$$(\alpha+\beta)_{\min} = 1 - \Phi\left[u_{\alpha/2} + \lambda\left(1 - \frac{1+u_{\alpha/2}^2}{4f}\right)\right] - \Phi\left[u_{\alpha/2} - \lambda\left(1 - \frac{1+u_{\alpha/2}^2}{4f}\right)\right] + 2\Phi(u_{\alpha/2}), \quad (5)$$

where

$$u_{\alpha/2} = u + \frac{1}{4f}\left[u^3 - u + \lambda(1+u^2)(1-e^{-\lambda^2})^{-1/2}\right],$$

$$u = -\frac{1}{\lambda}\cosh^{-1} e^{1/2\lambda^2}. \quad (6)$$

The last term in (5) equals the optimum value of α.

The upper half of the diagram shows the dependence of α and of $(\alpha+\beta)_{\min}$ on $\lambda = F\sqrt{n}$ and f, while the lower half shows the corresponding values of $t_{1-\alpha/2} = -t_{\alpha/2}$. With the aid of these curves we can determine the minimal value of the probability of first and second kind errors, provided n_+ and n_- are known. This probability is found to be a function of that value of F, which the experimenter undertakes to distinguish from the value F = 0. To the contrary, if a certain value of F is specified along with an upper limit of probable error, it is possible to find the number of observations $n = (\lambda/F)^2$ necessary to establish a deviation of F from 0.

Example: At n = 100 the value F = 0.1 is considered to be present when t > 1.098 and absent when t < 1.098, and the probability of error is 82%; at n = 6400, a value F = 0.1 is rejected when t < 4.087 and the probability of error is 0.018%. Another example: in order to clarify whether an asymmetrical interaction with intensity F = 0.01 exists, and in order to insure that the probability of the erroneous decision is less than 1%, it is necessary to carry out $n = (5.30/0.01)^2 = 280{,}000$ observations. Third example: an experiment yielded $n_+ = 5080$ and $n_- = 4920$; we then obtain t = 1.59 and f = 9998 ≫ 1, from which we conclude that the values F > 0.026 are rejected, and the probability of error in stating the presence of F = 0.02 is 45%, that for the presence of F = 0.002 is 99.0%, and for the absence of F = 0.05 is 1.5%. If, on the other hand, $n_+ = 5200$ and $n_- = 4800$, then t = 3.99 and f = 9998; the values F > 0.078 are rejected, and the probable error in assuming that F = 0.07 is present, is 0.08%, while that of confirming the presence of F = 0.01 is 80%.

The author is grateful to R. M. Ryndin who called his attention to the usefulness of solving this problem.

[1] G. J. Resnikov and G. J. Lieberman, Tables of the Non-central t-distribution, Stanford, 1957.

Translated by J. G. Adashko
223

ENERGY LOST TO RADIATION IN A GAS-DISCHARGE PLASMA

V. D. KIRILLOV

Submitted to JETP editor June 22, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) 37, 1142-1144 (October, 1959)

In all known experiments on the heating of a hydrogen plasma by Joule heat, only a small fraction of this heat serves to raise the plasma temperature.[1] It can be assumed that the energy is either carried away by the heated particles or is radiated. The present investigation was undertaken to clarify this problem.

The measurements were made with a cylindrical porcelain gas-discharge chamber (length L = 70 cm, diameter 22 cm) terminated on each end by copper electrodes 4 cm in diameter. The apparatus was evacuated to 10^{-5} mm mercury. The experiments were carried out at discharge currents of amplitude J_{max} = 13 to 45 kiloamp and half-period approximately 500 μsec. The initial deuterium pressures were 0.01—0.02 mm mercury and the intensity of the longitudinal magnetic field was H = 0 — 24,000 oe.

Under conditions satisfying the Shafranov stability criterion, we observed a plasma column with diameter a ~ 6 cm along the axis of the chamber.[2] We first describe briefly the probe measurements with the ionization chamber,* which have led us to attribute an important role to the radiation losses.

To count the charged particles that reached the wall of the discharge chamber, we used an instrument (Fig. 1) that combined an ordinary plane double probe (with electrodes A and B) and an ionization chamber B. From 20 to 70 volts were applied to the electrodes of the probe. The current in the probe circuit, a measure of the plasma den-

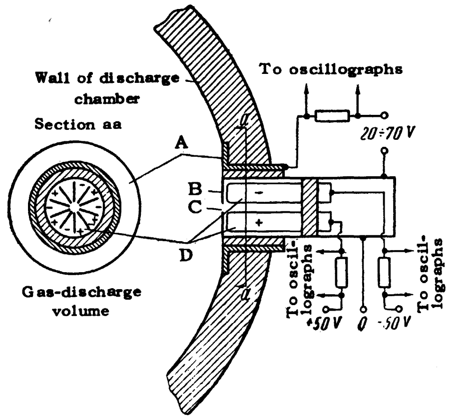

FIG. 1

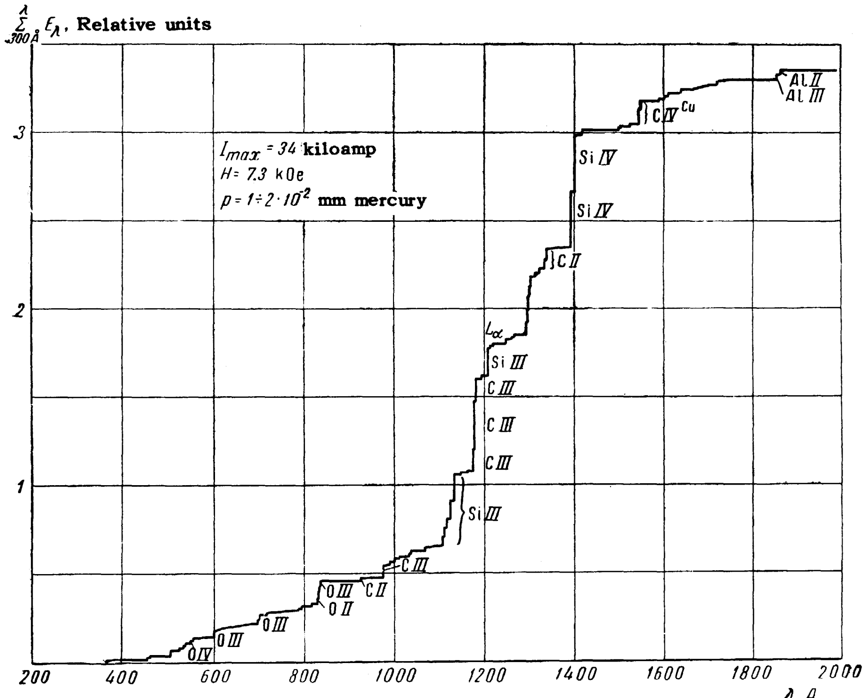

FIG. 2

sity at the wall, was registered with an oscillograph.

The ionization chamber comprised a metal container with a small (a fraction of a millimeter) opening C. The charged particles entered through the opening into the chamber and produced between two oppositely-charged groups of electrodes D a current which was registered by the oscillograph. The voltage between the electrodes (100 volts) was set to produce saturation current. The instrument was placed in the center of the discharge chamber. It was assumed that the current in the ionization chamber was proportional to the flow of the charged particles in the hole and consequently on the wall. Actually, at $H = 0$, when the discharge current flowed at random over the entire cross section of the chamber, good correlation was observed between the signals of the ionization chamber and of the double probe. Under stable conditions (at $H > 4LI_{max}/\pi ca^2$) the double-probe signal was increased by a factor of 10^5, while the current in the saturation chamber dropped only by a factor of 10 — 100. In this case the ionization-chamber current was proportional at each instant of time, in first approximation, to the electric power liberated in the plasma, and was practically independent of the pressure and of the value of H.

Test experiments with filters and diaphragms of complex shapes have demonstrated that under stable conditions the ionization-chamber current is due to photoelectrons emitted by the walls and electrodes of the chamber under the influence of light penetrating from the discharge through the opening. Reduction of the data, based on a reasonable assumption of the quantum yield of the photoeffect (~ 0.02) and of the quantum energies (~ 10 ev) has shown that the light carries away a considerable portion of the energy delivered to the plasma. The assumption that this light was due to ultraviolet radiation by the impurities was corroborated by tentative computations[3] and confirmed by spectrograms plotted with a DFS-6 vacuum spectrograph. The spectrum was registered on photographic film sensitized with sodium salicylate. The spectrum lines were identified and photometrically analyzed, so that the energy E_λ carried by the individual lines was determined in arbitrary units.

Figure 2 is a plot of ΣE_λ in the range from 300 to 2000 A and shows that the greater part of the light energy is contained in the wavelength interval 1100 — 1400 A (photon energy ~ 10 ev). The Lyman lines take a small fraction of the light energy (see table). The predominant portion is emitted by the ionized atoms of the carbon and the chamber wall material (silicon, oxygen, aluminum). The fraction of long-wave radiation ($\lambda > 2500 - 3000$ A) in the total light flux is also small, as found from experiments with a camera obscura, in which the film was placed either with the sensitized emulsion or with the backing side to the light. In the second case the film was not exposed.

The absolute light energy was measured with a thermoluminophor procedure. The thermoluminophor† was placed in a vacuum camera ob-

	Discharge conditions		Ratio
	I_{max} = 13.5 kiloamp, H = 7300 oe, p = 1 – 2 × 10^{-2} mm Hg	I_{max} = 34 kiloamp, H = 7300 oe, p = 1 – 2 × 10^{-2} mm Hg	
Total electric energy delivered to the plasma, kilojoules	2.8	11.9	4.3
Value of $\sum_{300\text{Å}}^{1900\text{Å}} E_\lambda$, arbitrary units	0.7	3.3	4.8
Fraction of light energy taken by the Lyman lines	1/180	1/580	
Fraction of the total energy (%) lost by radiation, based on measurements with thermoluminophor in three positions	65; 105; 65	80; –; 70	

scura at several distances from the small aperture (0.14 mm in diameter) so that various sections of the image of the plasma column were projected† on it. The total energy losses were calculated with allowance for the energy distribution of the radiation and the spectral sensitivity of the thermoluminophor, known only up to λ = 800 A. The data were extrapolated to the shorter wavelengths. The estimated possible error in the determination of the absolute value of the light losses does not exceed 50%. The results of the measurements with the thermoluminophor are listed in the table. The results of all the measurements show that the greater part of the energy delivered to the plasma is lost by radiation from the impurities. In view of this, it is difficult to count on success in heating a deuterium plasma by Joule heat without eliminating the sources of contamination.

The author thanks L. A. Artsimovich and N. A. Yavlinskiĭ for help in the work.

*The construction of the ionization chamber was developed by V. S. Mukhovatov in his diploma project.

†The thermoluminophor, calibrated in absolute energy units, was graciously furnished us by V. A. Arkhangel'skaya and T. K. Razumova, to whom the author expresses his gratitude.

[1] Butt, Carruthers, Mitchell, Pease, Thonemann, Bird, Blears, and Hartill, Second UN Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1958, P/1519.

[2] Golovin, Ivanov, Kirillov, Petrov, Razumova, and Yavlinskiĭ, ibid. P/2226.

[3] V. I. Kogan, Dokl. Akad. Nauk SSSR 128, No. 4, 1959, Soviet Phys.–Doklady, in press.

[4] Arkhangel'skaya, Vaĭnberg, and Razumova, Оптика и спектроскопия (Optics and Spectroscopy) 1, 1018 (1956).

Translated by J. G. Adashko
224

ANTIFERROMAGNETISM IN NiF_2

R. A. ALIKHANOV

Institute of Physical Problems, Academy of Sciences, U.S.S.R.

Submitted to JETP editor June 25, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) 37, 1145-1147 (October, 1959)

THE fluorides of the elements of the iron group (Mn, Fe, Co, and Ni) form an isomorphic series of compounds with a tetragonal lattice. Neutronographic studies of these compounds, conducted by Erickson,[1] show that they all have an antiferromagnetic structure at hydrogen temperatures. In the diffraction picture, at the locations of the reflections having indices (100), (111), (210), and (201), an increase of intensity over that of room temperature was observed. The absence of a (001) reflection for MnF_2, FeF_2, and CoF_2 indicates that the direction of the antiferromagnetic vector coincides with the tetragonal axis of the crystal. For nickel fluoride at 25°K some change of intensity in the region of the (001) reflection is noted. This is manifest by a small increase in the right arm of the (110) peak. On this basis, Erickson proposed a magnetic structure for NiF_2 somewhat different from that of the other fluorides. According to his data the spins are inclined at an angle of 10° from the tetragonal axis. The magnetic structure pro-