Sources of high-purity xenon gas for thermometry fixed points

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1. Introduction

All standard platinum resistance thermometer (SPRT) subranges of the International Temperature Scale of 1990 (ITS-90) extending below 0 °C include the triple point of mercury as a defining fixed point [1, 2]. Thus, increasingly restrictive global and local regulations that aim to eventually eliminate the mining, trade and use of mercury [3] threaten the ability of laboratories to realize the ITS-90, and work is underway to develop alternatives to mercury triple point cells for thermometer calibration [4].

Of the leading candidates being explored as alternatives to the mercury triple point, the triple point of xenon is by far the best placed from an interpolation perspective [4]. The desirable positioning of the xenon triple point was considered by the creators of the ITS-90 for inclusion in the scale, but it was rejected due to poor reproducibility of contemporary xenon fixed points, with mercury taking its place as a back-up choice [5].

The xenon reproducibility problem was later resolved as being largely due to chemical contamination by krypton impurities, and a specially prepared batch of ultra-high purity Spectra Gases "SG03" xenon containing 0.003 ppm† of krypton impurity yielded very flat melt plateaux with melting range within $\pm\ 10\,\mu\mathrm{K}$ [6]. A commercial xenon product from the same supplier (Spectra Gases "Dark Matter" xenon) containing 0.05 ppm of krypton or less was found to give broader but still satisfactory melt plateaux resulting in a triple point realization temperature close to that of SG03 [7]. The chemical impurity profiles of these two xenon gas samples are listed in table 1. On the basis of these experiments, it is recommended that krypton content in xenon triple point cells does not exceed 0.1 ppm, twice the limiting concentration specified in the commercial sample from reference [7].

Since a reliable low-krypton xenon supply is needed to make xenon a viable mercury replacement, efforts were undertaken to search for present day sources of such gas. The gas sources below represent a snapshot based on communication in 2020; the list of suppliers is not exhaustive and the new gas products in table 1 have not yet been tested in fixed points.

Even if xenon triple point cells become widely adopted by the thermometry community, the quantities of gas required will likely remain small compared to other xenon applications.

† Here the abbreviation "ppm" is used for part per million or 1×10^{-6}, measured as µL/L or µmol/mol in gas impurity assays.

A review of the global xenon marketplace was recently conducted by NASA in the context of sourcing large quantities of the gas for spacecraft propulsion purposes [8, 9].

2. Commercial sources

Commercial xenon is obtained as a byproduct at a few specially-configured oxygen extraction facilities. After the Spectra Gases "SG03" and "Dark Matter" xenon gas samples were sourced for the work reported in references [6, 7], significant corporate restructuring occurred in the commercial compressed gases marketplace: first Spectra Gases was purchased by Linde, then Linde sold several business units to Messer, and then Linde and Praxair merged; the old Spectra Gases business unit remains part of the new Linde. Commercial sources of low-krypton xenon confirmed in 2020 are listed below in alphabetical order. Other xenon suppliers worldwide were found by Internet search, *e.g.* in China and Ukraine, but either the impurity specifications were not sufficiently reliable for thermometry fixed points or no response was received on inquiry.

2.1. Air Liquide

The global rare gases group of Air Liquide confirmed that xenon gas meeting the specification listed in table 1 can be produced by Air Liquide and supplied worldwide, perhaps under the name "thermographic grade xenon." Prospective buyers should contact their local Air Liquide representatives.

2.2. Electronic Fluorocarbons (EF Gases)

Electronic Fluorocarbons LLC, also known as EF Gases, sources xenon elsewhere and then further purifies it. The resulting purified xenon can be shipped worldwide. The specification listed in table 1 is an example taken from an actual Certificate of Analysis of a recent large order of xenon supplied to a propulsion laboratory. Prospective buyers should direct inquiries to Sales@efgases.com.

2.3. Linde

The merged Linde / Praxair rare gases group produce "Linde Thermometry-grade Xenon" meeting the specification listed in table 1 from time to time, and can produce it on purpose with sufficient demand and lead time. Worldwide distribution is not a problem. Prospective buyers should contact their local Linde representatives.

2.4. Messer Canada

Messer Canada can supply xenon meeting the specification listed in table 1 and can arrange delivery to most countries around the globe. Prospective buyers should direct inquiries to Calvin.knaggs@messer-ca.com.

Table 1. Xenon gas impurity specifications, in ppm. Concentrations of impurity species appearing as "?" were not reported.

Impurity species	Spectra Gases SG03 [6]	Spectra Gases Dark Matter [7]	Air Liquide	EF Gases	Linde	Messer Canada	XENON1T [13]
Kr	0.003	≤ 0.05	< 0.05	0.016	≤ 0.05	< 0.1	$< 0.000\,000\,048$
N_2	< 0.1	≤ 1	< 1	< 0.1	≤ 0.01	< 1	?§
O_2	0.01	≤ 0.1	< 0.1	0.08	≤ 0.05	< 0.05	?§
H_2O	0.012	≤ 0.1	< 0.1	< 0.5	≤ 0.05	< 0.05	?§
CO_2	< 0.1	≤ 0.1	< 0.1	< 0.1	≤ 0.1	< 0.1	?§
CO	< 0.1	≤ 0.1	< 0.1	< 0.02	≤ 0.1	< 0.1	?§
THC*	< 0.1	≤ 0.1	< 0.1	< 0.03◇	≤ 0.1	< 0.1	?§
TFC*	?	?	?	< 0.02‡	≤ 0.1‡	< 0.1	?§
H_2	?	?	?	< 0.05	≤ 0.5	< 0.5	?§
Ar	?	?	?	0.016	≤ 0.1	< 0.1	?§

*Here THC and TFC respectively stand for total hydrocarbons and total fluorocarbons.

◇Specified as < 0.02 ppm methane and < 0.01 ppm C2–C6 hydrocarbons.

‡Specified as carbon tetrafluoride.

§The cryodistillation process is expected to result in greatly reduced levels of non-Kr impurities too, although these are typically not measured by the XENON project.

3. Academic collaboration

Attempts to detect prospective astrophysical dark matter particles rely on huge quantities of extremely pure liquid xenon: 1.3 tons for the XENON1T experiment and 5.9 tons for the upcoming XENONnT experiment [10, 11]. Such detectors require krypton impurity content to be far below what is achievable commercially, so the XENON project [12] has constructed a cryogenic distillation system capable of removing krypton from xenon to below the parts per trillion level [13]. This purification technology was originally invented in Japan by scientists from the XMASS project [14]; that experiment has since been decommissioned and the involved scientists joined the XENON project.

Compared to the large volumes of liquid xenon handled by the XENON project, the amount of xenon gas needed to fill even dozens of triple point cells is relatively small; a possible collaboration between the thermometry community and the XENON project could enable xenon point realizations of greater chemical purity than SG03. In initial exploratory discussions, a member of the XENON project seemed eager for their technology to be put to good use in other areas, but it is up to the Consultative Committee for Thermometry to take further official action.

Other major astrophysical experiments also use large quantities of low-krypton liquid xenon and could offer further collaboration possibilities for sourcing xenon for thermometry fixed points, for example: LZ [15–17], PandaX [18, 19] and EXO [20–22].

4. Conclusion

Xenon gas with sufficiently-low krypton impurity content for use in xenon triple point cells is now available from several sources. Researchers in the thermometry community are encouraged to build and test new xenon triple point cells so that manufacturers' impurity claims can be correlated with actual fixed point performance data.

Furthermore, while small xenon cells have been shown to be suitable for calibration of capsule-style standard platinum resistance thermometers [6, 7], work is urgently needed to establish the feasibility of large immersion-type xenon cells suitable for calibration of long-stem standard platinum resistance thermometers, perhaps by adapting realization techniques developed for large triple point of argon cells.

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