§20. Ion Quiver-Velocity Fusion

Kenmotsu, T. (Okayama Univ. of Science),
Nishikawa, T. (Okayama University),
More, R.

We have developed computer codes to analyze energy transfers important for fusion. We can test these codes by applying them to hypothetical laboratory fusion experiments.

In the course of this work we found that ion quiver motion in high-intensity laser interaction leads to a new type of fusion not included in the usual plasma simulation codes. Even if this type of fusion is not dominant, any new kind of controlled fusion reaction is interesting.

For this process, the important physics issues are: fusion reactions, geometry of the laser focal spot, relativistic electron and ion quiver velocities, and fusion reactions for moving Maxwell distributions. Since D and T ions have different quiver velocities, we calculate fusion reactions for D,T ions from Maxwell distributions centered on the two unequal quiver velocities.

We consider light pulses with peak focal-spot intensity $I_{peak} \sim 10^{22}$ W/cm^2 and pulse length $\tau \sim 1$ psec produced by an ultra-short pulse laser. We assume the laser is focused to high intensity in DT gas. DT molecules ionize early in the laser pulse. If the gas density is small compared to the critical density, the laser focus is not affected by the gas. Free electrons have relativistic quiver velocities and store energy ~ $(I\lambda^2)^{1/2}$. The ion quiver energy grows proportional to $I\lambda^2$, so the fraction of laser energy in the ions increases with I.

The ion quiver motion is a coherent oscillation, and D's, for instance, move together and have no collisions from the quiver motion. However D and T ions have different masses, and the relative motion of D, T can lead to collisions with a definite kinetic energy. At high enough intensity, these collisions cause ion quiver-velocity **(IQV)** fusion.

We can expect three kinds of fusion reactions occur in a DT gas target: a.) Ion quiver-velocity fusion from the DT quiver-velocity difference; b.) DT, DD reactions from ion thermal energy; and c.) Electrostatic beam-target reactions occuring after the laser pulse. Ion quiver-velocity fusion reactions occur only for DT or D-He^3, so experiments with varying gas composition could hypothetically distinguish IQV fusion.

IQV neutron source is localized in space and time.

The IQV fusion yield is proportional to

$$n_D \ n_T < \sigma(E_{rel}) > \Omega \ \tau$$

which includes the densities of deuterium and tritium ions, the fusion cross-section evaluated at the relative velocity of D, T quiver motion, averaged over the focal spot volume Ω and pulse length τ.

Our numerical calculations use formulas for the laser intensity in a diffraction-limited focal spot (including the important effect of depth of field) and average the reaction rate over the focal volume. The calculations are conservative because they omit three effects which raise the fusion yield: (1.) Reactions outside the focal spot as defined by first diffraction minimum, (2.) additional fusion reactions due to fusion alpha knock-ons (in this case energy-loss to electrons is very small), and (3.) enhancement of fusion cross-section by laser electric field.

If enough IQV fusion reactions occur, the composition dependence has a clear signature. As an example, we considered a gas cell containing 50% D, 48 % He^3 and 2% T. The DT and DHe^3 reactions reach maxima at different focussing.

For sufficiently generous laser parameters, there are many IQV fusion reactions.

Table I. Sample calculations of IQV fusion

10 PW laser	gas density is 0.8 x critical
DT gas target	$8.6\ 10^5$ reactions/shot
D-He^3 gas	7000 reactions
10 PW laser,	
DT droplet target	$4.7\ 10^8$ reactions
1 PW laser	
D-T gas	8500 reactions

IQV fusion experiments with mixed D$_2$-He^3-T gas could provide evidence for the existence of high laser intensities in the focal spot. However, the computer codes and subroutines we have developed are the main results of this work: These tools can be used to evaluate many kinds of fusion.

This work was presented as an invited talk in the Inertial Fusion Science and Applications (IFSA) conference held in Kyoto, Japan during September, 2001.