X-RAY SPECTRA FROM HIGHLY IONIZED IRON AND NICKEL*

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X-ray radiation is obtained from a point plasma produced by pinch effect Cohen *et al.* (1968) in a vacuum spark similar to that used by Lie and Elton (1971) with a 220 kA peak current. The extremely dense and hot minute plasma appears at a distance of 0.5 to 1 mm from the anode tip and has maximum dimensions of a few microns.

The spectroscopic observations are performed by means of a focusing Cauchois spectrometer so as to avoid effects of fluctuations in the source position.

Spectra between 1 and 2 Å of nearly completely stripped iron (Figure 1) and nickel were obtained. These spectra include optical transitions arising from a $2p$ to $1s$ electron jump in hydrogenic ions (Fe XXVI) and in helium-like ions (Fe XXV and Ni XXVII) as well as satellite lines due to inner-shell transitions in lower ionization stage species from lithium-like down to fluorine-like ions. The plasma radiation is distinguished

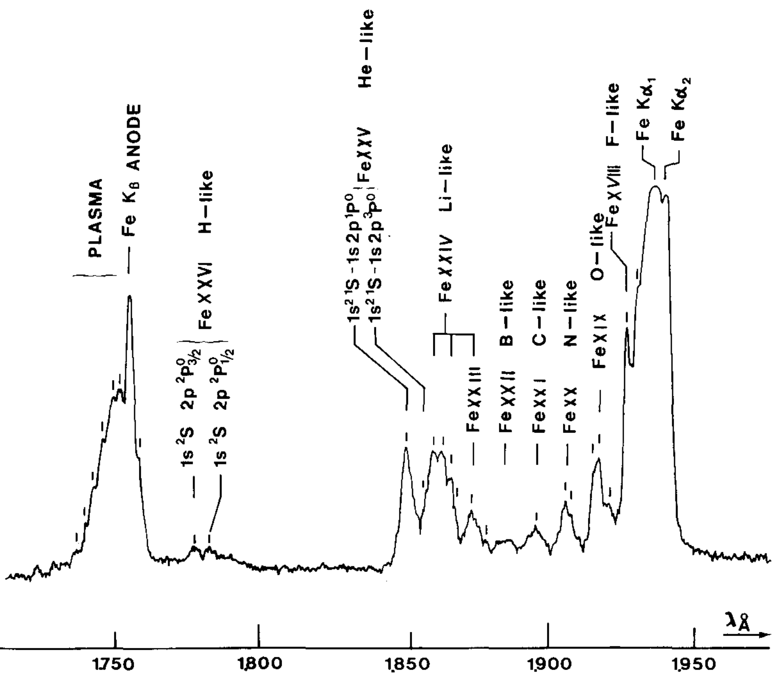

Fig. 1. X-ray spectrum of highly ionized iron.

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from the anode characteristic radiation ($K\alpha_1$, $K\alpha_2$ and $K\beta$) by means of a shadow technique using a tungsten wire placed between the source and the crystal.

The high spectral resolution achieved here, better than 0.3 X-unit, constitutes a substantial improvement relative to the previous observations on solar flares Neupert and Schwartz (1970), and on laboratory plasmas Lie and Elton (1970) concerning the Fe spectrum. This allowed us:

(1) to separate a number of line components;

(2) to identify a new line, attributed to the fluorine-like ion (Fe XVIII and Ni XX) in good agreement with theoretical prediction of House (1969) (this line was masked by the $K\alpha$ anode line in previous experiments Lie and Elton (1970) using a flat crystal);

(3) to discover a satellite feature emitted from the plasma also for the $K\beta$ line; and

(4) finally to verify experimentally by the shadow method a slight shift towards the longer wavelength side of $K\alpha$, as predicted by House (1969), which would be due to Fe VIII–X emission. This feature is not observed for the $K\beta$ line.

The intensity ratio of the hydrogenic ion Ly-αline and the helium-like ion resonant singlet in the case of Fe, would lead in steady state coronal approximation to an electron temperature T_e of about 4 keV. In fact the short time duration of te dense plasma (5×10^{-8} s) does not allow the reaching of a steady state. We therefore have to expect a still higher electron temperature in our transient plasma, the preceding value representing only a lower limit value.

Clearly broad lines such as the helium-like ion singlet are easily distinguishable from lines of lesser width such as the fluorine-like ion line. The instrumental function is determined by ordinary X-ray lines. Thus, assuming thermal Doppler broadening, we obtain an ion temperature of the order of 30 keV.

The results are consistent with the T_e measurement by Lie and Elton (1970) from a continuum radiation method.

References

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DISCUSSION

J. Kistemaker: What is the electron density in your spark?

B. S. Fraenkel: The electron density is of the order 10^{20} cm^{-3}.

F. Saris: First I would like to make a comment. In the field of atomic collisions one is studying X-ray production in ion-atom collisions by firing an ion beam through a gas or a thin film. In these experiments copious X-rays are observed from highly ionized particles. Secondly I would like to ask you to explain the shift towards longer wavelengths of the $K\alpha$ X-ray lines and why does this not occur for the $K\beta$ lines. In the above mentioned experiments one observes a shift to shorter wavelengths of the Fe $K\alpha$ lines (D. Burch *et al.*, *Phys. Rev. Letters* **26** (1971), 1355).

B. S. Fraenkel: This lengthening, for Fe VIII to Fe X, has been predicted by House, in Hartree-Fock calculations. This is only a very small amount, but it could be verified by our spectrograph. It is almost impossible to see this except with high resolution. Experimentally it does not show in the $K\beta$.

G. Mehlman-Balloffet: For such high density plasmas how do you explain such large differences between ionic and electronic temperatures?

J. L. Schwob: The electronic temperature given here is only a minimum value corresponding to a steady state, whereas our conditions are transient. Therefore a higher electronic temperature is to be expected.

H. Conrads: Did you determine the line profile? Is it Gaussian?

J. L. Schwob: We assume a Gaussian profile, we did however not determine it. The ion–ion collision time is extremely short relative to the life-time of the instability.

H. Conrads: Do you have any indication of a motion of the plasma-ball?

J. L. Schwob: None other than the short duration of the unstability before collapsing which is less than 5×10^{-8} s.

H. Conrads: From which direction did you observe the spectra?

J. L. Schwob: Perpendicular to the axis of the electrodes.

J. Kistemaker: What is the size of your plasma?

B. S. Fraenkel: The size is of the order of sphere with diameter of 1 to 3 μ. This can be shown by the pinhole camera photograph, and, specifically by the sharp edge of the image of the instability in the pinch.

H. -J. Kunze: In a rather similar device operating at a charging voltage of 10 kV we measure average electron temperatures of 30 keV using the foil absorption technique.

J. L. Schwob: This value agrees with our conclusions, which gave only a minimum electron temperature for a steady state, while we are in a transient regime, this implying higher temperatures.