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Beyond Dipole Effects in Atomic Processes

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Abstract

We attempt to answer the question: to what extent does physics beyond the nuclear point Coulomb level enter into observable properties of non-dipolar matrix elements in atomic processes such as photoionization, Rayleigh scattering and bremsstrahlung? We characterize these processes in terms of nuclear point Coulomb properties plus low multipole screening contributions. Except in photoeffect, the atomic form factor is also needed. In photoionization no higher than octupole, in Rayleigh scattering no more than quadrupole, screening contributions need to be included to achieve accuracy within a few percent. Similar considerations apply to bremsstrahlung.

I. DISCUSSION

Here we summarize the importance of higher multipole physics in atomic processes. For both photoionization and Rayleigh scattering we have examined the importance of higher multipole screening contributions to Coulombic matrix elements in physical observables. For photoionization this leads to a simple parameterization. But in Rayleigh scattering we must first partition the amplitude as the sum of the form factor (for which screening effects of higher multipoles are very important) and the anomalous scattering factors, in which screening contributions are only important in the lowest multipoles.

For photoionization we have demonstrated that, within the independent particle approximation (IPA), the only atomic information needed beyond nuclear Coulomb properties are (1) the bound state normalization constant, (2) the difference between reduced and nuclear point Coulomb reduced multipole matrix elements and (3) the corresponding differences between screened and Coulombic phase shifts associated with these transitions [1]. Furthermore no more than the first three multipoles of these screening contributions (beyond Coulomb properties) are ever needed to achieve an accuracy for physical observables that is within a 2% error limit.

In the case ($Z >\approx 50$) of moderate to high Z (for inner shells) and very high Z ($Z >\approx 75$, all shells) multipole screening contributions (which will be designated by Δ_j where j is the 2^j-pole) up to octupole are needed for an accurate (within 2%) description of photoionization. Conversely, in the case of low Z outer shells ($Z <\approx 15$ and $E_b <\approx 15\ ev$) with $l > 0$ only Δ_1 plus Coulomb properties are needed to describe photoionization. The behavior of Δ_j can be summarized as $\Delta_j \approx R^{j-1}(E, E_b)Q(E, Z)$, a function of binding energy E_b, electron kinetic energy E and Z that is based on (1) estimates of ratios $R(E, E_b)$ of successive multipole reduced matrix elements and (2) ratios $Q(E, Z)$ of screened and Coulombic matrix elements which are largely independent of j except for j=1.

We may describe the general dependence on bound states (i.e. quantum numbers n and l) and Z as follows. When $j > 1$, Δ_j increases rapidly with increasing Z (same subshell) and rather slowly with decreasing n (same Z and l). It is generally (but not always) larger in $s_{1/2}$ subshells than $p_{1/2}$. These trends are all reversed in the case of the much larger dipole screening contributions Δ_1. Also, with regard to E dependence, the E at which Δ_j is maximum tends to be near threshold for inner shells, but it shifts to higher energy ($\approx 1 - 10\ keV$) for outer shells for which Δ_j becomes small near threshold.

Rayleigh scattering can be characterized in a mannner quite similar to photoionization. The amplitude is separated into a form factor contribution plus real and imaginary anomalous scattering factors. In the case of forward angle scattering, the anomalous amplitudes are related to the photoeffect total cross section through the optical theorem and a dispersion relation, which suggests why a similar characterization of screening effects is possible. We find that for both forward and finite angle scattering the atomic information in Rayleigh scattering amplitudes is in the form factor plus the first few multipole terms of anomalous scattering factors [2]. As expected, for a given subshell the non-Coulombic higher multipole effects in Rayleigh scattering, anomalous amplitudes are similar to those in the corresponding photoeffect total cross section (σ_{PE}). In both cases no higher than quadrupole screening contributions beyond Coulomb are ever needed to achieve an accuracy of a few percent. The trends with respect to n, l and Z dependence are also similar to those in σ_{PE}. With regard to the full photon-atom scattering we find that, in addition to the screened form factor, in forward angle Rayleigh scattering only dipole screening contributions are needed to achieve an accuracy of a few percent, while quadrupole contributions are sometimes also required in finite angle scattering.

One can extend the conclusions for photoionization and Rayleigh scattering to bremsstrahlung. This process involves a similar combination of soft-photon-like features (elastic-electron scattering related to soft photon bremsstrahlung), characterized by the form factor for electron scattering, and photoeffect-like (bremsstrahlung tip region) features. This explains the success of simple characterization of the bremsstrahlung spectrum [3].

REFERENCES

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