SOVIET PHYSICS JETP VOLUME 31, NUMBER 5 NOVEMBER, 1970

BROADENING OF HYDROGEN SPECTRAL LINES DURING TURBULENT HEATING OF A PLASMA

A. S. ANTONOV, O. A. ZINOV'EV, V. D. RUSANOV, and A. V. TITOV

Submitted October 24, 1969

Zh. Eksp. Teor. Fiz. 58, 1567–1570 (May, 1970)

An attempt of a contactless determination of the degree of turbulence of a plasma is made on the basis of Stark broadening of the hydrogen H_β and H_γ spectral lines. The value of the turbulence, defined as the ratio of turbulent oscillation energy to plasma diamagnetism, is $\sim 1.6 \times 10^{-3}$.

As is well known, hydrogen atoms are subject to the linear Stark effect. By virtue of this, observation of the width of the spectral lines of the Balmer series makes it possible to obtain in relatively simple manner information concerning the electric fields in a plasma. In[1], a method was proposed for determining the average energy of the potential noise in a plasma from the magnitude of the Stark broadening of the H_β, H_γ, and H_δ lines for a magnetosonic discharge, where the intensity of the turbulent pulsations is small.

It was therefore of interest to determine the energy density of the noise in turbulence heating by currents[2], when the electric fields of the pulsations are sufficiently strong ($\tilde{E}_m > E_p$, where E_p is the intensity of the applied electric field and $\tilde{E}_m > E_0$, where $E_0 = 2.6en^{2/3}$ is the magnitude of the Stark field and characterizes the average effect of line broadening by the microfields of the plasma ions).

To this end, we used a toroidal setup of the "Tokamak" type with turbulent heating, described in detail in[3]. The discharge was produced in hydrogen at a pressure 5×10^{-4}–10^{-3} Torr. The longitudinal magnetic field reached 15 kG. The quasistationary current was turned on at the maximum of the field. The intensity of the electric, corresponding to a rapidly growing current with amplitude 5 kA, was 40 V/cm and was produced by discharging (in a transverse section through the jacket) a capacitor bank with $C \approx 20\ \mu F$ through an active resistance of 2 ohms. The plasma column inside the chamber was limited with a diaphragm having an aperture 2a = 4 cm.

The light emerged from the chamber through a peephole and was directed with the aid of a reflecting mirror and a long-focus condenser to the input slit of a UF-85 camera coupled to an ISP-51 spectrograph. The recording element was a photomultiplier. The light flux at the output of the optical system was analyzed with the aid of a moving slit, the width of which in most experiments was 50 μ. The accuracy of slit motion was within ±1 μ. The input slit had a width of 50 μ. The reproducibility of the process from experiment to experiment was monitored with the aid of a system consisting of a UM-2 monochromator with a photomultiplier at the output; the latter registered the total light of the investigated line.

In addition, we registered the following parameters: the quasistationary and "fast" currents, the amplitude of the circuit voltage, the diamagnetism of the plasma. Chord measurements were made of the concentration with two impact parameters a = 0 and a = 1.5 cm, using a microwave interferometer at a wavelength λ = 4 mm.

The plasma resistance was determined from the oscillograms of the "fast" current I and the circuit voltage U_g. The signal of the latter was registered from a voltage divider placed in the transverse gap of the jacket. In calculating the anomalous resistance of the plasma, we used the formula

$$R_a(t) = \frac{\alpha}{\tilde{I}}\left(\tilde{U}_g - \beta\frac{d\tilde{I}}{dt}\right), \tag{1}$$

where α = 0.7 is the coefficient of coupling between the primary winding of the transformer and the plasma loop, and β is a coefficient determined from the relation (1) at $R_a(t) = 0$. The maximum value of the resistance in the phase of turbulent heating was ~1 ohm, which exceeded by two orders of magnitude the resistance of the initial plasma prepared by the quasistationary current I_0.

Principal attention was paid in the experiments to the behavior of the pair of lines H_β and H_γ, since these lines are close to the maximum of the spectral sensitivity of the photomultiplier photocathode, and their Stark constants differ by a factor of 2[4]. Figure 1 shows typical oscillograms of the glow for the core and the wing of the $H\gamma$ line at the instant of operation of the "fast" current. The line profile is shown in Fig. 2 for different instants of time: a—after $\tau \approx 0.5\ \mu$sec, $\delta\lambda(H_\gamma) = 4$ Å; b—after $\tau \approx 2.5\ \mu$sec, $\delta\lambda(H_\gamma) = 2.5$ Å, when the anomalous resistance of the plasma has already vanished. In the latter case, the profile of the line duplicated with a great degree of accuracy a Gaussian profile (dashed line).

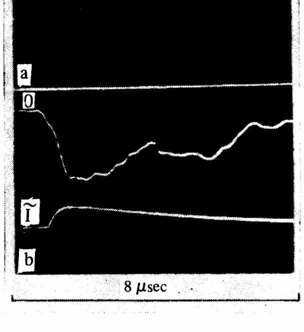

FIG. 1. Oscillograms of the glow of the spectral line of hydrogen H: a—on the wings, b—in the nucleus, an oscillogram of a "fast" current pulse I_m = 5 kA.

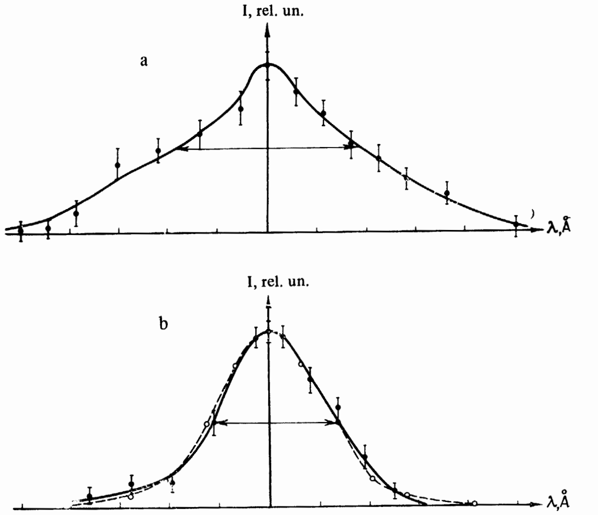

FIG. 2. Profile of hydrogen spectral line H_γ at different time intervals from the start of the turning on of the "fast" current: a—after $\tau \simeq 0.5$ μsec; $\lambda(H_\gamma) = 4340.4$Å, $\delta\lambda(H_\gamma) = 4.0$Å; b—after $\tau \simeq 2.5$ μsec; $\lambda(H_\gamma) = 4340.4$Å, $\delta\lambda(H_\gamma) = 2.5$Å.

Figure 3 shows the half-widths of the lines H_β and H_γ as functions of the time. The curves show two clearly pronounced maxima. The first probably results from the Stark broadening in turbulent electric fields. It is precisely in this time that the profile of the lines H_β and H_γ is far from Gaussian and a maximum of the anomalous resistance is registered. In addition, an estimate of the Stark broadening introduced by the plasma concentration (in our case $n \approx 6 \times 10^{18}$ cm^{-3}) is larger by one order of magnitude than the measured value.

The decrease of the half-width of the line is due to dissipation of the oscillation energy into heat, and the subsequent rise has probably a Doppler origin. The temperature of the neutral hydrogen atoms calculated from the line broadening, with allowance for the Stark effect, was 60–80 eV, and this can serve as a lower estimate of the ion temperature.

The line broadening, which is connected with the electric field by the relation

$$\Delta\omega = \frac{a}{2,6e}\tilde{E}_m,$$

makes it possible to determine the magnitude of the microfields: for the H_β and H_γ lines we have $\tilde{E}_m \approx 6$ keV/cm. Since measurements with the aid of a diamagnetic pickup yields $nT \approx 10^4$ erg, it follows that by knowing the energy density of the turbulent oscillations (assuming that ion sound builds up)

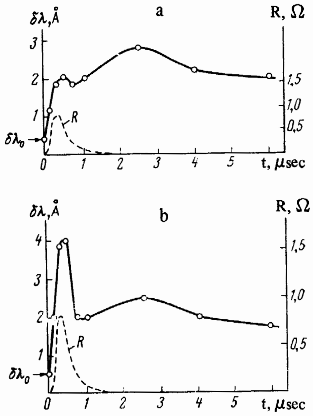

FIG. 3. Half-widths of spectral lines of hydrogen H_β(a) and H_γ(b) and anomalous resistance of plasma as functions of the time. $\lambda(H_\beta) = 4861.3$Å $\lambda(H_\gamma) = 4340.4$Å.

$$W = \frac{\omega_{0i}^2}{\omega^2}\frac{\tilde{E}_m^2}{8\pi},$$

we can estimate the degree of turbulence of the plasma $W/nT \approx 1.6 \times 10^{-3}$, corresponding to our earlier measurements of plasma radiation[3].

Thus, the use of Stark broadening of the Balmer lines of hydrogen makes it possible to determine by a contactless method the degree of turbulence of the plasma.

---

[1] I. A. Kovan, L. I. Kozorovitskiĭ, I. M. Podgornyĭ, V. D. Rusanov, V. P. Smirnov, A. M. Spektor, and D. A. Frank-Kamenetskiĭ, Atomnaya énergiya 25, 503 (1968).

[2] E. K. Zavoiskii, S. L. Nedoseev, L. I. Rudakov, V. D. Rusanov, V. A. Skoryupin, and S. D. Fanchenko, Paper C1/-24/L-1 at Third Internat. Conf. on Plasma Physics and Controlled Thermonuc. Fusion, Novosibirsk, 1968.

[3] V. Ya. Balakhanov, V. K. Zhivotov, O. A. Zinov'ev, G. D. Myl'nikov, V. D. Rusanov, and A. V. Titov, Zh. Eksp. Teor. Fiz. 56, 427 (1969) [Sov. Phys.-JETP 29, 233 (1969)].

[4] I. I. Sobel'man, Vvedenie v teoriyu atomnykh spektrov (Introduction to the Theory of Atomic Spectra), Fizmatgiz, 1963.

Translated by J. G. Adashko