Astron. Astrophys. 321, 1021–1023 (1997)

ASTRONOMY AND ASTROPHYSICS

Research Note

Branching ratio measurement of N^+ inter-system lines, $2s2p^3\,{}^5S_2 - 2s^22p^2\,{}^3P_{2,1}$

J.J. Curry, N.D. Gibson ⋆, and J.E. Lawler

Department of Physics, University of Wisconsin, Madison, Wisconsin 53706, USA

Received 23 September 1996 / Accepted 25 October 1996

Abstract. The N^+ inter-system lines, $2s2p^3\,{}^5S_2 - 2s^22p^2\,{}^3P_{2,1}$, at 2142.775Å and 2139.007Å in air have been observed in emission from a low-pressure inductively-coupled plasma. The measured ratio, A_{2143}/A_{2139} = 2.27 ± 0.23, overlaps the most recent calculation at 2.44 (Brage et al. 1996). A realistic analysis of uncertainties, and comparison with other laboratory measurements which do not agree with each other, demonstrates the difficulty in obtaining a more precise measurement.

Key words: atomic data – methods: laboratory

1. Introduction

Inter-system, or spin-forbidden, lines connecting low-lying levels are frequently used for astrophysical diagnostics (Smith et al. 1984). Such lines have been observed from various ionization stages of C, N, O, Al, Si, etc., in many astronomical objects (see, for example, *The Universe at Ultraviolet Wavelengths* 1981 or *Advances In Ultraviolet Astronomy* 1982). These weak transitions are necessary for determining column densities of many elements in the interstellar gas (Hobbs et al. 1982) and have also been widely used in constraining electron densities and temperatures in line sources.

An intriguing problem has arisen with respect to the branching ratio, $A_{^5S_2-^3P_2}/A_{^5S_2-^3P_1}$, of the $2s2p^3\,{}^5S_2 - 2s^22p^2\,{}^3P_{2,1}$ multiplet in carbon-like spectra including N^+ and O^{+2}. Several calculations of this branching ratio in N^+ have been published (Table 1), with the latest by Brage et al. (1996), yielding a value for this ratio of 2.44. A recent laboratory measurement, utilizing an atmospheric-pressure wall-stabilized arc, produced a ratio of 2.24 ± 0.06 (Musielok et al. 1996). Although uncertainties for the results of calculations are more difficult to estimate, Brage et al., feel that given the quoted experimental uncertainties, the difference between their result and this laboratory measurement is significant. More recently, the same experimental group has remeasured this ratio at 2.45 ± 0.04[1] (Bridges et al. 1996), which agrees with the calculation, but does not overlap their previous result. In addition, the same branching ratio in the isoelectronic system O^{+2}, which is expected, on the basis of calculations, to be very similar to the N^+ ratio, has been observed in several astrophysical sources (Kastner et al 1989). Due to the effects of optical depth, one would expect these observations to set a lower limit for the actual ratio. In fact, several sources exhibit a ratio around 3.0, although Kastner et al. (1989) have suggested that these high values are due to Bowen pumping.

An additional laboratory measurement, particularly if it makes use of a substantially different source than the wall-stabilized arc used by Musielok et al. (1996) and Bridges et al. (1996), is quite valuable. We have made such a measurement, observing the $2s2p^3\,{}^5S_2 - 2s^22p^2\,{}^3P_{2,1}$ spin-forbidden lines in N^+ at 2142.775Å and 2139.007Å from a low-pressure inductively-coupled plasma.

2. Experiment

We utilize a low-pressure, inductively-coupled plasma as a spectral source (Fig. 1) of N^+ (Eriksson 1957). The plasma is created in a 1-1/2 inch diameter fused silica tube (approximately 1 meter long), through which a small amount of high purity (99.999%) N_2 gas is allowed to flow. A six-turn radio-frequency (RF) inductive coil, is used to couple RF power into the plasma. The amount of power deposited is significant in determing the relative strength of atomic versus molecular emission. Contaminants in the quartz have been removed by repeatedly creating a discharge in the tube, thereby raising the quartz temperature to several hundred degrees Celsius, and then evacuating the tube to a base pressure of 5×10^{-7} Torr.

Send offprint requests to: curry@tristan.physics.wisc.edu

⋆ Present address: Department of Physics and Astronomy, Denison University, Granville, Ohio 43023

[1] This is a 1σ error bar for comparison with other results.

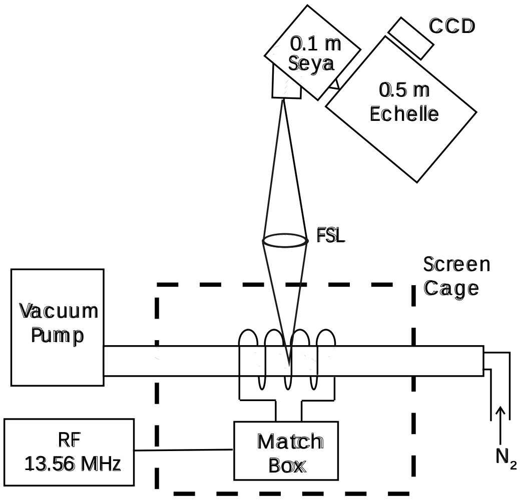

Fig. 1. Inductively-coupled N^+ plasma source and emission collection system. FSL: fused silica lens

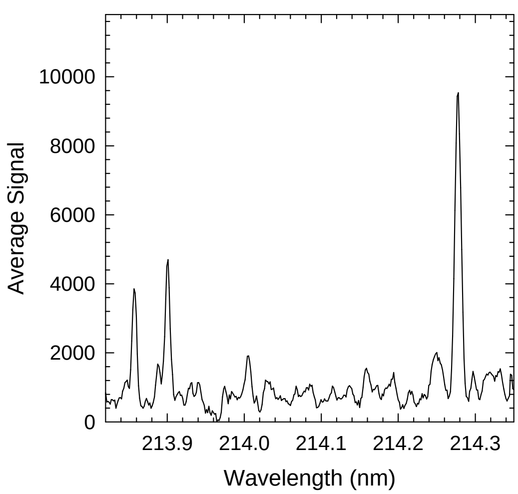

Fig. 2. The observed N^+ spectrum around 2140Å.

Table 1. Branching ratio for the $^5S_2\ -^3P_{2,1}$ inter-system lines of N^+, except where noted.

$A_{^5S_2-^3P_2}/A_{^5S_2-^3P_1}$	
Measurements	
2.27 ± 0.23	present work
2.45 ± 0.04	Bridges et al. (1996)
2.24 ± 0.06	Musielok et al. (1996)
Calculations	
2.44 (2.49 for O^{+2})	Brage et al. (1996)
2.47	Fischer and Saha (1985)
3.02	Cowan et al. (1982)
2.23	Hibbert and Bates (1981)
4.38	Dalgarno et al. (1981)

The emission collection system consists of a 1/2-meter spectrometer with an echelle grating, operating in 26^{th} order. A 0.1-meter Seya-Namioka pre-monochromator separates the overlapping orders of the echelle and the spectra are recorded by a CCD camera. The resolution limit of this system is measured to be 0.077Å. It is important to note that both branches from the $^5S_2$ level are observed simultaneously, thereby eliminating any errors due to fluctuations and drifts in the source. In addition, radiometric calibration is minimal because the two lines are only 3.8Å apart, whereas the bandpass of the pre-monochromator is quite broad compared to this interval.

3. Discussion

Under all experimental conditions such that the lines of interest are strong enough to be measured, our results remain consistent. However, the best regime for observing the N^+ forbidden lines is at RF powers greater than 1000 Watts and an N_2 gas pressure of approximately 10 mTorr. Under such conditions these lines are strongest, both on an absolute scale and relative to molecular emission. Figure 2 shows the observed N^+ spectrum around 2140Å. Integrated intensities for the two lines of interest yield a ratio A_{2143}/A_{2139} = 2.27, with a reproducibility of $\pm 1.8\%$. Although it is tempting to quote this latter number as the uncertainty in the measured ratio, a realistic estimate requires more careful consideration. The accurate measurement of such weak lines (the A-coefficient for the 2143Å line is on the order of $10^2 s^{-1}$ versus $10^8 s^{-1}$ for a typical resonance line), is hindered, in any source, by the increased complexity of the observed spectrum at the high sensitivities required. For instance, even though the 2143Å and 2139Å lines dominate the spectrum, there are several reproducible features (with relative intensities on the order of 10% or less) which obscure the true position of the baseline (i.e., indicate possible weak blends with the lines of interest).[2] This weak blending possibility must be fully appreciated in order to correctly assess the uncertainty in this measurement (the error due to reproducibility and radiometric calibration are small in comparison). We quantify our total uncertainty at $\pm 10\%$.

From the above discussion, it might appear that the measurement might be improved by having a better spectral source with less molecular emission. Such a source is not trivial to construct. Furthermore, the two features at 2138.9Å and 2142.5Å do not appear to be molecular in nature, or from contamination, but are closely correlated with the N^+ lines. We can change the discharge conditions to make obvious molecular bands stronger, yet these two features maintain roughly the same intensity relative to the N^+ lines. These features do not arise from other echelle orders, because we have also used a different pre-monochromator with a significantly different bandpass function and observe that the relative intensities compared to the observed lines remains roughly the same. (The feature at 2138.4Å is, however, possibly from a different echelle order.) This leads

2 We note that a weak unclassified N^{+2} at 2142.67Å is listed in Striganov and Sventitskii 1968.

us to consider the possibility that some of these features may be very weak N^+ lines, which could hinder this measurement in any source. We suggest that a more precise measurement can be obtained with significantly improved resolution in combination with a low-pressure source, such as we have used, in which line-broadening mechanisms are minimal. A lineshape analysis could then provide sufficient information on weak blending to reduce the uncertainties considerably.

In summary,we have observed the ${}^5S_2 - {}^3P_{2,1}$ spin-forbidden lines in N^+. The measured branching ratio A_{2143}/A_{2139} = 2.27 ± 0.23. This result is 7% smaller than the most recent advanced calcualtions (Brage et al. 1996), although this difference is within our estimated uncertainties. A more precise measurement is hindered by the fact that the observed lines are several orders of magnitude weaker than a typical allowed line.

Acknowledgements. This research is supported by NASA under grant NAGW-2908.

References

Advances in Ultraviolet Astronomy: Four Years of IUE Research 1982, Editors Y. Kondo, J.M. Mead, and R.D. Chapman, NASA Conference Publication 2238

Brage T., Hibbert A., and Leckrone D.S., 1996, submitted to ApJ

Bridges J.M., Wiese W.L., and Griesmann, 1996, Goddard High Resolution Spectrograph Science Symposium, Greenbelt, Maryland ,# 40

Cowan R.D., Hobbs L.M., and York D.G., 1982, ApJ 257, 373

Dalgarno A., Victor G.A., and Hartquist T.W., 1981 Geophys. Res. Lett 8, 603

Eriksson K.B.S., 1957, Arkiv Fysik 13, 303

Fischer C.F. and Saha H.P., 1985, Physica Scripta 32, 181

Hibbert A., and Bates D.R., 1981 Planet. Space Sci. 29, 263

Hobbs L.M., York D.G., and Oegerle W., 1982, ApJ 252, L21

Kastner S.O., Bhatia A.K., and Feibelman W.A., 1989, MNRAS 237, 487

Musielok J., Bridges J.M., Djurovic S., and Wiese W.L., 1996, Phys. Rev. A 53, 3122

Smith P.L., et al, 1984 Phys. Scripta T8, 88

Striganov A.R. and Sventitskii N.S., 1968, *Tables of Spectral Lines of Neutral and Ionized Atoms*, Plenum

The Universe at Ultraviolet Wavelengths 1981, Editor R.D. Chapman, NASA Conference Publication 2171

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.