Notice! The video cannot be seen directly on Web. One has to download the file in one's computer and see the video on it.

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Notes on "Video: Demonstration of the thermal edge flow in a rarefied gas"

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This is the explanatory notes on the video files uploaded at the same address as this article in Kyoto University Research Information Repository. The video files are the digitized version of video films chosen from the video records in the course of the experimental work published as Ref. [1].

In the experiment, it is demonstrated by a small windmill that a flow is induced near the edge of *uniformly* heated plate in a rarefied gas in such a way that a gas in front of the edge is pulled in along the plate.[1] The experiment is done in a cylindrical vacuum chamber (diameter 250 mm, height 300mm) of a glass bell jar on a steel base, where the pressure can be controlled between the atmospheric pressure and several pascals. A simple rectangular copper plate (about 100×200 mm) of 0.2 mm thickness with heaters along the shorter edges is set vertically in the chamber, with the longer edges vertical or horizontal. Flows induced around the longer edges are detected by small windmills (5- or 7-mm radius) made of plastic film. In the experiment, the temperature of the plate is uniform at about 44 °C when heated, and the room temperature is around 20 °C.[2]

In **Video1**, where the longer edges are vertical, with decrease of the pressure in the chamber, a horizontal flow is shown to be induced in such a way as for a gas in front of the vertical edge to be pulled in along the edge. The difference of the speeds of the rotation of the two windmills in the video does not mean that the flow speeds differ so much in the two positions, but it is due to the shape of the windmill, which is not symmetric with respect to the direction of rotation. The data around the other longer edge in Ref. [1] show this (or see Refs. [2] or [3]).

In **Video 2**, where the longer edges are horizontal, a vertical flow around the upper edge is shown. Here, with decrease of the pressure in the chamber, transition from an upward natural convection to a downward thermal edge flow is seen by the reversal of direction of rotation of the windmill.

More about the experiment and the thermal edge flow, which is not so popular as the thermal creep flow [4, 5], are given in Refs. [1]–[4]. The bell jar system

[1] The flow is called thermal edge flow now.

[2] The nonuniformity of the plate temperature is so small that the thermal creep flow due to it is negligible.

being a standard one found in most of chemistry departments and other apparatus being so simple, one can perform the thermal-edge-flow experiment, as well as the thermal-creep-flow one in Refs. [6, 7], by oneself easily. The thermal edge flow as well as the thermal creep flow is applied to a vacuum pump without a moving part (see, e.g., Refs. [4, 8, 9]). Incidentally, flows around an edge of a cooled plate are studied numerically in Ref. [10] (see also Refs. [1, 2, 3]).

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References

[1] Sone, Y. and M. Yoshimoto (1997), Demonstration of a rarefied gas flow induced near the edge of a uniformly heated plate, *Phys. Fluids* **9**, 3530–3534.

[2] Sone, Y. (2000), Flows induced by temperature fields in a rarefied gas and their ghost effect on the behavior of a gas in the continuum limit, *Ann. Rev. Fluid Mech.* **32**,779–811.

[3] Sone, Y. (2002), *Kinetic Theory and Fluid Dynamics* (Birkhäuser, Boston).

[4] Sone, Y. (2007), *Molecular Gas Dynamics* (Birkhäuser, Boston).

[5] Sone, Y. (1966), Thermal creep in rarefied gas, *J. Phys. Soc. Jpn* **21**, 1836–1837.

[6] Sone, Y. (1991), A simple demonstration of a rarefied gas flow induced over a plane wall with a temperature gradient, *Phys. Fluids A* **3**, 997–998.

[7] Sone, Y. (1991), Video file: Simple demonstration of a rarefied gas flow induced over a plane wall with a temperature gradient, *Kyoto University Research Information Repository* (http://hdl.handle.net/2433/120983).

[8] Sugimoto, H. and Y. Sone (2005), Vacuum pump without a moving part driven by thermal edge flow, in: M. Capitelli, ed., *Rarefied Gas Dynamics* (AIP, Melville, NY), 168–173.

[9] Sone, Y. and H. Sugimoto (2003), Vacuum pump without a moving part and its performance, in: A. Ketsdever and E. P. Muntz, eds., *Rarefied Gas Dynamics* (AIP, New York), 1041–1048.

[10] Aoki, K., Y. Sone, and N. Masukawa (1995), A rarefied gas flow induced by a temperature field, in: J. Harvey and G. Lord, eds., *Rarefied Gas Dynamics* (Oxford University Press, Oxford), 35–41.