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AUG 18 1999

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Presented at:

VIII International Conference on Megagauss Magnetic Field
Generation and Related Topics
Tallahassee Florida
October 18-23, 1998

To be submitted to:

Los Alamos
National Laboratory

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Isentropic Compression of Argon and Krypton Using an MC1 Flux Compression Generator

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Abstract

LANL and VNIIEF are performing a set of joint experiments to explore the conductivity and possible metalization of argon and krypton compressed to up to five times normal solid density. The experiments use a magnetic field of several megagauss, generated by a Russian MC1 generator¹, to compress a metallic tube containing solidified argon or krypton. A probe in the center of the tube measures the electrical conductivity to the walls, and a 70-MeV betatron serves as an x-ray source for three radiographic measurements of the compression. Several of these experiments for argon compressed to around 4 to 5 times solid density indicate a conductivity in the range of 10 to 100 $\Omega^{-1} \text{ cm}^{-1}$, well below that of a metal. For krypton preliminary results show a conductivity of order 1000 or more, indicating likely metalization of the compressed sample.

Experiment

We are studying argon and krypton under isentropic compression sufficient to cause them to become electrically conductive. The noble gases undergo phase transformations at high compression, but at the pressures of interest here they remain monatomic; thus molecular structure does not complicate the interpretation. As the density increases, the band gap becomes smaller, and as it becomes comparable with kT , electrons are increasingly able to move through the sample. In this experiment we measure the bulk conductivity of the sample, simultaneously radiographing it to determine its density near peak compression.

The experiment has been described previously² and is shown schematically in Fig. 1. Briefly, liquid nitrogen freezes a sample of argon or krypton inside a

Figure 1. Schematic of the isentropic compression experiment.

conducting tube on the axis of an MC1 flux compression generator. An axial magnetic seed field is compressed, reaching about 5 MGauss, compressing the tube and the sample to about half their original diameter. (Smaller seed fields give higher compression because the implosion is faster.) A probe on the axis of the sample sends current from a small capacitor bank through the sample to the tube walls, while in parallel the current flows through a 1- Ω reference resistor. The sample and probe are shown in Fig. 2. As the sample becomes conductive, the voltage across the resistor drops, giving a measurement of the sample conductivity. Details of the conductivity measurement will be published elsewhere.³ Three x-ray pulses from a 70-MeV betatron traverse the sample radially at times near minimum sample volume. A thin crystal converts the transmitted x-rays to visible light, and a streak camera records the images to determine the size at the x-ray pulse times. Hydrodynamic calculations determine most of the density information, and the three x-ray images, as well as data from a film pack, provide calibration points for the calculations.

Results

We ran several series of MC1 shots at the betatron to develop the techniques and collect data. One series included a Kr-Ar pair of 5-Mbar shots in the fall of 1997, several shots with completely insulated probes to study the insulators in the summer of 1998, and a series of 4 Mbar experiments in the fall of 1998. In addition, argon conductivity was measured a number of times earlier. In 1996 we did a series at higher compressions, but since we are not sure that there were not shocks during the implosions, those data are not reported here. After the 1997 these shots we spent some effort cleaning up the electrical noise on the conductivity signals and we improved the electronic imaging. We have just begun analysis on the most recent data, taken this past August, and the 1997 data required considerable data analysis and corrections. As this analysis is not yet completely finished, this paper is a progress report on our experiment.

Figure 2. Sample tube and conductivity probe.

Table I shows a summary of the data, other than the insulator studies. The conductivity data marked ‡ are preliminary data and not yet fully analyzed. Conductivity data marked * were taken with a tungsten probe in a ceramic sleeve. The tungsten was ground to a fine tip, about 12 μm diam, and ceramic adhesive filled the region around the tip. Subsequently we determined that the adhesive was considerably less insulating than the ceramic tubing, causing an error in the probe calibration factor, which increases the apparent value of the measured conductivity. This problem has not yet been resolved, and these values should be considered upper limits.

The results for argon at compressions between 4 and 5 times normal solid density indicate a conductivity of order 10 to 100. This has been explained as resulting from compressions that do not quite completely close the band gap,⁴ thus allowing electrons to "hop" from one atom to the next. For krypton, however, the conductivity is considerably larger. At 5 times solid density the conductivity appears to be 1000 or more. When compressed 4 times, the sample is apparently on the verge of becoming conductive, as one of two such experiments gave a conductivity of about 1000 while the other was around 10.

Table I. Summary of the isentropic compression shots.

Shot Name	Sample Material	Initial Field (kGauss)	Maximum Compression	Conductivity ($\Omega\text{ cm}$) ⁻¹
010895	Ar	160	4.9	8
020895	Ar	160	4.4	8
281097	Ar	143	4.3	170*
120898	Ar	165	3.9?	5‡
031197	Kr	142	4.1	8,000*
070898	Kr	168	3.9?	1,100‡
110898	Kr	168	3.9?	5‡

* Upper limit, analysis in progress.

‡ Approximate numbers, analysis in progress

The krypton data are still under analysis, but they may indicate a disordered (melted) sample with conductivity similar to a melted metal.

Figure 3. Conductivity voltage data for argon and krypton v. time in microseconds. The voltage is measured across a reference resistor in parallel with the sample. The drops in signals around 100 μ s indicate shunting of current through the samples at conductivity onset. When the samples decompress the voltage returns to its previous value. The ringing noise seen here was improved in later experiments. Krypton partially recompresses at 118 μ s.

References.

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