INVERSE BREMSSTRAHLUNG EFFECTS IN THE CORONAE OF
LASER-IRRADIATED PELLETS AND SLABS

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In recent, quasi-steady analyses of the spherical, ablative corona of a las­
er-irradiated pellet, absorption was assumed to occur at the critical den­
sity ncr /1-4/. Both classical and saturated heat-flux, and ion-electron
energy exchange were taken into account. If the ion charge number Z_i and
mass per unit charge M_i/Z_i, the instantaneous pellet radius r_a and laser
power W_L, and its wavelength (or equivalently n_cr), are given, one can ob­
tain quantities of interest such as the ablation pressure p_a, the critical
radius r_cr, and the mass ablation rate 47r_m, as dimensionless functions
(P_a = p_a/p_c r^2 v, r_cr/r_a, and T = u/v n_c n_c r) of the parameters Z_i, M_i/Z_i r cr v^2, and
heat-flux limit factors f. We have introduced P_c = E n_c r, a convenient
speed v = (r_c r v^2)/(n_c v), and the factor K of Spitzer’s classical heat-flux
(= KT^2/2 dT/dr, the electron temperature T being in energy units).

Lately the search for more ablative conditions in laser-irradiation of tar­
gets has moved the interest into shorter wavelengths (larger n_c r) and larger
pellet radii. For such conditions inverse Bremsstrahlung absorption in the
underdense flow can be substantial /5/. Here we attempt to quantitatively
determine that absorption using the model of Refs. /3/ and /4/. Inverse
Bremsstrahlung introduces into the model the electron mass m_e and the light
speed c, and is found here to be parametrized by the ratio m_c/m_e, which lies
close to unity for all cases of interest. Large values of n_c r and r_a lead to
relatively low W (1-10^3 typically). Recently Sanmartín et al. have considered
effects due to a suprathermal electron population generated by resonant ab­
sorption, at higher values of W (10^4-10^5); it was found that hot-electron
effects are parametrized by the ratio m_c/m_e too /6/.

Using the continuity equation nvr^2 = u (independent of r), the momentum and
energy equations for the quasineutral ion-electron fluid read
\[
\begin{align*}
\frac{\partial u}{\partial r} + \frac{2}{r} \frac{\partial}{\partial r} \left( r^2 \ln T \right) + \frac{1}{T \ln v} = 0, \quad r \leq r_c, \\
\frac{1}{2} \frac{\partial}{\partial r} \left( r^2 \ln v \right) = K T^{5/2} \frac{d}{dr} T + 0, \quad r > r_c
\end{align*}
\]
where v is the ion velocity and I the laser irradiance, which is given by
\[
\frac{1}{r_c^2} \frac{d}{dr} r^2 I = K I
\]
Here K is the absorption coefficient /7/. Equations (1)-(3) can be solved for
v(r), T(r), and W(r) = 4\pi r^2 I(r), and the eigenvalues \( u, r_{cr} \), and p_a, by using the
conditions
\[
T = 0, \quad v/r_a = u/v \quad \text{at} \quad r_a
\]
$T=0$, $W=W_L$ as $r \to r_c$.

$$v r^2 = \nu/n_{cr} \quad \text{at} \quad r_{cr}$$

either $r=r_{cr}$ or $2 = d\ln T/d\ln r$ where $\bar{m} v^2 = T$.

In Eqs. (2b) and (3) we assumed that the light power $W$, reaching the critical surface is absorbed there by some unspecified anomalous process. We also assumed that $Z_i \gg 1$; in this way the ion temperature is uncoupled (ion pressure and internal energy are negligible) and the problem is simplified. We use classical heat-flux everywhere, an approximation justified, for the $W$ values of interest, in Refs. /4/ and /6/.

The ratio $r_{cr}/r_a$ decreases as $\bar{W}$ decreases with $\bar{m} v/\bar{m} c$ fixed. We find that for $r_{cr} > 1.215 r_a$ the flow at $r_{cr}$ is supersonic (the sonic speed is reached at $r=1.215 r_a$); the solution for the range $r_a < r < r_{cr}$ is the same one given in Ref. /3/. The flow at $r_{cr}$ is sonic if $n^* r_a < r_{cr} < 1.215 r_a$; here $n^*$ is a function of $\bar{m} v/\bar{m} c$, and lies within the range $1-1.215$. For $r_a < r_{cr} < n^* r_a$ the flow at $r_{cr}$ is subsonic. When $r_{cr} = r_a$, the flow is subsonic. When $r_{cr} = r_a$, heat conduction is restricted to a thin layer surrounding the pellet.

If $(r_{cr}/r_a) \sim 1$, the results of Ref. /3/ are recovered for $\bar{m} v/\bar{m} c$ small.

If $(r_{cr}/r_a) \sim 1$, these results are recovered when $10^2 \times (\bar{m} v/\bar{m} c) W$ is small. The ratio $(\bar{m} v/\bar{m} c)/\bar{W}$ is proportional to the quantity $1/1 + n^*$ introduced by Mora /5/.

In Fig. 1(a) we have represented the fraction of laser power absorbed by inverse bremsstrahlung, as a function of $r$ for several values of $\bar{m} v/\bar{m} c$; also shown is the ratio $r_{cr}/r_a$. In Fig. 1(b) we represented the ablation pressure $P_a$ normalized to its value for $W=0$, $\bar{m} v/\bar{m} c=0$. The curves change behaviour when $r_{cr}/r_a > 1.215$, and again when $r_{cr}/r_a > n^* (\bar{m} v/\bar{m} c)$. Numerical data for $r_{cr}/r_a < n^*$ are not shown in the figure. Asymptotic results for low $\bar{W}$ $(r_{cr}/r_a)^{-1}$ are also presented. The mass ablation rate $\Delta m_p$ is the same of Ref. /3/ for $r_{cr}/r_a > 1.215$.

We have also considered large focal-spot irradiation of slabs, leading to one-dimensional, unsteady problems. We approximated the irradiance I in the rising-half of the laser pulse by a law $I(t) = I_0 (t/t)^s$. For large $2z$ and classical heat-flux one has the equations $(x>0, t>0)$

$$\begin{align*}
\frac{\partial n}{\partial t} + \frac{\partial}{\partial x} (n \nu x) &= 0, \\
\bar{m} \left[ \frac{\partial v}{\partial t} + \nu \frac{\partial v}{\partial x} \right] &= - \frac{\partial}{\partial x} \bar{n} T, \\
\bar{n} \left[ \frac{\partial T}{\partial t} + \nu v \frac{\partial T}{\partial x} \right] - \frac{3/2}{n} \frac{\partial}{\partial x} \bar{n} T^{5/2} &= \frac{s}{\bar{T}} \frac{\partial}{\partial x} \bar{T} = k I.
\end{align*}$$

There are two dimensionless parameters, as in the spherical case,

$$I_0 \frac{\bar{m} v}{r_{cr} W} \sim \frac{\bar{m} v}{\bar{m} c},$$

where $U = \bar{r}_{cr}/(\bar{m} v^{5/2})^{1/3}$. If $\bar{s} \ll 1$, conduction is restricted to a thin deflagration layer, which is quasisteady /8/. If, in addition, $s = 3/2$ the flow outside that layer is self-similar. We have determined all quantities for $1 < \bar{x} < 2$ for $(\bar{m} v/\bar{m} c)^{5/2} / \bar{W}$ large and small (when the results of Ref. /8/ are recovered). The ratio $(\bar{m} v/\bar{m} c)^{5/2} / \bar{W}$ is proportional to $1/1 + n^*$ a quantity
Fig. 1(a) Ratio of critical to pellet radius $r_{CR}/r_a$ and inverse Bremsstrahlung absorption $(W_l-W_{CR})/W_L$ and (b) ablation pressure $P_a$ (normalized), versus laser power $W_L$ (in dimensionless form), for values of $mV/m_e c$ indicated; ---, behaviour at low power.
introduced by Mora /5/. For the ablation pressure $P_a$ at $t = r$ we get
\[
\frac{P_a}{\rho_{cr}^{2/3} \gamma/3} = \frac{8}{5/3} \left( \frac{\sqrt{m_e c \rho_{cr}}}{\mu/m} \right)^{1/8} \left( \frac{\sqrt{m_e c \rho_{cr}}}{\mu/m} \right)^{1/8} \ll 1
\]

References


