Molekulāri kinētiskā teorija

2024-01-13

Iesildīšanās

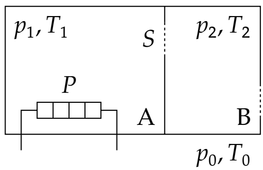
1° Cilindrisks trauks atrodas vakuumā bezsvara stāvoklī. Uz trauka apakšējās malas ir uzklāta plāna kārtiņa no cietas vielas ar molmasu μ. Kārtiņa lēni sublimē, un tādēļ trauks iegūst ātrumu. Trauka masa M, kārtiņas masa $m \ll M$, trauka temperatūra T nemainās laikā. Cik liels ir maksimālais ātrums, ko sasniegs trauks?

MKT un efūzija

2° Galvanometra spogulītis ir iekarināts kvarca diegā. Uz spogulīti krīt šaurs paralēls gaismas kūlis un, atspoguļojoties, nokrīt uz ekrāna, kas atrodas attālumā L no spogulīša. Gaisa temperatūra ir T. Novērtējiet, par cik palielināsies rādiuss gaismas plankumam uz ekrāna spogulīša siltumkustības dēļ. Spogulītim pagriežoties pa leņķi φ, diegā radās elastības spēku moments $M = -k\varphi$.

3° Natural uranium mainly consists of two isotopes, ^{238}U and ^{235}U, and the abundance of the latter is 0,7 %. Uranium is enriched by a multi-stage process, where at each stage evaporated UF_6 passes through a porous wall – a thin film with microscopic holes, much smaller than the mean free path of the molecules, but larger than the size of the molecules. How many stages are needed to increase the content of ^{235}U to 1,4 %? The molar mass of fluorine $\mu_F = 19\,\mathrm{g\,mol^{-1}}$.

4° Siltumizolēts trauks ir sadalīts divās daļās ar siltumizolējošu sieniņu A, kurā ir daudz mazu caurumu ar kopējo laukumu S. Identiski caurumi ar tādu pašu kopējo laukumu ir izveidoti vienā no trauka sienām B. Trauka pirmajā daļā ieslēdza sildītāju ar jaudu P. Trauks ir aizpildīts ar argonu un ir ievietots argona atmosfērā. Ārējais spiediens p_0 un temperatūra T_0 laikā nemainās. Novērtējiet stacionārus spiedienus (p_1, p_2) un temperatūras (T_1, T_2) abās trauka daļās. Skaitliskajam novērtējumam izmantojiet vērtības $P = 20\,\mathrm{W}$, $S = 10\,\mathrm{mm^2}$, $p_0 = 1{,}0 \cdot 10^5\,\mathrm{Pa}$, $T_0 = 300\,\mathrm{K}$, $\mu_{Ar} = 40\,\mathrm{g\,mol^{-1}}$.



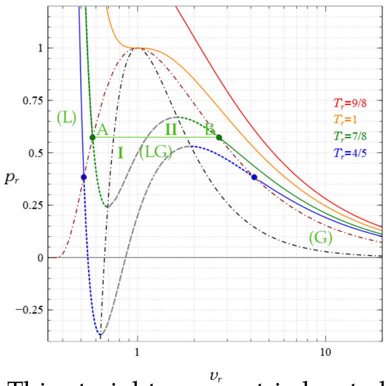
5° 3 km augstumā virs zemes putekļīšu koncentrācija gaisā ir $10^2\,\mathrm{cm^{-3}}$, bet tuvu pie zemes virsmas — $10^5\,\mathrm{cm^{-3}}$. Novērtējiet putekļīša vidējo masu, ja gaisa temperatūra ir 300 K.

Reālās gāzes

6° (*IPhO 2014*) With account of intermolecular attraction forces, van der Waals proposed the following equation of state that neatly describes both the gaseous and liquid states of matter

$$\left(p + \frac{a}{V^2}\right)(V - b) = RT,$$

where the amount of substance is assumed to be 1 mol. At temperatures below a certain critical value T_c, the van der Waals isotherm is non-monotonic. A real isotherm differs from the van der Waals isotherm by a straight segment AB drawn at some constant pressure p_lg. This straight segment is located between the volumes V_l and V_g and corresponds to the equilibrium of the liquid phase (L) and the gaseous phase (G). The pressure p_lg must be chosen such that the areas I and II in Fig. 1 are equal. With increasing temperature the straight segment AB on the isotherm shrinks to a single point when the temperature and the pressure reaches some values T_c and p_c, respectively.



(a) Express the van der Waals parameters a and b in terms of T_c and p_c.

(b) Estimate the diameter of gas molecules.

This part of the problem deals with the properties of water in the gaseous and liquid states at temperature $T = 100\,°\mathrm{C}$. The saturated vapour pressure at this temperature is known to be $p_\mathrm{lg} = p_0 = 1{,}0 \cdot 10^5\,\mathrm{Pa}$. The molar mass of water is $\mu = 18\,\mathrm{g\,mol^{-1}}$. It is reasonable to assume that the inequality $V_\mathrm{g} \gg b$ is valid for the description of water properties in a gaseous state.

(c) Express the volume of the vapour V_g in terms of R, T, p_0 and a.

If the system volume is reduced below V_g, the gas starts to condense. However, thoroughly purified gas can remain in a mechanically metastable state (called supercooled vapour) until its volume reaches a certain value $V_{\mathrm{g\,min}}$. The condition of mechanical stability of supercooled gas at constant temperature is $\mathrm{d}p/\mathrm{d}V < 0$.

(d) Determine the $V_\mathrm{g}/V_{\mathrm{g\,min}}$ ratio.

For the van der Waals' description of water in a liquid state it is reasonable to assume that $p \ll a/V^2$.

(e) Express the volume of liquid water V_l in terms of a, b, R and T.

Assuming $bRT \ll a$, find the following characteristics of water.

(f) Express the liquid water density ρ_l in terms of any or all of μ, a, b, R.

(g) Express the volume thermal expansion coefficient α in terms of a, b, R.

(h) Express the specific heat of water vaporization L in terms of μ, a, b, R.

(i) Considering the monomolecular layer of water, estimate the surface tension σ of water.

From equalities of areas and the van der Waals equation of state together with the approximations made in Part B, it can be shown that the saturated vapour pressure p_{lg} depends on temperature T as

$$1 + \ln p_{lg} = \ln \frac{a}{b^2} - \frac{a}{bRT}.$$

W. Thomson showed that the pressure of saturated vapour depends on the curvature of the liquid surface. Consider a liquid that does not wet a capillary. When the capillary is immersed in the liquid, the liquid in the capillary drops to a certain level because of the surface tension.

(j) Find a small change in pressure Δp_t of the saturated vapour over the curved surface of the liquid and express it in terms of vapour density ρ_g, liquid density ρ_l, surface tension σ and the radius of surface curvature r.

Metastable states, considered in part B3, are widely used in real experimental setups, such as the cloud chamber designed for registration of elementary particles. They also occur in natural phenomena such as the formation of morning dew. Supercooled vapour is subject to condensation by forming liquid droplets. Very small droplets evaporate quickly but large enough ones can still grow.

(k) Suppose that at the evening temperature of $T_e = 20\,°\mathrm{C}$, water vapour in the air was saturated, but in the morning, the ambient temperature has dropped by $\Delta T = 5{,}0\,°\mathrm{C}$. Assuming that the vapour pressure has remained unchanged, estimate the minimum radius of droplets that can grow. Water surface tension $\sigma = 7{,}3 \cdot 10^{-2}\,\mathrm{N\,m^{-1}}$.