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Diagnostics for super-hot plasmas in fusion reactors

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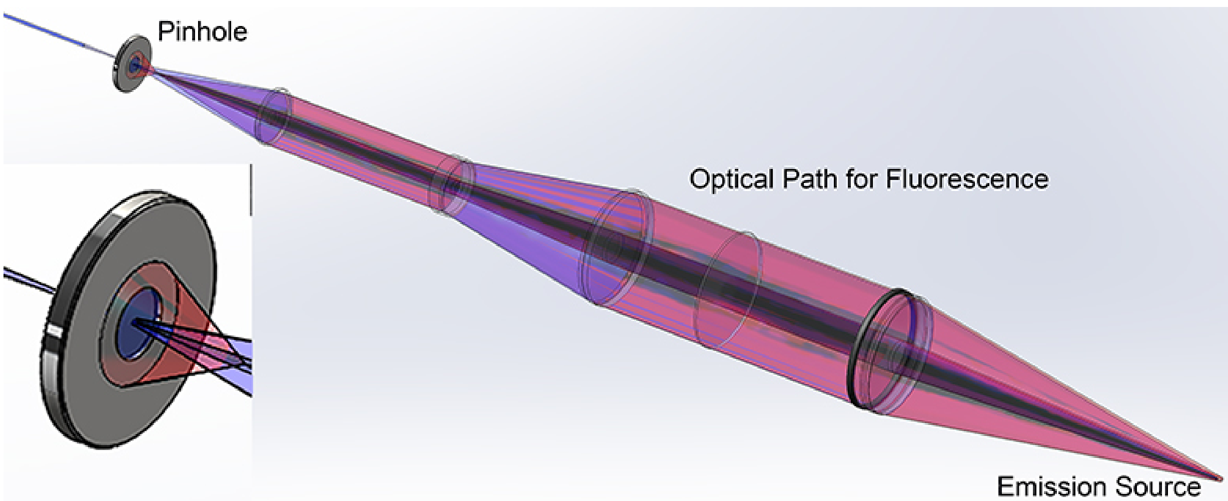

It’s tough to measure the concentration of the single or neutral hydrogen atoms in fusion plasmas. The temperatures reach tens of thousands of degrees or more. A new calibration technique to improve these measurements uses different fluorescence pathways in a laser-induced fluorescence measurement system. Xenon (blue) and krypton (red) fluorescence have different optical pathways in the measurement system. The krypton fluorescence does not make it through the pinhole. Xenon does. Using xenon as the calibration gas provides a fluorescence signal that is more similar to hydrogen, improving the calibration of the system for hydrogen density measurements. Credit: US Department of Energy

In the sun and other fusion plasmas, atoms of hydrogen and its isotopes are the fuel. Plasmas are gases that are so hot that electrons are knocked free of the atom, making the atoms electrically charged ions. The un-ionized atoms are called neutrals. On earth, accurately measuring neutral hydrogen concentration in plasmas could offer insights into future fusion experiments and impact the design of a future fusion-based energy source. To measure the hydrogen density, scientists need to use a calibrated measurement method. They used krypton gas, which absorbs two chunks of light energy at the same time (photons) and in turn emits another photon. The problem is the light emitted is not at the right wavelength for accurate hydrogen density measurements. In this study, scientists discovered that xenon atoms emit light at a wavelength that calibrates well with hydrogen and improves the measurements of neutral hydrogen density.

Knowing the concentration and location of the neutral hydrogen atoms within the super-hot plasma will help us understand and model the behavior of the plasma near the wall of the chamber. This will help in better controlling the plasma to create fusion energy in the laboratory. Discovering the two-photon sequence of events in xenon atoms significantly improves how scientists calibrate measurements of neutral hydrogen density in plasma experiments.

Controlled thermonuclear fusion is the process of fusing light elements into heavier elements to release energy for non-weapons applications. Typical elements to use as fuel are hydrogen and its isotopes, deuterium and tritium. Because the temperature in the plasmas created in these experiments ranges from tens of thousands to millions of degrees Kelvin, it is difficult to measure the location and concentration of the neutral hydrogen atoms. While scientists have obtained relative measurements of neutral density of hydrogen or its isotopes in fusion plasma experiments, hydrogen two-photon laser-induced fluorescence (TALIF) measurements calibrated with TALIF in xenon provide absolute values of density and very high spatial and temporal resolution.

Laser-induced fluorescence uses an intense laser beam focused to a tiny spot in the plasma. At the focal point of the laser, the light is so intense that atoms of hydrogen, deuterium, and tritium absorb two photons (energy packets of light) instead of the typical single photon. After the atoms absorb the two photons, they emit (fluoresce) a single photon of a different color. Measuring the emitted light tells scientists about the density of the neutral hydrogen atoms in the plasma. If scientists perform the same measurement in a known density of a gas such as krypton when the fusion experiment is turned off, they can absolutely calibrate the measurement and thereby measure the absolute density of the hydrogen isotopes inside the super-hot plasma. The calibration gas must also be able to absorb two photons at nearly the same laser wavelength as the hydrogen atoms. A major problem in performing such a measurement is that the spot from which the emission arises must be precisely located in the optics that collect the light.

Historically, scientists used krypton as the calibration gas because it was the only gas known to absorb deep ultraviolet photons at nearly the same wavelength as hydrogen. However, the wavelength of light emitted by krypton is so different from that of hydrogen that the lenses in the experiment focus the krypton light to a different spot than the hydrogen light. Therefore, when researchers adjust the lenses to obtain the best krypton calibration measurements, they reduce or eliminate the hydrogen signal. This study identifies a new calibration scheme using xenon for which the wavelength of the emitted light is nearly identical to the wavelength of the hydrogen emission.

With this new scheme identified, researchers can fill the fusion experiment chamber with cold xenon gas and optimize the experiment to obtain the best emission signal from xenon while simultaneously optimizing the experiment for subsequent hydrogen measurements. This discovery is a major advance in making calibrated neutral density measurements in thermonuclear fusion experiments.

More information: Drew Elliott et al. Novel xenon calibration scheme for two-photon absorption laser induced fluorescence of hydrogen, *Review of Scientific Instruments* (2016). [DOI: 10.1063/1.4955489](http://dx.doi.org/10.1063/1.4955489)

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