Numerical Simulation of an Atomic Cluster Explosion

The calculated time-history of a cluster of 5000 Xe atoms irradiated by a 200-fs, 780-nm laser pulse with a peak intensity of 10^{16} W cm^{-2} is illustrated in Fig. 1. The time-dependence of the nanoplasma parameters clearly shows field enhancement in the cluster, a resonance in the heating and an extremely rapid expansion (explosion) of the nanoplasma. The peak of the laser pulse is at t = 0 fs. At around t = -280 fs, when the intensity is ~4 x 10^{13} W cm^{-2}, a small number of free electrons are created through tunnel ionization. The electron density rises to reach $3n_{crit}$ at t = -270 fs [Fig. 1(c)]. At this point the field in the cluster is enhanced [Fig. 1(a)] and more electrons are liberated through tunnel, laser-driven and thermal ionization. The electron density is now higher than $3n_{crit}$ and the field inside the cluster is shielded from the external laser field. The tunnel and laser-driven ionization rates fall off, but electrons are still created through thermal collisions.

From t = -50 fs onwards, some electrons are able to leave the cluster, as the mean electron temperature is in the region of 100â€“1000 eV and the escape energy is ~200â€“2000 eV. The combined effect of the free-streaming of electrons out of the cluster and the hydrodynamic expansion of the cluster is that the electron density starts to fall, after peaking at over $50n_{crit}$. The field in the cluster again starts to rise as the electron density drops, so the tunnel and laser-driven ionization rates increase while the thermal collisional ionization rate falls. Near the peak of the laser pulse, at t = -12 fs, the electron density in the cluster drops to $3n_{crit}$. The resonantly increased heating rate causes the electron temperature in the cluster to soar to 25 keV [Fig. 1(b)]. The field in the cluster is also strongly enhanced and the peak intensity in the cluster reaches 2 x 10^{16} W cm^{-2}, twice the intensity outside. The electron free-streaming rate increases sharply as a significant number of electrons have energies above the then 4-keV escape energy.

The total charge on the cluster increases to 5.5 x $10^{4}e$, resulting in the Coulomb pressure increasing to 10 Mbar [Fig. 1(d)]. However, this is small compared to the hydrodynamic pressure due to the hot electrons of 200 Mbar. This pressure causes a sharp increase in the cluster expansion velocity. This is the explosion of the cluster. Once the nanoplasma density has dropped to â‰ˆ10^{17} cm^{-3}, the final expansion velocity of electrons and ions is 3.3 x 10^{7} cm s^{-1}, which corresponds to a maximum ion energy of ~80 keV. The final electron energy is much lower, only 30 eV, a consequence of their much lighter mass. However, electrons that free streamed away from the nanoplasma have energies in the 0.2â€“2 keV range. (underline added)

This simulation shows an extremely energetic laserâ€“cluster interaction, with ion energies close to 100 keV and electron energies of several keV. We will see that these predictions are borne out in experiments.

(click to enlarge)

See Also

3.14 - Vortex Theory of Atomic Motions 3.23 - Hydrodynamic Equations - Vortex Motions 5.8.5 - The complete Contraction Expansion Cycle is as follows 9.27 - Expansion and Contraction 13.04 - Atomic Subdivision 16.15 - Negative Electricity is Expansion Atomic Atomic Cluster Heating Atomic Cluster Ionization Atomic Cluster X-Ray Emission Atomic Clusters Atomic Force atomic mass atomic number atomic theory atomic triplet atomic weight diatomic Egyptian fraction expansion expansion Figure 13.06 - Atomic Subdivision Figure 14.10 - Proportionate Tonal Relations dictate Contraction or Expansion Figure 3.28 - Compression and Expansion Forces in Gyroscopic Motions Figure 9.10 - Phases of a Wave as series of Expansions and Contractions Figure 9.5 - Phases of a Wave as series of Expansions and Contractions Force-Atomic Formation of Atomic Clusters Hydrodynamic Expansion InterAtomic Ionization Energy Laser Cluster Interactions Law of Atomic Dissociation Law of Atomic Pitch Law of Oscillating Atomic Substances Law of Pitch of Atomic Oscillation Law of Variation of Atomic Oscillation by Electricity Law of Variation of Atomic Oscillation by Sono-thermism Law of Variation of Atomic Oscillation by Temperature Law of Variation of Atomic Pitch by Electricity and Magnetism Law of Variation of Atomic Pitch by Rad-energy Law of Variation of Atomic Pitch by

Temperature Law of Variation of Pitch of Atomic Oscillation by Pressure Models of Laser Cluster Interactions monatomic Nanoplasma subatomic