

NASA LAW, February 14-16, 2006, UNLV, Las Vegas

Atomic Oscillator Strengths in the Vacuum Ultraviolet

Gillian Nave, Craig J. Sansonetti, Csilla I. Szabo

National Institute of Standards and Technology, Gaithersburg, MD 20899

`gillian.nave@nist.gov`, `craig.sansonetti@nist.gov`, `csilla.szabo@nist.gov`

ABSTRACT

We have developed techniques to measure branching fractions in the vacuum ultraviolet using diffraction grating spectroscopy and phosphor image plates as detectors. These techniques have been used to measure branching fractions in Fe II that give prominent emission lines in astrophysical objects.

1. Introduction

Transitions in singly-ionized and doubly-ionized iron-group elements give rise to prominent emission lines from a wide variety of astrophysical objects. Some of the most important lines are formed when the upper energy level is excited by radiation from hydrogen at 1216 \AA (Ly- α), giving strong fluorescence lines from the vacuum ultraviolet to the infrared. Although these emission lines are important diagnostics of astrophysical plasmas, laboratory oscillator strengths are often unavailable.

The established way to measure accurate oscillator strengths for atomic lines combines the measurement of a lifetime of an upper energy level with a separate measurement of the branching fractions of all the lines emitted from that level. This technique relies on being able to observe *all* the spectral lines emitted by the upper level, which range down to Ly- α or below for many fluorescence lines. Methods of measuring branching fractions using Fourier transform (FT) spectroscopy have high accuracy, but are limited to wavelengths above about 1400 \AA . However, to obtain complete sets of branching fractions for singly- and doubly-ionized elements, it is necessary to observe spectral lines with wavelengths as short as 900 \AA or less. In recent work we have investigated the feasibility of using phosphor storage image plates to make radiometrically calibrated observations in this short wavelength region.

Phosphor image plates can be used as a direct replacement for glass photographic plates in high-resolution spectrographs. They are coated with a phosphor layer that can be excited into a very long-lived metastable state by an ultraviolet photon. Exposure of the plate produces a latent image in the phosphor that can be recovered by scanning the plate with

a red laser. Red light de-excites the phosphor which emits blue fluorescence that can be detected with a photomultiplier tube. The laser, scanning mechanism, and photomultiplier are housed in a compact reader. Previous experiments in our group have shown that image plates have good sensitivity at wavelengths below 500 Å (Reader et al. 1999). We have found that their sensitivity is similar to or better than photographic plates for wavelengths between 900 Å and 2300 Å, with some sensitivity to wavelengths as long as 3000 Å. Observations of a deuterium radiometric standard lamp with varying exposure times show that the plates have a linear intensity response over at least four orders of magnitude (Nave et al. 2005).

We have demonstrated a capability for making radiometrically calibrated observations in the spectral region short of 1400 Å. We have used it to measure branching fractions for transitions in Fe II that give prominent emission lines in astrophysical spectra. Our new technique combines the high resolution and broad spectral coverage of our 10.7 m normal incidence vacuum spectrograph (NIVS) with the linear intensity response of phosphor storage image plate detectors to produce results that approach the accuracy of FT methods in longer wavelength regions.

2. Experimental Technique



Fig. 1.— The 10.7-m normal-incidence vacuum spectrograph with foreoptics system.

Two different sources were used to generate the spectra of Fe II. The first is a high-current hollow cathode lamp (Danzmann et al. 1988), which we have used in our previous investigations of iron group and rare earth spectra. Although this source generates both neutral and singly-ionized spectra, high-excitation lines of singly-ionized spectra are weakly excited. For these lines we use a Penning discharge lamp (Heise et al. 1994), which generates singly- and doubly-ionized spectra, depending on the current and gas pressure. All spectra were radiometrically calibrated using a deuterium standard lamp.

In order to measure accurate branching fractions, it is necessary to ensure that all sources illuminate the spectrograph in the same way. We thus constructed a fore-optics system for our NIVS to image the spectral source onto the slit of the spectrograph and fully illuminate the grating. This system is shown in figure 1. The vacuum chamber **A** is evacuated with a turbomolecular pump. It contains two remotely adjustable mirrors which focus the light from the hollow cathode source **B** onto the slit of the spectrograph. These mirrors are of sufficient size to fully illuminate the grating, ensuring that small differences in the positioning of the sources do not affect the radiometric calibration. The mirrors are specially coated to have good reflectivity in the 1200 Å region.

3. Results

Transitions from the $3d^5({}^6S)4s4p\ x^6P^\circ$ levels in Fe II give prominent emission features in astrophysical spectra. The $x^6P_{3/2}^\circ$ and $3d^6({}^1D)4p\ w^2P_{3/2}^\circ$ levels interact strongly, giving unexpected doublet-sextet transitions for each transition between two sextet levels. These ‘parasite’ transitions have been studied in detail (Johansson et al. 1995) and oscillator strengths have been calculated for many lines throughout the ultraviolet. There are no laboratory oscillator strengths for any of these lines, but a number of these have been studied in HST/GHRS spectra, and astrophysical oscillator strengths have been derived for three pairs of lines at 1870.6 Å, 2325.3 Å and 2436.5 Å. We have measured spectra of Penning lamps from 1150 Å to 2300 Å, which we will combine with these astrophysical gf values to obtain experimental oscillator strengths for the multiplet UV 9 of Fe II around 1270 Å (see figure 2). Comparison of our experimental branching ratios with the calculated values of (Johansson et al. 1995) agree well in the region around 1270 Å, but the calculated branching ratios differ from our experimental values by over an order of magnitude at longer wavelengths.

In addition to these measurements in Fe II, we have used this technique to measure spectra of Fe III and Co III. These measurements are described in two other papers in these proceedings (Blackwell-Whitehead et al. 2006; Smillie et al. 2006)

This work was partially funded by NASA under inter - agency agreement W-10,255.

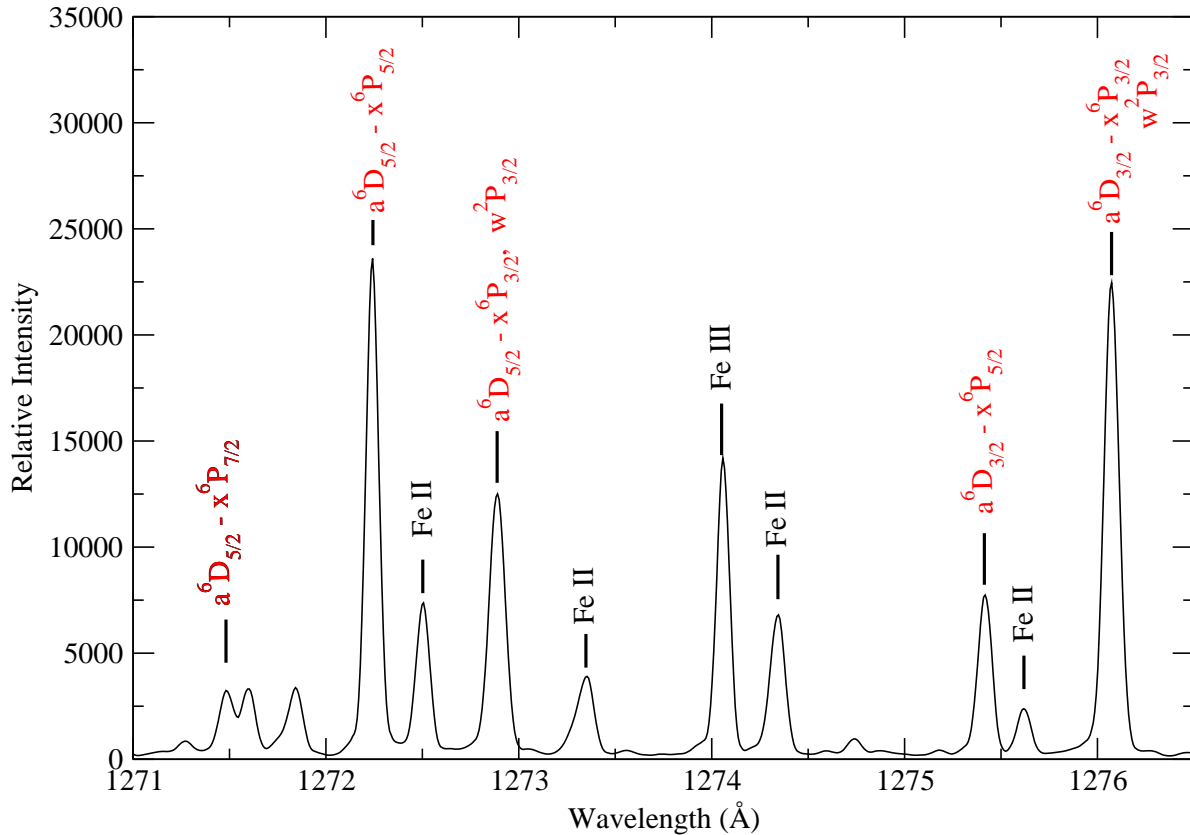


Fig. 2.— The region of the $a^6D - x^6P$ transitions in Fe II in the spectrum of a Penning discharge observed with phosphor image plates in the NIVS (UV 9).

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