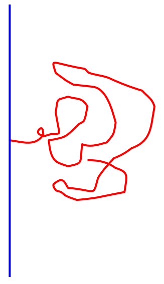
2012 11 8



❶

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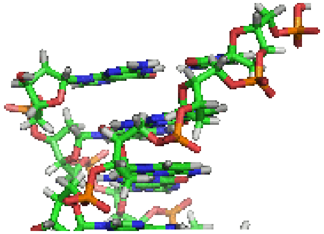
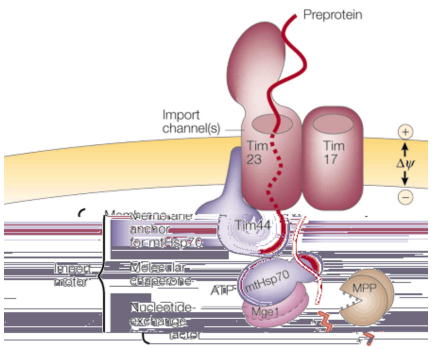
❹

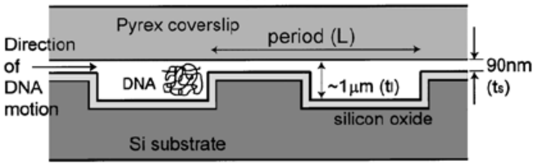


RNA



Reviews I

Nature



/

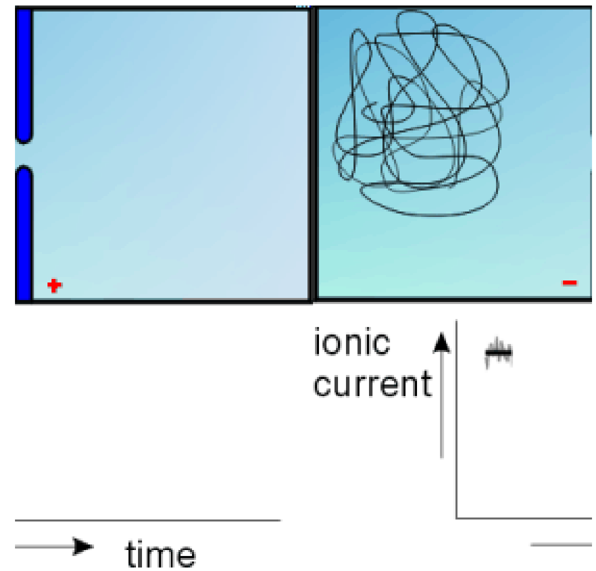
(GPC)

1989 DNA

D. Deamer

D. Branton

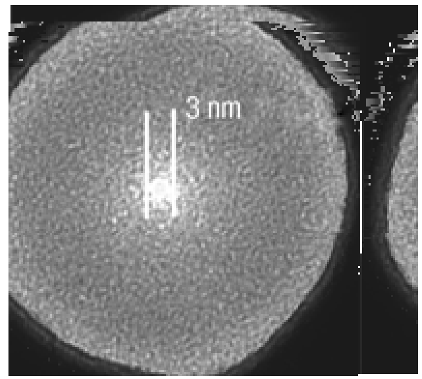
[**Science** 2012, *336*, 534]


ionic
current
time

(96)

(01)

(11)

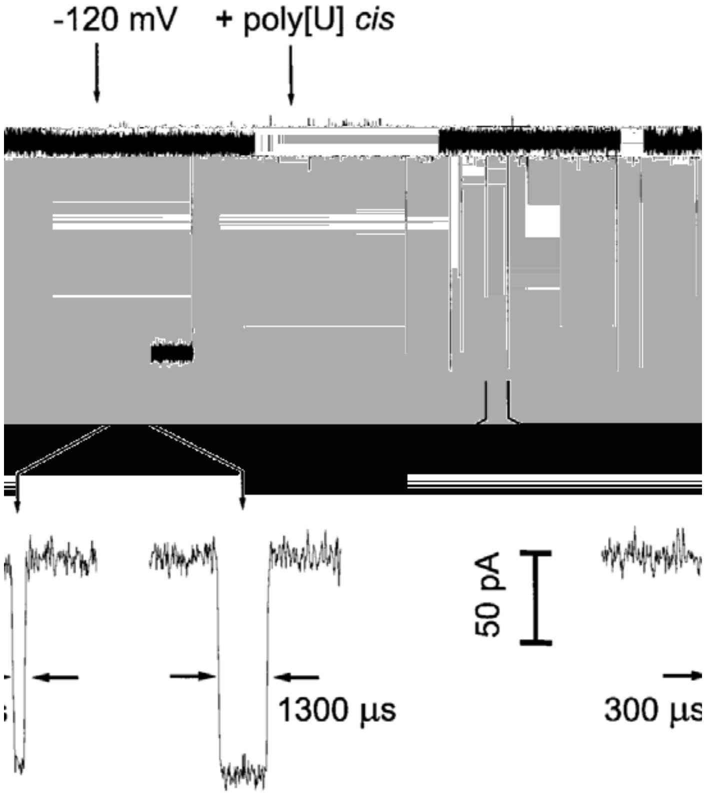


Song et al.,1996

Li, Golovchenko et al., 2001

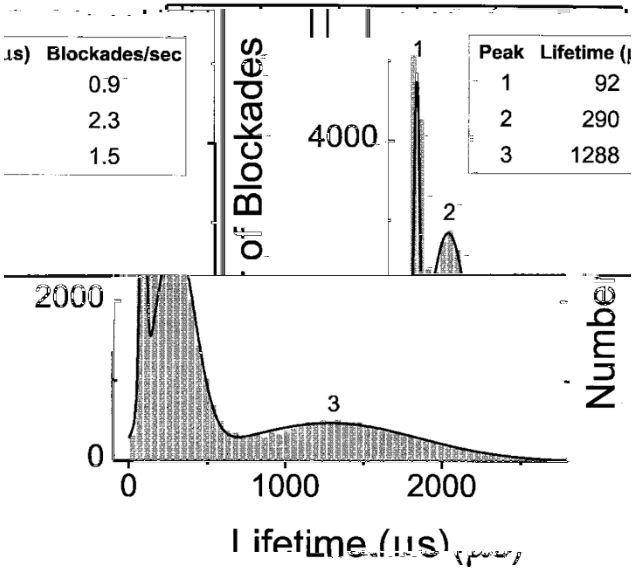
John Kasianowicz
Amit Meller
Alek Aksimentiev
Jens Gundlach
Hagan Bayley

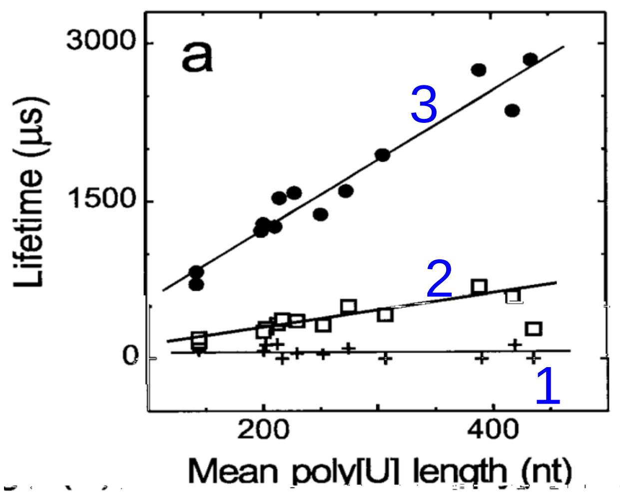
DNA



- Effective charge per nucleotide = 0.2 e in the pore lumen (2.4 e total)
- 5 pN force at 120 mV applied potential

[J. J. Kasianowicz, E. Brandin, D. Branton, and D. W. Deamer, *PNAS*, **93**, 13770 (1996)]





2 3

1

2

3

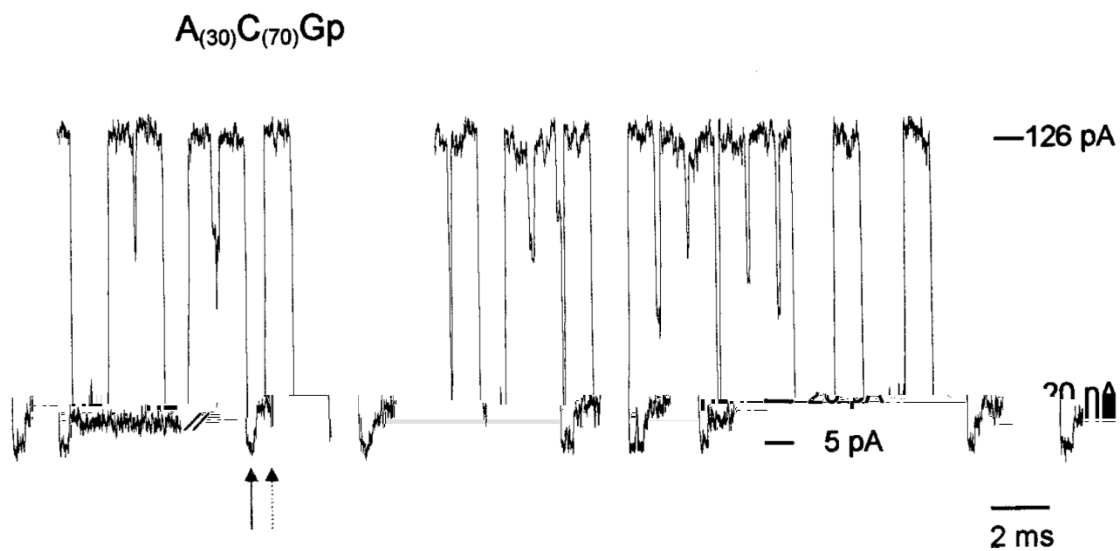
$$\tau \sim N^1$$

[Mathe *et al*. *PNAS*, **102**, 12377 (2005)]

RNA

150 125

20 μs/nt 3 μs/nt



[Akeson *et al*. *Biophys J.*, **77**, 3227 (1999)]

DNA

(<5%)

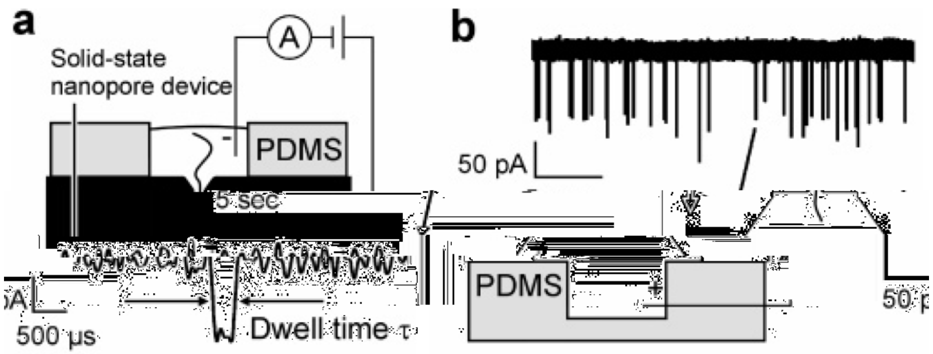
I_B

Poly(dA) Poly(dC)

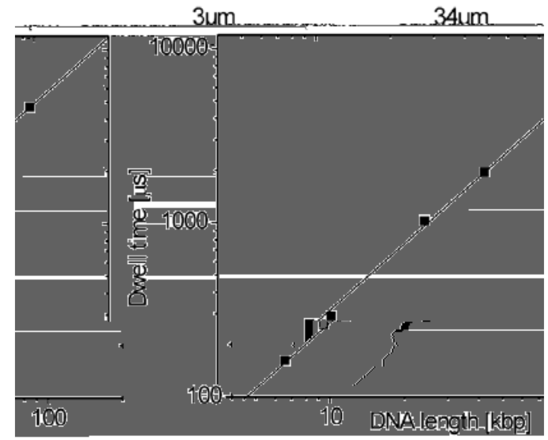
[A. Meller *et al*. *PNAS*, 97, 1079 (2000)]

2001

20nm, **10nm**



[C. Dekker *et al*. *Nano Lett.*, **5**, 1193 (2005)]



$$\tau \sim N^{1.27} = N^{2\nu}$$

8nm **4nm**

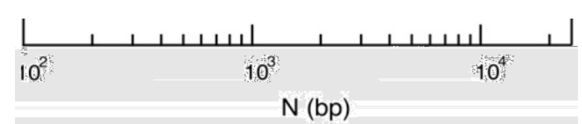
$$\tau \sim N^{2.28}$$

$$\tau \sim N^{1.4}$$

4nm

10nm

[A. Meller *et al*. *Biophys. J.*, **97**, 1079 (2000)]



Base by base

- 12
- DNA ( )

[U. F. Keyser, *J. R. Soc. Interface*, **8**, 1369 (2011)]
[B. Luan *et al.*, *Nanoscale*, **4**, 1068 (2012)]

2010

- **M. Drndic:** **1-5 nm** **5-10 nm**

[C. A. Merchant *et al.*, *Nano Lett.*, **10**, 2915 (2010)]

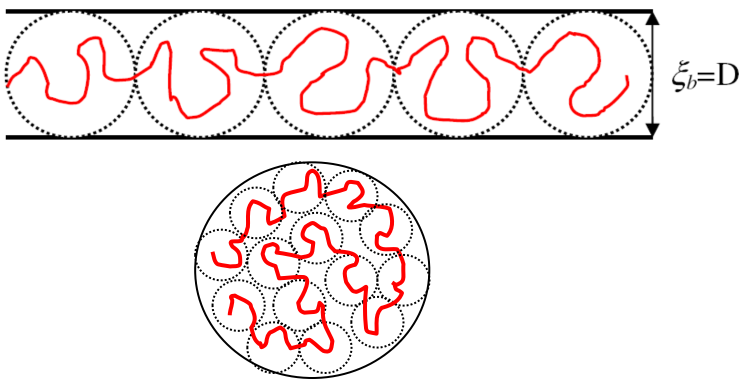
- **C. Dekker:** **22 nm**

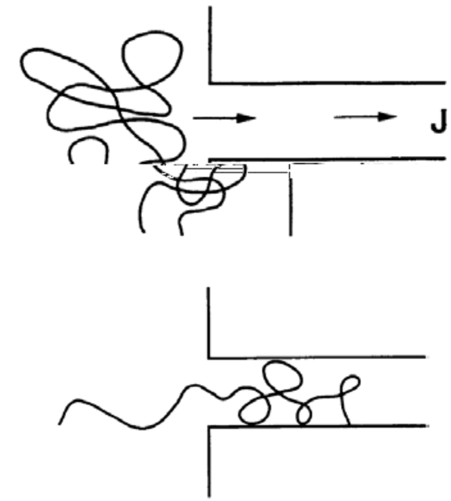
[G. F. Schneider *et al.*, *Nano Lett.*, **10**, 3163 (2010)]

- **J. A. Golovchenko:** **0.6-10 nm**
  2.4-5 nm

[S. Garaj *et al.*, *Nature*, **467**, 190 (2010)]

DNA





P. G. de Gennes

1991

M. Muthukumar, M. Kardar, A. Y. Grosberg,
K. Binder, J. F. Joanny, M. Rubinstein,
J. J. de Pablo, G. W. Slater

-

- DNA

  DNA RNA

-

  DNA

[Sung & Park *PRL*, 77, 783 (1996); Muthukumar *JCP*, 111, 10371 (1999)]

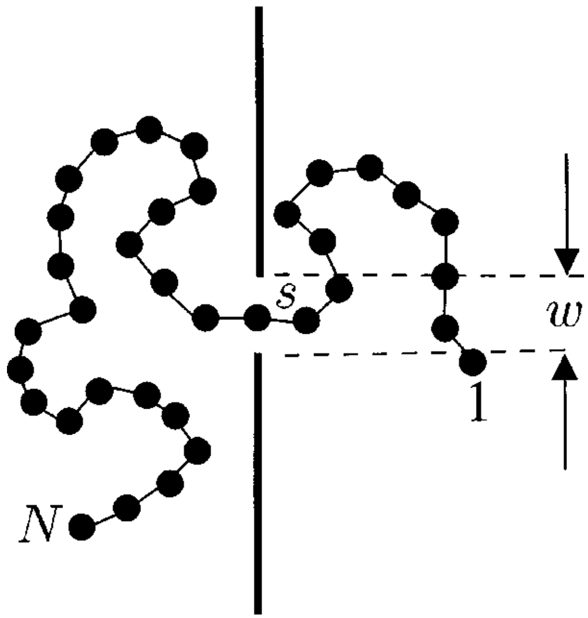
:

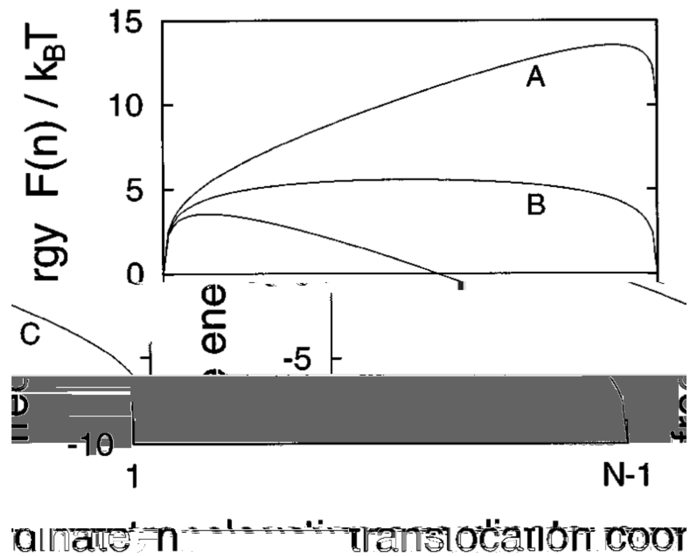
Gaussian ( )

,

( )

: $F(s) = (1-\gamma) k_B T \ln\left[(N-s)s\right] + s\Delta\mu$





$$\frac{\partial p}{\partial t} + \frac{\partial j}{\partial s} = 0$$

$$j = -D\left(\frac{\partial p}{\partial s} + \frac{p}{k_B T}\frac{\partial F}{\partial s}\right)$$

Fokker-Planck

Kramers' problem!

Sung (PRL, 77, 783, 1996)

Muthukumar (JCP, 111, 10371, 1999)

D=1/N

D N

$$\boxed{\tau_{trans} \sim N^2/D}$$

$$\boxed{\tau_{trans} \sim N^2}$$

?

$$\boxed{\tau_{trans} \sim N/D}$$

$$\boxed{\tau_{trans} \sim N}$$

bead-spring Langevin dynamics (LD)

[M. P. Allen, D. J. Tildesley, Computer Simulation of Liquid (Oxford Univ. Press, 1987)]

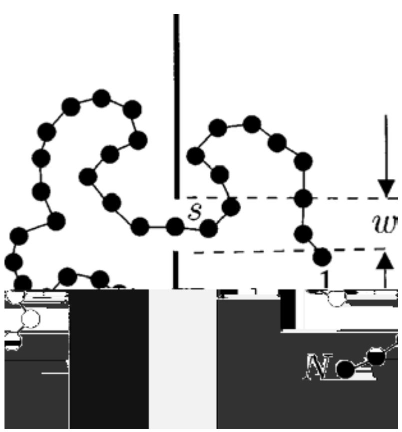
Equation of motion is given by

$$m\ddot{\mathbf{r}}_i = -\nabla_i(U_{\mathrm{LJ}} + U_{\mathrm{FENE}}) + \mathbf{F}_{\mathrm{ext}} - \xi\mathbf{v}_i + \mathbf{F}_i^R$$

$$U_{\mathrm{LJ}}(r) = 4\varepsilon[(\tfrac{\sigma}{r})^{12} - (\tfrac{\sigma}{r})^{6}]$$ **LJ**

$$U_{\mathrm{FENE}}(r) = -\tfrac{1}{2}kR_0^2\ln(1 - r^2/R_0^2)$$ **FENE**

$$\mathbf{F}_{\mathrm{ext}} = F\hat{x}$$



ε/σ

ε

σ

$$t_{\mathrm{LJ}} = (m\sigma^2/\varepsilon)^{1/2}$$

( )

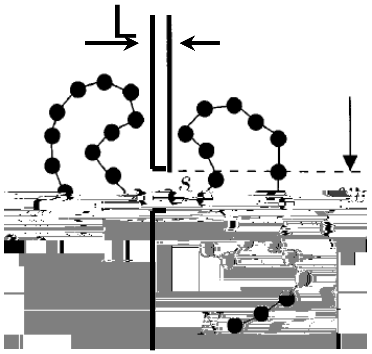
:

-
-

(1) ( )

(2) ( )

(3) (DNA)



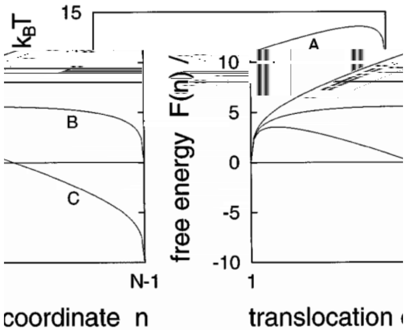
$$\tau \sim N^{\alpha}$$

N

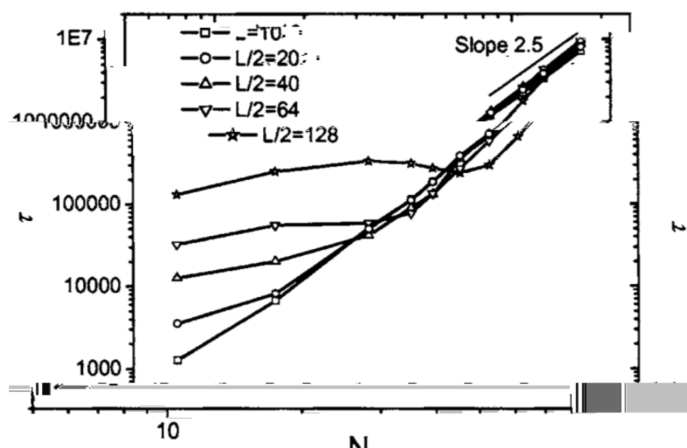
$$\tau > \tau_r \sim N^{1+2\nu} = N^{2.18}$$

Fokker-Planck $\tau \sim N^2$

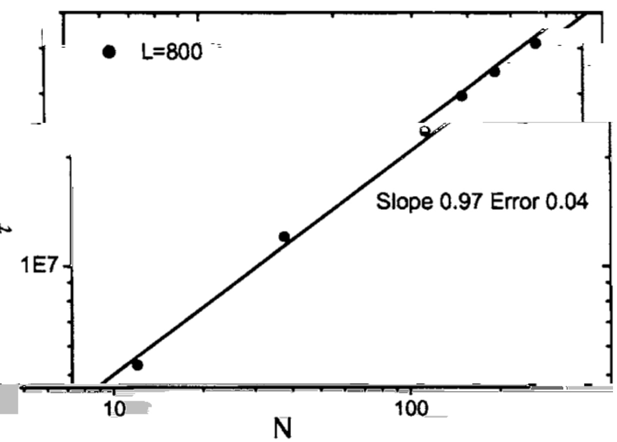
M. Muthukumar *J. Chem. Phys*. 1999, *111*, 10371]



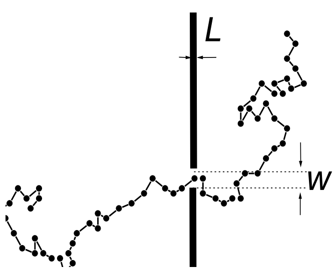
$$\tau \sim \frac{\left(R_g + L\right)^2}{D} = \begin{cases} N^{1+2\nu} & \left(L << R_g\right) \\ NL^2 & \left(L >> R_g\right) \end{cases}$$



(b)



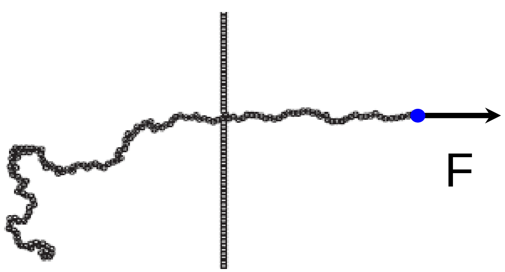
(a)



Luo* *et al.* **J. Chem. Phys.** 2006, *124*, 034714

(1)

$$\tau \sim \frac{R_{\parallel}(F)}{v(F)} \sim \begin{cases} N^{1+2\nu} & \left(F < k_B T / N^{\nu}\sigma\right) \\ N^2 F^{1/\nu-2} & \left(k_B T / N^{\nu}\sigma \le F \le k_B T/\sigma\right) \\ N^2 F^{-1} & \left(F > k_B T/\sigma\right) \end{cases}$$



...*Luo** *et al.* ***Phys. Rev. E*** 2007, *75*, 061912

(2)

✓

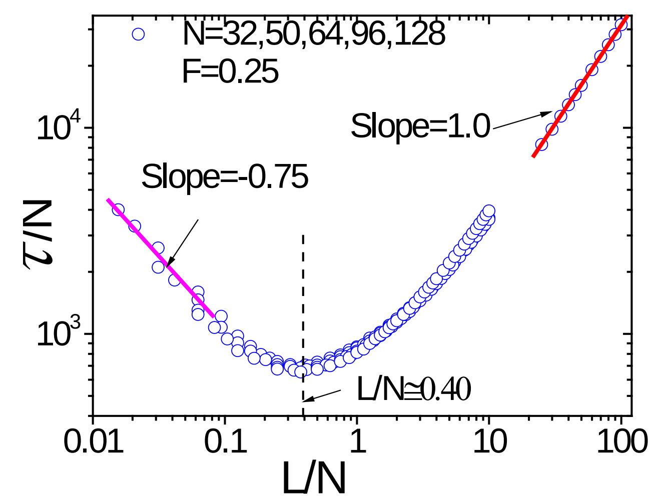
$$C R^{-1/3} \xi s(t) \frac{ds(t)}{dt} = s(t) F$$

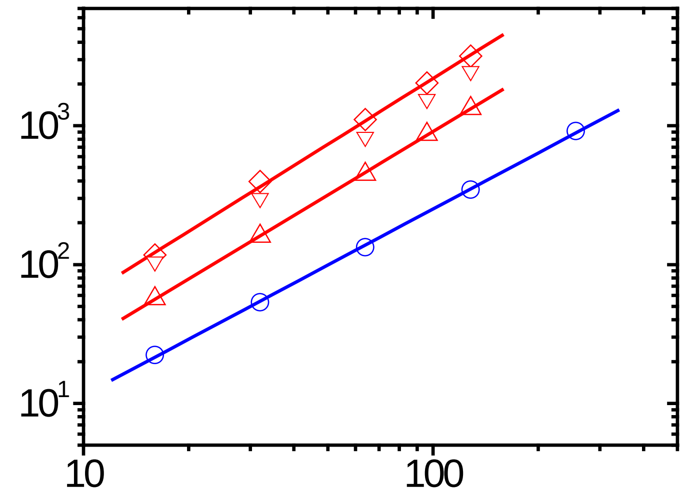
Luo* *et al.* ***J. Chem. Phys.*** 2011, *134*, 135102

✓

$$\tau \sim \frac{R_g + L}{v} = \begin{cases} N^{1+\nu} & (L << R_g) \\ L & (L >> R_g) \end{cases}$$

... Luo* ***Soft Matter*** 2012, *8*, 2769





Luo* *et al.* ***J. Chem. Phys.*** 2006, *124*, 114704; 2007, *126*, 145101

Luo *et al.* ***Phys. Rev. E*** 2008, *78*, 050901(R)

Luo* *et al.* ***Phys. Rev. E*** 2009, *80*, 021907

Luo* *et al.* ***Europhys. Lett.*** 2009, *88*, 68006

*...**Luo**** et al.* ***J. Chem. Phys.*** 2006, *125*, 124901

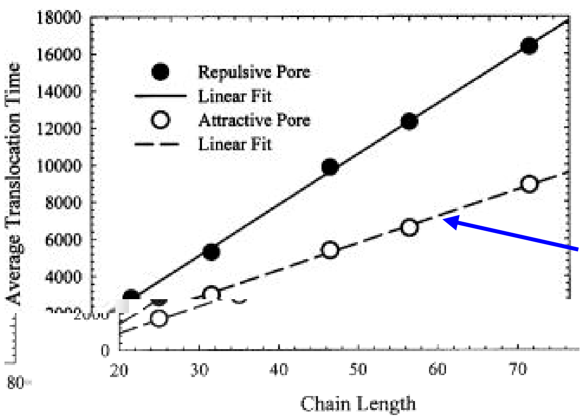
( )

(1)

Poly(dC): 120

Poly(dA): 330

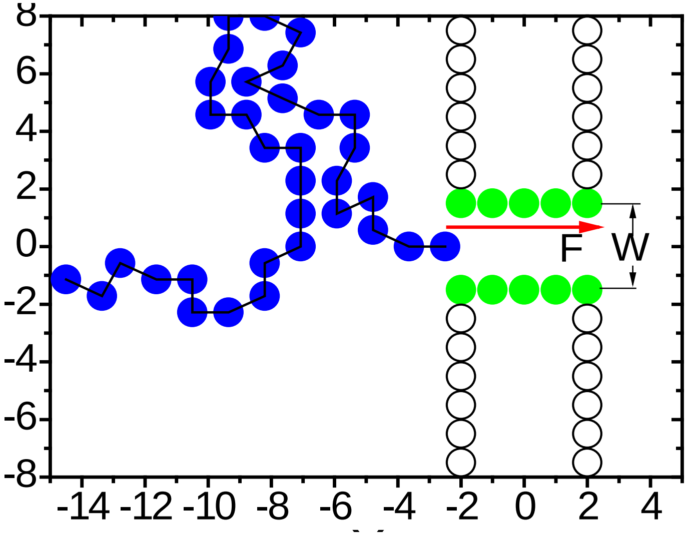
[D. Branton et al. *PNAS* 2000, *97*, 1079]



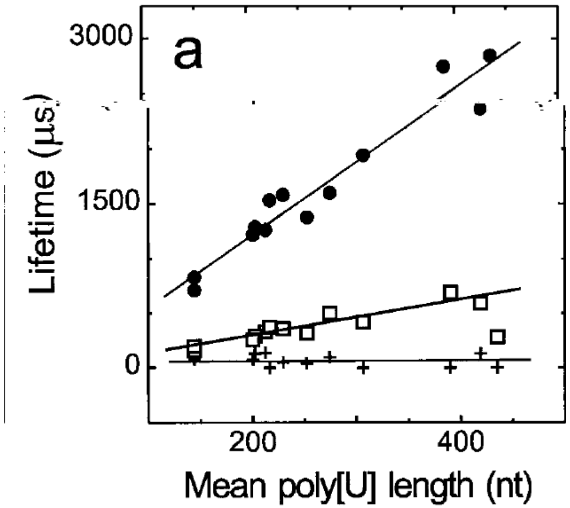
?

[G. D. Smith et al. *J. Chem. Phys.* 2003, *119*, 11475]

(1)



(1)



[D. Branton et al. PNAS, 1996, *93*, 13770]

(1) A C

Poly(dA)$_{100}$ Poly(dC)$_{100}$

(2)

(3)

DNA

*Luo** *et al.* ***Phys. Rev. Lett.*** 2007, *99,* 148102

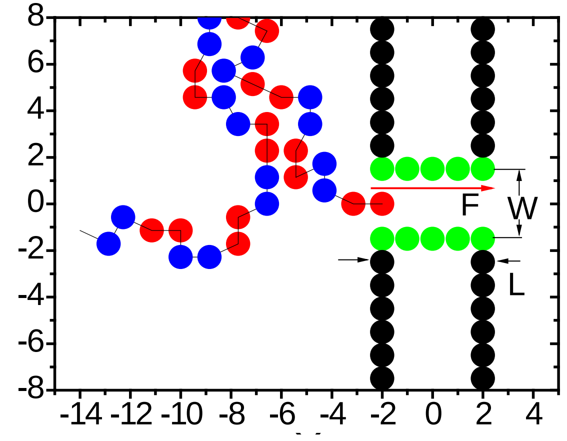
*Luo** *et al.* ***Phys. Rev. E*** 2008, *78,* 061918

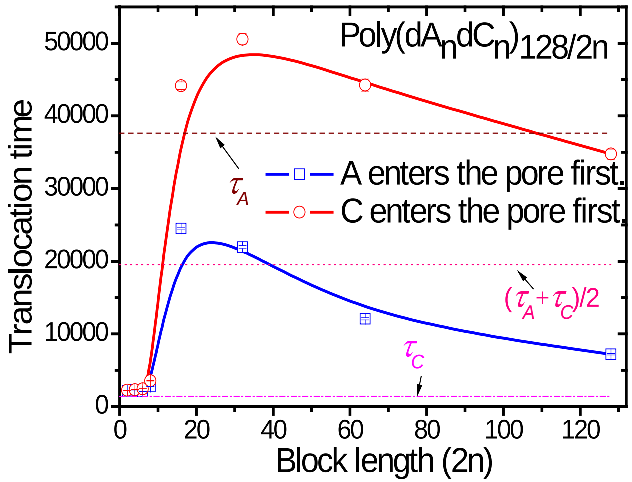
(2) DNA

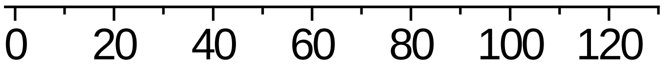
Poly($dA_{50}dC_{50}$) **Poly(dAdC)$_{50}$**

[D. Branton *et al. PNAS* 2000, *97*, 1097]

Poly($dA_n dC_n$)$_{128/2n}$ DNA

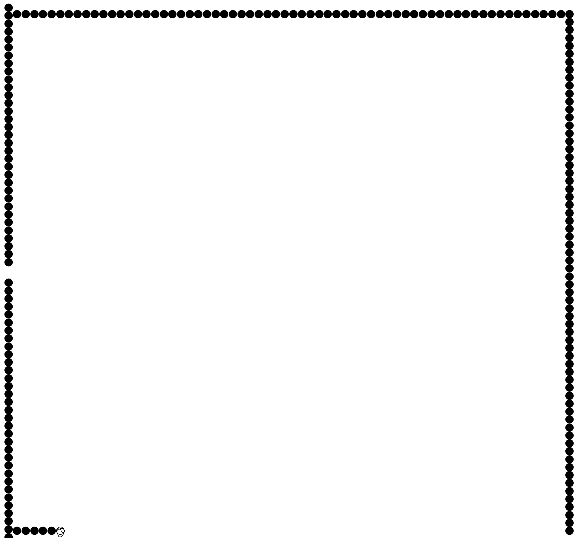


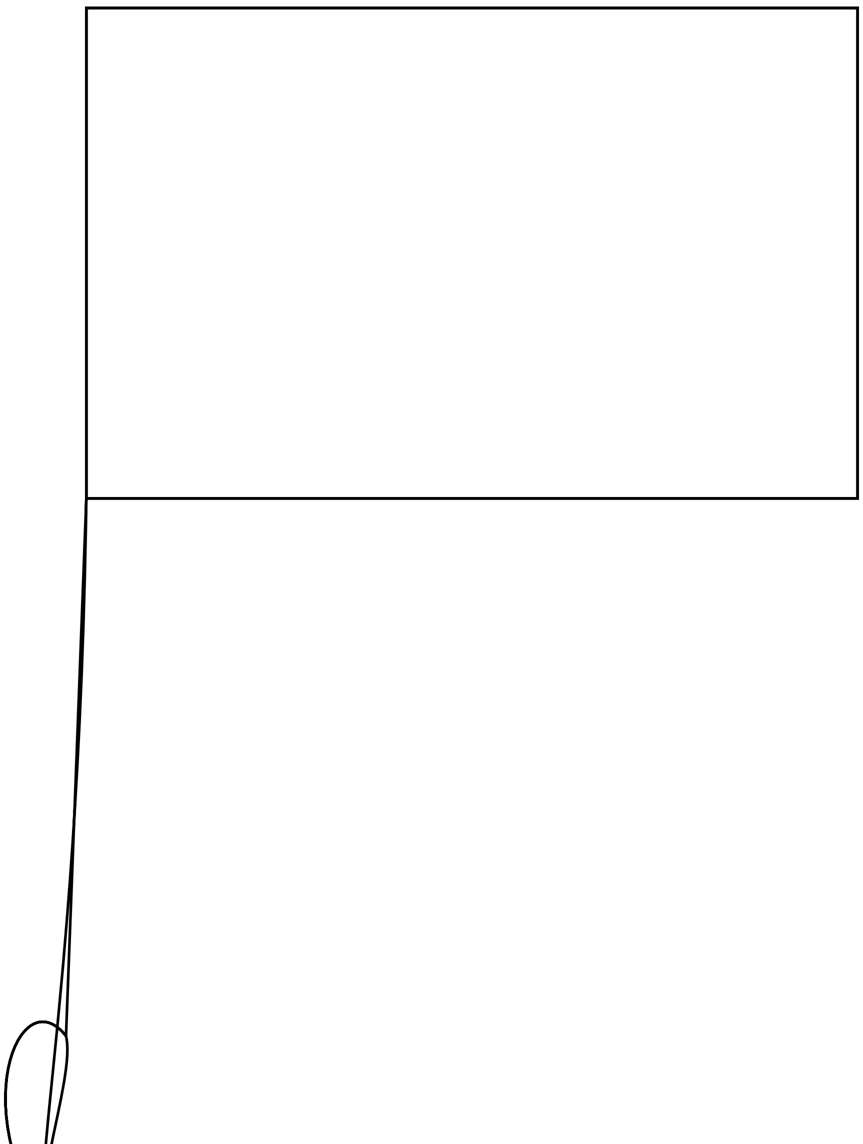


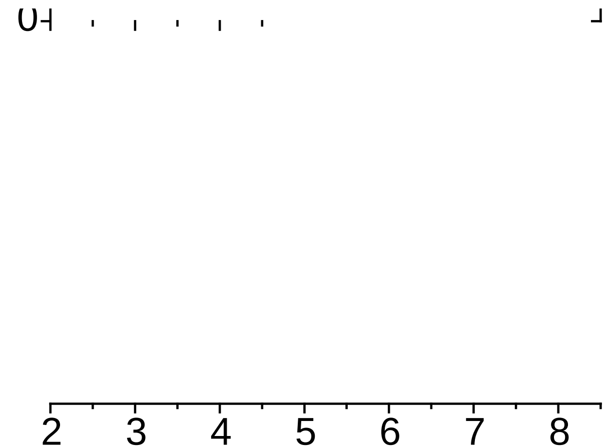


*Luo** *et al*. ***Phys. Rev. Lett.*** 2008, *100,* 058101
*Luo** *et al*. ***Phys. Rev. E*** 2008, *78,* 061911

(   )



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4
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批评指正!