Letters to the Editor

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NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 1145.

CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

Kramers' Absorption Law in Astrophysical Problems

KRAMERS' well-known absorption law¹, long used by astrophysicists in their calculations of the opacity of stellar material, was first derived from classical mechanics and the correspondence principle, and may be stated thus:

$$\alpha_\nu = 0.0104 \frac{Z^4 \lambda^3}{a_n n^3} g, \quad (1)$$

where α_ν is the atomic coefficient of continuous absorption, Z is the effective atomic number, λ is the wave-length in cm., n is the quantum number, a_n is the statistical weight of the n^{th} state, and g is a factor very nearly unity.

Wave mechanical calculations have confirmed this result² for hydrogen, but have shown that it does not apply to hydrogen-like atoms³, much less to other elements, as previously assumed. Laboratory measurements show that it is invalid for the alkalis⁴ and not exact for X-ray absorption⁵. However, equation (1) has never actually been verified from observations on atomic hydrogen, which must be made at pressures sufficiently low for external conditions to have no effect⁶.

It is not possible to measure the actual continuous absorption of light by hydrogen, but through Milne's fundamental relation⁷ between photo-ionization and recombination, Cillié⁸ has computed from equation (1) the relative numbers, p_n , of captures of electrons on the n^{th} level of a hydrogen atom in equilibrium with free electrons at an 'electron temperature', T_e . From an emission spectrum due to recombination we can determine the p 's observationally from the following equations:

$$p_n = \sum_{r=n}^{\infty} K_{r,n} I_{r,2}, \text{ for } n > 2 \text{ (Carroll)}, \quad (2)$$

p_2 = the number of quanta in the continuous emission at the head of the Balmer series. (3)

$I_{r,2}$ is the intensity of the $(r-2)^{\text{th}}$ Balmer line, and the K 's are functions of the Einstein transition probabilities, which have recently been calculated up to $n = 14$ by Menzel and Pekeris⁹.

Two published sources of Balmer emission intensities which might be used in equations (2) and (3) are measurements first in the solar chromosphere spectrum by Menzel and Cillié¹⁰, and secondly in the spectra of several planetary nebulae, measured at this Observatory¹¹. Recently I have also measured intensities in the spectrum from the electrically undisturbed region of an electrodeless discharge in hydrogen. In the nebulae and in the discharge it can be shown that the recombination of protons and electrons must account for almost the entire emission, and the electron temperatures have been measured (and found to be near 1000° K.). In the chromo-

sphere, however, as Menzel and Cillié point out, the mechanism of line formation is uncertain. Furthermore, no use can be made of their results because (a) their "Balmer continuous emission" must include the intensity of unresolved lines (Menzel¹² lists more than 2.6 lines of intensity greater than "O" per angstrom in that region), and (b) there may be further errors due to the calibration and standardization.

In this investigation the carefully estimated observational errors are such that the values of p_n listed in the accompanying table must be accurate to about 15 per cent for the nebulae and 5 per cent for the discharge. We are therefore justified in

RELATIVE NUMBERS OF CAPTURES ON LEVELS OF THE H ATOM

n	Observed p_n (1000° K.)		p_n from Kramers' law	
	Discharge	Nebulae	1000° K.	50,000° K.
2	0.012	0.675	0.039	21
3	17.9	—	40	13.5
4	10.0	10.0	10.0	10.0
5	5.53	5.9	5.0	7.5
6	2.62	3.7	2.0	6.2
7	1.19	—	—	4.9
8	0.725	(NGC. 7 62)	(NGC. 7027)	4.0
9	0.366	—	—	3.4
10	0.202	—	—	3.0

testing Kramers' law by comparing the observed p_n listed in columns 2, 3, and 4 with the theoretical values for $T_e = 1000^\circ \text{K.}$ (If the transition probabilities $A_{m,n}$ used are in error, Kramers' law must similarly be so, since it was calculated by the same methods as the $A_{m,n}$.)

Not only are the observed ratios $p_3:p_4:p_5$: etc. found to differ from those predicted in column 5, but also $p_3 \gg p_2$ (a peculiarity also observed for the alkali atoms¹³), whereas by Kramers' law $p_3 < p_2$.

We are thus forced to conclude that the use of Kramers' law in astrophysical problems is unjustified. A more detailed account of this investigation will shortly be communicated to the Royal Astronomical Society.

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¹ Kramers, H. A., *Phil. Mag.*, **46**, 837 (1923).

² Menzel and Pekeris, *Mon. Not. Roy. Astro. Soc.*, **96**, 77 (1935).

³ Phillips, M., *Phys. Rev.*, **39**, 905 (1932).

⁴ Lawrence and Edlefsen, *Phys. Rev.*, **34**, 233 and 1056 (1929).

⁵ Compton and Allison, "X-Rays in Theory and Experiment" (Macmillan, 1935).

⁶ Robertson and Dewey, *Phys. Rev.*, **31**, 973 (1928).

⁷ Milne, E. A., *Phil. Mag.*, **47**, 209 (1924).

⁸ Cillié, G. G., *Mon. Not. Roy. Astro. Soc.*, **92**, 820 (1932).

⁹ Carroll, J. A., *Mon. Not. Roy. Astro. Soc.*, **90**, 588 (1930).

¹⁰ Menzel and Cillié, *Harv. Circ.*, No. 401 (1935).

¹¹ Page, T. L., *Mon. Not. Roy. Astro. Soc.*, **96**, 604 (1936).

¹² Menzel, D. H., *Pub. Lick Obs.*, **17**, 39 (1931).

¹³ Mohler, F. L., *Rev. Mod. Phys.*, **1**, 216 (1929).