Atomic Data for Lighting Applications

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1 Introduction

Although lighting accounts for about 20% of U.S. electric power consumption, even the best white light sources convert only about one third of the power they consume to usable light. Improved discharge sources are a promising avenue for development of more efficient lighting, but lack of basic atomic data places fundamental limitations on this research. NIST is currently establishing a new experimental program aimed at determining atomic wavelengths, energy levels, and branching ratios that are needed for lighting applications. The centerpiece of this effort is a high resolution Fourier transform spectrometer recently installed at NIST. Its broad spectral coverage, high resolution, and linear intensity response will permit observation of almost all spectroscopic data of interest.

2 Atomic Data of Interest to Lighting

Rare earth metals are commonly used in metal halide lamps to provide a white light spectrum similar to that of natural light. Three elements of interest are thullium, holmium and dysprosium. These metals have very rich atomic spectra, with many thousands of lines throughout the visible region, but relatively little radiation in the ultraviolet and infrared regions. In many cases the atomic data for these elements are missing. Many energy levels remain to be found and many lines are unclassified. Transition probability data are needed, even for the strongest lines in the spectrum.

Fourier transform (FT) spectrometry offers many advantages for measuring these atomic data. Accurate measurements of line intensities are possible with the large dynamic range ($\sim 10^5$) and linear intensity response. A FT spectrometer measures all of the lines in the spectrum simultaneously, minimizing the effects of source drift, and its wide wavenumber coverage permits the measurement of all of the decay channels from a particular upper level simultaneously. The high resolution and signal-to-noise ratio allow blended lines to be easily distinguished and minimize the errors due to mis-identification of spectral lines.

3 The NIST Fourier Transform Spectrometer

Three years ago, NIST acquired a high-resolution FT spectrometer from the Los Alamos National Laboratory [1, 2]. The instrument has a spectral resolution of 0.0025 cm^{-1} and we currently have optics and detectors to cover the wavelength range from 200 nm to around 8 μm.

Two major improvements have been made since we acquired the spectrometer. First, the instrument has been installed in a new vacuum chamber. A vacuum chamber is needed both to eliminate the effects of air turbulence in the optical path, and to allow operation in the infra-red, where there are molecular bands from water vapor and carbon dioxide.

Figure 1: Comparison of the Dy line at 19338 cm^{-1} ($4f^{10}(^5I)6s\ ^6I_{17/2} - 4f^9(^6H^o)5d6s\ ^6H^o_{15/2}$) in the hollow cathode and electrodeless discharge lamp.

The second change has been a complete replacement of the data acquisition system. The new system, based on the method of Brault [3], uses two 20 bit A/D converters to sample the interferogram at a fixed sampling rate of 39.9 kHz. Laser fringes are recovered from the servo system used to control the catseye retroreflectors. Both the fringes and the A/D samples are referenced to the same 40 MHz clock, and the interferogram can then be recovered by using an interpolating digital filter. The digital filter increases the signal-to-noise ratio as it greatly reduces noise from outside the spectral region of interest. The new system is also much less sensitive to vibrations than the previous system, and hence ghosts from non-uniform sampling of the interferogram are reduced.

The instrument has been operating in the region from 250 nm to 2.5 μm since March, 1997. In addition to our observations of spectra of rare earth elements of interest to the lighting industry, we have been studying spectra of mercury, bismuth and krypton, which are of astrophysical interest.

4 The Spectrum of Dysprosium

The first spectra we are investigating in connection with our program of atomic data for lighting are those of neutral and singly-ionized dysprosium. Dysprosium is used in metal halide lamps, and accurate transition probability data are needed for modelling the lamp discharge. We are collaborating with Wickliffe and Lawler, of the University of Wisconsin, to measure branching ratios with our FT spectrometer, which will be combined with the Wisconsin lifetime data [4] to provide transition probabilities.

We have recorded spectra of high current hollow cathode lamps from 8500 cm^{-1} to 30000 cm^{-1} (1.2 μm to 330 nm) using our FT spectrometer. The cathode was a 60 mm long cylinder

of natural dysprosium with an 8mm diameter bore. Currents ranged from 100 mA - 500 mA and the carrier gas was 200 Pa of Ar. Radiometric calibration was done with a tungsten strip lamp. Dysprosium spectra were also recorded with the Chelsea FT 500 vacuum ultraviolet Fourier transform spectrometer at Lund University, Sweden. These covered the range 25000 cm^{-1} to 50000 cm^{-1} and were radiometrically calibrated with a deuterium lamp.

Natural dysprosium has four isotopes, and the spectral lines from the hollow cathode lamps are thus complicated by isotope structure. To assist in the analysis of these spectra we also recorded the spectrum of an electrodeless discharge lamp containing the single isotope ^{162}Dy. However the electrodeless discharge lamp is not as useful as the hollow cathode lamp for measuring branching ratios, as many spectral lines are strongly self-absorbed. Radiometric calibration is also less reliable as it is not possible to measure the transmission of the lamp envelope. Figure 1 compares a line in the hollow cathode lamp and the electrodeless discharge lamp. Although the line in the electrodeless discharge lamp is wider than the line in the hollow cathode lamp, it is not complicated by isotope structure.

So far we have obtained wavelengths for roughly 4000 Dy I and Dy II lines observed in the ^{162}Dy electrodeless discharge lamp. These have been used to revise the energy level values of 376 energy levels in ^{162}Dy I and 228 energy levels in ^{162}Dy II. Initial branching ratios have been obtained for some of the lower Dy II levels and even parity Dy I levels. These show good agreement with the preliminary branching ratios of Wickliffe and Lawler[5], who have used a different calibration technique, giving increased confidence in the radiometric calibration.

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The identification of commercial products in this paper does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the items identified are necessarily the best available for the purpose.

References

[1] D. Hof, B. A. Palmer, Rep. LALP-88-39, Los Alamos National Laboratory, Los Alamos, NM, Oct. 1988

[2] J. Simons, B. A. Palmer, D. E. Hof, R. C. Oldenborg, *J. Opt. Soc. Am. B* **6**, 1097 (1989)

[3] J. W. Brault, it Appl. Opt. **35**, 2891 (1996)

[4] J. J. Curry, E. A. Den Hartog, J. E. Lawler, *J. Opt. Soc. Am. B*, in press

[5] M. E. Wickliffe, J. E. Lawler, *private communication*