Journal of Astronomical History and Heritage, 13(2), 120-126 (2010).

THE ORIGIN AND DIFFUSION OF THE H AND K NOTATION

Jay M. Pasachoff
Williams College—Hopkins Observatory, Williamstown, Mass. 01267, USA.
E-mail: jay.m.pasachoff@williams.edu

and

Terry-Ann Suer
Stony Brook University, Stony Brook, NY 11794, USA.
E-mail: terry.suer@gmail.com

Abstract: Though many or most astronomers and astronomy students may think that H and K, as in the Ca II 'H and K lines', were named by Fraunhofer, actually only the H line was in Fraunhofer's original notation. He also used 'I' to indicate the end of the spectrum in his widely-reproduced 1814 drawing, of which an engraved version was published in 1817. We have searched references from nineteenth-century books and journals to find the first use of 'K' to indicate the ionized-calcium spectral line at 393.3 nm and located the probable first use and eventually the reuse of the notation.

Key words: spectroscopy, history, Sun, spectrum, Fraunhofer lines

1 INTRODUCTION

The H and K absorption lines of ionized calcium are the strongest in the solar spectrum, and are key for understanding a host of astronomical phenomena. Though today they are referred to as separate lines, K was originally considered and denoted as the twin companion of the H line. Through a survey of major nineteenth century publications on the spectrum we have been able to track down the evolution of the identity of the K line and its diffusion into general use.

The labeling convention for the major absorption lines is attributed to the German optician and glass manufacturer, Joseph Fraunhofer (1787–1826). Though he was not the first to notice divisions of the solar spectrum, he was the first to accurately measure their indices of refraction. He used the line positions to evaluate the quality of quartz prisms that he made. The 1814 measurements along with sketches of his observations were published in 1817 (Figure 1).

The absorption lines in this watercolor illustration are labeled alphabetically starting with 'A' at the red end of the spectrum, 'H' to designate the pair of dark lines near the violet end and 'I' at the violet end. 'K' was never used as a label in his work. According to the excerpts of a lecture delivered at Munich University (Hearnshaw, 1986: 27), Fraunhofer thought the two stripes at H to be "… the most extraordinary …" and pointed out that "… they are both almost completely the same." Details of Fraunhofer's drawing and etching appear in Hentschel (2002a), which also discusses other nineteenth-century images of the spectrum.

A dozen years before Fraunhofer's work, William Wollaston (1766–1828) had noted color zones, and separated them by letter, using both upper-case and lower-case letters (Figure 2). He used upper-case letters for the color borders, including D and E for the two limits of violet. His D is presumably a blend (at his resolution) of what today we know as the H and K lines.

Notations and vertical lines above and below Fraunhofer's spectrum, including vertical divisions of what we now know as a black-body curve, show that Fraunhofer still used capital letters to divide parts of the spectrum, while using lower-case letters for additional spectral lines.

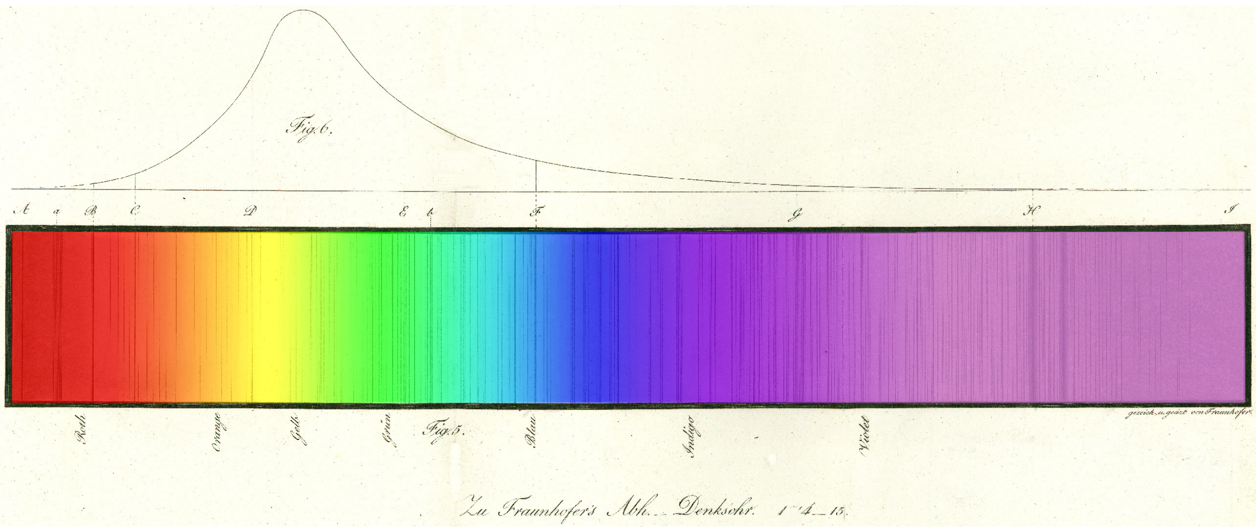

Figure 1: The 1814 map of the solar spectrum by Fraunhofer, with color added (after Fraunhofer, 1817).

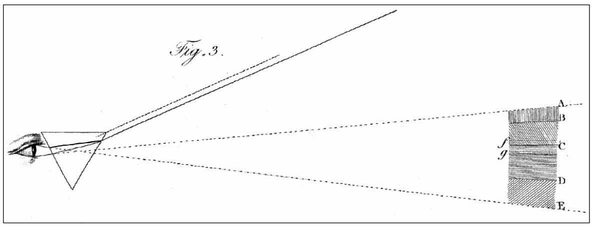

Figure 2: Drawing of the solar spectrum by Wollaston, showing his use of capital and lower-case letters, a scheme carried over by Fraunhofer (after Wollaston, 1802; courtesy: the Royal Society).

2 POST-FRAUNHOFER NOTATIONS

In 1842, Alexandre-Edmond Becquerel (1820–1891) of the Musée de l'Histoire Naturelle in Paris reproduced Fraunhofer's observations of the dark lines and saw further into the violet by using a flint glass prism, since flint glass has greater transmission than crown glass in the violet range. The light was focused onto a screen where he mounted a silver-nitride-coated Daguerreotype plate to capture the observations. This was the first attempt to study the spectrum photographically and he was the first to show that the Fraunhofer lines were zones of chemical inactivity (Hentschel, 2002a: 194). The resulting publication of the Fraunhofer lines was made from a copper engraving of the observation. The two calcium lines were once again labeled as H, with the letter H placed over today's H line.

When J. Norman Lockyer (1836–1920) reproduced Becquerel's map of 1842 on a reduced scale, he retained the nomenclature. Later in his article, he showed his own photograph of the spectrum, with the lines labeled H_1 and H_2 (1874).

This trend of using H to annotate the double calcium lines was broken for the first time in 1843 by John William Draper (1811–1882), a Professor of Chemistry at the University of the City of New York (now New York University), who labeled the lines as H and k (lower case) in order of decreasing wavelength (Figure 3). He experimented with different techniques of applying photography to spectroscopy and found several new lines beyond both ends of the then-known spectrum. It is not obvious why he chose to distinguish between the two lines, and the notation did not catch on for several decades. For further discussion of Draper's work, see Hentschel (2002b).

As observational techniques were invented and refined, many different maps of the solar spectrum appeared in print (see Hearnshaw, 2010). The wavelength range was extended, resolution of lines improved, and measurements of line positions made more precisely. There were even discussions on possible physical interpretations of the lines (Stanley, 2010). In the absence of standard notations there was some inconsistency in the labeling used in the resulting publications.

In 1852, George Stokes (1819–1903), then Lucasian Professor of Physics at Cambridge, extended the original spectrum further into the violet. He utilized the refractive properties of quartz in ultraviolet light as well as the ability of some materials to give off ultraviolet radiation under certain conditions. Unsure of how the many lines in this part of the spectrum related to the lines in the visible, he decided not to use the capital letters employed by Draper in 1843 but used lowercase letters from k to p on his metal relief engraving of the spectrum. Stokes' k corresponds to k on Draper's photographic spectrum (Stokes, 1852).

Though Stokes had some insights about the origins of the dark lines in the spectrum, Gustav Kirchhoff (1824–1887) and Robert Bunsen (1811–1899) at Heidelberg were the first to link the lines in the spectrum to chemistry. They demonstrated the existence of emission lines in the electric spark spectra of several known compounds (1860). Later Kirchhoff (1861; 1862) published these laboratory spectra along with a solar spectrum for comparison. The lines are labeled with the abbreviations of the elements, calcium being denoted 'Ca', for example.

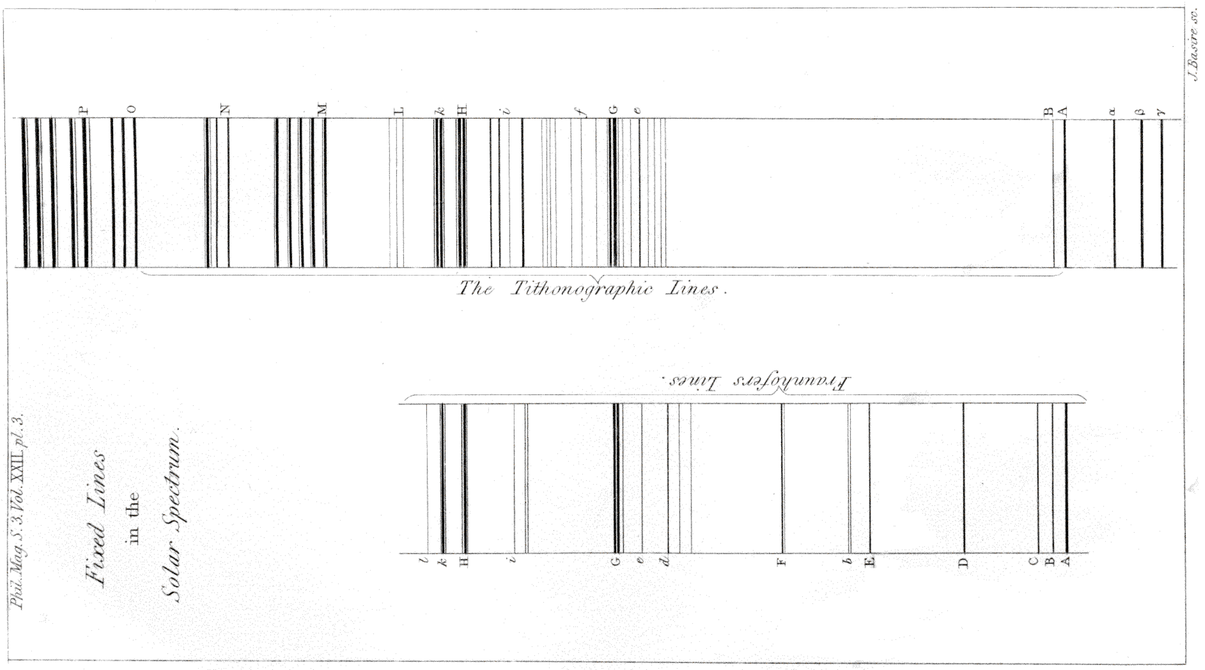

Figure 3: Map of the spectrum using k (after Draper, 1843: Plate III).

In 1864, Éleuthère Mascart (1837–1908) from the École Normale Supérieure in Paris published his atlas of the ultraviolet region of the spectrum. He replaced the glass optics of his spectroscope with prisms and lenses made of quartz or Iceland spar, which both have better transmission in ultraviolet light. His map contained nearly ten times as many spectral lines as its forerunners (Figure 4). He was the first person to use capital K to designate the second H line. (Coding showing that Mascart defined some notations, including K, appeared in Appendix 1 in Stratton, 1925: 183, which was included in Hearnshaw, 1986: 493-494.)

Not long after Mascart's map, high quality diffracttion gratings replaced prisms as the dispersive element in spectrum analysis. Anders Ångström (1814–1874) and his colleague, T. Robert Thalén (1827–1905), were among the first to publish a normal spectrum (Ångström and Thalén, 1866). They used H_1 and H_2 along with the abbreviation Ca to denote the calcium lines in their drawings (Figure 5). In 1868, Ångström published another map of the normal solar spectrum including detailed measurements of more than 1000 spectral lines. There and in a table (Figure 6) he used H_1, H_{11}, and Ca to label the calcium lines, with H' and H'' labeling the atlas chart, adding yet more variety to the notation.

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Raies	Sixième spectre		Cinquième spectre		Quatrième spectre		Valeur moyenne de Longueur d'onde	Différence
	m_6	λ	m_5	λ	m_4	λ		
	—	—	918,0	4016,53	708,0	4016,94	4016,73	20
	—	—	1047,0	4004,62	810,0	04,80	04,71	9
	—	—	—	—	839,0	4001,36	4001,36	—
	—	—	—	—	869,0	3997,78	3997,78	—
H_1	—	—	1446,0	3967,76	1119,0	3968,00	67,88	12
	—	—	*[1778,0	37,04]	—	—	—	—
H_{11}	—	—	1823,0	3932,82	—	—	3932,82	—

Figure 6: A table showing H_1 and H_{11} (after Ångström, 1868: Plate X of Tableaux section).

It was not until 1872 that K reappeared in the work of Marie Alfred Cornu (1841–1902), a colleague of Mascart. He set out to map the ultraviolet region of the spectrum using Ångström's normal spectrum as a template (Figure 7). In this publication he quoted one of Mascart's earlier maps, and this probably explains his use of K. Hermann Wilhelm Vogel (1834–1898), known for developing emulsions and sensitizers in photography, also quoted Mascart's maps and showed a diagram with H centered between H and K. However, he used the notation H and H' in the text, while discussing Fraunhofer's lettering (Vogel, 1875).

From the mid-1870s and onwards, the two calcium lines took on greater importance in the astronomical

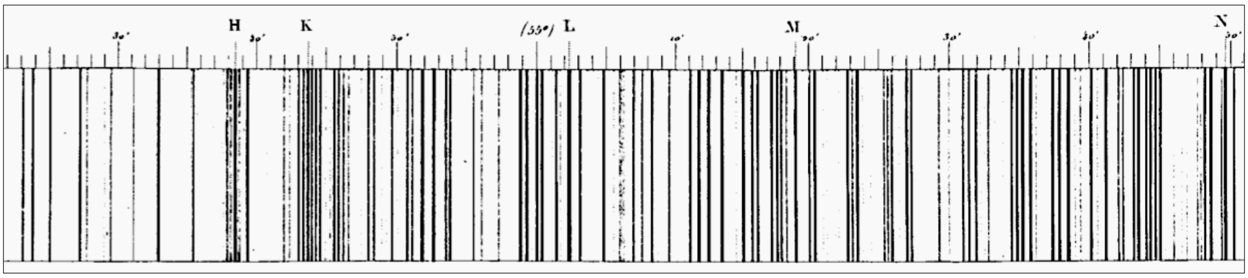


Figure 4: Small portion of the spectrum showing H and K (after Mascart, 1864: Figure 1 in Planche IV).

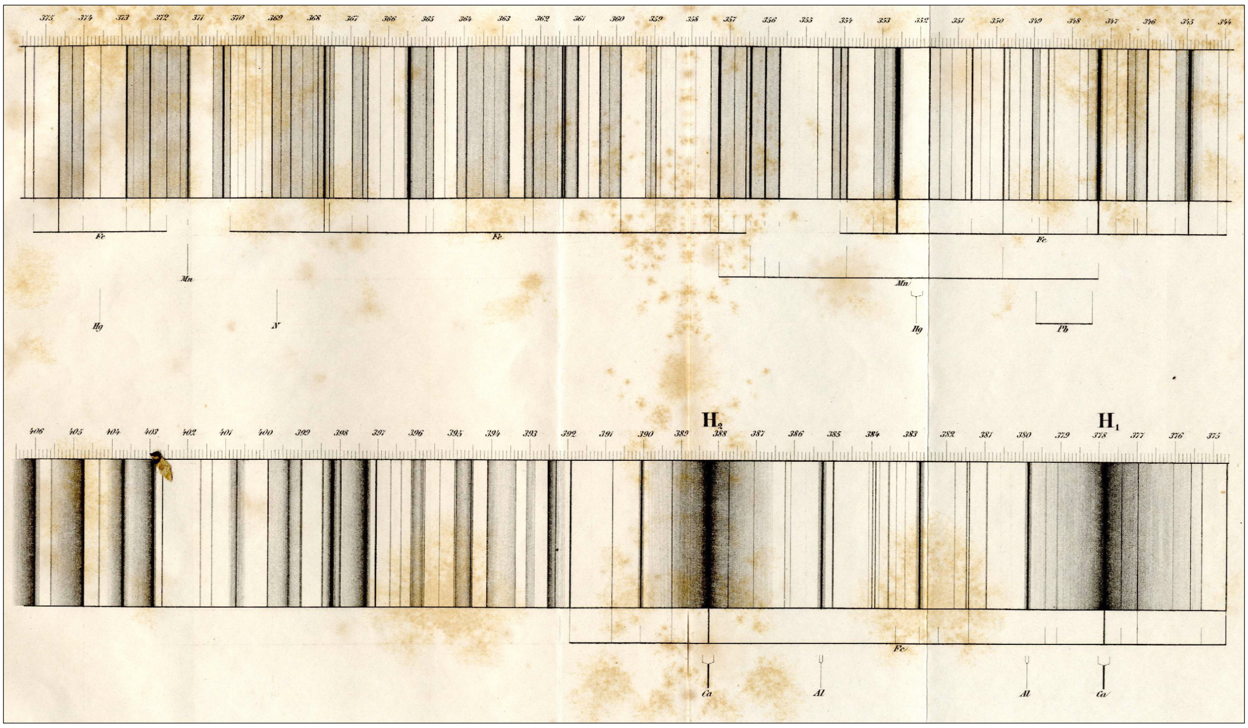


Figure 5: A spectrum including H_1 and H_2 (after Ångström and Thalén, 1866: Plate II).

community. While this was due to improvements in instrumentation and observing techniques it was also because of the interesting behavior that the two calcium lines displayed. In 1872, during the Mount Sherman Astronomical Expedition, Professor Charles A. Young (1834–1908), then of Dartmouth College, observed reversals of the Fraunhofer lines in spectra of the solar chromosphere and prominences and also found 170 new lines. He stated:

> The only lines of much importance are the two Hs at the extreme violet end of the spectrum. These were found to be constantly reversed … and I am pretty confident always reversed in the spectrum of sunspots … This reversal of the H lines does not involve at all the disappearance of the dark shade, but a bright streak rather than a line makes its appearance in the center of the shade … (Young, 1872).

Demonstrating the inconsistency of the time, in his book *Die Sonne* (1872), Fr A. Secchi refers to H and H' as labels in an image credited to Lewis Rutherfurd (p. 232), H and H' again in an image credited to Van der Willigen (p. 241), and H_1 and H_2 in a table (p. 247).

3 CURRENT NOTATION IS STANDARDIZED

In 1874 Norman Lockyer was still using the notation H_1 and H_2 (Figure 8). In 1878, he discussed the physical causes of the Fraunhofer lines and compared the solar spectrum and stellar spectra with laboratory results of dissociating calcium chloride. His drawing

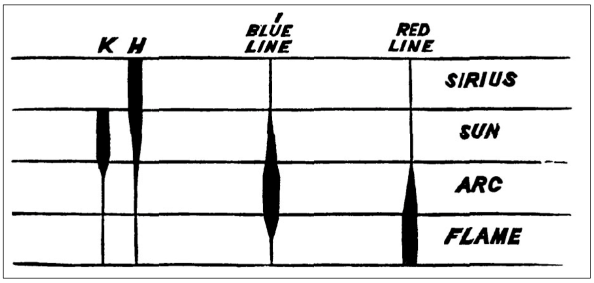


Figure 9: The K line in spectra of various objects (after Lockyer, 1878: 171).

(Figure 9) demonstrated how the widths of the H and K lines vary in the spectra of the Sun, Sirius and sodium chloride. He also attempted to link the line widths to the temperature variations in these bodies

The spectrum of Sirius used in Lockyer's work was obtained by the British amateur astronomer, William Huggins (Becker, 2010), and communicated privately before the latter published this material (1880). These observations by Huggins were crucial to establishing K as a line with unique behavior.

Astronomer George Ellery Hale (1868–1938) best summarized this work:

> Dr. Huggins arranged the stars observed in a series, in which the principal criterion of the position was the character of the K line. In Arcturus this line is broad and more diffuse than in the sun, in Sirius it has

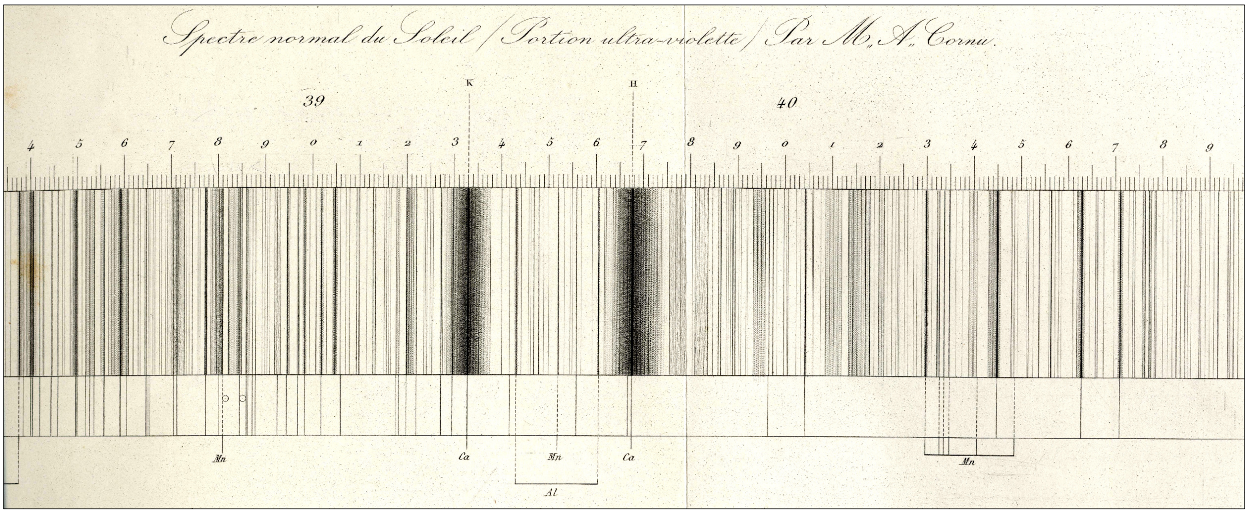


Figure 7: Portion of Cornu's map of the spectrum, with H and K notation (after Cornu, 1880).

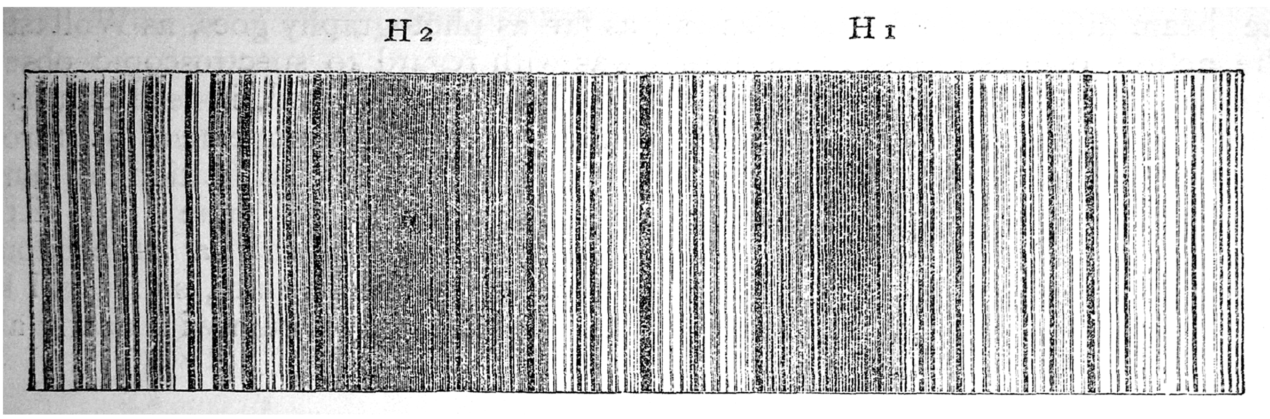


Figure 8: The H-lines in the blue end of the solar spectrum (after Lockyer, 1874: 110).

narrowed down to a fine, sharp line. Other stars give intermediate breadths and in some it has entirely disappeared. In the case of H the question is complicated by the nearby Hydrogen line, so it is best to consider only K. (Hale, 1892).

In the same work Hale went on to discuss the causes of the line reversals:

From the variations of this line it will be seen, apart from the interesting subject of stellar evolution so evidently suggested that the narrow dark line at the center is very possibly produced by the same substance which, vibrating under different conditions, causing by its absorption the broad dark band.

He referred to the lines as H^1 and K, to distinguish the first calcium line from hydrogen. He also compared the spectra of these stars to the solar spectrum map of Alfred Cornu who, as discussed earlier, quoted Mascart, the originator of the K notation.

To emphasize the varied use of notation during this period, we turn to the notebook of Margaret Huggins, the wife and collaborator of William. She used H_2 in 1877 to refer to the calcium line and on 23 October 1878, she referred to "… half the width of the second H line." (Figure 10). On 2 January 1880, she wrote: "The spectrum of Sirius is beautiful, and in this photograph one sees clearly the line H_2 (or K) faint and thin ..." (Figure 11). But by 30 June 1881, it was clear that K had entered into her standard notation. Referring to faint lines at that end of the spectrum between H and h and G and g, she wrote: "… the faint lines used in shading between and beyond the intensely [?] lines beyond K are also a guess." See also Figure 12, a stained-glass window from the Huggins Observatory (given to Wellesley College's Whitin Observatory by Lady Huggins), which notably extends only to Fraunhofer's original H.

This variation in nomenclature continued to occur on both sides of the Atlantic. J. Norman Lockyer (1887) used H^1 and H^2 in his figures of the solar spectrum. Astronomy handbook author George F. Chambers (1890) crediting E.W. Maunder for the spectroscopic chapter, wrote that "H is a pair of bands near the limit of vision in the extreme violet." (p. 302), but later referred to H and K (pp. 324 and 334). In 1892, Henri Deslandres (1853–1948) in Paris discovered the weak emission cores in the centre of the H and K lines which he labeled H_2 and K_2, and H_3 and K_3. C.A. Young used H and K in a 1904 article. It was not until the 1920s that K became the standard notation.

As it turns out, several misnomers and ambivalent notations were straightened out at the first International Astronomical Union meeting, held in Rome in 1922 (Hearnshaw, 1986: 256). There was a Spectral Classification Committee headed by Walter S. Adams (1876–1956)—the Adams Committee—whose job was to examine the notation for individual spectral lines. The Committee accepted that only some of the mostly century-old Fraunhofer symbols should be retained, only A, a, α, D, b, G, H and K were to be preserved because they are "… so well established that it does not seem desirable to abandon them… [while] for the hydrogen lines, the notation Hα, and Hβ, etc. should be adopted."

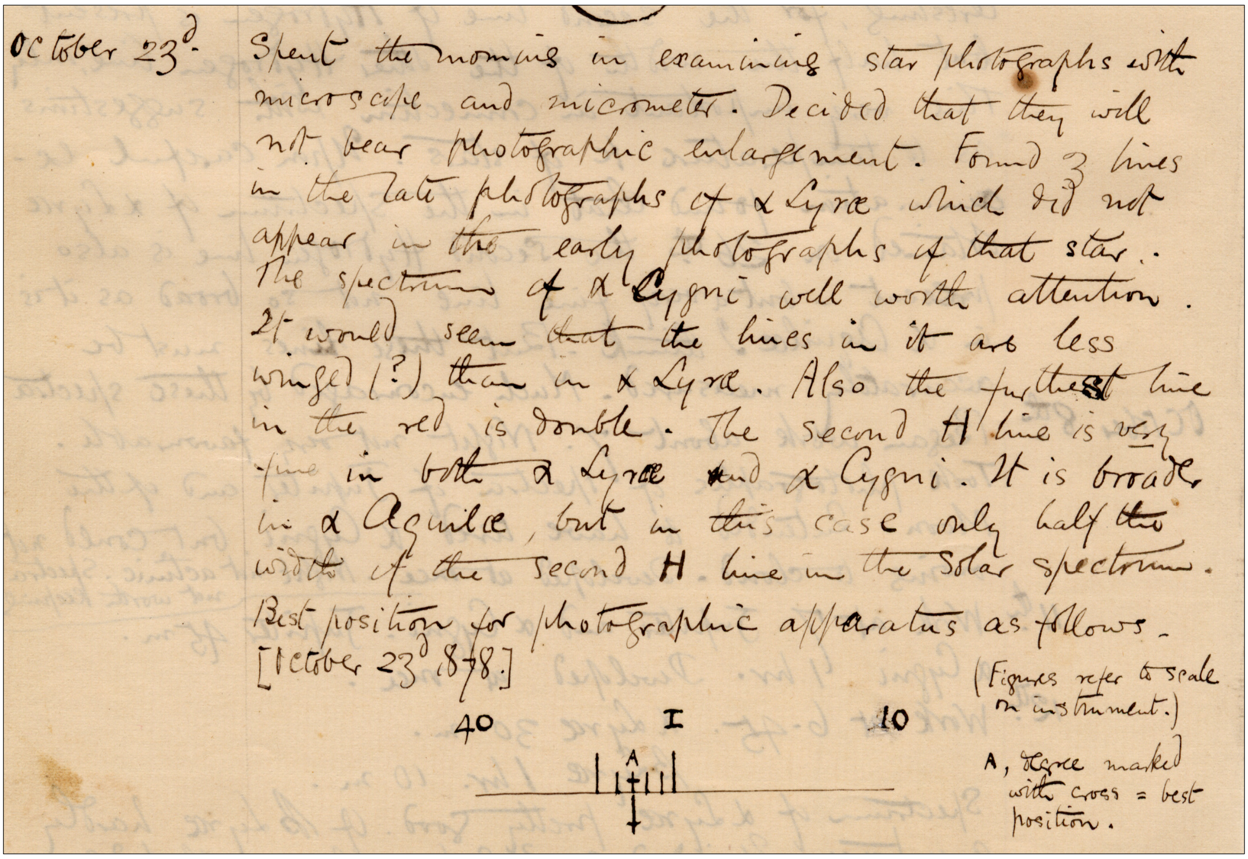
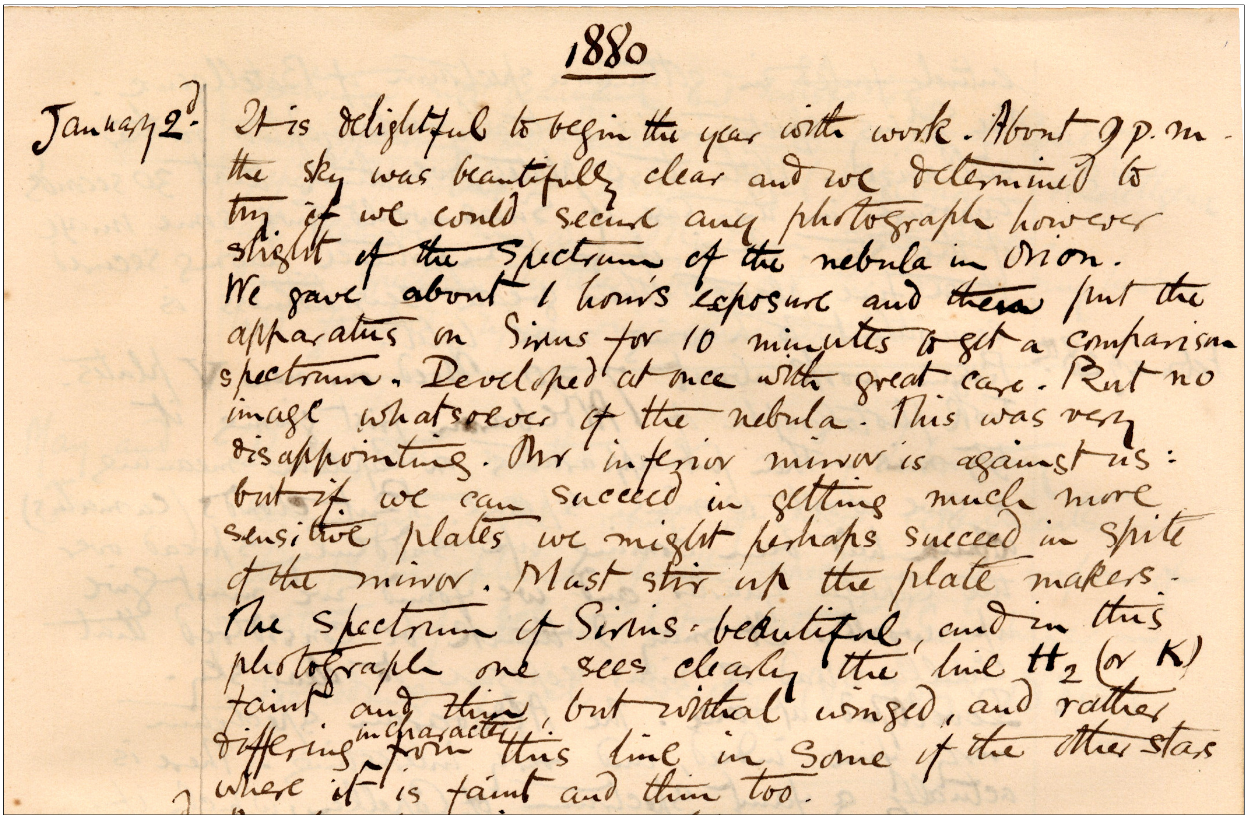

October 23d. Spent the morning in examining star photographs with microscope and micrometer. Decided that they will not bear photographic enlargement. Found 3 lines in the late photographs of α Lyrae which did not appear in the early photographs of that star. The spectrum of α Cygni well worth attention. It would seem that the lines in it are less winged (?) than in α Lyrae. Also the furthest line in the red is double. The second H line is very fine in both α Lyrae and α Cygni. It is broader in α Aquilae, but in this case only half the width of the second H line in the Solar spectrum. Best position for photographic apparatus as follows.
[October 23d 1878.]
(Figures refer to scale on instrument.)
40 I 10
A
A, [illegible] marked with cross = best position.

Figure 10: Margaret Huggins' notebook page from 23 October 1878, with a reference to "… the second H line …" (after Huggins, W. and M., 1856-1870).



1880

January 2d. It is delightful to begin the year with work. About 9 p.m. the sky was beautifully clear and we determined to try if we could secure any photograph however slight of the Spectrum of the nebula in Orion. We gave about 1 hour's exposure and then put the apparatus on Sirius for 10 minutes to get a comparison spectrum. Developed at once with great care. But no image whatsoever of the nebula. This was very disappointing. Our inferior mirror is against us: but if we can succeed in getting much more sensitive plates we might perhaps succeed in spite of the mirror. Must stir up the plate makers. The Spectrum of Sirius beautiful, and in this photograph one sees clearly the line H_2 (or K) faint and thin, but withal winged, and rather differing in character from this line in some of the other stars where it is faint and thin too.

Figure 11: Margaret Huggins' notebook page from 2 January 1880, with a reference to "… the line H_2 (or K) …" (Huggins, W. and M., 1856-1870; both images by permission of Wellesley College, Margaret Clapp Library, Special Collections).

4 CONCLUSION

Fraunhofer never originally labeled the K line. It was considered and labeled by many as the twin of H. Several labels, including H_2, k, H′, H_{II}, were assigned to the line for over a century. Once its unique behavior was observed, the K identity was established.

It was in stellar spectroscopy, incidentally, that this identity came out fully.

5 NOTES

1. Becquerel was later to become the father of Antoine-Henri Becquerel (1852–1908), who discovered radioactivity and shared the third Nobel Prize in Physics with Pierre (1859–1906) and Marie Curie (1867–1934).
2. A French version of the book is available online as *Le Soleil* (1875).

6 ACKNOWLEDGMENTS

At Williams College, we thank Wayne Hammond of the Chapin Library of Rare Books; Jodi Psoter and Helena Warburg of the Schow Science Library; Walter Komorowski of Library Systems; and Alison O'Grady and Jean Caprari of the Interlibrary Loan department for their assistance. We thank Judy Bausch of the Yerkes Observatory Library for the loan of the two Ångström volumes. We acknowledge the useful comments of a reviewer about the work of William Wollaston and the use of upper-case and lower-case letters as labels. One of us (JMP) thanks Michael Brown for his hospitality at the Department of Planetary Astronomy of the California Institute of Technology during part of the preparation of this paper. We also thank Joseph S. Tenn, the editor, for his thoughtful and useful questions and for his work in the shaping of this article's final form.

Figure 12: Stained-glass window, one of three originally at the Huggins home and observatory and now at Wellesley College's Whitin Observatory, Wellesley, MA, USA. (courtesy: Whitin Observatory, Wellesley College).

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Jay M. Pasachoff is Field Memorial Professor of Astronomy at Williams College, Williamstown, Massachusetts. He was President of the International Astronomical Union's Commission on Education and Development and he is Chair of its Working Group on Eclipses. Part of his Ph.D. thesis at Harvard was about the K-line in the Sun.

Terry-Ann Suer is a Ph.D. student at Stony Brook University in New York, where she studies planetary geochemistry. She is interested in applying small-scale material properties to the macroscopic behavior of planets. She approaches this work through modeling and experimentation. While at the California Institute of Technology, she worked on modeling the surface of Mars in 3 dimensions as well as on the properties of outer Solar System bodies. She is an alumna of Williams College.