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Calibrating optical tweezers—how ignorant can we be?

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In optical tweezers, a tightly focussed beam of light is used to trap and move microscopic particles, generating forces on the order of a piconewton with powers on the order of a milliwatt. Live biological specimens can be trapped and studied, and forces can be quantitatively measured in biological and other systems. In order to perform this last task—force measurement—it is necessary to calibrate.

Force measurement is usually performed using a known probe particle. This allows, for example, the dependence of the force on the position of the particle within the trap to be determined beforehand, and observation of the position of the particle as it is displaced within the trap by an external force allows that external force to be measured. In this case, the calibration procedure consists of finding the force–position relationship. Commonly-used methods include finding the power spectrum of position fluctuations due to Brownian motion, and the displacement produced by viscous drag due to a flow of known speed. Such a procedure takes advantage of much prior knowledge: the probe particle is known, and calibration can be performed with identical particles, and properties such as the size and shape of the particle and the viscosity of the surrounding medium.

However, if the probe particle is not known, or the surrounding medium is not known, the most commonly used calibration methods cannot be used. Therefore, we consider calibration in the presence of ignorance, rather than knowledge. We ask how accurately calibration can be performed if we do not know the size or shape of the probe particle, or the viscous or viscoelastic properties of the surrounding medium. Of particular interest is the case where the surrounding medium is non-uniform. While we can usually estimate the temperature accurately, this is not always the case, and we will consider the case where temperature is added to our ignorance list. Finally, calibration methods should be as simple as possible, and use instruments available in the typical laboratory in which optical tweezers are used for force measurements.

The key source of information about the particle in the trap is scattered light, either from the illumination light or the trapping beam. This can be collected either in the image plane, or as the angular distribution of the scattered light; these are Fourier transform conjugates. We will consider, in particular, how we can allow maximum ignorance by using both sources of information at once.