Helium, Neon And Argon

Part 9 of the series on physical and thermodynamic properties of chemicals covers these three major inert gases.

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The major inert gases—helium, neon and argon—find extensive uses in industry, e.g., in preparing and refining high-temperature materials, in preventing metal oxidation during welding, and in incandescent lighting, high-temperature plasmas and cryogenics. In addition, argon and helium are used in chemical reactions for transporting reactants, removing products, and modifying rates by dilution.

The usefulness of helium depends largely on its extreme properties, for example, lightness and nonflammability. Chemical inactivity is the primary reason for using large amounts of helium as a gaseous shield in welding magnesium, aluminum, stainless steel, titanium and other metals, as well as for degassing molten metals and preventing oxidation in metallurgical and chemical processes. Such applications are also influenced by helium's high heat conductivity and low solubility in molten metals. The slow rate of ionization of helium when bombarded with electrons adapts it to uses in the field of atomic physics.

Large volumes of helium are used in helium-oxygen breathing atmospheres for relieving patients with respiratory diseases, and for underwater divers. Because a mixture of helium with oxygen is much lighter than air, it flows through the lungs more rapidly.

The extremely low temperatures attainable with liquid and solid helium has opened a broad field of research near absolute zero.

To meet the authors, see *Chem. Eng.*, June 10, 1974, p. 78 (Yaws and Setty) and *Chem. Eng.*, Nov. 25, 1974, p. 100 (Hopper and Rojas).

Critical Properties—Table 9—1

Critical properties have been experimentally determined [*32,233,339-341,345,370,377-380,383,384,386,393,405*]. Critical temperatures from the various sources are in very good agreement. Critical volumes and pressures generally agree, with small deviations of 1.0 and 1.2%.

Heat of Vaporization—Fig. 9—1

Heat-of-vaporization data for helium [*345,397*] are available over the entire liquid range. The sources agree, with a deviation of only 3%. Results presented here are averages of available values from the literature. Data for neon and argon were extended to cover the complete liquid range of these gases by using Watson's correlation (Eq. 1—1).

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How To Use the Graphs

Each graph is outfitted with a key that lists references and explains just what part of the curve is determined experimentally, and what part is estimated from theoretical correlations.

The shaded squares denote the following:

- ▩ Data in this region are experimentally known.
- ◪ Experimental and correlated data used.
- ☐ All data in this region are correlated.

The "regions" referred to are the temperature ranges between the melting, boiling and critical points (m.p., b.p. and c.p., respectively), or in some cases, the specific temperatures noted in the key.

Physical Properties of the Major Inert Gases Table 9—1

Identification	Helium, He	Neon, Ne	Argon, Ar
State (std. conditions)	Gas*	Gas*	Gas*
Molecular weight, M	4.0	20.18	39.95
Boiling point, T_b, °C	−268.9 (4.3°K)	−246.0 (27.2°K)	−185.9 (87.3°K)
Melting point, T_m, °C	—**	−248.7 (24.5°K)	−189.3 (83.9°K)
Critical temp., T_c, °C	−268.0 (5.2°K)	−228.7 (44.5°K)	−122.4 (151°K)
Critical pressure, P_c, atm	2.26	26.5	48.1
Critical volume, V_c, cm³/g-mol	57.14	41.7	75.4
Critical compressibility factor, Z_c	0.305	0.303	0.293

*Colorless

**Helium will not solidify unless external pressure is applied.

Vapor Pressure—Fig. 9—2

Vapor-pressure data cover the entire liquid range for helium, neon and argon. Agreement among the data is very close, with deviations in most cases being 1 to 3%.

Heat Capacity—Fig. 9—3, 9—4

Because helium, neon and argon are monoatomic gases, the ideal-gas heat capacities at a given pressure are constant with temperature over a rather wide range. The ideal-gas heat-capacity values [*19*] are 1.24, 0.246 and 0.124 cal/(g)(°C).

Specific heat-capacity data for the saturated liquids are available [*47,345*] on both sides of the liquid-phase transition temperature (lambda point at 2.2 K). Data from the two sources agree very well in the low-temperature range. However, variations increase with temperature, and the deviation from the mean is about 10% as temperatures approach the critical.

Liquid heat-capacity data at constant pressure for neon and argon are presented without additional treatment [*47*]. Deviations are less than 6% for most of the neon data.

Density—Fig. 9—5

Liquid-density data cover the entire liquid range and agree closely. Deviations are 1.5, 1.4 and 1.0% for helium, neon and argon, respectively.

Surface Tension—Fig. 9—6

Surface-tension data were correlated with the Othmer relation (Eq. **1**—4). One linear curve each was sufficient for the neon and argon data. Two curves were required for helium, with an apparent change in slope occurring at the liquid transition point. Average deviations were less than 1.6, 1.0 and 3.0%.

Viscosity—Fig. 9—7, 9—8

Maitland and Smith [*294*] and Hanley and Childs [*402,403*] have reviewed gas-phase viscosity data and recommended the values presented here. The estimates from Eq. **4**—1 gave results approximately 3 to 5% lower at higher temperatures. Agreement of experimental data was very good, with the maximum deviations being less than 3.5, 4.0 and 7.0%.

Extensive viscosity data for the saturated liquids were extrapolated for full liquid-phase coverage. The unusual shape (rapid vertical shift) of the viscosity curve for helium arises from the liquid transition, which occurs at 2.2 K (same location as the vertical shift). Agreement of results among various investigators is good, with maximum deviations from the best fit being less than 8.6, 5.5 and 4.0% for the three gases.

Agrawal and Thodos [*337*] have recently correlated liquid-phase viscosity data for neon and argon, using the relationship:

$$\mu_L/\rho_r = \alpha_e^{\beta/T_r} \qquad (9\text{—}1)$$

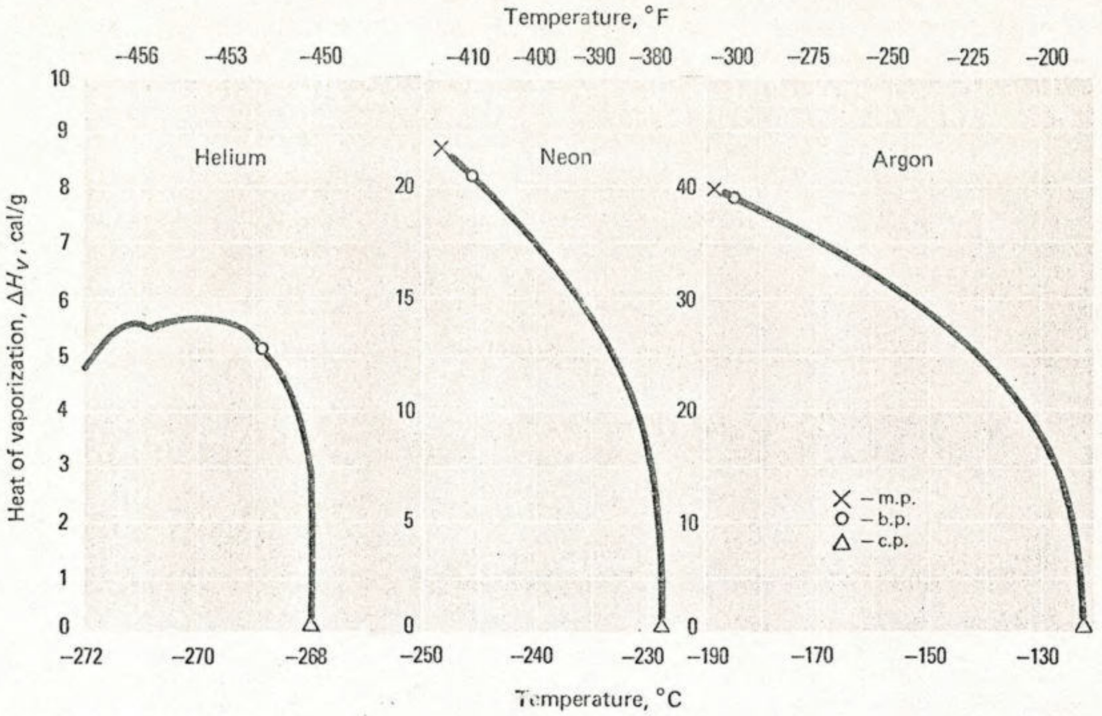
or

$$ln(\mu_L/\rho_r) = ln(\alpha) + \beta/T_r \qquad (9\text{—}2)$$

where μ_L = saturated-liquid viscosity, cp; ρ_r = reduced density, ρ/ρ_c; T_r = reduced temperature, T/T_c; α, β = constants.

In their correlations, a plot of μ_L/ρ_r versus $1/T_r$ yielded a straight line having a slope of β. Average deviations

(*Text continues on p. 94*)



Heat of Vaporization—Fig. 9–1

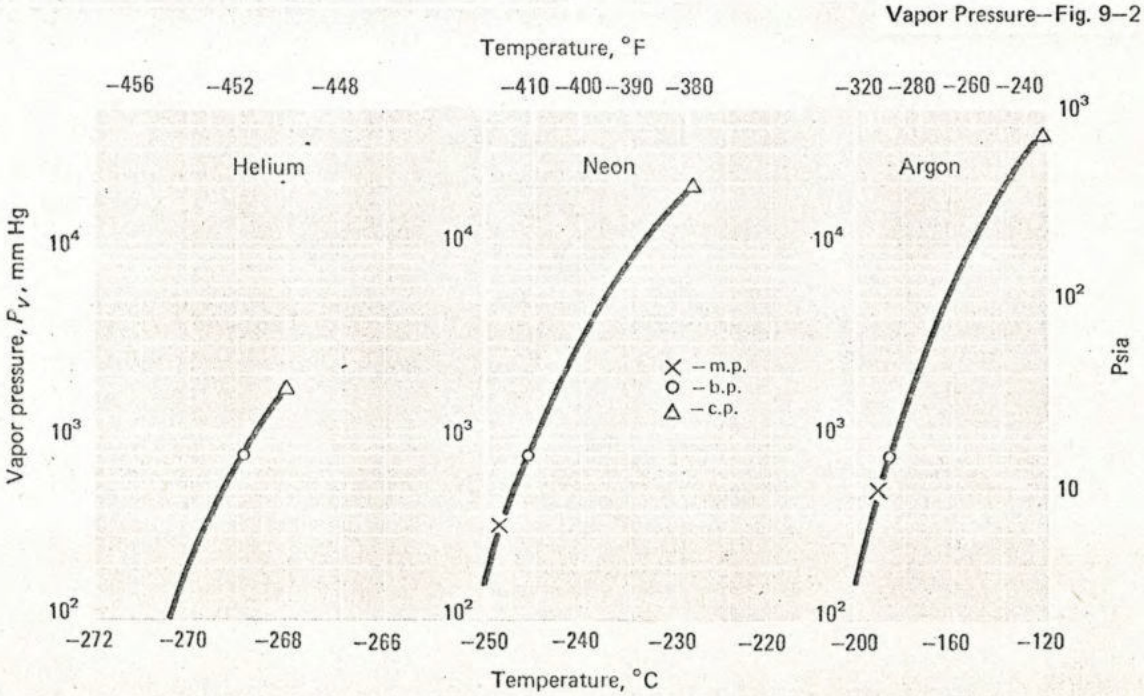
Fig. 9–1	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Helium	Laboratory data	Laboratory data	10,43,311,322,345,397
Neon	Laboratory plus correlations	Laboratory plus correlations	10,43,47,345
Argon	Laboratory plus correlations	Laboratory plus correlations	10,43,47,345

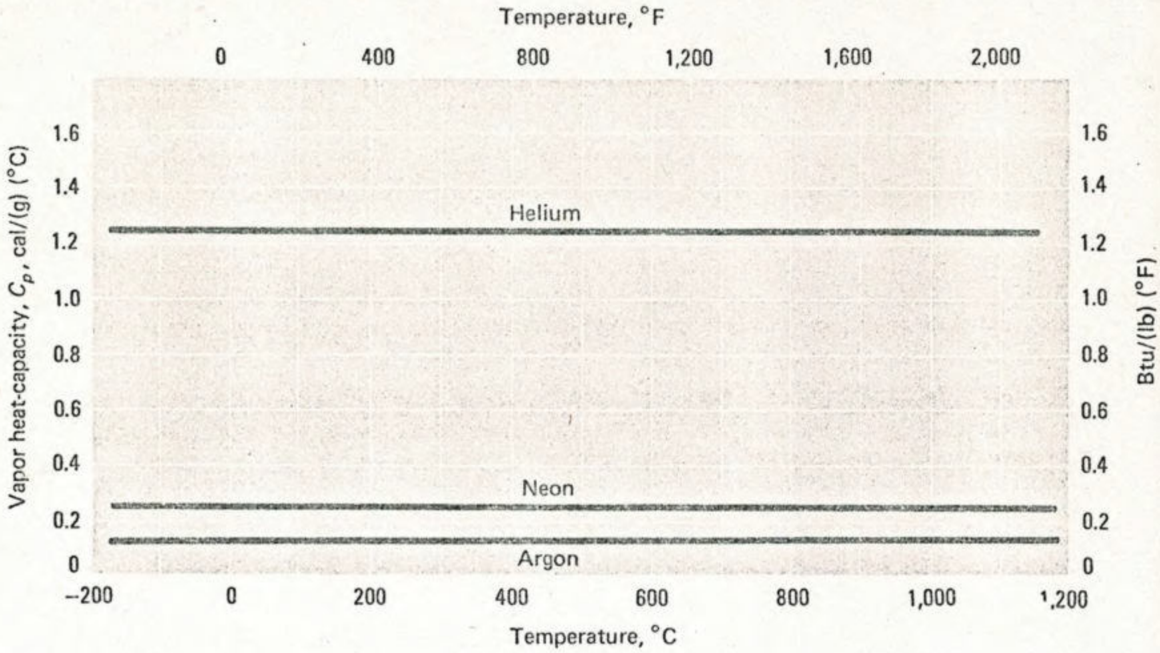
Laboratory data — Laboratory plus correlations — All corrected data

Fig. 9–2	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Helium	Laboratory data	Laboratory data	10,43,45,345,397
Neon	Laboratory data	Laboratory data	10,43,45,345,359
Argon	Laboratory data	Laboratory data	10,43,45,341,345,356,377,404

Laboratory data — Laboratory plus correlations — All corrected data

Vapor Pressure—Fig. 9–2





Vapor Heat Capacity—Fig. 9–3

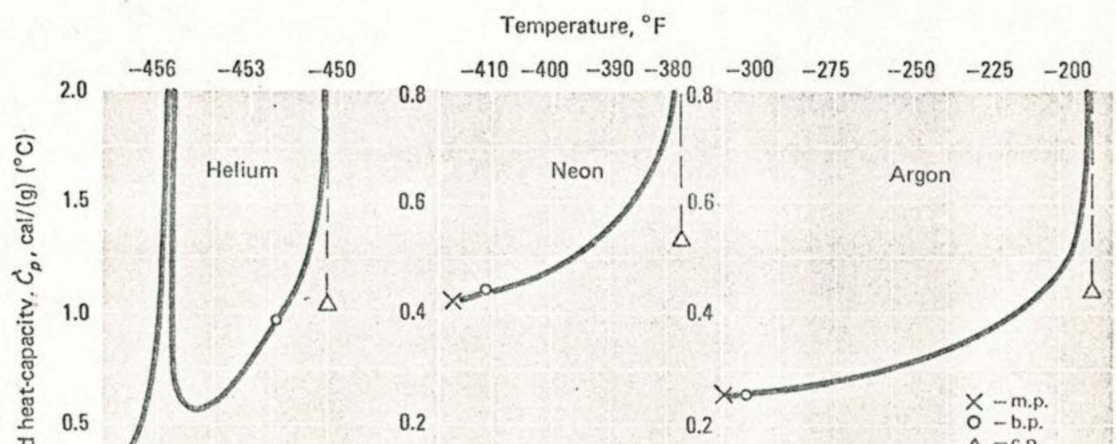
Fig. 9–3	Temperature Range, °C			References
	0–500	500–1,000	1,000–1,500	
Helium	Laboratory plus correlations	Laboratory plus correlations	Laboratory plus correlations	7,18,19
Neon	Laboratory plus correlations	Laboratory plus correlations	Laboratory plus correlations	7,18,19,47
Argon	Laboratory plus correlations	Laboratory plus correlations	Laboratory plus correlations	7,18,19

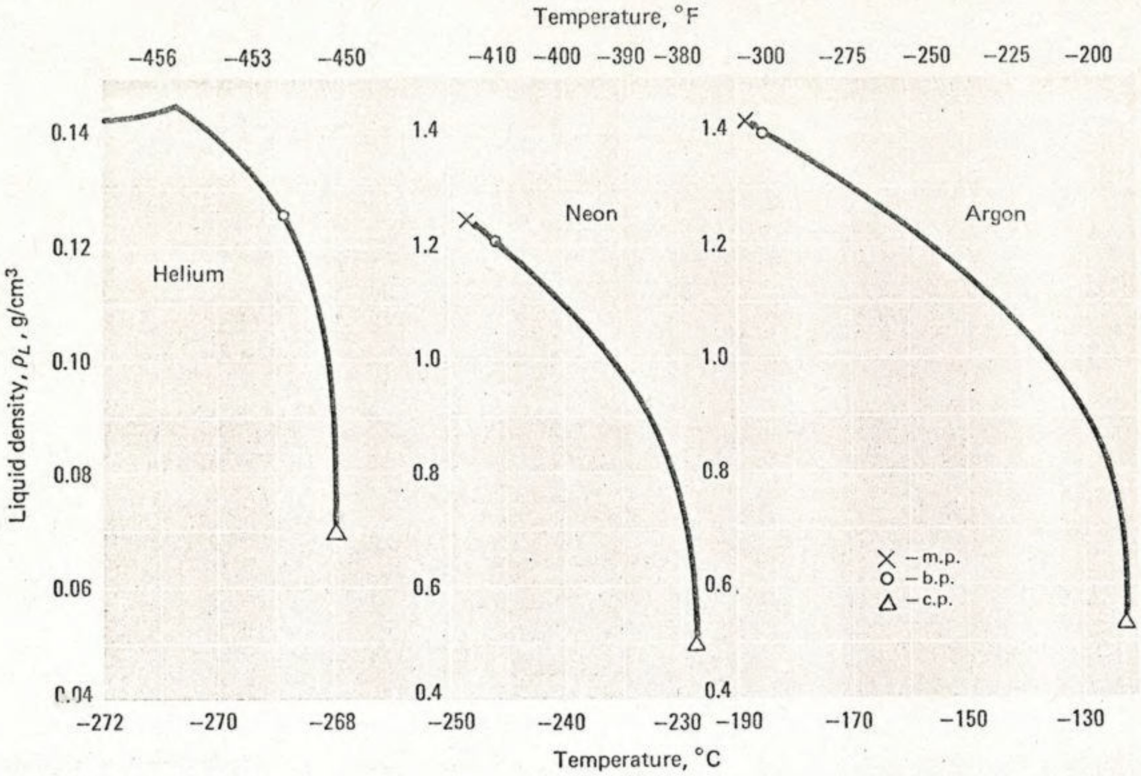
Laboratory data — Laboratory plus correlations — All corrected data

Fig. 9–4	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Helium	Laboratory data	Laboratory data	10,47,345
Neon	Laboratory data	Laboratory data	10,43,47
Argon	Laboratory data	Laboratory data	19,43,47

Laboratory data — Laboratory plus correlations — All corrected data

Liquid Heat Capacity—Fig. 9–4





Liquid Density—Fig. 9–5

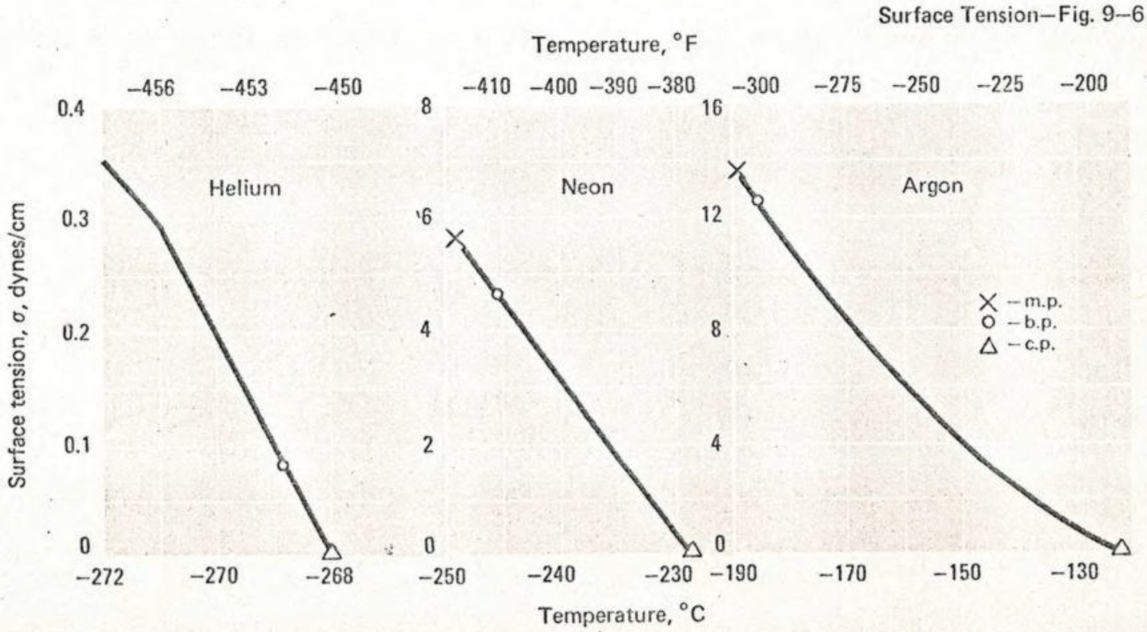
Fig. 9–5	Temperature Range m.p.–b.p.	Temperature Range b.p.–c.p.	References
Helium	■	■	10,43,345,383
Neon	■	■	10,43,337,345,364,384
Argon	■	■	10,43,149,337,345,358,365,382

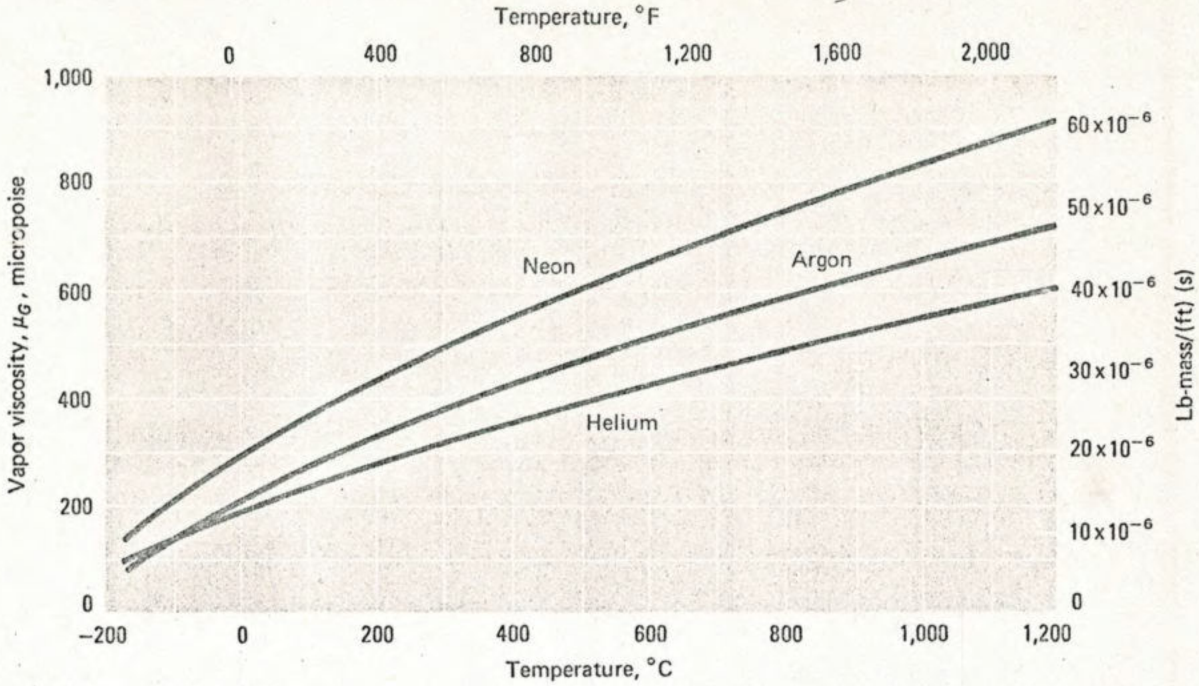
■ Laboratory data ◪ Laboratory plus correlations □ All corrected data

Fig. 9–6	Temperature Range m.p.–b.p.	Temperature Range b.p.–c.p.	References
Helium	◪	□	47,79,345
Neon	◪	◪	47,345
Argon	■	◪	47,79,310,342,345,382

■ Laboratory data ◪ Laboratory plus correlations □ All corrected data

Surface Tension—Fig. 9–6





Vapor Viscosity—Fig. 9–7

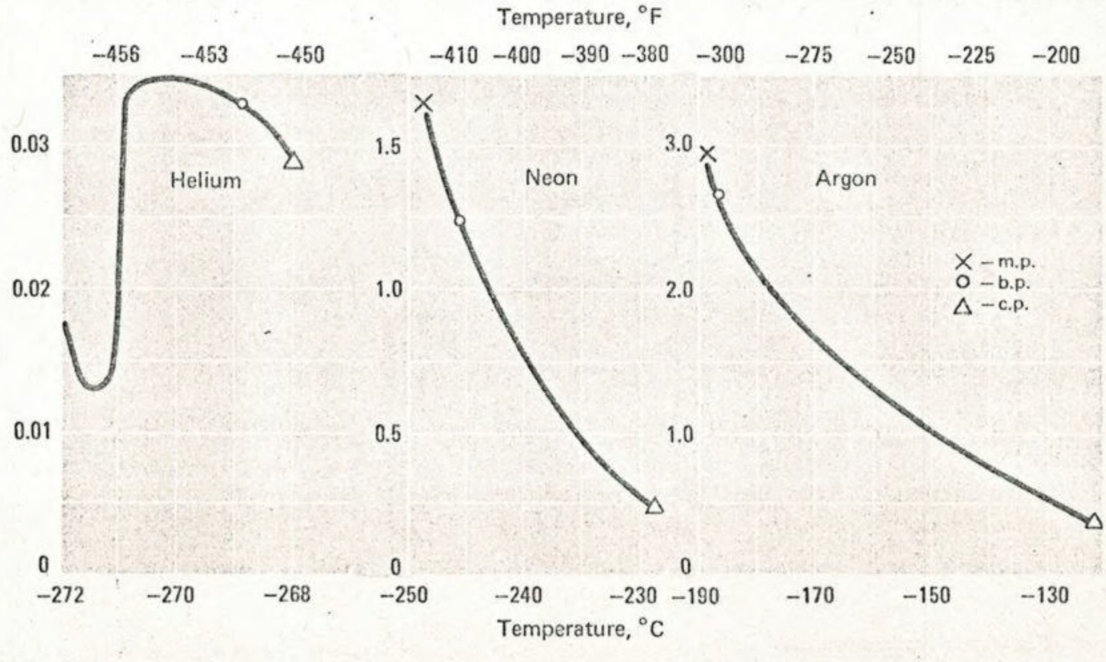
Fig. 9–7	Temperature Range, °C			References
	0–500	500–1,000	1,000–1,500	
Helium	■	■	■	18,43,47,158,269,270,274,278,281,291,294,306, 317,339,345,364,367,368,374,375,392,396
Neon	■	■	■	18,43,47,158,269,270,274,291,294,345,361,368, 369,374,375,382,407
Argon	■	■	■	18,43,47,158,270,281,291,293,294,345,348,362, 363,365,367,368,369,374,375,387,392,402,408

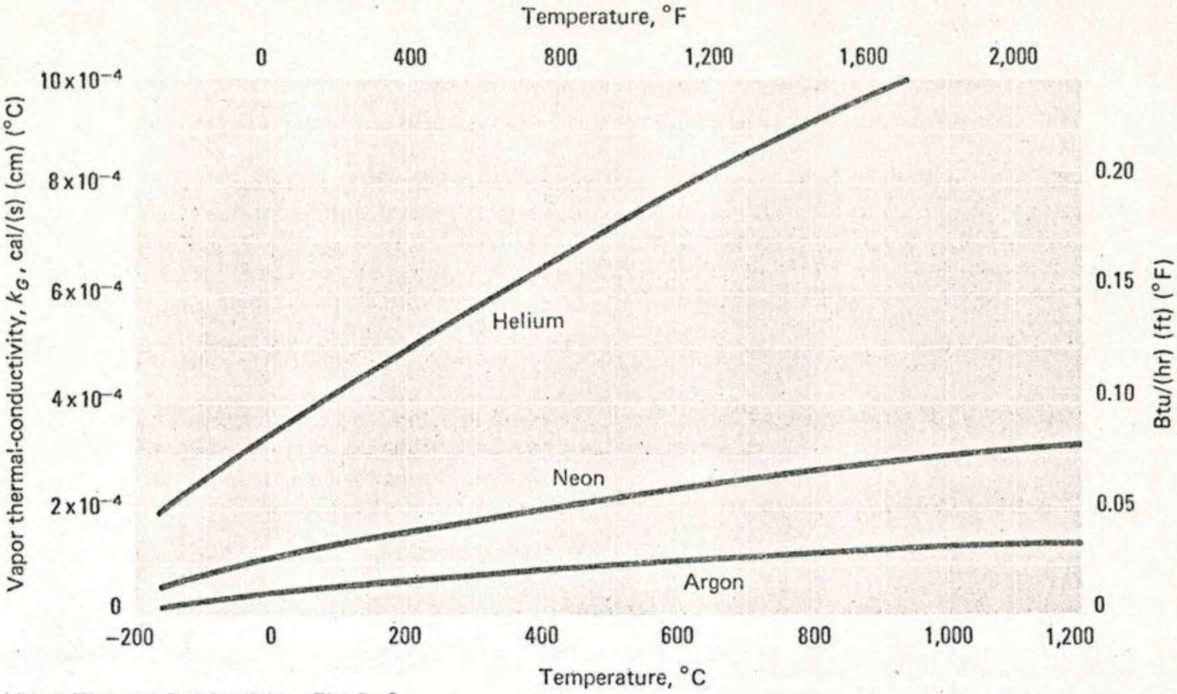
■ Laboratory data ◪ Laboratory plus correlations □ All corrected data

Fig. 9–8	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Helium	◪	◪	43,47,290,306,317,339,345,364,374,375,392,399
Neon	◪	◪	43,263,276,290,337,374,379,392
Argon	◪	◪	43,47,263,271,276,290,300,337,345, 365,374,375,402

■ Laboratory data ◪ Laboratory plus correlations □ All corrected data

Liquid Viscosity—Fig. 9–8





Vapor Thermal Conductivity—Fig. 9-9

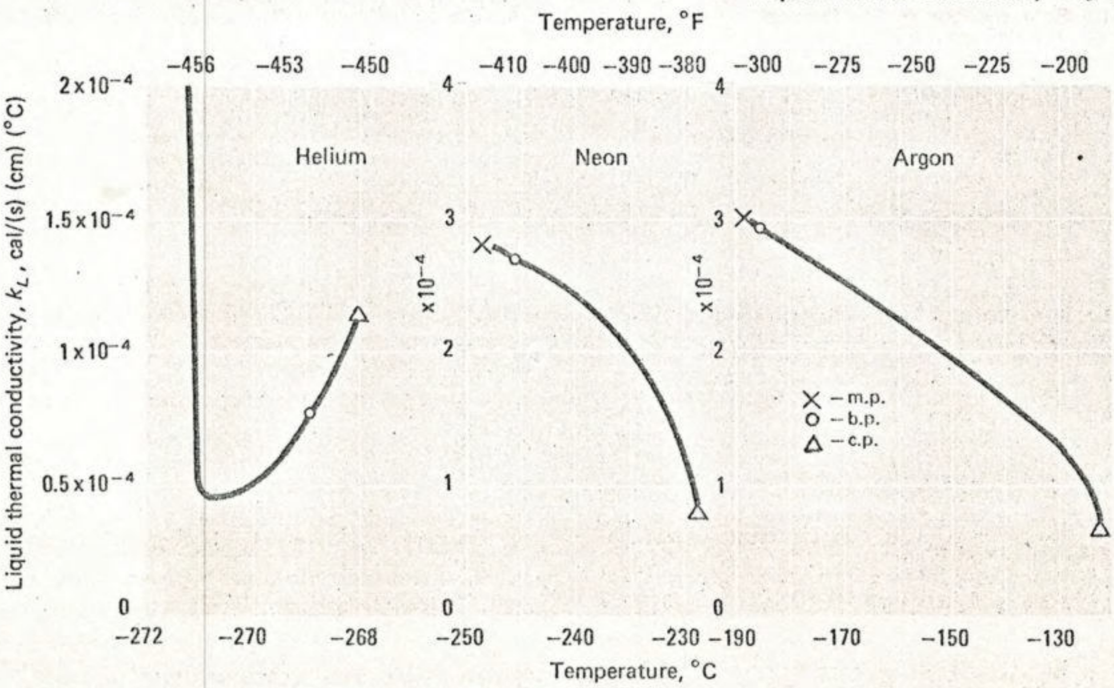
Fig. 9-9	Temperature Range, °C			References
	0–500	500–1,000	1,000–1,500	
Helium	■	■	■	18, 19, 43, 44, 47, 158, 267, 306, 317, 318, 323, 339, 345, 349, 350, 351, 353, 364, 366, 368, 373, 374, 375, 385, 392, 399, 401
Neon	■	■	◪	18, 19, 43, 44, 47, 158, 31?, 344, 353, 368, 374, 375, 390, 392, 401, 407
Argon	■	■	■	18, 19, 43, 44, 47, 158, 266, 293, 316, 318, 328, 344, 345, 349, 353, 363, 368, 373, 374, 375, 385, 389, 390, 392, 401, 402, 408

■ Laboratory data ◪ Laboratory plus correlations □ All corrected data

Fig. 9-10	Temperature Range		References
	m.p.–b.p.	b.p.–c.p.	
Helium	◪	□	19, 44, 47, 290, 345, 364, 374, 392, 399
Neon	◪	◪	19, 43, 44, 290, 374, 392
Argon	◪	◪	19, 43, 44, 47, 288, 290, 306, 316, 328, 345, 374, 392, 402

■ Laboratory data ◪ Laboratory plus correlations □ All corrected data

Liquid Thermal Conductivity—Fig. 9-10



of correlated values and experimental data were reported as 1.4% for neon and 2.4% for argon.

Thermal Conductivity—Fig. 9–9, 9–10

Investigators [*19,44,407,408*] have reviewed gas-phase thermal-conductivity data at atmospheric pressure for helium, neon and argon, and have selected recommended values. Deviations were reported to be 1 to 2% at temperatures below 200°C, and 5 to 10% at higher temperatures. More-recent results [*349,351,389,390*] are in agreement.

For liquid-phase thermal-conductivity data, the recommended values of TPM investigators were selected, based on good agreement with experimental data. The shape of the helium curve quite likely arises from the transition influences. Helium below 2.2 K is superconductive—several hundred times more than copper [*19*]. Uncertainties in the recommended values are reported to be 2 to 10% at lower temperatures, possibly increasing to 20 to 40% at the critical point.

A Note About Helium

Liquid helium is unique in many ways. When it was first liquefied in 1908, attempts to solidify the liquid were unsuccessful even at 0.8 K. However, at a pressure of 25 atm, helium solidifies at 1.0 to 1.5 K [*43*]. Further, as liquid helium is cooled, a transition occurs at about 2.2 K, forming a liquid called helium II. This transition (called the lambda point) marks the boundary between classical and quantum fluids [*43*].

Properties of helium II are much different than those of helium I. In this article, data above 2.2 K apply to liquid helium I, and those below to liquid helium II. In addition, it should be noted that the terms in each graphical insert for helium apply for the temperature range shown in the plot. #

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