Measurements of and Relation Between the Adhesion and Friction of Two Surfaces Separated by Molecularly Thin Liquid Films[1]

H. K. Christenson.[2] The results presented in this paper explain some interesting observations that I made in a recent study of the adhesion between mica surfaces in undersaturated vapors [1]. It was found that the measured pull-off force is critically dependent on the type of spring on which one of the surfaces is mounted. Early measurements with the surface force apparatus were performed with a simple leaf (single-cantilever) spring [2–4]. The pull-off force measured with such a spring is often much lower than that measured with a double-cantilever spring. In some cases the difference is as great as a factor of 5. In the particular case of mica surfaces in water vapor it was found that the higher the vapor pressure, the smaller the difference in the pull-off force measured with the two different types of springs. The difference was greatest when the surfaces were separated by dry nitrogen (over phosphorous pentoxide) and the values were approximately equal at a vapor pressure close to saturation.

As the remote end of a leaf spring is moved in order to effectuate separation of the surfaces, not only does the spring bend, but the surface mounted on it must slide against the fixed upper surface. By contrast, there is only negligible lateral motion of the surfaces when a double-cantilever spring is used. The amount of sliding of the surfaces with the leaf spring was measured and found to increase with the relative water vapor pressure (see Fig. 6 of reference 1). This correlated well with the fact that the measured values approached each other with increasing water vapor pressure. With the double-cantilever spring no sliding could be measured.

This is now nicely confirmed by this investigation of the effect of humidity on friction (Table 1 of the authors' paper). The frictional force decreases with increasing relative vapor pressure and this permits increased lateral sliding of the surfaces. When the frictional force is high, as is the case at low relative vapor pressures, the net result is that the surfaces come apart at a lower pull-off force than when they can easily slide against each other. The large frictional force that opposes lateral sliding in the dry state means that the effective stiffness of the spring is increased. The final separation is not in the normal direction but at a small angle with respect to the normal, with the tensile strength of the steel leaf spring contributing. The true spring constant is higher, which leads to pull-off for a smaller movement of the remote end of the spring.

Similar observations were made for vapors of nonpolar liquids such as cyclohexane and n-hexane [1]. The conclusion is that frictional forces may be important in many measurements that are designed primarily to determine adhesion.

[1]By A. M. Homola, J. N., Israelachvili, M. L. Gee, and P. M. McGuiggan, published in the October 1989 issue of the JOURNAL OF TRIBOLOGY, Vol. 111, No. 4, pp. 675–682.

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Additional References

1 Christenson, H. K., *J. Colloid Interface Sci.*, Vol. 121, 1988, p. 170.

2 Israelachvili, J. N., and Adams, G. E., *J. Chem. Faraday Trans.*, 1, Vol. 74, 1978, p. 975.

3 Israelachvili, J. N., Perez, E., and Tandom, R. K., *J. Colloid Interface Sci.*, Vol. 78, 1980, p. 260.

4 Fisher, L. R., and Israelachvili, J. N., *Colloids Surfaces*, Vol. 3, 1981, p. 303.

Authors' Closure

The authors appreciate the opportunity that Dr. H. K. Christenson has provided with his cogent remarks.

Referring to Dr. Christenson's comments, we would like to point out that the results presented in reference [1] were obtained using a double-cantilever spring for which lateral displacements, either during measurements of the pull-off forces or during applications of the load during sliding were negligible. This was further ascertained by noting that very similar adhesion forces were measured when the surfaces were separated under sliding or non-sliding conditions [2]. However, the point made by Dr. Christenson is valid and one should be careful to exclude any contributions of frictional forces to adhesion or pull-off forces. Such effects could arise when using a single cantilever spring but also more generally when using other spring systems where pull-off is accompanied by other unwanted displacements between surfaces such as shear, rotation, or rolling.

Additional References

1 Homola, A. M., Israelachvili, J. N., Gee, M. L., and McGuiggan, P. M., JOURNAL OF TRIBOLOGY, Vol. 111, No. 4, 1989, pp. 675–682.

2 Homola, A. M., Israelachvili, J. N., McGuiggan, P. M., and Gee, M. L., *Wear*, Vol. 136, 1990, pp. 65–83.