

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?

The screenshot shows a web browser window displaying the Chin Lab website. The browser's address bar shows the URL `https://ultracold.uchicago.edu`. The website's navigation menu includes 'People', 'Research', 'News', 'Publications', 'Education', 'Openings', and 'Internal'. The 'Education' menu is expanded, showing 'Physics Courses', 'SMART Program', and 'Taiwan Exchange'. A red arrow points to the 'Physics Courses' option. The main content area features a blue background with a pattern of light spots and a white line graph at the bottom. The text reads: 'Bose Fireworks' and 'The Cesium experiment uses parametric modulation to create matter-wave fireworks in a Bose-Einstein condensate of Cesium atoms.' A 'Read more' button is visible below the text. The Windows taskbar at the bottom shows the search bar and various application icons.

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Google Sheets: Onli...

Winter 2024 P471

Physics 47100 Introduction to Atomic Physics

Day/Time: MW 9:00 - 10:20 am

Location: KPTC 105

Lecturer: Cheng Chin cchin@uchicago.edu

Office: GCIS 107

Office Hours: TuTh 11 am - noon

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

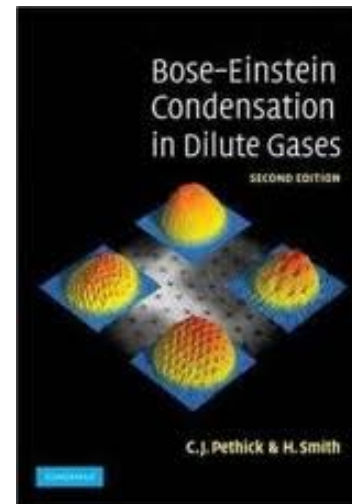
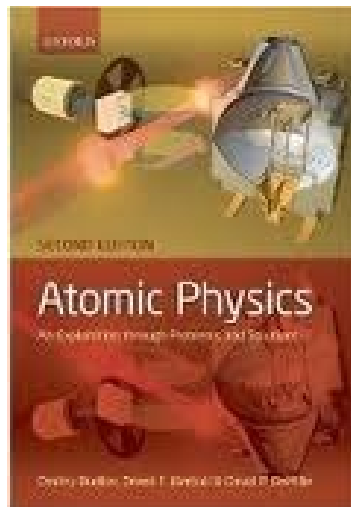
Evaluation

- Problem sets
- Presentation or term paper

Recommended Textbooks

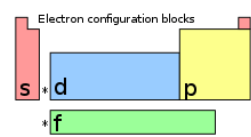
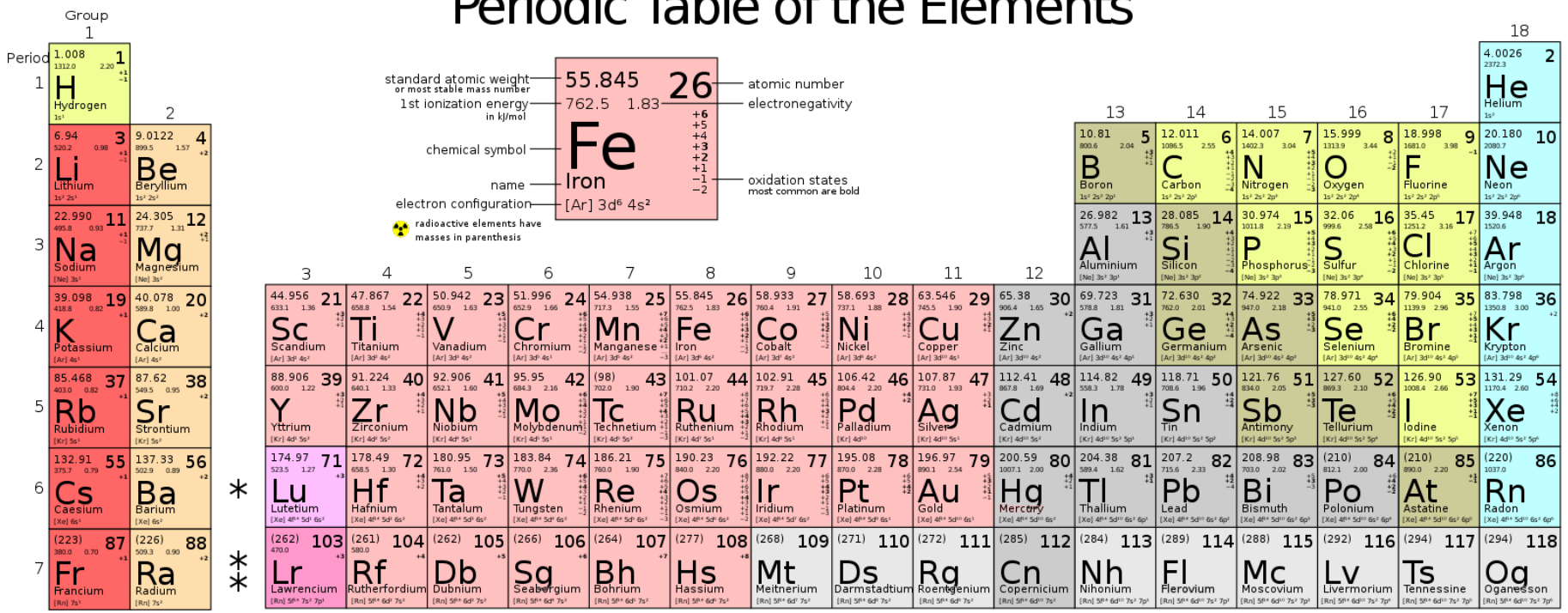
Atomic Physics, D. Budker, D. F. Kimball, D. P. DeMille 2010

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



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Periodic Table of the Elements



- Notes
- 1 u/mol ≈ 0.01093636 eV
 - all elements are implied to have an oxidation state of zero

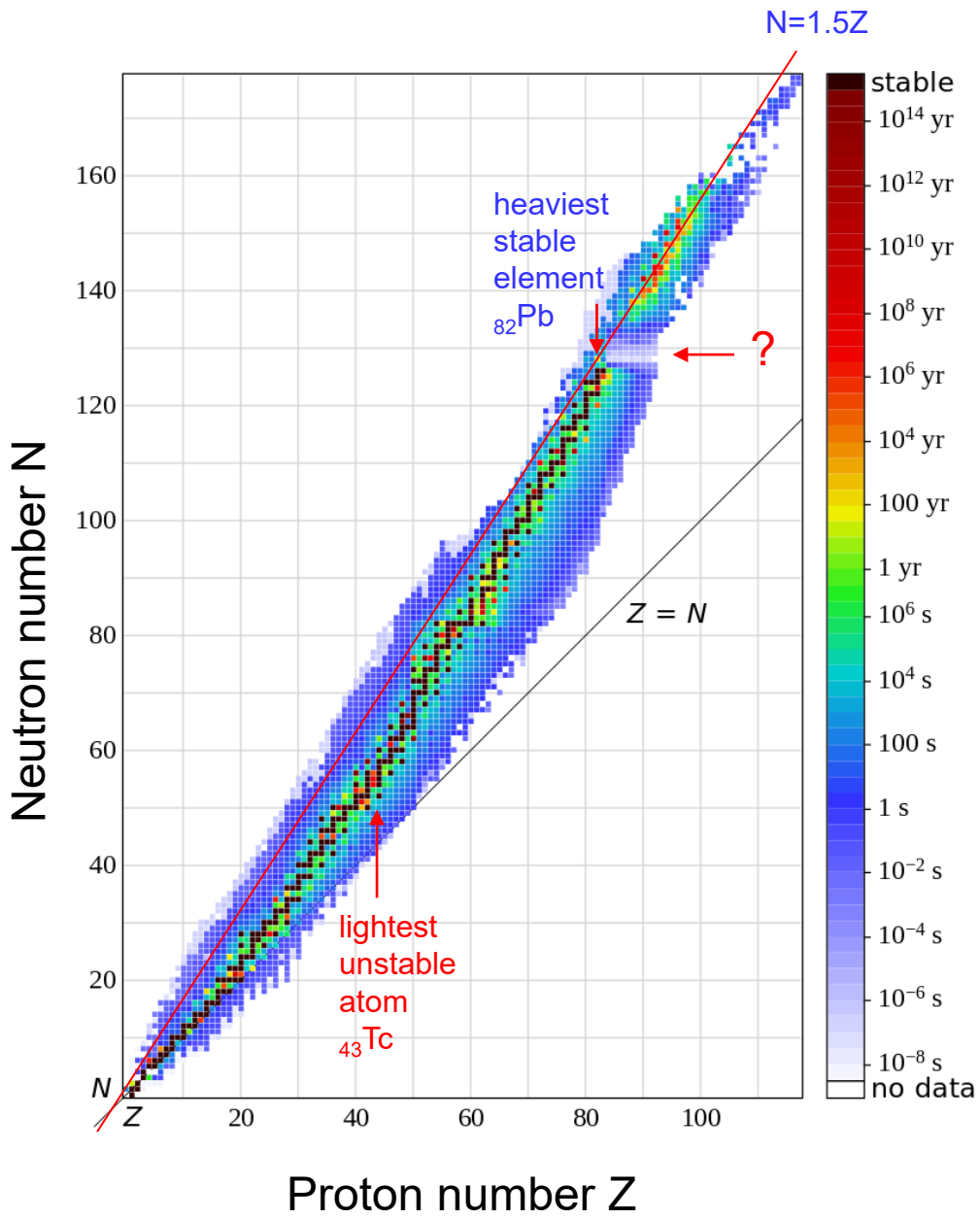
by Robert Campion / updated 2016, 2018



Atomic number $Z = \#$ of protons

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

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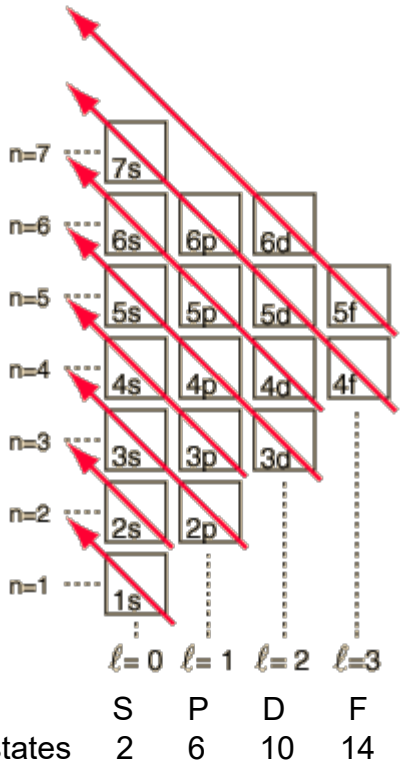
Isotopes of rubidium ($_{37}\text{Rb}$)

Main isotopes ^[1]			Decay	
	abundance	half-life ($t_{1/2}$)	mode	product
^{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

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

Electron configuration

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



Periodic Table of the Elements

																		1A											0
1	H																	He											
2	Li	Be											B	C	N	O	F	Ne											
3	Na	Mg											Al	Si	P	S	Cl	Ar											
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr											
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe											
6	Cs	Ba	* La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn											
7	Fr	Ra	+ Ac	Rf	Ha	106	107	108	109	110																			

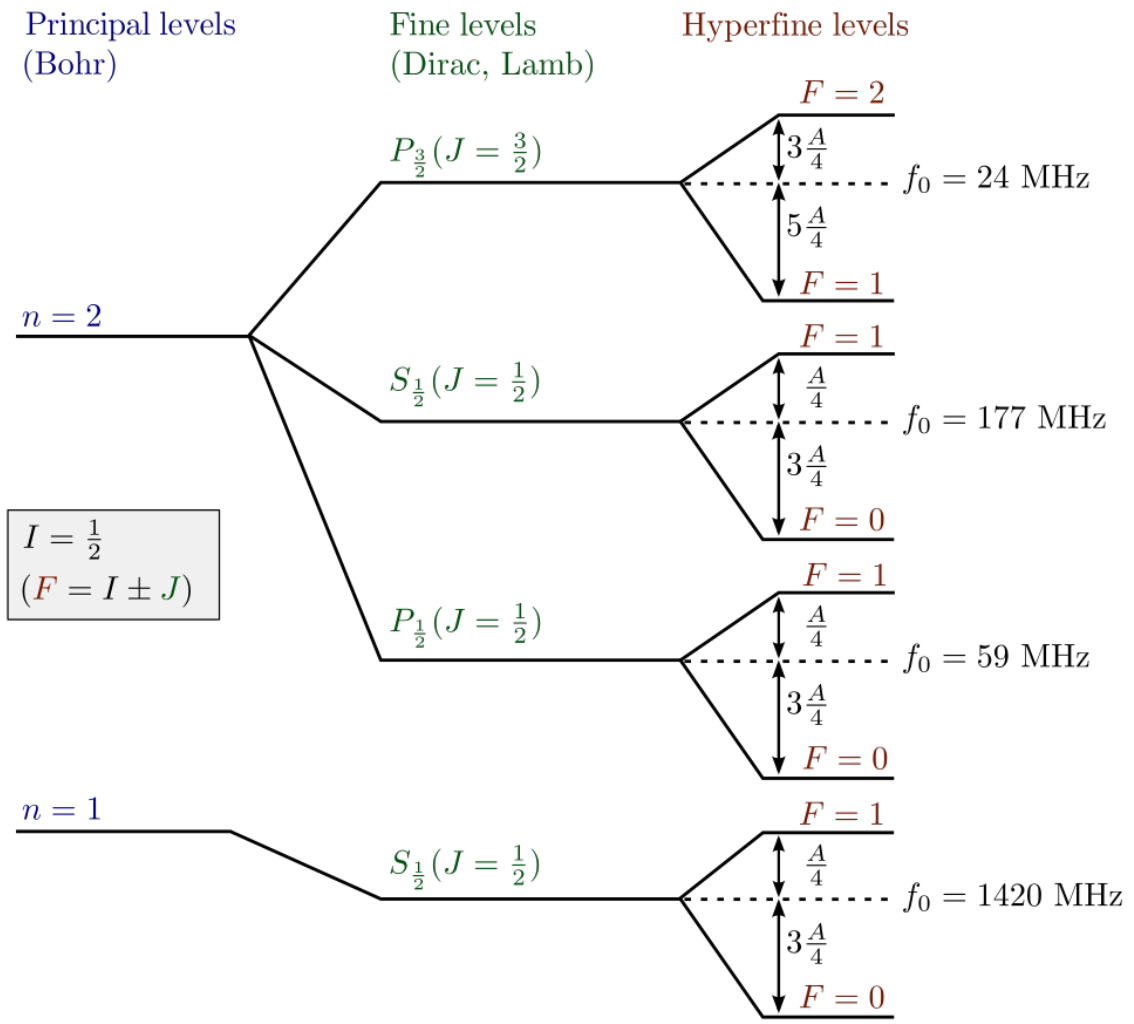
* Lanthanide Series	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
+ Actinide Series	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

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

What do S, P, D, F... mean?

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

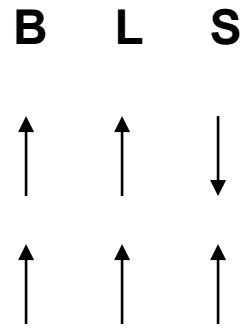
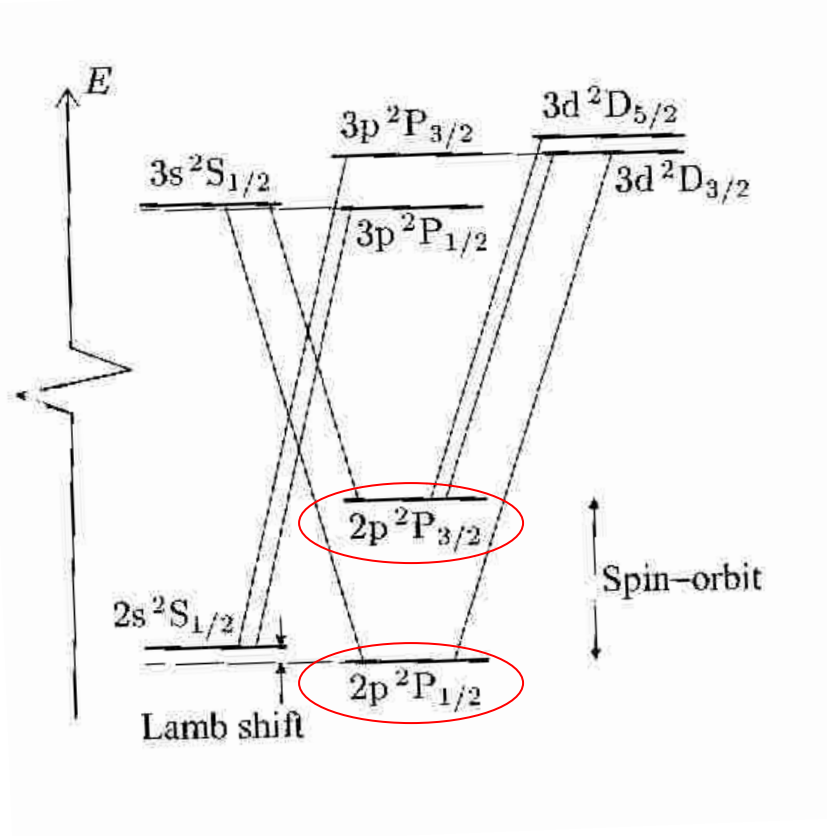
H



H and Alkali metals

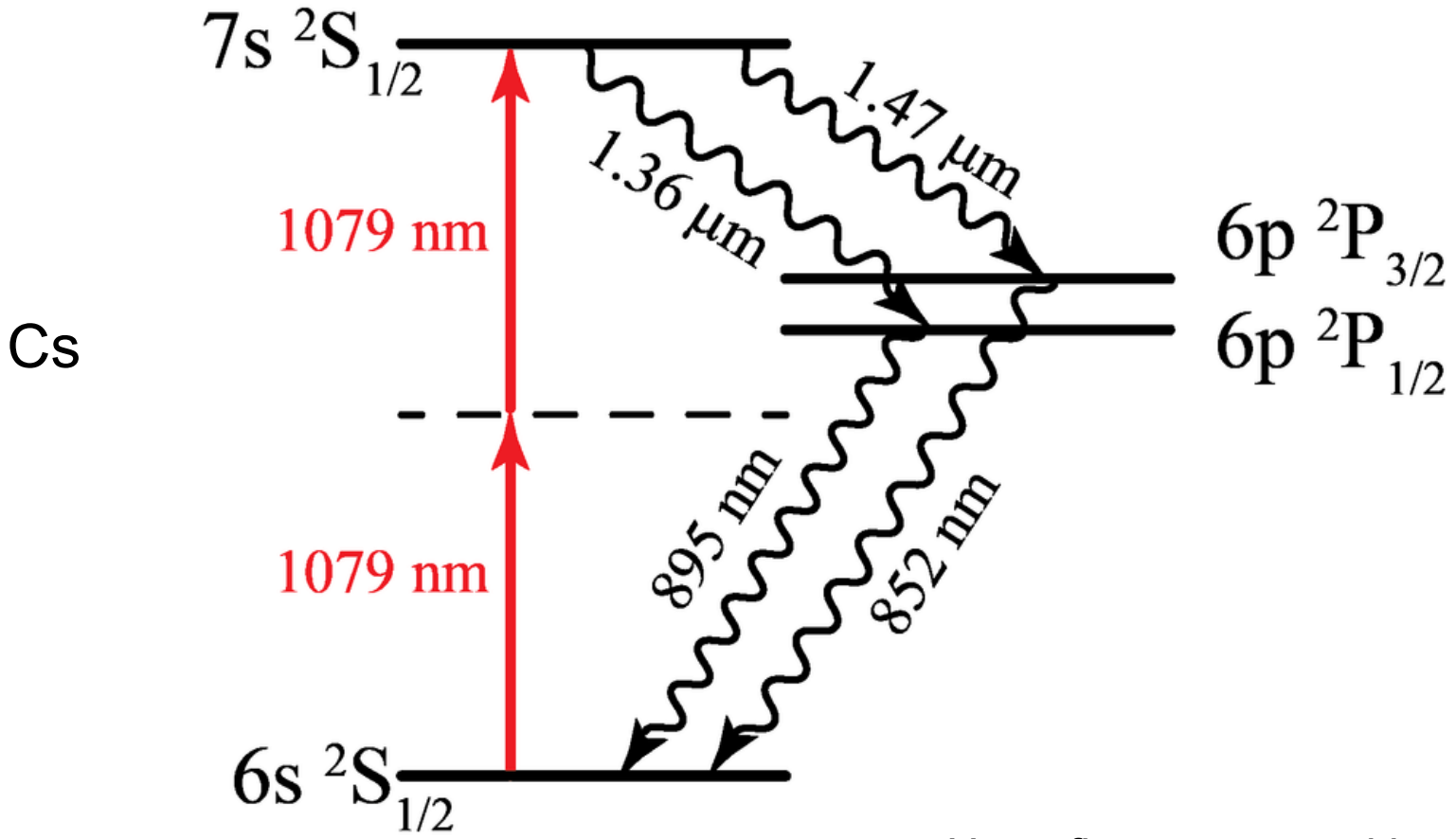
Fine structure: spin-orbit interaction

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



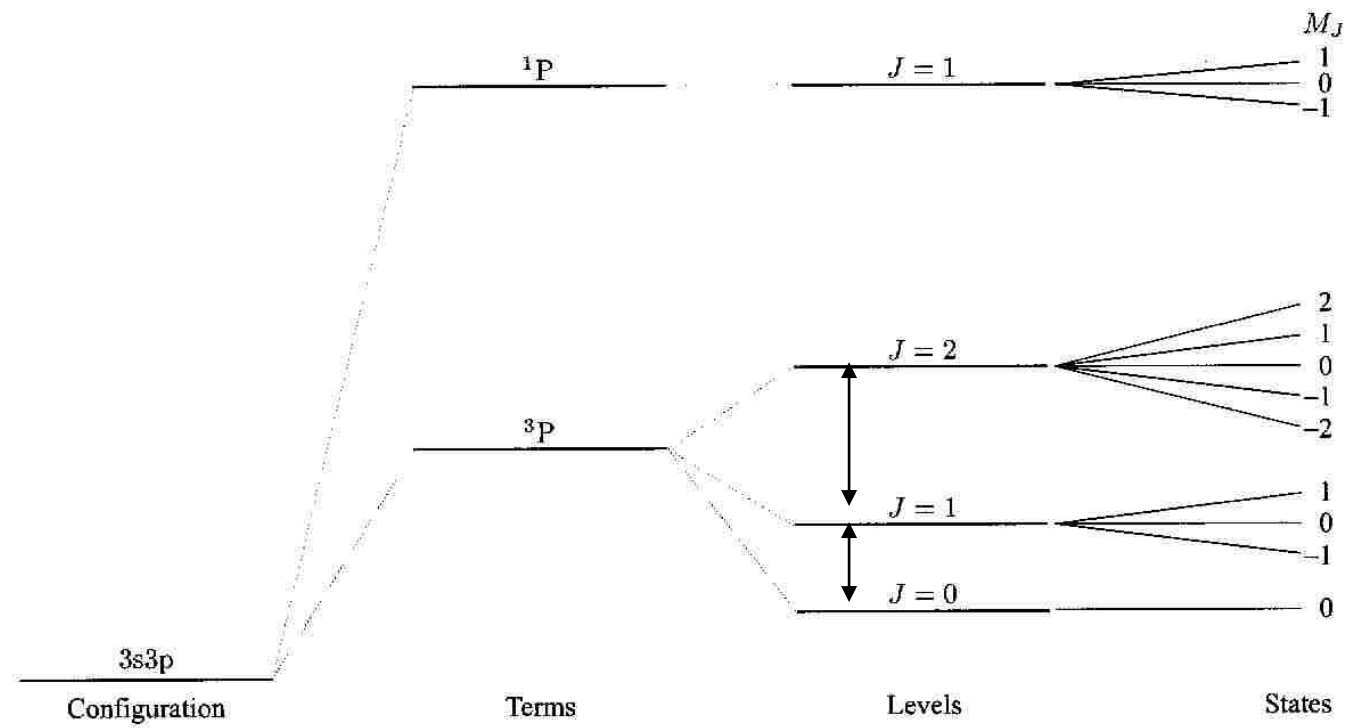
Term:
 $2s+1 L_J$

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



Hyperfine structure skipped here

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



e-e interaction

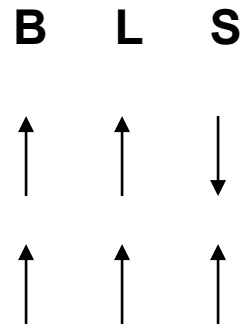
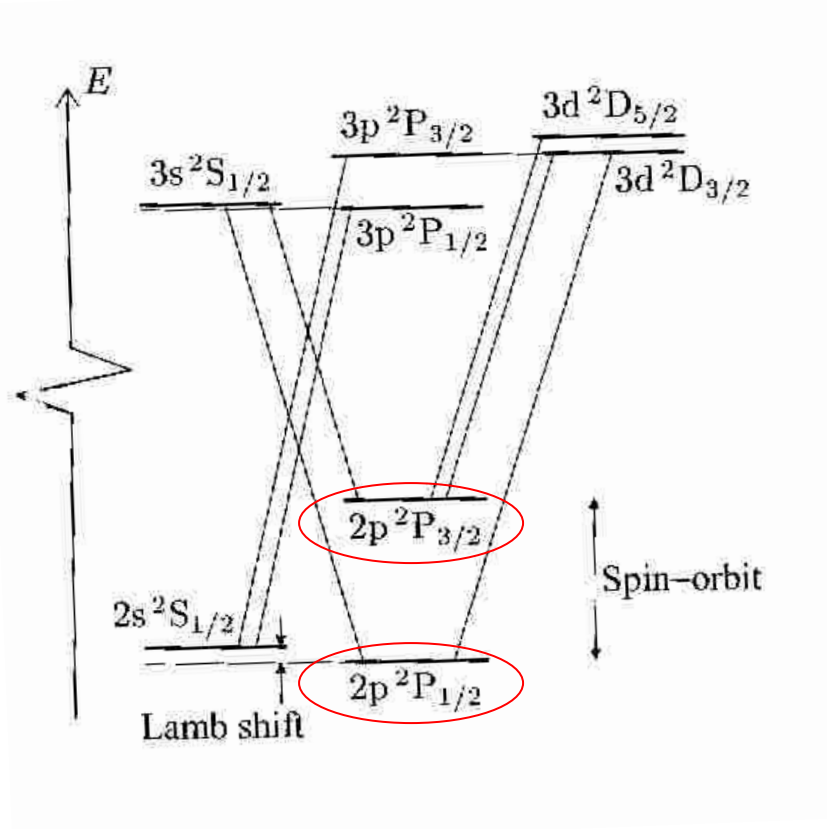
Spin-orbit interaction

Zeeman Splitting

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:

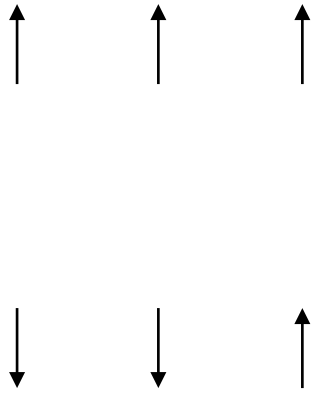
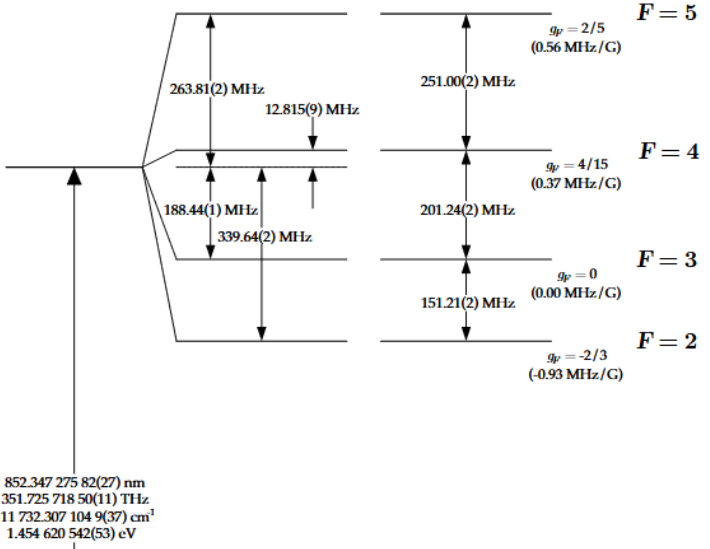
$2s+1 L_J$

Hyperfine structure
Spin-spin interaction

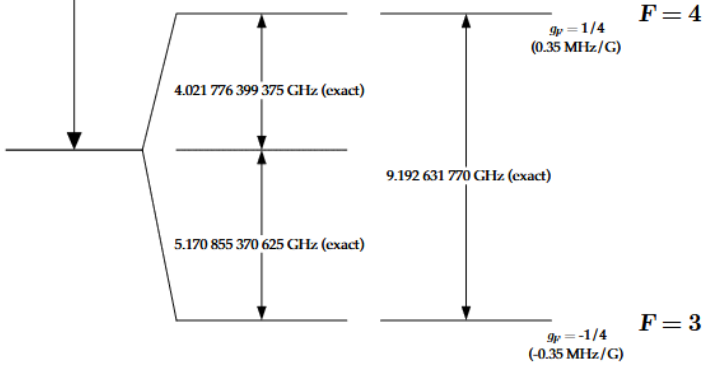
$F=L+s+i$

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

^{133}Cs
 $6^2\text{P}_{3/2}$



$6^2\text{S}_{1/2}$

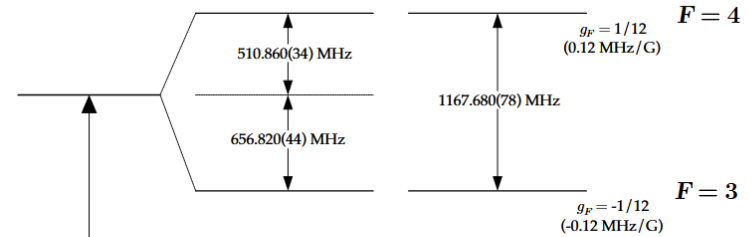


$L=0$ $s=1/2$ $i=7/2$

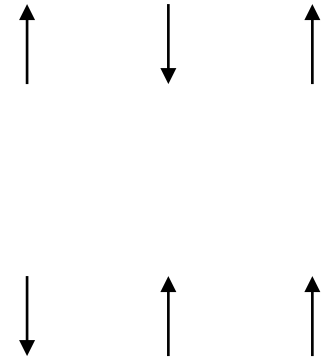


Hyperfine structure $F=L+s+i$ Spin-spin interaction

^{133}Cs
 $6^2\text{P}_{1/2}$

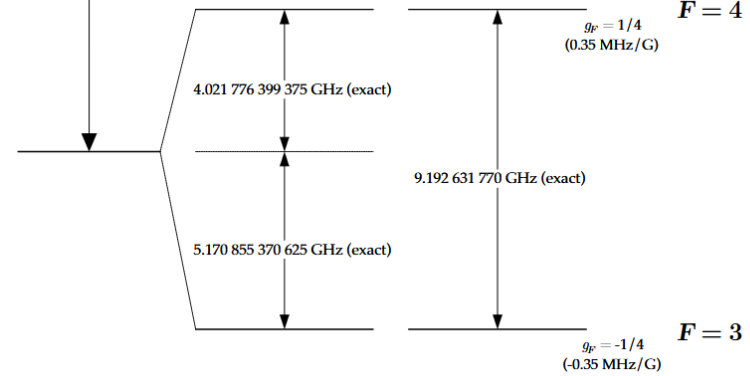


$L=1$ $s=1/2$ $i=7/2$



894.592 959 86(11) nm
335.116 048 807(120) THz
11 178.268 160 7(14) cm^{-1}
1.385 928 475(50) eV

$6^2\text{S}_{1/2}$

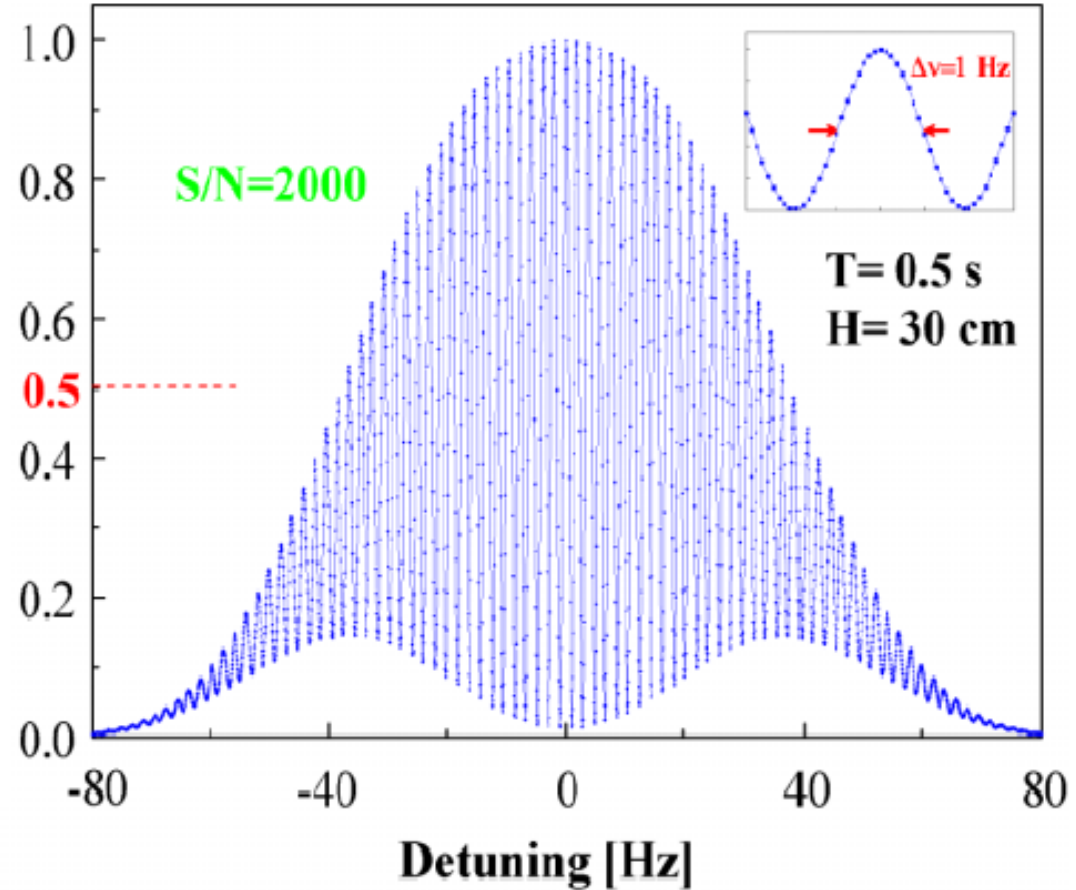
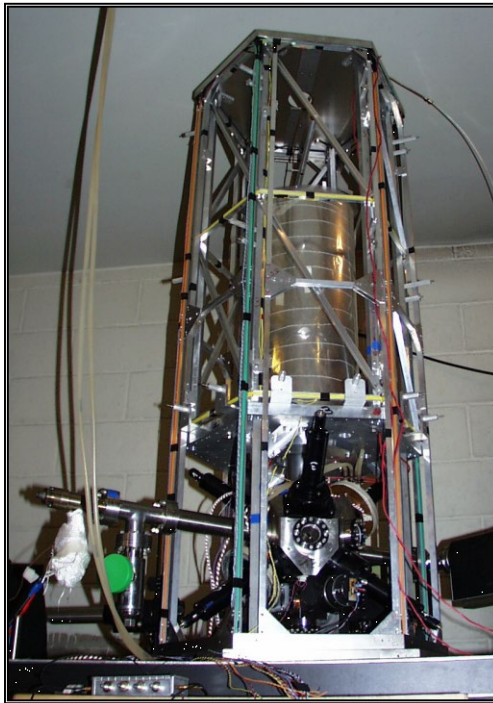


$L=0$ $s=1/2$ $i=7/2$



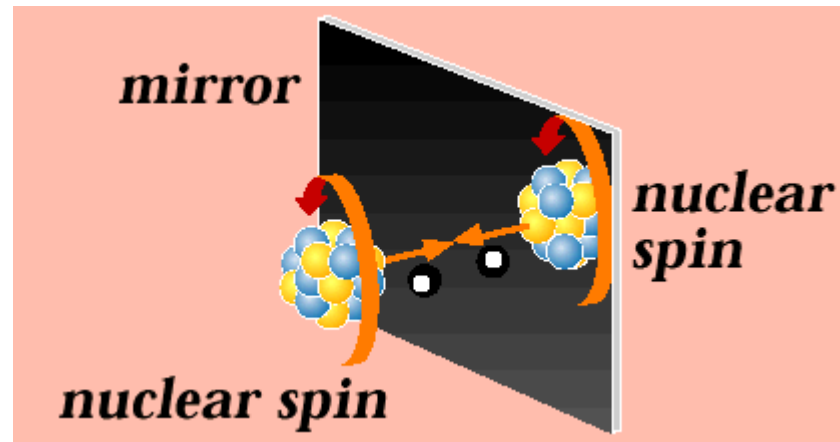
Ramsey fringes in atomic fountain

The BNM-LPTF Rubidium fountain



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

Test of fundamental symmetry



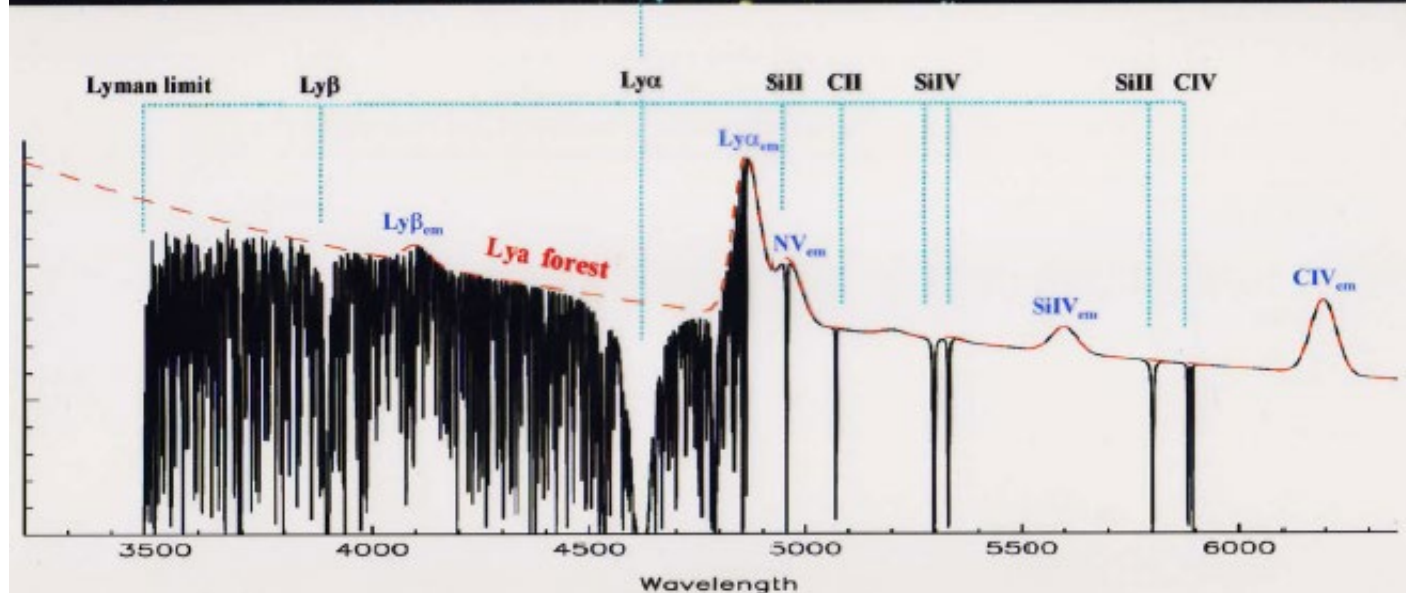
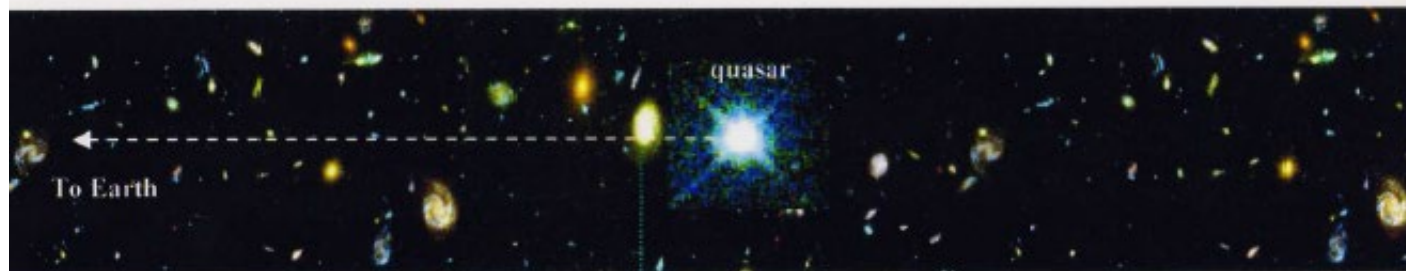
Example:

**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: $H=H_0+\varepsilon\mathbf{s}\cdot\mathbf{L}$ small ε
(*spin-orbit*)

Case 3: $H=H_0+\varepsilon\mathbf{s}\cdot\mathbf{L}+\delta\mathbf{s}\cdot\mathbf{i}$ small ε very small δ
(*spin-orbit + hyperfine*)

Next: $H=H_0+\varepsilon\mathbf{s}\cdot\mathbf{L}+\delta\mathbf{s}\cdot\mathbf{i}+\mathbf{s}\cdot\mathbf{B}$
(*spin-orbit, hyperfine and Zeeman effect*)

Remark:

1. δ is typically very small

2. $\mathbf{s}\cdot\mathbf{L}$ is not necessarily small compared to H_0

Zeeman effect in the ground state

$$H = A_s \cdot L + B_s \cdot i - \bar{\mu} \cdot \bar{B}$$

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

F=3/2

⁶Li
2²S_{1/2}

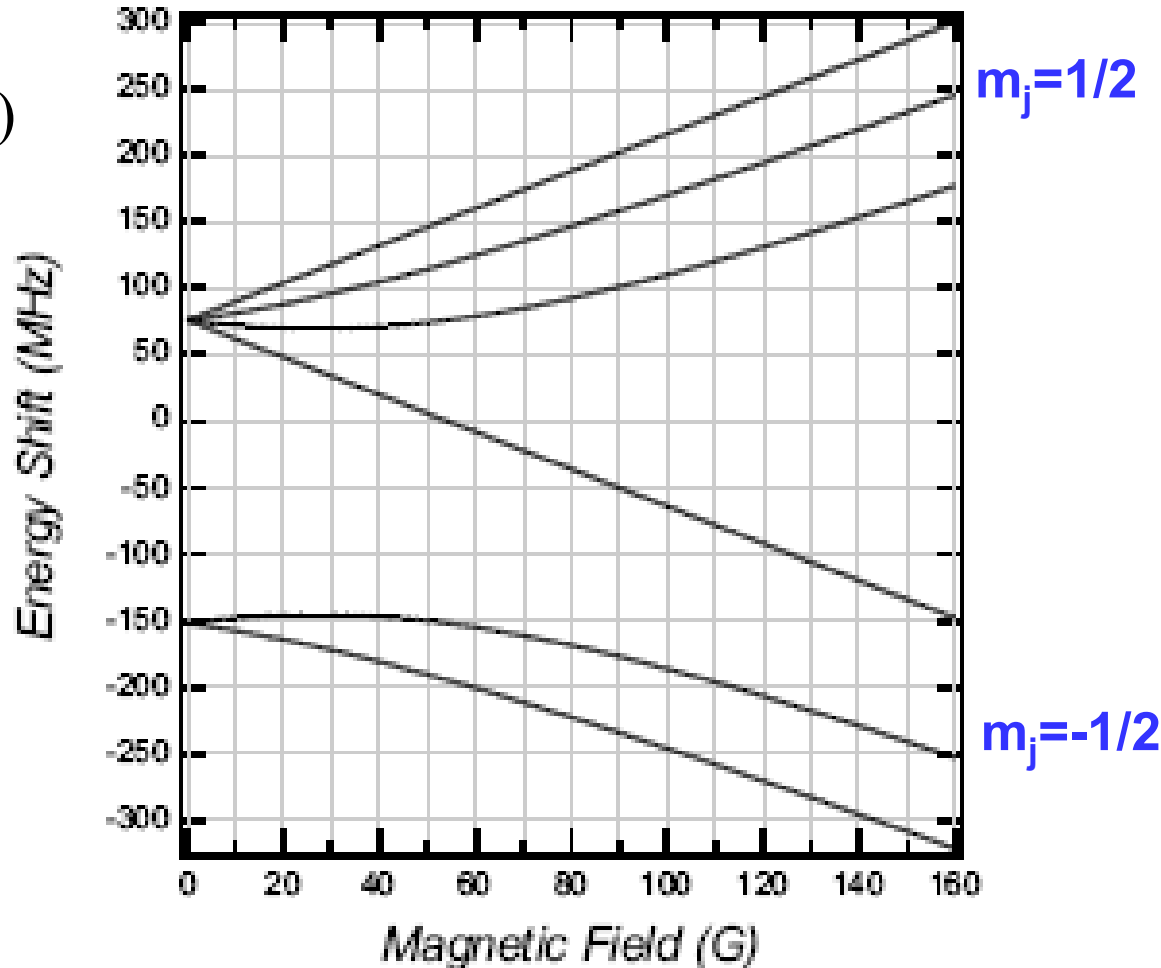
F=1/2

$$L = 0$$

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

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

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



Zeeman effect in the ground state

$$H = A_s \cdot L + B_s \cdot i - \vec{\mu} \cdot \vec{B}$$

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

${}^6\text{Li}$
 $2^2\text{P}_{3/2}$

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

$$L = 1$$

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

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

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

Energy Shift (MHz)

