Doubly Excited States – Some Comparisons of theory and experiments

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(Ph.D thesis work – Notre Dame 2005 is a study of doubly-excited sextet states in O IV)

Not published – part of Ph.D. thesis of Bin Lin

“Lining up the electron spins….”
or
“Exciting the inner shell electrons…”

3-electrons (lithium sequence) → quartets

[also sodium and other alkali sequences]

4-electrons (beryllium sequence) -> quintets

5-electrons (boron sequence) -> sextets

An important early paper: Example of the decay of the lowest (METASTABLE) state of these “high-spin states”

“*Decay of* $^4P^{5/2}$ *Autoionizing States of Ions in the Li Isoelectronic Sequence,”*

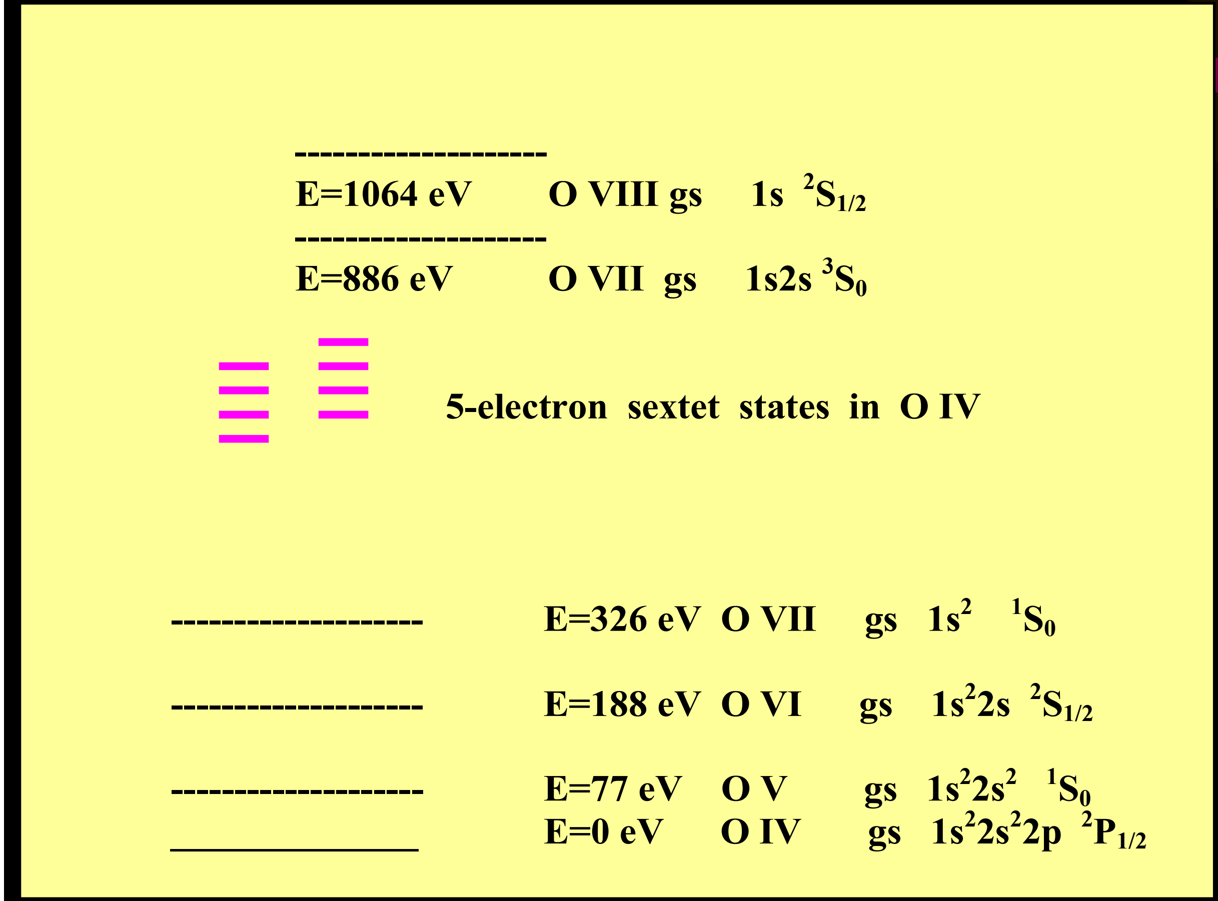
K.T. Cheng, C.P. Lin, and W.R. Johnson, Phys. Letts. 48A, 437 (1974).

Why are we interested in sextet states?

Why do we study Sextet states of boron-like Ions

- To check the QED effects
- Possible candidate for XUV/X-ray lasers
- To check the higher-order corrections
- Possible candidate for energy storage
- To check the MCHF method
- Offer new data for atomic physics database
- Offer new data for plasma physics database

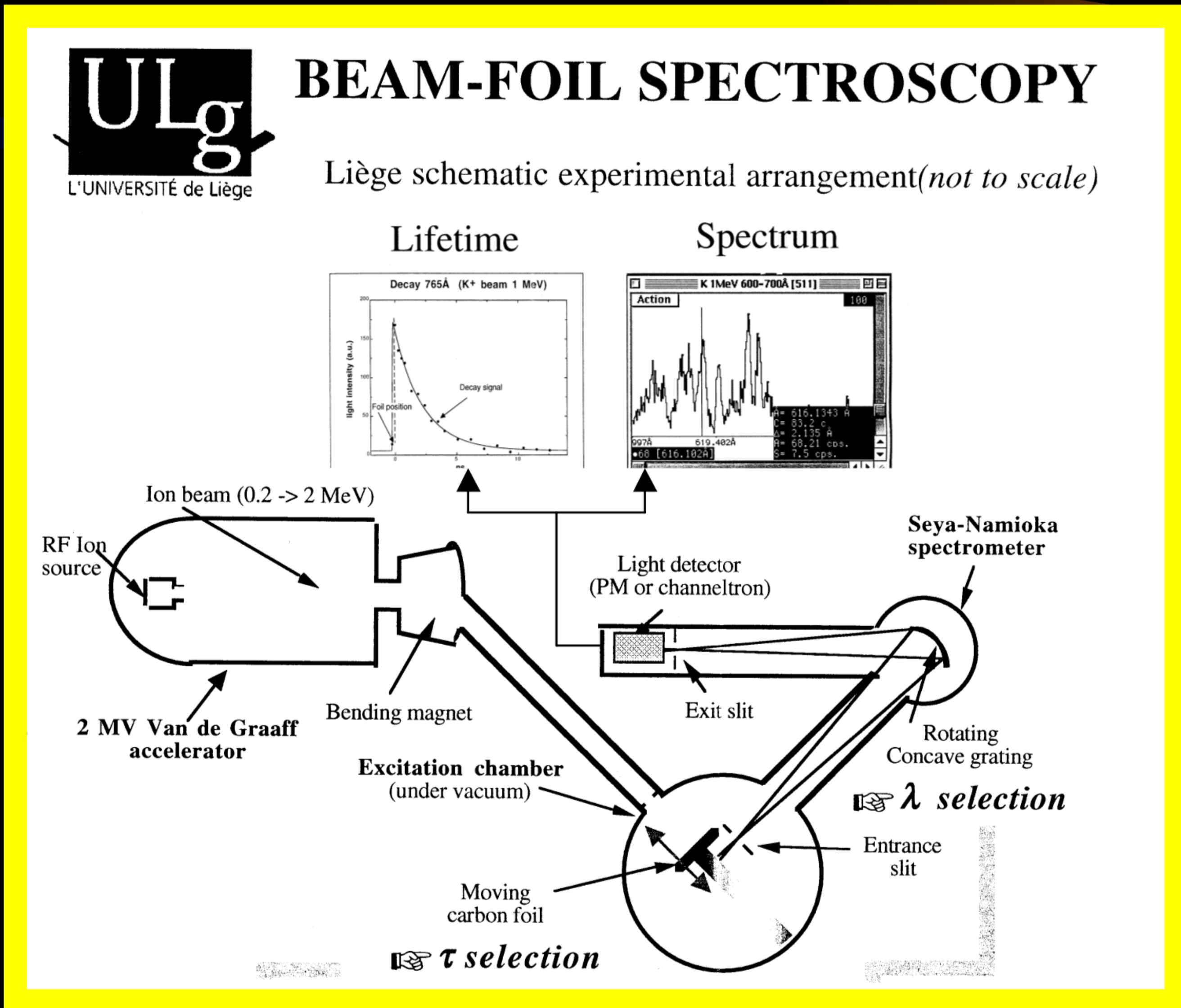
Doubly excited sextet states in boron-like ions



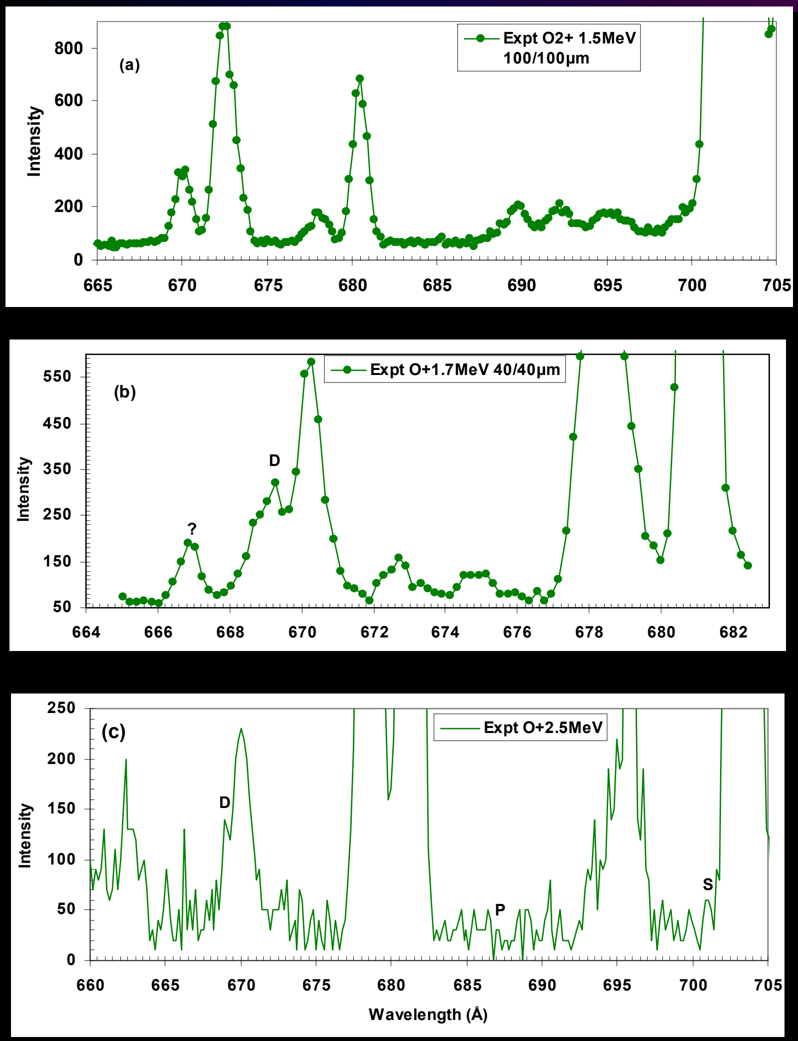
Term diagram of doubly excited sextet states in O IV.

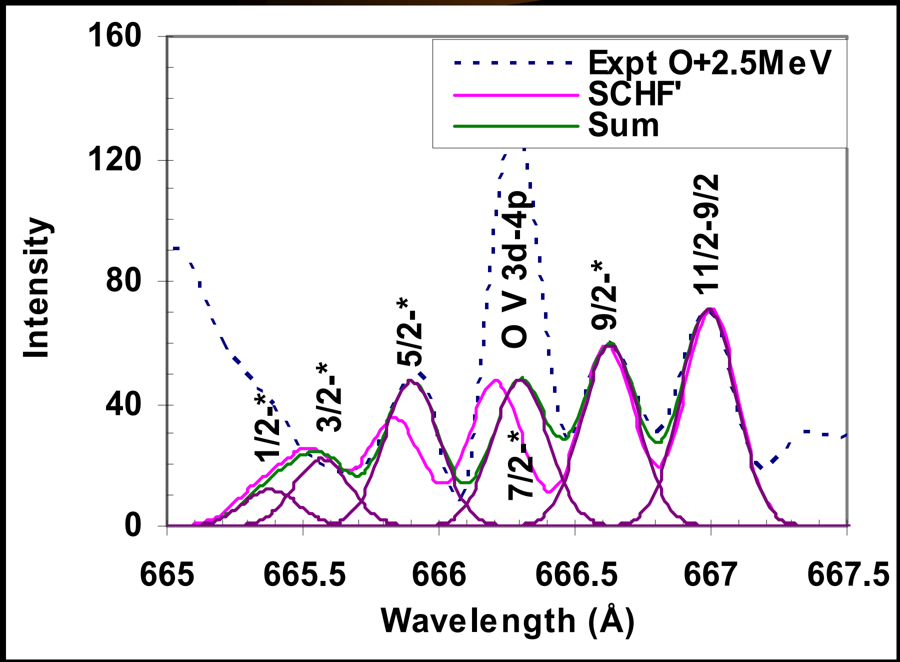
- Five electrons with aligned spins
- well above several ionization levels
- metastable: $\tau \approx 10^{-6}$ - 10^{-9}s.

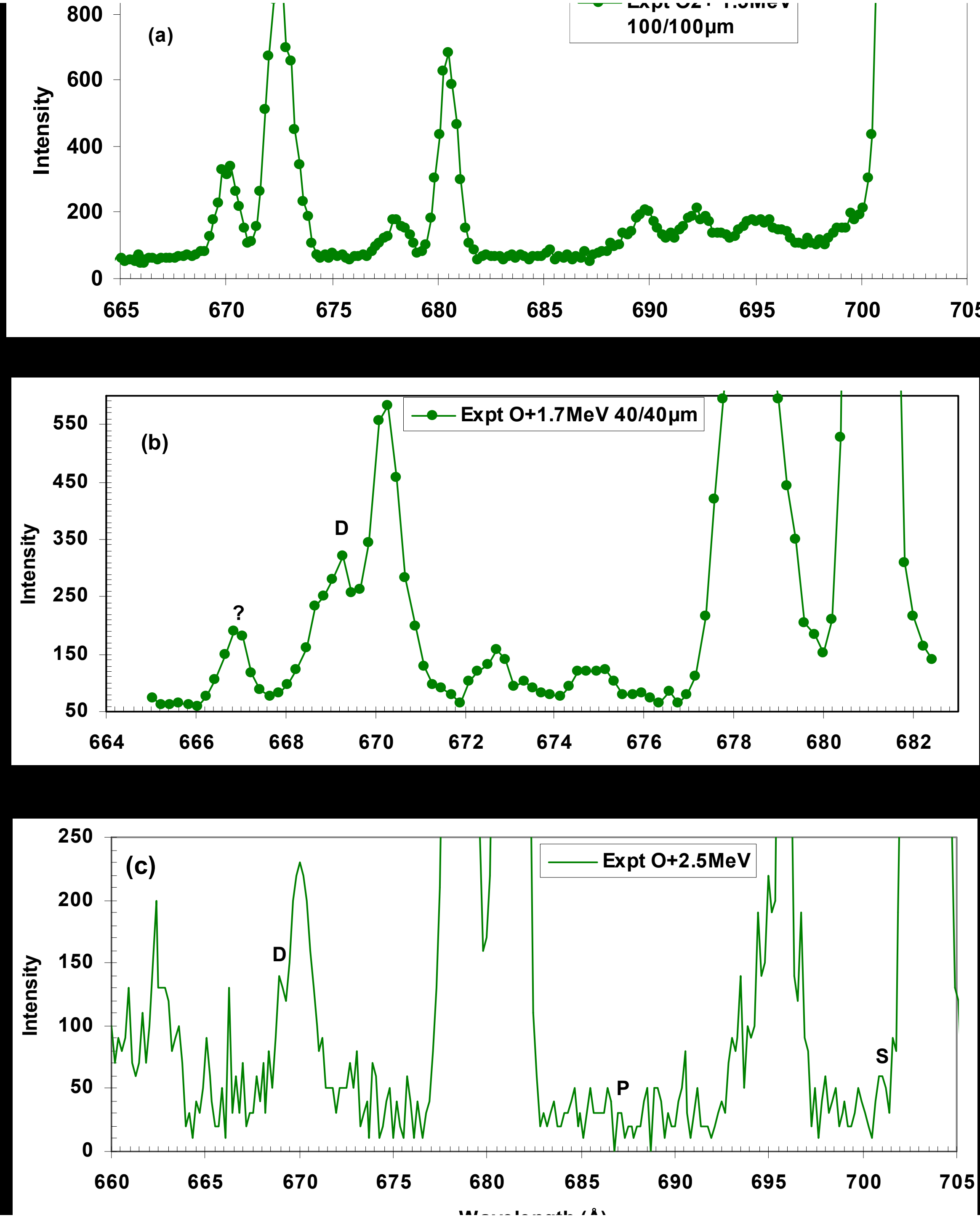
Fast beam-foil spectroscopy at the 2 MeV Van de Graaff accelerator at the University of Liège



The 1s2s2p²3d ⁶F$_J$-1s2p³3d ⁶D$_{J'}$ transitions in the beam-foil spectra of oxygen, recorded at the different energies. The beam energies and spectrometer slit widths are shown.

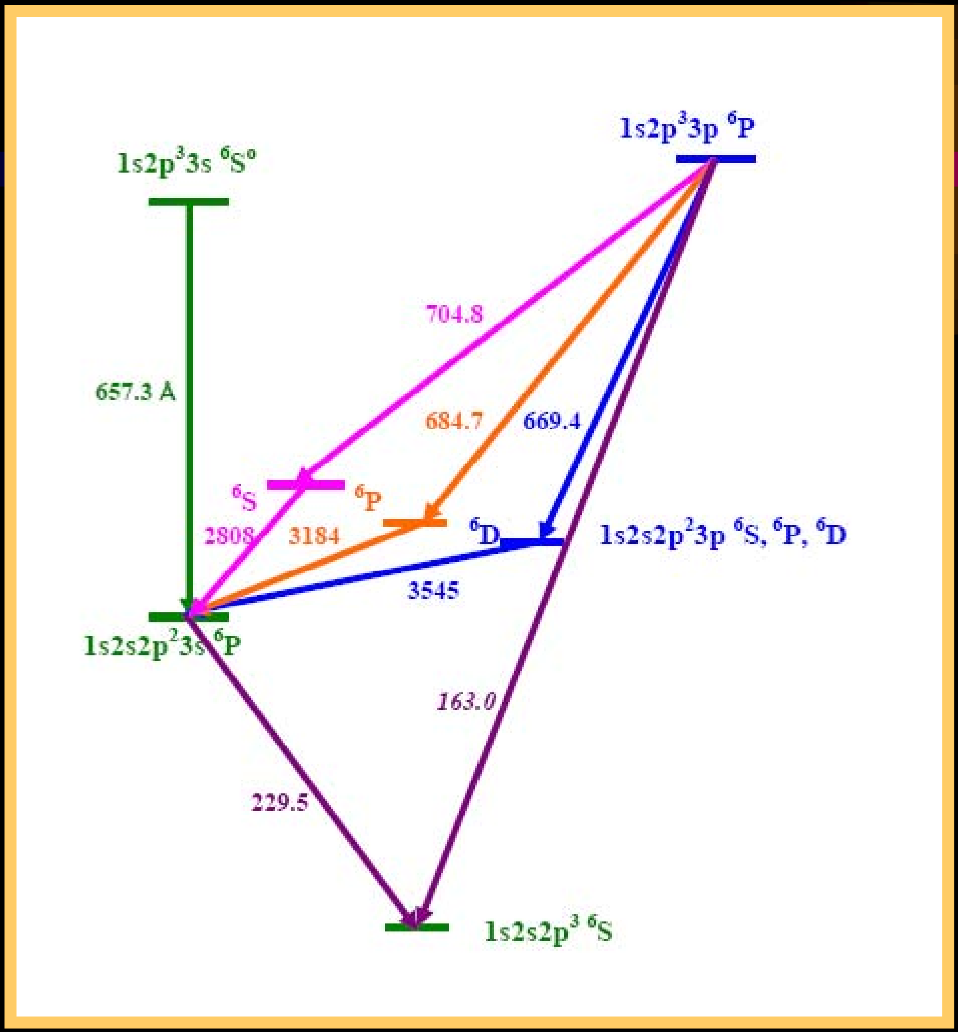






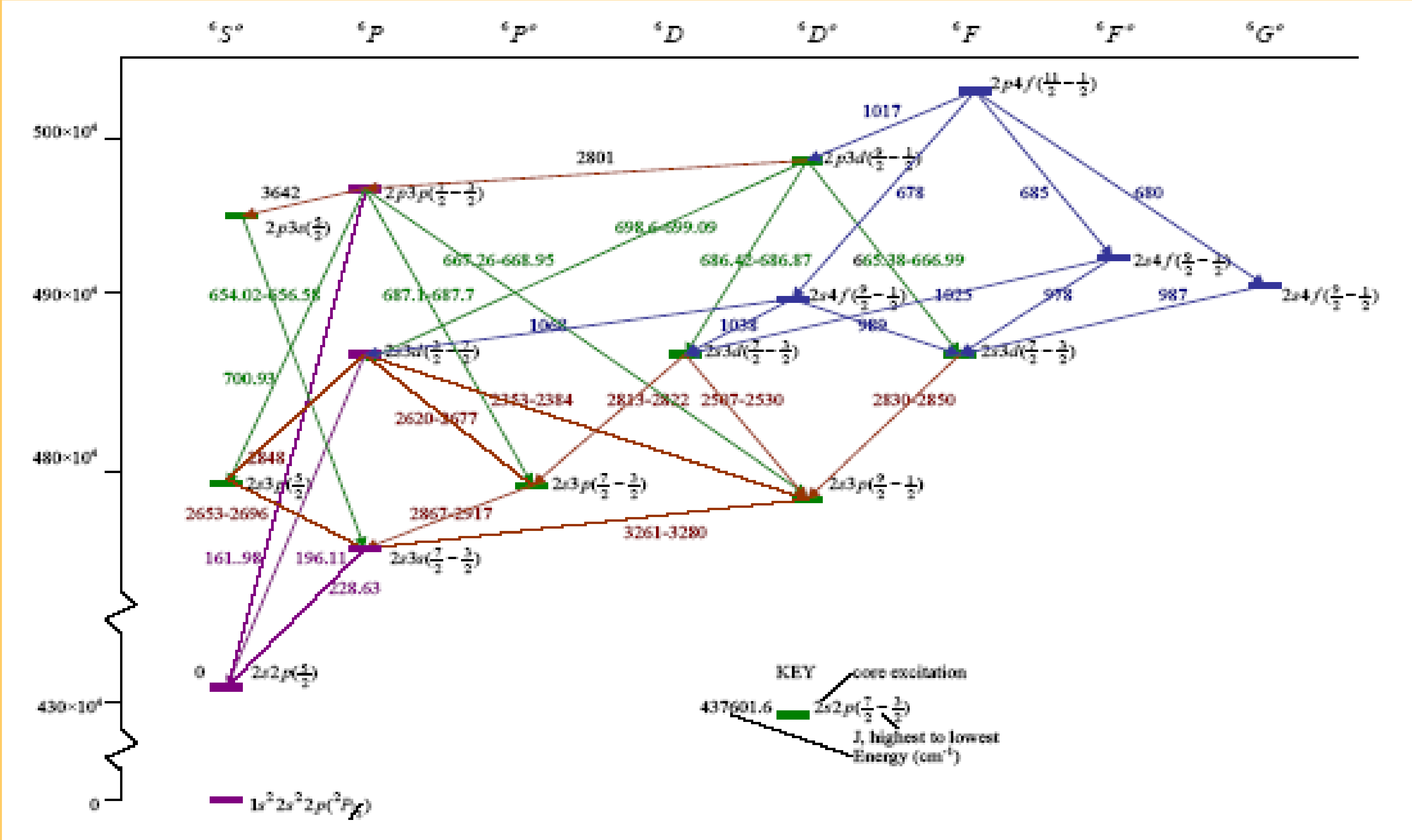
(a)
100/100µm
Intensity
0
200
400
600
800
665
670
675
680
685
690
695
700
705
(b)
Expt O+1.7MeV 40/40µm
Intensity
50
150
250
350
450
550
664
666
668
670
672
674
676
678
680
682
?
D
(c)
Expt O+2.5MeV
Intensity
0
50
100
150
200
250
660
665
670
675
680
685
690
695
700
705
D
P
S

The doubly excited sextet levels in O IV

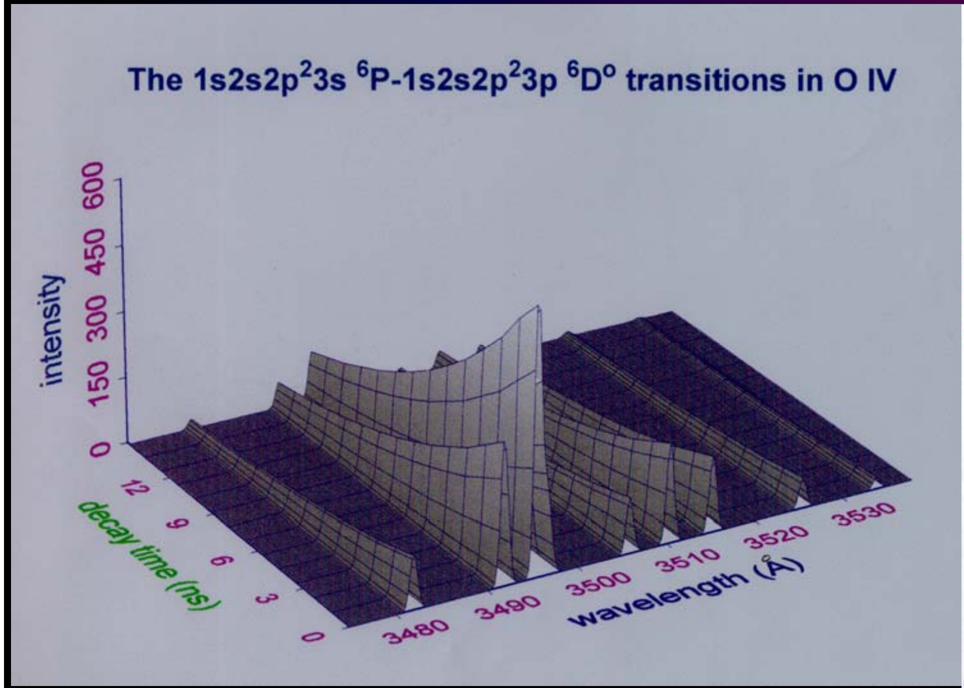


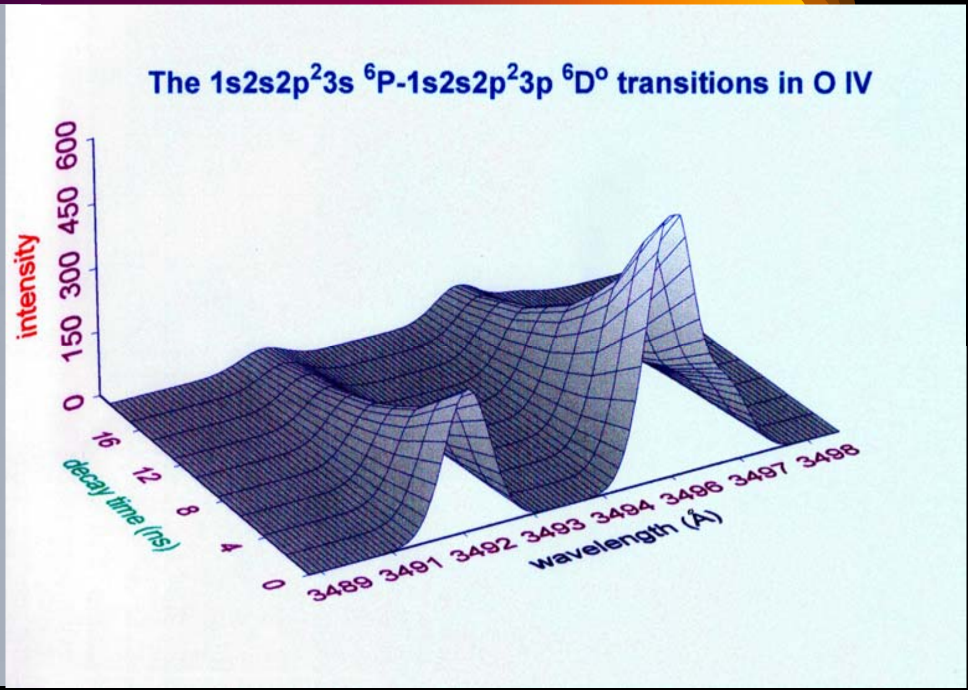
The transition wavelengths are in Angströms.

Grotrian diagram of doubly excited sextet levels $1s2p^2nln'l'\ ^6L$ in O IV. The units of wavelengths are Å.

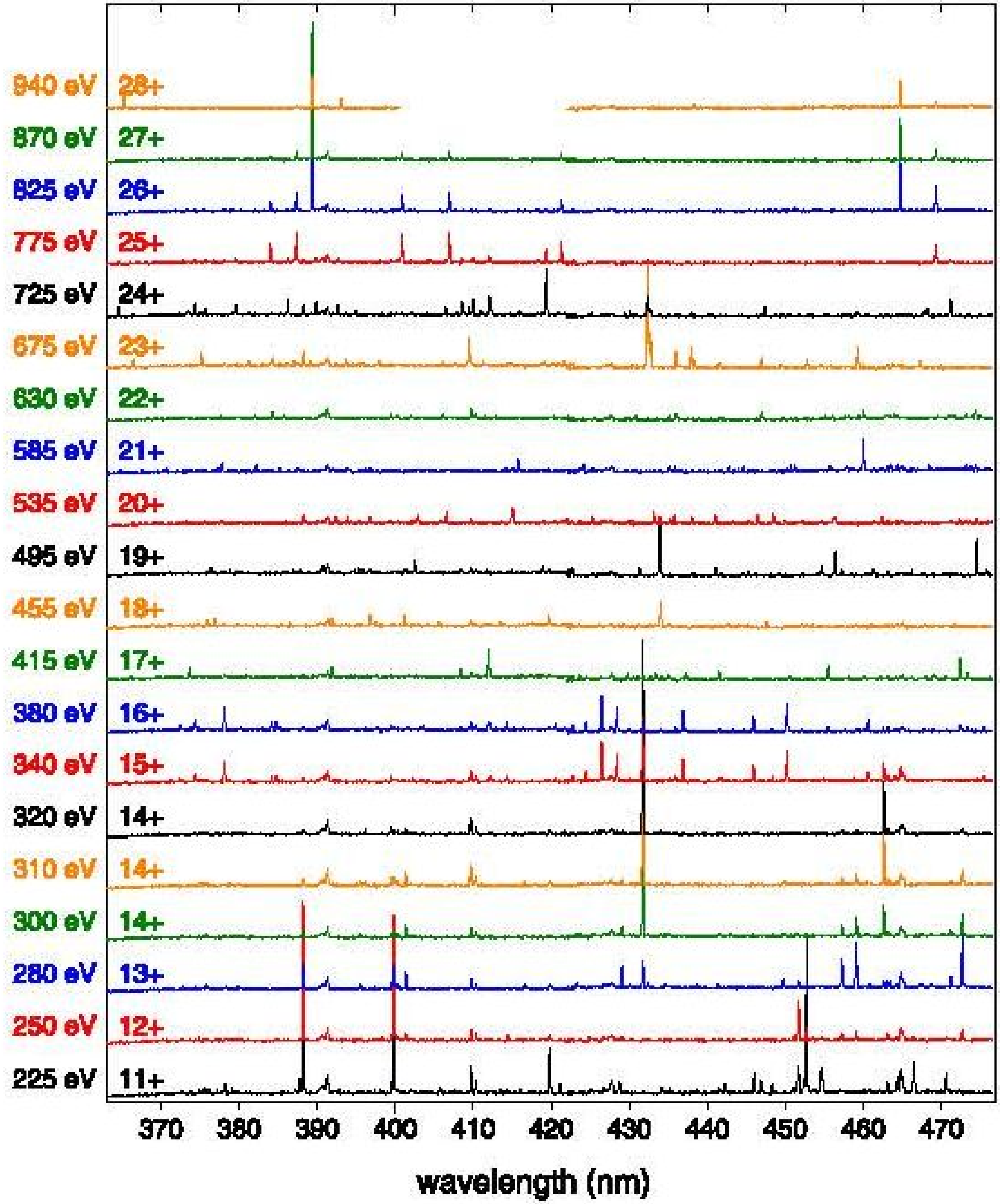


Decay curves of O IV sextets





EBIT spectra of Tungsten Tokyo 2012



Visible Transitions in Highly Charged Tungsten Ions: 365 - 475 nm

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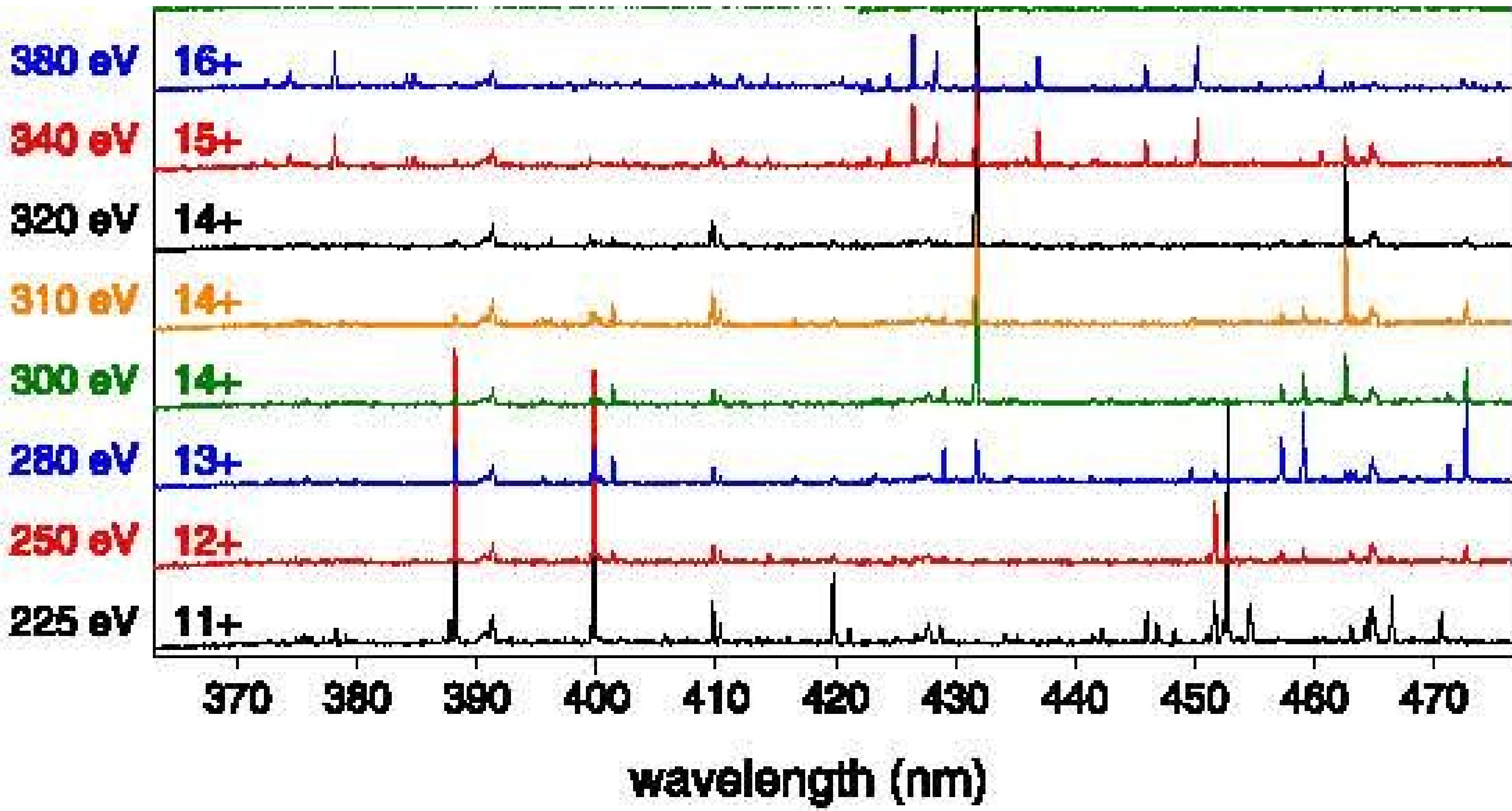

Lines identified by Fudan students!!

Table 1 Wavelengths (in air) of the observed visible transitions in highly charged tungsten W^{q+}.

q	wavelength (nm)
28	365.25*, 393.06*
26	389.41*, 464.68*, 501.99*
25	383.99*, 387.3*†, 400.88*, 406.92*, 421.28*, 451.15, 467.59, 469.21*, 493.62
24	364.58, 374.34, 375.70, 379.64, 386.23, 389.89, 392.62, 406.49, 408.58, 409.97, 412.2†, 419.35*, 425.17, 447.36, 467.80, 468.22, 471.18
23	366.48, 375.18, 381.25‡, 388.27, 389.19‡, 393.69‡, 409.44*, 411.28‡, 432.32*, 432.66, 437.90, 438.30, 441.52, 449.46, 459.25
22	384.32, 446.95
21	382.21, 385.16‡, 415.83, 424.17, 442.69, 444.58, 450.70, 451.17, 459.99, 463.50, 468.39
20	388.25, 402.91, 406.62, 415.06†, 422.05, 425.27, 433.14, 435.21‡, 435.82, 438.02, 448.47, 462.40
19	376.38‡, 402.52, 418.90‡, 433.89, 441.06, 456.43, 474.49
18	375.90, 376.85, 396.83, 397.42‡, 401.22, 419.68, 434.01
17	373.69, 391.93, 423.65‡
16	455.52‡, 472.39
15	372.41‡, 374.39, 378.14, 384.15, 384.76, 412.17, 414.29, 420.52, 424.45, 426.47, 428.43, 436.92, 450.23
14	462.59‡
13	457.26, 459.08, 472.68
12	401.38, 451.68
11	388.19, 399.81, 428.79‡, 446.04, 452.77, 454.64, 466.48
8	387.15, 405.73

*Reported in our previous paper [4, 6, 11], †blend lines, ‡weak lines.

Any “long-lived Rydberg transitions” in EBIT spectra?

For any Rydberg transition
Between n_1 and n_2 (easier than the GRASP code!)

$$E = \zeta^2 \times 109737(1/n_1^2 - 1/n_2^2)$$

Examples for W (12+) $\zeta = 13$ then

E(10-11) gives wavelength $\lambda = 310.7$ nm
E(11-12) gives wavelength $\lambda = 408.5$ nm
E(12-13) gives wavelength $\lambda = 524.9$ nm

Check the Japanese spectrum….

Conclusion:

NO Rydberg YRAST transitions seen

Therefore, lines must be between low-lying levels

Just a brief selection……….(from Sally)