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ELECTRICAL RESISTIVITY MEASUREMENTS OF A DENSE ALUMINUM PLASMA

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ABSTRACT

In this paper we report results of experiments to measure the electrical resistivity for a dense strongly coupled aluminum plasma. These plasmas cover the density and temperature range from near solid density and room temperature to .03x solid and 40 eV. These conditions give values of $\Gamma = 5-6$. Our results indicate the resistivity is higher in this regime than most theories. Only the results of some density functional calculations give results consistent with the data.

1. Introduction

The electrical resistivity of a strongly coupled plasma is a subject which has been investigated by theoreticians over the years¹⁻⁶. There have also been a few experiments done to measure the resistivity for strongly coupled plasmas⁷⁻⁹, but in general these have been done for densities much less than solid density. We are attempting here to extend the region of experimental investigation to ion densities near solid density and to compare our results to various theoretical predictions.

We have completed a set of experiments to investigate the electrical resistivity of a dense strongly coupled aluminum plasma. We use an exploding wire technique where the wire is tamped by lead glass, an insulator, which limits its expansion to a subsonic rate. By measuring the current, voltage, size, and rate of expansion we can determine the resistivity of the plasma.

2. Description of the Experiment

This experiment is very similar to previous experiments on which we have reported¹⁰. The experimental setup is described in detail there and here we will briefly summarize our procedure and note differences from the previous experiment. We create a strongly coupled plasma by passing 200 kA of electric current through a 100 micron diameter wire encapsulated by lead glass. This lead glass tamper is the major difference from our previous work and this produces a higher density and temperature plasma due to the stronger tamping than quartz glass. The plasma conditions produced are densities initially at 6×10^{22} ions/cm³ at about 1 eV and dropping to densities of 1.8×10^{21} ions/cm³ at temperatures of 35-40 eV.

To determine the electrical resistivity, we must measure the current, voltage, and size of the conducting plasma. We use a Rogowski coil to measure the current and a

capacitive voltage probe, correcting for the inductance of the load. This allows us to determine the resistance of the plasma. The diameter of the plasma is measured using an x-ray framing camera. The camera we use is described in more detail elsewhere¹¹ but in general it can take temporally and spatially resolved images at different x-ray energies. The size of the channel is determined from the images obtained and the magnification. Attempts were made to determine the plasma temperature using these measurements, but due to the high density plasma which flows into the vacuum region we were unable to determine the temperature at the source.

We also use a visible framing camera to image the shock that is produced in the lead glass from the aluminum plasma. The position of the shock front provides a useful comparison to the simulations and assists in the validation of these simulations and therefore our determination of the properties of the aluminum plasma.

3. Results

Figure 1 shows a plot of the position of the shock front as a function of time. The individual points represent data from several shots and the curves are from two different simulations. The dashed line is from a simulation using the electrical resistivity developed by Rinker⁵, while the straight line assumes the resistivity for the aluminum is some factor times the Rinker value. This factor is time dependent and peaks at a value of 2 at 100 ns into the current pulse. Both these simulations overestimate the shock radius at late times, which we interpret as overestimating the pressure in the plasma. Though the simulation based on the Rinker resistivity does better here, it underestimates the energy deposited into the load. The time dependent multiplier better matches the energy input into the plasma, yet clearly seems to overestimate the pressure. This is likely due to a problem in the equation of state model for aluminum in this range.

Figure 1. Position of the shock front in the lead glass. (--- Simulation using Rinker resistivity. — Simulation using the time dependent multiplier times Rinker resistivity.)

The measurements of the radiation emitted from the end of the plasma using the x-ray framing camera were useful in measuring the radius of the plasma, but could not be used for determining the temperature. This was because of the high density plasma flowing into the viewing region and absorbing radiation from the tamped aluminum plasma. Attempts to simulate and measure the properties of this expanding plume proved unsuccessful. We therefore had to rely on simulations to estimate the temperature of the aluminum plasma. These simulations were checked for a sensitivity to the equation of state model used and compared to the data.

The highest energy channel on the x-ray camera was used to measure the radius of the conducting channel. The results from those measurements and a comparison of the data to the predictions of the simulations is shown in figure 2. Here we see again that at early times the simulation does well, but by the later times the measured radius is smaller than that predicted. This again is consistent with the shock data and indicates that the equation of state models are overestimating the pressure for the plasma.

Figure 2. Radius of the plasma discharge versus time. (- - - Simulation using Rinker resistivity.
 — Simulation using time dependent multiplier times Rinker resistivity.)

We use these results to compare the resistivities determined from the experiment to theoretical predictions. By using the densities and temperatures from the simulation, we can calculate the resistivity for aluminum for a few different theoretical models. The results are shown in figure 3. Here we see that the resistivity predicted by the time dependent factor multiplying Rinker's values does a reasonable job of reproducing the data. Without this multiplicative factor the Rinker values are below the data. We can do the same for the model developed by Lee and More⁴ and although this model has a similar shape to the data, it still is consistently low. The only model we find that is within error bars of the data is the density functional model of Perrot⁶. This also appears too low for the peak resistivity value but is too high at late times. In this graph we show error bars both for the data and for some of the theoretical calculations. This is to indicate the temperatures we are using to determine the resistivity predicted by these models is

uncertain. We estimated this error bar based on an uncertainty of 20% in the temperature.

Figure 3. Electrical resistivity of the plasma versus time. (— Data, ···· Time-dependent factor times Rinker, ---- Rinker, - · - · Perrot, - - - - Lee and More.)

4. Conclusions

We have carried out an experiment to measure the electrical resistivity for a dense strongly coupled aluminum plasma. The results of these experiments indicate that most theories underestimate the resistivity in this range and only calculations using the density functional theory of Perrot and Dharma-Wardana is consistent with the data.

5. Acknowledgements

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6. References:

1. D.B.Boercker, F.J.Rogers, and H.E.DeWitt, *Phys.Rev. A* **25**, (1982) 1623.
2. R.Cauble and W.Rozmus, *J.Plasma Phys.* **37**, (1987) 405.
3. H.Kitamura and S.Ichimar, *Phys.Rev. E* **51**, (1995) 6004.
4. Y.T.Lee and R.M.More, *Phys.Fluids* **27**, (1984) 1273.
5. G.A.Rinker, *Phys.Rev. A* **37**, (1988) 1284.
6. F.Perrot and M.W.C.Dharma-Wardana, *Phys.Rev. A* **36**, (1987) 238.
7. Y.V.Ivanov, V.B.Mintsev, V.E.Fortov, and A.N.Dremin, *Zh.Eksp.Teor.Fiz.* **71**, (1971) 216 [*Sov.Phys.JETP* **44**, (1974) 112].
8. I.M.Isakov, A.A.Likal'ter, B.N.Lomakin, A.D.L Opatin, and V.E.Fortov, *Zh.Eksp.Teor.Fiz.* **87**, (1984) 832 [*Sov.Phys.JETP* **60**, (1984) 473].
9. J.F.Benage,Jr., W.R.Shanahan, E.G.Sherwood, L.A.Jones, and R.J.Trainor, *Phys.Rev. E* **49**, (1994) 4391.
10. J.F.Benage,Jr. and W.R.Shanahan, in *Strongly Coupled Plasma Physics*, eds. H.M.Van Horn and S.Ichimar (Univ. of Rochester Press, Rochester, N.Y.,1993).
11. J.F.Benage,Jr., E.G.Sherwood, and S.E.Linzey, *Rev.Sci.Instr.* **63** (1992) 5049.