Saturation of Continuum-Continuum Transitions in Multiphoton Absorption

In a series of papers[1,2] the solvable model of step-by-step excitations within the continuum introduced by Białynicka-Birula[3] has been applied to a description of recently observed phenomenon of above-threshold ionization.[4] In their recent Letter,[1] Deng and Eberly have identified a new dimensionless saturation parameter $Z_{12}=\pi^2|V_{12}|^2\rho_1\rho_2$ proportional to the intensity of the laser light and to the square of the free-free atomic dipole matrix element. A saturation laser intensity I_{sat} is then defined by the condition $Z=1$. The question arises: Are free-free matrix elements large enough to make I_{sat} several orders of magnitude smaller than the "atomic" laser intensity I_{at} (10^{17} W/cm^2)? The latter is necessary if the proposed physical picture is to be consistent with experimental observations.

We checked the above for the case of the hydrogen atom, for which the free-free matrix elements are available analytically.[5] The results are presented in Figs. 1 and 2. In Fig. 1, the logarithm of I_{sat} is plotted for $l\rightarrow l+1$ and $l\rightarrow l-1$ transitions with photon energy ~ 1.2 eV—similar to that used in Ref. 4. We see that, indeed, the saturation intensity can be of the order of 10^{13} W/cm^2 but only for the transitions with the lowest angular momenta. The decrease of the free-free matrix element with increasing l is simple to understand. Such a matrix element determines the probability of absorption or emission of the photon. We know that the process is possible only in the presence of forces (when the electron is accelerated). The high-l scattering states, classically, correspond to the peripheral trajectories with lower acceleration. At the intensity 10^{13} W/cm^2, the laser field matches the Coulomb field at a distance ten times larger than the Bohr radius. Thus, if the step-by-step model is correct, the angular distribution of outgoing electrons should reveal the presence of only a few of the lowest partial waves. Since, however, the $l\rightarrow l+1$ transitions are easier to saturate than $l\rightarrow l-1$ and the I_{sat} decreases somewhat higher in the continuum, the drift toward larger l as we go to higher peaks is expected.[6] An experiment on the angular distribution in the above threshold ionization is therefore urgently needed.

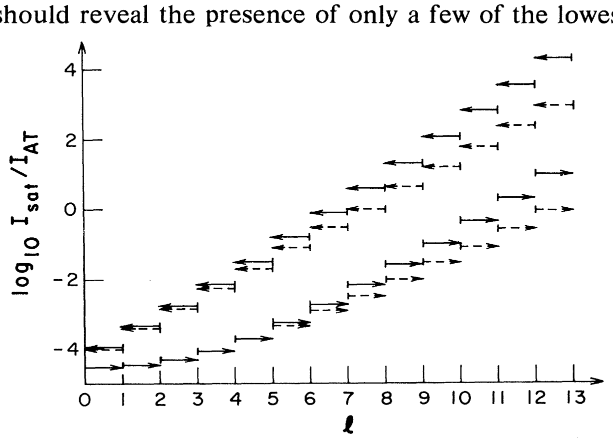

FIG. 1. The logarithm of I_{sat}/I_{at} for $(l,m=0)$ to $(l\pm 1,m=0)$ free-free transitions in hydrogen. The energy of the photon is 0.045 a.u. (~ 1.2 eV) and the lower of the two scattering states has energy 0.01 a.u. (~ 0.28 eV) (solid arrows) and 0.02 a.u. (~ 0.55 eV) (dashed arrows).

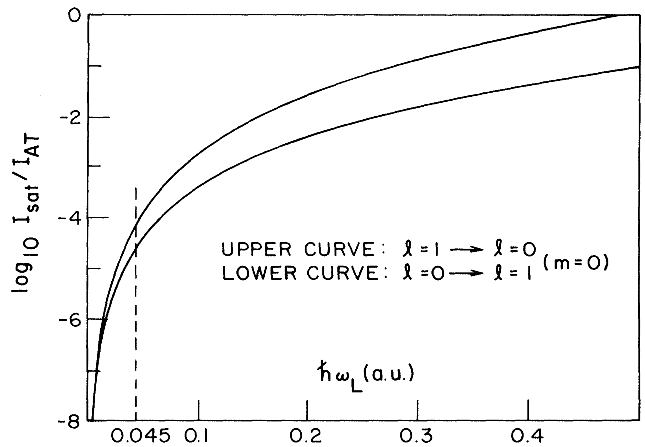

FIG. 2. The logarithm of I_{sat}/I_{at} for $(l=0)\rightleftarrows(l=1)$ free-free transitions in hydrogen vs photon energy (atomic units). The result depends very weakly on the energy of the lower state for $0.01\lesssim E\lesssim 0.1$ a.u.

In Fig. 2 we show the variation of I_{sat} when the energy of a single photon is changed. It is clear that saturation is possible only for low-energy photons.

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Kazimierz Rzążewski[(a)] and Rainer Grobe[(b)]
Joint Institute for Laboratory Astrophysics
University of Colorado and
National Bureau of Standards
Boulder, Colorado 80309

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[(a)]Permanent address: Institute for Theoretical Physics, PL-02-668 Warsaw, Poland.

[(b)]Permanent address: Physics Department, Universität Essen, D-4300 Essen 1, W. Germany.

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