Six Lines to Tell a Story

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Earlier Vanadium Results

- echelle and FTS spectra
- 836 transition probabilities
- covers 238 – 916 nm
- FTS hyperfine constants for 26 levels
- hyperfine patterns for hundreds of stellar lines
- V abundance of Sun and HD 84937
EXPERIMENTALLY MEASURED RADIATIVE LIFETIMES AND OSCILLATOR STRENGTHS IN NEUTRAL VANADIUM

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Received 2015 July 6; accepted 2016 March 24; published 2016 June 14

ABSTRACT

We report a new study of the \textit{V} \textit{i} atom using a combination of time-resolved laser-induced fluorescence and Fourier transform spectroscopy that contains newly measured radiative lifetimes for 25 levels between 24,648 cm\textsuperscript{-1} and 37,518 cm\textsuperscript{-1} and oscillator strengths for 208 lines between 3040 and 20000 \textit{Å} from 39 upper energy levels. Thirteen of these oscillator strengths have not been reported previously. This work was conducted independently of the recent studies of neutral vanadium lifetimes and oscillator strengths carried out by Den Hartog et al. and Lawler et al., and thus serves as a means to verify those measurements. Where our data overlap with their data, we generally find extremely good agreement in both level lifetimes and oscillator strengths. However, we also find evidence that Lawler et al. have systematically underestimated oscillator strengths for lines in the region of 9000 ± 100 \textit{Å}. We suggest a correction of 0.18 ± 0.03 dex for these values to bring them into agreement with our results and those of Whaling et al. We also report new measurements of hyperfine structure splitting factors for three odd levels of \textit{V} \textit{i} lying between 24,700 and 28,400 cm\textsuperscript{-1}. 
Recent Vanadium Results

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ABSTRACT

We report a new study of the V¹ atom using a combination of time-resolved laser-induced fluorescence and Fourier transform spectroscopy that contains newly measured radiative lifetimes for 25 levels between 24,648 cm⁻¹ and 37,518 cm⁻¹ and oscillator strengths for 208 lines between 3040 and 20000 Å from 39 upper energy levels. Thirteen of these oscillator strengths have not been reported previously. This work was conducted independently of the recent studies of neutral vanadium lifetimes and oscillator strengths carried out by Den Hartog et al. and Lawler et al., and thus serves as a means to verify those measurements. Where our data overlap with their data, we generally find extremely good agreement in both level lifetimes and oscillator strengths. However, we also find evidence that Lawler et al. have systematically underestimated oscillator strengths for lines in the region of 9000 ± 100 Å. We suggest a correction of 0.18 ± 0.03 dex for these values to bring them into agreement with our results and those of Whaling et al. We also report new measurements of hyperfine structure splitting factors for three odd levels of V¹ lying between 24,700 and 28,400 cm⁻¹.
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We report a new study of the V\textsubscript{i} atom using a combination of time-resolved laser-induced fluorescence and Fourier transform spectroscopy that contains newly measured radiative lifetimes for 25 levels between 24,648 cm\textsuperscript{-1} and 37,518 cm\textsuperscript{-1} and oscillator strengths for 208 lines between 3040 and 20000 Å from 39 upper energy levels. Thirteen of these oscillator strengths have not been reported previously. This work was conducted independently of the recent studies of neutral vanadium lifetimes and oscillator strengths carried out by Den Hartog et al. and Lawler et al., and thus serves as a means to verify those measurements. Where our data overlap with their data, we generally find extremely good agreement in both level lifetimes and oscillator strengths. However, we also find evidence that Lawler et al. have systematically underestimated oscillator strengths for lines in the region of $9000 \pm 100$ Å. We suggest a correction of $0.18 \pm 0.03$ dex for these values to bring them into agreement with our results and those of Whaling et al. We also report new measurements of hyperfine structure splitting factors for three odd levels of V\textsubscript{i} lying between 24,700 and 28,400 cm\textsuperscript{-1}.
Recent Vanadium Challenge

\[ \log(gf)_{\text{New}} - \log(gf)_{\text{Pub}} < 1\sigma \]
\[ \log(gf)_{\text{New}} - \log(gf)_{\text{Pub}} < 2\sigma \]

6 discrepant lines at
\[ \lambda = 9000 \pm 100 \text{ Å} \]

Holmes+2016
Vanadium Reanalysis

\[ A_{ul} = \frac{BF_{ul}}{\tau_u} \]
The Reliability of Lifetimes
The Reliability of Lifetimes

> 40% of all elements!
The Reliability of Lifetimes

DenHartog+2014
The Difficulty of BFs
The Difficulty of BFs

![Graph showing wavelength and wavenumber for V/Ar, 500 mA]
The Difficulty of BFs

\[ \sim x2 \text{ in } \lambda \]
The Importance of Calibration

Wood+2018
The Importance of Calibration

Wood+2018
Improving the Ar I and II branching ratio calibration method: Monte Carlo simulations of effects from photon scattering/reflecting in hollow cathodes

J.E. Lawler, E.A. Den Hartog
Vanadium Reanalysis Results

\[ z^4D_{1/2}^0, E_{up} = 20606.467 \text{ cm}^{-1} \]

\[ z^4D_{3/2}^0, E_{up} = 20687.769 \text{ cm}^{-1} \]

\[ z^4D_{5/2}^0, E_{up} = 20828.481 \text{ cm}^{-1} \]

\[ z^4D_{7/2}^0, E_{up} = 21032.503 \text{ cm}^{-1} \]
Lawler+2014 analyzed V I in Sun and metal-poor HD 84937 → neither has strong neutral V absorption in the red
Astrophysical Sanity Check

Arcturus atlas
gf values: Lawler+2014

$\lambda < 890\text{nm}$: $\langle \log \epsilon \rangle = 3.54$, $\sigma = 0.04$, 49 lines

$\lambda > 890\text{nm}$: $\langle \log \epsilon \rangle = 3.55$, $\sigma = 0.03$, 6 lines
So...what's the big deal?
So...what's the big deal?
Astronomy’s Push to the Infrared

IGRINS: Immersion Grating Infrared Spectrograph

APOGEE: APO Galactic Evolution Experiment

[credit: Sloan Digital Sky Survey]
[credit: Random Currents]
Astronomy’s Push to the Infrared

James Webb
Space Telescope
Astronomy’s Push to the Infrared

• It’s the responsibility of the lab astro community to respond

• Upcoming work
  – Utilize our new V spectra to refine transition probabilities in the IR
  – Study (long overdue) of Ti I IR transition probabilities
    • Submission later this year
Acknowledgements

- Scott Bergeson & Thad Walker

(Pun Intended)

- Stellar Collaborators: Chris Sneden and John Cowan

- Betsy Den Hartog

- Gillian Nave

- Jim Lawler
I’ve known Jim in many ways…

• Undergraduate Professor
  – 307: Intermediate Laboratory

• Undergraduate Research Advisor

• Graduate Professor
  – 545: Atomic Structure

• Graduate Research Advisor

• Collaborator
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- Graduate Research Advisor
- Collaborator
- Mentor
Parting Thoughts
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Figure 4.55  Frustrated total internal reflection.
Parting Thoughts

Figure 4.55  Frustrated total internal reflection.

Fourier transform infrared (IR) spectrometer
“To be a good researcher, you don’t have to know everything. You just have to know one thing better than anyone else.”

– Jim Lawler
Resolution of the Discrepancy?

Holmes+2016