Spectroscopy for Rare-Earth Dopant Cross Sections

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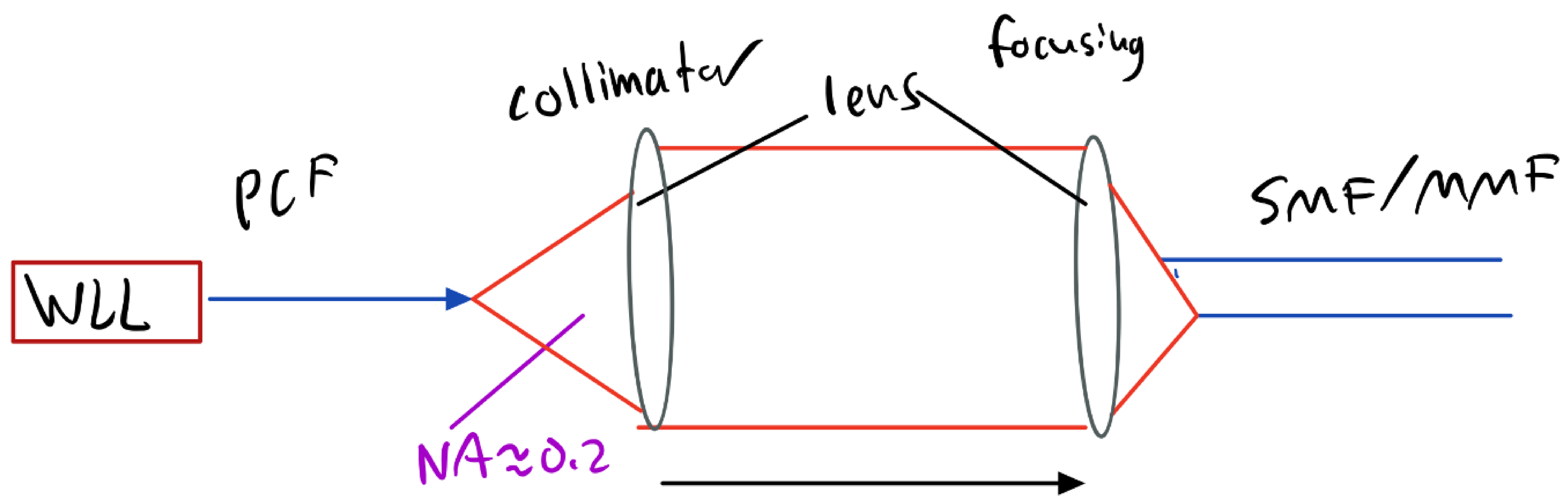
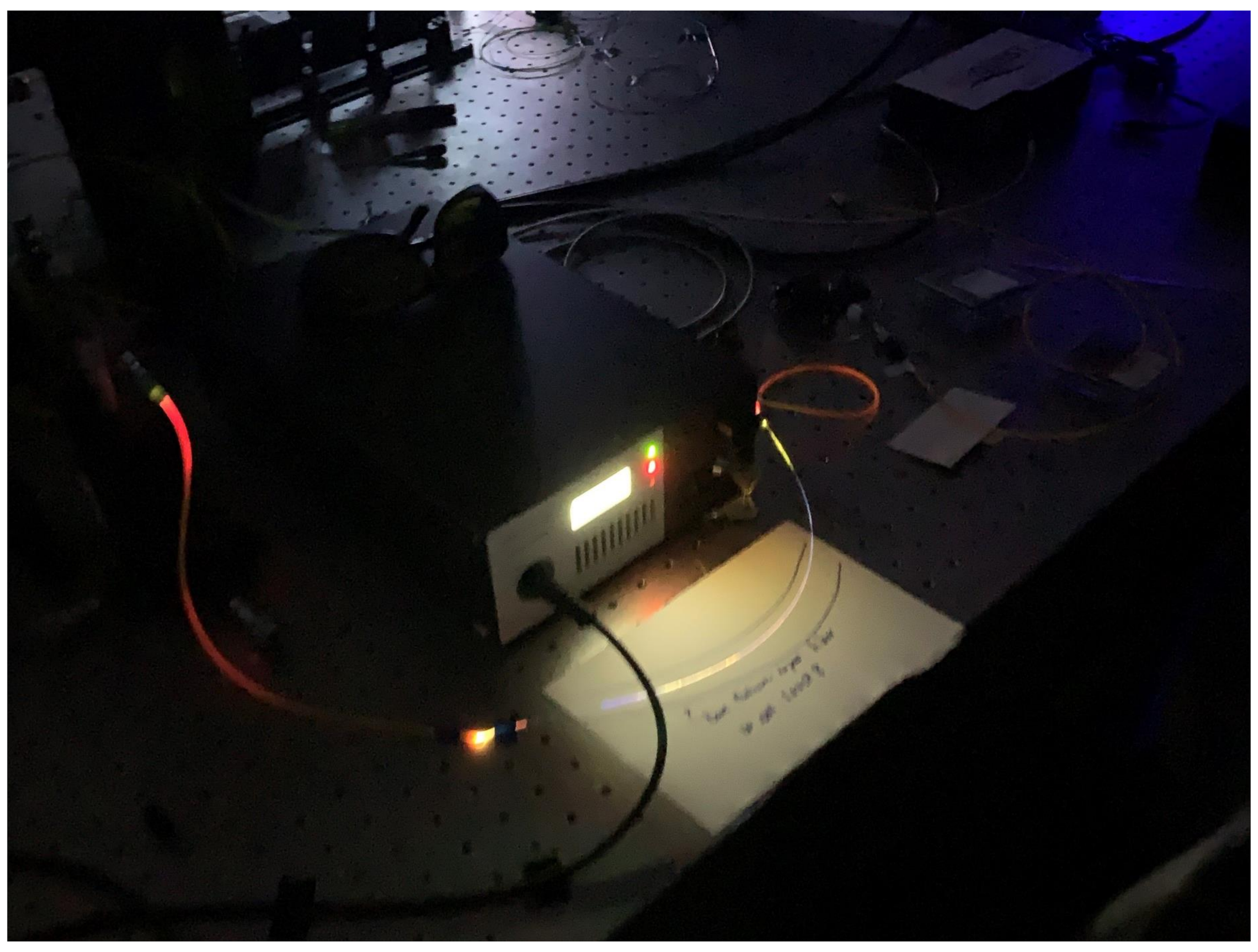
Introduction

My research was for the most part centered around building a setup for finding rare-earth dopant cross sections using spectroscopy. The diagram to the right is a setup where a White Light Laser (WLL) sends light through a PCF to be collimated and then focused into a Single Mode Fiber (SMF) or Multimode Fiber (MMF). The SMF/MMF connects to a spectrometer which we will use to measure the absorbance. My literature review is mainly focused on how to calculate the emission cross section from the measured absorbance data. We implemented the theory we learned from the literature into our own setup, which can be seen in the image below.





450 nm – 2400 nm

Theory

$$\sigma_{ji}(\lambda) = \sigma_{ij}(\lambda)\frac{Z_i}{Z_j}\exp\left[hc\left(\frac{1}{\lambda_{ZL}} - \frac{1}{\lambda}\right)\Big/kT\right] \qquad (3.44)$$

$$Z_{i,j} = \sum_k g_k \exp\left(-E_k \big/ kT\right) \qquad (3.45)$$

McCumber Theory is "an alternative way to obtain the emission cross section is to make use of the method of reciprocity" [3, p. 55]. A benefit of the McCumber theory is that the excited state lifetime isn't a variable in the theory [3, p. 55]. For 3.44, "the wavelength λ_{ZL} corresponds to the peak absorption wavelength and is related to the energy E_{ZL} through $E_{ZL}=hc/\lambda_{ZL}$. The subscript 'ZL' denotes the 'Zero Line' energy, indicating the transition between the lowest energy levels in each multiplet of both the lower and upper level" [3, p. 56]. "Z_i and Z_j are the partition functions of the lower and upper level, respectively, having a Boltzmann distribution according to equation 3.45, in which kT is ~208cm^{-1} at room temperature (T=300K)" [3, p. 56], "g_k is the degeneracy of the energy level, and the crystal field levels E_k are measured from the lowest crystal field level of the corresponding multiplet" [3, p. 56]

FL EQUATIONS [3, P. 55]

$$\sigma_{ji}(\lambda) = \frac{\lambda^4}{8\pi c n^2}\frac{\beta}{\tau_{ji}}\frac{1}{\Delta\lambda_{eff,e}}\frac{I_e(\lambda)}{I_{peak,e}} \qquad (3.42)$$

→ Simulated emission cross section [3, P. 50]

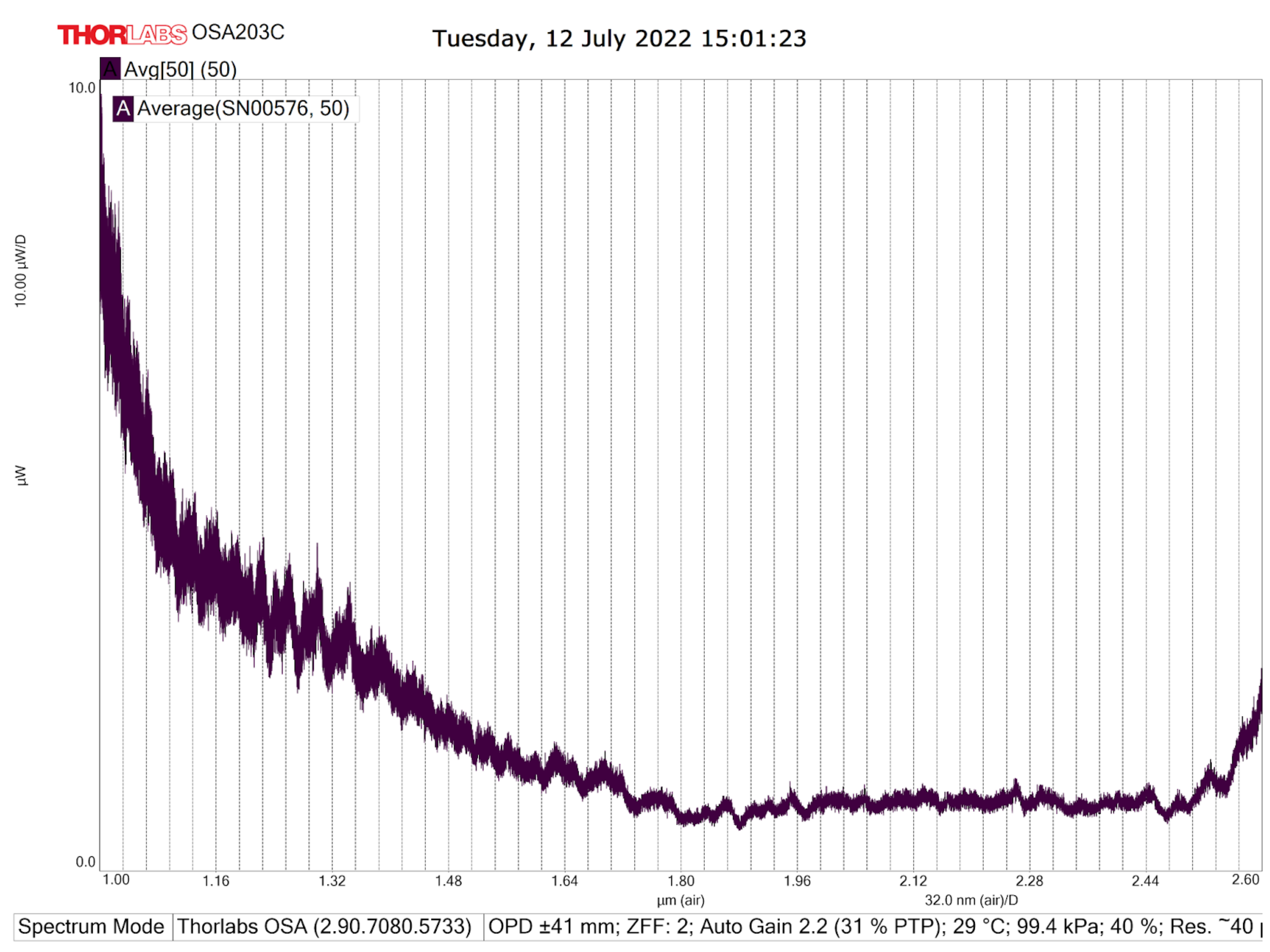
$$\sigma_{ij}(\lambda) = \frac{g_j}{g_i}\frac{\lambda^4}{8\pi c n^2}\frac{\beta}{\tau_{ji}}\frac{1}{\Delta\lambda_{eff,a}}\frac{I_a(\lambda)}{I_{peak,a}} \qquad (3.43)$$

→ wavelength dependent absorption cross section [3, P. 50]

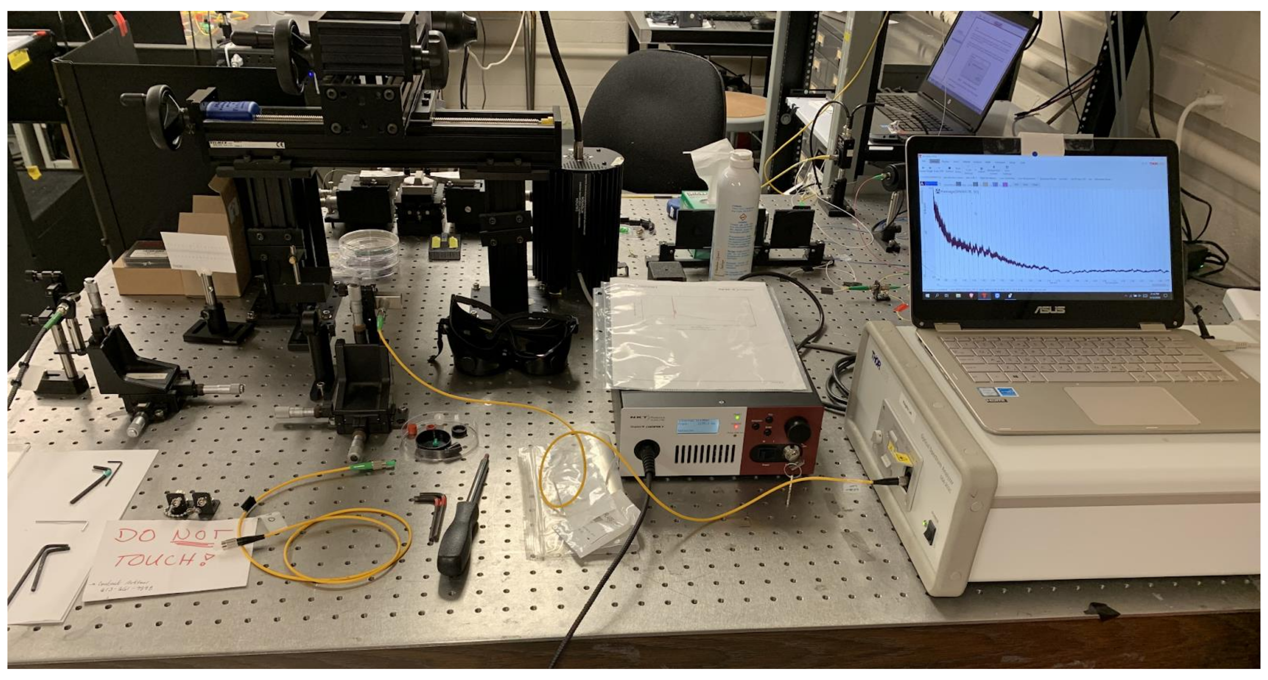
where:

- β is the branching ratio
- n is the numerical appature [3, P. 55]
- τ_{ji} is the excited state lifetime of level j [3, P. 51]
- "I_{peak} is the maximum intensity of the spectral feature, while subscripts e and a denote the emission and absorption spectrum, respectively" [3, P. 55].
- "g_i and g_j are the degeneracy's of the corresponding energy levels" [3, P. 51].

Procedure



The picture below shows our setup in its early stages. The free-space coupling was difficult but after many tries, we were successful with the alignment. The OSA in the picture is 1000-2600 nm and is from Thorlabs. Initially, we used the Thorlabs OSA for all our measurements. At first, we used the two-micron green laser before we tested the WLL. On our first day of testing, we had a mixture of measurements for the green laser and the WLL. One of our goals is to feed these csv files into MATLAB to get the cross section. The graph in the picture above is a screenshot from the Thorlabs software for the OSA. Our first test of the WLL was with SMF input in the 1000-2600 nm range. Unfortunately, the OSA couldn't detect the peak of the absorption spectra because the fiber has its own; this is likely the reason why the graph is cut off. From this point we decided to test two Ocean Optics spectrometers which have a combined range equivalent to the WLL's. Replacing the fiber is another option we explored, and we added a thulium doped fiber to one end in our setup.



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