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INFLUENCE OF STRONGLY FLUX-LIMITED ELECTRON THERMAL CONDUCTION ON BURN OF LASER IMPLODED DT SPHERES

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INTRODUCTION

Electron thermal conduction plays an important role in the dynamics of laser-imploded fusion material. The laser energy is being absorbed in a small region near the critical surface, where the plasma frequency equals the laser frequency. From there the energy has to be spread over the whole ablation region and, also, has to be transported to the interior of the target by thermal conduction. By comparison of plane target experiments with one-dimensional hydrodynamic calculations, it has recently been found [1] that the electron thermal conduction could have anomalously low values due to some microturbulence or due to internally generated magnetic fields. If these low values, particular to plane targets, should also be found in spherically symmetric implosions of DT spheres, the laser approach to fusion would be threatened. Calculations performed at Culham [2] and Los Alamos [3] show, in fact, that the energy gain from DT implosions decreases strongly with decreasing electron thermal flux.

It is the purpuse of this Letter to point out another, however related, detrimental effect of decreasing thermal flux. It will be shown by numerical calculations using MEDUSA, a one-dimensional Lagrangian hydrodynamics code built at Culham [4], that low thermal conductivity makes it difficult to tune the laser pulse: the region of pulse parameters leading to positive energy gain shrinks seriously with decreasing thermal conductivity.

PHYSICS MODEL

In the numerical calculations the electron thermal flux, F, is usually taken as [1]

$$\begin{aligned} F &= (F_c^{-1} + F_L^{-1})^{-1} , \\ F_c &= - K_c \nabla T_e \\ F_L &= f n_e k T_e (k T_e/m_e)^{\frac{1}{2}} \end{aligned} \tag{1}$$

where F_c is the classical thermal flux, determined by the conductivity, K_c, and F_L the free streaming limit. The electron density, mass and temperature are denoted by n_e, m_e and T_e, respectively. f is a dimensionless number, which should be of order one, if anomalous microeffects are absent. However, Malone et al. [1] find f values as small as $0.03 \leqslant f \leqslant 0.1$. The microeffect responsible for this anomaly is certainly radius dependant, so f, in fact, is also radius dependant. We ignore this radial dependance. And since we ignore the nature of the microeffect, we have no possibility to make a model for this dependance. We therefore assume f to be constant over the whole sphere.

The calculations presented here all use CO_2 laser light with a pulse of the form [5]

$$\dot{E}(t) = \begin{cases} \dot{E}_o (1 - t/\tau)^{-p} & , E \leq E_{in}, \\ o & , E > E_{in}, \end{cases}$$

where $\dot{E}(t) = dE/dt$ is the power at time t. $\dot{E}_o$, τ, p and E_{in} are the free parameters, which for optimal burn have to be adjusted to the pellet size and to the physical model.

MEDUSA may be used with ideal gas equations of state for both electrons and ions, but it also offers the possibility of including electron degeneracy effects. Since the calculation times are substantially increased by including electron degeneracy, it is interesting to know, whether the omission of the degeneracy would affect the general features of the problem to be solved. In order to investigate this point, the energy gain, Y, from a 60 μgr pellet has been calculated versus $\dot{E}_o$, the initial power of the laser pulse, for three different physical models, Fig. 1. In model a and b ideal electrons have been taken, but the initial gas temperatures have been chosen different by a factor 10, whereas model c allows for electron degeneracy. Model c has the same initial temperature as model b. The other parameters have been chosen to be E_{in} = 50 kJ, $\tau = 2 \cdot 10^{-8}$ sec, p = 2 and f = ∞. The yield, Y, is decreasing by a factor 2, when the initial temperatures are increased from 10^3 °K to 10^4 °K. On the other hand, the optimal power, $\dot{E}_o^*$, increases by a factor 2, when allowance is made for electron degeneracy.

Since the effect of electron degeneracy is of the same order as that induced by uncertainties such as the initial temperature, the initial ionization or the radial dependance of f, it is sufficient to use an ideal electron model. We assume that the general features of the problem to be solved are unaffected by small parameter changes within the range of the above mentioned uncertainties. We accept thereby errors in the numerical values of calculated quantities.

RESULTS

For the study of the flux limit effects we have chosen a 60 μgr pellet with 10^3 ^oK initial temperature. In Fig. 2 results similar to those obtained at Culham and Los Alamos are presented. Cases of more stringent flux limit, however, are considered here. The dependance of the "partially optimized" input energy E_{in}^* and the yield Y is shown versus 1/f. E_{in}^* has been only partially optimized in order to spare computer time. p = 2 has been used for all points except the last one, 1/f = 30, where a full optimization has been made. The values of $\dot{E}_o^*$ and τ, characterizing the laser pulse used, are also shown in Fig. 2. The yield drops rapidly with increasing 1/f and the necessary input energy increases by an order of magnitude in the parameter region considered. The last point, 1/f = 30, has been found only after a series of runs, where the density in the pellet center has been optimized. From Fig. 3 it becomes clear, why this last point has been difficult to find. In this figure the yield is shown versus the laser pulse parameter p for an input energy $E_{in} = 1.25\ E_{in}^*$. Not only does the yield decrease with decreasing heat flux [2,3], but the parameter range for positive energy balance also shrinks appreciably. For the lowest value, f = .03, advanced by Malone et al. [1], the parameter range is 7 times narrower as for f = .3, a value close to that commonly taken. Higher input energy does not remedy this problem. The range stays as narrow as it is even for three times higher input energy.

Therefore the tuning of the laser pulse becomes more critical with decreasing thermal conduction. So the experimental probability for good shots is reduced. This fact has to be taken into account in efficiency considerations. It will, however, not endanger the proof of feasability, because a sufficient number of shots should always contain some good ones.

To conclude, we may say that an anomalously stringent flux limit may threaten the success of the laser fusion approach even more than previously thought [2,3]. The question is now, whether such a stringent flux limit, seen in plane target experiments, is to be expected in spherically symmetric implosions as well. The answer is not clear as long as the micro-effect responsible for the stringent flux limit is not known. If it is due to internal magnetic fields, the effect should be much more important in plane targets than in spherical implosions, since these fields are absent in an ideally symmetric spherical implosion. If, on the other hand, it is due to microturbulence, the effect might be equally important for plane and spherical targets.

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FIGURE CAPTIONS

Fig. 1 The ratio between output and input energy, Y, versus the initial power, $\dot{E}_o$, for three different models: (a) ideal electrons, initial temperature $T_o = 10^3$ °K, (b) ideal electrons, initial temperature $T_o = 10^4$ °K, (c) electron degeneracy possible, $T_o = 10^4$ °K.

Fig. 2 The optimal energy gain, Y, and the respective laser pulse parameters E^*_{in}, τ and $\dot{E}^*_o$ versus the flux limit parameter 1/f.

Fig. 3 The energy gain, Y, versus the laser pulse exponent p for different values of the flux limit parameter f.

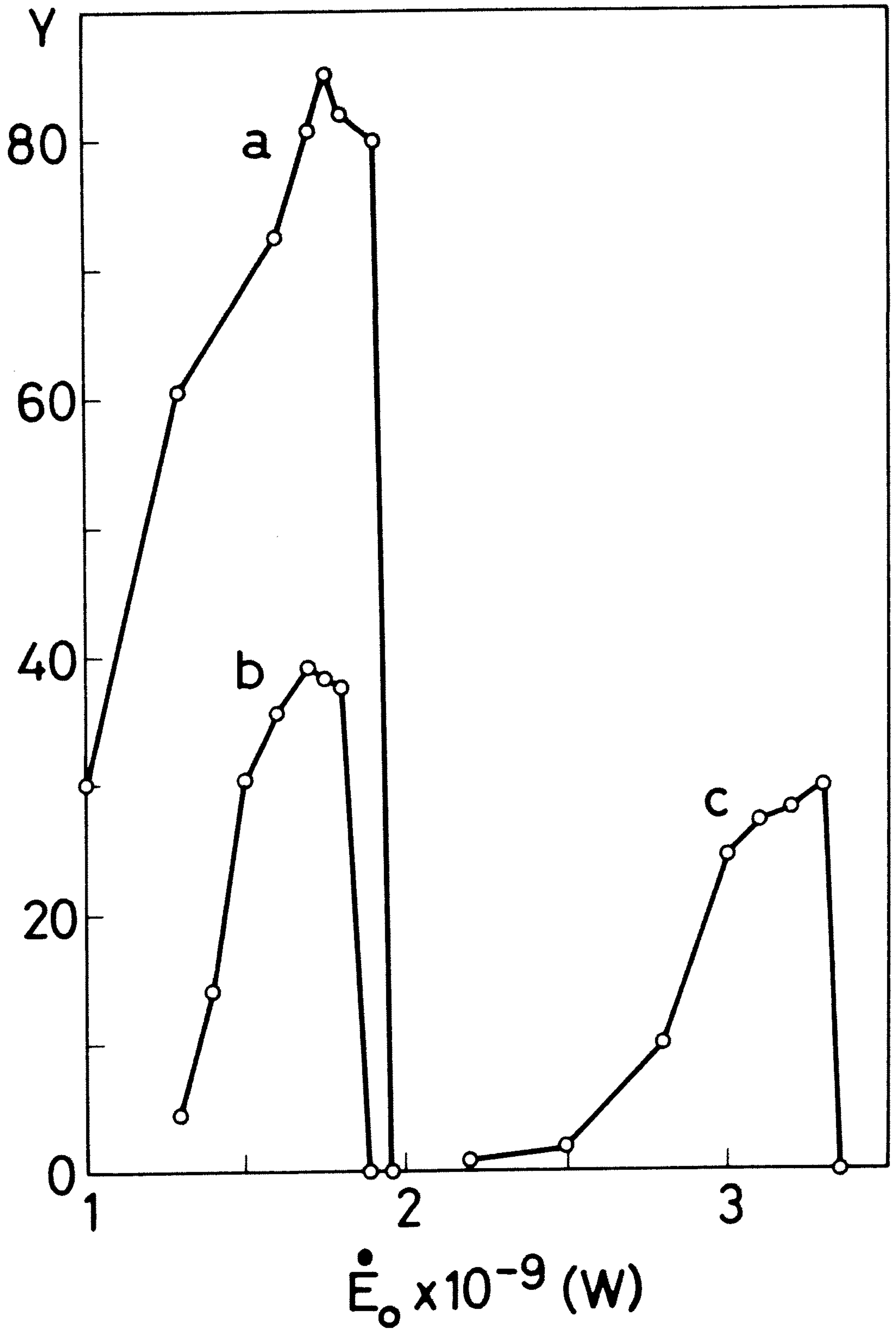

Figure 1

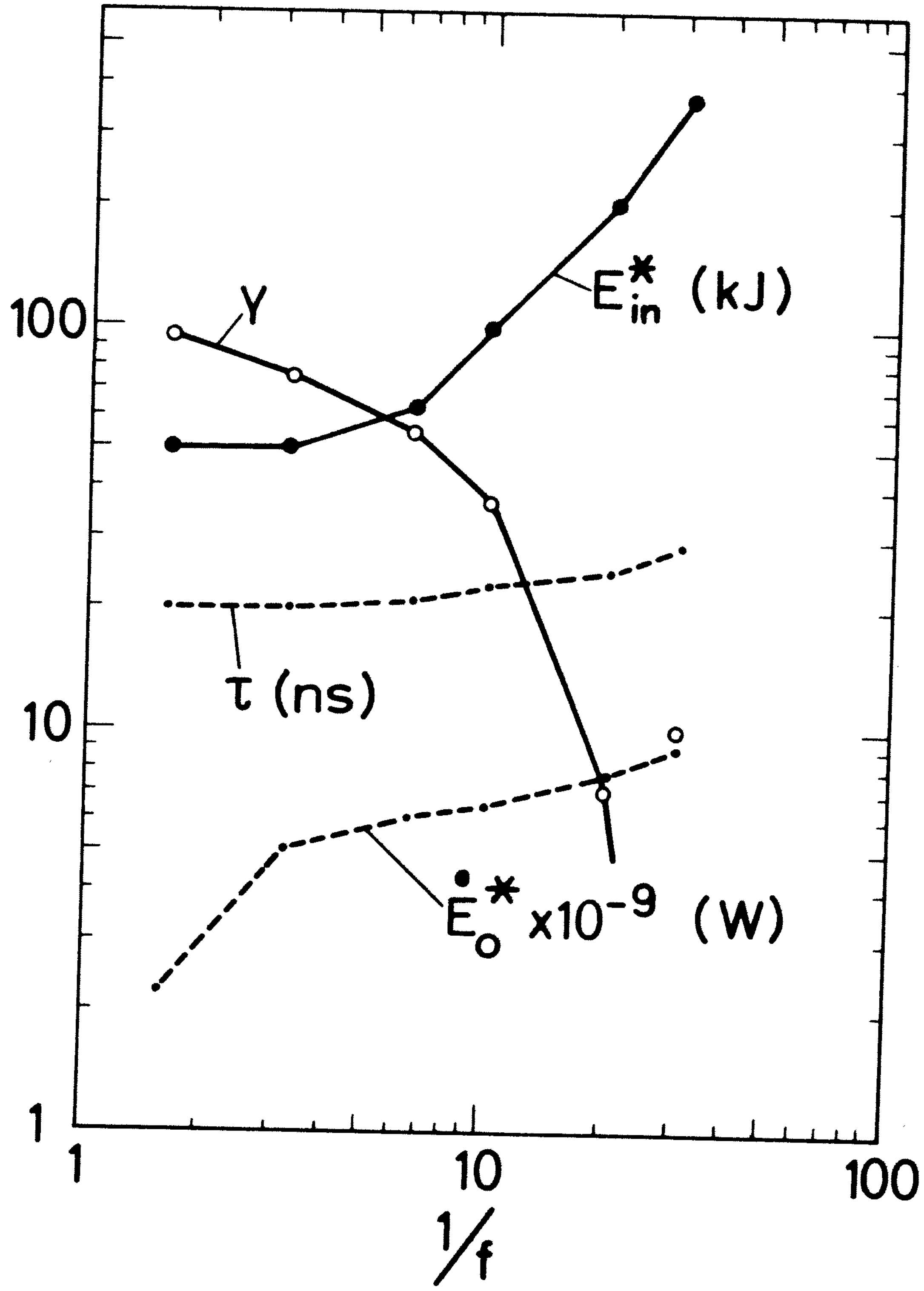

Figure 2

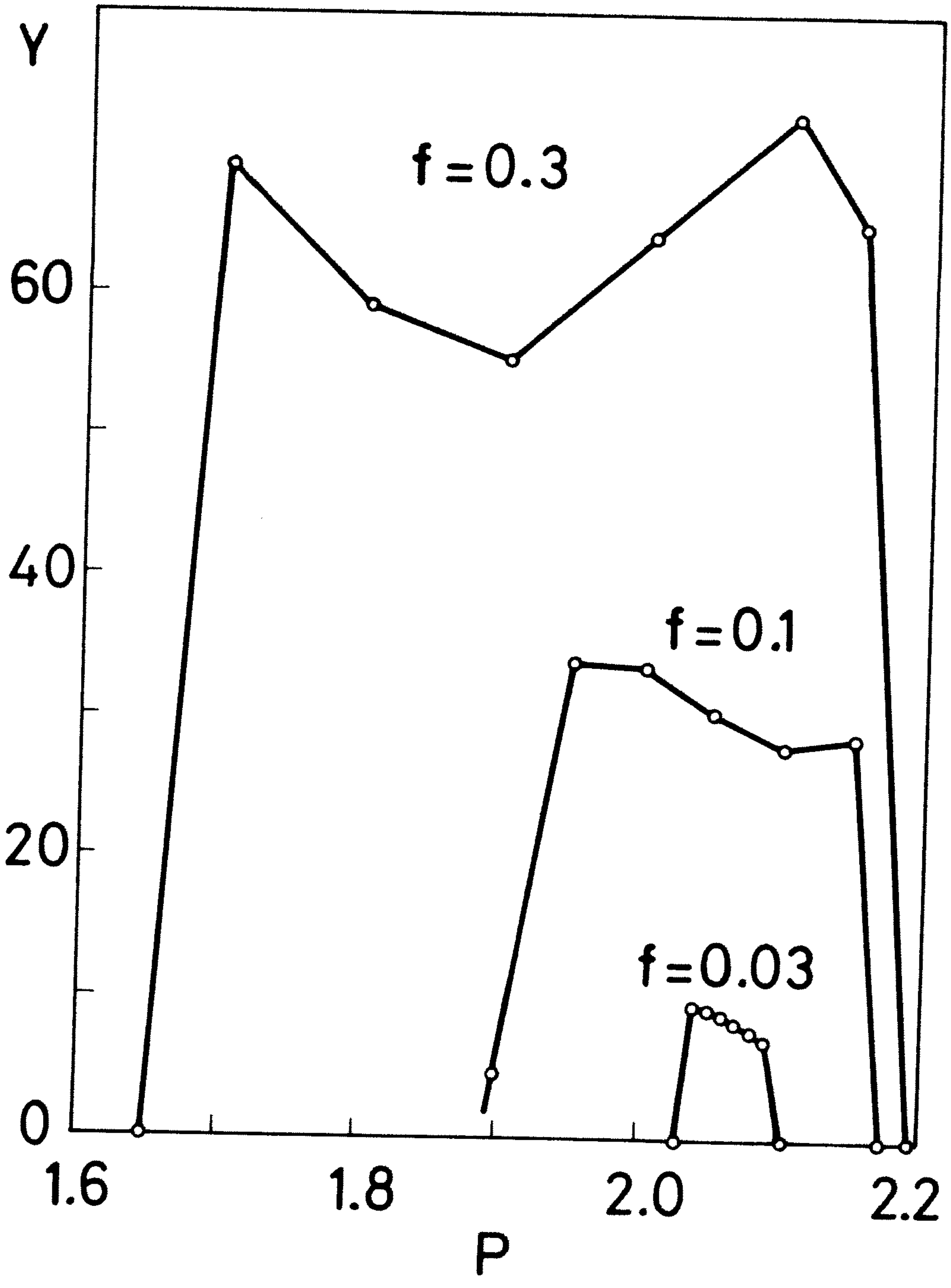

Figure 3