LECTURE 2 : THE FORCE TRANSDUCER

Outline :

Objectives: To understand the basic principles of how high resolution force transducers function, their physical limitations, and applications.

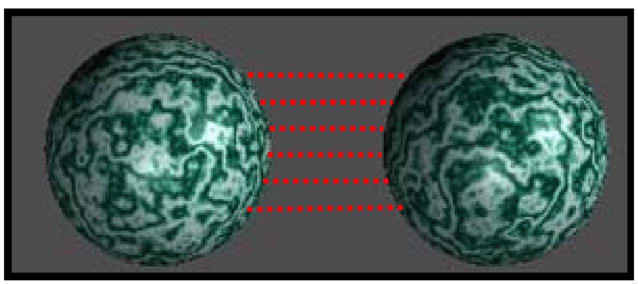
Readings: Course Reader Documents 6-8

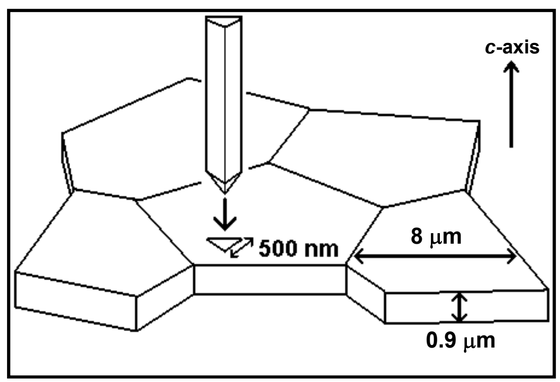
The study of forces, motions, energies, and deformations : much of 3.032 was *continuum mechanics*

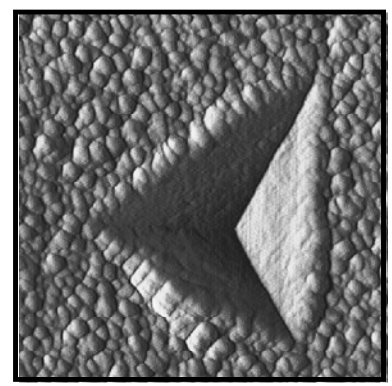
LAST TIME : WHAT IS NANOMECHANICS?→subset of the field of nanotechnology, involving nN-scale forces <u>or</u> nm-scale displacements (nano=$1 \bullet 10^{-9}$)

1. Noncontact : High Resolution Force Spectroscopy, surface forces measurement (e.g. electrostatics, van der Waals forces, etc.)

2. Contact : Nanoindentation, single cell tensile testing (e.g. elasticity, plasticity, → dislocations) etc.

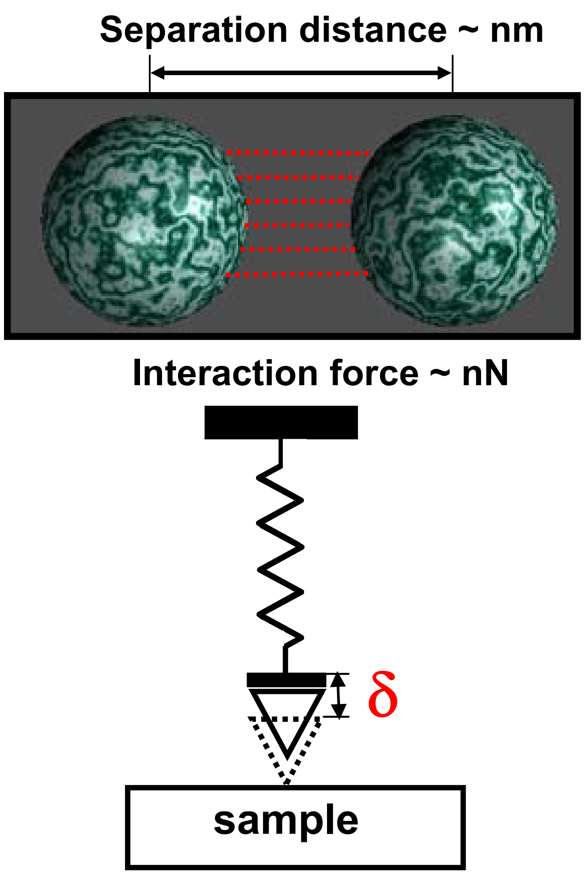






HOW CAN WE MEASURE SUCH TINY FORCES?

i.e. nN (=1•10^{-9} N), even pN (=1•10^{-12} N) ! → typical engineering structures are Newtons



Force Transducer- sensor device that responds to an external force where you can output and record that response

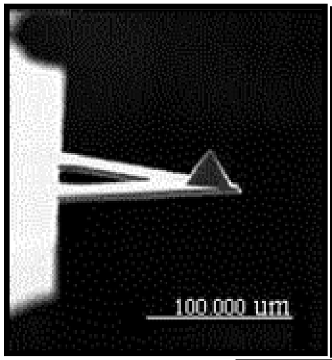
Transducer Calibration - determine the relationship between the externally applied force and output signal to automatically convert to a force

1) high sensitivity and 2) small in dimensions, fine probe (~ nm)

● Typically a **spring** (not conventional!) which deflects in response to a external force, δ= transducer (spring displacement), know the elastic properties (stiffness) of the spring (i.e. Hooke's Law) you can convert into force, F.

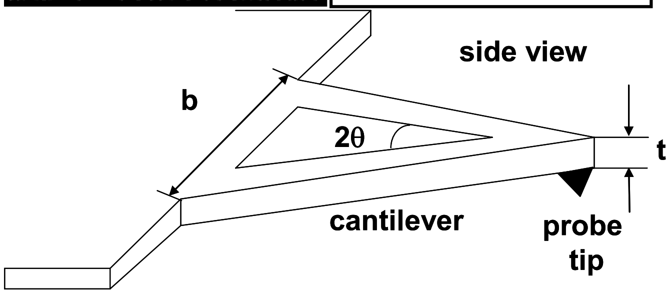
$$F = k\delta$$

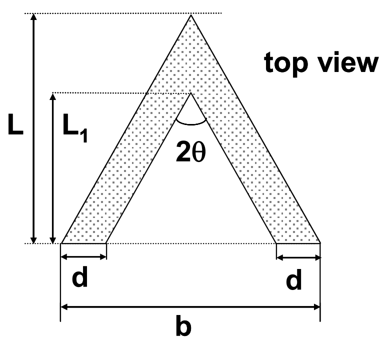
EXAMPLE OF A FORCE TRANSDUCER- Microfabricated Cantilever Beams With Nanosized Probe Tips



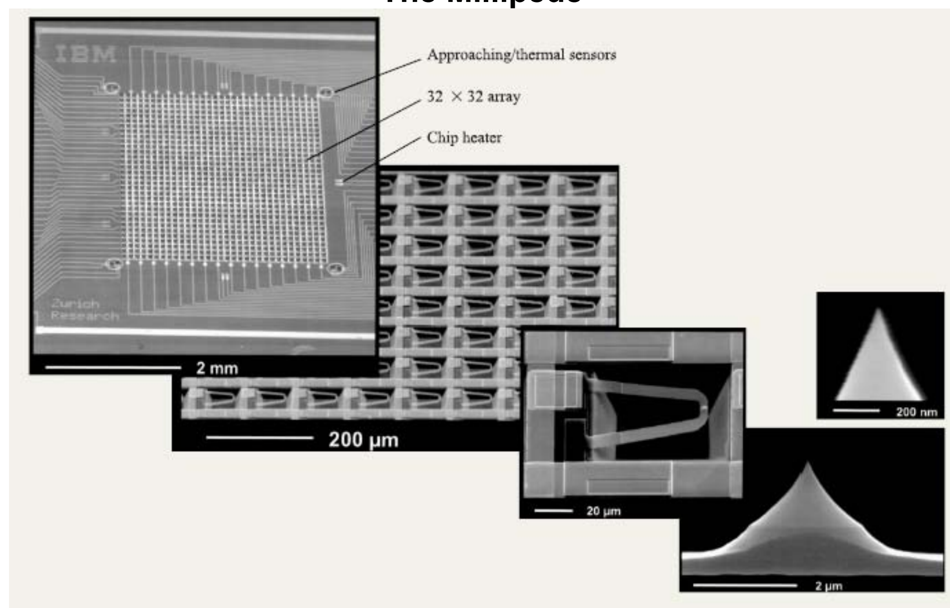
Typical Values :

b= 150 μm
θ=35°
L=200 μm
L_1=150 μm
t =0.6 μm
d = 18 mm





The Millipede



Vettiger, et al. *IBM J. Res. Develop.* 44 3 2000 323

Potential Applications :
1) thermomechanical data storage in thin polymer media - High throughput 2) imaging/characterization
3) nanolithography
4) atomic and molecule manipulations

ATTACHMENTS TO NANOSIZED PROBES AT THE END OF MICROFABRICATED CANTILEVERS

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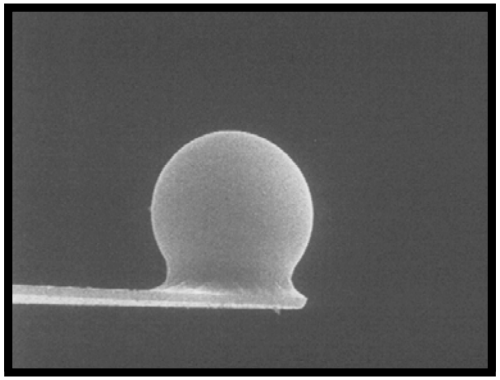
to copyright restrictions.

Single Cell *Dictyostelium Discoideum* (Benoit, et al. *Nature Cell. Bio* **2000**, 2 (6), 313.)



Colloid : Seog, Ortiz/ Grodzinsky Labs 2001

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to copyright restrictions.

Nanotube Tips (Biomolecule Functionalized) :
Wong et al. *Nature* **1998**, *394* (6688), 52.

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E. Coli Bacteria Ong, et al. *Langmuir* **1999**, 15, 2719.

Nanotube Tips :

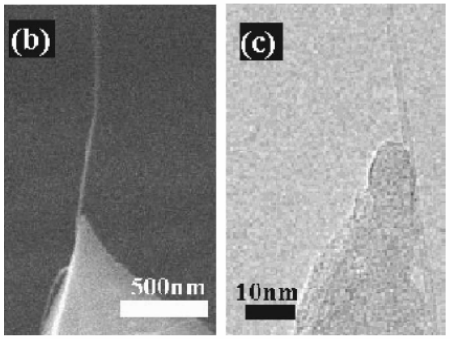
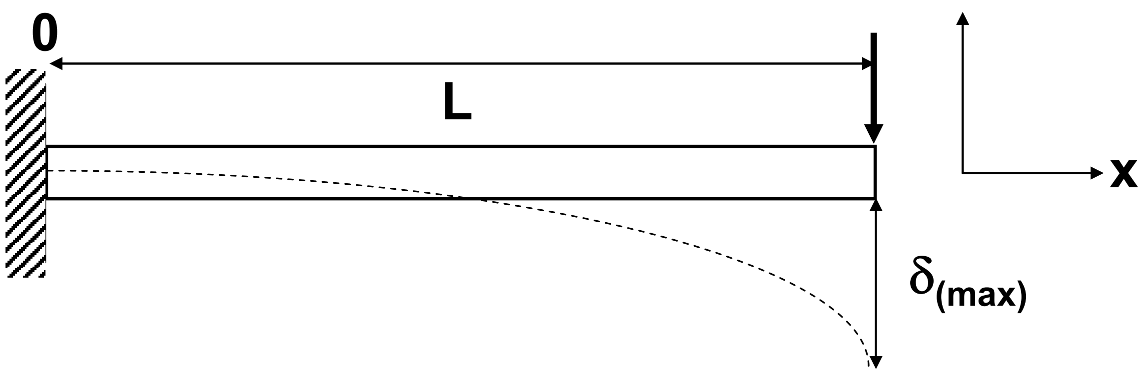
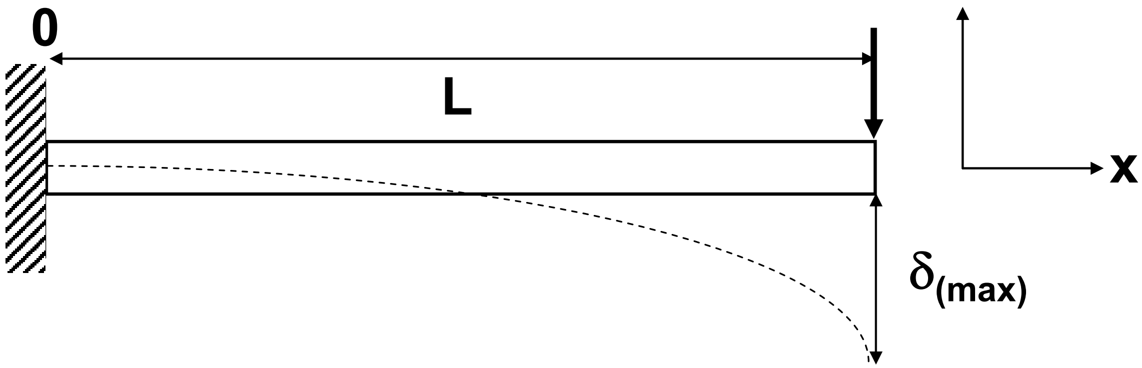


Fig. 2b and c in Yenilmez, E. et al. "Wafer scale production of carbon nanotube scanning probe tips for atomic force microscopy." *Applied Phys Lett* 80, no. 12 (2002): 2225.

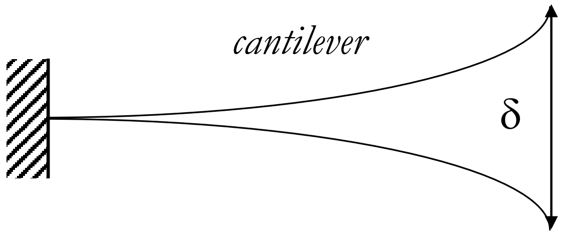
CANTILEVER BEAM THEORY

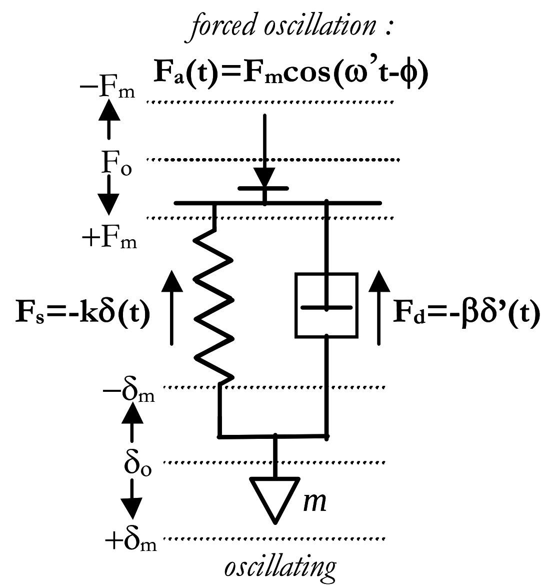


CANTILEVER BEAM THEORY (CONT'D)



LIMIT OF FORCE DETECTION : THERMAL OSCILLATIONS

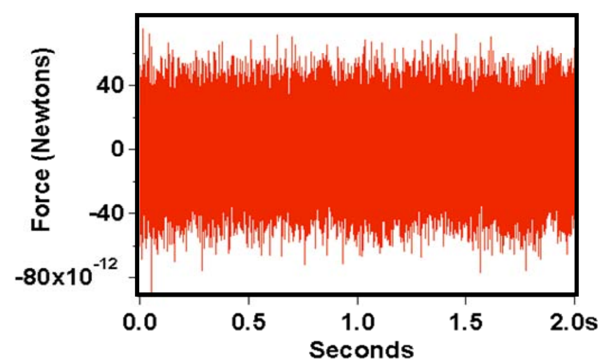




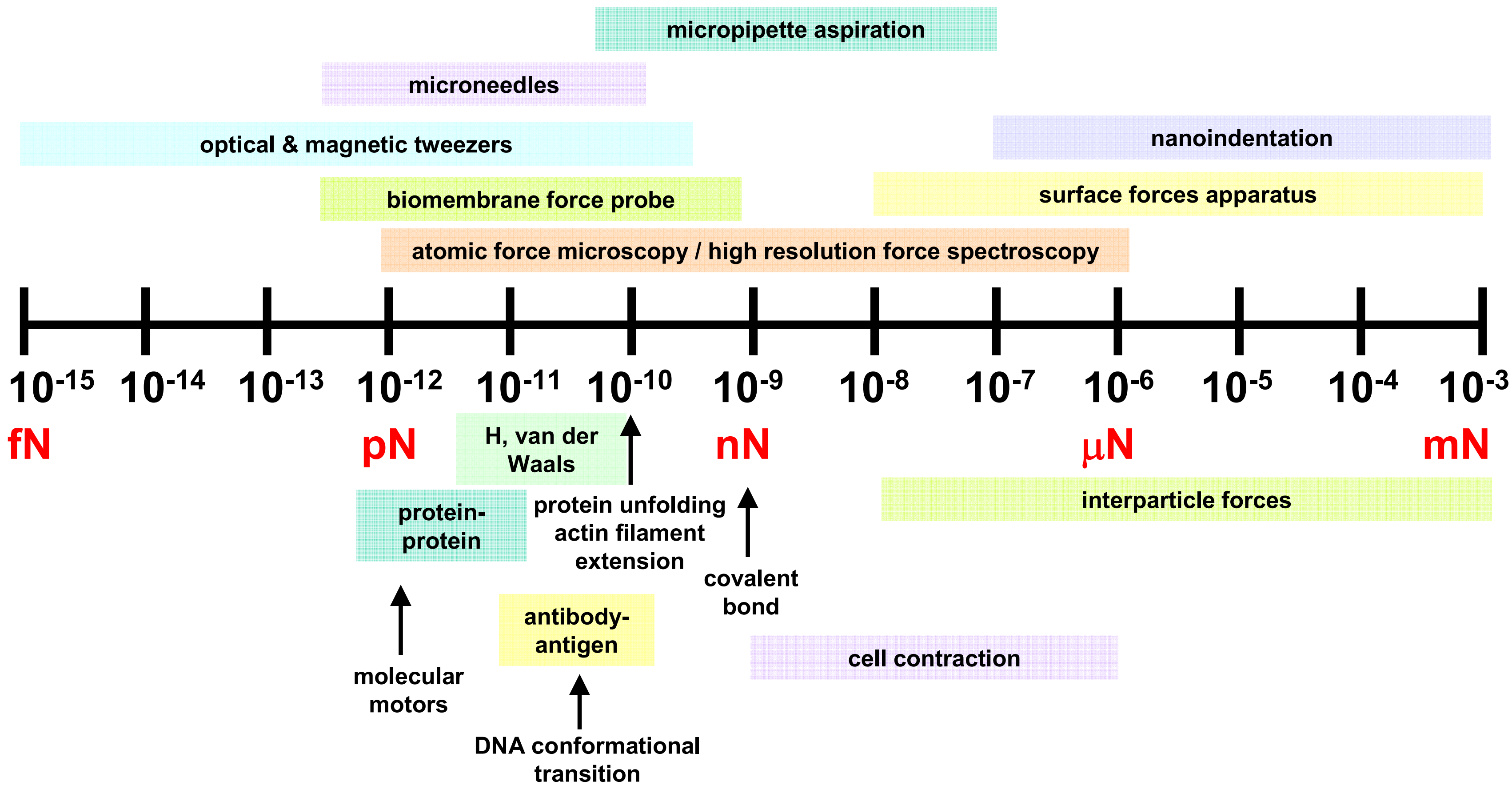
In the absence of any externally applied forces [e.g. far away from the cantilever surface], a high resolution force tranducer will oscillate at its natural resonant frequency (maximum displacement of the amplitude of the oscillations) due to a non-zero thermal energy, k_BT (room temperature)= $4.1 \bullet 10^{-21}$ J → **the system can be modeled as a driven, damped harmonic oscillator**.

These oscillations are the background noise in the nanomechanical experiment and are given by the following equation :

$$F_{min} = 1.007t\left(\frac{w}{lQ}\right)^{1/2}(E\rho)^{1/4}(k_BTb)^{1/2}$$



FORCE RANGE FOR VARIOUS NANOMECHANICAL INSTRUMENTS



BIOSENSORS

Podcast: Lipid Bilayer Formation
Guest: Professor **Jurgen Fritz** (International University Bremen; soon to be Jacobs University Bremen, Germany)
Citation : Pera, I. & Fritz, J. Sensing lipid bilayer formation and expansion with a microfabricated cantilever array. *Langmuir*. 23, 1543-1547 (**2007**)