2-1-1996

Response to "Comment on 'A paradox involving the second law of thermodynamics' " [Phys. Plasmas 2, 1893 (1995)]

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(Received 21 August 1995; accepted 24 October 1995)

[S1070-664X(96)01602-1]

Jones offers two comments on the experiments simulating a second law paradox.[1] Briefly, the paradox rests on the ability of small, ''non-perturbing,'' self-emissive probe immersed in a plasma to float electrically at a potential different than that of the electrically grounded blackbody walls which enclose the plasma. The potential difference is exploited to do work at the expense of the heat bath, in apparent violation of the second law. In his Comment, Jones addresses the experiment only—the theoretical underpinnings are not considered—in particular, he raises more explicitly some nonidealities alluded to in the article (Ref. 1, p. 1898), suggesting them as possible sources of the experimental currents and voltages. He suggests that possibly: (1) the probe/plasma/diagnostic circuit operates as a thermocouple; or (2) the influx of cold atoms into the cavity deposit (unequal) charges on surfaces.

In response to possibility (1), there does not seem to be an obvious *a priori* reason why the probe/plasma/wall system should constitute a thermocouple, nor why inclusion of a cold diagnostic circuit into the loop (if it is properly anchored to a thermal reservoir, as it was in the experiment) should give rise to spurious voltage readings. In fact, care was taken to avoid unnecessary solid state thermoelectric effects and to make account of one that did arise. Ideally, one would wish the entire experiment—cavity, probe, vacuum vessel, diagnostic circuit, experimenter, and laboratory—to reside at the same high temperature so that thermoelectric voltages and currents could be eliminated. This was impractical. Instead, probe, cavity, and diagnostic circuit were designed to minimize these effects. For example, in Experiment 7 the probe, load resistor, cavity walls, diagnostic, and grounding wires from the cavity to the diagnostic's thermal reservoir were all composed of tantalum. By symmetry, one would expect little or no thermoelectric potential to develop between probe and walls, yet still sizable potentials ($\geqslant 700$ mV) were observed. Several other aspects of the probe-wall potential, V_{pw}, were inconsistent with interpretation as solid-state thermoelectric effects, but each can be explained via plasma effects. First, V_{pw} displayed rapid and very nonlinear magnitude changes. For example, the -260 mW potential change discussed in Experiment 7 (interval $B \rightarrow C$ in Fig. 4) developed over a temperature variation of 200 K; such a rapid, nonlinear excursion over such a small temperature change is difficult to interpret as a thermoelectric effect, but it can be explained well as the onset of Richardson emission and plasma production. Second, V_{pw} could be quickly changed with virtually no change in cavity temperature merely by introducing atomic potassium (interval $D \rightarrow E$ in Fig. 4). While this can be explained easily due to changes in plasma density, it is more difficult to explain as a thermoelectric effect. Third, the V_{pw} versus temperature curves show systematic changes over several thermal cyclings which are often seen when plasma systems are baked out; these are difficult to explain as thermoelectric effects since they should be more reproducible. Fourth, similar V_{pw} versus temperature curves were observed regardless of the elemental composition of the probe, probe leads, or load resistor; one might have expected more variation if thermoelectric effects were dominant. For example, in Experiment 9 four metal probes with very different work functions were simultaneously heated in a single tantalum cavity and displayed comparable voltages, V_{pw}. In all, the magnitudes, temporal variations, and other parametric dependencies of the probe-wall potentials are difficult to explain as thermoelectric effects, but are consistent with plasma effects.

Jones' suggestion, however, is well-taken: a fully equithermal experiment would be more convincing than the ones performed. This might involve optical, rather than electrical, diagnostics or perhaps simply a very low-power, high-temperature motor inside the cavity.

In response to comment (2), the temperature of the cavity atoms seems irrelevant to the operation of the paradox so long as the probe and walls are composed of the same material.

[1]D. P. Sheehan, Phys. Plasmas **2**, 1893 (1995).

 1070-664X/96/3(2)/706/1/$10.00