# Density, Viscosity, and Thermal Conductivity of Liquid Boron Trichloride

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**The density, viscosity, and thermal conductivity of liquid boron trichloride were determined at atmospheric pressure in the range from −40° to +10° C. and fitted in this range by standard equation forms.**

AS PART OF AN EFFORT to develop specialized techniques for measuring various liquid heat transfer properties, the density, viscosity, and thermal conductivity of liquid boron trichloride were determined at atmospheric pressure in the range from −40° to +10° C. The criteria for the measurement techniques were desirability of small sample size, remote measurement capability, variable temperature, adaptability to a closed vacuum system, and ease of operation.

## EXPERIMENTAL

**System Equipment.** An all-glass vacuum system was constructed for purification and transfer of the boron trichloride. A two-pressure nitrogen system was used for sample transfer where evaporation and condensation could not be used. A carbon dioxide controlled-temperature test chamber was connected to the glass transfer system. The test apparatus for the property measurements was placed in a constant-temperature bath located within the test chamber. This arrangement eliminated the small thermal cycling effect of the test chamber.

**Preparation of Boron Trichloride Samples.** The boron trichloride (Stauffer) had the following provided analysis:

| | |
|---|---|
| $BCl_3$ | 98.8% |
| $Cl_2$ | <0.77% |
| $COCl_2$ | <0.5% |
| Sulfur | None |

This was condensed at −78° C. as a solids-free, clear yellow liquid. The liquid was distilled in a three-step vacuum distillation train, the middle third cut of each step being retained for the next step. The resulting liquid, still slightly yellow, was scrubbed with mercury at 0° C. to remove the chlorine. The clear, colorless liquid product was used in this study. No further analysis of this product was made.

**Density.** The density was determined in a specially constructed magnetic densimeter, a small glass float containing an iron core which was held on the bottom of a sample tube by a small external electrical field. The field current was slowly decreased until the float left the bottom of the sample tube. This departure current was used to read the density from the density-current calibration plot. The apparatus was designed so that electrical heating effects were minimized. Details of the construction of the densimeter and the associated mathematical analysis are reported elsewhere (*7*).

The densimeter was calibrated at 25° C. with aqueous potassium and sodium bromide solutions over the range from 1.3592 to 1.4374 grams per cc. These solution densities were determined with a Westphal balance. Calibrations were also made with liquid sulfur dioxide from +10° to −40° C. over the density range from 1.4599 to 1.5332 grams per cc. Literature values (*3*) of the sulfur dioxide density were used. Although these calibration ranges did not quite overlap, they appeared to be in agreement, and a density-current calibration plot was made from these data.

Boron trichloride was condensed into the sample tube and current measurements were made at 5° C. intervals from +5° to −40° C. The pressure was maintained at 760 mm. of Hg with nitrogen.

**Viscosity.** The viscosity apparatus consisted of a modified Ubbelohde suspended-level glass viscometer (*5*). This was used as a comparative viscometer, so that dimensions were not critical. The 0.5-mm. capillary was about 128 mm. long. The liquid volume was about 9 ml. A two-pressure nitrogen transfer system was used to pump the liquid into the viscometer reservoir.

The viscometer was calibrated with acetone at +24° C., carbon tetrachloride at +25° and 0° C., and distilled water at +24° C., using literature values (*3*) of viscosity. These data were used to obtain the calibration constants, $A$ and $B$, in the viscometer equation (*5*)

$$\mu = \rho[A\tau - B/\tau]$$

No further low-temperature calibration was made, since the constants did not change over a 25° C. span.

Boron trichloride was condensed into the apparatus and viscosity measurements were made at 5° C. intervals from −40° to +10° C.

**Thermal Conductivity.** The thermal conductivity apparatus was a thin-wire cylindrical assembly consisting essentially of a 0.0038-inch platinum heating filament centered in a ground 0.375-inch borosilicate glass tube. A four-lead arrangement similar to that of Cecil and Munch (*2*) was used to eliminate lead resistance effects and minimize end effects. The apparatus is described in detail elsewhere (*7*).

Although the thermal conductivity method is an absolute one, a check on the apparatus was made by measuring the thermal conductivity of methanol at 25° C., which has been reported in the literature (*2*).

## RESULTS AND DISCUSSION

**Density.** The density results (Table I) are also shown in Figure 1 for comparison with the single value reported by Briscoe *et al.* (*1*). The data were fitted by the equation

$$\rho = 1.3730 - 0.002159\,t - 8.377 \times 10^{-7}\,t^2 \qquad (1)$$

with a maximum deviation of 0.07%.

**Viscosity.** The viscosity of liquid boron trichloride (Table I) is illustrated in Figure 2. These data were fitted by the equation

$$\mu = \frac{0.34417}{1 - 0.0069662\,t - 5.9013 \times 10^{-6}\,t^2} \qquad (2)$$

with a maximum deviation of 0.8%.

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Table I. Density, Viscosity, and Thermal Conductivity of Liquid Boron Trichloride

| Temp., °C. | Density, Grams/Cc. | Viscosity, Centipoise | Thermal Conductivity, Cal./Cm.-Sec.-° C. | |
|---|---|---|---|---|
| | | | Mean value | 95% confidence limits |
| −44 | 1.4674 | | | |
| −40 | 1.4571 | 0.4794 | | |
| −35 | 1.4470 | 0.4599 | | |
| −30 | 1.4369 | 0.4406 | $27.3 \times 10^{-5}$ | $26.8 < (k \times 10^5) < 27.9$ |
| −25 | 1.4268 | 0.4215 | | |
| −20 | 1.4162 | 0.4024 | | |
| −15 | 1.4056 | 0.3850 | | |
| −10 | 1.3945 | 0.3684 | $26.7 \times 10^{-5}$ | $26.5 < (k \times 10^5) < 27.1$ |
| −5 | 1.3837 | 0.3548 | | |
| 0 | 1.3728 | 0.3429 | | |
| +5 | 1.3621 | 0.3325 | | |
| +10 | | 0.3236 | $25.2 \times 10^{-5}$ | $24.8 < (k \times 10^5) < 25.5$ |

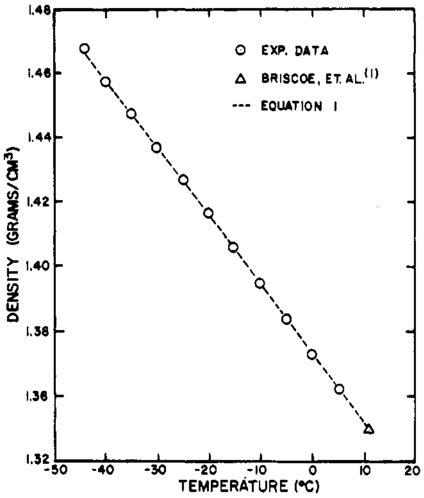

Figure 1. Density of liquid boron trichloride

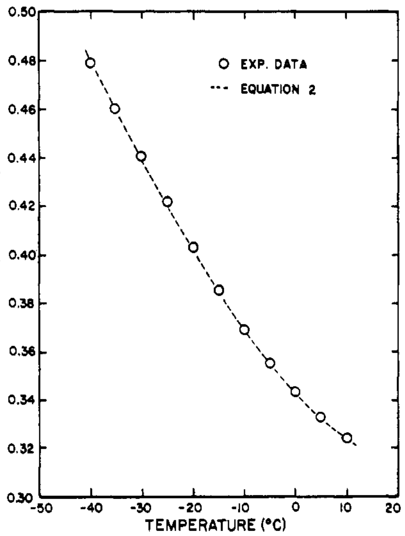

Figure 2. Viscosity of liquid boron trichloride

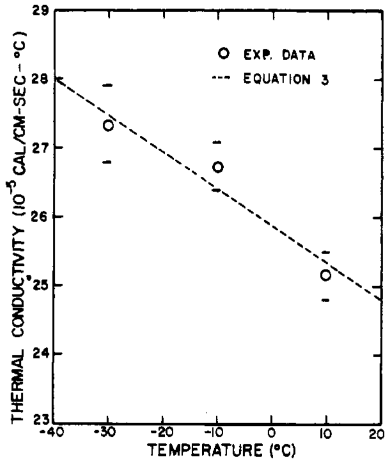

Figure 3. Thermal conductivity of liquid boron trichloride

Viscosity data for liquid boron trichloride were also reported by Luchinskiĭ (*4*). These were not at all in agreement with the present results. Luckinskiĭ reported viscosity results calculated from measurements of kinematic viscosity and density and no thorough comparison was possible.

**Thermal Conductivity.** Thermal conductivity data were obtained at only three temperatures. Since there was some scatter in the raw data and the calculation procedure involved the calculation of a derivative, the results are reported in Table I as 95% confidence limits and shown as short horizontal lines in Figure 3. The mean values at each temperature were fitted with a straight-line equation because the quadratic term was statistically insignificant. This equation, illustrated in Figure 3, is

$$k = 10^{-5}\,[25.88 - 0.525\,t] \tag{3}$$

Sakiadis and Coates (*6*) also fitted thermal conductivity data with a linear expression.

## NOMENCLATURE

$A, B$ = viscometer calibration constants
$k$ = thermal conductivity, cal./cm. sec. ° C.
$t$ = temperature, ° C.
$\mu$ = viscosity, centipoise
$\rho$ = density, grams/cc.
$\tau$ = viscometer flow time, sec.

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