ANALYSIS OF THE DENSITY AND REFRACTIVE INDEX OF NEON FROM EXPERIMENTAL VALUES OF THE DIELECTRIC PERMITTIVITY

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Results of a dielectrometric investigation of neon are used to compute the density by means of a virial expansion of the molar polarization, and also the refractive index by means of the dispersion of polarizability.

A dielectrometric method permits performance of noninertial and local recording of the density of a capacitive sensor whose electrical signal agrees optimally with the automated control diagram of a technological process [1].

Moreover, the refractive index n can be computed by means of the measured values of the dielectric permittivity ε of compressed nonpolar gases by eliminating the necessity to conduct more complex refractometric investigations [1] methodically.

To go from the measured values of ε to the molar density ρ we apply the virial expansion of the molar polarization P [2] by virtue of whose rapid convergence three of its terms are sufficient to describe ε not only for compressed nonpolar gases but also fluids:

$$P = \frac{\varepsilon - 1}{\varepsilon + 2}\frac{1}{\rho} = A_\varepsilon + B_\varepsilon\rho + C_\varepsilon\rho^2, \tag{1}$$

where A_ε, B_ε, C_ε are the dielectric virial coefficients, by knowing which we can compute the values of ρ by means of measured values of ε and (1) and can compare them with those calculated by means of the equation of state [3]

$$Z(\rho, T) = 1 + \sum_{i=1}^{m}\sum_{j=1}^{n} b_{ij}\rho^i\tau^j, \tag{2}$$

where b_{ij} are coefficients of a polynomial and $\tau = T/T_{cr}$ is the reduced temperature.

Presented in Fig. 1 are results of an experimental investigation of the dielectric permittivity of neon on a modified installation [4, 5] in a 77-573 K temperature range and at pressures to 60 MPa with a 0.07% error. High purity neon (99.9725 vol. %) was used to measure the dielectric permittivity.

Changes in the capacitance C(p, T) of a cylindrical capacitor as a function of the temperature and pressure were recorded during the experiment. The dielectric permittivity was computed from the formula

$$\varepsilon = \frac{C(p, T)}{C_0(T)}\left(1 + \frac{p \cdot 10^{-5}}{1{,}767 - 0{,}00067T}\right), \tag{3}$$

where C(p, T) is the capacitance of a capacitor filled with the gas under investigation, $C_0(T)$ is the capacitance of an evacuated capacitor, and p is pressure.

The expression (3) takes account of the change in the geometric dimensions of the capacitor with temperature and pressure. Temperature deformations are taken into account by measuring the dependence of the evacuated capacitor capacitance on the temperature. Taking account of the change in geometric dimensions of the capacitor with the pressure change is realized by the factor in parenthesis in (3).

The density is computed from the equation of state [3] and the dependence $\varepsilon(\rho)$ is constructed (Fig. 2). Comparison between the results obtained with the data in [6] in which experimental values of $\varepsilon(\rho)$ are presented for 298 K in the 200-800 MPa range yields agreement within the limits of experiment error ($\delta\varepsilon$ = 0.07%).

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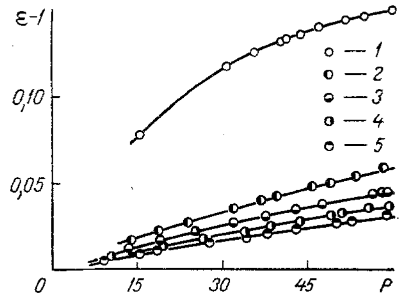

Fig. 1. Results of an experimental investigation of the dielectric permittivity of neon: 1) T = 77.35 K; 2) 273.15; 3) 373.15; 4) 473.15; 5) 573.15. P, MPa.

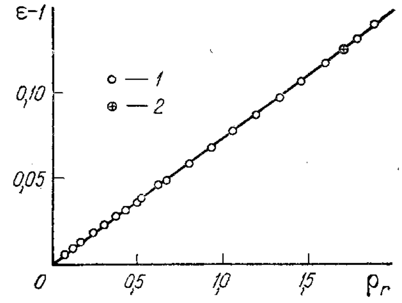

Fig. 2. Dependence of the dielectric permittivity of neon on the reduced density: 1) T = 77.35-573.15 K; 2) 298 [6].

To calculate the density by means of the measured dielectric permittivity, the values $A_\varepsilon = 0.996 \pm 0.001$ cm³/mole, $B_\varepsilon = -0.22 \pm 0.02$ cm⁶/mole², $C_\varepsilon = -0.9 \pm 0.3$ cm⁹/mole³ are taken from [6]. The density calculated from ε by means of (1) differs from that computed by means of (2) by not more than 0.6% in the 77-573 K temperature range at pressures to 1000 kg/m³. The error $\delta\rho$ in determining the neon density calculated from (1) is 0.1% for $2\rho_{cr}$ because of the uncertainty of each of the values A_ε, B_ε, C_ε, and 0.5%, because of the error $\delta\varepsilon$ in measuring the dielectric permittivity ε. The total value of the error in the density calculated by means of (1) in the $(0.5\text{-}2)\rho_{cr}$ range does not exceed 0.8%.

Therefore, the main contribution to $\delta\rho$ is given by the error in measuring the dielectric permittivity. In the best case $\delta\varepsilon$ is successfully reduced to 0.01% of $(\varepsilon-1)$. Then $\delta\rho$ due to the measurement of ε does not exceed 0.01% and the error in the value of A_ε is the main contribution to $\delta\rho$. It must be noted that for helium whose value of A_ε is known with high accuracy 0.51725 ± 25.10^{-6} cm³/mole, the total error in the density calculated by means of the virial equation (1) does not exceed 0.1% for double the critical density.

To set up a connection between the static dielectric permittivity and the refractive index n we examine the viral expansion of the molar refraction R(ω) [7] similar to (1):

$$R(\omega) = \frac{n^2-1}{n^2+2}\frac{1}{\rho} = A_R + B_R\rho + C_R\rho^2, \tag{4}$$

where A_R, B_R, C_R are the refraction virial coefficients.

Let us introduce the function F(ω) describing the dispersion of the molar refraction

$$F(\rho,\ \omega) = \frac{R(\rho,\ \omega)}{P(\rho)}. \tag{5}$$

Solving (1), (4), and (5) jointly, we obtain an equation connecting the refractive index n with the dielectric permittivity ε

$$n^2 = \varepsilon + \frac{3P\rho}{(1-P\rho)^2}[F(\omega)-1]. \tag{6}$$

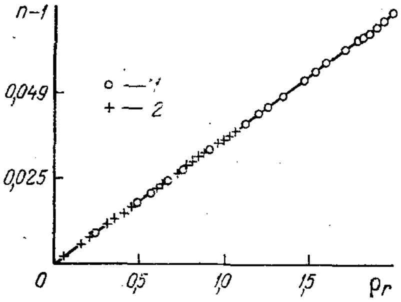

Fig. 3. Dependence of the neon refractive index on the reduced density: 1) values of n calculated from data on the dielectric permittivity; 2) values of n from refractometric investigations [10].

Substituting the Clausius–Massotti function in place of the molar polarization, we write

$$n^2 = \varepsilon + \frac{1}{3}(\varepsilon - 1)(\varepsilon + 2)[F(\omega) - 1]. \tag{7}$$

For isolated molecules the dispersion function has the form

$$F(\omega) = \frac{\alpha(\omega)}{\alpha_0} = f(\omega), \tag{8}$$

where $\alpha(\omega)$ is the dynamical polarizability of the molecules, α_0 is the static polarizability, and $f(\omega)$ is the dispersion factor [8]

$$f(\omega) = \sum_s \frac{f_s}{\omega_s^2 - \omega^2}.$$

Here f_s is the strength of the s-th oscillator, ω_s is the natural vibrations frequency of the s-th oscillator, and ω is the electromagnetic wave frequency. However, determination of the dispersion is a complex problem, consequently, the dispersion factor is ordinarily calculated by means of the Cauchy relationship [9]

$$f(\omega) = 1 + \sum_{i=1}^{n} \frac{A_i}{\lambda^{2i}},$$

where λ is the wavelength and A_i are empirical constants.

Substituting (8) into (7), we obtain an equation connecting the refractive index with the dielectric permittivity with the dispersion dependence of isolated molecules taken into account

$$n^2 = \varepsilon + \frac{1}{3}(\varepsilon - 1)(\varepsilon + 2)\, d(\omega), \tag{9}$$

where $d(\omega) = f(\omega) - 1$ is the dispersion factor.

The neon refractive index was computed from measured values of the dielectric permittivity for $\lambda = 623.99$ nm with 0.07% error ($f(\omega) = 1.0056$) by means of the equation (9) we obtained. Results of the computation and their comparison with refractometric measurement data for the index of refraction [10] are presented in Fig. 3. Data on the 100 K isotherm and for pressures to 24 MPa were taken from [10] because of the attainment of the maximal density on this isotherm.

As is seen from Fig. 3, the results of calculating the refractive index from measured values of the dielectric permittivity are in agreement with experimental values obtained by an interference method, within the limits of computation error.

In conclusion, the importance of further development of nontraditional methods of determining the density must be noted. The main advantage to finding ρ and n by means of values of ε is in its relative methodological simplicity and the possibility of investigating the latter within a broad range of state parameters. Moreover, determination of the dependence $\varepsilon(\rho)$ permits the production of sensors for inertialess checking of the mixture density and concentration in technological processes with derivation of information on automated control systems of technological processes (ACSTP).

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THERMAL CHARACTERISTICS OF WATER FOAMS

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As the size of foam cells increases natural convection arises and the thermal conductivity of the foam starts to grow with the foam ratio remaining constant. The factor that takes into account the effect of convection is determined.

The use of water foams for extinguishing fires has motivated the study of their thermal characteristics: thermal conductivity and thermal diffusivity. On the one hand, the protective layer of foam should make it possible to remove through it a quite intense flux of heat released on the burning surface. On the other hand, heat fluxes due to conduction or radiation, heating this protective layer with a certain intensity, can increase the temperature in the volume of the foam itself to such an extent that the foam will completely evaporate. To make quantitative estimates and predictions of the intensity of the processes indicated above it is necessary to know the effective thermal conductivity λ_e of foams of different origin and structure. Since the thermal conductivity of the gas phase λ_g in air bubbles is approximately one to two orders of magnitude lower than that of water λ_l, of which the liquid interlayers forming the envelopes of the gas bubbles consist, the main heat transfer can be concentrated along the tortuous liquid framework of the foam on the one hand, while the heat flux repeatedly encounters air gaps of bubbles in its path that do not conduct heat well on the other. It is well known, for example, that in a system of granular layers of hard particles "turned inside out" with respect to the foam it is precisely these air interlayers, which contain components of the mixture with relatively low thermal conductivity, that form the main resistance to heat transfer. In building construction, the thermal insulating properties of barriers can be increased by inserting air interlayers, as done, for example, in doubly glazed windows. The principal defect of such air interlayers in barriers is that as the thickness of the cavity increases, convection flows, facilitating heat transfer through the interlayer and degrading its thermal insulating properties, arise. For this reason, instead of macroscopic air interlayers preference is given to cavities filled with small particles of a solid phase (crushed stone, cinders, cotton, wool), the air gaps between which are so small that the convection arising can be neglected in practice. The correction to the effective thermal conductivity caused by natural convection is given by [1]

$$\varphi = 1 + 0.5\,\mathrm{Ra}, \tag{1}$$

where the so-called Rayleigh criterion

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