2·2° K. In no case in helium II was a purely laminar flow observed, although in the case of the two shorter capillaries the curves might indicate a semi-turbulent condition. If we assume the flow to be laminar and calculate the viscosity from Poiseuille's formula, we obtain a value of $7 \cdot 8 \times 10^{-5}$ C.G.S. units with $R = 280$, which agrees with Burton's value for a capillary of somewhat the same length. On the other hand, shortening the capillary length to 6 mm. appears to have very little effect on the velocity, and lengthening the capillary to 40 cm. has the effect of decreasing the velocity only by a factor of five at 2·160° K. Lengthening the capillary also has the effect of making the velocity much more independent of pressure. It is noted that although the velocity through long capillaries increases with decreasing temperature, the velocity through the shorter capillaries actually decreases by about 5 per cent from 2·160° to 1·165° K. For purposes of comparison, a measurement of the flow in helium I, just above the λ-point, was made. The flow was observed to be laminar for low velocities and turbulent for high velocities. The viscosity was found to be $1 \cdot 4 \times 10^{-4}$ C.G.S. units, which is in fair agreement with previous measurements.

J. F. Allen.
A. D. Misener.

Royal Society Mond Laboratory,
Cambridge.

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Effect of Collisions on the Intensities of Nebular Lines

There appears to be a widespread misconception concerning the effect of electron collisions on the intensities of forbidden lines. The prevailing view appears to be that, at high densities, collisions of the second kind operate to de-excite atoms from the metastable levels before the atoms have a chance to radiate, and that only at low densities, as in the gaseous nebulæ, can a sufficiently high population of atoms be obtained to give appreciable intensity to the forbidden lines. The mathematical reasoning advanced to support this argument[1] is as follows. Let $N_1 b_{12}$ be the number of atoms excited per second from the ground to the metastable level by inelastic electron impact, which process is ordinarily assumed to be the predominant source of excitation. Let $N_2 b_{21}$ be the number of super-elastic collisions per second. Let A_{21} be the Einstein probability of spontaneous emission. Then the intensity of the line may be written:

$$I = \frac{N_1 b_{12}}{b_{21} + A_{21}} A_{21} h\nu \qquad (1)$$

The customary argument is that the increase of b_{21} with density causes the value of I to decrease.

The fallacy in the reasoning lies in the fact[2] that the excitation coefficients, b_{12} and b_{21}, both being proportional to the electron density, keep exactly in step. Furthermore, they are closely related, so that one may be expressed in terms of the other. Equation (1) is easily transformed to the following equivalent expression:

$$I = N_1 \frac{\tilde{\omega}_2}{\tilde{\omega}_1} e^{-h\nu/kT} \left(\frac{1}{1 + A_{21}/b_{21}}\right) A_{21} h\nu, \qquad (2)$$

where the $\tilde{\omega}$'s refer to the statistical weights of the respective levels. Since practically all the atoms are in the lower level, we may regard N_1 to be the total number of atoms in the assembly. The first factor represents a Boltzmann distribution, which would be accurately attained if A_{21} were zero. The second factor, enclosed in parentheses, is always less than unity. A_{21} is an atomic constant. I reaches a maximum when $b_{21} \gg A_{21}$, that is, when the electron density is *high*. This conclusion is the reverse of that stated in the first paragraph.

Part of the misunderstanding may arise from the erroneous belief that if the probability of collisional de-excitation is greater than the probability of emission, the atoms do not have time to radiate. This reasoning would imply a difference between an atom that arrived in a metastable state 10^{-8} seconds ago and one that may have existed in that level for some seconds. The argument would imply that the quantum equation,

$$I = N_2 A_{21} h\nu \qquad (3)$$

is wrong. The intensity depends solely on the population and atomic constants, and the highest intensity occurs when N_2 is greatest.

When equation (2) is applied to the normal lines, with high values of A_{21}, we discover that serious departures from thermodynamic equilibrium, with consequent fading of permitted lines, may be expected at densities from 10^6 to 10^8 times greater than for the forbidden lines. Where, in a nebula, the forbidden lines may occur with intensities not far from their thermodynamic values, the permitted lines will have their intensities greatly decreased from the laboratory values. The predominance of the forbidden lines in nebular spectra, therefore, is attributable, not to the effect of collisions in de-exciting an atom before it has a chance to radiate, but to the weakness of the permitted lines. The high absolute intensity of the forbidden lines is explicable only in terms of the large total mass of the nebulæ. The predominance of normal lines in laboratory spectra is due chiefly to the high values of the associated Einstein A's, though collisions of excited atoms with the cool walls of a tube, an essentially irreversible process, may affect the relative intensities.

The foregoing analysis can be extended to atoms with more than one excited level. One may also show that removal of the atoms from the metastable levels by radiation processes does not result in an appreciable lowering of the level population, in contradiction to the results of Eddington[3].

Note added in proof (Sept. 19). Kaplan[4] reports that certain forbidden lines, observed in the nitrogen afterglow, drop in intensity as the pressure goes down. He remarks, "Since these radiations originate in relatively forbidden transitions, it is of considerable astrophysical interest to report an increase in intensity with pressure rather than the expected decrease." The observational proof of the points raised in the foregoing letter seems to be already available.

Donald H. Menzel.

Harvard Observatory,
Cambridge, Mass.
Aug. 19.

[1] cf., Bowen, I. S., *Rev. Mod. Phys.*, **8**, 55 (1936).
[2] cf., Fowler, R. H., "Statistical Mechanics" (2nd ed.), 677–684.
[3] Eddington, A. S., *Mon. Not. Roy. Astro. Soc.*, **88**, 134 (1927).
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(*Continued on p.* 669.)

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