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FINAL REPORT

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MEASUREMENTS OF QUANTUM ELECTRODYNAMIC SENSITIVE TRANSITIONS IN Na-LIKE AND Cu-LIKE IONS

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DISCLAIMER

The object of this research was to use the GDL laser at the Laboratory for Laser Energetics at the University of Rochester to measure the energies of spectral transitions that would be of importance for testing the accuracy of calculations used to predict properties of plasmas found in inertial fusion experiments as well as in tokamaks and x-ray lasers.

The general method to be used for this experiment was to focus the beam from the GDL laser to a small point so as to create a laser-produced plasma of the material of interest. Light from the plasma was to be photographed with a 2.2-m grazing incidence spectrograph transported to Rochester from NIST. The region of observation was 10 - 300 Å.

In the initial phase of the work a series of spectrograms were made of highly ionized iron. For this a special target chamber was fabricated at NIST and interfaced to the light beam from the GDL laser. As shown in Fig. 1, the target of pure iron was positioned in the chamber with its flat surface vertical and lying along the entrance axis of the spectrometer. The exact position of the target was fine-tuned for optimal illumination of the spectrometer by taking a series of photographic spectra in which the target and GDL focussing lens were moved in synchronism along the axis of the focussing lens. The position of the lens relative to the target was then fine-tuned by taking a series of spectra in which only the lens was moved along its axis. In this way excitation of the plasma could be controlled so as to emphasize either the very highest stages of ionization or somewhat lower stages.

The results for iron provided valuable data for Li-like iron, Fe^{23+}. Fig. 2 shows an example of the spectrum obtained in the region of 30 - 40 Å. The lower spectrum shows intense lines of Fe^{23+}, obtained by focussing the GDL beam tightly onto the target surface. For the upper spectrum the GDL beam was focussed slightly in front of the target, producing lines of Fe^{23+} that are much reduced in intensity.

The lines of Fe^{23+} in the 30-40 Å region were observed for the first time in this experiment. Measurement of their wavelengths provided the following comparison with *ab initio* values calculated with the Dirac-Fock quantum mechanics computer code of Desclaux.

Table 1. Measured and Calculated Wavelengths (Å) for the n=3-4 Transitions of Fe^{23+}

Transition	Measured[a]	Calc[b]
3s $^2S_{1/2}$-4p $^2P_{3/2}$	30.743±0.004	30.742
3s $^2S_{1/2}$-4p $^2P_{1/2}$	30.895±0.004	30.894
3p $^2P_{1/2}$-4d $^2D_{3/2}$	31.637±0.004	31.637
3p $^2P_{3/2}$-4d $^2D_{5/2}$	31.968±0.004	31.971
3p $^2P_{3/2}$-4d $^2D_{3/2}$	32.00 ±0.02	32.023
3d $^2D_{3/2}$-4f $^2F_{5/2}$	32.377±0.002	32.385
3d $^2D_{5/2}$-4f $^2F_{7/2}$	32.478±0.002	32.485

[a] Present measurement.
[b] Value calculated with the DF code of Desclaux.

Clearly, for these transitions the calculations are highly reliable. By using these n=3-4 transitions, for which the energy levels are nearly hydrogenic, an improved ionization energy for Fe^{23+} was determined as 2046.11±0.17 eV .

With all of the measure data at both low and high wavelengths an improved set of one-electron energy levels for Fe^{23+} was derived, as shown in Table 2.

Table 2. $1s^2nl$ Energy Levels of Fe^{23+}

Term	J	Energy level (cm^{-1})	Uncertainty (cm^{-1})	Interval (cm^{-1})
2s ^2S	1/2	0		
2p ^2P	1/2	391 983	8	128 774
	3/2	520 757	14	
3s ^2S	1/2	9 272 500	1 700	
3p ^2P	1/2	9 378 200	2 600	38 900
	3/2	9 417 100	2 700	
3d ^2D	3/2	9 459 000	1 700	13 600
	5/2	9 472 600	2 400	
4s ^2S	1/2	12 464 400	700	
4p ^2P	1/2	12 508 900	1 600	16 000
	3/2	12 524 900	1 600	
4d ^2D	3/2	12 539 200	2 200	6 000
	5/2	12 545 200	2 700	
4f ^2F	5/2	12 547 600	1 700	4 000
	7/2	12 551 600	2 400	
5p ^2P	1/2	13 943 400 [a]	5 800	8 200 [b]
	3/2	13 951 600 [a]	5 800	
5d ^2D	3/2	13 960 500	5 500	4 800
	5/2	13 965 300	5 500	
6p ^2P	1/2	14 730 900 [a]	6 500	4 700 [b]
	3/2	14 735 600 [a]	6 500	
6d ^2D	3/2	14 735 100	6 200	4 400
	5/2	14 739 500	6 200	
7d ^2D	3/2	15 208 600 [a]	6 500	900 [b]
	5/2	15 209 500 [a]	6 500	

[a] Fine-structure interval not resolved experimentally; center-of-gravity of term set at experimental position; interval set equal to DF value.

[b] Value calculated with the DF code of Desclaux.

A complete report on these data was published: "Laser-produced and tokamak spectra of lithiumlike iron, Fe^{23+}," J. Reader, et al., J. Opt. Soc. Am. B 11,1930 (1994).

After completing the observations for Li-like iron, the GDL laser was shut down for the planned upgrade to much higher energy. The 2.2-m spectrograph was shipped back to NIST.

Extensive work was undertaken to interface the NIST target chamber to the 30-cm-diameter beam of the upgraded GDL laser. The general plan of the new interface is shown in Fig. 3. In addition to the large tubes and flanges, a new support system for the interface system was designed. The entire interface system was fabricated in the NIST shop and installed on the 2.2-m spectrometer with target chamber. The system was checked for vacuum integrity and prepared for transport to Rochester.

The NIST system is now ready for use with the upgraded GDL laser. According to information from Rochester, it is expected that this upgrade will be completed about July 1995, at which time new observations with the 2.2-m spectrometer will be undertaken. We are in contact with Rochester personnel regarding plans for these new observations.

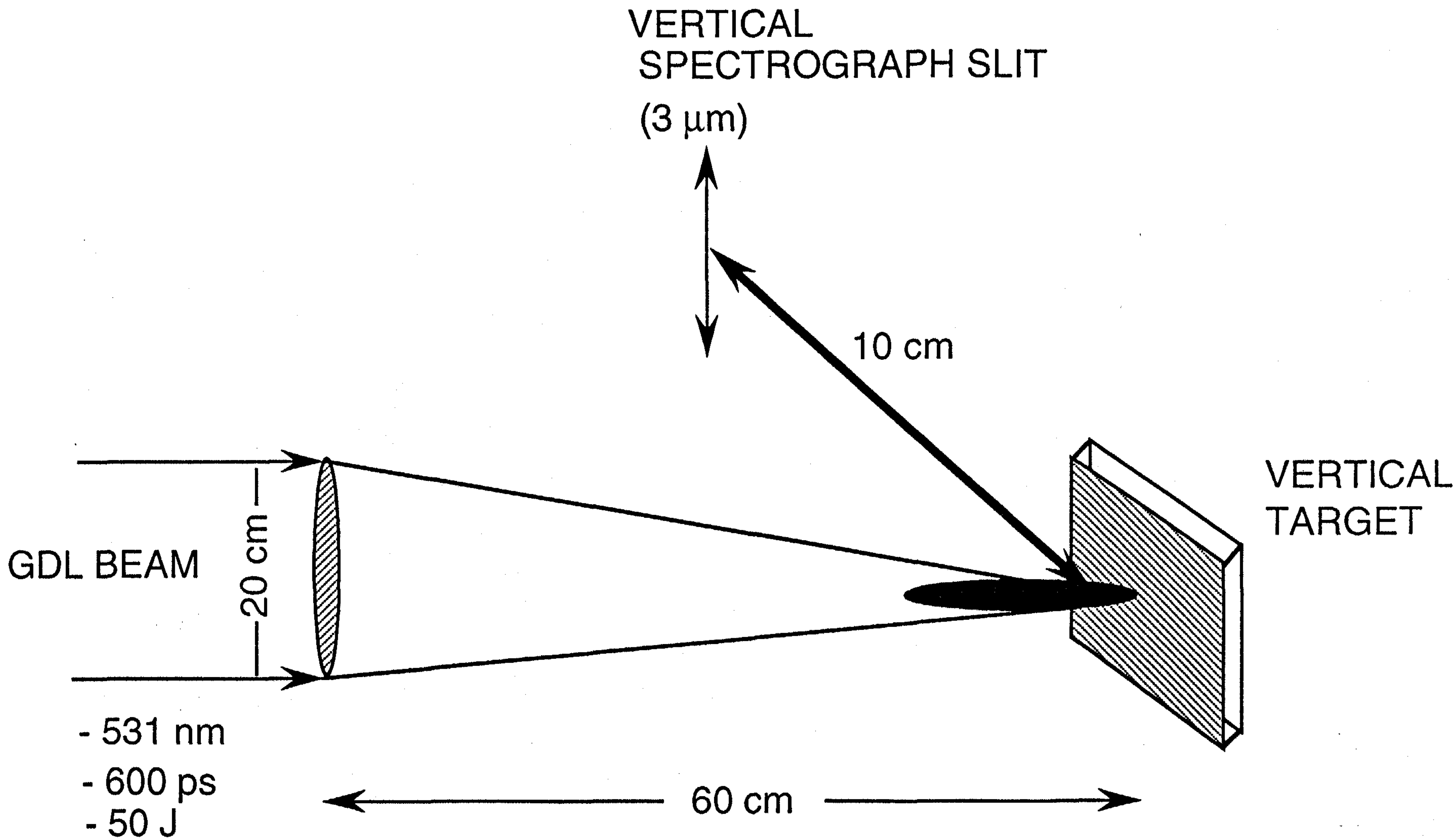
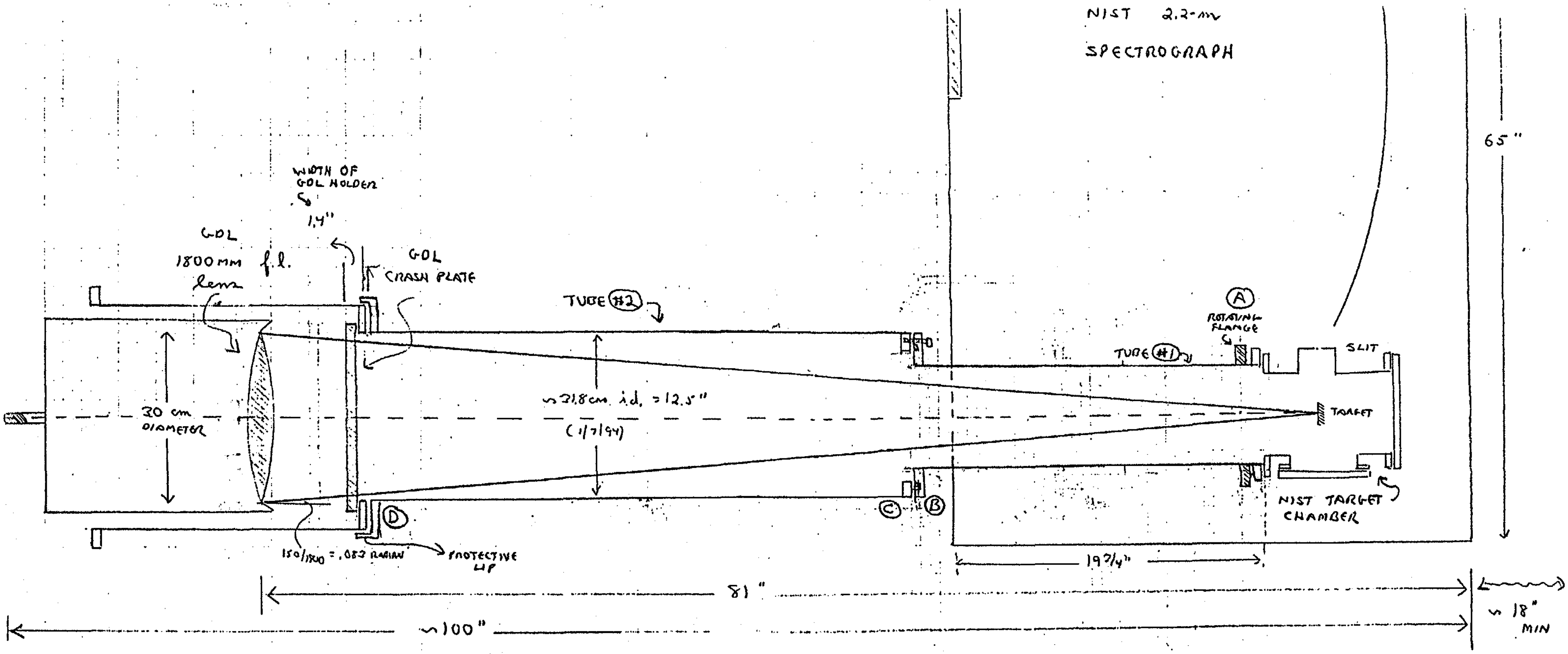

VERTICAL
SPECTROGRAPH SLIT
(3 μm)
10 cm
VERTICAL
TARGET
GDL BEAM
20 cm
- 531 nm
- 600 ps
- 50 J
60 cm

Fig. 1



1/7/94
- if we are 5" from lens,
diameter will be ≈ 278 MM
= 10.98" ⇒ TOO BIG FOR
PRESENT FLANGE !!

PLAN OF NIST 2.2-M SPECTROGRAPH AT ROCHESTER GDL

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SCALE 5:1

Fig. 3