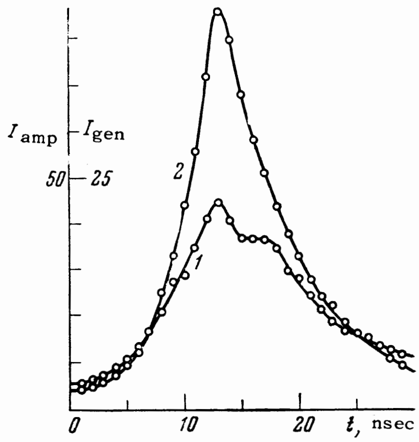

FIG. 2

time the maximum inversion in the crystal occurred.

The laser emits a single pulse having an energy of up to 1.8 joules. The energy was measured with a calorimeter [3]. The pulse shape in a case where the total energy was one joule is shown in Fig. 2, curve 1. The abscissa is marked in nanoseconds and the ordinate in arbitrary power units.

The pulse was detected with a fast photodetector having a time resolution of 1.5 nanoseconds.

The laser pulse was amplified in a laser amplifier. (The amplifier consisted of a crystal with coated end faces and a similar pump source.) At the amplifier output a single pulse was observed having an energy up to 8 joules. The pulse shape for a case in which the total energy was 3.3 joules is is also shown in Fig. 2, curve 2. The pulse shortening and the steepening of the front edge are clearly visible (the position of curves 1 and 2 with respect to each other is arbitrary).

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TURBULENT HEATING OF A PLASMA IN A LINEAR DISCHARGE

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In the course of experiments concerned with the anomalous interaction between plasmoids produced in a system designed for turbulent heating [1] we have observed intense heating of electrons as evidenced by intense x-ray radiation of great hardness emanating from the plasma volume. This effect cannot be attributed to turbulent heating by a magnetohydrodynamic wave since it is observed relatively rarely and has also been observed in control experiments in which the shock-excited circuit that produces the wave was not operated. It has been determined that the intense heating is observed in those cases in which an appreciable part of the energy of one of the injectors is discharged through the plasma along the magnetic field to the other injector. A linear experiment has been set up in which the discharge occurs between the end electrodes of the injectors and the effect is observed to be completely reproducible.

In Fig. 1 we show oscillograms of the longitudinal current obtained with a resistance of 0.1 Ω connected between the injectors. The current first grows aperiodically and then becomes characteristic of a periodic discharge. Intense heating of the plasma electrons is observed in this case. It should be noted that the experimental conditions

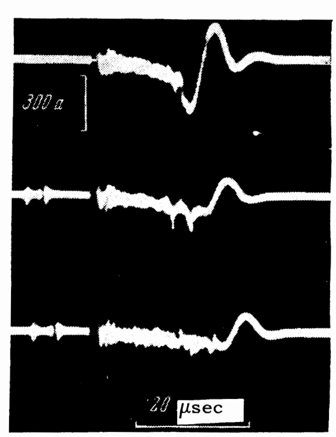

FIG. 1. Oscillograms of the longitudinal current. It is evident from the oscillograms that the heating due to the instability lasts from 14–20 μsec.

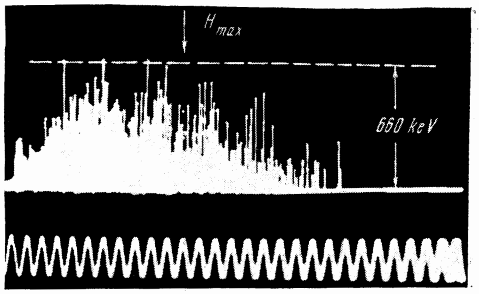

FIG. 2. Oscillograms of the x-ray radiation from a deuterium plasma. The oscillogram was obtained with an NaI(Tl) scintillation counter. The arrow indicates the peak magnetic field. Calibration of the photon energy was accomplished by means of a Cs^{137} source with a photon energy of 660 keV. The period of the calibration signal is 0.1 msec.

reported here are very different from the usual conditions in linear discharges [2,3] and are closer to those that obtain in the work of Fanchenko et al.[4] In the present experiments the current flows through a fully ionized plasma with a density of approximately 10^{12} cm^{-3} produced by the plasma injectors. It is also important to note that the magnetic field is a mirror system in which hot particles can be trapped.

In Fig. 2 we show an oscillogram of the x-ray radiation from the plasma which is adiabatically compressed by a factor of 25 after current heating. The magnetic field is 350 Oe when the injectors and the linear discharge are triggered. The field at maximum compression is 9×10^3 Oe. Using oscillograms of this kind we have obtained the spectral distribution of the electron bremsstrahlung as a function of energy. This distribution is given in Fig. 3 on a semilogarithmic scale for the time interval 600—1200 μsec. The slope of the line corresponds to an electron temperature of approximately 200 keV. The compression factor for this time interval is approximately 15. The bremsstrahlung intensity can be used to estimate an upper limit for the plasma density $n < 2\text{-}5 \times 10^{12}$ cm^{-3} at peak compression. Microwave transmission measurements at $\lambda = 3$ cm indicate

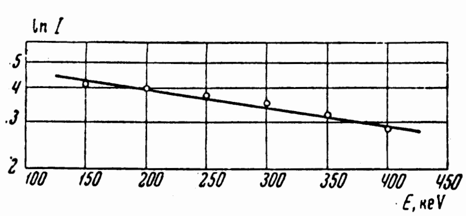

FIG. 3. Spectral distribution of the bremsstrahlung from a deuterium plasma plotted on a semi-logarithmic scale. The slope of the line corresponds to an electron temperature of 190 keV.

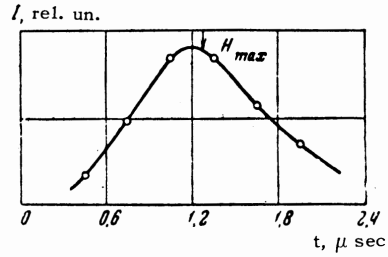

FIG. 4. Neutron yield from a deuterium plasma. The curve is plotted from data taken from oscillograms obtained with the neutron counter. The arrow indicates the peak magnetic field.

that the plasma density is greater than 10^{12} cm^{-3} during compression.

In these experiments we have observed neutrons in addition to bremsstrahlung; the neutron yield is approximately 10^5 per pulse. The neutrons are detected in a 14-liter plastic scintillator (control experiments show that slow neutrons are not recorded by the counter). The neutron yield from a deuterium plasma is shown as a function of time in Fig. 4. In this case the plasma injection and heating occur at a field of 1800 Oe while the heated plasma is compressed by a factor of 5. The diameter of the experimental chamber is 150 mm. Assume that the ions have a Maxwellian velocity distribution cut off at the energy at which the ion Larmor radius becomes greater than the chamber radius; if the ion temperature is estimated from the neutron yield at peak compression we find an ion temperature of approximately 3 keV when $n \approx 5 \times 10^{12}$ cm^{-3}. The time dependence of the neutron yield and bremsstrahlung indicates stable plasma confinement for approximately 2 msec.

The heating of the electrons and ions observed in these experiments and the oscillograms in Fig. 1 can be explained by an instability produced by current flow in the plasma.[2,5] Theory predicts that the current in the plasma is unstable if the streaming velocity of the electrons is greater than the electron thermal velocity $c_s \sim \sqrt{T_e/M}$. The electrons are retarded and excite plasma oscillations. The retardation length λ is given approximately by

$$u / \gamma = (u / \omega_p)(M / m)^{1/3},$$

where γ is the maximum growth rate for the instability and $\omega_p = \sqrt{3 \times 10^9 n}$ is the plasma frequency. This length is small compared with the distance between the electrodes of the injectors $l \sim 10^2$ cm. Actually, the energy of the streaming motion of the electrons cannot exceed the voltage drop between the injectors V. In these experiments $V \sim 10$ keV and consequently $u < 3 \times 10^9$ cm/sec and $\lambda \lesssim 3 \times 10^9 \times 10/\sqrt{3 \times 10^9 n} < l$ if $n \gtrsim 10^8$. Hence we can introduce an effective conductivity $\sigma = e^2 n\lambda/mu \approx \omega_p$ and write Ohm's Law

$$I = V / R_{\text{eff}}, \quad R_{\text{eff}} = l \cdot 10^{12} / \sqrt{3 \cdot 10^9\, nS}$$

(the cross section of the pinch $S \approx 50$ cm^2).

The resistance derived in this way is of the same order as the experimental value of R. Consider Fig. 1. At the transition to the oscillatory regime the current is approximately 200-300 A so that R = 30-50 Ω. If it is assumed that the density at this time is 10^{12} cm^{-3} then $R_{\text{eff}} \approx 30$ Ω. The qualitative nature of the curve can be explaned as follows: The trap is filled by plasma in 10-15 μsec. During this time interval the current increases because the resistance R_{eff} is being reduced. As the density increases the streaming velocity $u \sim n^{-1/2}$ is reduced. At some value of n the velocity u becomes smaller than the critical value, the instability is quenched, and the anomalous resistance disappears. This instant of time may be related to the onset of the periodic discharge.

The ion heating can arise as a result of an instability due to opposed ion streams or as a result of Landau damping of the oscillations excited by the electron current.

Thus, in these experiments we have observed an anomalously high resistance and intense electron heating in the plasma in a linear discharge that takes place along the magnetic field in the "probkotron." This effect in conjunction with adiabatic compression results in a plasma characterized by a density greater than 10^{12} cm^{-3}, an electron temperature of approximately 200 keV and an ion temperature of approximately 3 keV. Plasmas of this kind have been confined in the probkotron for the entire lifetime of the magnetic field, which is approximately 2 msec.

In conclusion the authors wish to thank A. I. Gorlanov for his help in the experiments.

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SPECTRAL DISTRIBUTION OF THE EFFECT OF QUENCHING OF THE RECOMBINATION RADIATION OF GERMANIUM BY INFRARED LIGHT

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In an earlier paper [1], we reported the quenching of the recombination radiation of germanium by the illumination of the sample with spectrally unresolved infrared light. The present note reports the preliminary results of a study of the spectral distribution of this effect.

Ge disks, of about 10 mm diameter and from 4 mm to 50 μ thick, were placed in a special holder. Minority carriers were injected by illumination with white light from an incandescent lamp, the light having been passed first through a water filter 100 mm thick so that only the wavelengths $\lambda < 1\,\mu$ reached the sample. This light was modulated at 117 cps by means of a rotating disk with apertures. The same surface of the sample could be illuminated with unmodulated monochromatic infrared radiation coming from a monochromator. A PbS photoresistor, placed next to the unilluminated side of the sample, served as the receiver of the recombination radiation. The signal from the PbS was fed to a measuring circuit, consisting of a resonance amplifier, a synchronous detector and an automatic recorder.

The germanium sample, together with the PbS receiver, was placed in a metal Dewar with KBr windows and cooled with liquid nitrogen.

The integral intensity of the recombination radiation was measured with and without the additional illumination of the sample by means of infrared light. Some of the infrared light reached the PbS receiver after passing through the sample. Because of this, the working point of the photoresistor characteristic shifted, which in turn altered the magnitude of the signal generated by the recombination radiation being measured.