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CALCULATED RAMSAUER-TOWNSEND EFFECT IN ^{4}He-^{4}He COLLISIONS*

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The purpose of this Letter is to point out that at low bombarding energies ($E_{\text{c.m.}} \simeq 0.16$ meV) the conditions for an atomic Ramsauer-Townsend effect are satisfied in collisions between neutral helium atoms. This is of interest as a predicted example of the effect for atoms and because of its possible relation to the unusual properties of bulk helium at low temperatures.

The Phillipson-Morse-Dalgarno (PMD) potential used by Bernstein and Morse[1] in recent calculations of the differential and total cross sections for He-He scattering is assumed to describe the interaction. Except at forward angles, the angular distributions computed with this potential disagree qualitatively with those computed[1] with Lennard-Jones (12-6) and exp-6 potentials even though the depth and radial location of the potential minima are coincident. The most prominent feature of each potential is a repulsive core which is surrounded by a shallow attractive well with a depth of 0.8 meV. On the other hand, the total cross sections for the three potentials are not as sensitive to the details of the potentials as shown by the similar energy dependence and the fair quantitative agreement with one another and with the meager experimental data in the energy range 10 to 1000 meV.

Varshni[2] and, more recently, Bruch and McGee[3] have calculated the second virial coefficient for the PMD potential in the temperature range 50 to 1500°K and find reasonable agreement above 150°K. At the lower temperatures the computed values lie above the experimental data. The difference is, however, comparable with the spread in the data.

In order to extend the results of Bernstein and Morse[1] both in energy and angle and to assist in the design of a scattering experiment, a computer program for the calculation of the ^{4}He-^{4}He scattering cross sections has been written. Calculations are being made using several different intermolecular potentials in the energy range 8 to 60 meV and these will be presented elsewhere.[4]

Because of the unusual gaslike properties of helium at low temperatures which are ascribed to the small attractive part of the ^{4}He-^{4}He interaction potential, the calculations have been extended downward in energy to investigate the behavior of the total cross section and phase shifts in the vicinity of the condensation energy ($E_{\text{c.m.}} = kT$, $T = 4.2$°K). Curves obtained for the PMD potential are shown in Fig. 1. The total cross section and phase shifts for $l = 0$, 2, and 4 partial waves are plotted as functions of center-of-mass energy in meV.

The sharp dip in the total cross section (Fig. 1) at 0.16 meV is associated with the passage of δ_0 through 0°, and the other phase shifts are small. These are the conditions[5] for the Ramsauer-Townsend effect for ^{4}He-^{4}He scattering. Finite contributions from the second and fourth partial waves prevent the cross section from reaching zero.

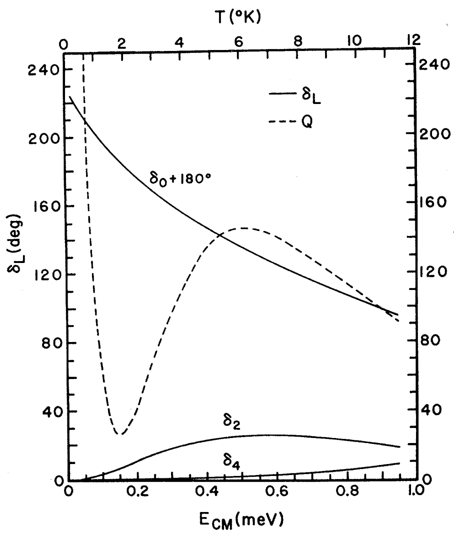

FIG 1. Computed total cross section and phase shifts for helium-helium scattering at low energies. The ordinate scale is the same for the total cross section Q in units of $\AA^2$ as for the phase shifts δ_L in degrees.

The Bose-Einstein statistics of systems of ^{4}He particles is important in that the odd partial waves are absent. A p-wave contribution would fill in the total cross-section minimum and the significant value of δ_1 would violate the conditions for the Ramsauer-Townsend effect. In the limit that δ_0 is a multiple of 180° and $\delta_L = 0$ for $L > 0$, the Ramsauer-Townsend conditions are those of perfect transmission.

A temperature scale determined by $kT = E_{\mathrm{c.m.}}$ is shown in Fig. 1 and the value of T corresponding to $\delta_0 = 0°$ is 2.2°K. The minimum in the total cross section is somewhat lower, ~2.0°K, because of the contributions from the second and fourth partial waves. The close agreement of the temperature associated with the Ramsauer-Townsend effect with that for the helium lambda point, 2.17°K, is provocative. A collision between two helium atoms with a high probability for transmission through one another is suggestive of certain superfluid properties of liquid helium II. It is interesting to note that the energy (temperature) for the Ramsauer-Townsend effect for an atom-atom collision in a dense gas is expected to decrease as the pressure increases since the average potential for an atom decreases due to long-range attractive forces.

An extrapolation of the δ_0 curve to zero energy yields an intercept value of 50°, approximately midway between the values 0° and 90°, the two nearest values of $\delta_0(E_{\mathrm{c.m.}} = 0)$ which satisfy Levinson's theorem.[6] The lowest energy in these calculations is 0.01 meV. Since a detailed plot of δ_0 against wave number shows a break downwards for decreasing small values, it is assumed that δ_0 approaches 0° as $E_{\mathrm{c.m.}}$ goes to zero. Thus there is no state at zero energy for this potential.

At $T = 4.2$°K, the boiling point for liquid ^{4}He, the total cross section is near a maximum, but no sharp discontinuities are apparent in the curves (Fig. 1). Long-range and possibly many-body forces are involved which do not enter into the atom-atom scattering results.

While any reasonable potential for the ^{4}He-^{4}He interaction is expected to produce a Ramsauer-Townsend effect at low energies, the exact energy of the effect and extent to which the conditions are satisfied depend on the details of the potential. The energies of the minima in the total cross-section curves computed by de Boer and Michels[7] and by Halpern and Buckingham[8] using different potentials are in satisfactory agreement with the value found here while those given by Massey and Mohr[9] and by Buckingham and Massey[10] are substantially lower. The sensitivities of the calculated results to the parameter values of several potentials are being studied.

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