

MEASUREMENTS OF THE ANISOTROPY IN THE TOTAL CROSS SECTIONS OF
 Na_2 -NOBLE GAS SYSTEMS BY MEANS OF LASER-INDUCED FLUORESCENCE

A.G. Visser, L.K. van der Meij, J.P. Bekooy and J. Korving

Huygens Laboratorium, Rijksuniversiteit Leiden, The Netherlands

1. Introduction. Studies of collisional alignment in molecular beams can yield information about the anisotropic part of the scattering cross section [1]. Here we report on measurements of the degree of alignment in Na_2 beams arising from scattering by noble gases. Use is made of the technique of laser-induced fluorescence.

The possibility of collisional alignment was first pointed out by Ramsey [2]. For (nonspherical) homonuclear diatomics the scattering cross section is dependent on the orientation of the molecule with respect to the relative velocity of the colliding particles [3]:

$$\sigma = \sigma_0 (1 + \gamma P_2(\hat{g} \cdot \hat{J})) . \quad (1)$$

Here σ_0 is the isotropic part of the total cross section and \hat{g} and \hat{J} are unit vectors along the relative velocity and the angular momentum respectively. After scattering one obtains for the molecular beam intensity ($\gamma \ll 1$)

$$I = I_0 [\exp(-n\ell\sigma_0)] [1 - \gamma n\ell\sigma_0 P_2(\hat{g} \cdot \hat{J})] , \quad (2)$$

where n denotes the density of the scattering gas and ℓ the scattering length. I_0 and I are the intensities before and after scattering. As the attenuation of the beam depends on the orientation of \hat{J} the spatial distribution of the angular momenta in the attenuated beam is of the form

$$n(\hat{J}) = 1 + a_2 P_2(\underline{u} \cdot \hat{J}) . \quad (3)$$

Here \underline{u} denotes a unit vector along the beam axis. The quantity a_2 can be measured by the method of laser-induced fluorescence. This is done by measuring the fluorescence intensity I as a function of a magnetic field H which rotates the molecular alignment over a certain (Zeeman) precession angle β_2 . The value of a_2 is then obtained from the relative change of the fluorescence intensity with field on and off, $\frac{I(H) - I(H=0)}{I(H=0)}$ (for details see ref. [1]). When a_2 is known the value of the anisotropy parameter γ is found from

$$\gamma = a_2 R/\ell n (I/I_0) , \quad (4)$$

where R is a correction factor (of the order of 1) which accounts for the angular resolution and the velocity distribution of both the scattering gas and the molecular beam. Experiments have been performed for the systems Na_2 - (Ne, Ar, Kr, Xe). Furthermore, values have been obtained of the isotropic part of the total cross section (σ_0) for these systems from measurements of the attenuation under well known scattering conditions:

$$\sigma_0 = -\frac{1}{n\ell} \ln(I/I_0) . \quad (5)$$

2. **Experimental.** A schematic diagram of the apparatus is shown in fig. 1. The Na_2 beam is produced by a high temperature nozzle source. The beam, defined by skimmer and collimators, passes through a scattering chamber and is subsequently crossed with plane polarized laser light. The 4765 Å line of the argon laser is used to induce transitions from the $v'' = 0, J'' = 28$ level of the $X^1\Sigma_g$ electronic ground state to the $v' = 6, J' = 27$ level of the $B^1\Pi_u$ state. The single mode laser is frequency stabilized by a feedback system which locks the frequency to the maximum of the fluorescence emission [1].

The scattering chamber consists of two regions with different scattering lengths ℓ_1 (1 cm) and ℓ_2 (2 cm). By measuring the attenuation for these two scattering lengths, accurate results are obtained for the total cross sections as corrections are avoided for the outflow of the scattering gas. For the measurement of the density of the scattering gas a calibrated ionization gauge was used.

3. **Results.** In table I the directly measured values, σ_{exp} , are shown for the total cross section of the systems studied. After correcting these values for the angular resolution and the velocity distributions of both scattering gas and molecular beam one obtains the desired isotropic total cross sections σ_0 . The values shown in table I are the cross sections at a relative velocity of 1350 m/s. From σ_0 the Van der Waals constant C_6 can be derived using [4]

$$C_6 = \left(\frac{\sigma_0}{8.083}\right)^{5/2} h_g , \quad (6)$$

which are also tabulated.

The parameters γ , describing the anisotropy in the total cross section are obtained from measurements of a_2 (see eq. (4)). In table I the values of γ are given, already corrected for the angular resolution and the velocity distributions.

It should be noted that γ increases going from Xe through Kr to Ar but drops abruptly for Ne. The relatively small anisotropy for Na₂-Ne can be understood qualitatively taking into account the glory undulations in the anisotropy [3]. The following regions in the velocity dependence of the anisotropy can be discerned [5]:

glory region	$g^* < 0.4$
transition region	$0.4 < g^* < 2$
repulsive region	$g^* > 2$,

with $g^* = \frac{hg}{\epsilon r_m}$, the reduced relative velocity; ϵ and r_m are the usual parameters of the isotropic potential.

In the glory region the anisotropy oscillates around a constant value, which is determined by the anisotropy in the attractive part of the potential. Under our experimental conditions the (estimated) values of the reduced relative velocity for the systems Na₂-Ar, Kr, Xe (see table I) show that the value of γ is obtained at the low velocity side of the glory region. Due to the fast oscillations in this region and the low velocity-resolution the oscillations are strongly quenched. Hence the anisotropy as measured is close to the constant value expected for a purely attractive potential. Therefore γ may be related to q_6 , the anisotropy parameter of the attractive part of the potential by the equation (see ref. [3])

$$\gamma = \frac{1}{20} q_6 .$$

The resulting values of q_6 are also shown in Table I. For the system Na₂-Ne the situation is different. Here the reduced relative velocity is higher and the anisotropy is measured in the neighbourhood of the first, wide glory minimum of the anisotropy. Hence it is not possible to describe the anisotropy as measured by only one anisotropy parameter of the potential.

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Table I

Experimental results. All symbols are defined in the text.

system	σ_{exp} A ²	σ_0 A ²	C_6 10 ⁻⁶⁰ ergcm ⁶	$\gamma \times 10^2$	g^*	q_6
Na ₂ -Xe	674 ± 20	935 ± 34	2050	1.12 ± .34	.026	.22 ± .07
Na ₂ -Kr	557 ± 18	738 ± 29	1130	1.88 ± .30	.040	.38 ± .06
Na ₂ -Ar	495 ± 15	631 ± 23	770	2.37 ± .23	.052	.47 ± .05
Na ₂ -Ne	222 ± 5	244 ± 7	71	.76 ± .32	.40	---

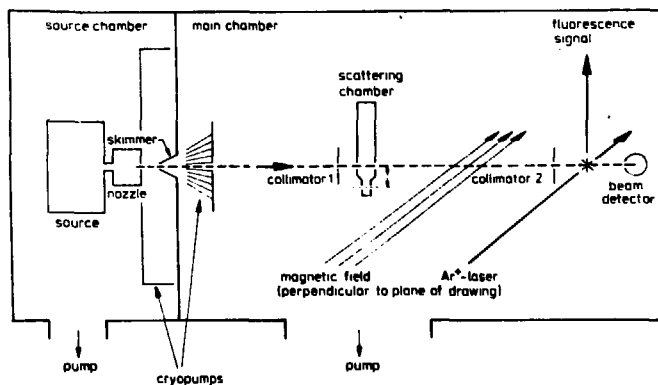


Fig. 1 Experimental set-up