Review

• Diffusion/Brownian Motion can be understood as a “Random Walk” caused by molecular collisions

• $<x^2> = 2dDt; \quad d = \# \text{ of dimensions}$

Can use this to estimate transit times

Example: A protein’s diffusion constant is $D = 0.4 \text{ um}^2/\text{s}$. How long, on average, does it take to travel 2 um due to diffusion?

$t = <x^2>/(2D) = 5 \text{ s}$
Diffusive vs. Ballistic Motion

**Diffusion**

\[ \langle x^2 \rangle = 2dDt \]

\[ \langle x^2 \rangle \sim t \]

**Ballistic**

\[ x = vt \]

\[ x^2 = v^2t^2 \]

\[ x^2 \sim t^2 \]

Can use this to determine what’s causing a particle’s motion!
Example: Tracking Membrane Phospholipids

[Lee et al., JCB, 1993]

Diffusive!
Another way to look at it:

**Diffusion**
\[
\langle x^2 \rangle \sim t
\]
\[
\ln \langle x^2 \rangle \sim \ln(t)
\]
\[
\ln \langle x^2 \rangle \sim \ln(t)
\]

**Ballistic**
\[
x^2 \sim t^2
\]
\[
\ln(x^2) \sim \ln(t^2)
\]
\[
\ln(x^2) \sim 2\ln(t)
\]

In General: \[
\langle x^2 \rangle \sim t^m; \quad \ln \langle x^2 \rangle \sim m\ln(t)
\]

What about values of \( m \) other than 1 or 2?
In General: \( \langle x^2 \rangle \sim t^m; \quad \ln \langle x^2 \rangle \sim m \ln(t) \)

- \( m = 2 \)  
  Ballistic

- \( 1 < m < 2 \)  
  “Superdiffusion”  
  Diffusion + Ballistic  
  e.g. molecular motors

- \( m = 1 \)  
  Diffusion

- \( m < 1 \)  
  “Subdiffusion”  
  Diffusion in a crowded environment
A Crash Course in Molecular Microbiology

Promoter - Binding site for RNA polymerase
- A "promoter" is an operator for RNA polymerase
- Required for genes to be expressed

Gene - Sequence of bases (A, T, G, C) that encodes information to make a protein

Operator - Specific sequence of bases which is recognized and bound by regulatory proteins

Escherichia coli DNA

E. coli Genome
4.6 Million Base Pairs

“Operator”
- Specific sequence of bases which is recognized and bound by regulatory proteins
Gene 1

Gene 2

Gene 3

Gene 4

Gene is “ON”
Example: mRNA tracking in *E. coli*

- **GFP**
- **“Green Fluorescent Protein”**
- **MCP**
- **“MS2 Coat Protein”**

Transcription

- **rfp**
- **96x MS2 bs**

[Golding and Cox, PNAS 2004; Golding and Cox, PRL 2006]
Intracellular mRNA motion is subdiffusive!

$\Rightarrow$ Cytoplasm is highly crowded

$D \sim 10^{-2} \text{ um}^2/\text{s}$