Precision Densimetry for Primary Temperature Metrology

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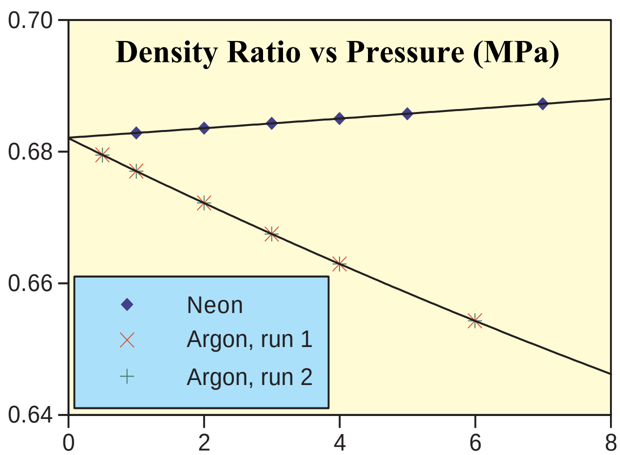
CSTL Program: *Measurement Science for Future Standards and Technology*

This work was designed to address biases in the currently accepted international temperature scale (ITS-90).

Temperature is among the most important quantities in a vast array of applications, yet recent work at NIST and other National Metrology Institutes (NMIs) provides strong evidence that the currently accepted temperature scale, known as ITS-90, differs from the true thermodynamic temperature by about 11 mK at 505 K. This work has been done with acoustic resonators, which are the leading alternative to the traditional constant volume gas thermometer for the determination of thermodynamic temperatures. The present work explores a third, independent method and so would provide a consistency check on the acoustic results. This is important for any redefinition of the temperature scale. The new method is related to gas thermometry but avoids many of the practical difficulties, which have led to its virtual abandonment by the NMIs. With a constant-volume gas thermometer, the temperature is derived from the pressure ratio of a fixed quantity of gas at some temperature T and a reference temperature, usually the SI defining temperature of 273.16 K. However, with the densimeter, the pressure is held constant, and the density ratio measured at several pressures and extrapolated to zero pressure to yield the temperature.



This research has included numerical studies to determine the optimum working gas and the measurement uncertainties needed to obtain a thermometer with an uncertainty of a few thousanths of a kelvin. Argon is the best gas with neon a close second.

This work is enabled by a new apparatus in CSTL, which is proving to be more accurate than older methods by a factor of ten. This densimeter operates on the familiar Archimedes (buoyancy) principle and provides an absolute determination of density. Several twists on the conventional Archimedes experiment—including a differential weighing with two sinkers and a magnetic suspension coupling to separate the balance from the fluid being measured—reduce the uncertainties and allow operation over a wide range of temperature and pressure. For this project, experiments over the range of 234 K to 505 K with argon, nitrogen, and neon as the working gas have been carried out. Experimental protocols and data analysis have been demonstrated. Systematic errors in the magnetic suspension coupling were found, but, while not small enough to ignore, they were reproducible at the level of a few micrograms. While these experiments have demonstrated the feasibility of the method, the present densimeter has uncertainties that are too high for temperature metrology—in particular, the uncertainty in the sinker volumes is large. The method was inverted and used with the measured data to determine, *in-situ*, the sinker volumes as a function of temperature. This reduced the uncertainties in the sinker volumes, and thus the uncertainties of fluid densities measured with this apparatus, by a factor of four compared to values computed using literature values of thermal expansivity. Further development of this method into a temperature standard would require a significant effort involving temperature, pressure, density, length, and mass metrologists, but no insurmountable obstacles are forseen.