Breakthrough unravels photoelectric effect

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An international team including theorists from the Department of Electromagnetic Processes and Atomic Nuclei Interactions of the MSU Institute of Nuclear Physics managed, for the first time in the history of photoelectric studies, to eliminate one serious obstacle that hampered these investigations for many years—namely, the nuclear magnetic moment. This work was recently published in *Physical Review Letters*.

In contrast to the apparent simplicity that brought Einstein his Nobel Prize, the photoelectric effect is quite complicated to analyze in general, especially when the atom contains a large number of electrons. Like the many-body problem in classical mechanics, the quantum many-body problem is very difficult to conceptualize and remains a serious challenge for theory. Hence, the principal role in this field is played by experiment. However, it is difficult to unravel data associated with the atomic photoeffect itself from a variety of other effects due to essentially irrelevant phenomena.

Not the least among the latter phenomena is the spin (and thus the magnetic moment) of the atomic nucleus. It may be thought of as the quantum generalization of the angular momentum in classical mechanics, which is calculated as the product of the linear momentum (mass times velocity) of a particle and its position vector relative to the axis of rotation. Each proton and each neutron in the nucleus possess their own magnetic moment. While these moments tend to largely compensate each other, the resultant moment does not always have to vanish. Any residual "hyperfine" moment, even though relatively small, may dramatically influence the process of the photoelectron emission. A non-zero nuclear spin spoils the picture, in particular when the atom is excited.

A collaboration of seven physicists from Italy, France, Germany, and Russia chose to perform their study on xenon—the element previously used to resolve mysterious features in the atomic photoeffect. Being a noble gas, xenon is very convenient for such studies: it does not form chemical bonds and does not contaminate the apparatus with its compounds. Even more important in the choice was that, among all the noble gases, only xenon has stable isotopes with both zero and non-zero nuclear magnetic moments. Furthermore, xenon is an interesting atom by its own rights, due to the large number of electrons and the associated complicated dynamics of its electron shells.

The experimental design suggested isotope separation with the help of a mass-spectrometer. Subsequently, each of the isotopes was excited with synchrotron radiation and simultaneously irradiated with a wavelength-tunable laser beam. All ejected electrons were counted and sorted by energy and scattering angle.

All this seems simple, but the reality is much more complicated. The first targets excited by synchrotron radiation were obtained in the late 1990s, but the principal difficulty was combining two radiation beams, laser and synchrotron. Moscow theorist A. N. Grum-Grzhimailo, one of the collaborators, says that only a few people in the world are currently capable of solving this problem. One of them—Michael Meyer from the European XFEL GmbH based in Hamburg (Germany)—contributed to the experiment described above. The actual experiment was carried out using a unique beamline with variable polarization, maintained by the group of Laurent Nahon at the French synchrotron SOLEIL.

The task was to provide a theoretical interpretation for the photoeffect on the excited xenon atom, isolated from the influence of the nuclear magnetic moment. Despite the collective of 54 electrons, the gradual improvement of the existing theoretical models finally led to success in describing the pure atomic photoelectric effect. This work, A. N. Grum-Grzhimailo says, is paving the way for a large class of studies with artificially disabled nuclear magnetic moments and for complicated atomic processes with isotope selection that we could previously not even think about.

More information: "Isotopically Resolved Photoelectron Imaging Unravels Complex Atomic Autoionization Dynamics by Two-Color Resonant Ionization." P. O'Keeffe, E. V. Gryzlova, D. Cubaynes, G. A. Garcia, L. Nahon, A. N. G.rum-Grzhimailo, M. Meyer. *Phys. Rev. Lett.* 111, 243002 (2013). DOI: 10.1103/PhysRevLett.111.243002

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