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COMMENT ON
ENERGY DEPOSITION IN LASER-HEATED PLASMAS

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ABSTRACT

A simple connection between the x-ray spectrum and the number and energy distribution of suprathermal electrons in laser-heated plasmas has been suggested by Brueckner. This relation is shown to depend sensitively on an inaccurate approximation to an integral occurring in the model.

Brueckner¹ has calculated the number and energy distribution of suprathermal electrons produced in laser-heated plasmas using only the experimental x-ray spectrum. His derivation is, however, in error and his formulae should not be applied. In particular, conclusions to be drawn from his analysis applied to experimental examples are inconsistent with a correct analysis.

We begin with Eq. (5) of Ref. 1 (which is based on the unstated assumption that the collisional drag uniformly dominates the other energy losses),

$$\frac{d\epsilon_{\text{rad}}}{d(h\nu)} = \frac{2}{3\pi} \frac{e^2}{\hbar c} \frac{\langle Z^2 \rangle}{mc^2 \langle Z \rangle} \int_{h\nu}^{\epsilon_0} \frac{\ln \lambda_{\text{rad}} d\epsilon}{\ln \lambda_{\text{coll}}},$$

where

$$\lambda_{\text{coll}} = (3/2e^3)(\theta^3/\pi n_e)^{1/2}, \text{ and}$$

$$\lambda_{\text{rad}} = \frac{\epsilon^{1/2} + (\epsilon - h\nu)^{1/2}}{\epsilon^{1/2} - (\epsilon - h\nu)^{1/2}}.$$

At this point it was argued that $\ln \lambda_{\text{coll}}$ and $\ln \lambda_{\text{rad}}$ are slowly varying functions. The approximation of $\ln \lambda_{\text{rad}}$ by a constant, 2.0, is insufficient. It

varies from zero to infinity over the range of integration, as $h\nu/\epsilon_0$ goes to zero. Also, the evaluation of $\ln \lambda_{\text{coll}}$ was numerically incorrect; it should have been 13.1 rather than 7.85 at 10 keV and $10^{21}/\text{cm}^3$.

Actually the indicated integration may be performed analytically. We have from Ref. 1:

$$\frac{d\epsilon_{\text{rad}}}{d(h\nu)} = \frac{\lambda_z}{mc^2} \cdot \frac{1}{2} \int_{h\nu}^{\epsilon_0} \ln \frac{\epsilon^{1/2} + (\epsilon - h\nu)^{1/2}}{\epsilon^{1/2} - (\epsilon - h\nu)^{1/2}} d\epsilon,$$

$$\text{where } \lambda_z = \frac{4}{3\pi} \frac{e^2}{\hbar c} \frac{\langle Z^2 \rangle}{\langle Z \rangle} \frac{1}{\ln \lambda_{\text{coll}}}.$$

Here we have only to change variables to $x^2 = (1 - h\nu/\epsilon)$ and to integrate by parts to obtain

$$\frac{d\epsilon_{\text{rad}}}{d(h\nu)} = \frac{\lambda_z}{mc^2} \cdot \frac{1}{2} \cdot$$

$$\left[\left(\epsilon_0 - \frac{h\nu}{2} \right) \ln \left[\frac{1 + (1 - \frac{h\nu}{\epsilon_0})^{1/2}}{1 - (1 - \frac{h\nu}{\epsilon_0})^{1/2}} \right] - \epsilon_0 (1 - \frac{h\nu}{\epsilon_0})^{1/2} \right]$$

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which replaces equation (6) of Ref. 1:

$$\frac{d\epsilon_{\text{rad}}}{d(h\nu)} = \frac{\lambda_z}{mc^2} \cdot \left[(\epsilon_0 - h\nu) \right] .$$

We also note that in the limit of low energy, $h\nu \rightarrow 0$, our result diverges (in the infrared catastrophe) while the original equation (6) is finite. In the limit of high energy, $h\nu \rightarrow \epsilon_0$, our result becomes

$$\lim_{h\nu \rightarrow \epsilon_0} \frac{d\epsilon_{\text{rad}}}{d(h\nu)} = \frac{\lambda_z}{mc^2} \frac{2\epsilon_0}{3} \left(1 - \frac{h\nu}{\epsilon_0}\right)^{3/2} ; \text{ that is, it}$$

goes to zero faster than the original result. Thus, the approximation in Ref. 1. is never a good functional form although it may coincidentally give reasonable numerical values for certain arguments. Not being a good functional form, it should not be differentiated. With our result substituted into equation (7) of Ref. 1, the resulting

$$\frac{dE_{\text{rad}}}{d(h\nu)} = \int_{h\nu}^{\infty} n(\epsilon_0) \frac{d\epsilon_{\text{rad}}}{d(h\nu)} d\epsilon_0$$

cannot be differentiated to obtain the results reported in Eqs. (9), (10), and (11). That such simple (non-integral) formulae may be derived is a consequence of the special kernel in Eq. (8) of Ref. 1. In particular, the number of fast electrons and their energy cannot be simply obtained from the experimental x-ray spectrum as stated in Ref. 1. The correct inversion to $n(\epsilon_0)$ from experimental $dE_{\text{rad}}/d(h\nu)$ is not obvious and probably needs to be done with trial-and-error numerical integration. In any case, the values of N_{fast} and E_{fast} obtained through Eqs. (10) and (11) of Ref. 1 should not be used.

REFERENCES

1. K. A. Brueckner, Phys. Rev. Lett. 36, 677 (1976).