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INERT-GAS ENERGY-ACCOMMODATION COEFFICIENTS ON TUNGSTEN

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UDC 533.06

Measurements have been made of the energy-accommodation coefficients for inert gases on the thermally cleaned and partially controllable surface of tungsten at about 300°K under conditions of oil-free pumping.

It is necessary to specify the boundary conditions in order to solve problems on heat transfer in low-density gases in the presence of solid surfaces. These boundary conditions contain physical quantities dependent on the interaction of the gas molecules with the surface at the microscopic level. Energy-accommodation coefficients (EAC) provide important information on the microscopic processes at such surfaces [1].

It is shown from theory and experiment [2] that energy accommodation may play a decisive part in heat transfer at very low gas pressures, when the mean free path of the molecules is much larger than the characteristic geometrical dimensions of the problem.

These accommodation coefficients are dependent on various physicochemical factors related to the nature and state of the gas and surface. The variety of factors hinders theoretical examination of the accommodation. When the scope for theory is restricted, information from experiment has to provide a basis for defining limits in gasdynamic processes, and it can also assist in improving theoretical models.

There is now extensive experimental evidence on EAC for gases on metals. In recent years, experiments have been performed at a high level [3-6]. However, most experimental studies have a major disadvantage arising from lack of control on the state of the surface. As a rule, authors give only the temperature at which the surface was cleaned by thermal desorption, together with information on the vacuum.

We have measured EAC for inert gases on tungsten by a nonstationary heated-filament method. The extent of removal of contaminants was determined by the thermal flash method, and also from the change in emissivity. Recrystallization during the heat treatment was detected by x-ray examination.

The methods of determining the EAC have been used before and are described in detail in [7, 8]. Figure 1 shows the apparatus. The following are the basic parameters: limiting vacuum in the measurement chamber during pumping $\sim 2 \cdot 10^{-9}$ mm Hg, rate of pressure rise in the chamber due to gas desorption from the walls and leaks at the level of 10^{-8} mm Hg per hour, pressure sensitivity of the capacitance micromanometer about 10^6 Hz/mm Hg, and heating temperature of the high-vacuum part of the equipment not less than 250°C.

We used highly purified He, Ne, Ar, Kr, and Xe. Measurements were made on filaments made from group A tungsten: diameter 50 μm, length 300 mm. The surface was cleaned from traces of oxides and graphite lubricant (aquadag), and also from adsorbed gases by heating

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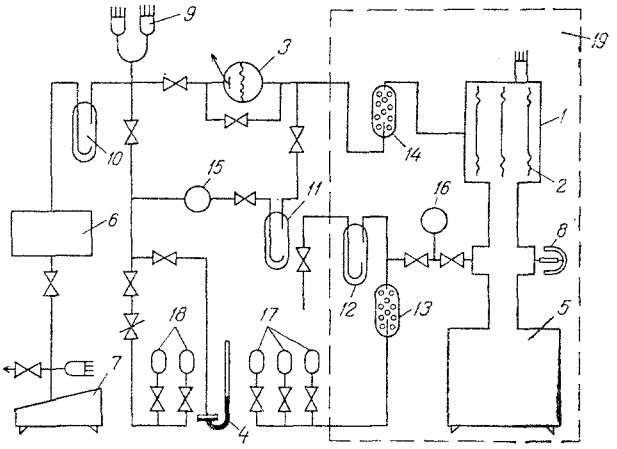

Fig. 1. The apparatus: 1) measurement chamber; 2) tungsten filament; 3) capacitance; micromanometer; 4) mercury manometer; 5) NMDO-025 magnetic-discharge pump; 6) diffusion pump; 7) forevacuum pump; 8) magnetic ionization pressure transducer; 9) ionization-thermocouple pressure meter; 10-12) nitrogen traps; 13, 14) adsorption traps; 15, 16) calibrated volumes; 17) vessels containing Ar, Kr, and Xe; 18) vessels containing He and Ne; 19) heated vacuum zone.

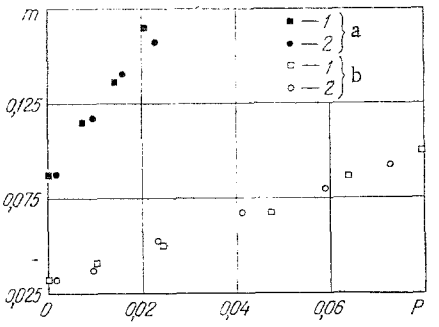

Fig. 2

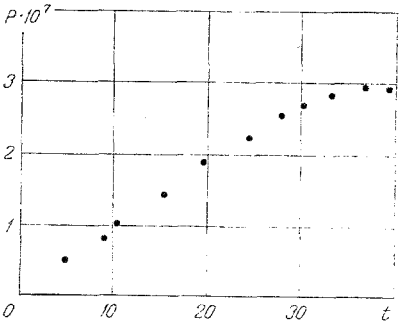

Fig. 3

Fig. 2. Filament cooling rates for various pressures of He (1) and Ne (2) at 300°K on uncleaned (a) and thermally cleaned (b) surfaces of tungsten. Thermal cleaning performed by heating to 3000°K, m, 1/sec; P, mm Hg.

Fig. 3. Diagram for the thermal flash method, $P \cdot 10^7$ mm Hg; t, min.

the filaments in a vacuum of $2 \cdot 10^{-9}$ mm Hg at about 3000°K for 20 sec. Additional gas purification was provided by silica gel and activated charcoal adsorption traps, which were cooled by liquid nitrogen.

The measurement procedure consisted in deriving the cooling rate of the tungsten filament as a function of the gas pressure [7]. The measurements were made at a temperature of about 300°K. Two series were performed. In the first we related the EAC to the emissivity and the degree of cleaning from aquadag, surface oxides, and adsorbed films of residual gases. In the second series, we measured the EAC for the inert gases on the cleaned and partially controllable surface.

Figure 2 and Table 1 give the results from the first series; Fig. 2 shows that on heating the filament to 3000°K there is a reduction in the slope representing the cooling rates for He and Ne on pressure, while there is a considerable reduction in the cooling rate as measured under high vacuum (intercept on the ordinate).

TABLE 1. Measured EAC for He and Ne and Emissivity ε for Uncleaned and Thermally Cleaned Surfaces of Tungsten at About 300°K

Gas	EAC		Emissivity	
	uncleaned surface	thermally cleaned surface	uncleaned surface	thermally cleaned surface
He	0,460±0,007	0,105±0,002	0,42±0,02	0,071±0,004
Ne	0,766±0,009	0,218±0,004	0,42±0,02	0,062±0,004

TABLE 2. Measured EAC for Inert Gases on Thermally Cleaned Tungsten at About 300°K

Gas	Our results	Data from other sources		
	EAC	EAC	author	year
He	0,105±0,002	0,05	Roberts [10]	1932
		0,02	Menzel [3]	1970
Ne	0,218±0,004	0,07	Roberts [10]	1932
		0,04	Menzel [3]	1970
Ar	0,356±0,005	0,272	Menzel [3]	1970
		0,82	Mitchells [10]	1932
Kr	0,518±0,008	0,407	Menzel [3]	1970
Xe	0,595±0,008	0,673	Menzel [3]	1970

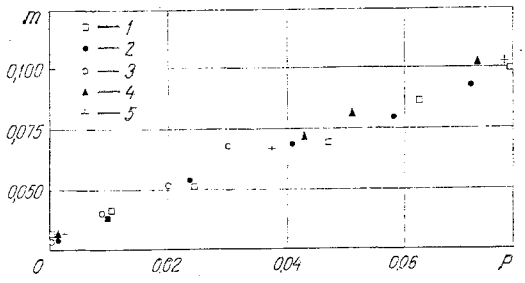

Fig. 4

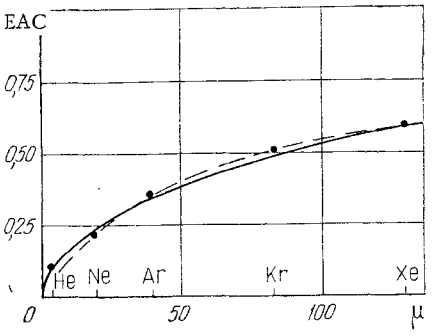

Fig. 5

Fig. 4. Measured cooling rates for various pressures of He (1), Ne (2), Ar (3), Kr (4) and Xe (5) at 300°K with a thermally cleaned tungsten surface.

Fig. 5. Measured EAC for inert gases on a thermally cleaned surface of tungsten at 300°K in relation to atomic mass. The points are measured EAC; the solid line has been constructed from empirical formula (3); and the broken line is from Baulet's modified formula [2], μ, amu.

The cooling rate under high vacuum was used to calculate the emissivity on the basis of analytic expressions for the corrections for the heat transfer from the ends of the filament and for the radiative heat transfer [8]. The relative error in determining the emissivity was not more than 5%.

The EAC for He and Ne before and after heating the filament are very much dependent on the state of the surface, as is the emissivity (Table 1). Subsequently, the emissivity was used to estimate the extent of removal of oxides and aquadag. It was assumed that the emissivity of the surface contaminants is close to one. The emissivity of cleaned tungsten was calculated from the following formula [9]:

$$\varepsilon_0 = 7.54\,(r_0T)^{1/2} - 63.5\,(r_0T) + 673\,(r_0T)^{3/2}. \quad (1)$$

The emissivity of clean tungsten was compared with the values for the specimen before and after heating. The proportion of the surface covered by contaminants was calculated from

TABLE 3. Values of Inert-Gas Condensation Coefficients on Tungsten at About 300°K Calculated from (4)

Gas	Condensation coefficient	Gas	Condensation coefficient
He	0,067±0,001	Kr	0,119±0,02
Ne	0,051±0,001	Xe	0,251±0,04
Ar	0,089±0,001		

$$X = \frac{\varepsilon - \varepsilon_0}{1 - \varepsilon_0}. \tag{2}$$

Before heating, 40% was so covered, and after heating this fell to 4%. Therefore, heating to 3000°K for 20 sec is sufficient to remove most of the surface contaminants. X-ray examination before and after heating showed that the annealing did not produce substantial recrystallization. This was evidently due to the short heating time.

The thermal flash method was used to determine the time required to accumulate a monolayer of residual gases on the cleaned filament. The method has been described in [10]. Current pulses were passed through the filament, each of which heated it to about 3000°K. The times between the pulses increased successively. A magnetic ionization transducer recorded the pressure pulses produced by the gas desorption. Figure 3 shows the results. The time required to fill a monolayer is about 30 min. As the time required for one EAC measurement was not more than 10 min, one can assume that the experiments were performed with the surface 70% free of adsorbed residual gases.

Figures 4 and 5 show the results from the second series. Figure 4 shows the dependence of the cooling rate on the inert-gas pressure. It is clear that the slope is largely independent of the nature of the gas. The expression for the cooling rate in the molecular state [7] indicates that the EAC for inert gases differ as the square roots of the masses. Goodman [11] has previously indicated a trend of this type for He and Ne. Table 2 gives the values of the EAC derived from the experiments, along with data from other sources.

Figure 5 shows the dependence of the EAC on the atomic mass, together with approximating curves calculated from Baulet's modified formula [2] and an empirical formula of the form

$$\alpha = \alpha_{He}(\mu/\mu_{He})^{1/2}. \tag{3}$$

The results agree well with such simple approximations because, evidently, the EAC at 200°K and above for clean surfaces are determined mainly by the mechanics of the collision between the gas atoms and those in the surface acting as hard spheres, without any marked effect from trapping and adsorption. This is confirmed by the calculations on the trapping coefficients performed from a standard model [12]:

$$\alpha = c + (1 - c)\alpha_0. \tag{4}$$

The value of α_0 was calculated from Baulet's modified formula [2] for the energy-accommodation coefficient in the hard-sphere model:

$$\alpha_0 = \frac{2.4\mu\mu_W}{(\mu + \mu_W)^2}. \tag{5}$$

Table 3 gives the values calculated from (4). These coefficients include not only potential parameters but also a factor related to the surface roughness, and therefore they are over estimates. Nevertheless, the values are small for all the inert gases, which shows that the simplified hard-sphere model is applicable to describe these EAC.

NOTATION

ε_0 is the emissivity of pure tungsten, dimensionless; r_0, specific resistance of tungsten, Ω·m; ε, emissivity of actual tungsten surface; α, energy accommodation coefficient, dimensionless; α_0, energy accommodation coefficient from modified Boulet formula [2]; α_{He}, energy accommodation coefficient of He on tungsten; μ, atomic mass of gas molecules, car-

bon units; μ_{He}, atomic mass of an He molecule, carbon units; μ_W, atomic mass of W atom, carbon units; c, condensation coefficient, dimensionless; P, gas pressure, mm Hg; m, cooling rate of tungsten filament, 1/sec; X, fraction of tungsten covered with contaminants, dimensionless.

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"EQUILIBRIUM" APPROXIMATIONS IN THEORY OF RADIATIVE HEAT TRANSFER

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UDC 536.33

Two methods are proposed for approximately taking into account the selectivity and anisotropy of radiation characteristics in calculation of radiative heat transfer. Both methods are shown to be sufficiently reliable and effective.

Accounting for selectivity and anisotropy is the most difficult problem in calculations and studies of radiative heat transfer. It therefore is important to develop approximate but still sufficiently accurate and reliable methods of calculating radiative heat transfer with these features taken into account. Such methods can be developed along two main lines. In the first line, the approach is based on simplifying assumptions regarding the radiation characteristics of bodies and media which participate in the heat transfer (selectively gray, gray, diffuse, diffuse-specular, or other approximations). In the second line of development, one makes no assumptions pertaining to the radiation characteristics of materials, but accepts some premises regarding the characteristics of the radiation which interacts with the bodies and the media within a given system.

In this study, two approximations will be considered along the second line, called "equilibrium" approximations on account of the assumed equilibrium distribution of spectral intensity with respect to any integral radiation characteristics.

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