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(2.1) $F = 1\,pN$

$m = 100\,kDa$

$1\,Da = 1.66 \cdot 10^{-24}\,g$

$= 1.66 \cdot 10^{-27}\,kg$

$F = m \frac{d^2x}{dt^2}$

$\frac{dx}{dt} = v_0 + \frac{F}{m} \cdot t$

$\frac{dx}{dt}(1ns) = 0 + \frac{F}{m}(1ns) = \left(\frac{10^{-12} N \cdot 10^{-9} s}{1.66 \cdot 10^{-27}\,kg} \right)$

$= 6.02 \cdot 10^{5}\ m/s$

$\gamma = 60\ \frac{pN \cdot s}{m}$

$m \frac{dv}{dt} + \gamma v = F \rightarrow v(t) = \frac{F}{\gamma}\left[1 - e^{-t/\tau}\right]$

so $v(\infty) = \frac{F}{\gamma} = \frac{1\,pN}{\left(60\,\frac{pN \cdot s}{m}\right)} = \frac{1}{60}\,\frac{m}{s}$

(2.2) Assuming that viscosity affects the drag coefficient linearly, then

$\gamma_{cytoplasm} = 10^3 \cdot \gamma_{H_2O} = 10^3 \cdot 60\ \frac{pN \cdot s}{m} = 6 \cdot 10^4\ \frac{pN \cdot s}{m}$

Then $v(\infty) = \frac{F}{\gamma} = \frac{1}{60 \cdot 10^3}\,\frac{m}{s} = \frac{1}{6} \cdot 10^{-4}\ m/s$. very slow.

under~~a~~ damped motion would be

(24) $k \cong 1 \frac{N}{m}$

$$m \frac{d^2x}{dt^2} + kx = F$$

$m \cong 100$ ng

$$\omega = \sqrt{\frac{k}{m}} = \sqrt{\frac{1 \, N/m}{10^2 \cdot 10^{-9} \cdot 10^{-3} \, kg}} = \sqrt{\frac{10^9 \cdot 10^3}{10^2} \frac{N}{m \, kg}} = \sqrt{10^{10} \frac{N}{m \, kg}}$$

$$= 10^5 \sqrt{\frac{kg \frac{m}{s^2}}{m \, kg}} = 10^5 \, 1/s = 10^5 \, Hz$$

$\gamma \cong 1 \frac{\mu N \cdot s}{m}$

over v.s. under damping is determined by

over damping $\Rightarrow \gamma^2 > 4mk$

& under damping $\Rightarrow \gamma^2 < 4mk$

This gives $\left(10^{-6} \frac{N \cdot s}{m}\right)^2 \overset{?}{\gtrless} 4 (10^2 \cdot 10^{-9} \cdot 10^{-3} kg)\left(\frac{1N}{m}\right)$

$$10^{-12} \frac{N^2 s^2}{m^2} \; ? \; 4 \cdot 10^{-11} \frac{kg \, N}{m}$$

$$\Rightarrow \quad 10^{-12} \frac{kg^2 \frac{\cancel{m^2}}{s^4} \cdot s^2}{\cancel{m^2}} \; ? \; 4 \cdot 10^{-11} \frac{kg^2}{s^2}$$

$$10^{-12} \frac{kg^2}{s^2} < 4 \cdot 10^{-11} \frac{kg^2}{s^2}$$

The motion is under-damped.

(2.5) $E \sim 100 \cdot 10^{-21}$ J

$F \sim 6 \cdot 10^{-12}$ N

$F \cdot \Delta x = E$

$$\Delta x = \frac{E}{F} = \frac{10^2 \cdot 10^{-21} \text{ J}}{6 \cdot 10^{-12} \text{ N}} = \frac{1}{6} \cdot 10^{-19+12} \text{ m} = \frac{10^{-7}}{6} \text{ m}$$

(2.6) $F \approx 0.5$ pN

$v \sim 25$ μm/s

$$P = Fv = .5 \cdot 10^{-12} \cdot 25 \cdot 10^{-6} \text{ Nm/s}$$
$$= 5^3 \cdot 10^{-15} \cdot 10^{-6} \text{ J/s}$$
$$= \frac{E_0 n}{1 s} \quad \text{w/} \quad E_0 = 10^2 \cdot 10^{-21} \text{ J}$$

$$n = \frac{5^3 \cdot 10^{-19} \text{ J/s}}{10^{-19} \text{ J/s}} = 125.$$

(2.7) $$F = \frac{1}{4\pi\epsilon_0\epsilon} \frac{q_1 q_2}{r^2}$$

$\epsilon_0 = 8.854 \cdot 10^{-12}$ $C^2/N \cdot m^2$

ϵ = dielectric constant.

$q = 1.602 \cdot 10^{-19}$ C

$$F = \frac{1}{4\pi \cdot \epsilon_0 (80)} \frac{q^2}{(10^{-9})^2}$$

$$= \frac{1}{4\pi \cdot (8.854 \cdot 10^{-12} \, C^2/N \cdot m^2)(80)} \frac{(1.602 \cdot 10^{-19} \, C)^2}{(10^{-9} \, m)^2}$$

$F = 2.88 \cdot 10^{-12}\,N = 2.88\,pN$ ✓

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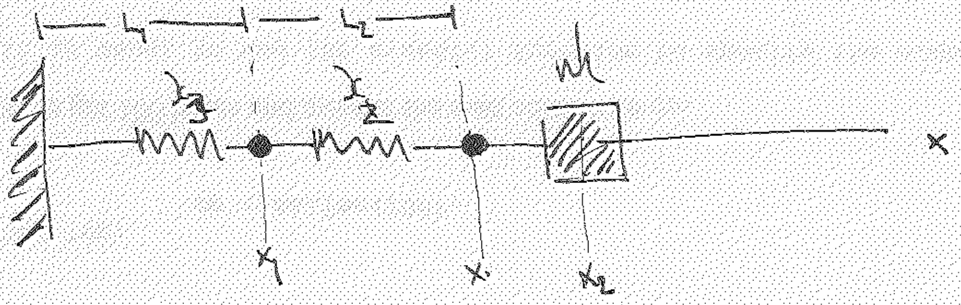
(2B)

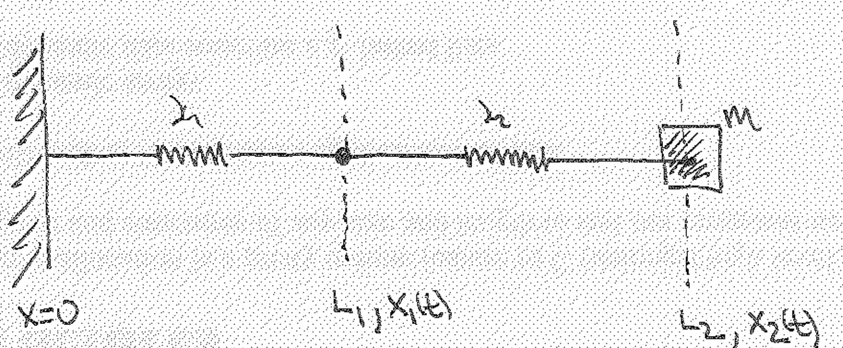


let spring k_1 have nature length L_1 & spring k_2 have natural length L_2

Then Force on part x_1 would be $F = -k_1(x - L_1)$

$F =$

should get $F =$



* $x_2 = L_2$

$x_1 = L_1$

Force on $m = 0$

$F = -k_1(x_2 - L_2 + x_1 - L_1)$

$= -k_1(x_2 - L_2)$

$- k_1(x_1 - L_1)$

Then a free body diagram based on m gives

$$m\frac{d^2x_2}{dt^2} = \cancel{k_2(x_2 - x_1)} - k_2 \ \ldots$$

L_1 & L_2 are fixed locations on the x axis

See Note * Then if $x_2 > L_2$ $F < 0$ ✓

$x_2 < L_2$ $F > 0$ ✓

$$m\frac{d^2x_2}{dt^2} = -k_2(x_2-L_2) - k_1(x_1-L_1)$$

A free body diagram on $x_1(t)$ gives

$$\cancel{m\frac{d^2x_1}{dt^2}}^{0} = \cancel{-k_1(x_1-L_1) - k_2(x_1-L_1)}$$

as $m=0$ $-k_2(x_2+x_1-L_2-L_1)$

$$-k_1(x_1-L_1) \qquad *$$

Thus based on eq * one gets

~~Sqex~~ x -

$$-k_2(x_2-L_2) - k_2(x_1-L_1) - k_1(x_1-L_1) = 0$$

$$-k_2(x_2-L_2) \quad -(k_2+k_1)(x_1-L_1) = 0$$

$\Rightarrow$ $x_1 = -\dfrac{k_2}{(k_2+k_1)}(x_2-L_2) + L_1$ then the equation for x_2

becomes

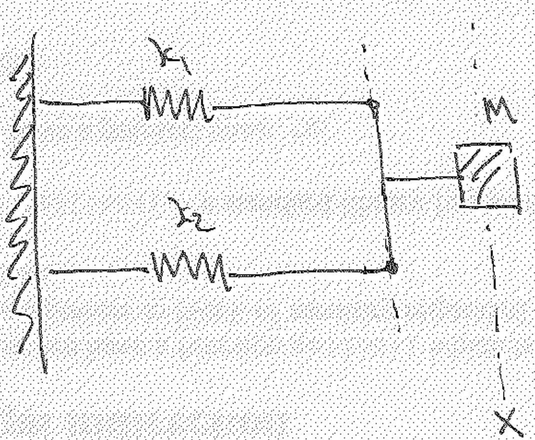
$$m\frac{d^2x_2}{dt^2} = -k_2(x_2-L_2) - k_1\left(\frac{-k_2}{k_1+k_2}\right)(x_2-L_2)$$

$$= \frac{\left(-k_2(k_1+k_2) - k_1k_2\right)}{(k_1+k_2)}(x_2-L_2)$$

$$m\frac{d^2x_2}{dt^2} = \left(\frac{-k_1k_2 - k_2^2 - k_1k_2}{k_1+k_2}\right)(x_2 - L_2)$$

$$= -k_2\frac{(k_1+k_2+k_2)}{k_1+k_2}(x_2-L_2)$$

What went wrong?

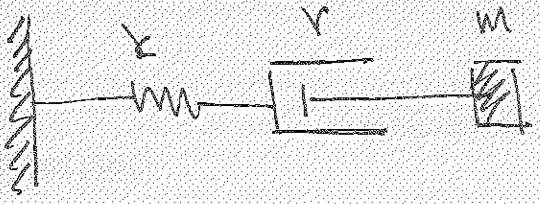


$$m\frac{d^2x}{dt^2} = -k_1(x-x_0) - k_2(x-x_0)$$

$$=$$

How do?

2.9

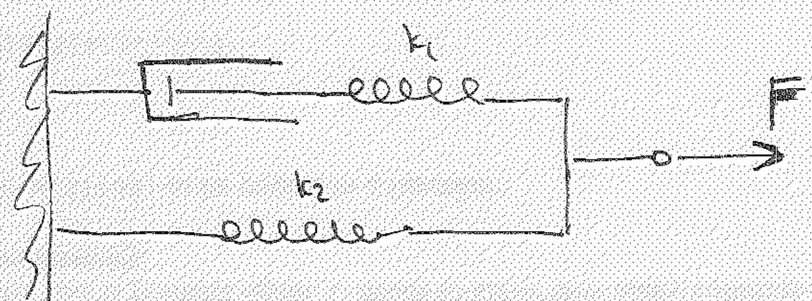


$$m\frac{d^2x}{dt^2} = -rv - kx$$

$\cancel{m\frac{d^2x}{dt^2} + kx}$

$$m\frac{d^2x}{dt^2} + r\frac{dx}{dt} + kx = 0$$

2.10



How do?

(3,1) $E \sim 40\,\text{MPa}$ Act of young mod

$$k = \frac{(40 \cdot 10^{6})(10^{3} \cdot 10^{-3})^{2}}{100 \cdot 10^{-3}} \qquad \frac{F}{A} = E\frac{\Delta L}{L}$$

$$F = E\left(\frac{A}{L}\right)\Delta L$$

$$\Rightarrow k = \frac{EA}{L}$$

$$k = \frac{4 \cdot 10^{7}}{10^{-1}} \frac{\text{Pa} \cdot \text{m}^2}{\text{m}} = 4 \cdot 10^{8}\ \text{Pa} \cdot \text{m} = 4 \cdot 10^{8} \frac{\text{N}}{\text{m}} =$$

(3,2) $F_{10\text{kg}} = mg = (10\text{kg})(9.8\,\text{m}/\text{s}^2) \simeq 10^{2}\,\text{N}$

$$\Delta L = \frac{L \cdot F}{E A} = \frac{(10^{2} \cdot 10^{-3}\,\text{m})(10^{2}\,\text{N})}{(40 \cdot 10^{6}\,\text{Pa})(1\,\text{m}^2)} = \frac{10}{4 \cdot 10^{7}} \frac{\text{m}\cancel{\text{N}}}{\cancel{\text{Pa}} \cdot \text{m}^2} = \frac{10^{-6}}{4}\,\text{m}$$

(3,3) actine $E \sim 2{,}3 \cdot 10^{9}\,\text{Pa}$

$A \sim 20 \cdot 10^{-18}\,\text{m}^2$

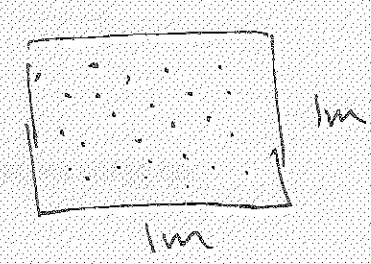
$L \sim 10^{-6}\,\text{m}$

$$k = \frac{E \cdot A}{L} = \frac{2{,}3 \cdot 10^{9} \cdot 20 \cdot 10^{-18}}{10^{-6}} \left(\frac{\text{Pa} \cdot \text{m}^2}{\text{m}}\right)$$

$$= \frac{2{,}3 \cdot 10^{-8}}{10^{-6}} \cdot (\ ) = \ldots$$

(3.4) $\sigma \sim 10^{15}$ fibs/m^2

$A_{fib} \sim 20 \cdot 10^{-18} m^2$



fraction $= \dfrac{10^{15} \cdot 20 \cdot 10^{-18}}{1 m^2} = 20 \cdot 10^{-3} = 2 \cdot 10^{-2}$

Don't see how to compute Young's modulus from # of fibers per square ft of area ...

(3.5) $$\tau = \frac{\gamma}{k} = \frac{3\pi\eta L}{(EA/L)} = 3\pi\eta \frac{L^2}{EA} \sim \frac{3\pi\eta}{E}$$

pick η = value for H_2O

$= 10^{-3}$ Pa·s

$E \sim 1$ GPa for typical biological mat'l

$$\tau = \frac{3\pi (10^{-3}) \text{ Pa·s}}{10^{+9} \text{ Pa}} = 3\pi \cdot 10^{-12} s \sim 9 \cdot 10^{-12} s \sim 10^{-11} s$$

$= 10$ ps

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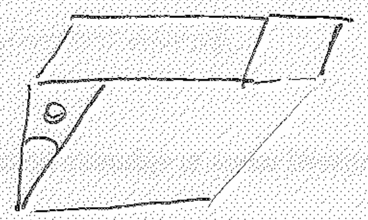
(3b)

$$\frac{F}{A} = G\theta$$



G = shear modulus

$$G = \frac{E}{2(1+\sigma)}$$

σ = poisson's ratio: amount that crossection of block changes when length contracts/extends

$$\frac{\Delta w}{w} = \sigma \frac{\Delta L}{L} \qquad -1 \le \sigma \le 0.5$$

$$\sigma = 1/2 \Rightarrow G = \frac{E}{2(3/2)} = \frac{E}{3}$$

most mat $0.2 \le \sigma \le 0.5$

$$\frac{F}{A} = \eta \frac{d\theta}{dt} + G\theta$$

$$\Rightarrow \theta(t) = \frac{F}{A \cdot G}\left[1 - \exp\left(-\frac{t}{\tau}\right)\right] \qquad \tau = \frac{\gamma}{\kappa} = \frac{\eta}{G}$$

$\eta = 4 \cdot 10^{-3}$ Pa·s

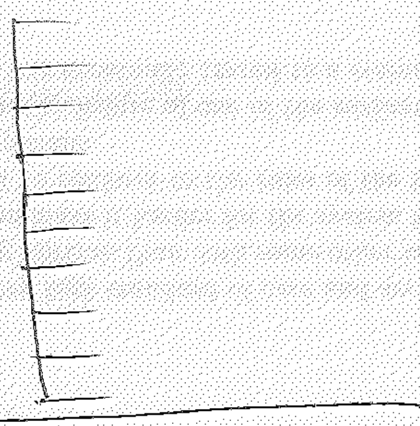
$E \sim 1$ GPa

$$\sigma = 1/4 \qquad G = \frac{E}{2(1+\sigma)} = \frac{1 \cdot \text{GPa}}{2(5/4)} = \frac{2}{5}\,\text{GPa}$$

$$\tau = \frac{4 \cdot 10^{-3}\ \text{Pa·s}}{(2/5)10^{+9}\ \text{Pa}} = 10 \cdot 10^{-3} \cdot 10^{-9}\ \text{s} = 10^{-11}\ \text{s} = .1\ \text{ps}$$

4.1

$$\frac{N_i}{N_0} = e^{\varepsilon_i / kT}$$



$N_0 = 1000 \qquad \varepsilon_i = kT \cdot i$

$N_0 =$

$N_1 = N_0 e$

$$p_i = \frac{1}{Z} e^{-\frac{U_i}{kT}} \qquad Z = \sum \exp\left(\frac{-U_i}{kT}\right)$$

$$= \sum_{i=0}^{9} \exp\left(-\frac{U_i}{kT}\right) = \sum_{i=0}^{9} \exp(-i)$$

$$= 1.581$$

$$p_0 = \frac{1}{1.581} = .632$$

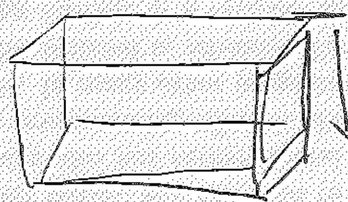
$\rightarrow \quad N_0 = 632$

$$p_1 = \frac{e^{-1}}{Z} = .23 \ldots \qquad N_1 = 238$$

$$p_2 = \frac{e^{-2}}{Z} = .0856 \Rightarrow \quad N_2 = 85$$

$\rho_3 = .03149$ $N_3 = 31$ etc...

4.2



$\rho = \rho_0 e^{-z/20mm}$

$\rho_0 = 19.3\ g/cm^3$

?

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4.3 Since the mass has not changed during the run. I don't see why the centrifuge results would do

4.4 Maybe the electrical charge around the sodium ion creates a greater drag on the ion than would be traditionally found.

?

4.5 $r = 1\mu m$

$\rho = 1.1\ g/cm^3$ $V_{rms} = \sqrt{\frac{3kT}{m}} = \ldots$

$m = (\frac{4}{3}\pi r^3)\rho$

$$v_{rms} = \sqrt{\frac{3(1.381\cdot10^{-23}\ J/k)(300k)}{\frac{4}{3}\pi(10^{-18})(1.1\cdot10^{-3}\ kg/100^3\ m^3)}} =$$

What is the correlation time of this velocity?

$\Delta x = v_{rms}\cdot\tau$

(4.6) 100 kDa

$m = 166\cdot10^{-24}\ kg$

$[D] = \frac{L^2}{T}$

$\tau = \sqrt{}$

$$\left(\frac{D}{d^2}\right)^{-1} = \tau \Rightarrow \tau = \frac{d^2}{D}$$

$$t = \frac{x_0^2}{2D} = \frac{(40\ nm)^2}{2(60\ \frac{pN\cdot s}{m})}$$

$\cancel{D = \frac{kT}{\gamma}}$

$$= \frac{(40\ nm)^2}{2(67\ \frac{\mu m^2}{s})} = \frac{1600}{2(67)}\ \frac{nm^2}{\frac{\mu m^2}{s}} = 11.9\ \frac{10^{-18}\ m^2}{10^{-12}\ m^2}\ s$$

$$= 11.9\cdot10^{-6}\ s = 11.9\ \mu s$$

... use eq 4.12

(4.7) $U(x) = |x|$

$$\langle U \rangle = \int_{-\infty}^{\infty} p(x)\,U(x)\,dx$$

$$= \frac{1}{Z}\int_{-\infty}^{+\infty} e^{-U(x)/kT}\,U(x)\,dx = \frac{\int_{-\infty}^{\infty} e^{-U(x)/kT}\,U(x)\,dx}{\int_{-\infty}^{+\infty} e^{-U(x)/kT}\,dx}$$

$$= \frac{\int_{-\infty}^{+\infty} e^{-|x|/kT}\cdot |x|\,dx}{\int_{-\infty}^{\infty} e^{-|x|/kT}\,dx} = \frac{\int_{0}^{\infty} e^{-x/kT}(x)\,dx}{\int_{0}^{\infty} e^{-x/kT}\,dx}$$

$$= \frac{\cancelto{0}{\left.\frac{x e^{-x/kT}}{\left(-\frac{1}{kT}\right)}\right|_0^{\infty}} + \frac{1}{\left(\frac{1}{kT}\right)}\int_0^{\infty} e^{-x/kT}\,dx}{\left.\frac{-e^{-x/kT}}{\left(\frac{1}{kT}\right)}\right|_0^{\infty}}$$

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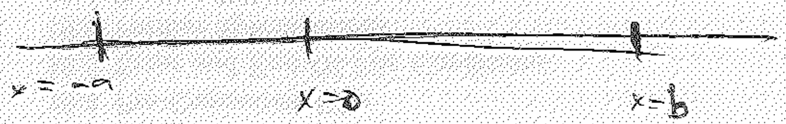
$$= \frac{e^{-x/kT}}{\left(-\frac{1}{kT}\right)}\Bigg|_0^\infty = \frac{1}{\frac{1}{kT}} = kT \checkmark$$

4.8



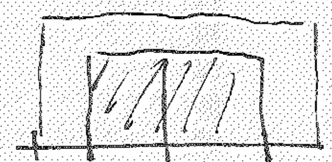
P_{-a} = prob particle gets to $-a$.

P_b = prob particle gets to b.

How do?

$$\frac{P_b}{P_a} \approx$$

$$\frac{x_0^2}{2D} = t$$ time to get a distance x_0 from origin in both directions.



4.9

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4.9 $D_{thermal} = \frac{k}{c\rho}$

(a) $D_{thermal} = \frac{.606\ W/m\cdot K}{(4.18\ kJ/kg\cdot K)(997\ kg/m^3)} = 1.454\cdot 10^{-4}\ \frac{W}{m\cancel{K}}\cdot\frac{\cancel{kg}\cdot\cancel{K}}{kJ}\cdot\frac{m^3}{\cancel{kg}}$

$= 1.454\cdot 10^{-4}\ \frac{\cancel{J}}{s}\cdot\frac{m^2}{10^3\cdot\cancel{J}} = 1.5\cdot 10^{-7}\ m^2/s$

$= .15\ \frac{mm^2}{s}$ About ~~1000~~ 100 times larger than ionic diffusion

$D_{ion} = 1.33\cdot 10^{-3}\ \frac{mm^2}{s} = .00133\ \frac{mm^2}{s}$

(b) $D = \frac{kT}{6\pi\eta r}$ $\eta =$ ~~kinematic~~ dynamic viscosity.

$\left\{ r = \frac{kT}{6\pi\eta D} = \frac{(1.381\cdot 10^{-23}\ J/K)(300K)}{6\pi(1\cdot 10^{-3}\ \frac{N}{m^2}\cdot s)(1.5\cdot 10^{-7}\ m^2/s)} \right\}$

$J = N\cdot m$
$N = J/m$

~~Stokes law~~

$= \frac{1.381\cdot 10^{-23}\cdot 300}{6\pi(10^{-3})(1.5\cdot 10^{-7})}\ \frac{J\ \cancel{K}}{\cancel{K}\ \frac{N\cdot \cancel{s}}{\cancel{m^2}}\cdot\frac{\cancel{m^2}}{\cancel{s}}} = 1.46\cdot 10^{-12}\ m$

(c) looking for 1st passage time for $t = 3\,\text{nm}$.

$$t = \frac{x_0^2}{2D} = \frac{9\,\text{nm}^2}{2(.15\cdot 10^{-6}\ \text{m}^2/\text{s})} = \frac{9\cdot 10^{-18}\ \text{m}^2}{2(.15\cdot 10^{-6}\ \text{m}^2/\text{s})}$$

$$= 3\cdot 10^{-11}\,\text{s} = 30\ \text{ps}$$

Why different?

For 3D expansion

$$t \stackrel{?}{=} \frac{x_0^2 + y_0^2 + z_0^2}{2D} = \frac{r_0^2}{2D} = \cdots$$

(1) T "tense" 1% denser

R "relaxed"

$m = 100\,kDa$

$\therefore \quad \dfrac{\rho_T}{\rho_R}$

How could diff densitys be measured?

$P \Delta V$

$V_{total} = 120\ nm^3$ for 100kDa protein

? Can't solve problem?

(2) $\Delta x = 2\,nm$

$P_{open} = 1/2 \qquad F = ? \quad) \quad P_{open} = .9$

$P_{closed} = 1/2$

~~P_{open}~~ From pg 80 $\quad P_{open} = \dfrac{1}{1 + \exp\left[\frac{-F\Delta x}{kT}\right]}$

$$(.9)\left(1 + \exp\left(\frac{-F\Delta x}{kT}\right)\right) = 1$$

$$\exp\left(\frac{-F\Delta x}{kT}\right) = \frac{10}{9} - 1 = 1/9$$

$$\frac{-F\Delta x}{kT} = \ln(1/9)$$

$$F = \frac{kT}{\Delta x}\ln(9) = \ldots \qquad T = 298\,k$$

(S3) $S_1 = \frac{2\,pN}{nm}$ $\quad S_2 = \frac{1\,pN}{nm}$

$P_1 \cong 1 \quad P_2 \cong 0$

From eq S.4 we get

$$\Delta G = \Delta G^0 - F\Delta x^0 - \frac{1}{2}F^2\left[\frac{1}{k_2} - \frac{1}{k_1}\right]$$

Since $\frac{[E_2]}{[E_1]} = \frac{P_2}{P_1} = \exp\left[-\frac{\Delta G}{kT}\right] = \exp\left[\frac{-\Delta G^0}{kT}\right]\exp\left[\frac{-F\Delta x - 1/2\,F^2(1/k_2 - 1/k_1)}{kT}\right]$

to change the concentration by e^{-1}

0 for same resting length

$$-F\cancel{\Delta x} - \frac{1}{2}F^2\left(\frac{1}{k_2} - \frac{1}{k_1}\right) = -kT \quad \Rightarrow \ldots \quad \text{solve for } F.$$

(5.4) $\cancel{\frac{S}{P} = 10 \left(\frac{S}{P}\right)_E}$

$$\frac{[S]}{[P]} = 10 \frac{[S]_E}{[P]_E}$$

$$=$$

$$\exp\left[-\frac{\Delta G}{kT}\right]$$

$\equiv 1$ By hypothesis

$$= \exp\left[-\frac{\Delta G^0 - F\Delta x}{kT}\right] = \cancel{K^0_{eq}} \exp\left[\frac{F\Delta x}{kT}\right] = 10$$

set

$$\rightarrow \quad F = \frac{kT}{\Delta x} \ln(10)$$

Work $= F \cdot \Delta x = kT \ln(10)$ Does this represent ~~prom~~ per molecule work or full blown total work?

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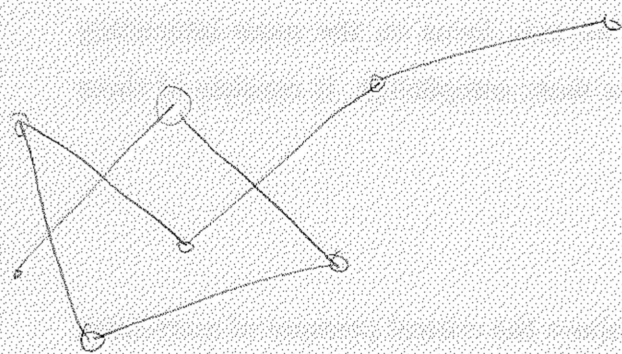
(6.1) running ~ 1 s $v = 30\ \mu m/s$

tumbling ~ .1 s

(a)



$D = \frac{kT}{\gamma}$ Einstein relation

$Re = \frac{\rho L v}{\eta}$

η = viscosity Pa·s

$F_d = -\gamma v = -6\pi\eta r v$

?

(b) $r = 1\ \mu m$ $\eta = .7$ mPa·s

$T = 37°C$

?

(6.2) $V \propto l^3$ $v = .85$ rev/s

$V = C l^3$

(a) $.85$ rev/s $= C(2\ \mu m)^3$?

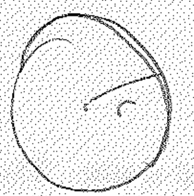
(b) ?

6.3 $\frac{I}{A} = C\theta$

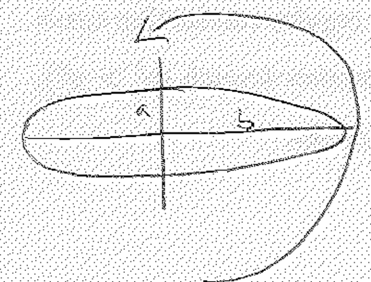
T = torque

θ = torsion

(a) ?



(b)



$e = \frac{a}{b}$

?

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(9.1) Assume $[A_n] = k e^{-n/n_0}$

Then $n_{avg} = \sum_{k=1}^{\infty} n \cancel{k} [A_n] = \sum_{n=1}^{\infty} n k e^{-n/n_0}$

req $\sum_n [A_n] = C$ $= k \sum_{n=1}^{\infty} n e^{-n/n_0} = k \frac{\partial}{\partial(1/n_0)} (-1) \sum_{n=1}^{\infty} e^{-n/n_0}$

(9.2) ?

(9.3) ?

(9.4) ?