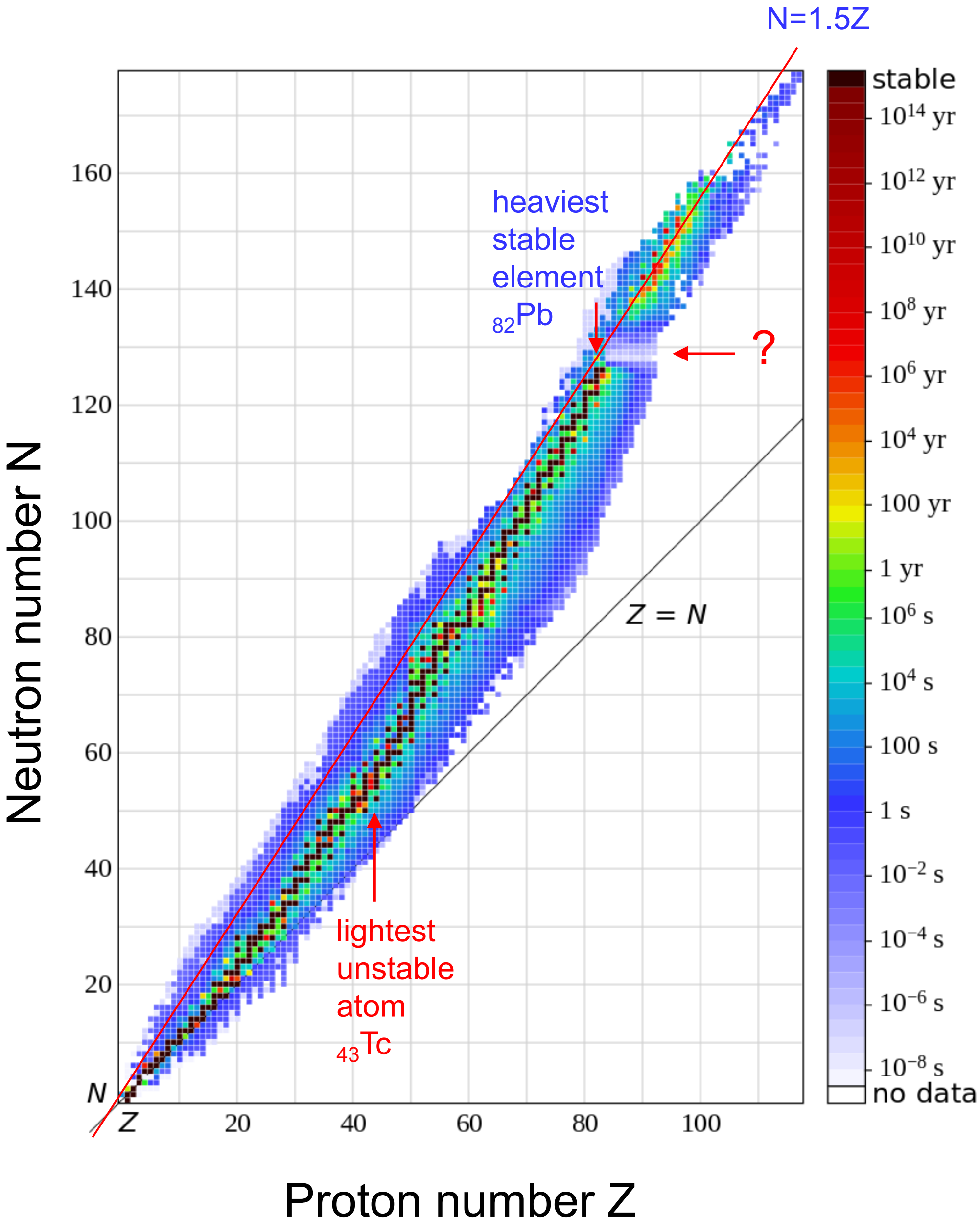


Atomic number Z = # of protons

Mass number A=Z+N = # of protons + neutrons

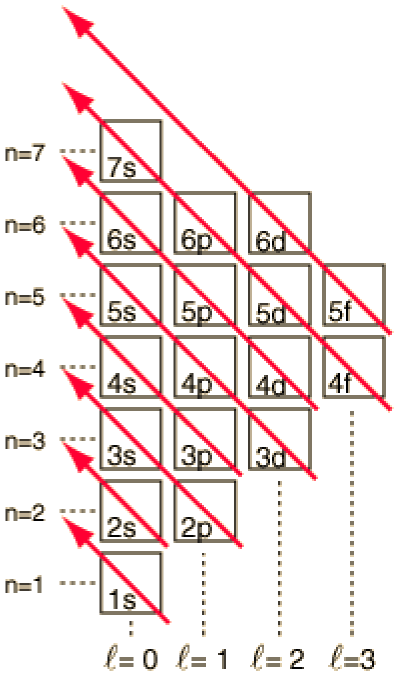


Isotopes of rubidium ($_{37}$Rb)

Main isotopes[1]			Decay	
	abun-dance	half-life ($t_{1/2}$)	mode	pro-duct
^{82}Rb	synth	1.2575 m	β^+	^{82}Kr
^{83}Rb	synth	86.2 d	ε	^{83}Kr
			γ	–
^{84}Rb	synth	32.9 d	ε	^{84}Kr
			β^+	^{84}Kr
			γ	–
			β^-	^{84}Sr
^{85}Rb	72.2%	stable		
^{86}Rb	synth	18.7 d	β^-	^{86}Sr
			γ	–
^{87}Rb	27.8%	4.97×10^{10} y	β^-	^{87}Sr

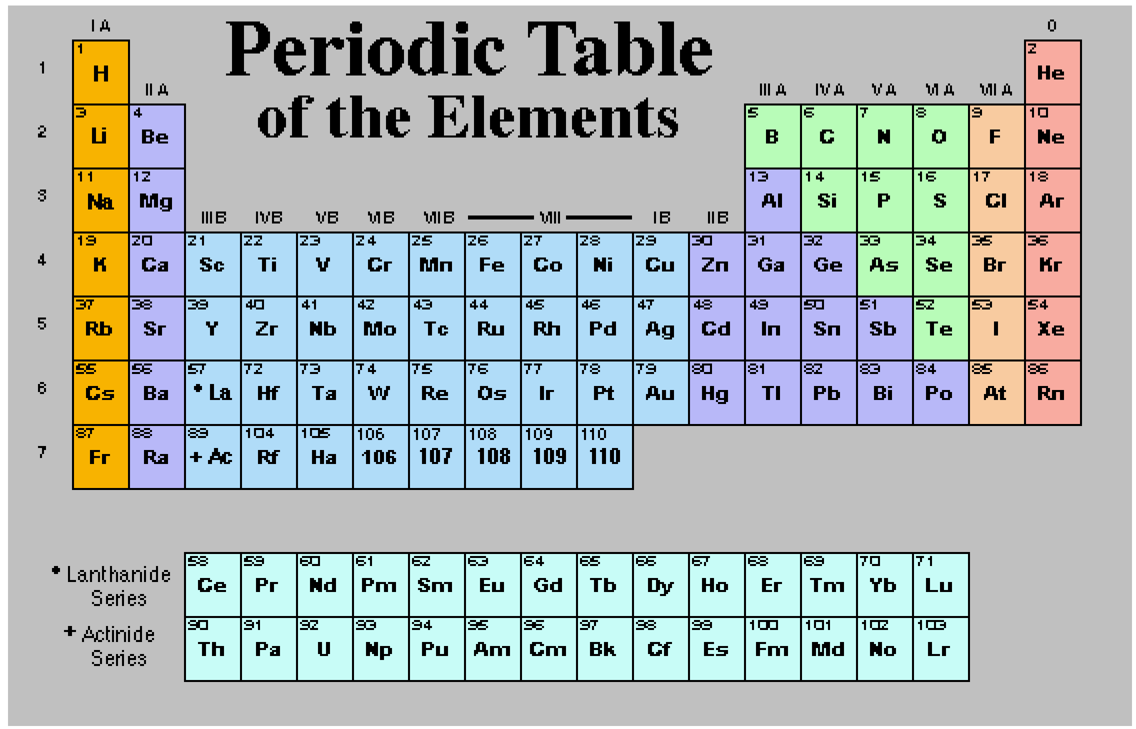
$$27.8\% = 72.2\%\, e^{-\frac{T}{49.7B\,yrs}}\ ?$$

Electron configuration



	S	P	D	F
# of states	2	6	10	14

S S D D D D D D D D D P P P P P filled

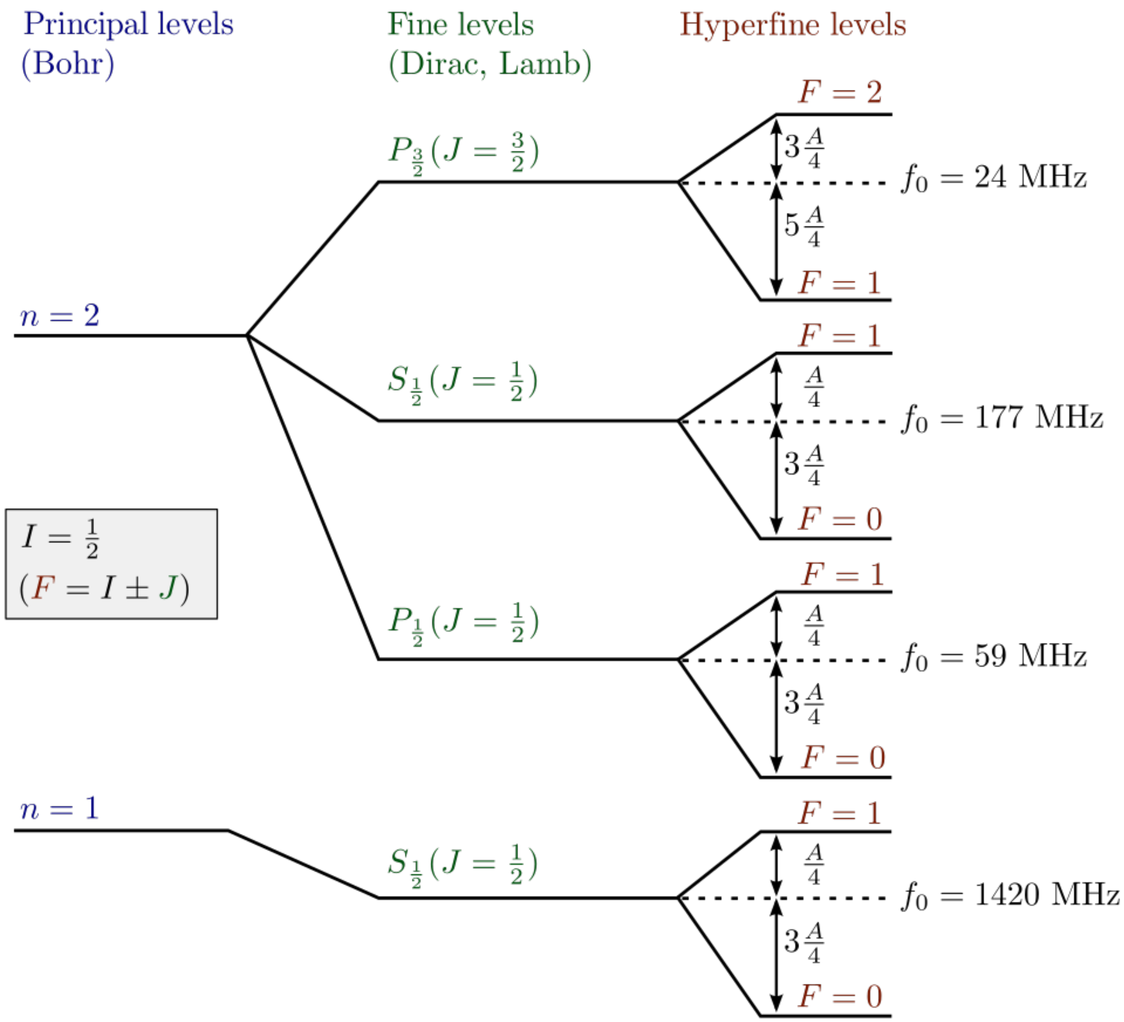


F F F F F F F F F F F F F F

What do S, P, D, F… mean?

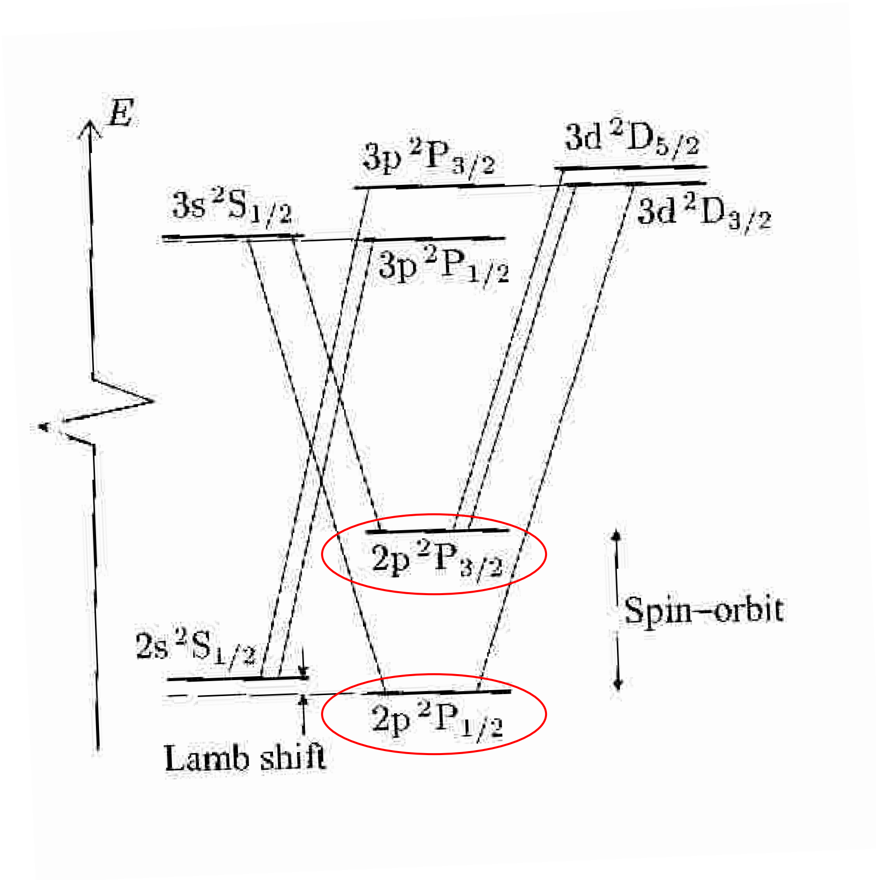
Term symbol: $^{2s+1}L_J$ J=L+S: Total electron angular momentum

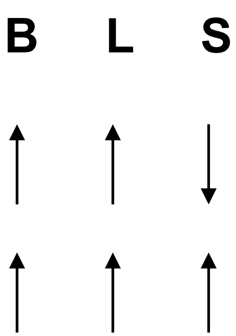
H



H and Alkali metals
Fine structure: spin-orbit interaction

$$H = -\vec{\mu} \cdot \vec{B}_L \sim g_s \mu_B \vec{s} \cdot \vec{L} \sim J(J+1) - l(l+1) - s(s+1)$$



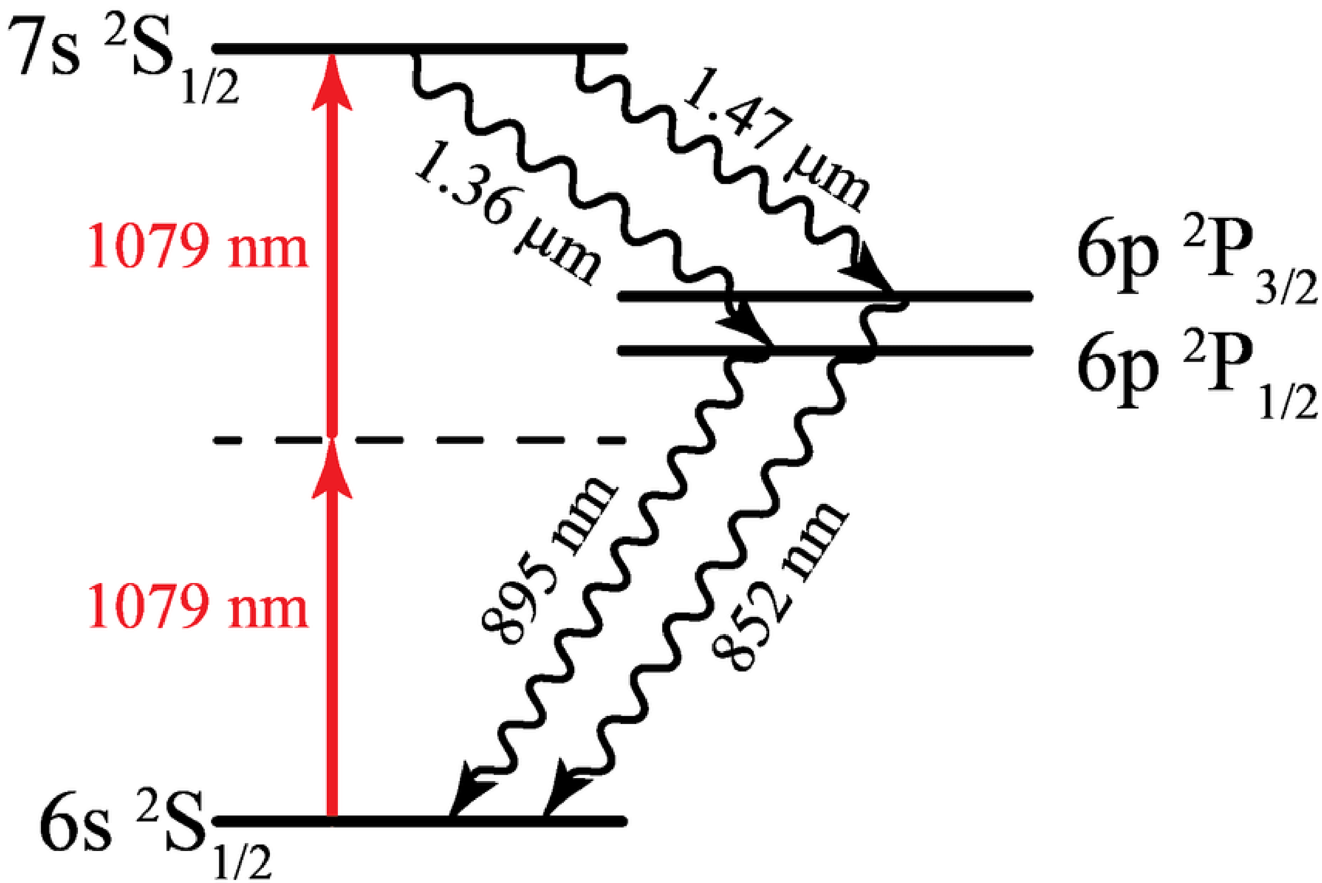


Term:

$^{2s+1}L_J$

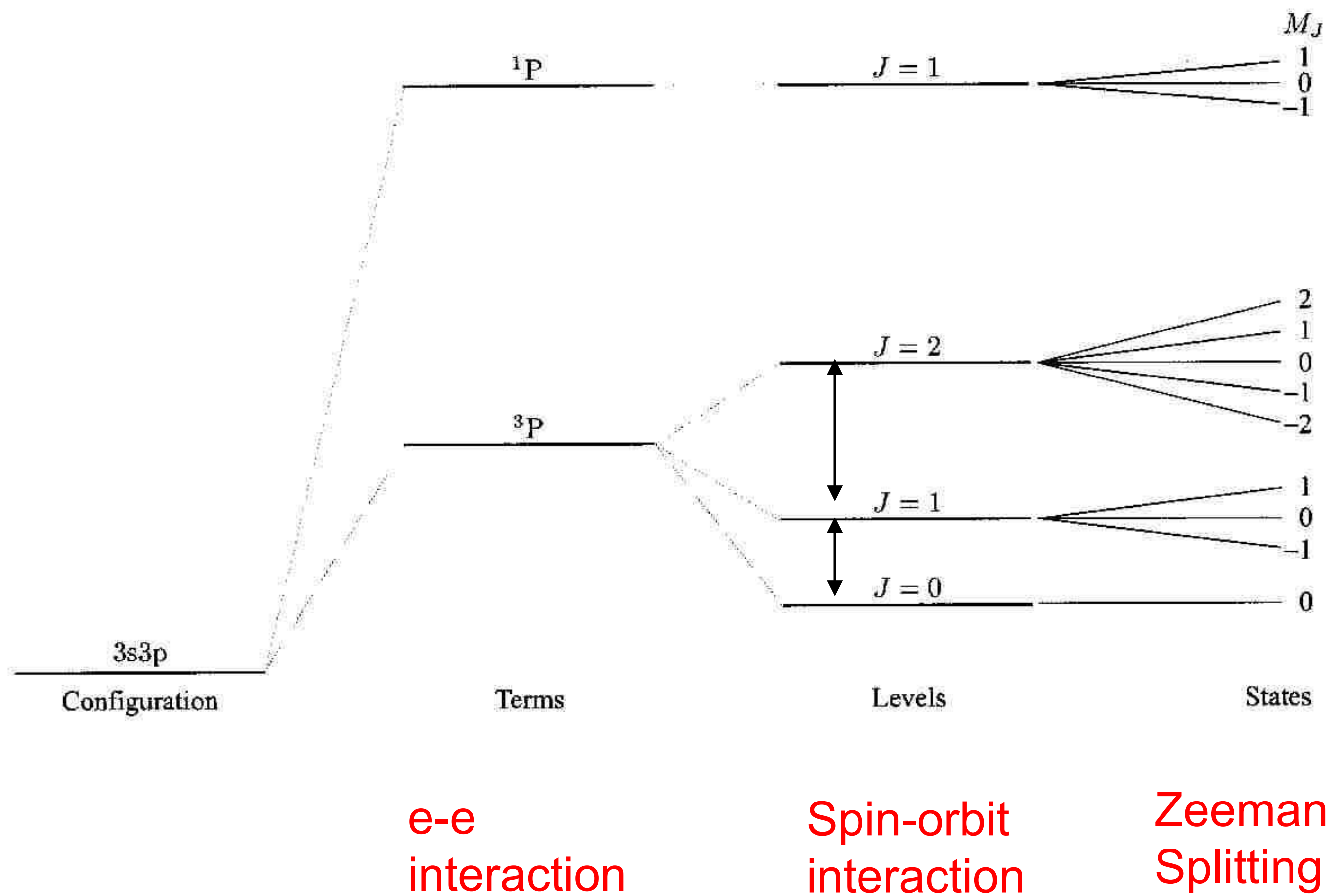
Term symbol: $^{2s+1}L_J$ J=L+S: Total electron angular momentum

Cs



Hyperfine structure skipped here

Term symbol: $^{2s+1}L_J$ J=L+S: Total electron angular momentum



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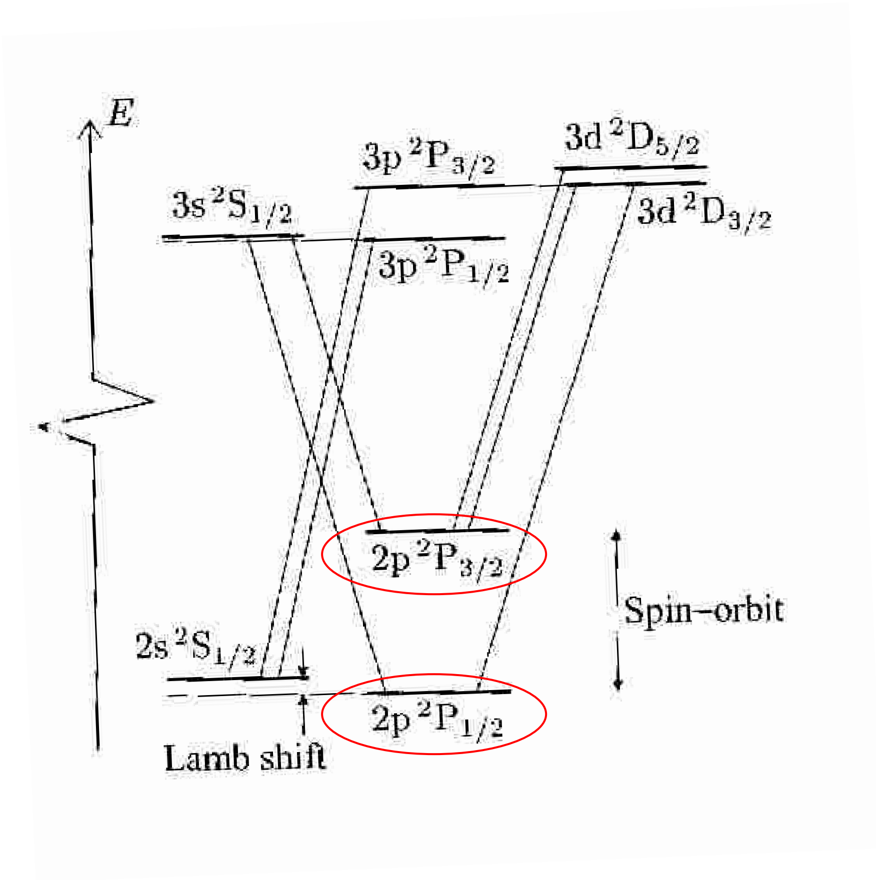
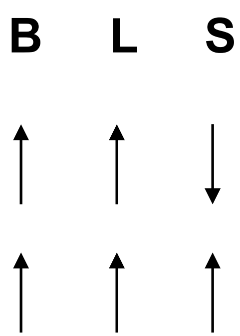
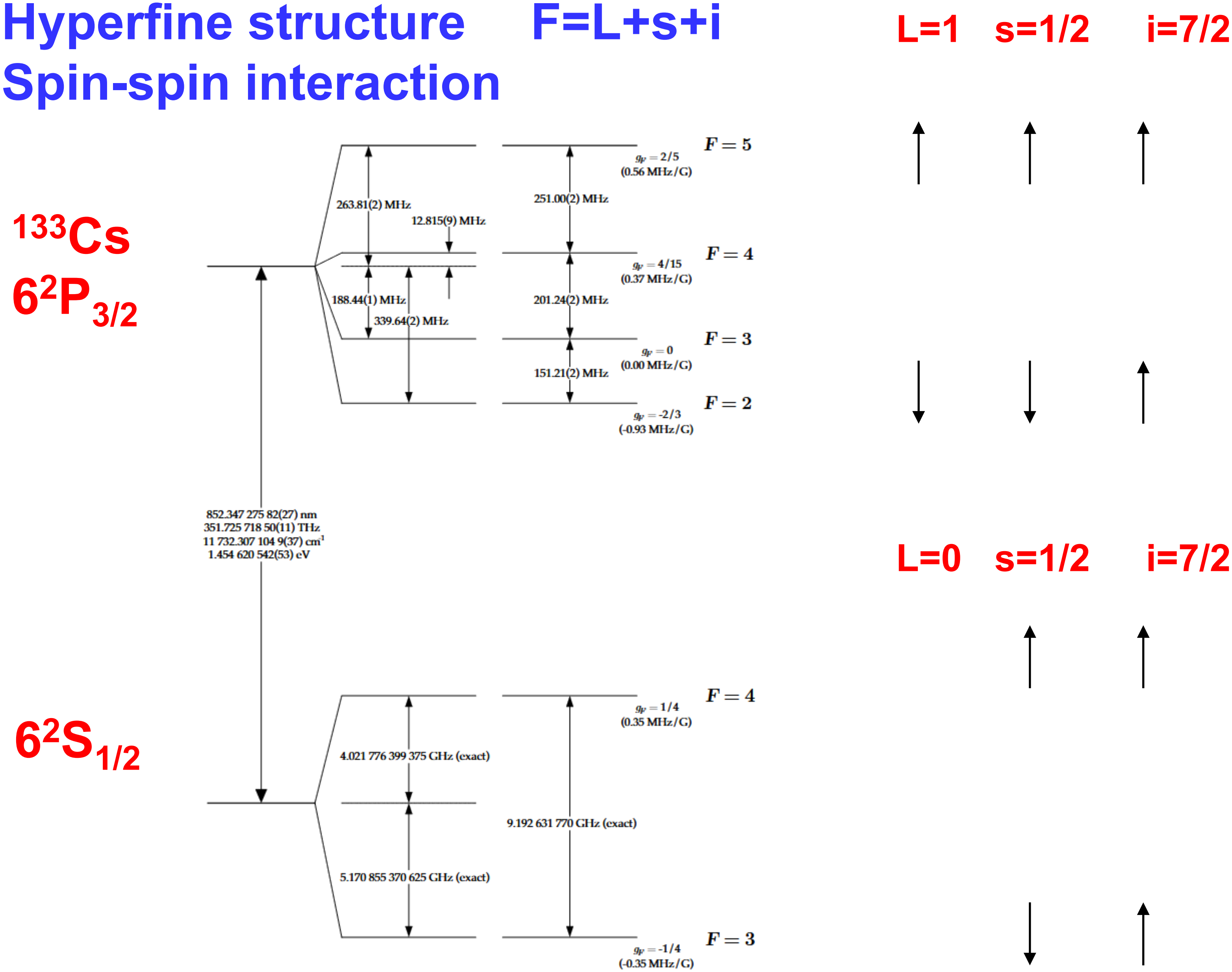




Term:

$^{2s+1}L_J$

Hyperfine structure F=L+s+i
Spin-spin interaction

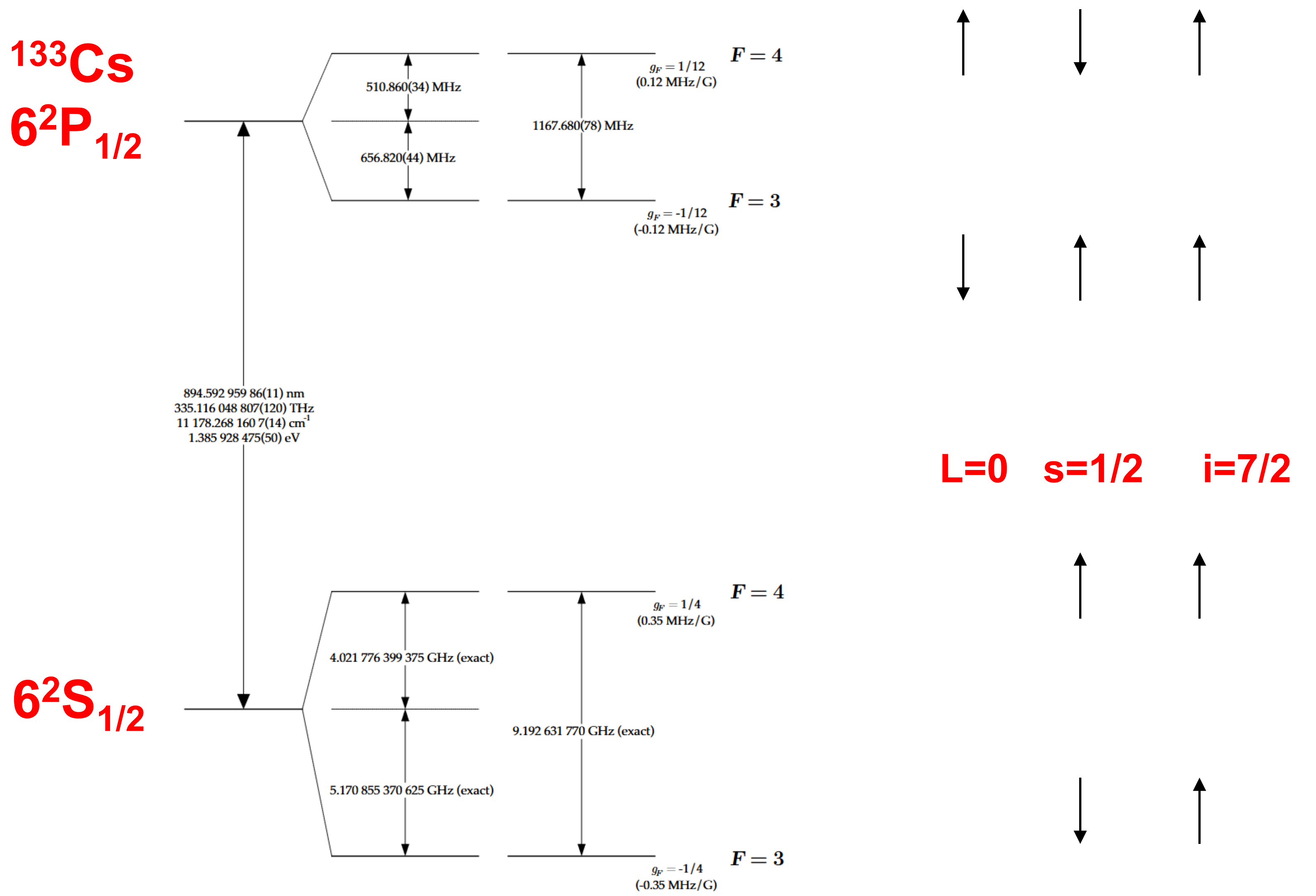


Hyperfine structure F=L+s+i

Spin-spin interaction

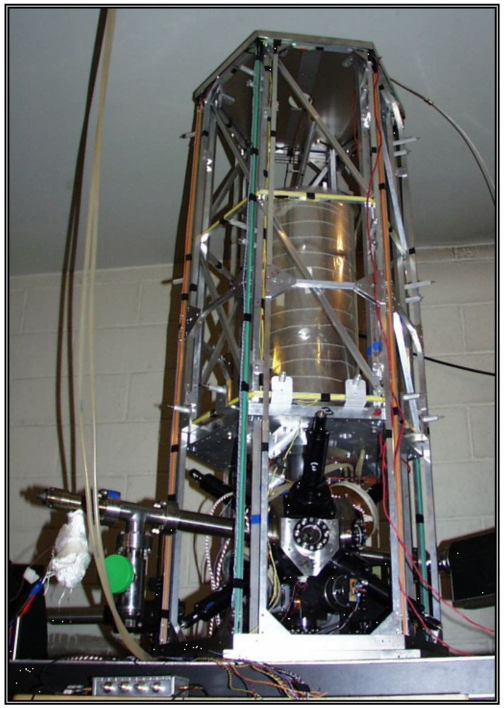
L=1 s=1/2 i=7/2

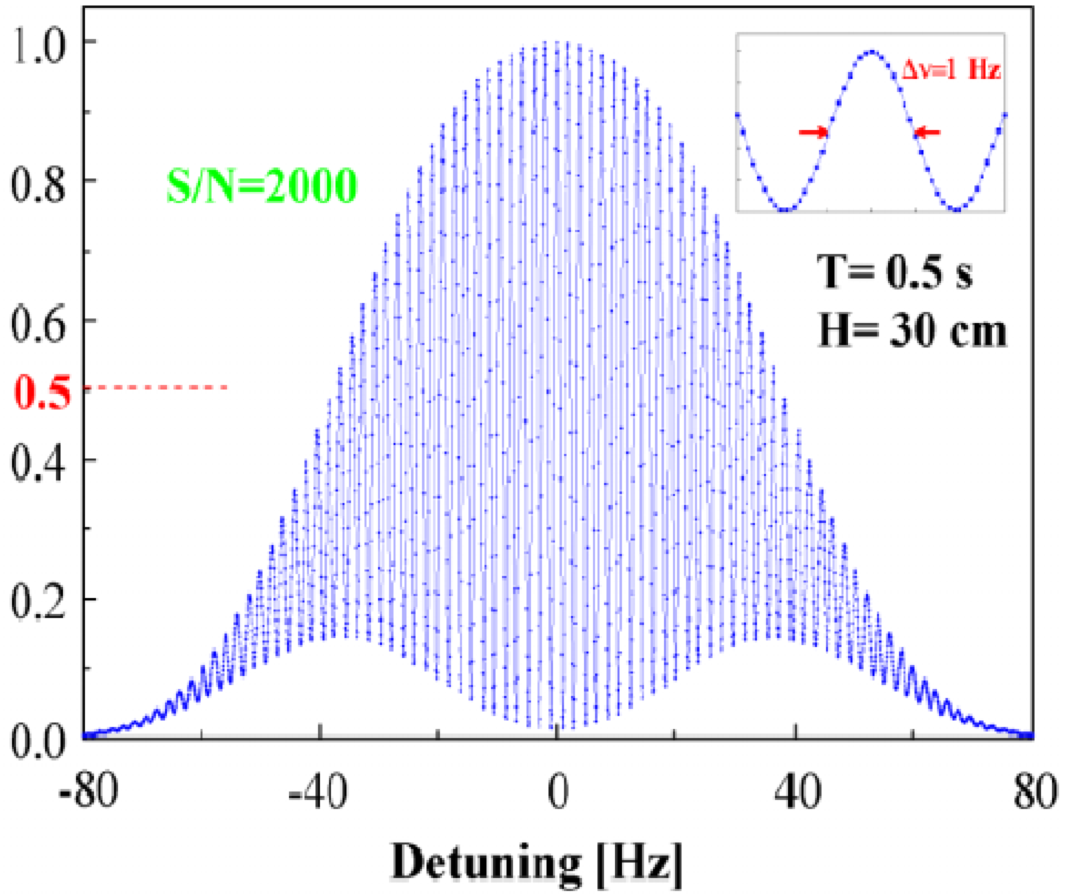
L=0 s=1/2 i=7/2



Ramsey fringes in atomic fountain

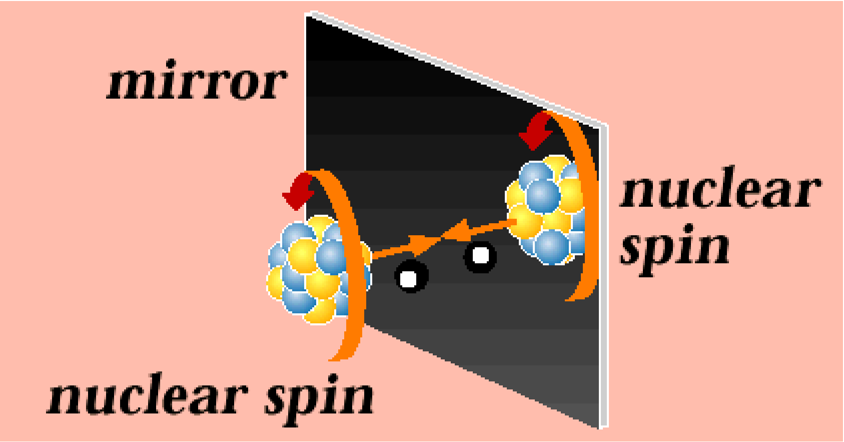
The BNM-LPTF Rubidium fountain





G. Santarelli et al., PRL 82, 4619 (1999)

Test of fundamental symmetry



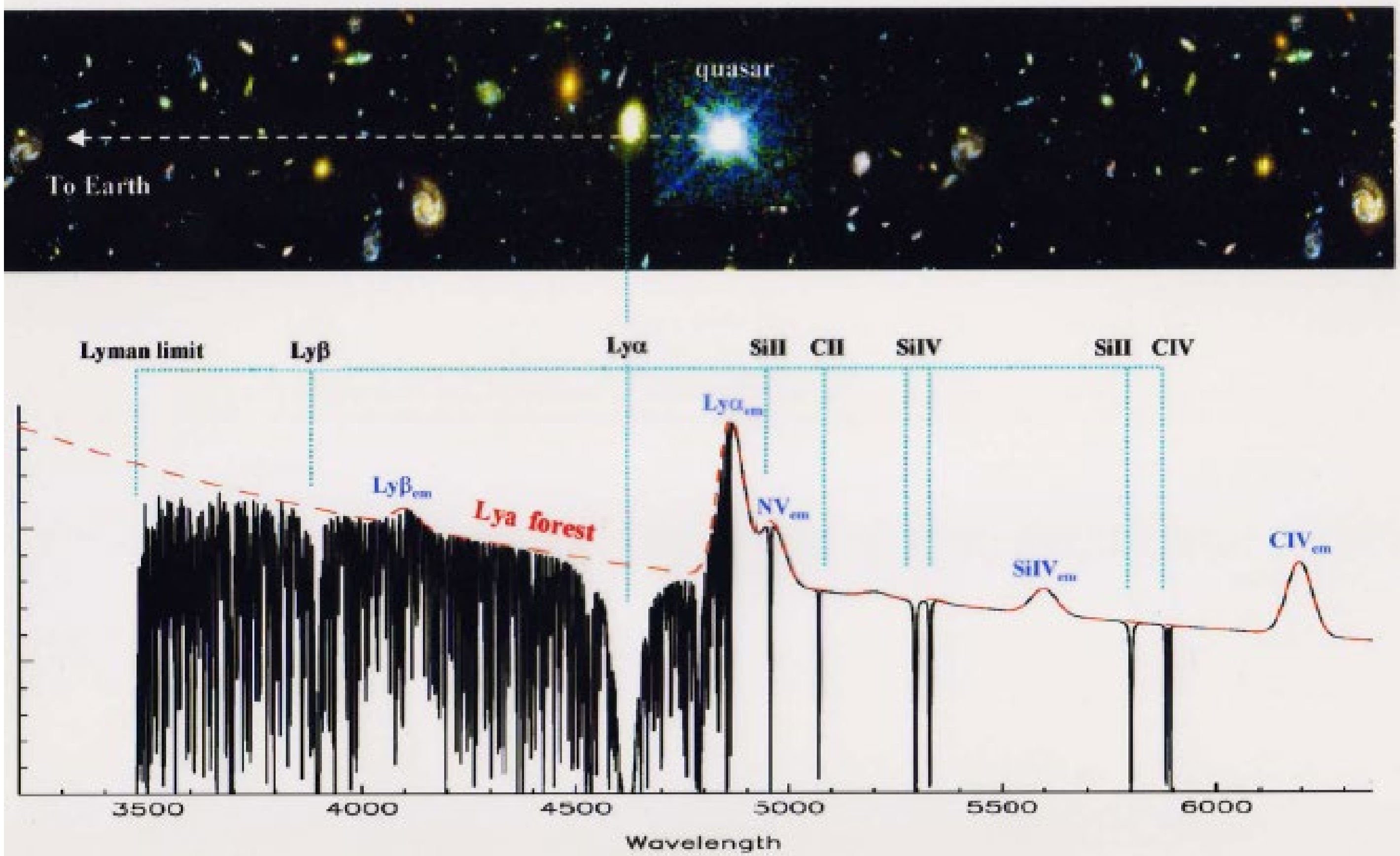
Example:

Electric dipole moment of electrons and ground state atoms

T-reversal symmetry and CPT invariance

Variation of Fundamental constants

4.2 Astrophysical constraints:
Quasars - probing the universe back to much earlier times



So far we have considered ….

Case 1: $H=H_0$ diagonal in s and L

Case 2: $H=H_0+\varepsilon s \cdot L$ small ε

(spin-orbit)

Case 3: $H=H_0+\varepsilon s \cdot L+\delta s \cdot i$ small ε very small δ

(spin-orbit + hyperfine)

Next: $H=H_0+\varepsilon s \cdot L+\delta s \cdot i+s \cdot B$

(spin-orbit, hyperfine and Zeeman effect)

Remark:

1. δ is typically very small
2. $s \cdot L$ is not necessarily small compared to H_0

Zeeman effect in the ground state

$$H = As \cdot L + Bs \cdot i - \vec{\mu} \cdot \vec{B}$$

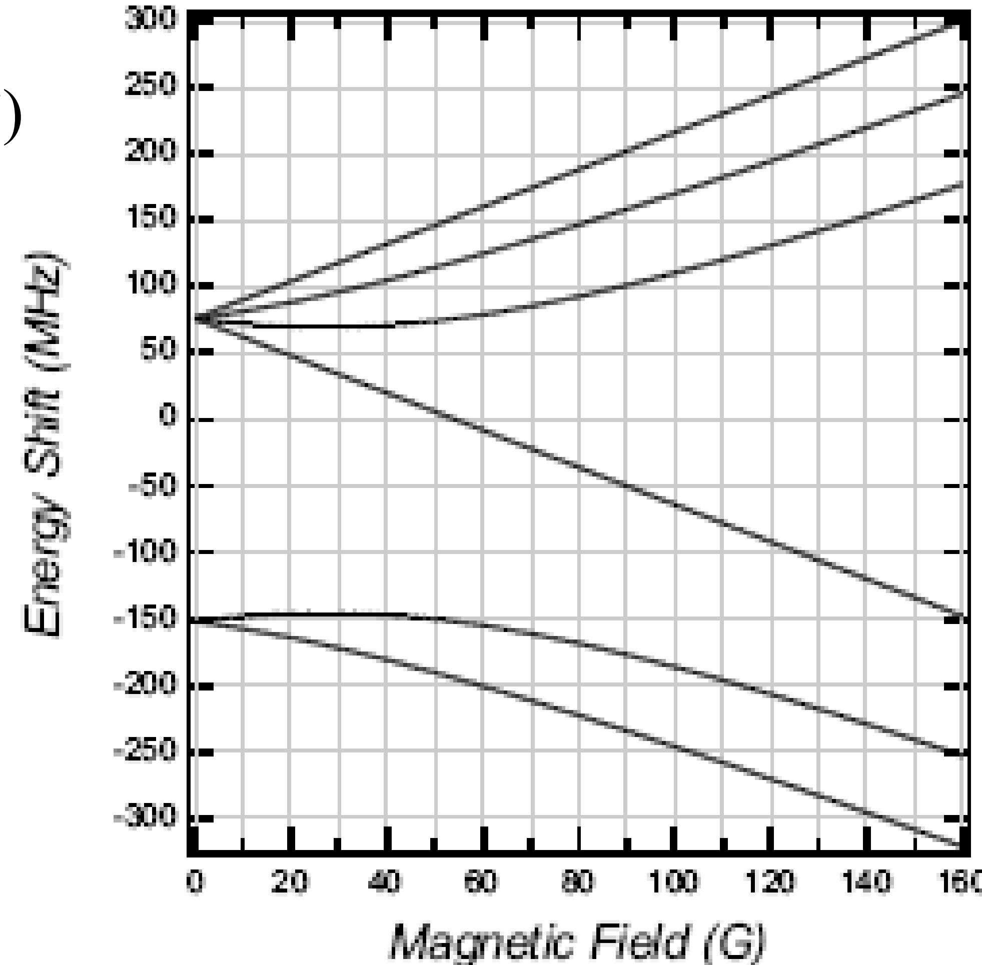
$$\vec{\mu} = -\frac{\mu_B}{\hbar}(g_s S + g_L L + g_i i)$$

F=3/2

^{6}Li

$2^2S_{1/2}$

F=1/2



m_j=1/2

m_j=-1/2

$L = 0$

$s = 1/2$ $\quad g_s = 2.002$

$i = 1$ $\quad g_L = 1.000$

$F = L + s + i$ $\quad g_i = 0.0004$

Zeeman effect in the ground state

$$H = As\cdot L + Bs\cdot i - \vec{\mu}\cdot\vec{B}$$

$$\vec{\mu} = -\frac{\mu_B}{\hbar}(g_s S + g_L L + g_i i)$$

^{6}Li

$2^2P_{3/2}$

F=1/2
F=3/2
F=5/2

$L = 1$

$s = 1/2 \qquad g_s = 2.002$

$i = 1 \qquad g_L = 1.000$

$F = L + s + i \qquad g_i = 0.0004$