Supplementary Material

Data processing

In figure S1 we show the data processing of a sample carbon nanotube (CNT) in our experiment. The image processing is shown in figure S1 (a) where the position of the centroid of the CNT is identified and continuously tracked during the experiment. In figure S1 (b) we show the extracted CNT position as a function of time, background fluid motion has been spotted.

Rotational diffusion time scale

In order to verify that the rotational motion of the CNTs is not affecting our measurement of their translational diffusion, here we estimate the rotational diffusion time scale of the CNTs in mineral oil using the formula given below,

$$T_{rot} \approx \frac{2\pi^3(2a)^3\mu}{3k_BT\ln e}, \tag{1}$$

where a is the major semi-axis-length, μ is the fluid viscosity, and e is the aspect ratio of the particle. The rotational diffusion time scale of the CNT is plotted against the CNT length in figure S2. Since we are combining at least 10 of 400s-long time windows to calculate the translational diffusion coefficient at each field strength, and with the average length of the CNTs in our experiments being 3.5μm, it is safe to say we are tracking the CNT long enough that the rotational diffusion is statistically stationary and thus is unlikely to affect our measurement of translational diffusion coefficient.

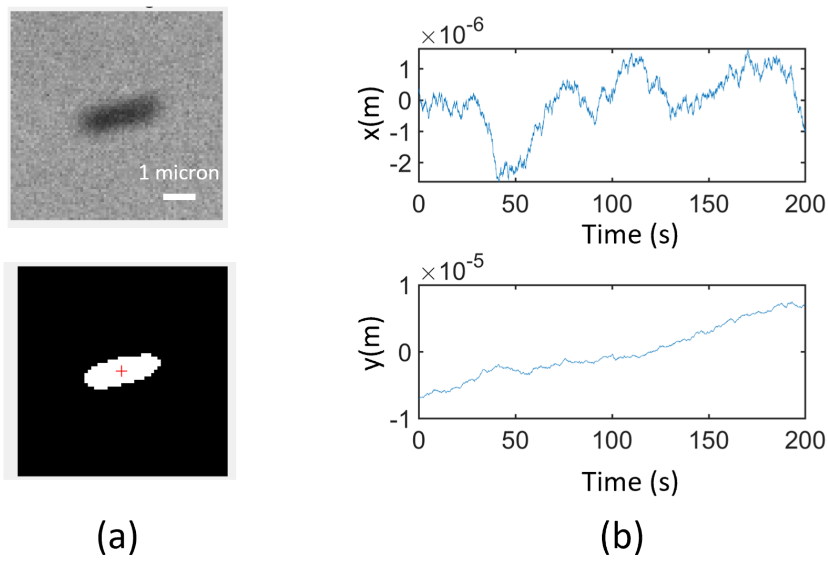

Figure S1: Data processing of a sample CNT.

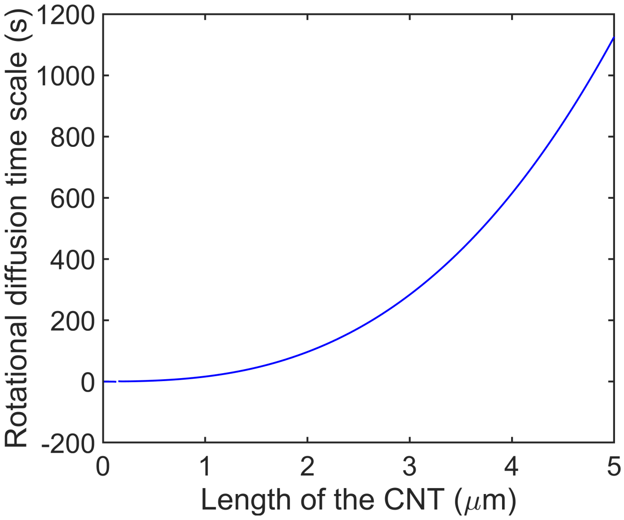

Figure S2: The rotational diffusion time scale of CNT in mineral oil is plotted against the length of the CNT.

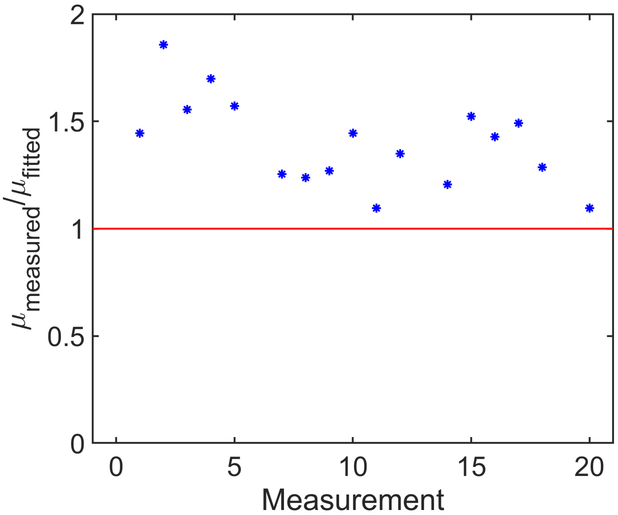

Figure S3: Here we plot the ratio of measured viscosity and the fitted viscosity. 20 individual measurements are presented.

Validation

In order to validate our experimental method, we apply the same single particle tracking technique on spherical iron particles and extract the viscosity of the mineral oil from the measured diffusion coefficient,

$$\mu = \frac{k_B T}{6\pi r D}, \tag{2}$$

with r being the radius of the iron spheres and D being the measured diffusion coefficient. Since we have used fluid viscosity as an adjustable parameter in comparing the experimental and theoretical diffusion results of CNTs, we then plot the ratio of the measured viscosity and the fitted viscosity in figure S3. It is clear that the measured viscosity is greater than the fitted viscosity with the ratios lying in between 1 and 2. It is possibly because the iron spheres are usually close to the bottom slides (due to their high density) during the measurement, thus the apparent viscosity measured by us is greater than the true value due to boundary effect. Other factors that might be contributing to this difference include 1) variations in particle dimensions, 2) unwanted fluid motion, and 3) errors in tracking the particle location (particle out of focal plane).