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NASA TN D-2522

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NASA TN D-2522

INTENSITY AND INTENSITY RATIO OF PRINCIPAL SINGLET AND TRIPLET LINES OF MOLECULAR HYDROGEN

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

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SUMMARY

The work reported by Brasefield on the densities of the principal singlet and triplet lines of molecular hydrogen was transformed into intensity units. To accomplish this, a calibration curve for Brasefield's photographic plates was determined with the aid of results reported by Kruithof and Ornstein on two of the same spectral lines. The intensities resulting from the transformation are presented as a function of electron energy for the 19- to 220-electron-volt range. The intensity ratios for some of the singlet and triplet lines are presented as a function of electron energy.

INTRODUCTION

The only available studies of the singlet and triplet lines of molecular hydrogen as a function of electron energy are by Brasefield (ref. 1) and by Kruithof and Ornstein (ref. 2). Brasefield's extensive results, however, are not given in a usable form. Using the data of Kruithof and Ornstein, the authors have put Brasefield's results in a form suitable for the spectroscopic diagnostics of a hydrogen plasma.

Brasefield measured the densities of the principal lines of the singlet and triplet system of molecular hydrogen as a function of the energy of incident electrons in the range from 19 to 220 electron volts. His experimental apparatus, which is typical for this type of study, consisted of a vacuum chamber in which thermionically emitted electrons from a cathode were electrically accelerated through a grid into a field-free region containing molecular hydrogen at 30 microns of mercury pressure. Optical studies were made in this field-free region, where the accelerated electrons were essentially monoenergetic. Brasefield did not calibrate his photographic plates because his main interest was to obtain the electron energy at which the maximum intensity of a given spectral line occurs; therefore, all of his results were reported as line densities or as the ratio of line densities. From both a theoretical and a practical standpoint, however, the line intensity is more often the important parameter. For example, singlet and triplet line intensity ratios have been used for spectroscopically determining the electron energy of a helium plasma (ref. 3). If a calibration curve could be attained for the photographic plates used by Brasefield, his density measurements could then be transformed into the more useful intensity units.

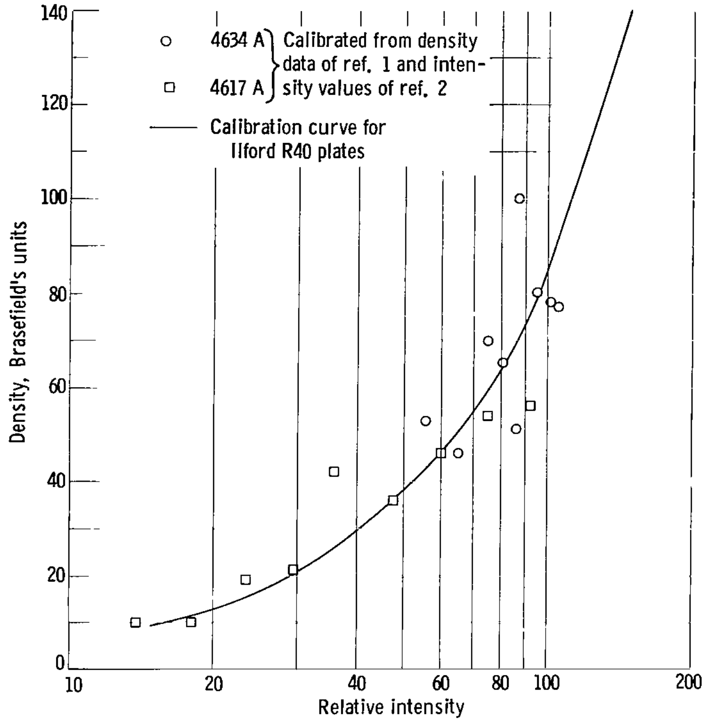


Figure 1. - Cross plot of data of Brasefield with those of Kruithof and Ornstein compared with curve from modern version of Brasefield's plates.

Kruithof and Ornstein studied two of these principal lines for molecular hydrogen, namely, the 4617-angstrom triplet line and the 4634-angstrom singlet line. They determined the intensity of these lines from about 14 to 50 electron volts. With the aid of these results, a calibration curve for the photographic plates used by Brasefield was attainable. The resulting calibration curve is presented in this report. With it, Brasefield's results are replotted in relative intensity units, which yield the corresponding electron excitation function, and in intensity ratios as a function of electron energy. Although these functions were obtained indirectly, they are probably the only ones presently available for these spectral lines, and, as such, must serve until more direct determinations are reported.

ANALYSIS

The spectral response of a photographic plate is some function of the logarithm of the intensity of the light source (ref. 4) and can be expressed for any given wavelength as

$$D = f(\log cI) \tag{1}$$

where

D photographic density

f function

c constant

I intensity (arbitrary units)

In terms of the photographic negative, D is generally defined as (ref. 4)

$$D = -\log T \tag{2}$$

where T is the relative transmittance or fraction of incident light flux passing through the exposed film.

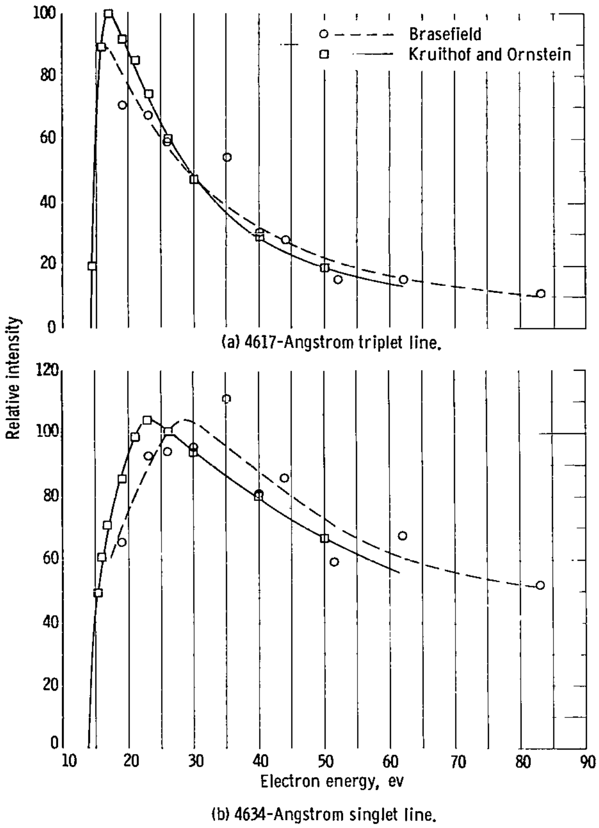


Figure 2. - Comparison of Brasefield data with those of Kruithof and Ornstein for 4617- and 4634-angstrom hydrogen lines.

A calibration curve for the photographic plates used by Brasefield can be determined by assuming that, at a given electron energy, the densities of the 4617- and 4634-angstrom spectral lines obtained by Brasefield were produced by intensities at that electron energy identical to those reported by Kruithof and Ornstein in reference 2. In order to put the two lines reported by Kruithof and Ornstein on the same intensity scale, equation (1) required that the intensities for one of the lines be multiplied by a proper constant. This constant was easily obtained because Brasefield observed that the density produced by the 4634-angstrom line excited by 52 electron volts was equal to the density produced by the 4617-angstrom line excited by 26 electron volts; therefore, the intensity of the light producing these two lines should have been the same at these respective electron energies. A plot of density as a function of log intensity (eq. (1)) from Brasefield's density data and the modified intensity data of Kruithof and Ornstein yielded the calibration curve for Brasefield's photographic plates (fig. 1). The solid curve in figure 1 is a calibration curve for a modern version of the Ilford photographic plates used by Brasefield. It should also be noticed that the density scale in figure 1, which is larger than the usual density scale (eq. (2)) by a factor of 100, is the same as that used by Brasefield. In the transformation of Brasefield's data, the solid calibration curve in figure 1 was used since it is a reasonable representation for the actual points.

Another point that should be considered is the variation of spectral sensitivity and the gradient of film over the wavelength range of interest. From the information available on more recent films, the film sensitivity is relatively constant over a wavelength range from 3500 to 6400 angstroms. Because Brasefield's photographic exposures were on the toe of this calibration curve, the effect of any variation in film sensitivity or gradient was minimized.

DISCUSSION

The calculated intensity as a function of electron energy for the data from reference 1 is compared with the intensity from reference 2 in figure 2 for the 4617-angstrom triplet line and the 4634-angstrom singlet line. The energy at which the maximum intensity is reached for the 4634-angstrom line was determined with the aid of reference 1, which shows that all singlet lines reach a maximum at about 30 electron volts. The maximum for Brasefield's data occurs at a slightly higher electron energy than that reported by Kruithof and Ornstein because Brasefield kept the current to the plate and the grid constant, while Kruithof and Ornstein kept only the plate current constant.

The intensity derived from the Brasefield's data as a function of electron energy is shown in figure 3 for the singlet lines and in figure 4 for the triplet lines. The 35-electron-volt point in each figure was ignored in drawing the curves because it always tended to be unexpectedly high. The

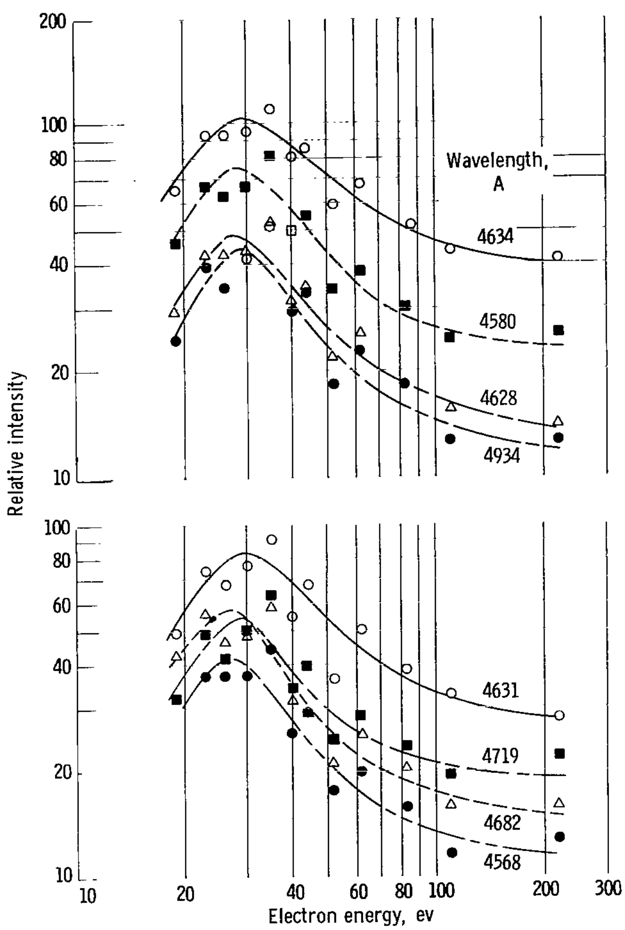


Figure 3. - Intensity of some hydrogen singlet lines as function of electron energy.

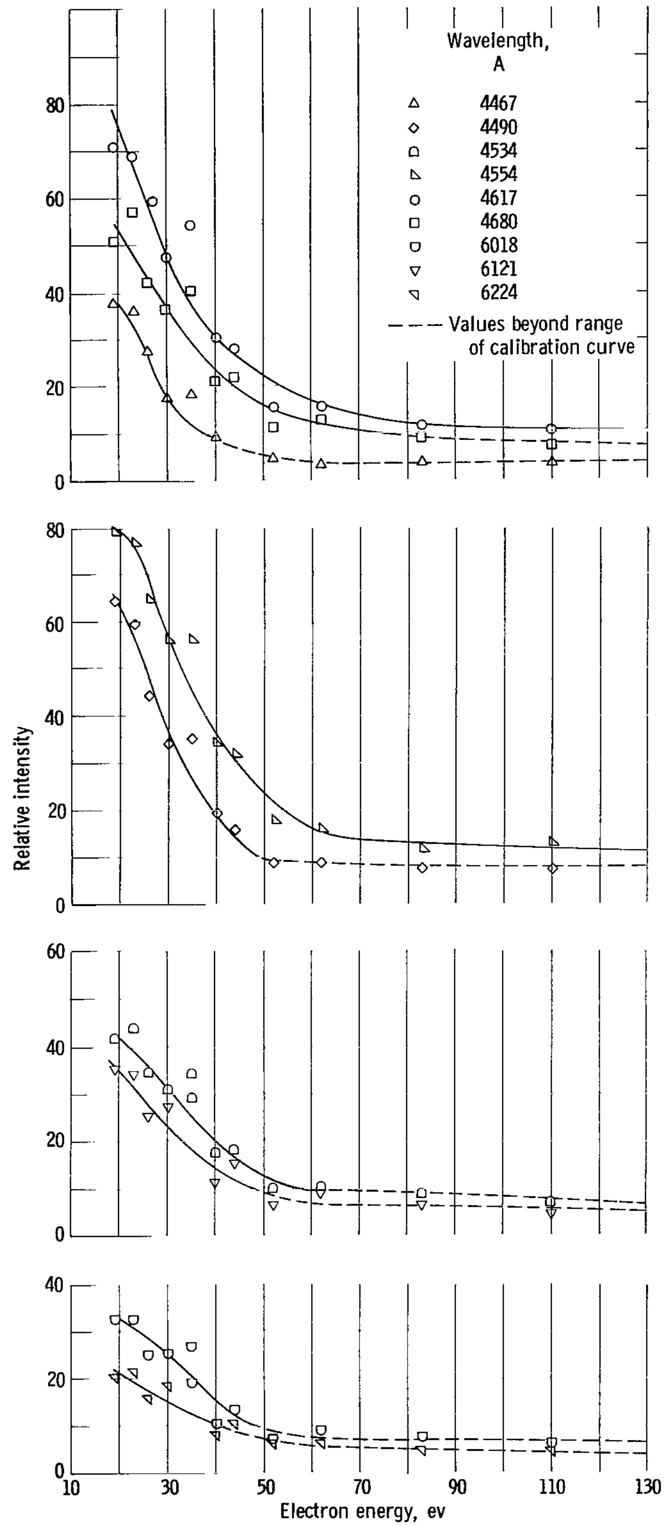
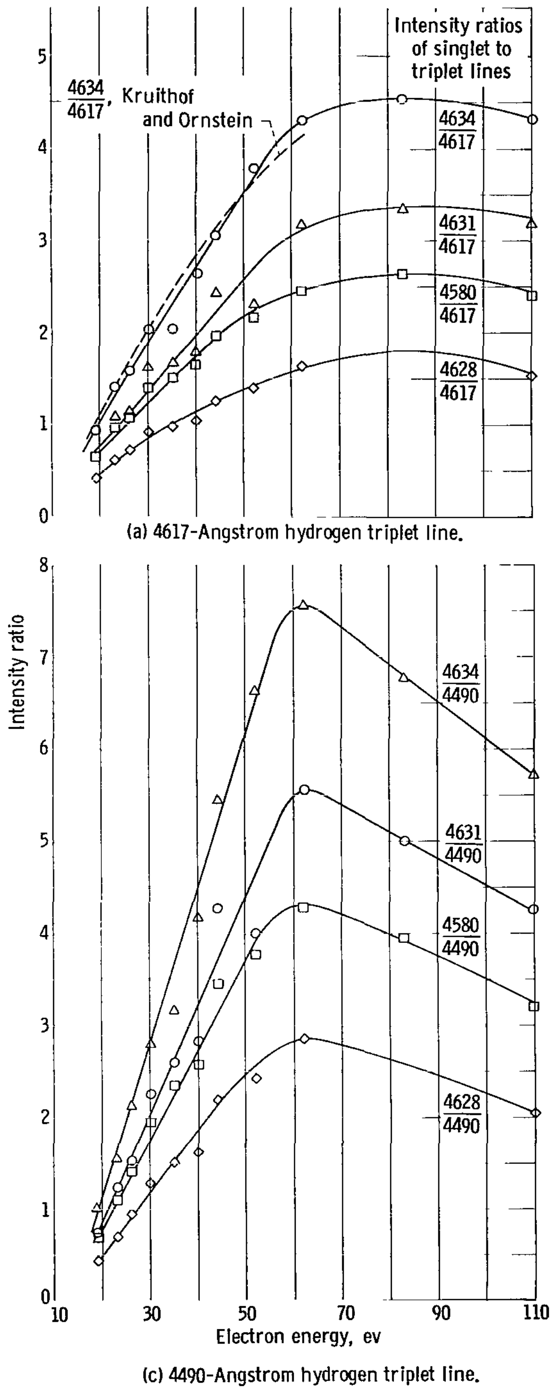


Figure 4. - Intensity of some hydrogen triplet lines as function of electron energy.



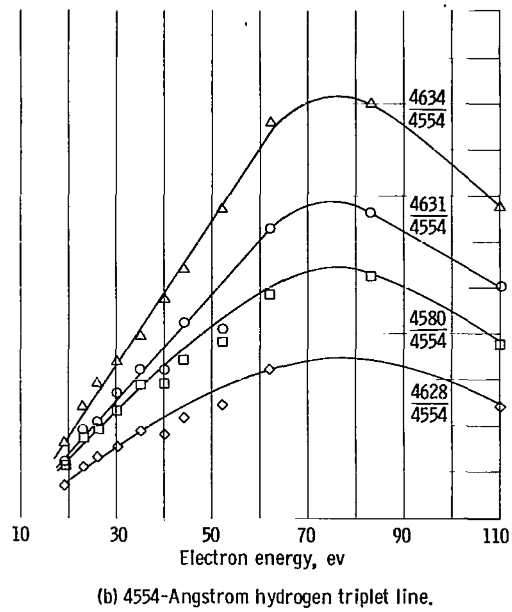


Figure 5. - Comparison of ratios of singlet-line intensity to triplet-line intensity as function of electron energy.

excitation function values for relative intensity less than 10 in figure 4 are shown as broken lines because they are beyond the range of the calibration curve. Lines reported in reference 1 corresponding to relative intensity less than 10 are omitted.

Figure 5 compares the ratios of the intensities of the singlet wavelengths 4634, 4631, 4628, and 4580 angstroms (fig. 3) to the intensities of the wavelengths of the three strongest triplet lines, 4617, 4554, and 4490 angstroms (fig. 4) as a function of electron energy. In figure 5(a) a comparison of the 4634/4617 intensity ratio with that given by Kruithof and Ornstein is shown, and agreement between them is quite good.

CONCLUDING REMARKS

From a cross plot of Brasefield's photographic density data for 4617- and 4634-angstrom molecular-hydrogen spectral lines with the intensity data given by Kruithof and Ornstein for these two lines, a calibration curve for the photographic plates used by Brasefield was determined. Even though the calibration curve was obtained by using two lines of nearly adjacent wavelengths, the curve should be satisfactory over the entire spectrum of Brasefield's work because he was working at the toe of the emulsion calibration curve where the change in gradient with wavelength is minimal. With the aid of this calibration curve, Brasefield's results were converted into consistent relative intensity units, which are more useful in plasma physics. Also presented are curves of intensity ratios for some of the singlet and triplet lines as a function of electron energy. The curves should be useful for spectroscopically determining the electron energy of a hydrogen plasma.

Experimental studies with hydrogen plasmas that are in progress at the Lewis Research Center have indicated that the electron energies calculated from the intensity ratios of the 4628- and 4580-angstrom lines to the 4554-angstrom line presented herein are consistent with other data from current NASA experiments.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, September 21, 1964

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