Internal Conversion and Electron Bridge Processes in Th-229

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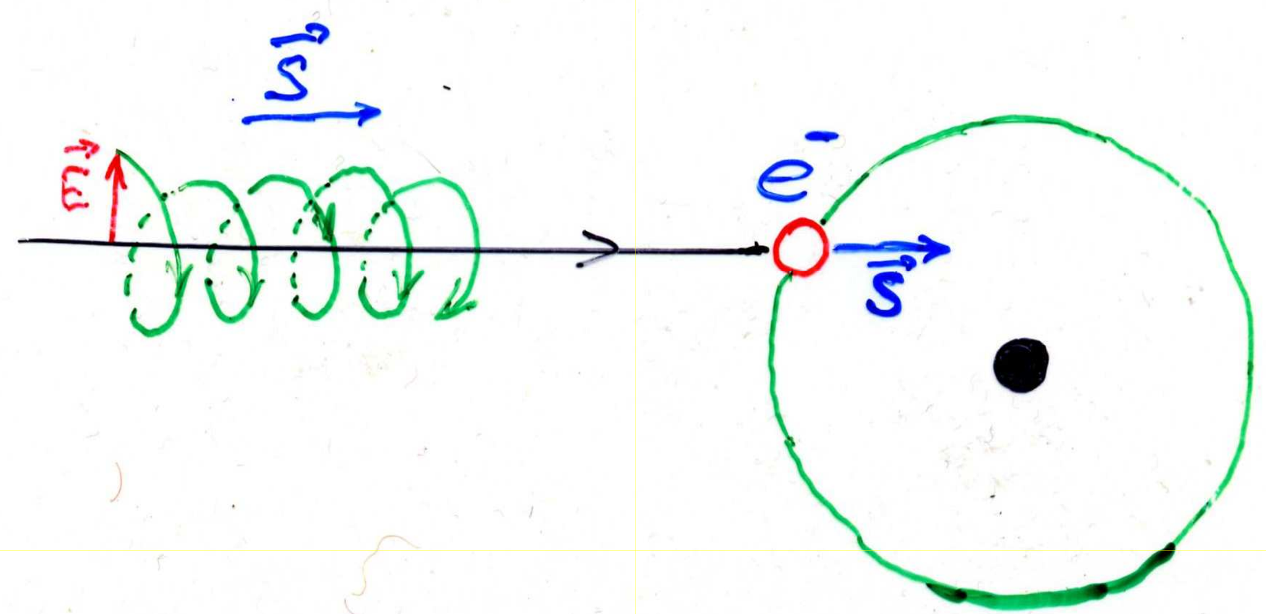
Laser pumping of the isomer via resonance atomic transition *7s-8s* is justified. In singly ionized atoms of Th II, discussed in [1], its energy is just close to the energy of 7.6 eV. This transition is optimal due to the combination of high internal conversion coefficient with the large cross section of photoexcitation.

- **Historical Remarks**
- **Triggering the energy through the electronic shell**
- **Discovery of BIC**
- **Laser assisted triggering**
- **Pumping the isomers**
- **Further prospects**

Radiation Optical Pumping

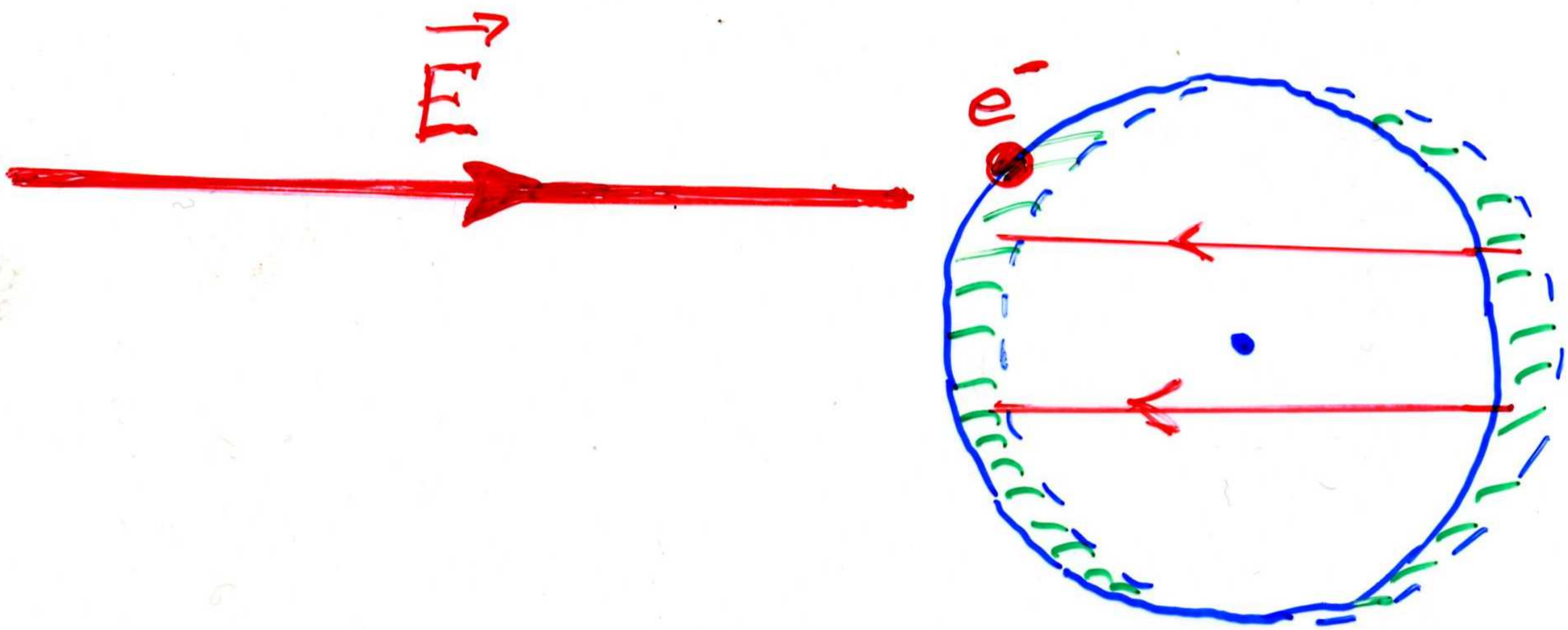
Fission RADOP (Bemis et al.)

β RADOP



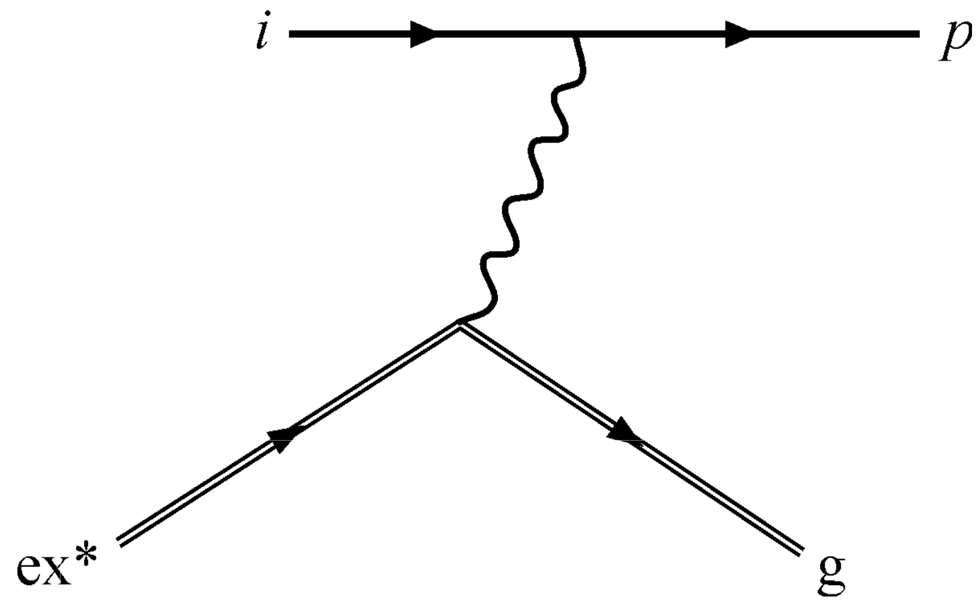
BIC, NEET, TEE, NEEC, PFBIC ….

Screening role of the shell

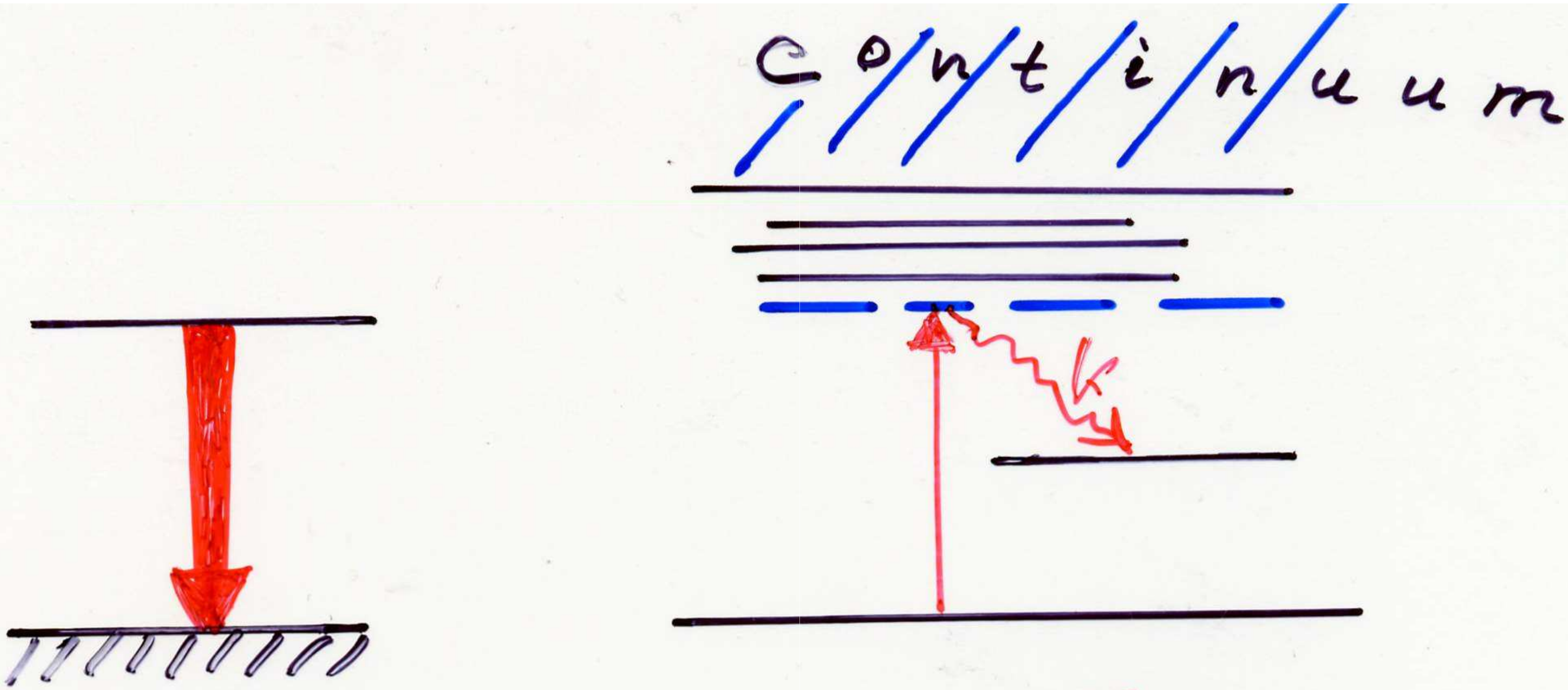


Internal conversion

$$\alpha = \Gamma_c / \Gamma_\gamma$$



Resonance Internal Conversion



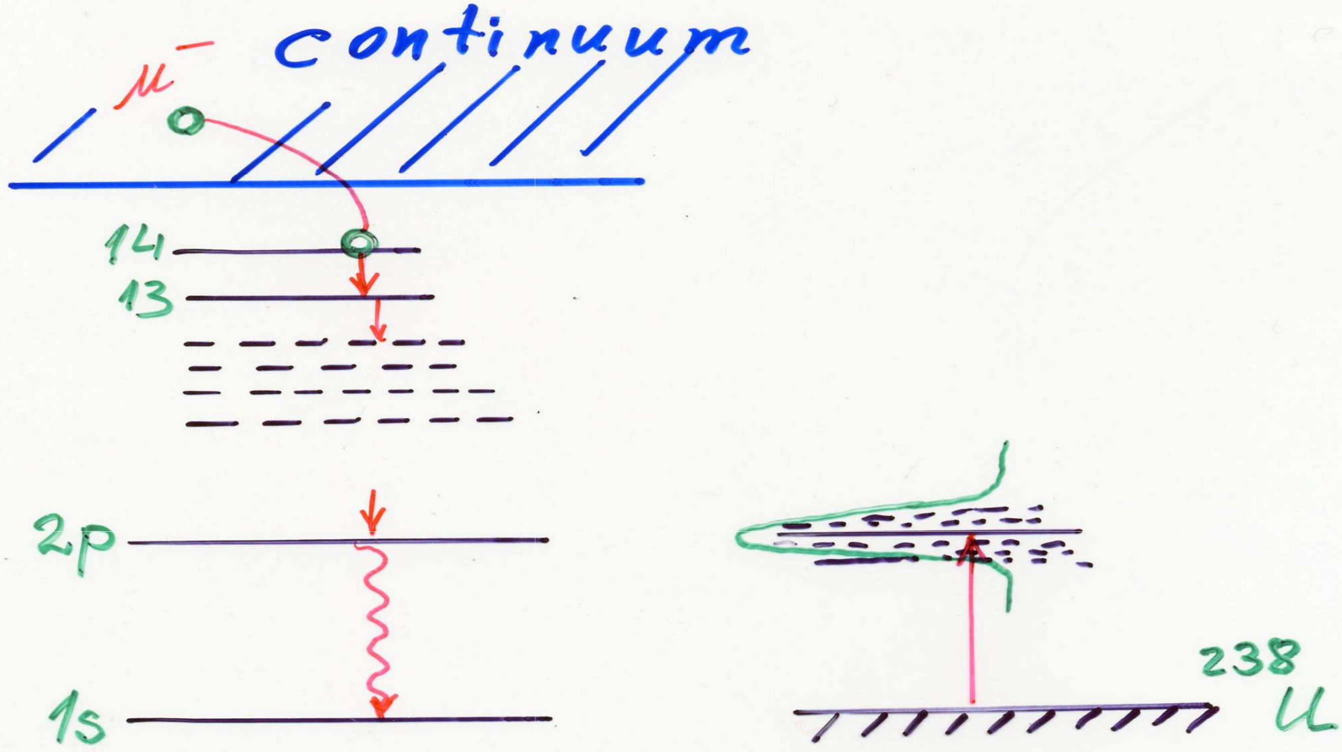
ICC: $\alpha = \Gamma_c / \Gamma_\gamma$

$$R = \frac{\alpha_a \, \Gamma / 2\pi}{\Delta^2 + (\Gamma/2)^2} \equiv \frac{\Gamma_c}{\Gamma_\gamma}$$

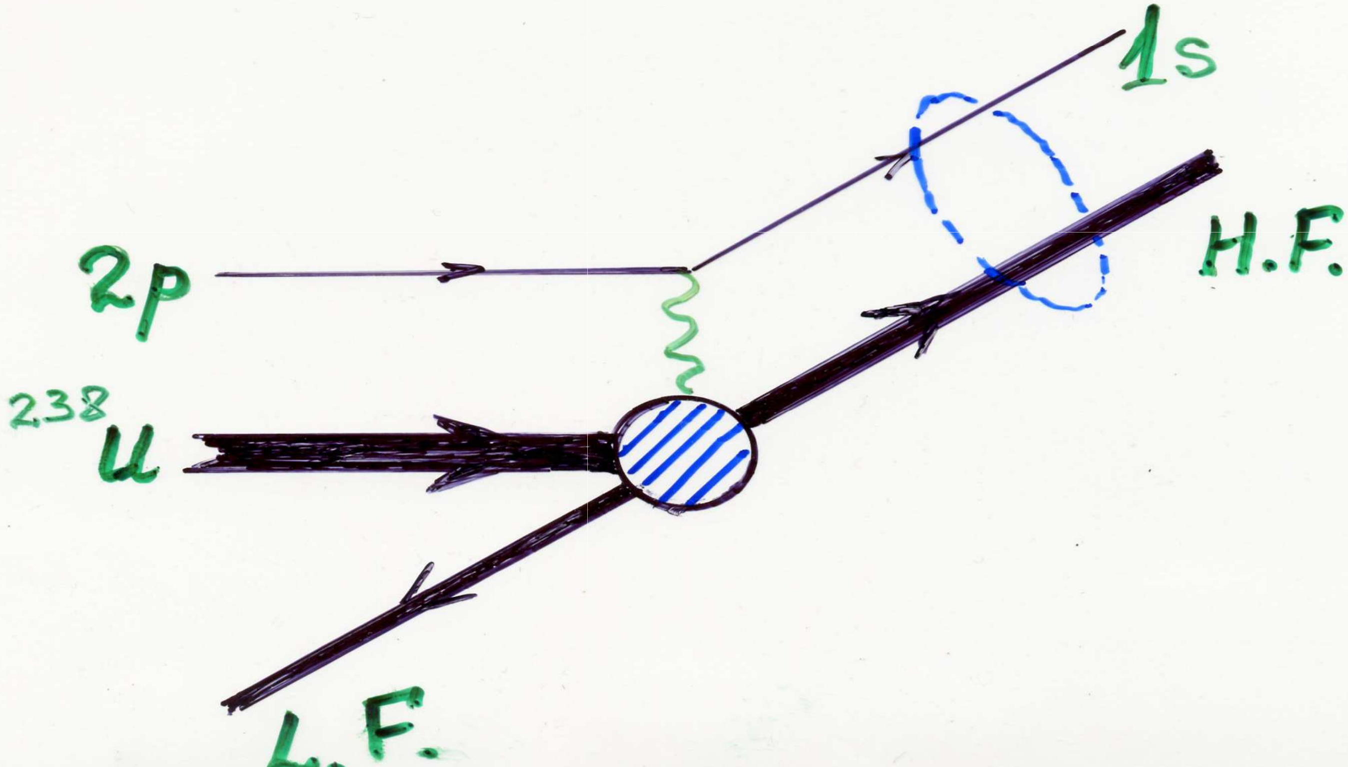
$$\alpha^{n\kappa}(ML) = \pi\alpha\omega\frac{N_i(2j+1)(\kappa+\kappa_i)^2}{L(L+1)} \times \begin{pmatrix} j_i & j & L \\ \frac{1}{2} & -\frac{1}{2} & 0 \end{pmatrix}^2 |\mathscr{R}_{n\kappa}(ML)|^2.$$

$$_{n\kappa}(ML) = \int_0^\infty [g_{n\kappa}(r)f_i(r) + f_{n\kappa}(r)g_i(r)]X_L(\omega r)r^2 d$$

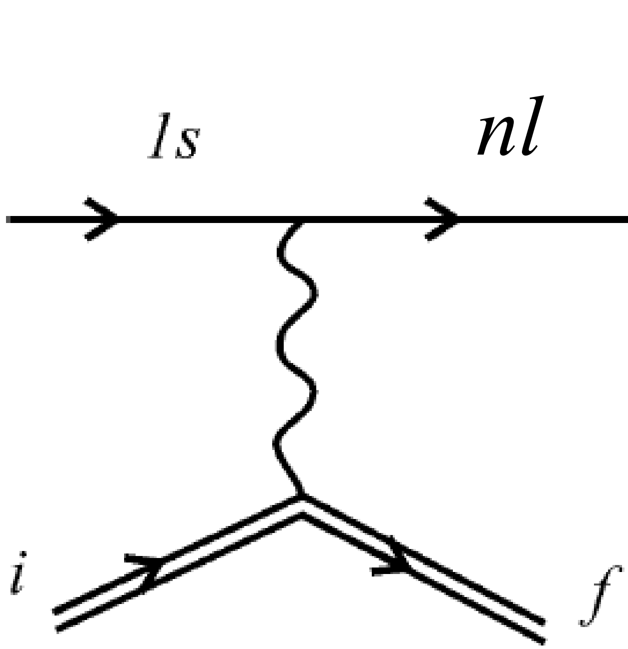
$$X_L = \begin{cases} h_L^{(1)}(\omega r) \text{ for } r > R_0, \\ j_L(\omega r)\dfrac{h_L^{(1)}(\omega R_0)}{j_L(\omega R_0)} \text{ for } r \leq R \end{cases}$$



μ⁻
continuum
14
13
2p
1s
238
U



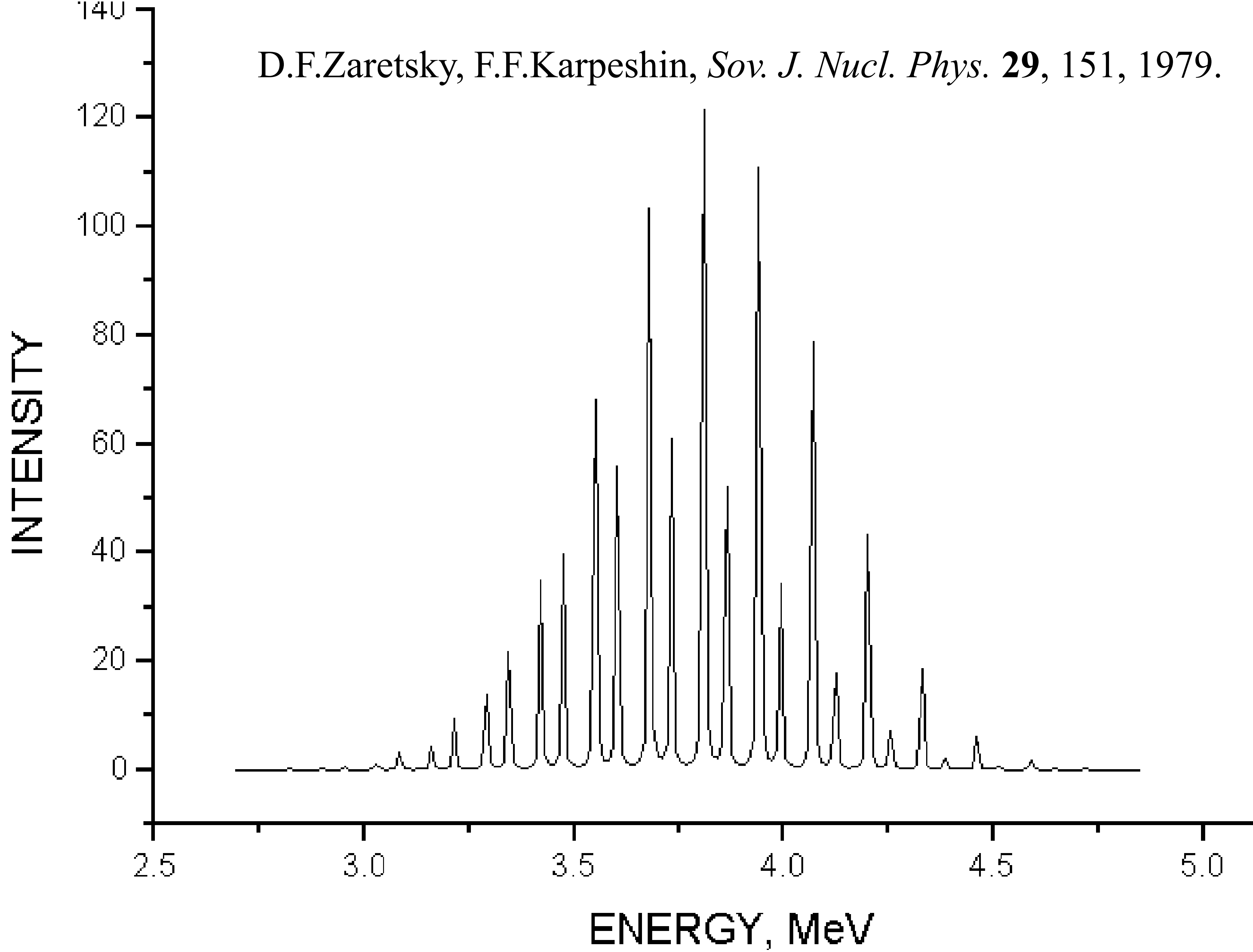
1s
H.F.
2p
238
U



$$G(\mathbf{r},\mathbf{r}') \approx \frac{\psi_{nl}(\mathbf{r})\rangle\langle\overline{\psi}_{nl}(\mathbf{r}')}{E_\gamma - E_0 + i\frac{\Gamma^a}{2}}$$

Resonance approximation:

$nl = 2p$


D.F.Zaretsky, F.F.Karpeshin, *Sov. J. Nucl. Phys.* **29**, 151, 1979.
INTENSITY
140
120
100
80
60
40
20
0
2.5
3.0
3.5
4.0
4.5
5.0
ENERGY, MeV

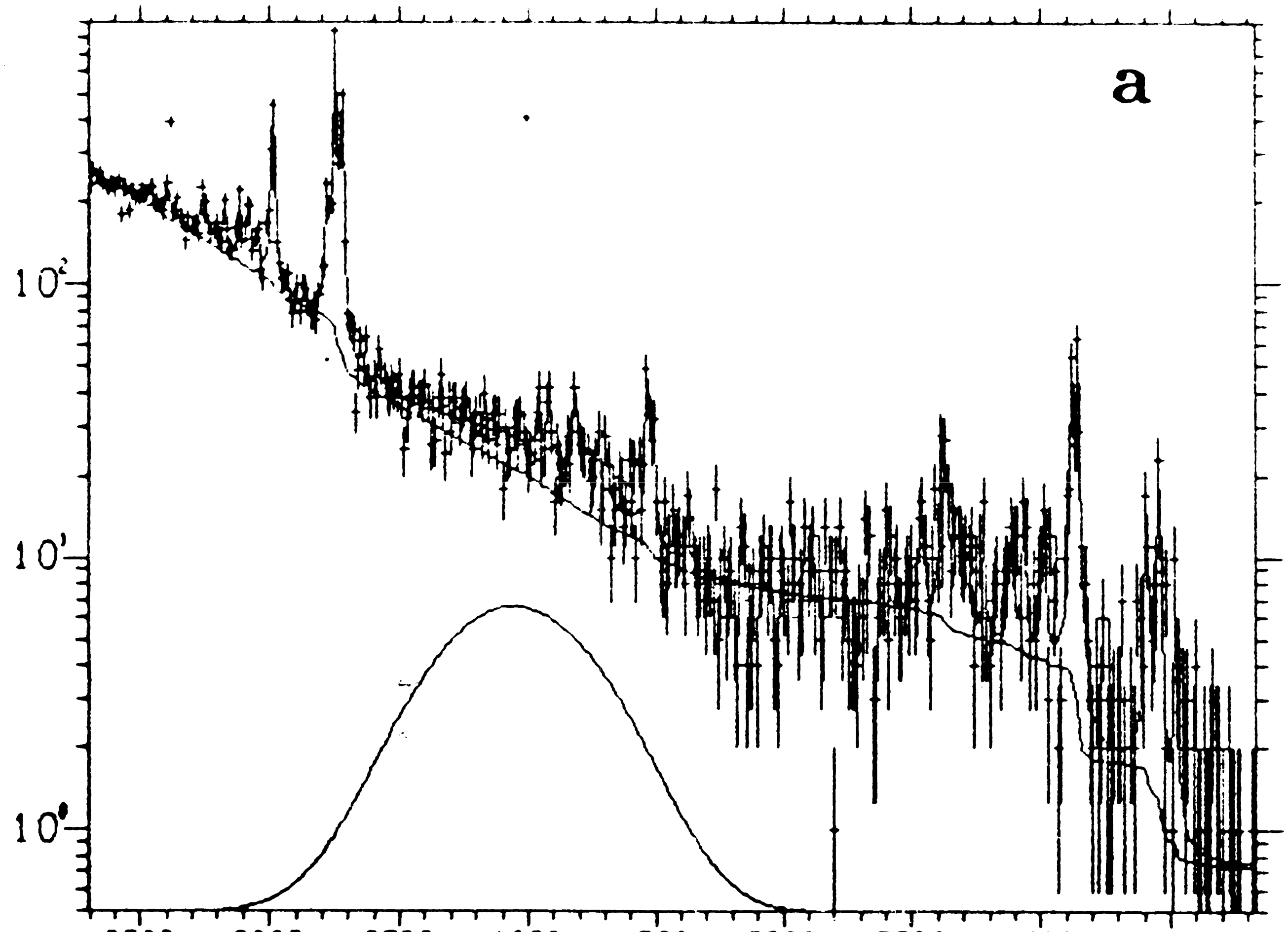
Phys. A 345, 425–426 (1993)

ZEITSCHRIFT
FÜR PHYSIK A

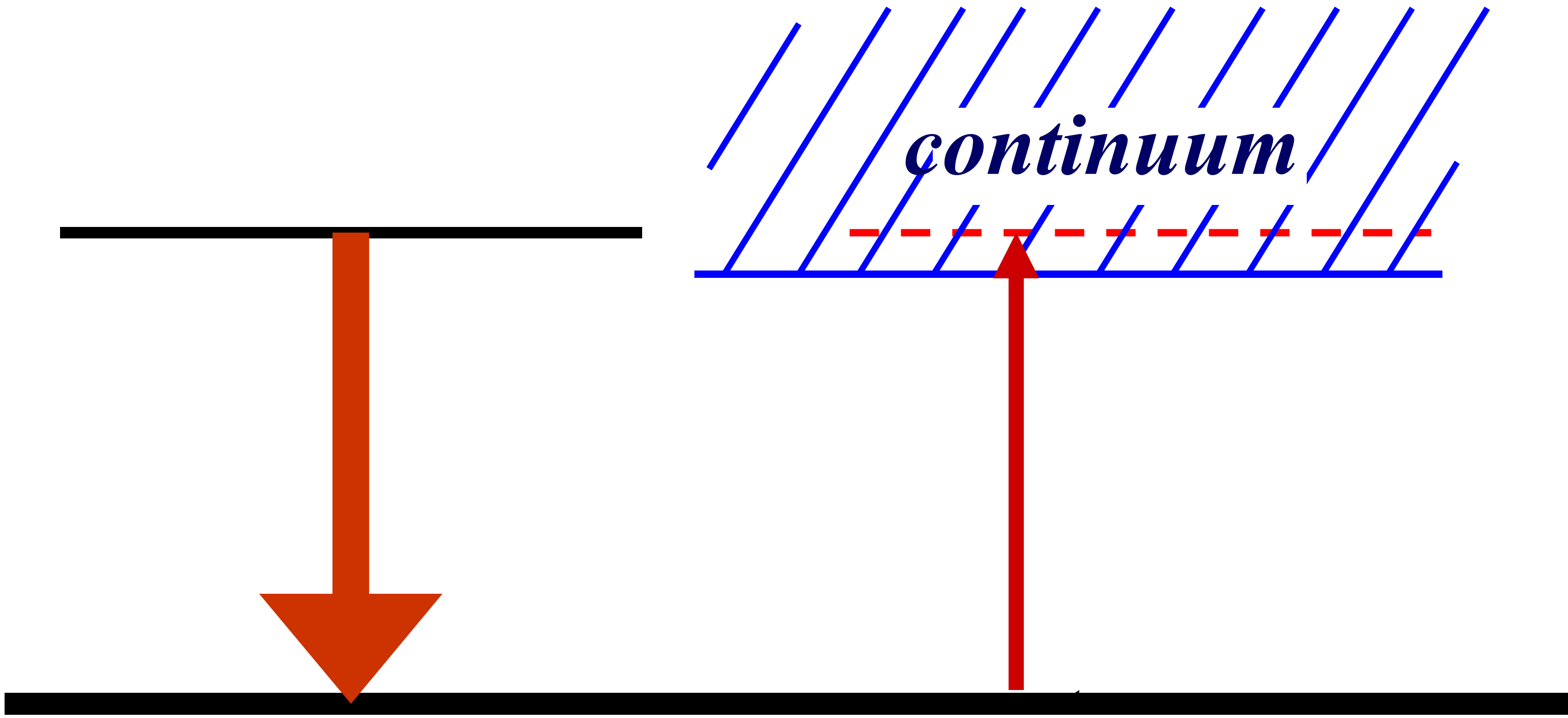
hort note

xperimental evidence for muonic *X*-rays from fission fragments

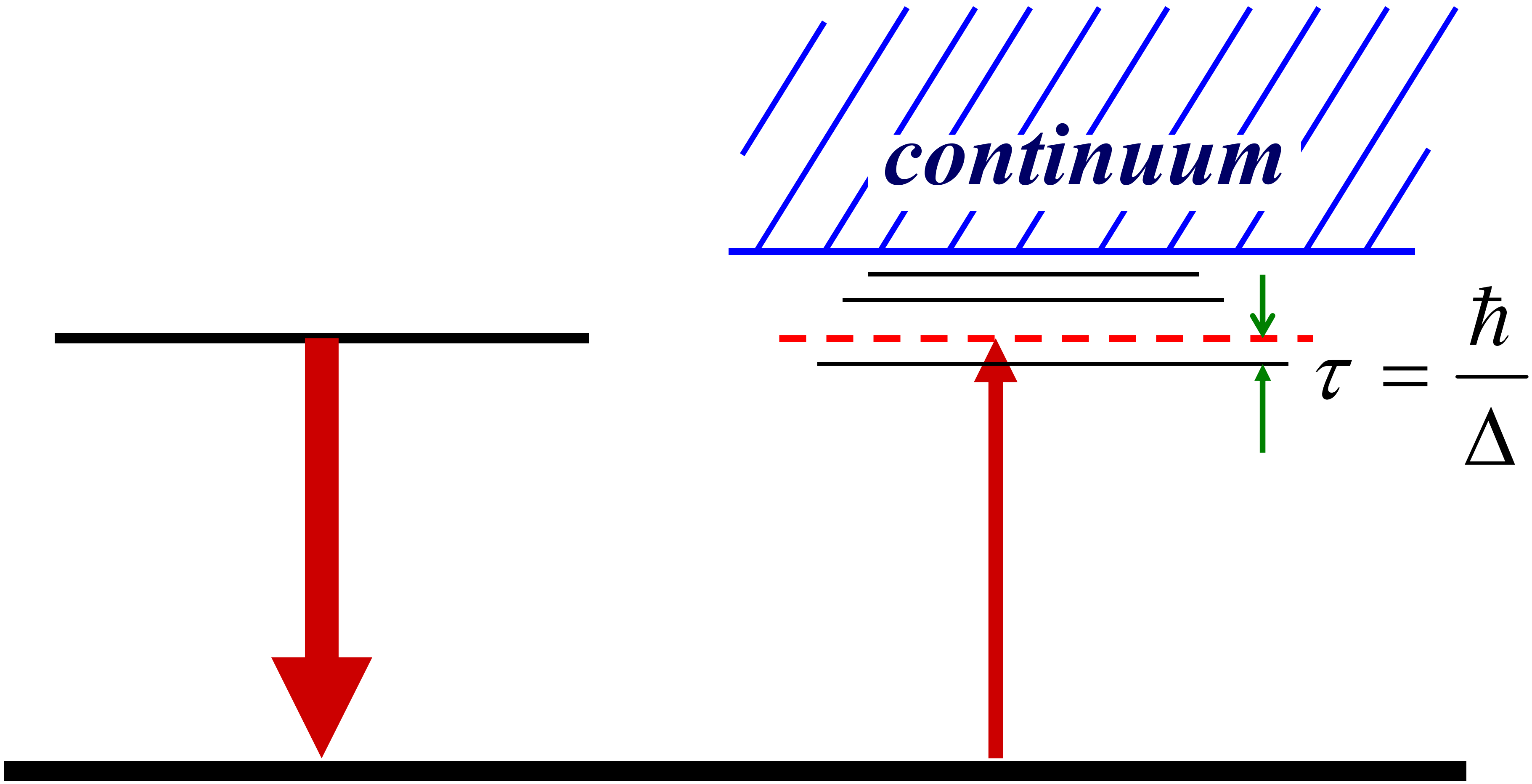
Rösel[1,*], F.F. Karpeshin[2], P. David[1], H. Hänscheid[1,**], J. Konijn[3], C.T.A.M. de Laat[4], H. Paganetti[1], F. Risse[1,***], . Sabirov[5], L.A. Schaller[6], L. Schellenberg[6], W. Schrieder[1,+], A. Taal[4]



Traditional IC



Resonance IC



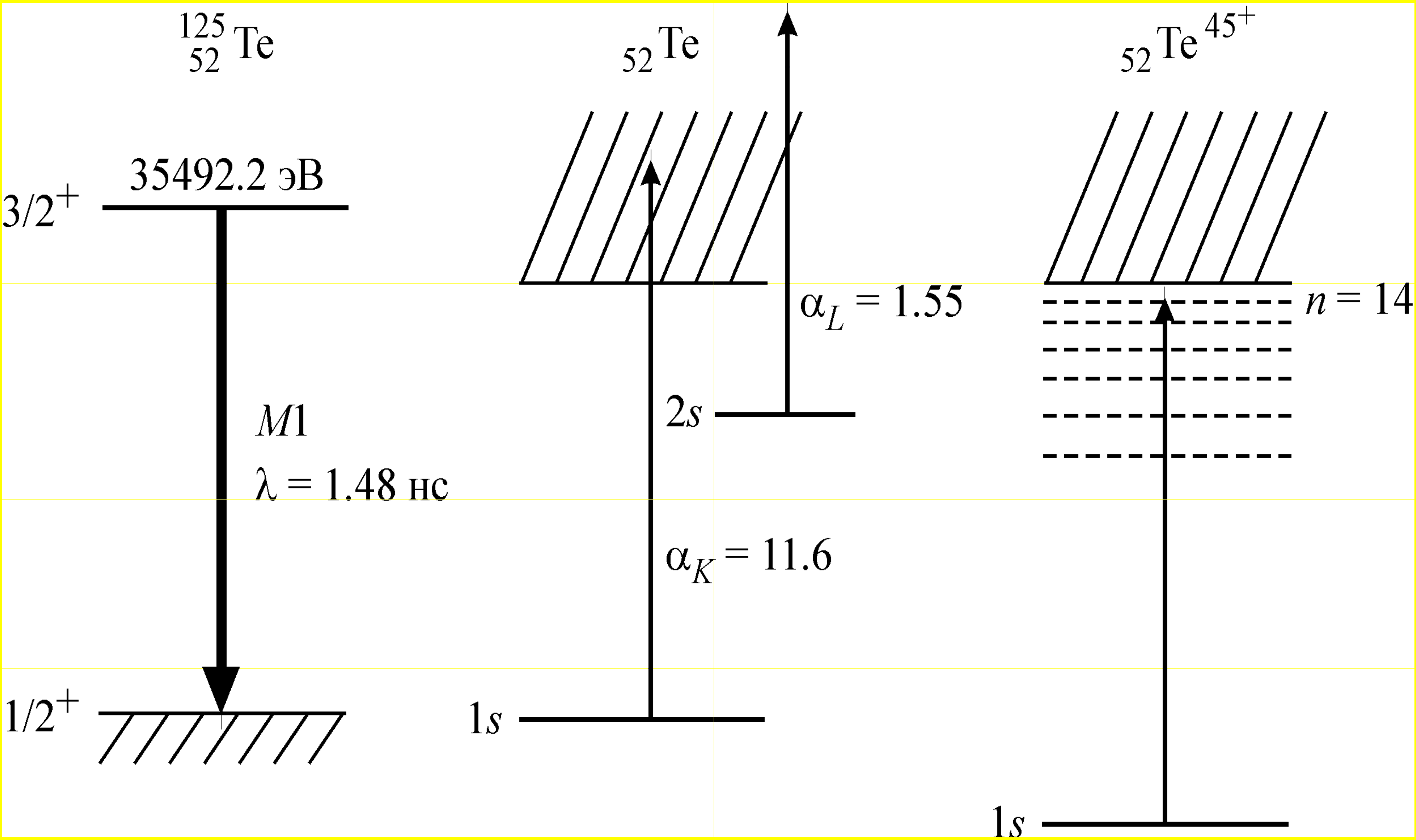
INTERNAL CONVERSION CHAEACTERISTIC FEATURES

TRADITIONAL	RESONANCE
ICC: $\alpha(\tau L;\omega) = \Gamma_c / \Gamma_\gamma$ α -- dimesionless	$R = \alpha_d \dfrac{\Gamma_a / 2\pi}{\Delta^2 + (\Gamma_a / 2)^2}$ α_d ~ [MeV]; R -dimesionless
α – smoothly depends on ω	R – sharply resonant
α – independent of spectator electrons	R – depends on the presence of spectator electrons

α = R at the boundary

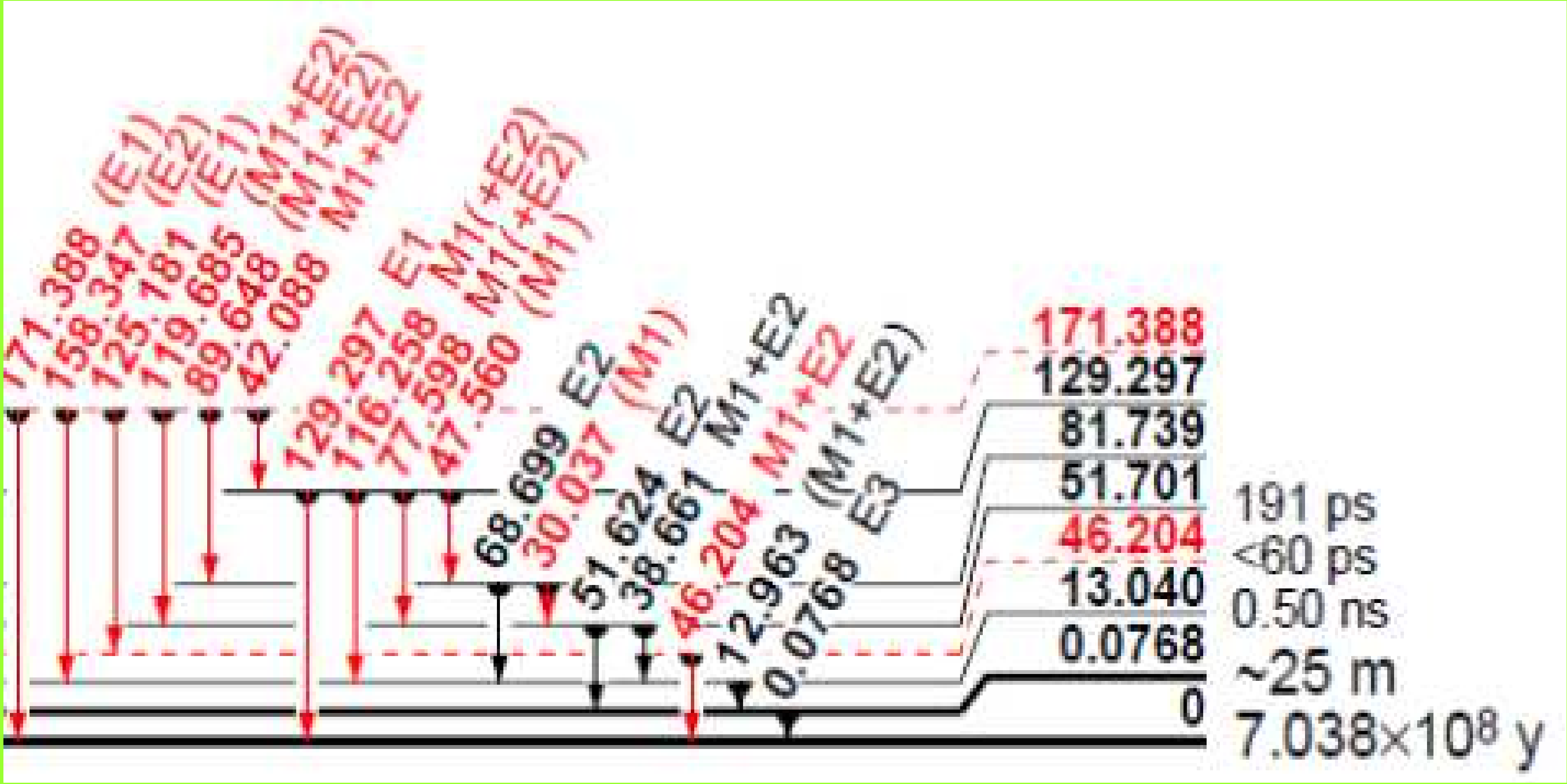
Discovery of RC in ^{125}Te

F.F.Karpeshin, M.R.Harston, F.Attallah, J.F.Chemin *et al.*,
Phys. Rev. **C53** (1996) 1640

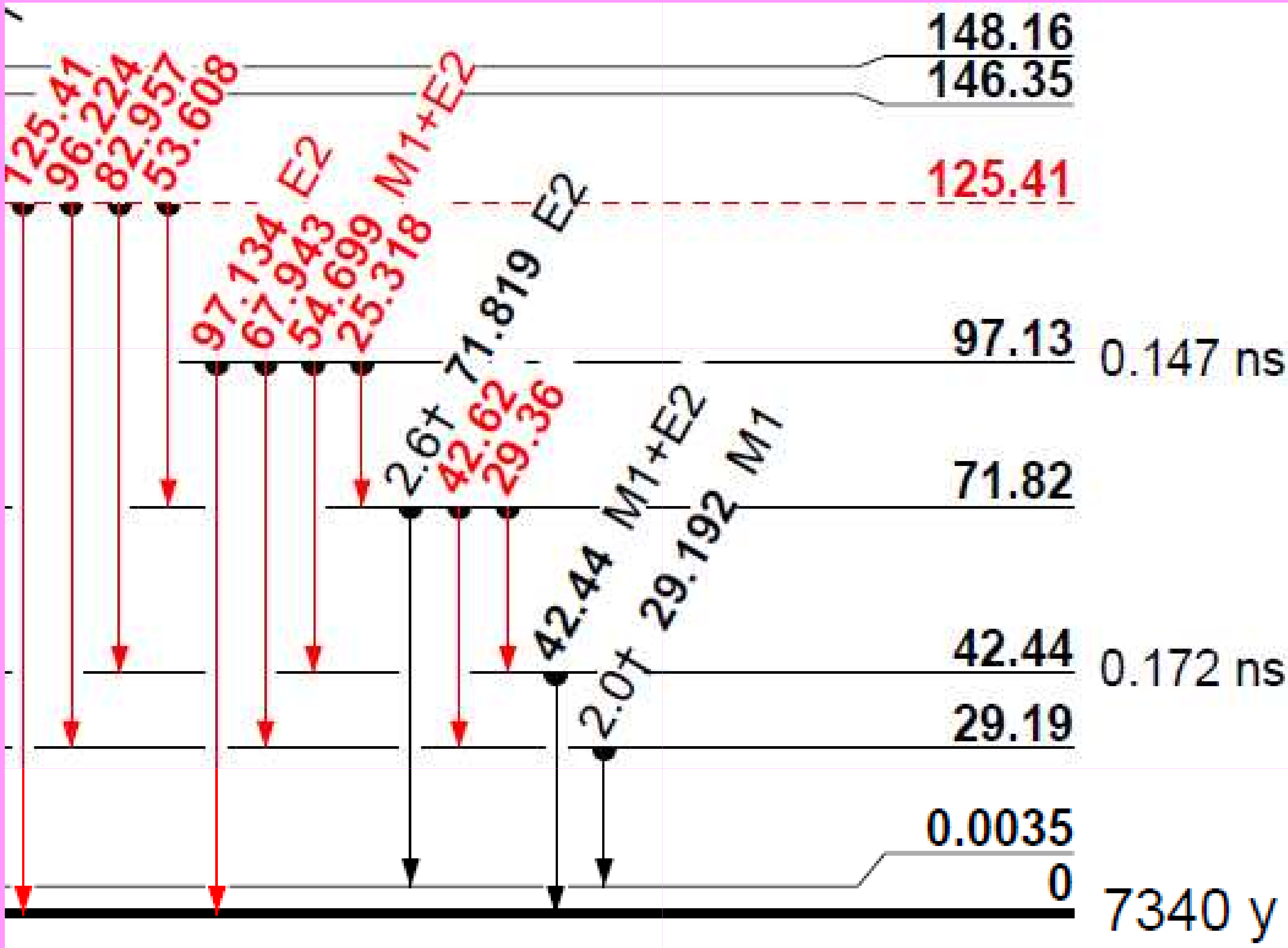


q (IONIZATION)	λ, ns	
	Expected	Experim.
44	1.5	< 2
45	~ 10	< 2
46	~ 10	< 2
47	~ 10	6 ± 1
48	~ 10	11 ± 2

NUCLEI WITH LOW-LYING ISOMERIC STATES



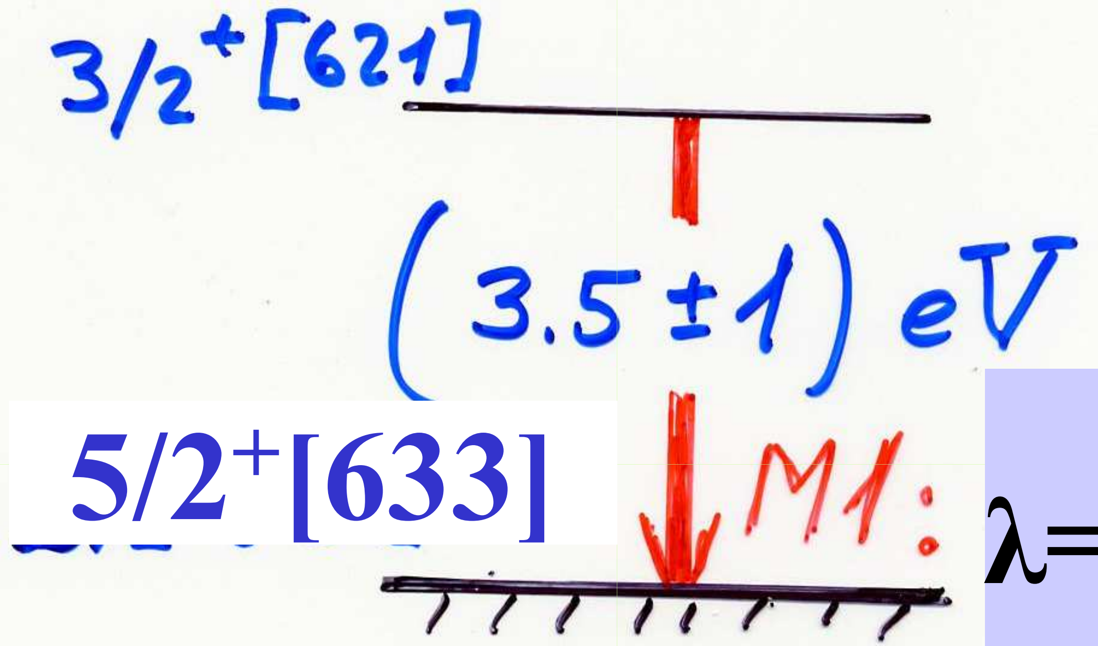
$^{235}_{92}U$



148.16
146.35
125.41
97.13
0.147 ns
71.82
42.44
0.172 ns
29.19
0.0035
0
7340 y
125.41
96.224
82.957
53.608
E2
M1+E2
97.134
67.943
54.699
25.318
71.819 E2
2.6†
42.62
29.36
42.44 M1+E2
2.0†
29.192 M1

$^{229}_{90}Th$

ENERGY DOUBLET IN ^{229}Th



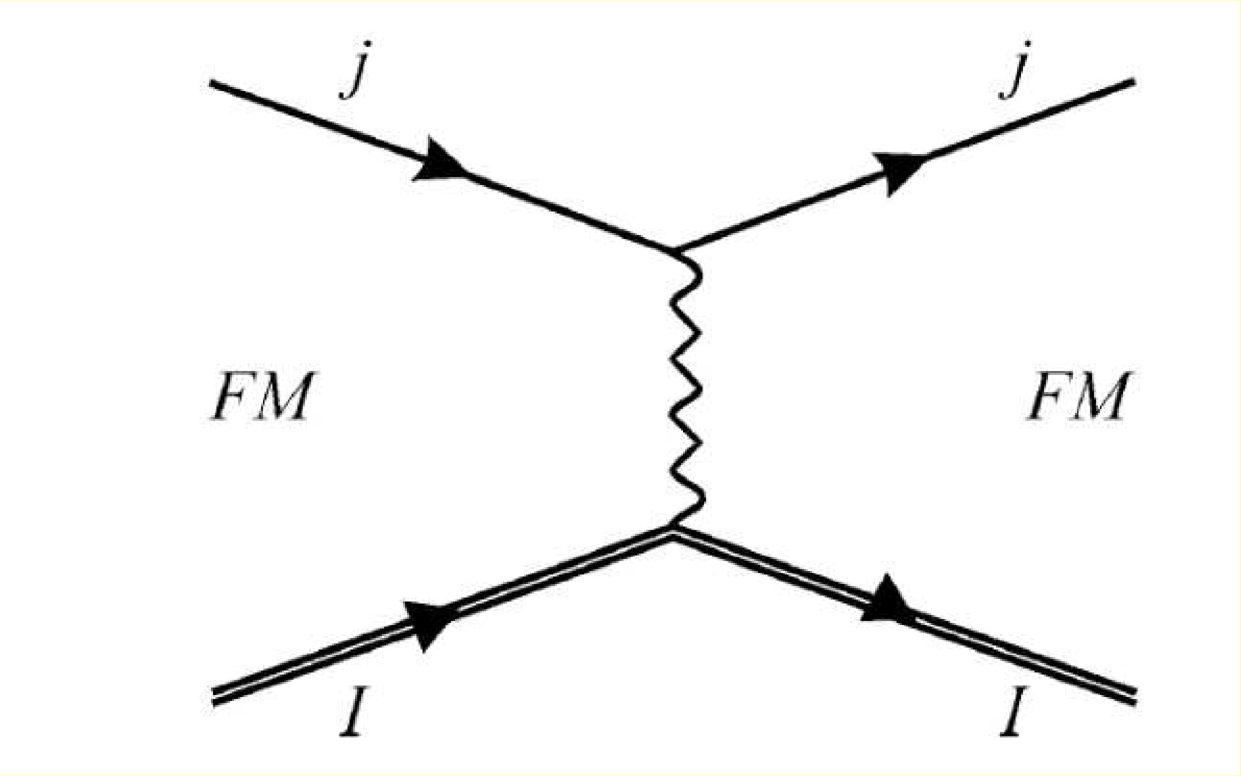
5/2^{+}[633]

λ= 1 ÷ 50 h

^{229}Th

Hyperfine splitting as RC

F.F.Karpeshin, *Particles and Nuclei*, **37**, 522, 2006



Rates of transitions between the hyperfine-splitting components of the ground-state and the 3.5 eV isomer in $^{229}Th^{89+}$

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(Received 14 January 1998)

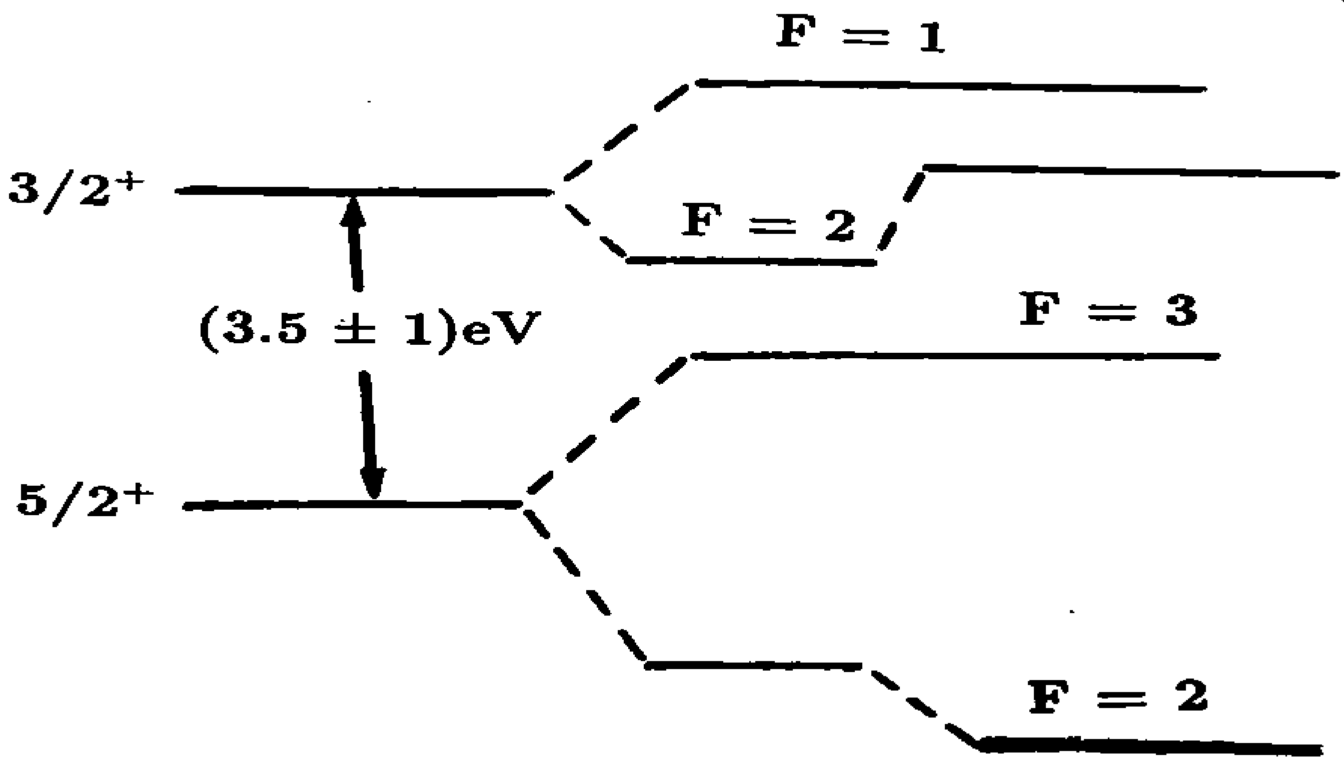
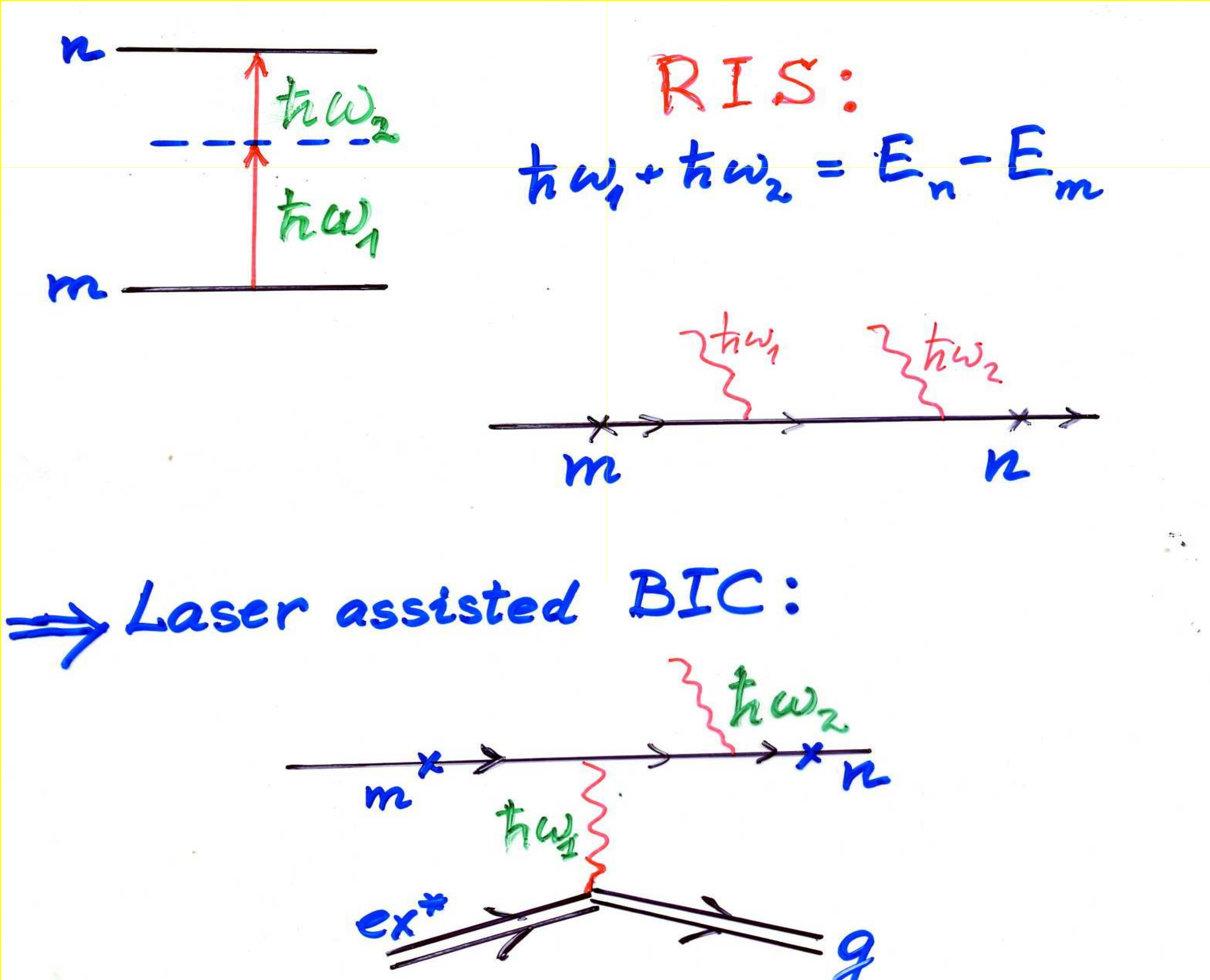


TABLE I. Calculated energies ω and mean lifetimes τ for radiative transitions between the four states of hfs in the $^{229}Th^{89+}$ ion. Calculations have been performed for the magnetic-interaction matrix elements used in Ref. [2]. For a discussion of the role of uncertainties in these matrix elements, especially dramatic for the $F_i = 1 \rightarrow F_f = 2$ up transition, see Sec. III.

E_{isom} [eV]	4.5		3.5		2.5	
Mixing β^2 [%]	1.35		2.06		3.51	
Transition $F_i \rightarrow F_f$	ω [eV]	τ [s]	ω [eV]	τ [s]	ω [eV]	τ [s]
1 → 2 up	0.12	24.0	0.10	41	0.08	82
1 → 2 low	5.24	0.022	4.26	0.026	3.28	0.033
2 up → 3	4.11	0.031	3.13	0.046	2.15	0.085
2 up → 2 low	5.12	0.013	4.16	0.017	3.20	0.023
3 → 2 low	1.01	0.060	1.03	0.056	1.05	0.054

LASER ASSISTANCE OF BIC AND TEEN



Physics Letters B 282 (1992) 267–270
North-Holland

PHYSI

Study of ^{229}Th through laser-induced resonance internal co

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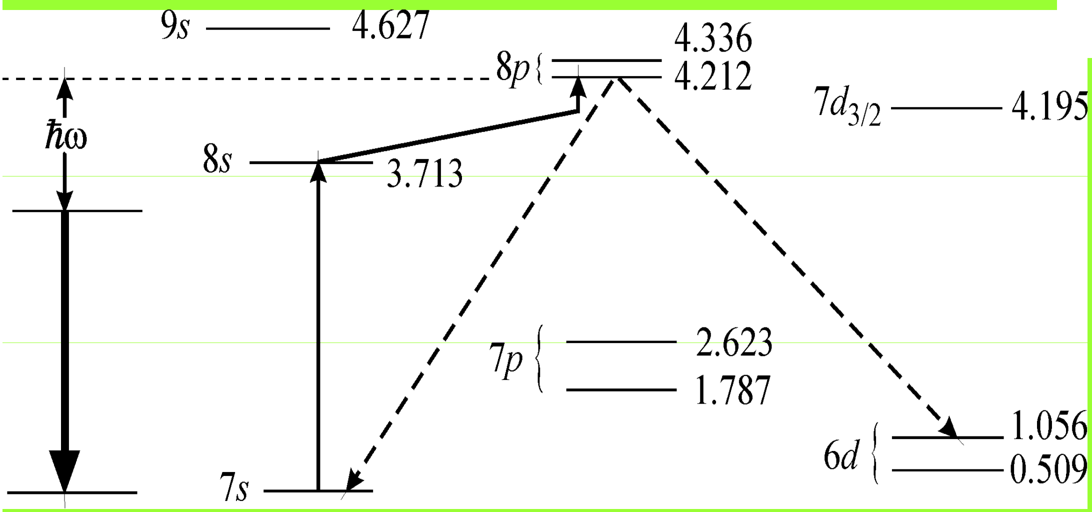
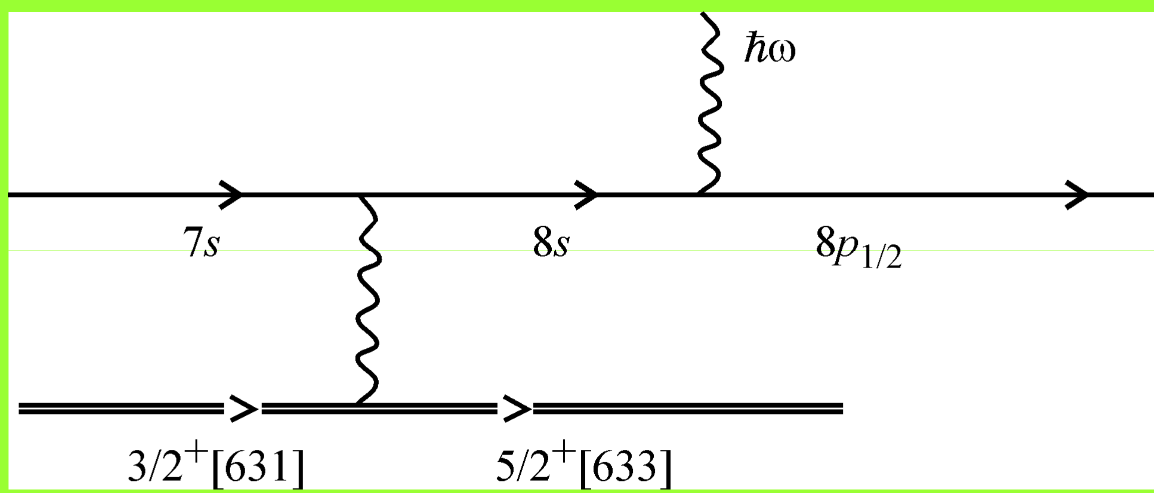


$$R \cong 500(\mathcal{E}/\Delta)^2$$



EET ⇄ TEEN

M. Morita, Prog. Theor. Phys. **49**, 1574 (1973)

⇓

resonance or bou
discrete, subthreshol
conversion

ctually, non-radiative muon transition is **NEμ**

Direct laser assistance of NEET: ***impossible*** because of immediate response through TEEN (F.F.Karpeshin, *Hyperfine Interactions* **143:** 79–96, 2002).

The limitation on *both* the duration and power of the laser pulse.

For this reason, a mechanism like a low one *may be misleading*.

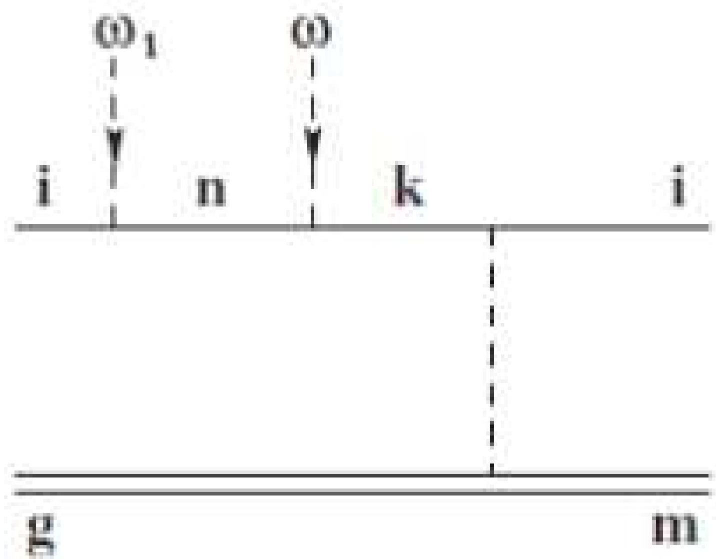


FIG. 1. Two-photon electronic bridge process. The single and double solid lines relate to the electronic and the nuclear states, respectively. The dashed lines are the photon lines.

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Nuclear Physics A 654 (1999) 579–596

NUCLEAR PHYSICS A

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3.5-eV isomer of ^{229m}Th: How it can be produced

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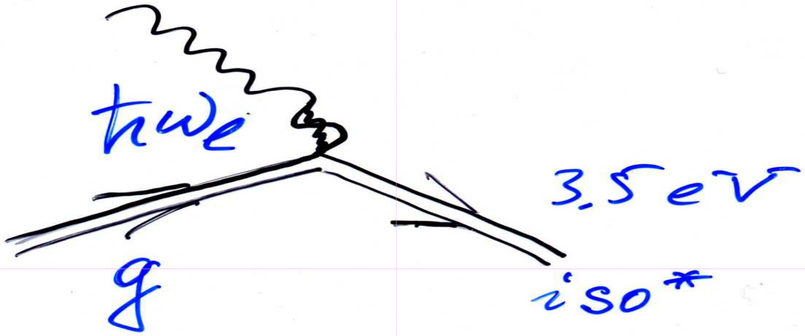
Abstract

Various schemes of producing the 3.5-eV isomer of ^{229m}Th by radiative pumping the atom of ^{229}Th in the ground state are considered. Due to the resonance properties of the electron shell, some of the schemes turn out to be more effective than radiative pumping the bare nucleus of the same element.

PACS: 20.00

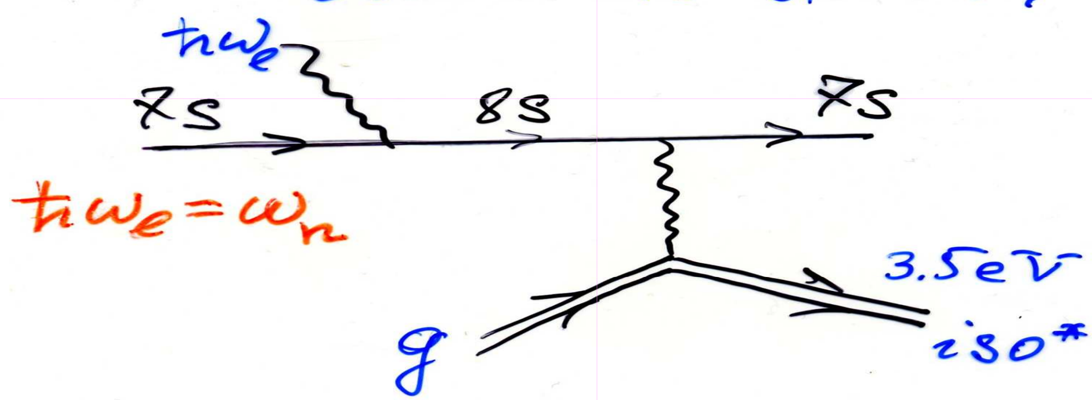
Pumping bare nucleus:

^{229}Th

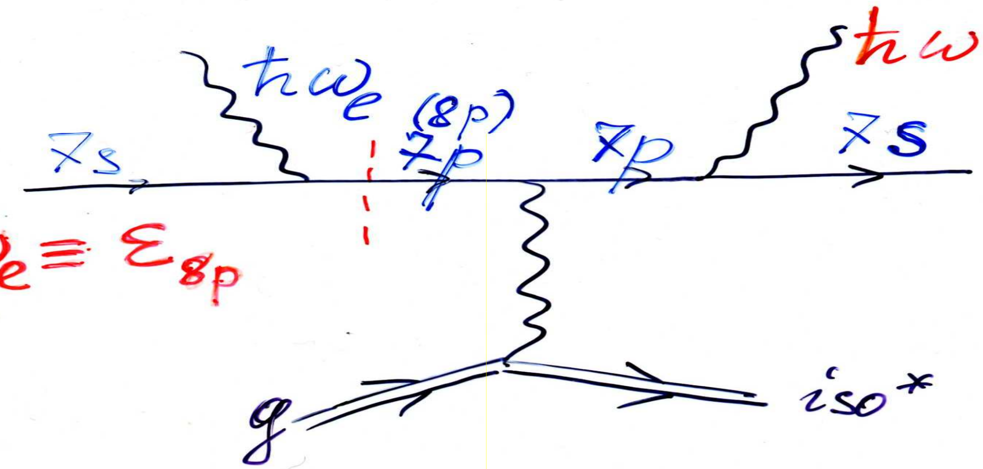


$$\sigma_\gamma(\omega) \simeq 170 \text{ mB for } \Gamma_e \sim 10^{-5}\,\text{eV}$$

Pumping through full electron shell:

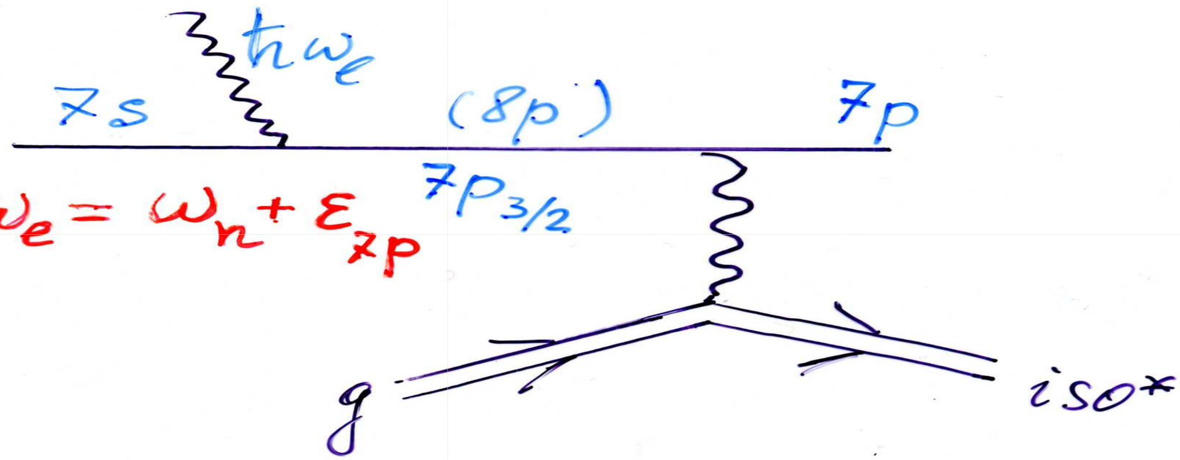


$$R \equiv \frac{\sigma_\gamma^{(r)}(\omega_e)}{\sigma_\gamma(\omega_e)} = 0.0016$$



$\hbar\omega_e \equiv \varepsilon_{8p}$

$$R \equiv \frac{\sigma_\gamma^{(r)}(\omega_e)}{\sigma_\gamma(\omega)} \sim 0.017$$

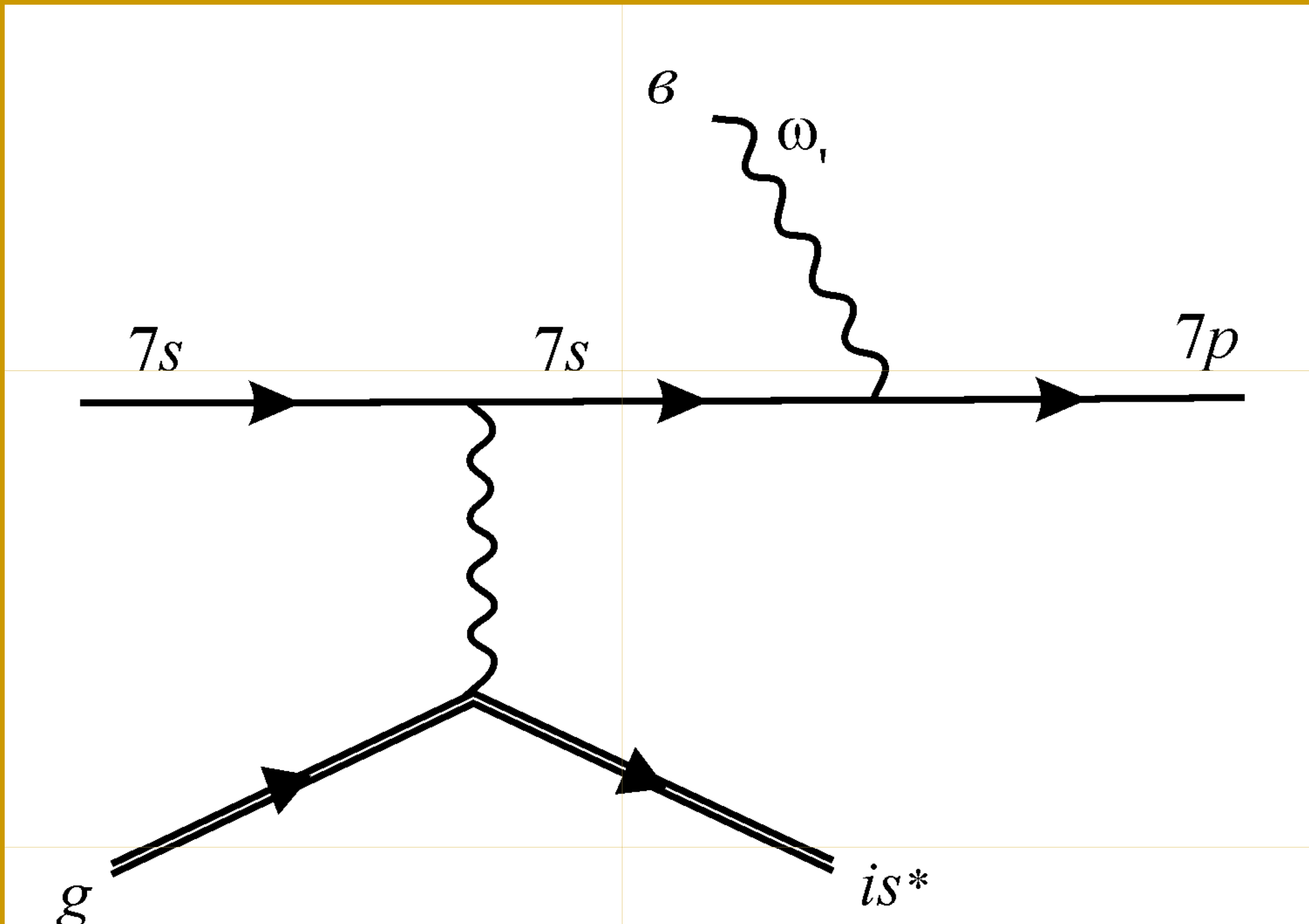


$\omega_e = \omega_n + \varepsilon_{7p}$

$\omega_e = \omega_{nucl} + \omega_{7s-8p}$ – unknown.

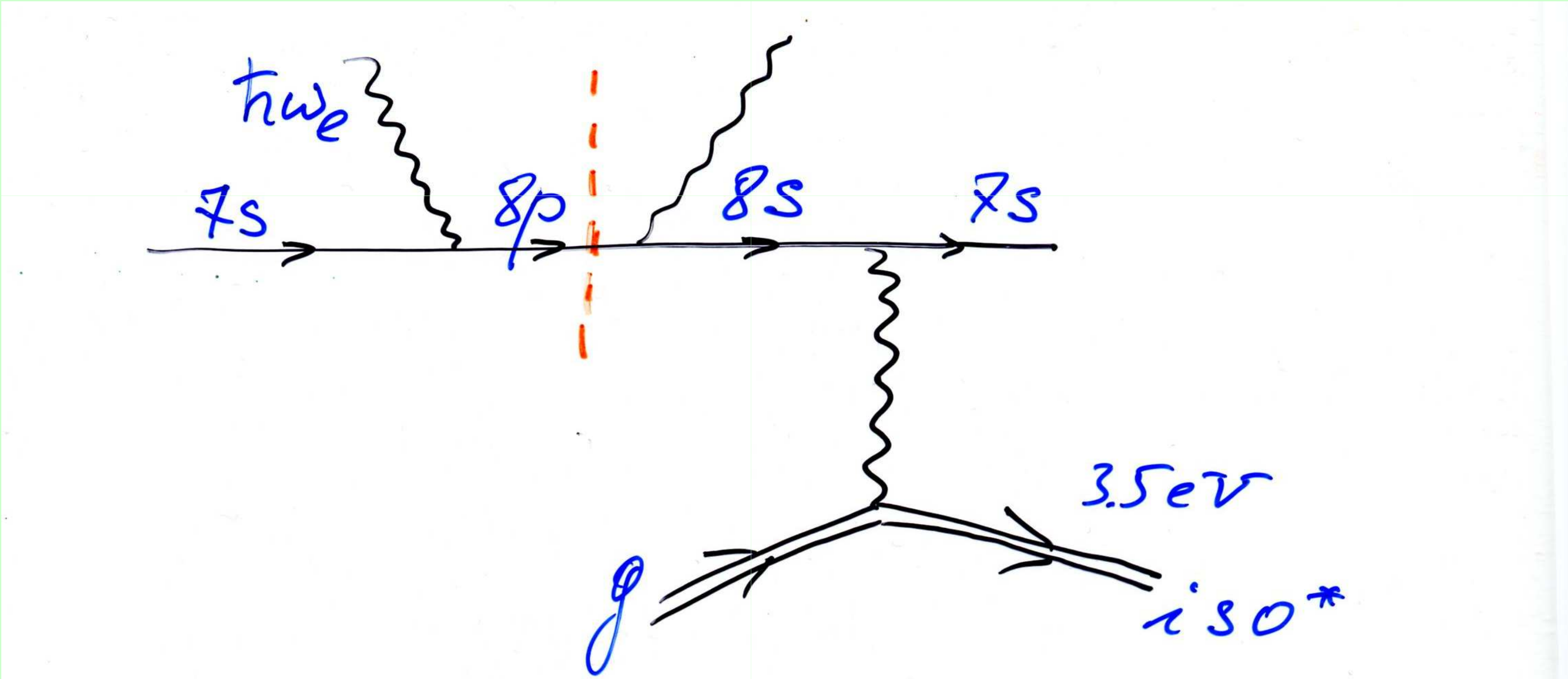
$R \simeq 40$

⇒ "Неупругий", но эффективный



$R \approx 962$

Most effective scheme: adopts population inversion



$$R = \sigma_\gamma^r(\omega_1)/\ \sigma_\gamma(\omega) \sim 2\times10^3$$

Outgoing photon makes the mechanism *irreversable*!.

SUMMARY

1. **The shell really appears to be a good resonator**
2. **BIC experimentally observed to be an effective deexcitation channel, adopting resonance tuning by laser**
3. **Stripping the shell as a trigger: 5-orders enhancement of the decay rate in the H-like Th**
4. **Way of two-photon pumping the isomer has limitations due to back decay via the electron bridge, supported by the pumping field itself. Population from an higher lying electronic level looks more efective and deprived of the limitations.**
5. **Laser-assisted NEET for pumping isomers and TEEN for triggering their energy.** ***Population inversion*** **of the 3.5 eV isomer of ^{229}Th is offered by laser-assisted NEET. Does not matter whether the isomer energy is 3.5 or 7.6 eV!**