Manipulating Lorentz and Fano spectral line shapes

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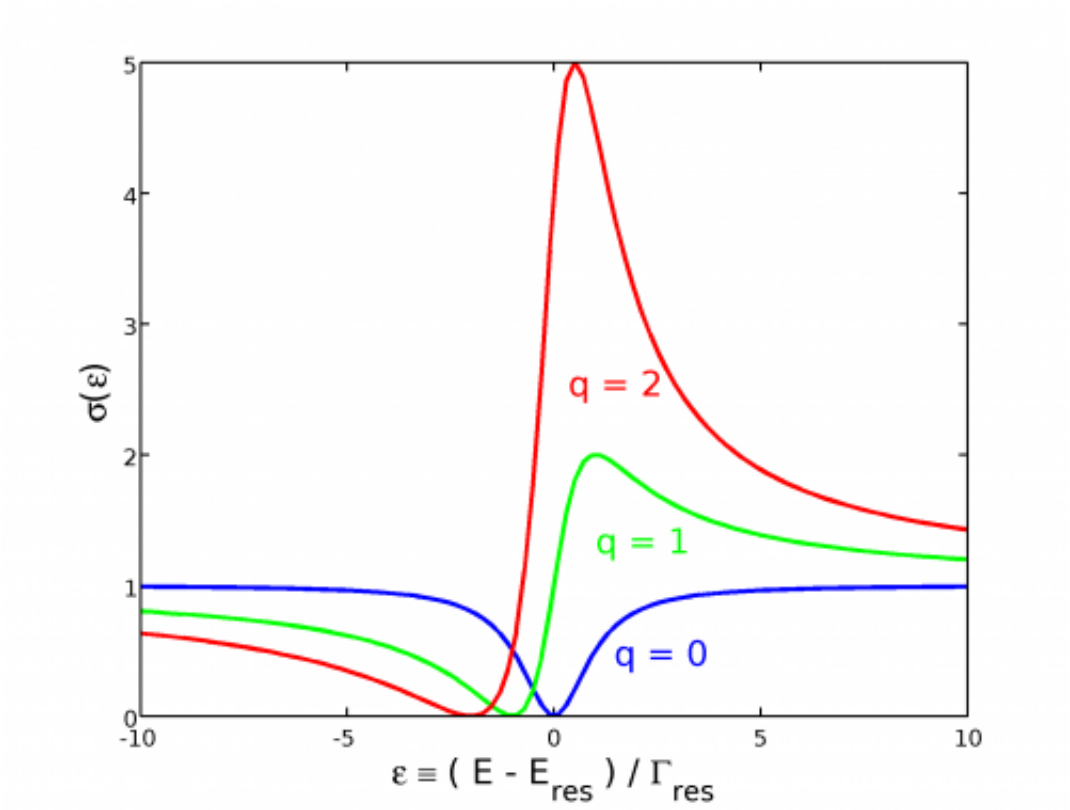

Fano Resonances. Credit: Wikipedia Commons

(Phys.org) —It is widely known that the optical properties of certain materials can be modified by using lasers to control the quantum states of their optical electrons. Lasers that can generate ultra-short pulses in the attosecond range at very high power can now be used to probe and

control nanostructures like photonic crystals, metal hole arrays, and conductance in quantum dots. The light absorption spectrum of a material reveals critical details about its microstructure. Depending on different factors, this spectrum can take on a symmetric Lorentzian line shape, or an antisymmetric Fano line shape. A new paper in *Science* now demonstrates that this absorption profile can by changed from a Lorentzian shape, to a Fano shape, by manipulating laser intensity. Led by Christian Ott, from the Max Planck Institut in Germany, the researchers achieved this by co-propagating a broadband UV pulse train with a "few cycle" near-infrared (NIR) beam in a helium target.

In Fano resonance, interference between a background and a resonant scattering process gives rise to the asymmetric line shape. A theoretical explanation of this process was first given by Ugo Fano, who studied the inelastic scattering of electrons off of helium. It is now a commonly observed phenomenon found in many areas of physics and engineering. In spectroscopy, the observed spectral line positions show the energy levels of excited quantum states, while the line shapes are determined by how the material relaxes after light is absorbed. Controlling this absorption by coupling the material to an intense optical laser has led to unique discoveries like, for example, electromagnetically-induced transparency, and slow or stopped light.

Performing these kinds of manipulations in the extreme UV, and soft x-ray frequency regime has been a challenge. Ott and the other researchers were able to show that this kind of control can be extended to inner-shell electrons by tuning the time delay between an extreme UV laser, and an IR laser. Specifically, at a laser intensity of $2TW/cm^2$, they were able to turn doubly excited asymmetric states into symmetric Lorentzian states. At lower intensities, they were also able to turn symmetric line shapes of singly excited states into asymmetric ones. Their explanation is that in the presence of the NIR laser, additional phase is acquired by the Fano resonances, which changes the line profiles.

In general, the Fano resonance line shape is caused by interference between two scattering amplitudes. One is due to scattering within a continuum of background states, and the other due to an excitation of a discrete resonant state. The resonant state energy must be within the energy range of the background state to generate the effect. Near the resonant energy, the amplitude of the background scattering tends to vary slowly with energy, while the resonant scattering amplitude changes quickly both in phase and magnitude. This variation is what creates the asymmetric shape.

The researchers only presented data for a fixed time delay. Extending these experiments to many different time delays may be a good follow-up study. Although the experiments here were done in helium gas, the authors note that there is no reason why these mechanisms should not be applicable to molecules, or excitons in condensed phase or mesoscopic materials. A change in the absorption profile can also be interpreted as a measure of an induced phase shift of a complex quantum-mechanical state amplitude in a laser field. With that in mind, numerous applications within spectroscopy and even quantum-state holography may exist in the near future.

More information: Lorentz Meets Fano in Spectral Line Shapes: A Universal Phase and Its Laser Control, *Science* 10 May 2013: Vol. 340 no. 6133 pp. 716-720. DOI: 10.1126/science.1234407 (On *ArXiv*: arxiv.org/abs/1301.1454)

ABSTRACT
Symmetric Lorentzian and asymmetric Fano line shapes are fundamental spectroscopic signatures that quantify the structural and dynamical properties of nuclei, atoms, molecules, and solids. This study introduces a universal temporal-phase formalism, mapping the Fano asymmetry parameter q to a phase ϕ of the time-dependent dipole response function. The formalism is confirmed experimentally by laser-

transforming Fano absorption lines of autoionizing helium into Lorentzian lines after attosecond-pulsed excitation. We also demonstrate the inverse, the transformation of a naturally Lorentzian line into a Fano profile. A further application of this formalism uses quantum-phase control to amplify extreme-ultraviolet light resonantly interacting with He atoms. The quantum phase of excited states and its response to interactions can thus be extracted from line-shape analysis, with applications in many branches of spectroscopy.

Commentary: www.sciencemag.org/content/340/6133/694.full