2nd Time Around: Design, Build, and Performance of MIRE-2, an Accurate Gas Refractometer

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In 2017 we reported a failed effort to determine the Boltzmann constant, based on highly-accurate measurements of the refractivity of helium gas at known temperature. (The polarizability of helium, calculated from first-principles, allows conversion of refractivity to density; Boltzmann's constant was the remaining unknown in the ideal gas equation.) For the past two years we have been attempting to fail better, by building a second-generation apparatus, with the goal of establishing a pressure scale more universal and accurate than one based on the properties of restricted materials and/or inconclusive artifacts.

Some things are easier the second time around. We now know window pathlength error is about 8 times larger than what has been assumed in 30 years' measurement of the refractive index of air—we know the mechanisms behind the oversight, and, by design, we can reduce the error by a factor of 3 (and also gain an additional factor of 2 by increasing cell length). We now know how to align laser beams within ±8 μrad and to locate them relative to a datum within ±15 μm—essential requirements in mitigating window pathlength error and estimating length of the gas path. We now know that a gas metrology experiment must have automation planned into it at conception.

Some things were not easy, being encountered for the first time. Generating and understanding a pressure to within 1 μPa/Pa reproducibility required some of the most careful dimensional characterization, supported by flow and distortion modelling. To convert a cell length measured at 20 °C to an operating temperature of 0.01 °C required measurement of the thermal expansion of fused quartz glass more accurate than anything done before. Knowledge of the temperature of a gas path within 0.2 mK required much thermal characterization of gradients. Finally, a laser interferometer underwater tends toward wetness.

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