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Quantum vacuum standards: making practical tools out of cold trapped atoms

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The Thermodynamic Metrology Group at NIST has launched an effort to create vacuum standards based on fundamental physics. Quantum and photonic based sensors are technologies that can change the way the SI is disseminated for pressure and vacuum. Furthermore, they hold promise as small, compact, and field-deployable sensors that are themselves primary standards requiring no calibration. In the ultra-high and extreme-high vacuum (UHV an XHV) regime, we are developing a cold-atom vacuum standard (CAVS) as part of the nascent Cold-Core Technology program, slated to develop practical metrology-quality sensors based on ultra-cold atom technology. The CAVS will use ultra-cold atoms to sense the absolute number density of gas molecules in the vacuum. If we want to measure the amount of gas we have in a chamber, we can do so by counting collisions between molecules of that gas and ultra-cold atoms in a magnetic trap. The trap lifetime is a direct measure of the background pressure. When a room-temperature background gas molecule collides with an ultra-cold atom in a shallow magnetic trap it ejects the atom with near unit probability. The measured loss-rate of cold-atoms from the magnetic trap is directly related to the number density of the background molecules, so that the absolute vacuum pressure is fundamentally determined from the measured loss-rate and the collision rate between the cold-atoms and the background gas. In addition to building the CAVS, we are presently building a dynamic expansion system to operate in the UHV and XHV in support of our efforts to build a cold-atom vacuum standard. In this presentation, we will discuss progress on the NIST program to build the CAVS and associated challenges in creating a vacuum standard based on ultra-cold atoms. Results from outgassing and other studies conducted to meet the challenges of building standards in the UHV and XHV will also be discussed. Other efforts in the group to build quantum and photonic-based sensors and standards will also be summarized, including photonic silicon sensors for temperature measurement, and dynamic gas pressure standards using absorption spectroscopy. We will also discuss NIST's work toward replacing legacy mercury manometers with a new, photonic-based standard that relies on quantum chemistry calculations of helium's refractive index. These efforts represent a foundational shift in the way thermodynamic quantities are measured. Because this new class of devices are based on fundamental physics, they don't require calibration, and thus hold great promise to shape the future of measurement both at the academic level and in the field.