Quantifying Molecular Forces: Sensitivities and Spring Constants without Touching a Surface

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In force measurements with micromachined cantilevers the application of Hooke's law ($F = -kx$) requires two quantities: x, the distance the flexing cantilever moves and the spring constant, k.

The optical lever is the most commonly used method for measuring the deflection of a cantilever. The sensitivity of the optical lever can be characterized by the "inverse optical lever sensitivity" or $Invols$, where $x = Invols \cdot \Delta V$ where ΔV is the voltage measured by a position sensitive detector.[1] The most common method for quantifying $Invols$ requires that the lever be brought into contact with a rigid surface and then moved a known distance (a force curve). The slope of the resulting cantilever deflection vs. distance yields $Invols$. One disadvantage of this technique is that it requires a "hard" contact between the tip and sample. As was pointed out by D'Costa and Hoh,[2] in some situations, such as the case of a chemically or biologically sensitized tip, any contact between the tip and sample might not be desirable. In the case of surfaces coated with soft samples such as cells, it is sometimes simply not possible to find a hard contact region. In the case of chemical or biological sensing cantilevers, there may not be a surface anywhere near the tip against which to press. D'Costa and Hoh used a simple method to estimate the optical lever sensitivity by moving the spot across the position sensitive detector a known distance. In the limit that $Invols$ is determined by the beam shape at the detector position, this method works well. Because it is not sensitive to actual motion of the cantilever, this method does not account for differences in the cantilever geometry or changes in the alignment of the spot on the lever. These issues become even more critical as the length scale of cantilevers shrink.[3]

The method reported here allows $Invols$ to be calibrated without touching the sample surface by measuring the drag on the lever as it moves through the fluid. A cantilever moving through a fluid will be deflected by a viscous drag force. The measured cantilever deflection is converted to a force using $F_{hyst} = k \cdot Invols \cdot \Delta V$. If the cantilever is moving at a speed v through the fluid, we characterize the dissipative force $F_{hyst} = -b_{hyst}v$, with a damping coefficient, b_{hyst}.

Within the context of the simple harmonic oscillator (SHO) model, the damping coefficient is related to the spring constant k, the resonant frequency ω_0 and the quality factor Q by $b_{therm} = \frac{k}{\omega_0 Q}$. Sader[4] has shown that the SHO model only holds when dissipative effects are small. This is *not* the case with typical cantilevers in fluid. While a detailed analysis of the damping is beyond the scope of this work, experimentally, we have found that the thermal and hysteretic damping coefficients are related by $b_{hyst} = \kappa \cdot b_{therm}$, where κ is a phenomenological factor of order 1 that depends on the fluid properties, hysteresis frequency, tip-sample separation and lever geometry. This allows us to calculate a value for $Invols$, all in terms of quantities measured away from the surface:

$$Invols_{hyst} = \frac{\kappa v}{\omega_0 Q \Delta V}. \tag{1}$$

Once a value for $Invols$ has been determined, the thermal spectrum can be used to find the value of the cantilever spring constant.[5] Finally, because the damping depends on the tip-sample separation, the hysteresis provides a reliable method of positioning the tip close to the sample without touching.

References

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