WORMLIKE CHAINS

• Thin Elastic Filaments / Young's modulus

\[
\text{Bending Energy} = \frac{1}{2} \frac{E I}{L} \frac{1}{R^2} \quad \text{radius of curvature}
\]

2nd moment of inertia

• Persistence Length

\[
\langle t(s) \cdot t(s+\Delta s) \rangle = \exp \left[ -\frac{EI}{mT} \Delta s \right]
\]

\[
\frac{EI}{mT} = \ell_p \quad \text{persistence length}
\]

• Bending Energy

\[
\frac{\text{Energy}}{\text{Length}} = \frac{\frac{2T}{\ell_p}}{2} \left( \frac{2t}{ds} \right)^2
\]

\[
\ell_p = \frac{K_F}{2}
\]

• Relation of WLC & FSC

\[
\langle R \cdot R \rangle_{\text{wlc}} = 2 \ell_p^2 \left[ \frac{1}{\ell_p} + \exp \left( -\frac{L}{\ell_p} \right) - 1 \right]
\]

Rigid \( \ell_p/L \gg 1 \) \quad \langle R^2 \rangle \to L^2

Flexible \( \ell_p/L \ll 1 \) \quad \langle R^2 \rangle \to 2 \ell_p L \quad \Rightarrow \ell_p = \frac{L}{2}

\]
After Bustamante et al., *Current Opinion in Structural Biology*, 2001
Graph (Figure 2.) removed due to copyright considerations

\[
U = \int_0^1 \frac{\hbar t L_p}{2} \left( \frac{\partial \langle s \rangle}{\partial s} \right)^2 ds
\]

Difficult in general to solve...

Marko & Sigija (1995): limits for \( L_p / L \ll 1 \)

trick: equipartition of energy

small force

\[ f_z \approx \frac{3}{2} \frac{\hbar T}{L_p} \left( \frac{\langle z \rangle}{L} \right) \]

large force

\[ f_z \approx \frac{1}{4} \frac{J_2 T}{L_p} \left( 1 - \frac{\langle z \rangle}{L} \right)^{-2} \]

interpolation

\[ f_z = \frac{J_2 T}{L_p} \left[ \frac{1}{4(1 - \frac{\langle z \rangle}{L})^2} + \frac{\langle z \rangle}{L} - \frac{1}{4} \right] \]
Images removed due to copyright considerations.
See Figures 1, 2, and 3 and Table 1 in Isambert, Herve, et al. "Flexibility of Actin Filaments Derived from Thermal Fluctuations." *Journal of Biological Chemistry* 270 (19) 12 May 1995, 11437-11444.
After Fig. 1 and 2 in Sun, Y. et al. "Mechanical Properties of Single Type II Collagen Molecule." Paper No: 0082, 48th Annual Meeting of the Orthopaeedic Research Society.

**Stretching a procollagen II molecule with an optical tweezers**

**The force-extension curve of a single collagen II**

Image removed due to copyright considerations.

Modeling Extreme Extension: Ising Model
Cizeau & Viovy 1997

Images removed due to copyright considerations.
Figure 1 in Leger, J. F. et al. "RecA binding to a single double-stranded DNA molecule: A possible role of DNA conformational fluctuations."

Muscles

(a) Skeletal muscle
Myofiber (muscle cell)

Myofibril
Plasma membrane
Nucleus
Sarcomere

I band
H zone
Z disk
A band

molecular motor
semiflexible polymer

Z disk
Myosin thick filament
Actin thin filament
M line
Nebulin

resting elasticity

4/1/02 10.537
Pulling on Titin

"Sawtooth profile"

Image removed due to copyright considerations.
Figure 1 in Marszalek, Piotr E., et al. "Mechanical unfolding intermediates in titin modules." Nature 402, 100-103 (04 Nov 1999).
Importance of Ig Domains

Titin

http://www.ks.uiuc.edu/Research/titinIg/

Ig = immunoglobulin domains

Several hydrogen bonds
Images removed due to copyright considerations.
Assembly of actin at the leading edge of migrating cells