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POTENTIALS OF THE REPULSIVE INTERACTION OF NOBLE-GAS ATOMS

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The study of the forces of interaction between atoms and molecules is of great interest in connection with the study of various properties of matter, the passage of fast particles through matter, etc. Since observation of elastic scattering makes it possible to record the direct effect of a collision, one of the most convenient means of obtaining information on the forces of interaction between atoms and molecules is the so-called molecular-beam method. The study of the elastic scattering of a beam of particles in principle makes it possible to reconstruct the form of the potential function over the entire reasonable interval of distances. However, in a single experiment it is impossible to obtain data on the whole potential curve, and it becomes expedient to study its separate sections.

Fig. 1. 1 –ion source; 2 –magnetic analyzer; 3 –charge-exchange chamber; 4 –monitor and capacitor deflecting unneutralized ions; 5 –scattering chamber; 6 –receiver and recording devices

In a sufficiently wide interval of mutual distances the repulsive interaction of atoms can be described by a power law $V(r) = K/r^s$. In this case the classical theory of scattering leads to a simple relation between the effective cross section for scattering through small angles and the parameters of the potential K and s

$$S(\theta_0, E) = \pi\left(KC(s)/E\theta_0\right)^{2/s}.$$

Here $S(\theta_0, E)$ is the cross section for scattering through angles greater than θ_0; E is the particle energy; $C(s)$ is a numerical factor depending on s; θ_0 is the minimum deflection angle determined by the aperture (1).

From this relation it is evident that, having experimental data on the dependence of $S(\theta_0)$ on E, it is easy to find K and s. Indeed, on a logarithmic scale this dependence is represented by a straight line with slope equal to $-2/s$. The quantity K, for known s, can be determined from the same dependence.

The condition for scattering through small angles is readily realized if one uses a beam of fast particles with energies of the order of 10^2-10^3 eV. With such beams it is possible to study the repulsive interaction in the energy range 0.1-10 eV.

Fig. 2

Figure 1: Fig. 2

It may be noted that precisely this region is of greatest interest for determining the kinetic properties of gases at temperatures above 1000°.

To carry out experiments on the study of elastic scattering, an apparatus was constructed, the block diagram of which is shown in Fig. 1. The source of a monoenergetic beam homogeneous in mass was implemented on the basis of a standard MS-1 mass spectrograph, whose ion beam was converted into a neutral one by charge exchange. The energy interval of the particles of the neutral beam was from 0.6 to 4 keV. The use of a detector employing secondary electron emission (an open-type electron multiplier) makes it possible fully to satisfy the small ion currents ($\sim 10^{-9}$ A) characteristic of mass spectrometry. The target is a small volume with narrow slits, filled with a chemically pure gas at a known pressure. The pressure was measured directly in the target by means of an ionization manometric lamp operating in a special mode.

Table 1

System	K	s	Δr, Å
He–He	2.8	3.9	0.87–1.27
Ne–Ne	78	7.65	1.7–2.18
Ar–Ar	171	6.06	2.26–3.14
He–Ar	22.6	5.15	1.63–2.06
He–Ne	10.3	5.61	1.3–1.65
Ne–Ar	99.5	6.56	1.93–2.49

Recording the attenuation of the beam intensity as it passes through a gas target of known density makes it possible to determine the scattering cross section for angles greater than the aperture angle. Processing these experimental data (obtained by averaging no fewer than 10 measurements), taking into account the finite width of the beam and the dimensions of the target, made it possible in turn to determine the potential parameters for the following systems: He–He, Ne–Ne, Ar–Ar, He–Ar, He–Ne, Ne–Ar. Control of the absence of double collisions was carried out by the standard method, from the linearity of the dependence of the cross section on the pressure in the target.

Fig. 2. 1 –data of work ([2]); 2 –data of the present work; 3 –data of work ([3])

Table 1 gives the potential parameters for the systems studied and the range of distances Δr in which they are valid. A potential of the form $V = K/r^s$ is suitable in a limited region, the limits of which can be determined from the expression for $S(\theta_0, E)$. It is clear that as long as, on a double logarithmic scale, the dependence of the measured cross section on energy is linear, this potential can be used. Extrapolation beyond the experimentally determined region of linearity requires great caution. The range of realizable distances is easily determined if one takes into account that, in scattering through small angles, the impact parameter b practically coincides with the distance of closest approach r. Since, by definition, the cross section is equal to $S(\theta_0, E) = \pi b^2$, then $r = \sqrt{S(\theta_0, E)/\pi}$. Thus it is easy to obtain $r_{\min} = \sqrt{S(E_{\max})/\pi}$ and $r_{\max} = \sqrt{S(E_{\min})/\pi}$.

In Fig. 2, for the Ar—Ar system, a comparison is made between the data of the present work and the experimental data of work ([2]) and theoretical calculations carried out on the basis of the statistical model of the atom ([3]). The comparison shows good agreement of the data; analogous agreement is also found for the He—Ar and Ne—Ar systems. However, for the He—He, Ne—Ne, and He—Ne systems there is a discrepancy with the theoretical values. Po-

The data obtained make it possible to check the empirical combining rule ([5]), well justified for gases in the low-temperature region. According to this rule, the potential of a mixed system (for example, He—Ar) is determined as the geometric mean of the potentials of the corresponding like systems (He—He, Ar—Ar). Using the data of Table 1, it is easy to obtain for He—Ar the values $s = 4.98$, $K = 21.9$; for He—Ne, $s = 5.77$, $K = 14.8$; for Ne—Ar, $s = 6.85$, $K = 1.15$. These values are close to those determined from scattering data, which justifies the use of combining rules for the repulsive potentials of the systems studied.

A comparison of the values of the potential energies found in the present work and in ([2–4]) reveals quite satisfactory agreement (Fig. 2), but the numerical values of the parameters s and K differ noticeably. In particular (Table 1), for the parameter s, at identical approach distances there is a systematic deviation from the values obtained in ([2–4]) by an amount of the order of 2; this in turn also accounts for the discrepancy in the values of K.

Since the value of s is determined from the slope of the dependence of the cross section on the energy, the degree of monochromaticity of the beam has a substantial influence on s. Insufficient homogeneity of the beam can change the dependence of the cross section on the energy and, accordingly, the value of s. It may be assumed that this is the main source of the discrepancy noted above.

The results for helium in the range of distances less than 1 Å, as also in work ([4]), show deviations from the theoretical results. Therefore one should suppose that the cause of this widely discussed ([3]) discrepancy is not experimental inaccuracies. In accordance with ([6]), it may be assumed that this discrepancy is due to the nonadiabaticity of collisions at such close approaches. An analogous situation also occurs in the case of neon and, apparently, can be explained in the same way.

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Note: Figure translations are in progress. See original paper for figures.