

In the past decade, Atomic Force Microscopy (AFM) and Optical Tweezers (OT) have revolutionised molecular science by measuring picoNewton forces over lengthscales from 1 to  $10^4$  Angstroms. In our laboratory, we have a Cell Robotics Optical Tweezer Apparatus which has been extensively modified for our experiments in polymer and colloids science. The apparatus consists of an optical trap which weakly “holds” a micron-sized bead. The trap is formed by a focused laser beam which is refracted through the transparent bead. The refracted rays differ in intensity over the volume of the colloidal bead and exert a force on the bead, drawing it towards the region of highest light intensity. The optical trap is harmonic near the focal point: the optical force acting on a colloidal particle position at  $x$  within a trap centered at  $x_0$  is  $F_{\text{opt}} = -k(x-x_0)$ , where  $k$  is the trapping constant which can be tuned by adjusting the laser power. In this way, the optical trap generated by the OT serves to both localise a colloidal particle and to measure the small, sub-picoNewton scale forces acting on the particle. With substantial modifications, our OT apparatus probes forces at small lengthscales and over small timescales which are necessary in studies in nonequilibrium statistical mechanics and polymer/biopolymer science.



### Probing Thermodynamics of Small Systems over Small Timescales using Optical Tweezers

In past decades there have been few, if any, *experimental* demonstrations of new concepts in Equilibrium and Non-equilibrium Statistical Mechanics, primarily because this scientific area is considered to be ‘mature’ with few unsolved fundamental problems. However, starting in 1993, Denis Evans and his colleagues formulated a set of new non-equilibrium theorems which has practical implications for the behaviour of nano-systems. Despite the many applications in both fundamental science and engineering, the results of this theorem had not been demonstrated in any real or experimental system. Force measurement techniques such as AFM and OT probe very small energies, forces, and distances and can be used in experiments designed to test and demonstrate these theorems. We have been using a modified OT to demonstrate experimentally some of Evans’ non-equilibrium theories by measuring picoNewton forces acting on a colloidal bead over nanometre to micron distances, allowing us to monitor the bead’s energy fluctuations on the order of thermal energy. In particular we have demonstrated that the Transient Fluctuation Theorem (TFT) describes the trajectories of an optically trapped bead subject to solvent flow field. In addition to this and other experiments initiated in 2002, we have used Langevin dynamics to analytically re-derive experiment-specific TFT. (with G.M. Wang, D. Carberry, E. Mittag, D.J. Evans, and D.J. Searles, [Griffith U.]

### Optical Tweezers for Biopolymer Studies

By attaching streptavidin coated latex beads to the ends of modified DNA, we are able to use an optical trap and micropipette to stretch a single bead-DNA-bead assembly and to study the interactions of specific binding proteins on DNA. In 2002, we have modified the OT apparatus to carry out these experiments. We have incorporated new piezo translators and a control system for automated stretching of the chain, modified the fluid cell for solution exchange and

electrophoresis, and automated the control of laser power, data acquisition, and stage translation. In conjunction with the Protein Synthesis & Evolution group headed by Nick Dixon, we are investigating the chemical protocols for attaching the beads to the ends of double-stranded DNA chains. (*with G.M. Wang, D. Carberry, N.E. Dixon*)



PhD student David Carberry, and Drs Edie Sevick and Genmiao Wang discuss research, cricket, cars, . . . at tea-time.

<http://rsc.anu.edu.au/sevick.html>