NASA TECHNICAL NOTE

NASA TN D-2148

NASA TN D-2148

RESONANCE SCATTERING AT LYMAN-ALPHA BY AN ATOMIC HYDROGEN CELL

by

J. E. Blamont and P. Delache
Centre National de la Recherche Scientifique
France

and

A. K. Stober
Goddard Space Flight Center
Greenbelt, Maryland

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1964

RESONANCE SCATTERING AT LYMAN-ALPHA BY AN ATOMIC HYDROGEN CELL

By J. E. Blamont and P. Delache

Centre National de la Recherche Scientifique
France

and

A. K. Stober

Goddard Space Flight Center
Greenbelt, Maryland

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Office of Technical Services, Department of Commerce,
Washington, D.C. 20230 -- Price $0.50

RESONANCE SCATTERING AT LYMAN-ALPHA BY AN ATOMIC HYDROGEN CELL

by

J. E. Blamont and P. Delache

Centre National de la Recherche Scientifique

France

and

A. K. Stober

Goddard Space Flight Center

SUMMARY

This paper describes the experimental conditions for direct photoelectric observation of the optical resonance and polarization of the hydrogen Lyman-alpha line (1216A).

CONTENTS

RESONANCE SCATTERING AT LYMAN-ALPHA BY AN ATOMIC HYDROGEN CELL

by

J. E. Blamont and P. Delache
Centre National de la Recherche Scientifique
France

and

A. K. Stober
Goddard Space Flight Center

INTRODUCTION

Rocket and satellite studies of the Lyman-alpha (1216A) line emitted in the upper atmosphere have been made using detectors which have large bandwidths, such as ion chambers with various window materials and filling gases (References 1 and 2), or photomultipliers with cesium iodide or copper iodide photocathodes (Reference 3). High-resolution photographic measurements have been made with a grating spectrograph (Reference 4) and photographic plates; the system requires long exposures and a recovery system to obtain data.

This paper is concerned chiefly with the experimental results of a hydrogen (filter) cell and ion chamber for obtaining photoelectric data.

Hydrogen Cells

Lyman-alpha is the resonance line of the hydrogen atom. If a cell containing a large number of hydrogen atoms is placed in front of the detector and is excited by an incident beam of light, the hydrogen atoms will absorb selectively the central frequency (core) of the Lyman-alpha emission from the existing beam with a width that is a function of the temperature of the atoms and their number density (optical thickness). This experiment has been performed by the Naval Research Laboratory (Reference 5). The number density of the hydrogen atoms is not very critical when the exciting spectrum is a line spectrum containing a narrow Lyman-alpha emission line. In such a cell there is a lower limit for the density of hydrogen atoms above which the cell will absorb all the Lyman-alpha contained in the exciting beam. Such a system, a broad bandpass filter with a narrow absorption feature, can be used when the energy of the spectrum of interest is defined by the detector (1050 to 1300A for an ion chamber) and contains two parts of the same order of magnitude:

the absorbable part, centered at the Lyman-alpha line with a width of 10^{-2} A; and the remainder of the spectrum from 1050-1300A, nonabsorbable. This system cannot be used to observe the Lyman-alpha radiation coming from the sun, the absorbable part being too small compared with the non-absorbable part (not more than 1 part in 100).

On the contrary, a scattering cell, where the resonance light, scattered by hydrogen atoms, is observed at 90 degrees of the incident beam, is equivalent to a very narrow band filter (about 10^{-2} A). Of course, the "transmission" in the center of the line will be small because the geometry of the cell forbids the detection of all the scattered photons, but the transmission will be exactly zero (except from the effects of stray light) for all the other wavelengths.

DESCRIPTION OF THE EXPERIMENT

The first cell was a rather complicated cell, Figure 1(a), in which the hydrogen atoms were produced by dissociation of hydrogen molecules on a hot tungsten wire. The cell contained two filaments mounted in light horns located out of direct view of the detector. Four LiF (lithium fluoride) windows were epoxy-sealed to the cell. One was the "entrance" window facing the monochromator light source, and one the "exit" window on the opposite side of the cell for observing the direct (absorbed) light. Two other windows were mounted at right angles to the light beam: one near the entrance window, and one near the exit window.

Hydrogen was allowed to enter the cell through a palladium leak. The cell was isolated from the vacuum system by a stopcock, thus permitting evacuation and pressure regulation.

The Light Source

The light source system was a 3-meter high-dispersion vacuum monochromator illuminated by a hydrogen-discharge continuum lamp. The resolution of the monochromator was on the order of 1/20A at Lyman-alpha emission.

Experiments with the First Cell

The absorption was first observed. The first problem was the outgassing due to the large diameter of the filaments, high filament current needed, and envelope glass temperature. A good test for the "true" absorption was obtained by observing a band of the hydrogen molecule. When the heating of the filament would not create any absorption at 1234A, an absorption measurement would be made at Lyman-alpha.

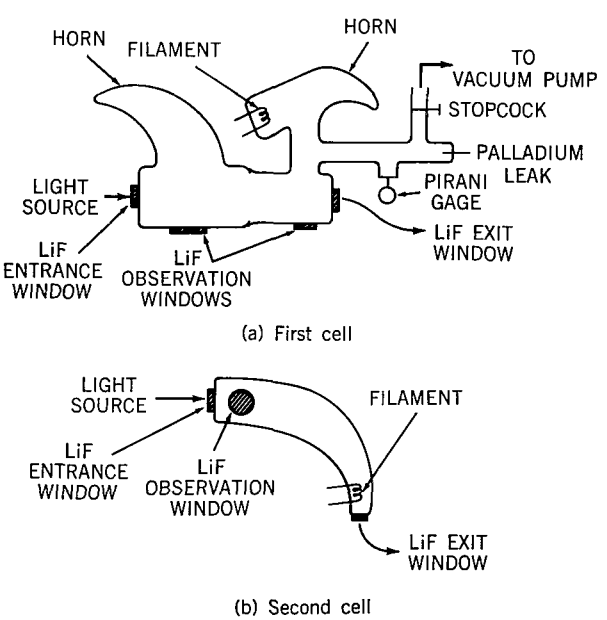

Figure 1—Atomic hydrogen cells.

The Lyman-alpha profile of the light coming out of the system was observed by scanning the line with the monochromator, with and without the filament heated. This profile was already strongly self-reversed because of the hydrogen atoms at the exit port of the light source. However, a careful study of the profiles showed that this reversal was higher in the presence of hydrogen atoms in the cell. Under these conditions, even with very large slits, it was impossible to see any resonance signal at either of the two windows.

Modification of the Light Source

To have a higher intensity in the center of the Lyman-alpha line, the density of hydrogen inside the lamp was lowered by running the discharge with a mixture of helium and hydrogen. The procedure was the following:

A discharge was started in pure helium. The Lyman-alpha profile was observed with the slits of the monochromator compatible with the detector sensitivity. This may not be the Lyman-alpha line of the hydrogen atoms left in the gas of the helium tank but the H-alpha line of singly ionized helium; its intensity was very small. The hydrogen pressure was slowly increased by using a needle valve. As the intensity of Lyman-alpha increased, the line profile did not self-reverse. It then appeared that conditions changed very suddenly in the discharge lamp; the profile became strongly self-reversed, and the total intensity increased greatly. At the same time, the color of the discharge in the light source changed from orange to red. It was thus possible to determine the best conditions (maximum intensity, minimum self-reversal) from the color of the discharge.

The Second Cell

The design of the second cell, Figure 1(b), took into account the facts mentioned above.

The small rhenium wire heater filament was mounted on an aluminum oxide ring and required 5 watts for white heat. The detectors were attached directly to the windowless cell by O-rings or Apiezon wax seals.

The outgassing problem was solved by eliminating the taper joint system of the first cell and by using a secondary pump.

The stray light was removed by the use of a light horn; however, the detector at the bottom of the horn "saw" part of the direct (absorbed) light reflected on the curved part of the horn.

The palladium leak system was the same as that used on the first cell. Pressure was measured with a thermocouple gage. Foreign gas could be introduced into the cell through a needle valve. (The experimental apparatus is shown in Figure 2).

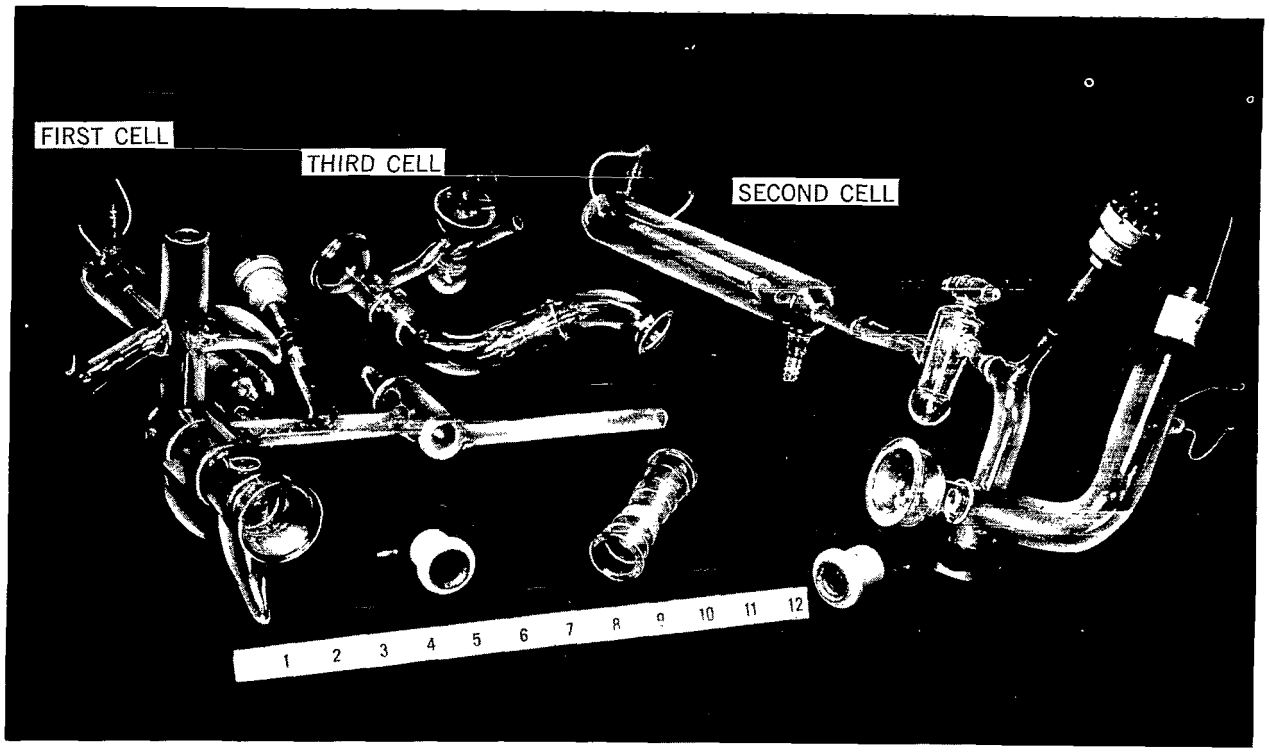

Figure 2—The experimental apparatus.

Results Observed

With the above-mentioned conditions, both absorbed and scattered light signals were observed.

A typical recording is shown in Figure 3. On the left channel, the scattered light signal is seen and, on the right channel, the absorbed light signal.

Reading from below, we (1) start with Lyman-alpha excitation and atomic hydrogen (filament-heated); (2) close the shutter – that is, suppress the excitation – and both signals fall to zero (the zero of the left recorder is not the zero of the chart paper); (3) return to the former situation, Lyman-alpha + hydrogen; (4) stop heating the filament (no more atomic hydrogen). The "absorbed" signal rises back to the value marked Lyman-alpha, and the resonance signal falls to zero at the same time, indicating no stray light. Then we (5) close the shutter, and the absorbed signal falls again to zero while the resonant signal does not show any variation. This indicates that the filament is not seen by the detector. It can be noted at this point that another proof of the fact that there are hydrogen atoms which absorb and

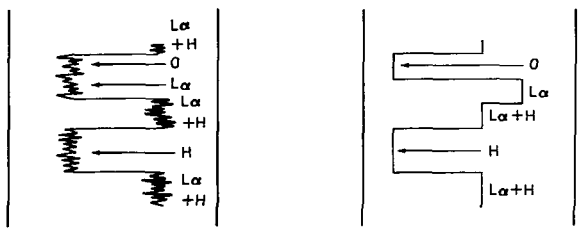

Figure 3—Recording scattered light and absorbed light.

scatter the light, and not any outgassing, is the very short time constant of variation of the signals. We can say that it is less than the electronic time constant (0.2 second).

A study of the resonance signal as a function of the hydrogen pressure showed that a maximum of scattered light was obtained at the total pressure of 30 to 40 microns. Introduction of helium makes the signal drop by a factor of 2 or more, whatever the total pressure is.

Evaluation of the Number of Hydrogen Atoms in the Cell

This is a rather difficult point, since we do not know whether the density is uniform throughout the cell. However, the density can be evaluated from two experiments:

1. By constantly increasing the filament heat, the absorption reaches a plateau while the resonance signal is still increasing. This seems to indicate that the optical thickness of the whole system between the entrance window and the detector is rather high (2 or more).

2. The resonance signal increases but does not reach a maximum. However, at higher filament current the light we observe is roughly 1/1000 of the "absorbable light"; the absorbable light is that part of the light effectively absorbed as observed by the bottom detector (30 percent of the increasing light). If an optical depth of 1 is assumed, the scattered light would be 1/500 of the incident absorbable light. Since an optical depth of 1 is 10^{12} atoms/cm^2, it is believed that the density in hydrogen atoms is on the order of 10^{11} cm^{-3}. The dissociation of hydrogen is then on the order of 10^{-4}.

Best Performance Obtained

Power dissipated in the filament for maximum resonance signal: 6 watts
Hydrogen pressure for maximum resonance signal: 30 microns
Signal-to-noise ratio: 20

A Third Cell for Observing the Polarization of the Lyman-Alpha Light

Figure 2 shows the three cells: the first cell at the left, the horn-shaped cell at the right, and a third one in the center. This cell was made to observe the polarization of the light at Lyman-alpha by reflection from a LiF crystal at the Brewster angle. A Malus-type design was adopted. We observed a reflected light strongly polarized (at least 90 percent) with a reflection coefficient of the order of 15 percent. This system will be used for measuring the polarization of the Lyman-alpha airglow.

(Manuscript Received September 18, 1963)

REFERENCES

1. Chubb, T. A.; and Friedman, H., "Photon Counters for the Far Ultraviolet," *Rev. Sci. Inst.* 26(5):493-498, May 1955.

2. Stober, A. K., "Ceramic Vacuum Ultraviolet Ion Chambers," NASA Technical Note D-1180, March 1962.

3. Dunkelman, L., Fowler, W. B., and Hennes, J. P., "Spectrally Selective Photodetectors for the Middle and Vacuum Ultraviolet," *Appl. Optics* 1(6):695-700, November 1962.

4. Purcell, J. D., and Tousey, R., "The Profile of Solar Lyman-α," *Memoirs Soc. R. Sci. Liege* 4:283-294, 1961.

5. Morton, D., and Purcell, J. D., "Observations of the Extreme Ultraviolet Radiation in the Night Sky Using an Atomic Hydrogen Filter," *Planet. Space Sci.* 9:455-458, August 1962.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546