**Molecular Motors**

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**What is a Molecular Motor?**

- Generates Mechanical Motion using
  - Electrical energy
  - Chemical energy
- “Mechanochemical” Enzyme
- Motion drives metabolic functions
- Essential, Robust, Varied
- Works at Molecular Level … Nano
- Artificial “Motors” have been made

**Why should you care about Molecular Motors?**

**Biologists**
- Essential proteins
- Important for myriad biological processes

**Physicists/Engineers**
- Robust and efficient nanoscale machines
  - Can we make our own?

**Health**
- Motor Neuron degeneration, Body asymmetry...

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**What kind of motion do Motors generate?**

- Linear
- Rotary

<table>
<thead>
<tr>
<th>DNA based</th>
<th>Protein based</th>
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</thead>
<tbody>
<tr>
<td>Use of Genetic Information (RNA Polymerase)</td>
<td>Moving muscles (Mycosin)</td>
</tr>
<tr>
<td>Making Proteins (Ribosome)</td>
<td>Moving things in the cell (Myosin, Kinesin, Dynein)</td>
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</tbody>
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**Rotary Molecular Motors**

[Image: http://www.sciencedaily.com]
Rotary Motors play a critical role in your body ...

- They make the linear motors work
- ATP is the energy source …

\[
\text{Glucose} \quad \text{Respiration} \rightarrow \text{ATP}
\]

\[
\text{A-P-P-P + H}_2\text{O} \rightarrow \text{A-P-P + P}_i + \text{H}^+
\]

\[
10^{-19} \text{ Joules} = 25 \text{ kT} = 100 \text{ pN-nm}
\]

Unitary Biological forces are ~ picoNewtons

Making ATP … The Rotary F\textsubscript{0}F\textsubscript{1} ATP synthase motor

Experimental approaches to understand F\textsubscript{1} -- ATPase

Linear Motors as ATPases

Rower

Porter

Rower ~ 0.01
Porter ~ 1

Rowers – Muscle Myosin

Large Linear arrays  \rightarrow  Rapid Motion

Spudich, 2001

Movie from Ron Vale group
Porters: The need for long range Transport

Diffusion does not help...

Time for diffusion $\sim x^2 / 2D$ ; $D = k_BT / 6\pi\eta R$

$D$ = Diffusion constant; $x$ = Distance moved; $k_B$ = Boltzmann constant; $T$ = Temp; $\eta$ = Viscosity; $R$ = Dimension

$D \sim 1$ micron$^2$/sec for 50 nm diameter synaptic vesicle in Neuron

To travel 1 metre:
Need $\sim 16,000$ years

Need active linear transport

An example of Transport...

Changing colour

What is it like to be a Motor inside the Cell?

Overdamped motion

Motors walk on stepping stones
They know which way to go...
Magnitudes...

- Typical displacements ~ 10 nm
  - Human hair ~ 100,000 nm
- Typical forces ~ PicoNewtons (10^{-12} N)
- Velocity ~ 1 micron/sec (100 mm/day)
- Kinesin - step occurs every 8 msec on an average

Models ...

- Thermal Ratchet
- Powerstroke
- Optical Trap

\[ \text{Force} = -K \cdot x \]
Rowers -- Force, Working stroke measurements

Porters and their force generation

Hand over Hand or Inchworm?
Myosin and Kinesin … Same at the Core

Vale and Milligan, 2000