The thermodynamic properties of 1-bromoadamantane in the gaseous state

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Abstract

The saturated vapour pressure over two crystalline phases (crI and crII) of 1-bromoadamantane in the temperature range from 288 to 323 K was measured by the integral Knudsen effusion method with the use of a modified effusion cell with an enlarged surface of sublimation. The temperature dependences of p_{sat} are the following:

for crII between $T = 288.4$ and 309.9 K:

$\ln\{p_{sat}(crII) (Pa)\} = (30.33 \pm 0.44) - (8608 \pm 137) \cdot (T(K))^{-1}$,

for crI from 309.9 to 323.0 K:

$\ln\{p_{sat}(crI) (Pa)\} = (27.07 \pm 0.81) - (7600 \pm 252) \cdot (T(K))^{-1}$.

The sublimation enthalpy for the compound at $T = 303.0$ K was measured in a differential heat-conducting microcalorimeter of the Calvet type, $\Delta_{sub}H_m^\circ(303.0 \text{ K}) = 71.77 \pm 0.31 \text{ kJ mol}^{-1}$, which agrees with the value obtained by the effusion measurements, $\Delta_{sub}H_m^\circ(298.1 \text{ K}) = 71.6 \pm 1.1 \text{ kJ mol}^{-1}$, within the experimental errors. The molar thermodynamic functions of 1-bromoadamantane in the ideal gaseous state were calculated by the statistical thermodynamic method. The complete set of the fundamentals necessary for the above calculations was made up from the experimental IR and Raman spectral data and the results of DFT calculations (B3LYP/6-31G*). The enthalpy of formation for 1-bromoadamantane was evaluated in terms of three different approaches. The thermodynamic analysis of some reactions with 1-bromoadamantane was performed.
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1. Introduction

In the last few decades adamantane derivatives have found widespread applications in medicine due to their diverse pharmacological action. Such behaviour is likely to be determined by their specific molecular structure. The derivatives contain the hydrophobic adamantane cage (which provides penetration of these molecules straight into a cell through the lipid membrane) with various hydrophilic substituents (which are responsible for biological activity as well as relatively rapid assimilation and transportation of the substances to the required center). The spectrum of the biological activity of these medications is very wide [1–4]: they possess neuroprotective and neuromodulating action, they are also used for treatment for numerous virus diseases (e.g. influenza, hepatitis, etc.), for stimulation of the immune system, and so on. For example, amantadine and the structurally similar derivatives of 1-aminoadamantane are able to prevent disfunction and death of nerve cells under a number of different

cerebral afflictions such as Parkinson's and Alzheimer's diseases, hypoxic brain damage, neuroinfections and stroke [1]. It should be pointed out that the syntheses of the pharmaceutically active adamantane derivatives are characterized by low yields of the target products (less than 10%). The optimization of the conditions of their production requires detailed thermodynamic information.

1-Bromoadamantane is an intermediate in the synthesis of the majority of the adamantane-based drugs. The investigation of the thermodynamic properties of 1-bromoadamantane in the condensed state was presented earlier [5]. The study of its properties in the gaseous state is also important since this information can be used to offer an optimal way to organize the purification process both for intermediates and target products at different production stages. Furthermore, this can enable technologists to take into account a possible loss of the substance because of its volatility. That is why the experimental and theoretical investigation of the thermodynamic properties for 1-bromoadamantane in the gaseous state has been carried out in the present work.

2. Experimental

2.1. Sample preparation

A commercial sample of 1-bromoadamantane (Aldrich Chem. Co., Inc.) with the mass fraction purity >0.99 was purified by triple recrystallization from acetone and subsequent sublimation at $T = 313$ K and $p = 0.4$ kPa. The final mass fraction purity of the sample obtained was 0.9984 as determined by g.l.c. with a flame-ionization detector. A single peak associated with the impurity was detected in the descending branch of the main peak. The impurity is likely to be 2-bromoadamantane—a structural isomer of 1-bromoadamantane. In this case, it would give a minor contribution to the vapour pressure and the sublimation enthalpy of the target compound.

2.2. The calorimetric determination of the sublimation enthalpy

The measurement of the sublimation enthalpy for 1-bromoadamantane was performed in a differential heat-conducting microcalorimeter of the Calvet type MID-200 with special calorimetric cells described earlier [6,7]. In every individual experiment, a sample was placed into one of the stainless-steel cells that was then hermetically sealed with a nickel membrane. The calorimeter was equilibrated to a constant temperature and afterwards the membrane was punctured with a special removable needle. The substance was sublimed in vacuum with residual pressure of about 1–0.1 Pa. The electric signal proportional to the heat flow induced by the evaporation process was recorded by a voltmeter. The uncertainty of the sublimation enthalpy determination was found to be: $\pm 5 \times 10^{-3} \times \Delta_{\mathrm{sub}} H_{\mathrm{m}}^{\circ}$ [6,7].

The molar enthalpy of sublimation $\Delta_{\mathrm{sub}} H_{\mathrm{m}}^{\circ}$ for the compound under study was calculated with the following equation:

$$\Delta_{\mathrm{sub}} H_{\mathrm{m}}^{\circ} = (Km)^{-1} \cdot M \cdot \int_{t=0}^{\tau} \Delta E \, \mathrm{d}t, \tag{1}$$

where m is the mass of the sample under vacuum; M its molar mass; K the calorimetric constant of the cell at the average temperature; ΔE the thermocouple voltage corresponding to the temperature difference between the cell and the thermostat at the point in time t; $\int_{t=0}^{\tau} \Delta E \, \mathrm{d}t$ the integrated signal recorded by the voltmeter in the course of the experiment; τ is the duration of the experiment.

The calibration of the cells used in the present work was carried out in a series of independent experiments using chromatographic-purity naphthalene since there are reliable data on the thermodynamics of its sublimation [8,9]: $\Delta_{\mathrm{sub}} H_{\mathrm{m}}^{\circ}$ (298.15 K) $= 72.60 \pm 0.60$ kJ mol^{-1} and $\overline{\Delta_{\mathrm{cr}}^{\mathrm{g}} C_{\mathrm{p}}^{\circ}} = -(34 \pm 2)$ J K^{-1} mol^{-1}.

2.3. The integral Knudsen effusion method

The saturated vapour pressures over two crystalline phases of 1-bromoadamantane in the temperature range 288–323 K were determined by the integral Knudsen effusion method. The device construction and the measurement procedure were described in detail earlier [10]. The uncertainty of the vapour pressure determination by the Knudsen method did not exceed $\pm 5 \times 10^{-2} \times p_{\mathrm{sat}}$.

In most cases, solid organic compounds have small values of thermal conductivity and, hence, an increase in the contact surface of the solid substances with the walls of an effusion chamber is of great importance for facilitating heat transfer. The evaporation surface should also be enlarged in order to accelerate attainment of equilibrium in the system 'condensed phase—vapour', especially under conditions of dynamic effusion. Both these ideas have been realized in a new modified effusion cell (Fig. 1) for the determination of vapour pressures of solid substances. The cylindrical container of 27 mm length and 10 mm internal diameter was made of stainless steel. Sixteen canals (1 mm diameter and 17 mm length) were drilled in the base of the cell. Before the measurements, a thin layer of the substance was spread all over the inner walls of the cell and then pressed against them.
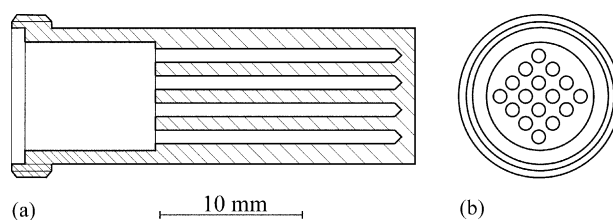

Fig. 1. The scheme of the modified cell for the effusion measurements of saturated vapour pressures of solid samples: (a) the sectional view and (b) the view from above.