Experimental evidence of oscillatory dependence of effective viscosity on the Knudsen number for nitrogen and argon gases in the transition regime

D. Moronta and M. García-Sucre
Escuela de Física y Matemáticas, Facultad de Ciencias, Universidad Central de Venezuela (UCV), Caracas 1051, Venezuela and Centro de Física, Instituto Venezolano de Investigaciones Científicas (IVIC), Apartado 1827, Caracas 1010A, Venezuela
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Experimental evidence is reported of an oscillatory dependence of an effective viscosity on the Knudsen number for nitrogen and argon gases in the transition regime, which in our experimental setting corresponds to the range of pressures from 1 μm to $\sim$20 μm column of Hg at $T=293$ K. These results support that the damped oscillatory dependence of the stress on the Knudsen number, previously reported for helium, is a property of gases in the transition regime.

Viscosity of gases in the transition regime has been studied by several authors.[1–6] The transition regime occurs when the Knudsen number N_{Kn} is ~ 1, where $N_{Kn} \equiv l/L$, l is the mean free path, and L is a characteristic dimension of the system. It is well known that the viscosity of gases in the continuum regime ($N_{Kn} \ll 1$) is independent of N_{Kn},[7] provided that the density does not become too high.[8,9] Furthermore, the viscosity in the continuum regime is an intrinsic property of the gas, while in the transition and Knudsen ($N_{Kn} > 1$) regimes the viscosity depends on the flow geometry. For our purposes, to study the dependence of the viscosity on N_{Kn} in the transition regime, we will introduce the term "effective viscosity," defined as the ratio of the actual stress to the continuum stress.

We report here the effective viscosity of N_2 and Ar gases for different values of the Knudsen number in the range $0.1 < N_{Kn} \leq 1$. In an experiment reported previously,[5] a damped oscillatory dependence of the effective viscosity on the Knudsen number was found for helium. The experimental results reported here for N_2 and Ar support such a damped oscillatory dependence.

Our measurements have been performed using a torsion pendulum viscometer described in Ref. 5, with improvements in the systems of gas injection and pressure measurement. This instrument has a distance $L=5$ cm between the fixed and moving surfaces. In Figs. 1 and 2 we have represented the experimental viscosity of N_2 and Ar, respectively, for the pressure range $p=1$ to 20 μm of Hg and $T=293 \pm 0.2$ K.

The measurements were performed in the following way: The range of pressure $p=1-20$ μm of Hg was swept three times, measuring the viscosity each 1 μm of Hg. Consecutive pressure intervals of 1 μm of Hg width were arbitrarily defined in order to average all viscosity points falling in the same pressure interval. The standard deviations of the ef-

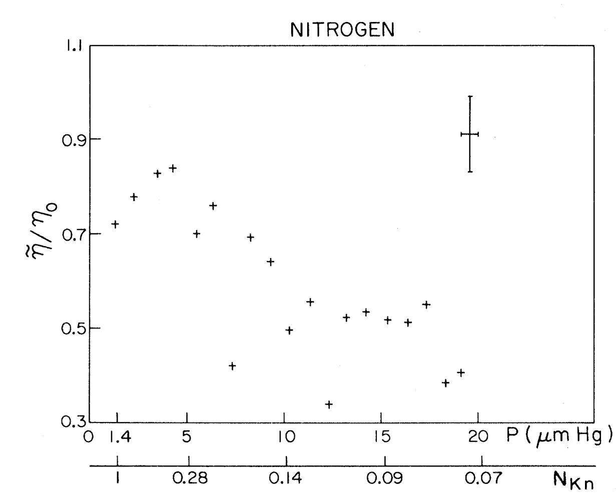

FIG. 1. Effective viscosity $\tilde{\eta}/\eta_0$ of nitrogen vs pressure from $p=1$ to 20 μm of Hg with $T=293 \pm 0.2$ K. The pressure is also expressed in terms of the Knudsen number N_{Kn}, taking for the molecular diameter $d_{N_2}=3.15$ Å, which corresponds to the viscosity value in the continuum regime. Each point stands for an average of experimental values. The error bars associated with each experimental point are represented in the upper right of the figure.

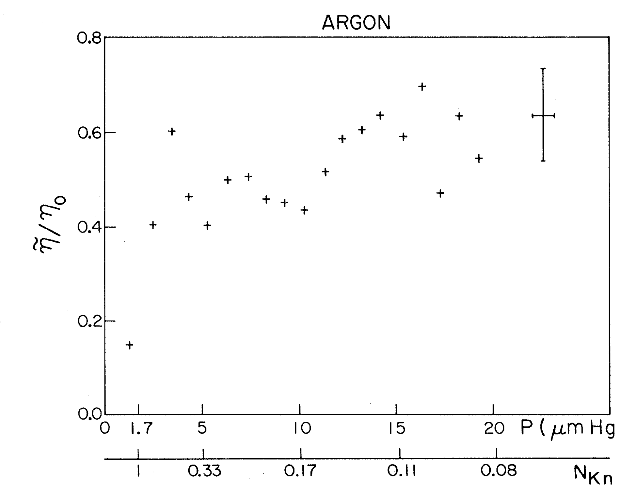

FIG. 2. Effective viscosity $\tilde{\eta}/\eta_0$ of argon vs pressure from $p=1$ to 20 μm of Hg with $T=293 \pm 0.2$ K. The Knudsen numbers appearing in the horizontal axis were calculated taking $d_{Ar}=2.88$ Å, which is the value obtained from the viscosity value in the continuum regime.

fective viscosity do not differ too much for different channels. Therefore we have chosen typical vertical and horizontal errors which are represented in the right upper part of Figs. 1 and 2. The experimental vertical standard deviations were 0.09 and 0.1 for N_2 and Ar, respectively.

The experimental results illustrated in Figs. 1 and 2 indicate that for N_2 and Ar gases in the transitions regime the effective viscosity $\tilde{\eta}/\eta_0$ depends on $N_{\rm Kn}$ in an oscillatory damped way. Yet these oscillations seem to be superimposed on a sustained decrease (Fig. 1) or increase (Fig. 2) of $\tilde{\eta}/\eta_0$ with $N_{\rm Kn}$. Furthermore, departures of some points from the main sequence occur.

In a forthcoming paper different theoretical models of gases in the transition regime[1–6] will be used and compared in order to explain these experimental results.

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