Larry J Curtis 1935-2020:

A brief history: his revelations in atomic structure and dynamics

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Abstract

I will very briefly review the 40 year career of Larry Curtis and his discoveries both experimental and theoretical in atomic physics.

The focus will be limited to three atomic physics areas in which he played a principal part: these include the first observations of light from oriented atoms; observations of light from doubly-excited states in light atoms (helium and lithium). These include the verification of the only light ever observed from a negative atomic ion; thirdly, his theoretical analysis multiple exponential decays, enhancing the precision of beam-foil measurements of atomic lifetimes.

Finally, some reminiscences about his personal life, his Swedish honorary doctorate, his wife Maj Rosander, and other European adventures.

Larry's address at the 1992 University of Toledo Graduation Ceremonies

…… A lot of nice things have happened to me since my Commencement. I'd like to recount for you one example, that occurred exactly 13 years after my graduation. I had been invited by the President of Stockholm University to supervise the Examination of a Swedish Doctoral Candidate. I can recall my thoughts at that time; I was addressing the faculty in an elegant Grand Hall in Stockholm; I was dressed in white tie and tails; I was speaking entirely in Swedish; and I was describing some fascinating new research developments. It was an exhilarating examination: That particular Doctoral Candidate is now the Vice Chair of Physics in the Royal Swedish Academy of Sciences, and he supervises the selection and awarding of the Nobel Prizes. But I remember thinking to myself as I stood there: "How did a kid from Libbey High School get into this place?"
………….

WHO?

Indrek Martinson

Early research activities

Larry played varsity baseball in high school and college; (*tried out for pro-baseball!)*
later, he played the violin in community symphony orchestras, operas, operettas, and musical comedies

Undergraduate at University of Toledo.   (1954-58)

1. He worked with Ed Foster to design and construct a subcritical nuclear reactor.
2. Summer job at the Surface Combustion Corporation developed and prototyped a Pelletizing Furnace for Taconite ores at the mining site.

Graduate at University of Michigan.   (1958-1963)

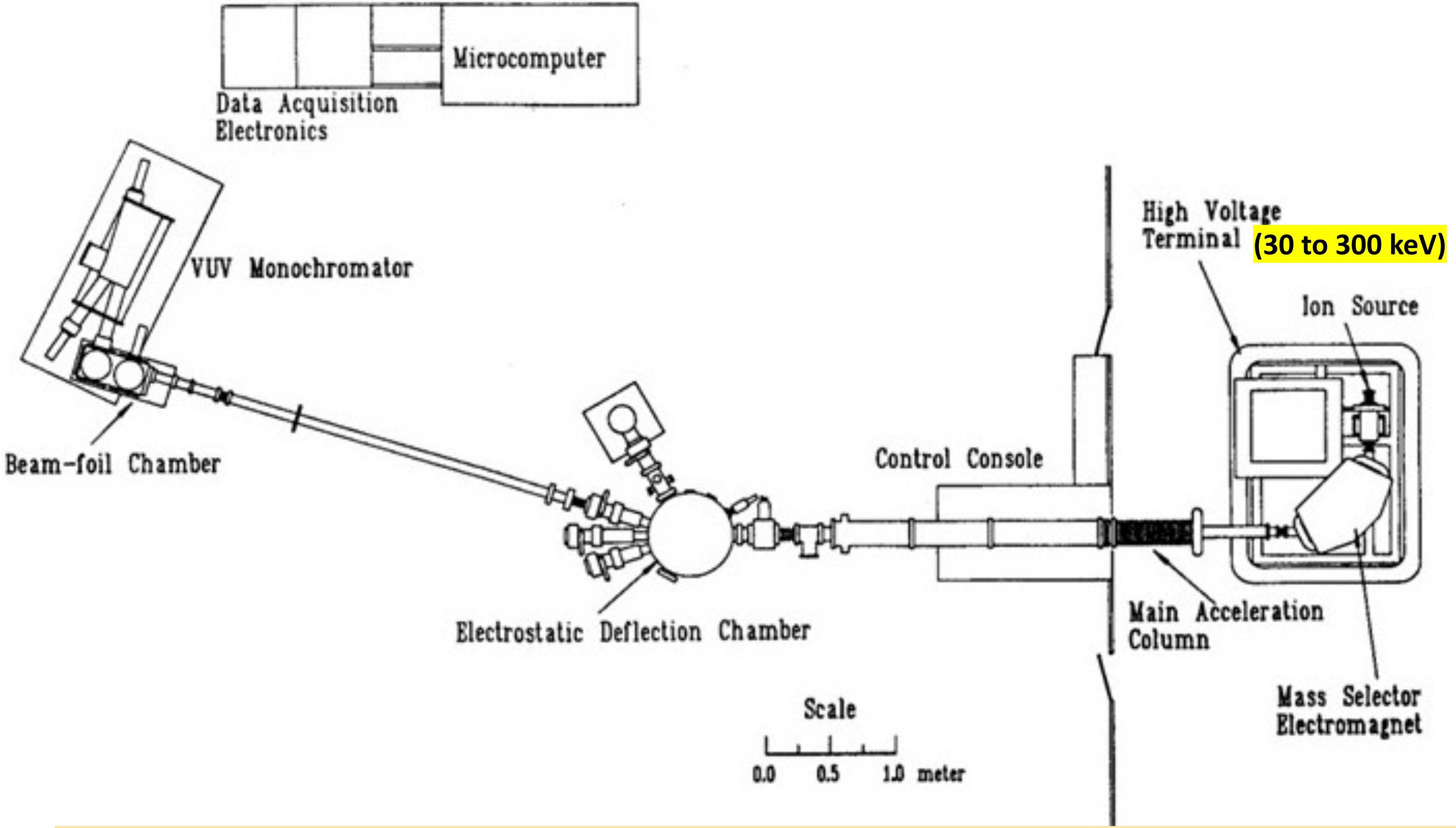
1. Mentor Martin Perl: PhD. Degree in high energy physics.
2. Summer: Woods Hole Oceanographic Institution: constructed a hydrophone array to study the ocean floor by continuous seismic profiling (boat followed by dolphins).

Larry returned to the Physics and Astronomy Department at Toledo (1962)

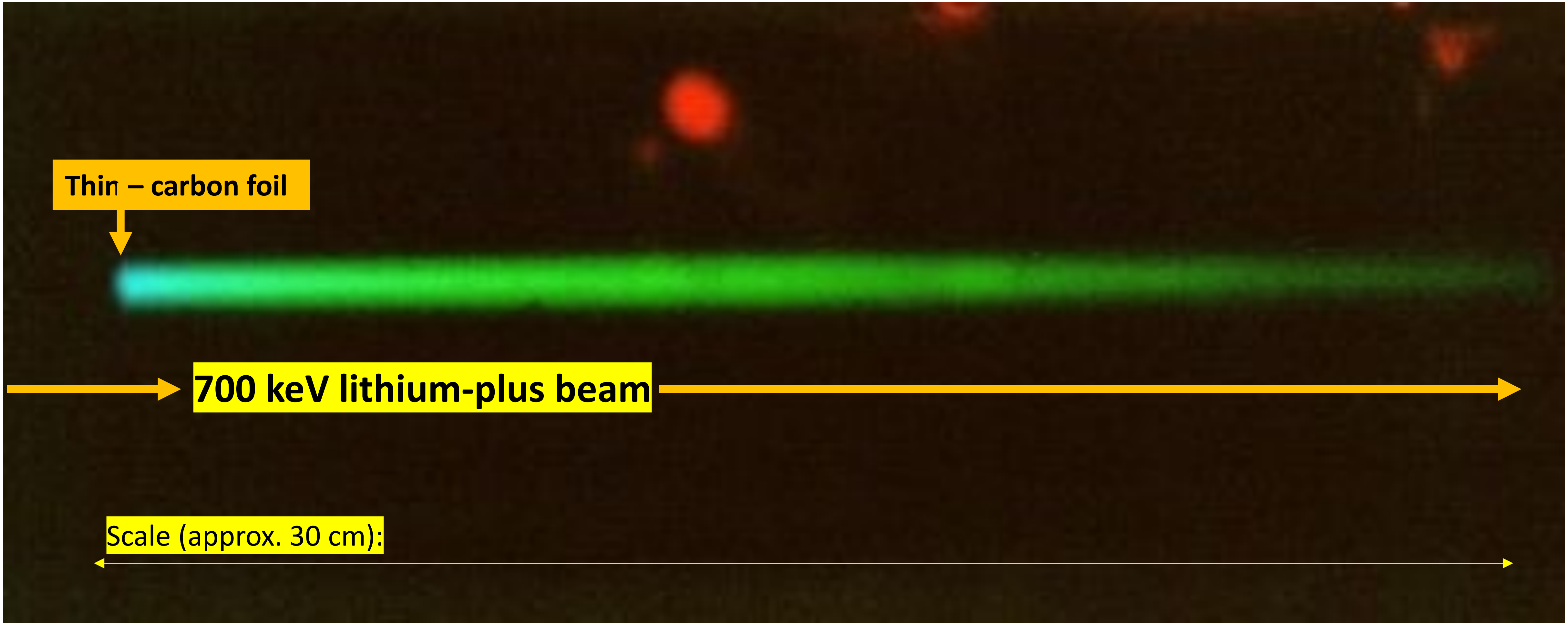
- worked with Professor Dick Schectman to develop a new accelerator for atomic physics studies …

Toledo and Atomic Physics became his bases for the rest of his life….

Was your early career similar?   A broadening of understanding many physics areas?



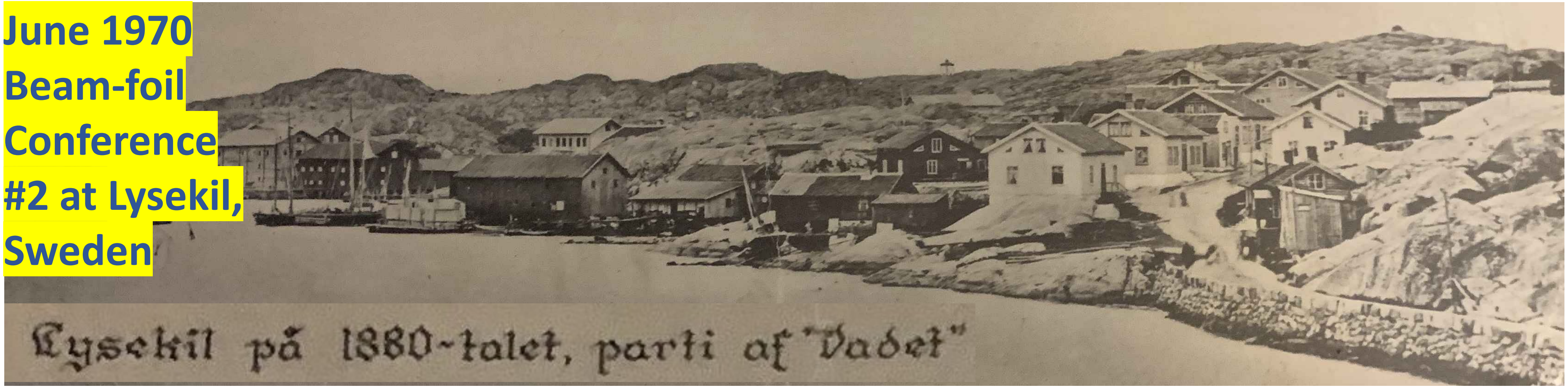
Schematic of the general layout of the Toledo Heavy Ion Accelerator facility (THIA)



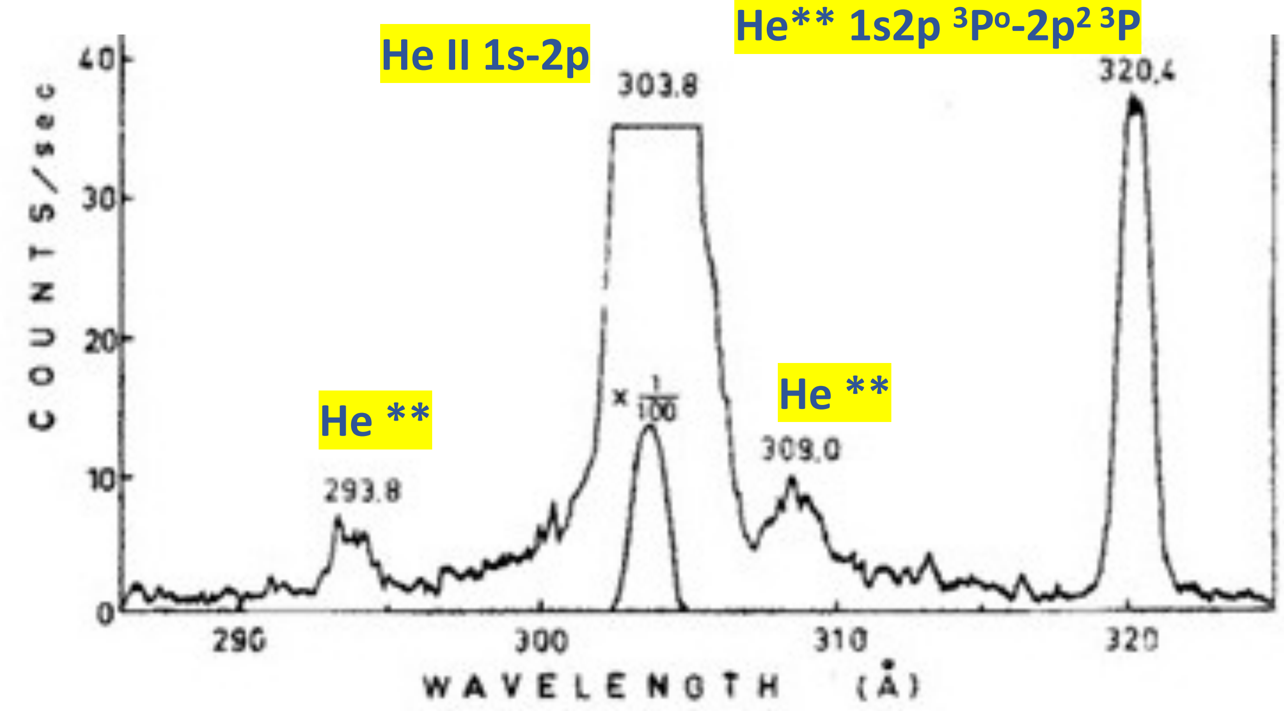
Blue light: Hydrogenic Li(++) Li III n=4-5 transition (fast decay)

Green light: 2-electron Li(+) Li II 1s2s ^3S - 1s2p ^3P transition

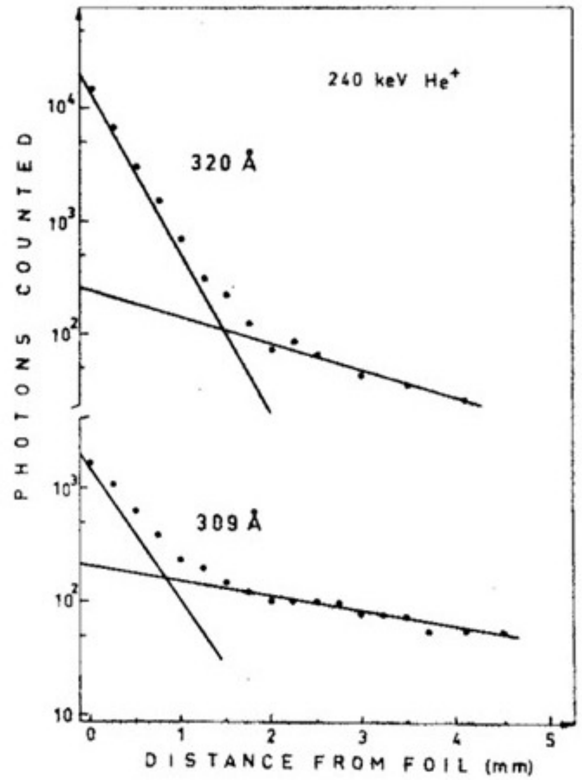
(photo taken at Villeurbanne France, 1972, approximately 2 minute exposure)



First Observations of He I Doubly excited states - - working on a Saturday!



Beam-foil spectrum of helium (E=240 keV). between 285 and 325 Å. Photons detected with a Bendix channeltron, movable along the Rowland circle designed by Hilke, H.Oona, L. Lundin



H. G. Berry, I. Martinson, **L. J. Curtis**, and L. Lundin, "Lifetimes of Some Doubly Excited Levels in Neutral Helium," Phys. Rev. A 3, 1934-7 (1971)

Notes:

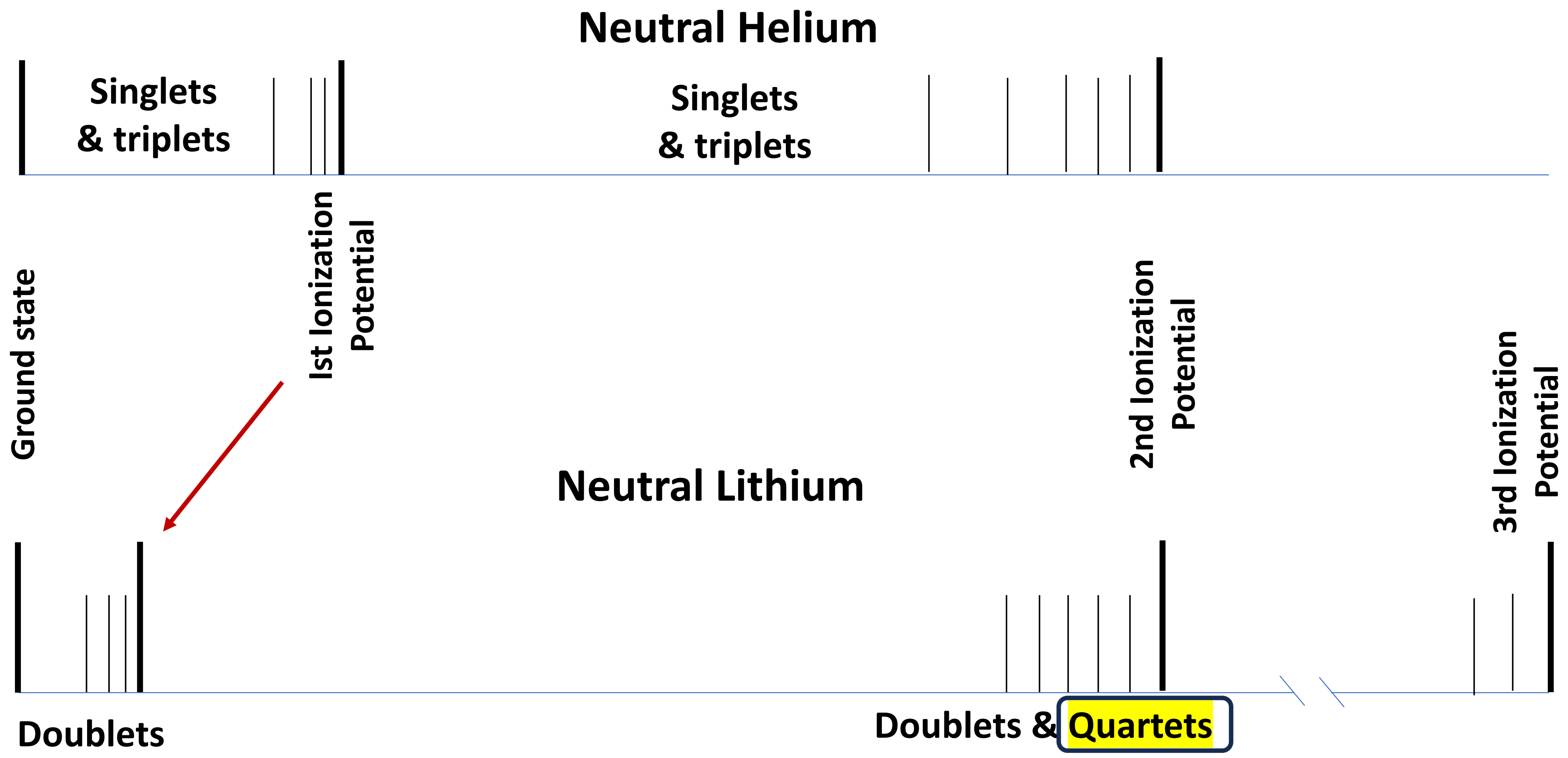
The 320A line decay time is 80 picoseconds

The He II 303.8A line is "Lyman alpha" of 1-electron helium

TABLE I. Transitions and radiative lifetimes of doubly excited levels in He I.

Observed wavelength (Å)[a]	Transition	Calculated wavelength (Å)	Lifetime of upper level (nsec) This work	Theory
285 ± 1	$1s2s\,^3S - sp23-\,^3P$ (?)	285.3[b]		
293.8	$1s2s\,^1S - sp23-\,^1P$	294.0[c]	0.116 ± 0.020	0.36[c]
295.2	$1s2p\,^1P - 2p3p\,^1P$	295.2[d]		
306 ± 1	$1s3p\,^3P - 2p3p\,^3P$ (?)	305.8[e]		
309.0	$1s3p\,^1P - 2p3p\,^1P$	309.0[d]	0.105 ± 0.015	0.0975[d]
311.0	$1s3s\,^1S - sp23-\,^1P$	311.0[c]		
320.4 ± 0.3	$1s2p\,^3P - 2p^2\,^3P$	320.3[d]	0.080 ± 0.007	0.0803[d]

Why are Doubly-excited states in Atoms and Ions Interesting??



Similar energy level structures for all isoelectronic ions for 2 and 3 electrons…

WHY NOT for atoms and ions with more electrons????

A little twist in the beam foil lithium spectra – 10 years later..

About 10 years after the Lysekil conference, Carlos Bunge at the University of Mexico proposed a new and surprising identification of one of the transitions in the beam-foil lithium spectra:

C.F. Bunge, Phys Rev. Letters, 44, 1450 (1980)

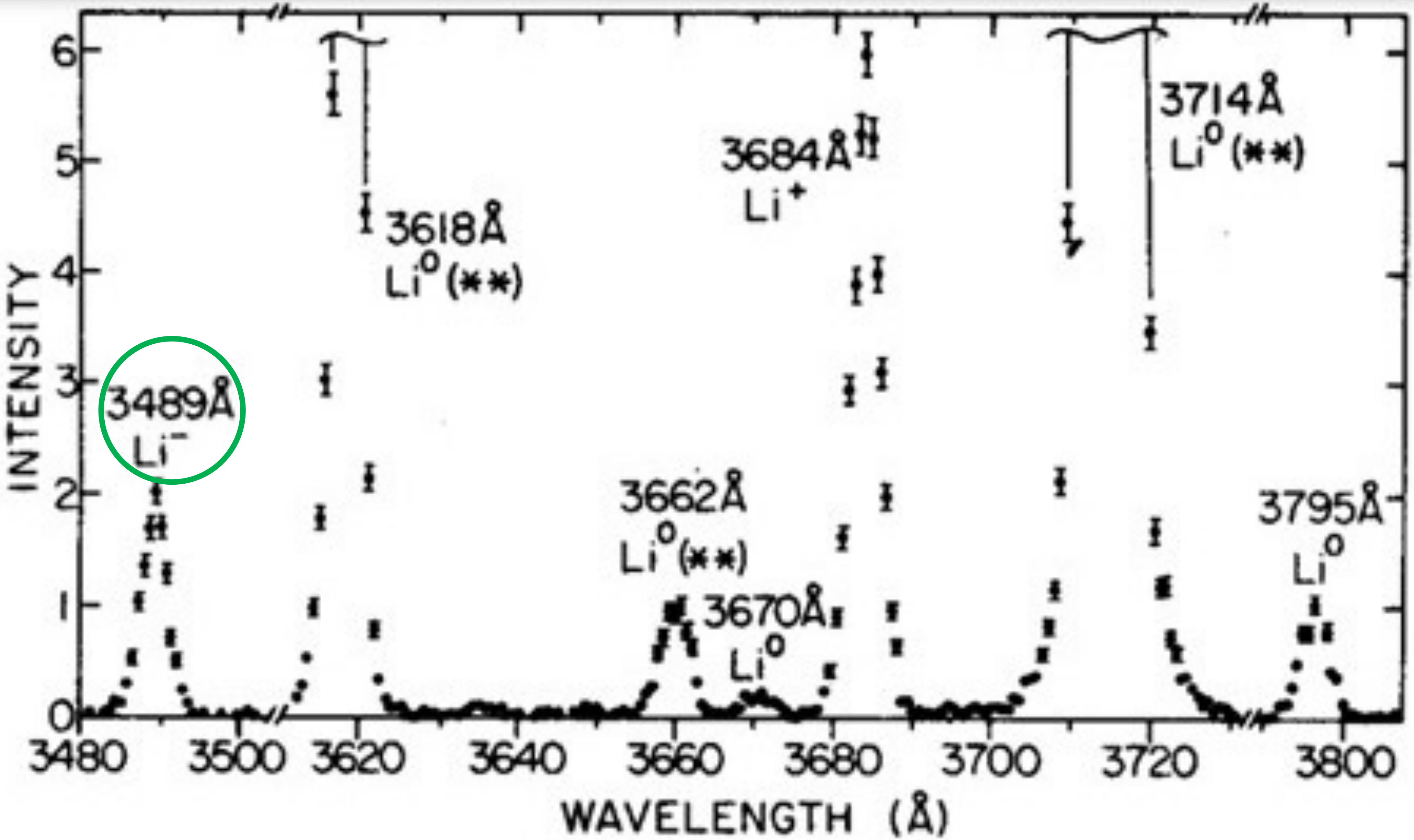
His proposal: A transition observed at 3489Å is a transition in Lithium with 4 electrons i.e. In a NEGATIVE ION

Notes

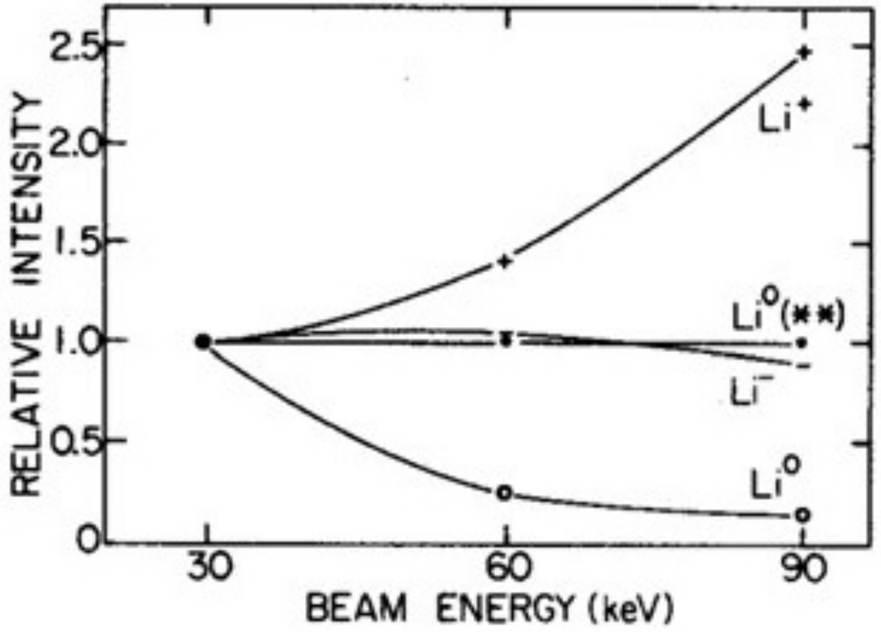
1. Most atoms cannot bind an extra electron to the central nuclear Coulomb potential.
2. Negative ions can only support a finite number of electronic states.
3. Most negative ions decay rapidly by electron emission.
4. No optical transitions from negative ions had previously been observed.
5. To my knowledge no others have been observed since.

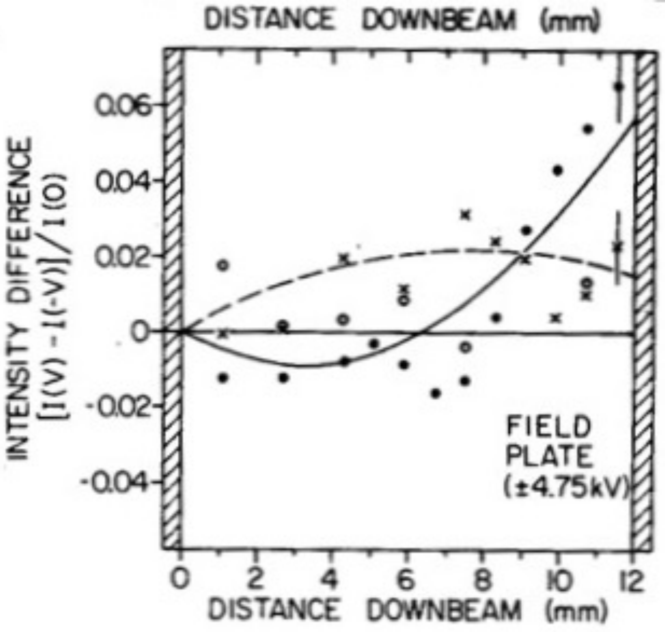
The FUN begins….. The race to prove Carlos right or wrong!

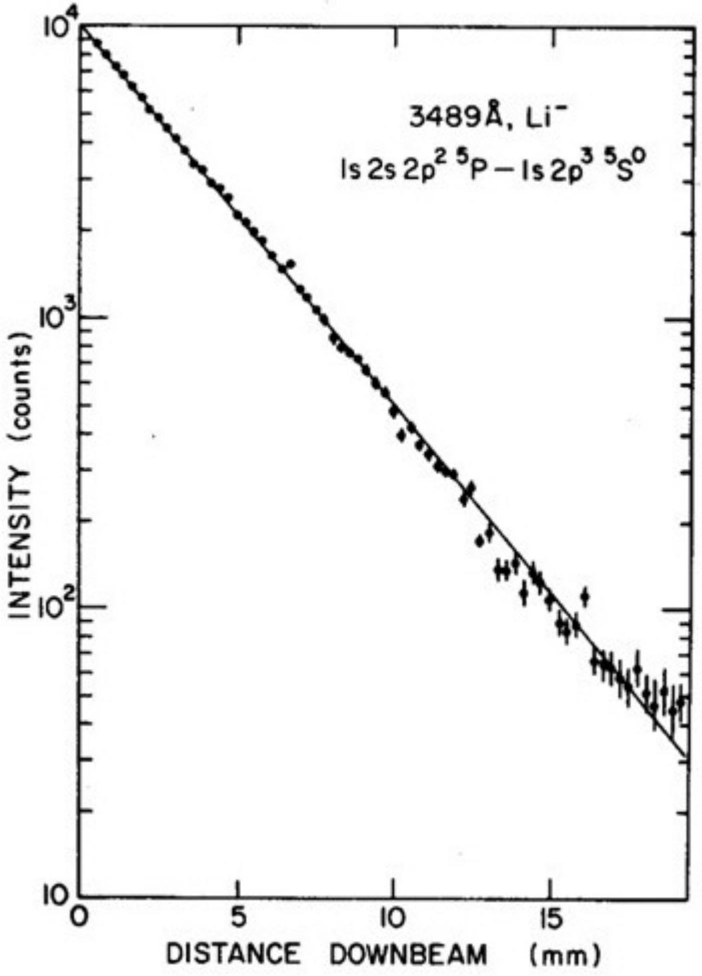
Curtis et al. Phys Rev. Letters, 45, 1321 (1980)



3489Å
Li⁻
3618Å
Li⁰(**)
3662Å
Li⁰(**)
3670Å
Li⁰
3684Å
Li⁺
3714Å
Li⁰(**)
3795Å
Li⁰
INTENSITY
WAVELENGTH (Å)
0
1
2
3
4
5
6
3480
3500
3620
3640
3660
3680
3700
3720
3800







Ion	Theory (Å)	Experiment (Å)
Li^-	3489[a]	3489[c]
Be I	1821[b]	1909[c]
B II	1279[b]	1324.5[d]
C III	989[b]	1015.6[e]
N IV	807[b]	825[e]
O V	682[b]	695[e]
F VI	589[b]	597[f]
Ne VII	519[b]	•••

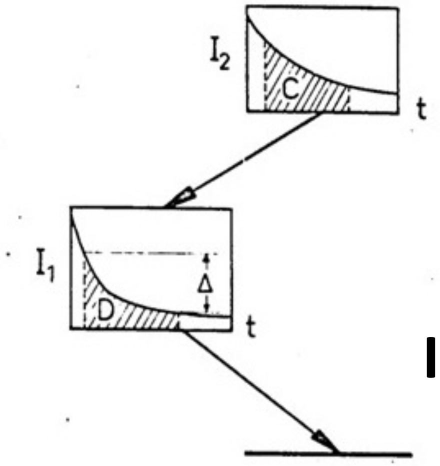
1. Intensity dependence on beam-energy
2. Intensity change with E-field direction
   (the "FISH CURVE")
3. Single exponential decay
4. Identifications in isoelectronic series

ANDC* solving a principal Beam-Foil Problem (What is it??)

Physics Letters
34A, 169 (1971)

A MEANLIFE MEASUREMENT OF THE $3d^2D$ RESONANCE DOUBLET IN SiII BY A TECHNIQUE WHICH EXACTLY ACCOUNTS FOR CASCADING

L. J. CURTIS*, H. G. BERRY and J. BROMANDER
Research Institute for Physics, Stockholm, Sweden



$$\tau_1 \mathrm{d}I_{1m}/\mathrm{d}t = \xi I_{2n}(t) - I_{1m}(t),$$

where $\xi \equiv \tau_1 A_{1m} A_{21} E_{1m} / A_{2n} E_{2n}$

Integrate => $\tau_1 = a(t_\mathrm{I}, t_\mathrm{F}) - b(t_\mathrm{I}, t_\mathrm{F})\xi,$

where

$$a \equiv \int_{t_\mathrm{I}}^{t_\mathrm{F}} \mathrm{d}t\, I_{1m}(t)/[I_{1m}(t_\mathrm{I}) - I_{1m}(t_\mathrm{F})],$$

$$b \equiv \int_{t_\mathrm{I}}^{t_\mathrm{F}} \mathrm{d}t\, I_{2n}(t)/[I_{1m}(t_\mathrm{I}) - I_{1m}(t_\mathrm{F})].$$

*Arbitrarily
Normalised
Decay
Curves

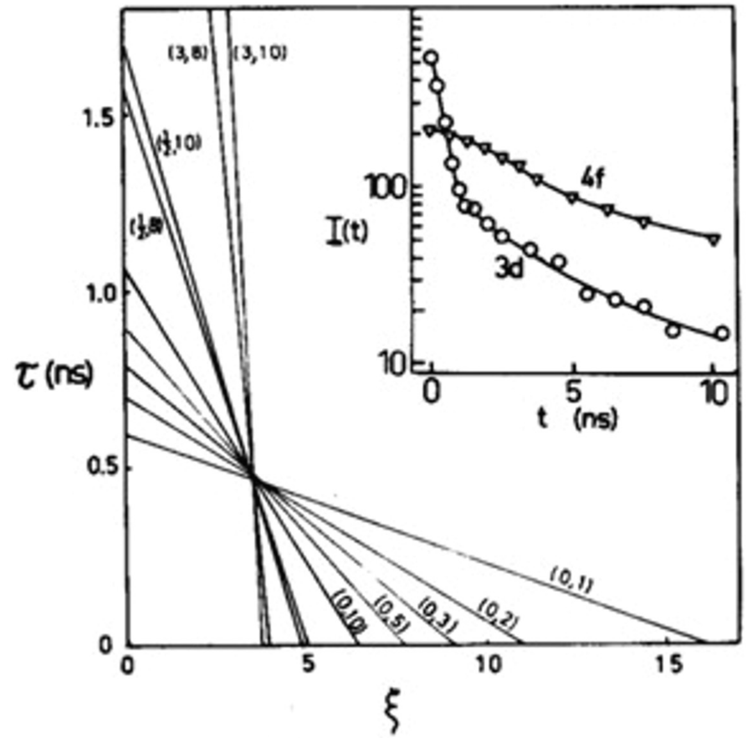


Fig. 1. Measured decay curves (inset) and parametric $\xi - \tau$ plot for data integration limits $(t_\mathrm{I}, t_\mathrm{F})$. A common intersection occurs at $\xi = 3.5$ and $\tau = 0.47$.

Explanation – **Avoidance of the multiple exponential non-linear fitting problem; incorporates 2 not 1 multi-exponential curves.**

The Toledo Atomic Physics Gang

Dick Schectman

David Ellis (theorist)

Larry Curtis

H. G. Berry, L. J. Curtis, D. G. Ellis, and R. M. Schectman,
''*Anisotropy in the Beam-Foil Source,*'' Phys. Rev. Lett. 32, 751-4 (1974)

Tilted Foils

Preliminary explanation…

→ Standard perpendicular foils yield cylindrical symmetry excitation, atomic alignment, and linear polarization.

Fine structure states (spectrally unresolved) are coherently excited

---> Quantum beats with frequencies of close lying fine & HF structures

Example:
Li II transition 1s2s ^3S – 1s4p ^3P
First 5 ns of decay:
Analyze (a) by fits of five frequencies as shown below
(b) Fourier transform data
(Measurement in linear polarized light)

WHAT CHANGES for a Tilted Foil excitation??

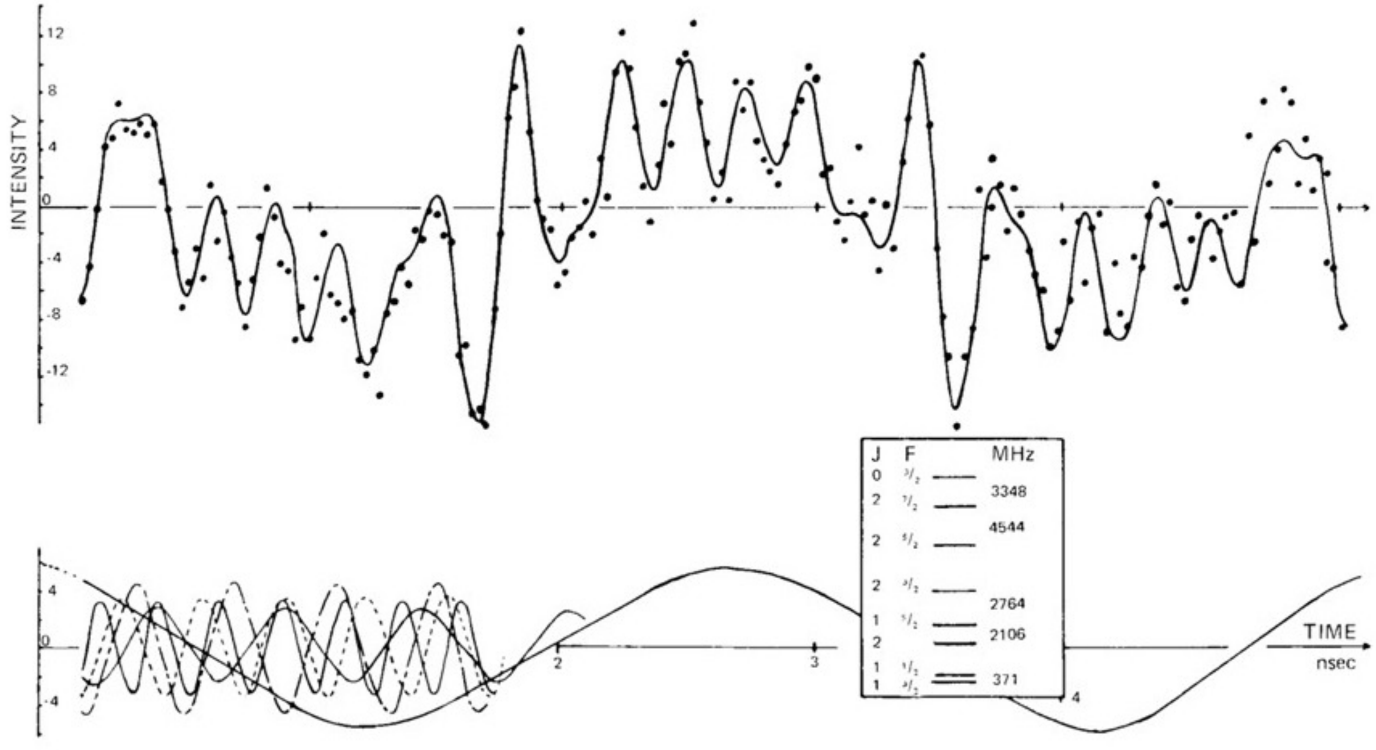
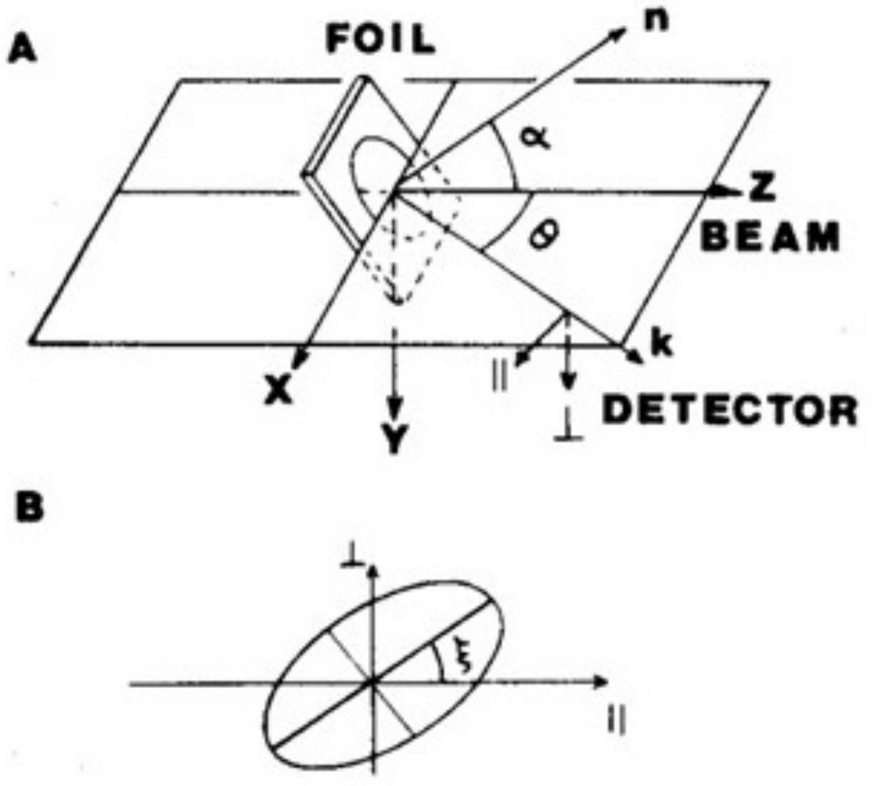


Figure 1. Modulations in the decay $4p(^3P)$. ^{7}Li II. The five contributing frequencies and the energy levels are shown below.

Experiment & Viewing Geometry



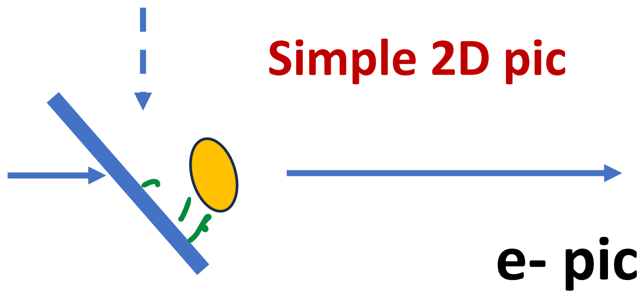
Beam and viewing geometry.

We made observations at light emission angle **θ** = 90º (perpendicular to the ion beam), and at **θ** = 53º – the two results agreed.

Assuming the beam-foil interaction takes place at the **Final surface** We have lost **cylindrical symmetry!**

Initial discussions with K.T.Lu (Fano student)

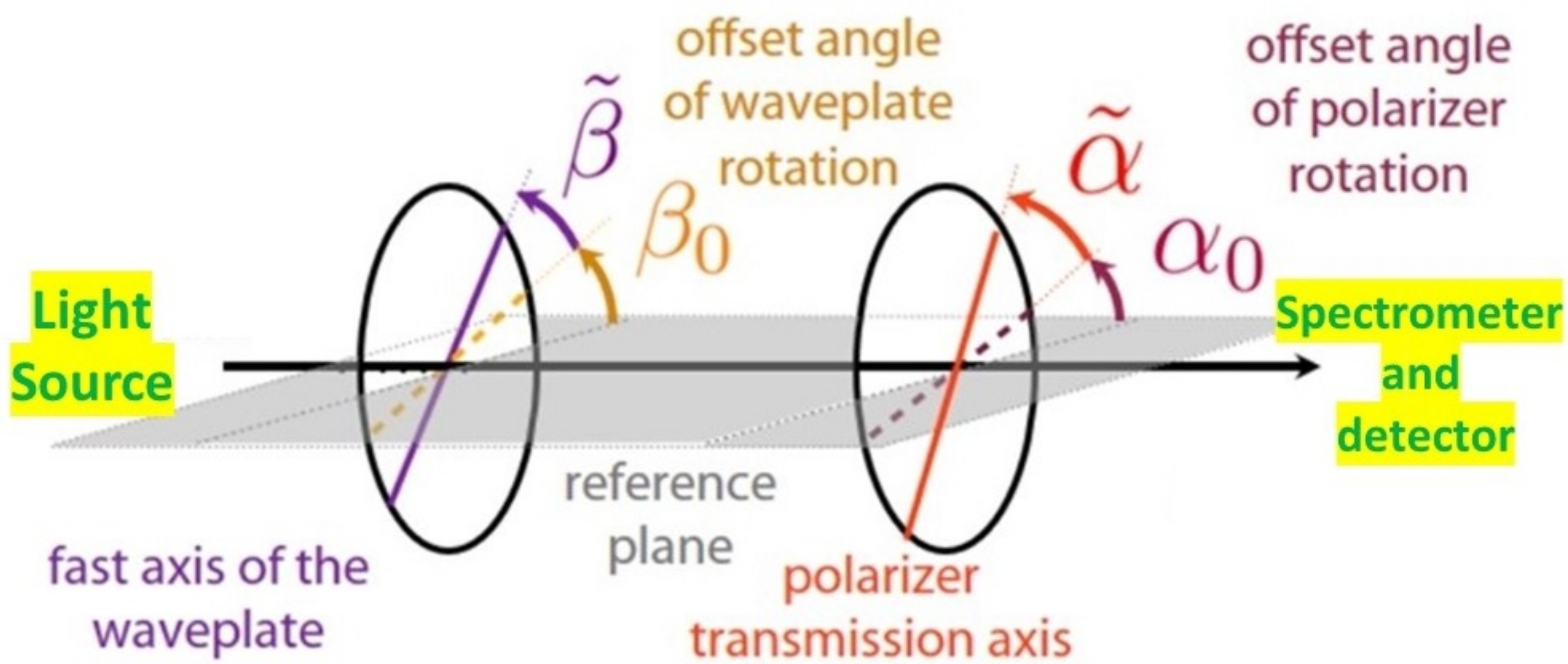
Simple 2D pic



e- pickup/loss/excitation most likely closest to surface

(the dashed vertical line indicates later experiments of light yields Ions scattered from surfaces)

Our Detector of linear and circular polarization – viz the 4 Stokes parameters I, M, C, S (figure adapted from recent -2022- paper by an ex-graduate student of mine)



Fix the polarizer transmission axis, and rotate the ¼-wave plate manually record the pass-through intensity of the 5016Å 1s2s ^1S – 1s3p ^1P transition of neutral helium.

("Carefully chosen!")

Brief analysis (you may have already used these equations in other experiments- (or you can ignore)

The atomic final state is a $^1S_0$ state, it is spherical => **ALL** atom angular momentum components (asymmetries) are taken away by the emitted light

These are defined by the 4 Stokes parameters I, M, C, S.

In the geometry shown above, these are:

$$I = I_0[2 + (\tfrac{3}{10})^{1/2}\rho_0{}^2(2 - 3\sin^2\theta) + (\tfrac{9}{5})^{1/2}\rho_2{}^2\sin^2\theta],$$

$$M = I_0[-3(\tfrac{3}{10})^{1/2}\rho_0{}^2\sin^2\theta - (\tfrac{9}{5})^{1/2}\rho_2{}^2(1+\cos^2\theta)],$$

$$C = I_0\tfrac{6}{5}\sqrt{5}\,\rho_1{}^2\sin\theta, \quad S = I_0 2\sqrt{3}\,\rho_1{}^1\sin\theta.$$

Here I_0 is a normalization constant, the second-rank tensor components $\rho_0{}^2$, $\rho_1{}^2$, $\rho_2{}^2$ define the alignment, and the first-rank component $\rho_1{}^1$ measures the orientation.[6]

The ratio C/M measures the tilt angle ξ of the polarization ellipse to the beam-detector plane. It must be zero for an untilted (normal) foil. Thus, ξ being positive we find that the major axis of the ellipse always lies between the beam axis $\hat{z}$ and the foil surface normal $\hat{n}$.

$$M/I = \langle L_y{}^2 - L_z{}^2\rangle/\langle L_x{}^2\rangle,$$

$$C/I = 2\,\mathrm{Re}\langle L_y L_z\rangle/\langle L_x{}^2\rangle,$$

$$S/I = -\hbar\langle L_x\rangle/\langle L_x{}^2\rangle,$$

Note 1: David Ellis published separately his calculations of the general relationships between density matrix components and Stokes parameters, and the several angular momentum components

Note 2: His work was superseded shortly afterwards by Fano and Macek's introduction of generic alignment and orientation parameters A and O.

Results:

Density-matrix components.

Foil tilt angle (deg)	$\rho_0^2/\sqrt{30}$ $\langle 1\|\rho\|1\rangle - 1/3$	$\rho_2^2/\sqrt{5}$ $\langle 1\|\rho\|-1\rangle$	$i\rho_1^2/\sqrt{10}$ $\mathrm{Im}\langle 0\|\rho\|1\rangle$	$+\rho_1^1/\sqrt{6}$ $-\mathrm{Re}\langle 0\|\rho\|1\rangle$
0	−0.030(12)	−0.016(9)	⋯	⋯
20	−0.027	−0.012	−0.017(5)	0.009(8)
30	−0.024	−0.008	−0.015	0.027
45	−0.018	+0.0002	−0.028	0.029

Columns 2 to 4 are alignment parameters combinations of M and C; column 4 = 0 for cylindrical symmetry

Column 5 is the orientation Also =0 for no tilt

Positive values of the orientation mean that the atom is spinning into the acute angle of the foil surface. We colloquially call that "giving the atom some English" – as in playing billiards

Following Edlen ……

Edlén, B. Handbuch der Physik Vol. 27 pp 80-220
Berlin (1964) but finished Oct. 1960

L. J. Curtis, "Bengt Edlén's Handbuch der Physik Article - 26 Years Later," Physica Scripta 35, 805-10 (1987)

Larry concludes this paper, after giving many new examples, "The semiempirical methods presented by Professor Edlén …. remain the primary predictive tools of atomic spectroscopy today, and may contain clues to an improved theoretical understanding of the dynamics of complex atoms"

A **few** of Larry's papers on these themes….

70. "Semi-Empirical Oscillator Strengths for the Cu I Isoelectronic Sequence"
76. "A Semi-classical Formula for the Term Energy of a Many Electron Atom"
78. "Semi-Empirical Calculations of Fine Structure Splittings ... in the Mg I Isoelectronic Sequence"
79. "Semiclassical Parameterization of the $l \geq 3$ Energy Levels in Cs I"
80. "Semiempirical Regularities in the Spectra and ...of Heavy and Highly Ionised Atoms"
81. "A Semiclassical Formulation of Term Energies and Electrostatic Intervals in He"
87. "Semiclassical Parametrization of the 6snh - 6sni - 6snk Intervals in Ba I"
115. "Semiempirical Confrontations between Theory and Experiment in Highly Ionised Complex Atoms,"
116. "Semiempirical Specification of Singlet-Triplet Mixing Angles, Oscillator Strengths, and g-factors.."

Extra !!

A couple of tidbits…

1.

45. L. J. Curtis, "On the αZ Expansion for the Dirac Energy of a One-Electron Atom,'' J. Phys. B: Atom. Mol. Phys. 10, L641-5 (1977).

The Dirac energy of a one-electron atom is given by

$$\frac{E(n,j,Z)}{mc^2} = \left(1 + \frac{(\alpha Z)^2}{[n - j - \frac{1}{2} + \sqrt{(j+\frac{1}{2})^2 - (\alpha Z)^2}]^2}\right)^{-1/2}$$

Substitute

$$x \equiv (\alpha Z/n)^2$$
$$b \equiv n/(j+\tfrac{1}{2})$$

$$E/mc^2 = [1 + x/[1 - (1 - \sqrt{1 - b^2 x})/b]^2]^{-1/2}.$$

Which is of The form

$$\boxed{E/mc^2 = (1 + xv)^{-1/2}}$$

2.

107. R. R. Haar and L. J. Curtis, "The Thomas Precession Gives g_e-1, not g_e/2,'' Amer. J. Phys. **55,** 1044-5 (1987).

$$\Delta E = \omega\cdot\mathbf{S} = (g_e - 1)\frac{Zke^2}{2(mc)^2}\frac{\mathbf{L}\cdot\mathbf{S}}{r^3},$$

Where

$$g_e = 2 + (\alpha/\pi) - 0.657(\alpha/\pi)^2 + \cdots$$

The self energy term is 0.23%, larger than the reduced mass term of .05%

N.B. use (g-1) NOT g/2 (see your textbook!!!)

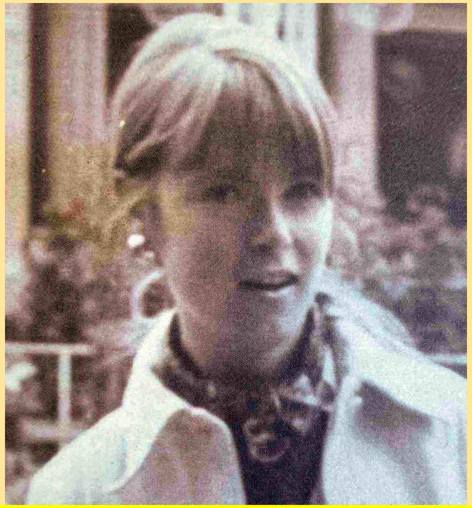
Maj and Larry and Sweden, 36 years together 1970 - 2006

Young Larry 1970 at Lysekil

Maj Curtis – 2003, with her cat

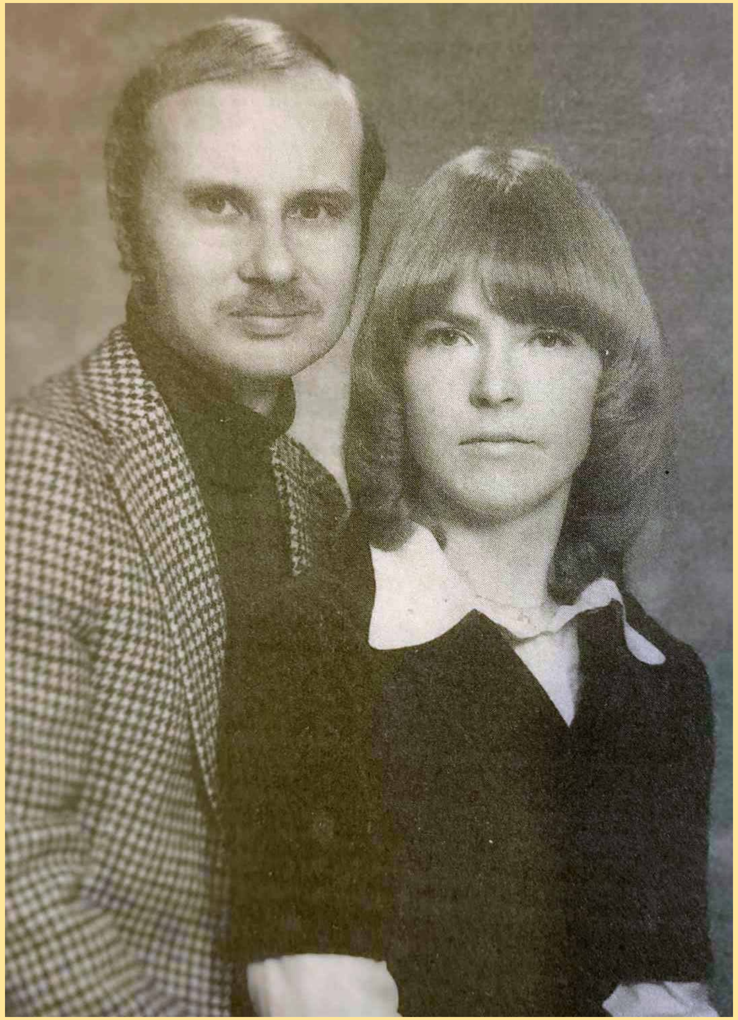
Larry, Martin Perl, Maj
Nobel Prize ceremony 1995

Larry, Maj
President & wife of
Lund University
At Honorary Doctorate
ceremony 1999



Across a crowded room - 1970

Stockholm Summer - 1971



Marriage – 9 November 1971

Old Tucson - 1994

Larry and Maj