Nano-Scale Engineering –III
Bio-Molecular Motors for Engineering

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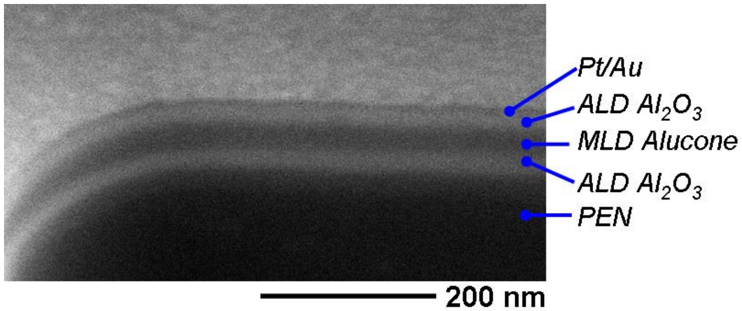
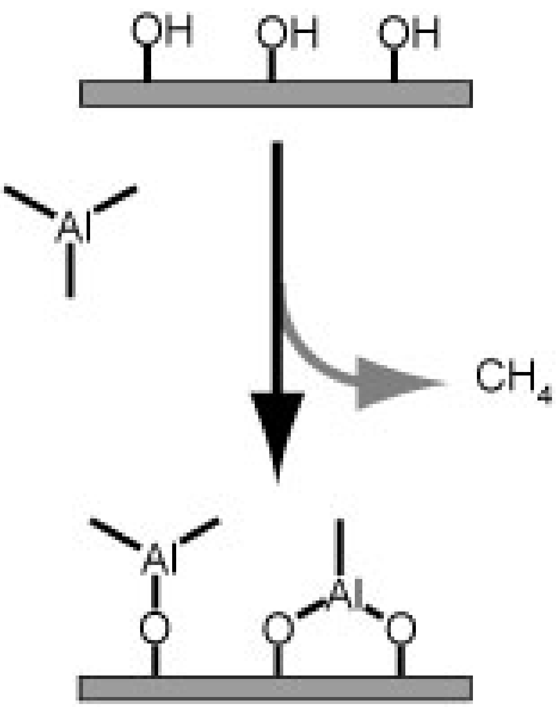
iMINT

MLD of Hybrid Organic-Inorganic Polymers: Alucones

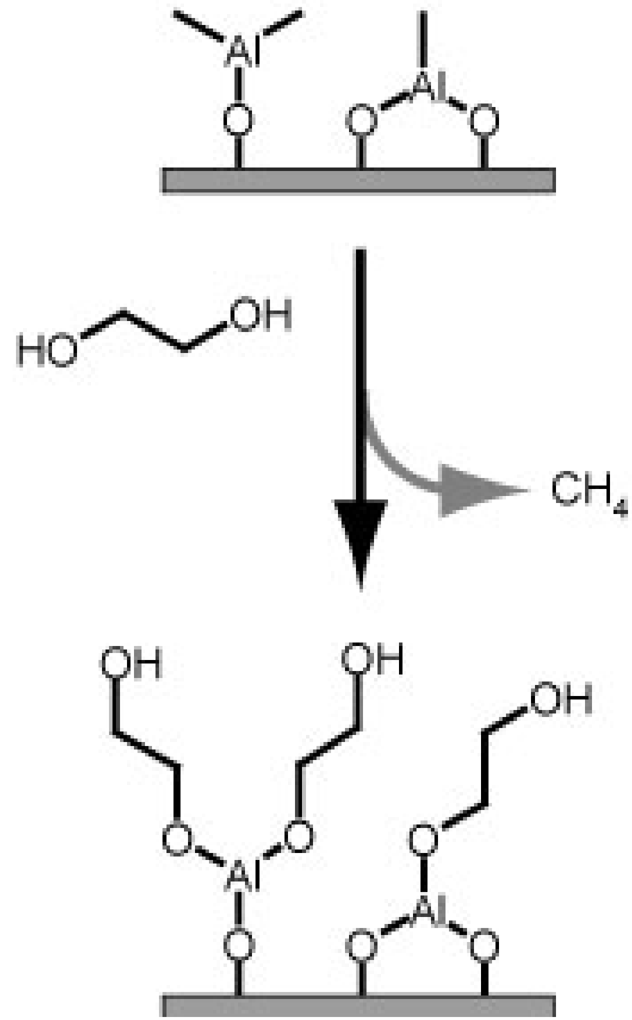
(Steve M. George, CU-Boulder)



(A) Trimethylaluminum



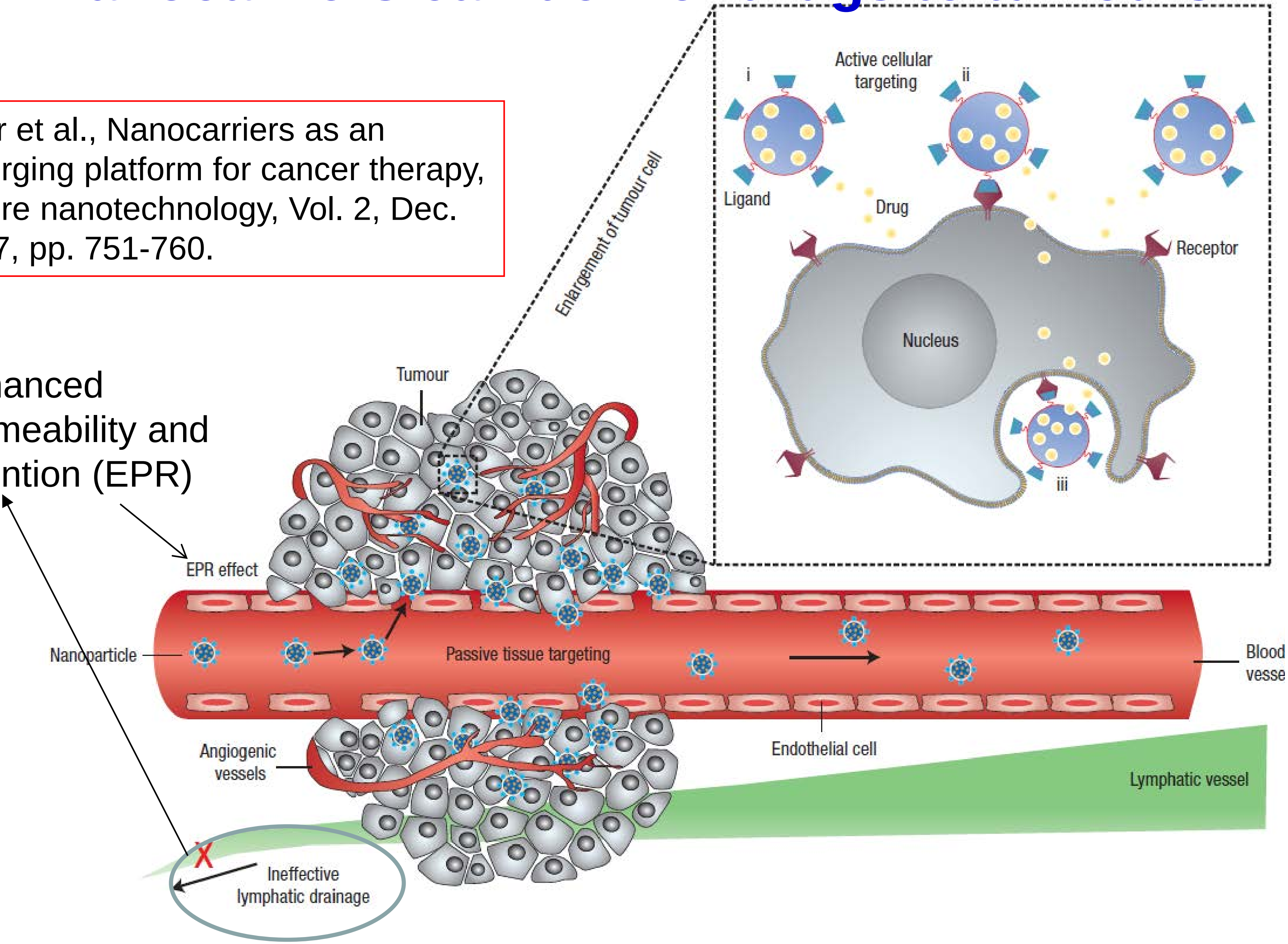
(B) Ethylene Glycol

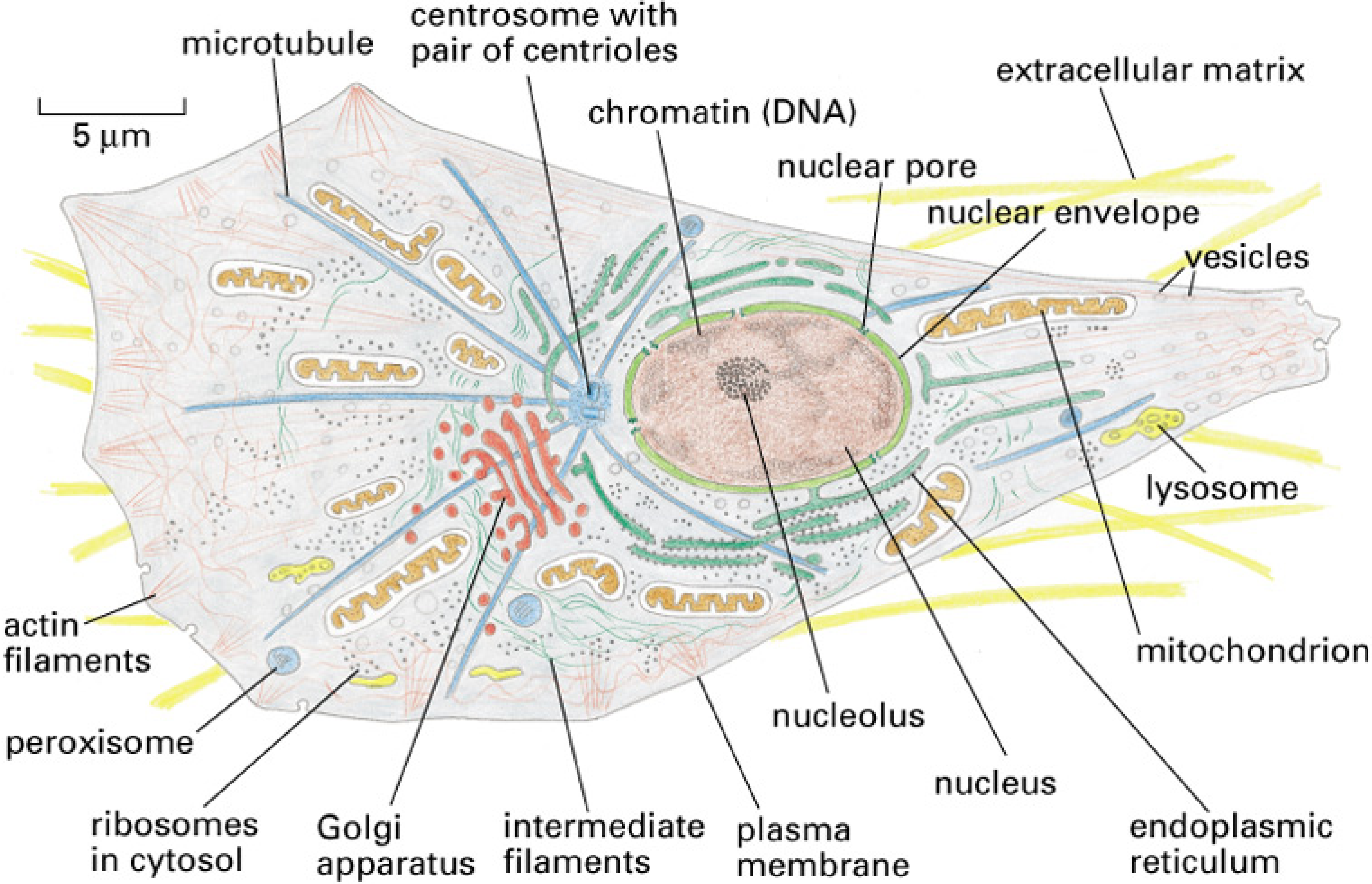


Different mechanisms by which nanocarriers can deliver drugs to tumours

Peer et al., Nanocarriers as an emerging platform for cancer therapy, nature nanotechnology, Vol. 2, Dec. 2007, pp. 751-760.

Enhanced permeability and retention (EPR)

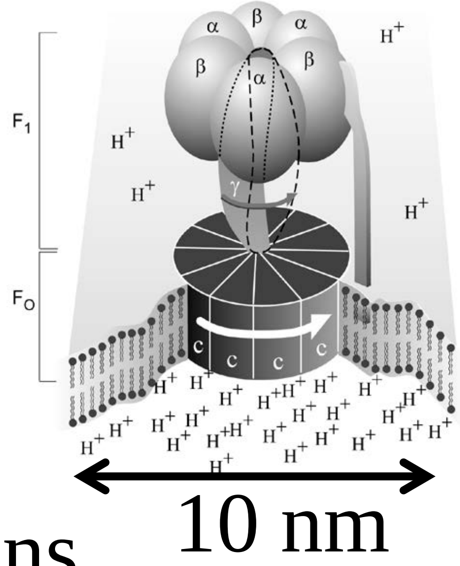


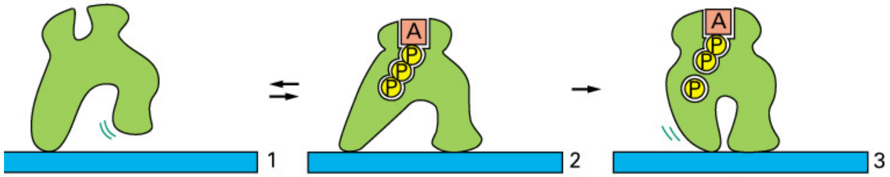


A Biological Cell

Contents

- Bio-molecular motors
  - Rotary motors: ATP Synthase
  - Linear motors: myosin and kinesin
  - Efficiencies > 50% in room temperature
- Molecular Shuttles
  - Kinesin and microtubules
- Guiding channels
- Loading and unloading
- Control: Caged ATP
- Polymerization of protein chains





Microtubule as Tracks

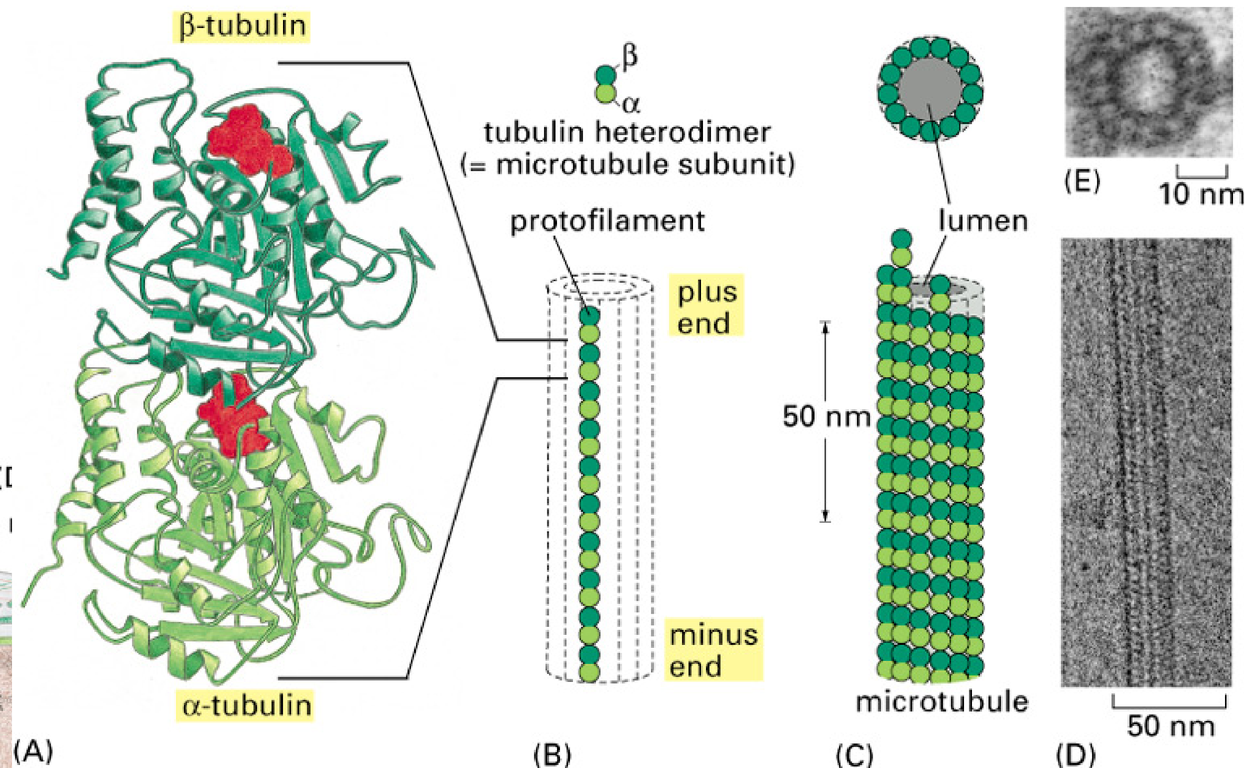


Figure 16–6. Molecular Biology of the Cell, 4th Edition.

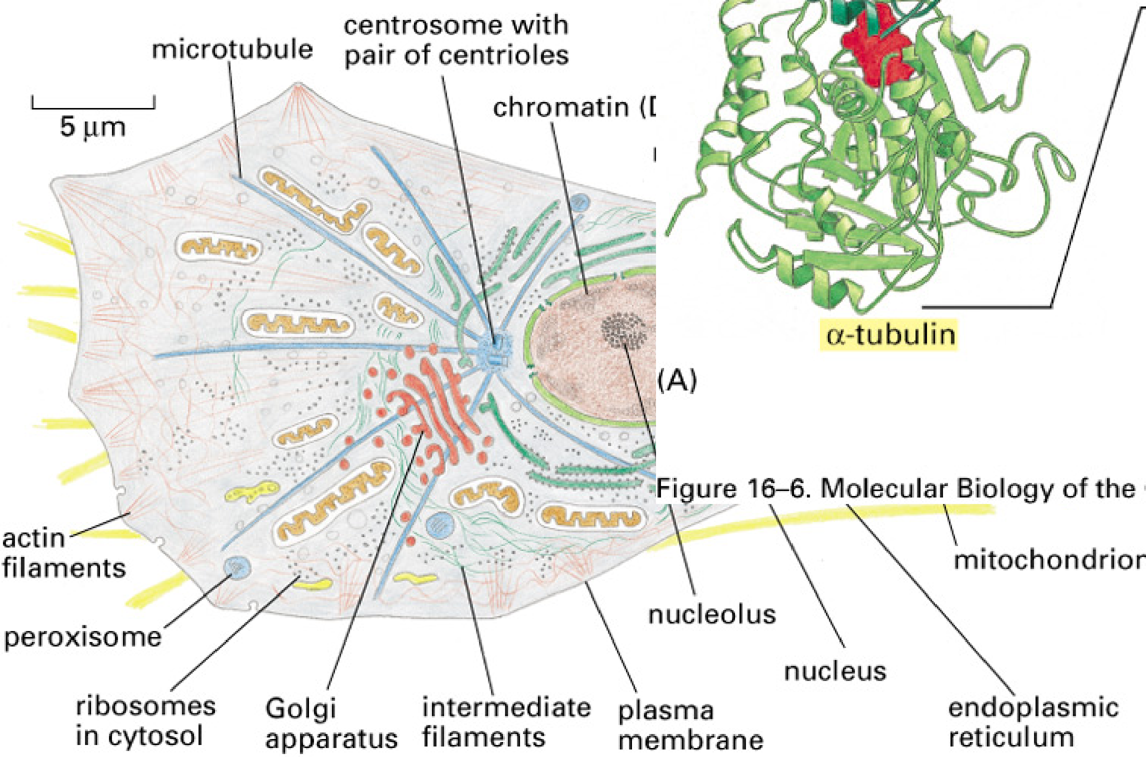
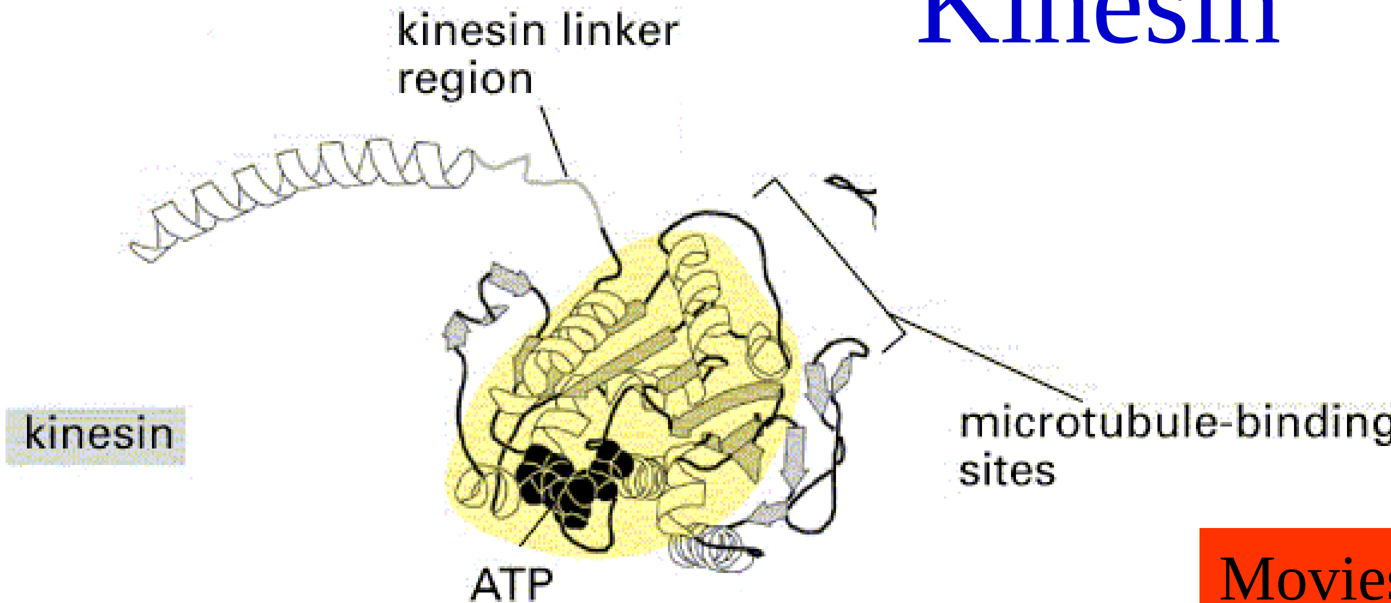
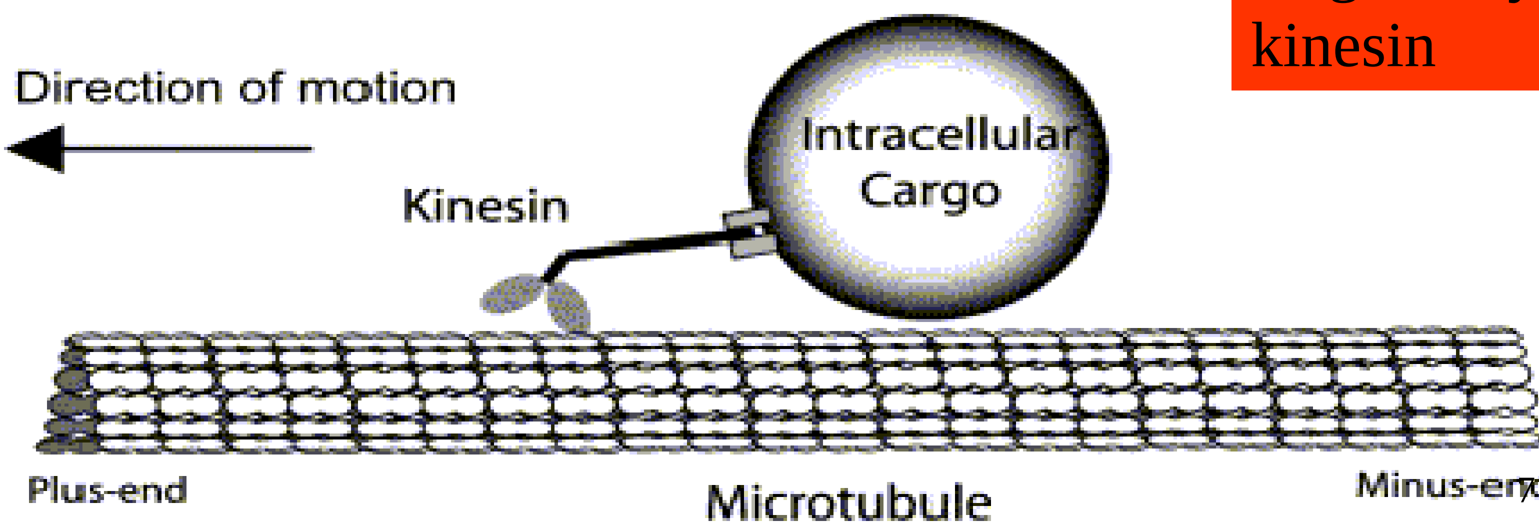


Figure 1–31. Molecular Biology of the Cell, 4th Edition.

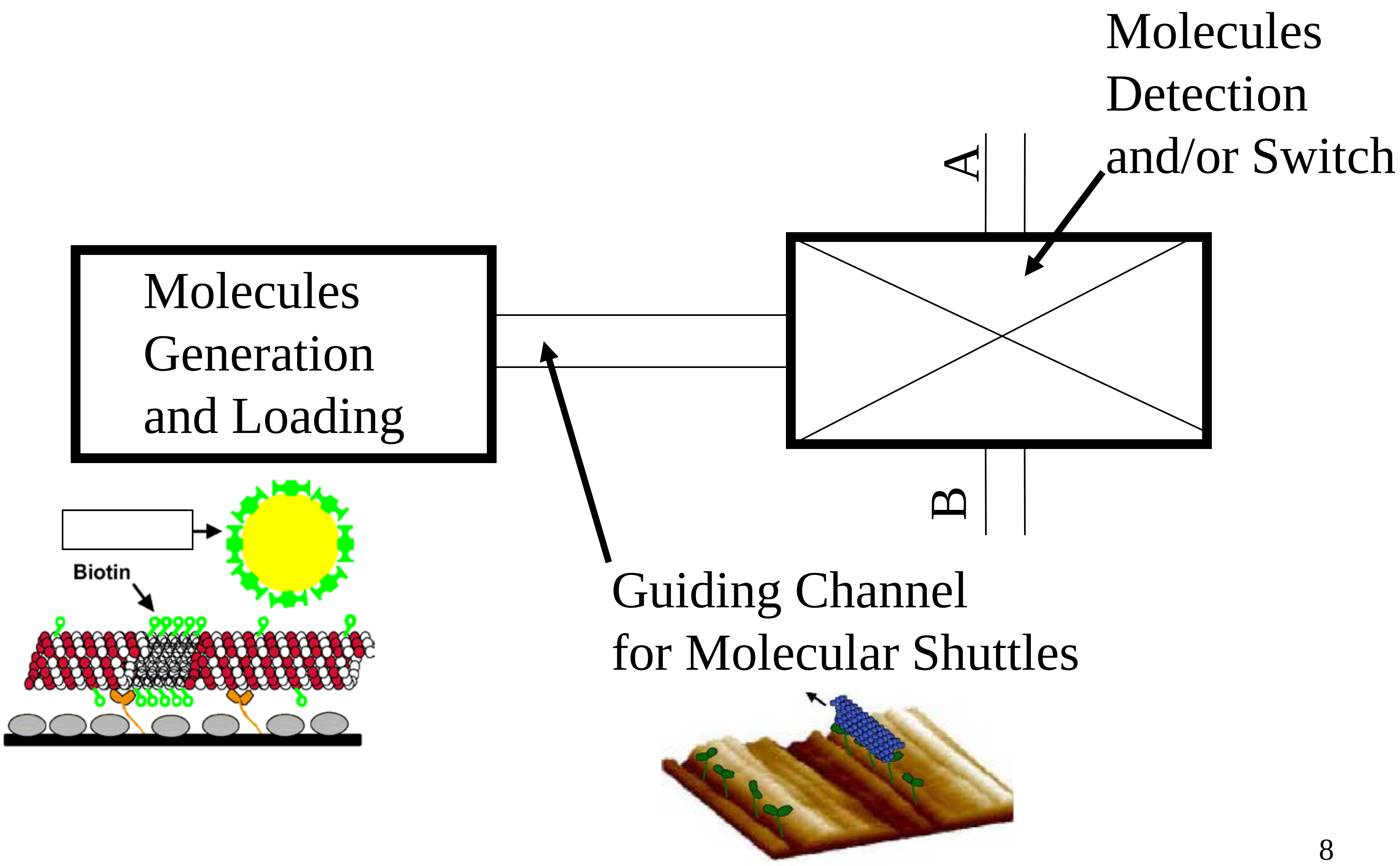
Kinesin



Movies: cargo carrying kinesin

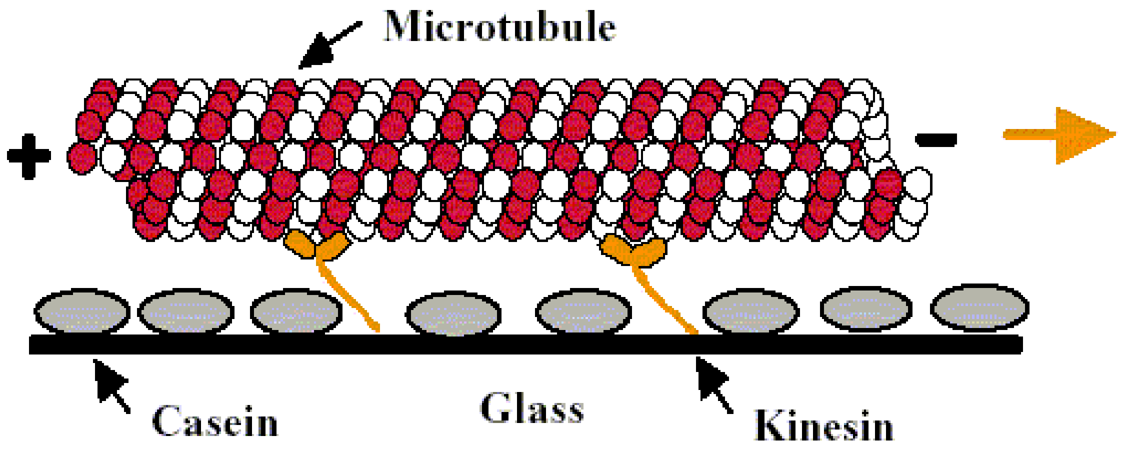


Bio-Molecular Motors as Building Blocks for Engineering Systems



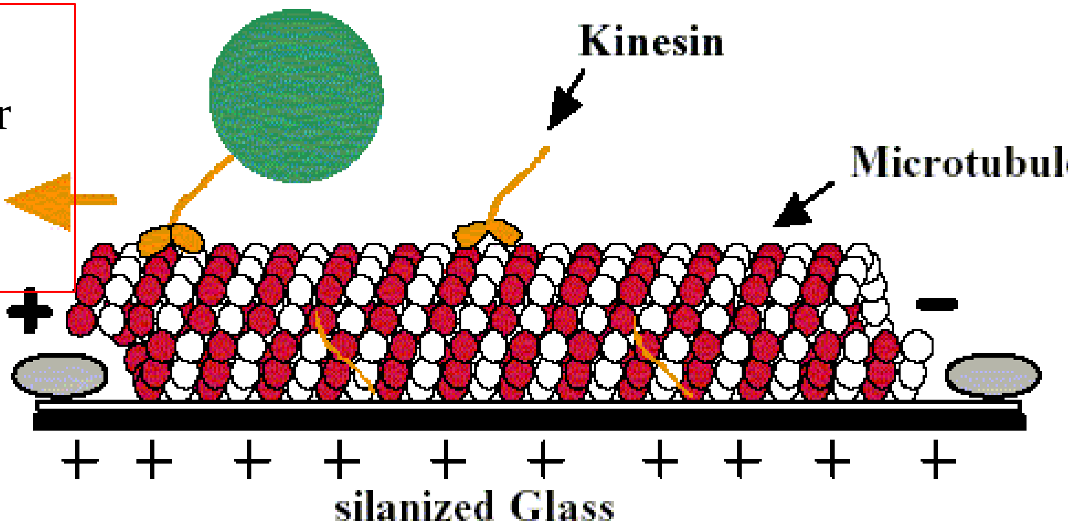
Molecular Shuttles: Two Options

Gliding geometry



Bead geometry

- ~1 µm/second
- ~8 pN force for a single motor
- MT: 25 nm in diameter and many µm long.



H. Hess and V. Vogel, Rev. Mol. Biotechnol. 67(2001)

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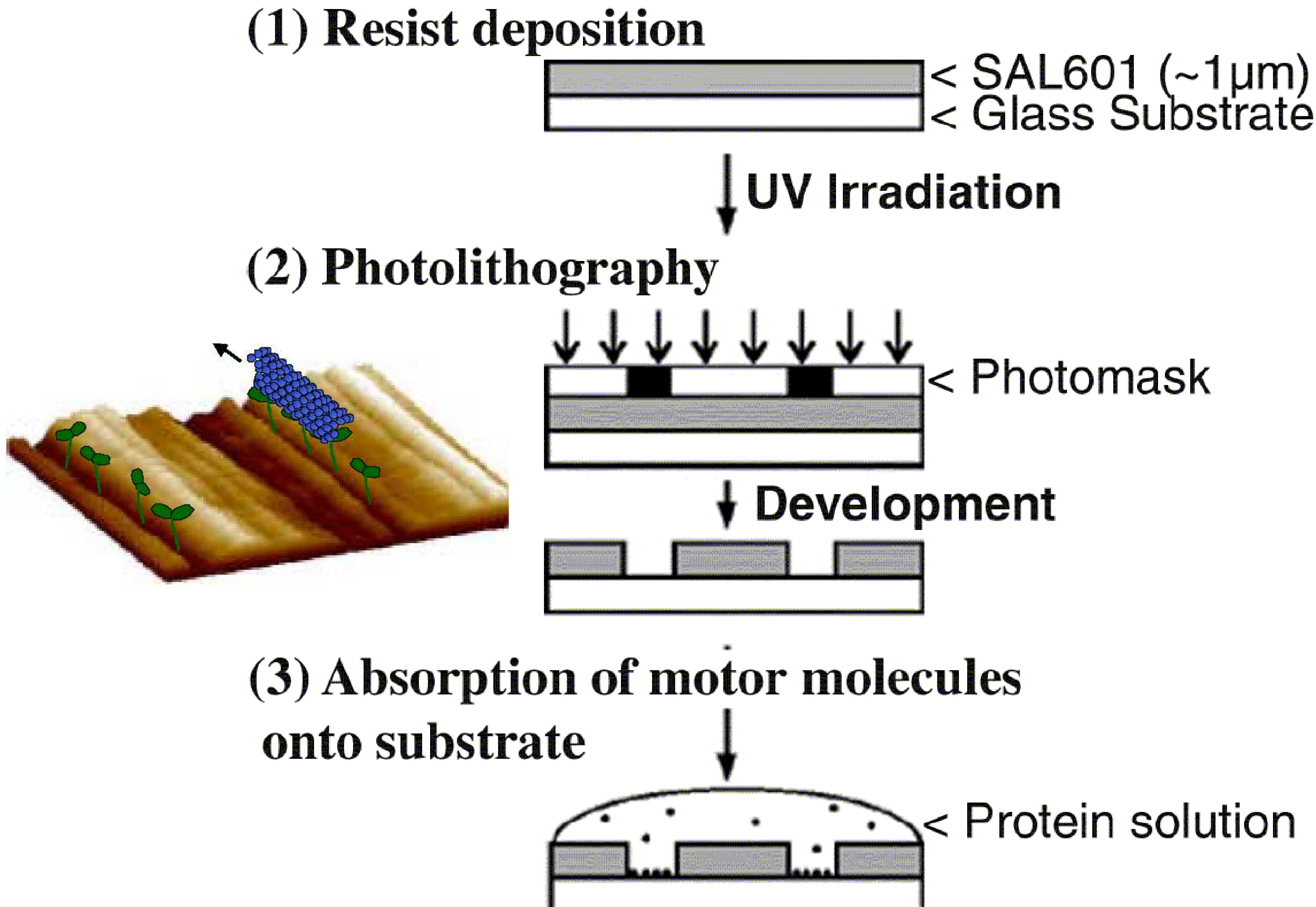
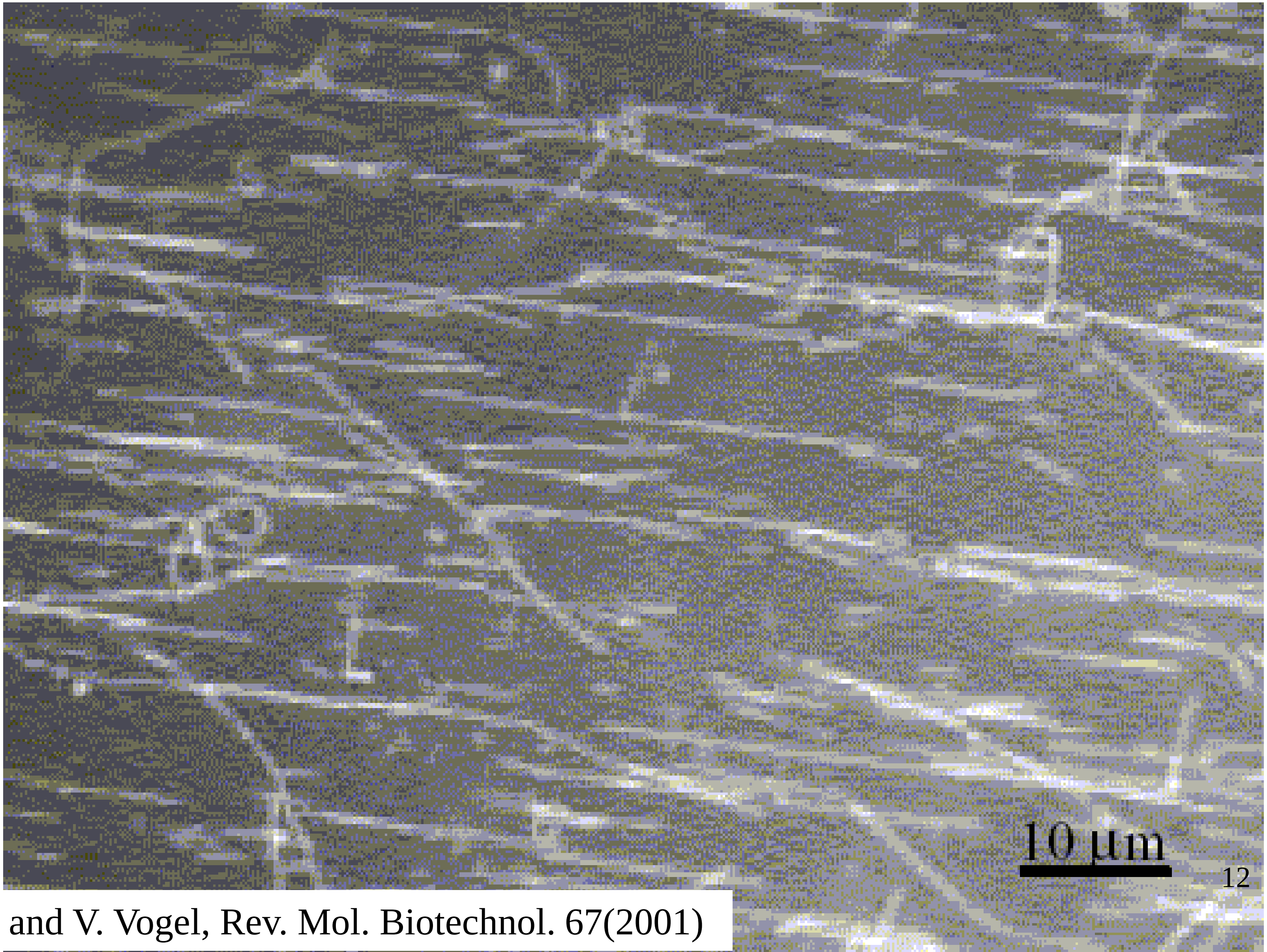
Movie: random movement



Protein Motors (Kinesin) Deposited

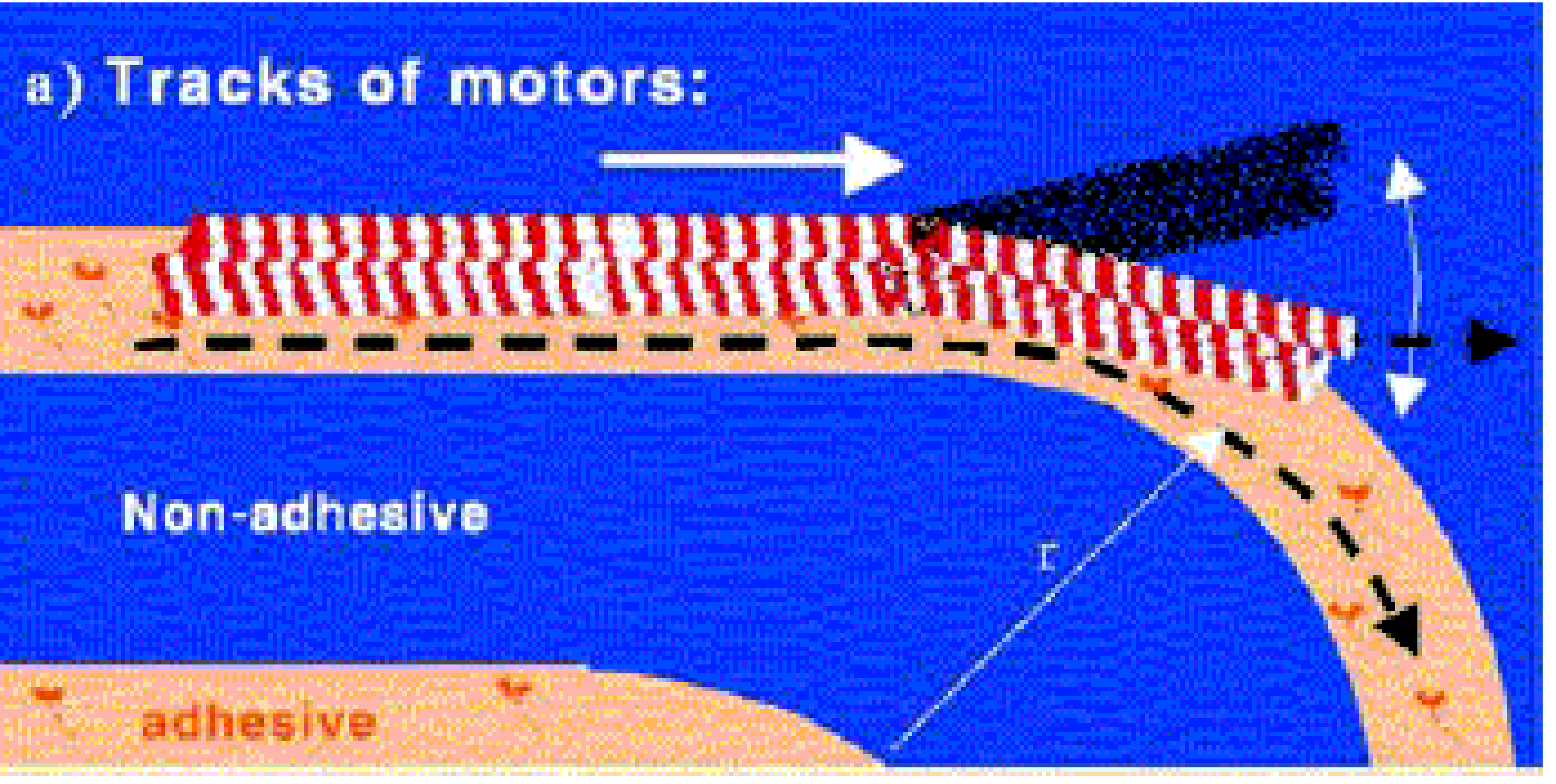
Hiratsuka et al., Biophysical J., 1555 (2001)

Microtubules Moved in Tracks



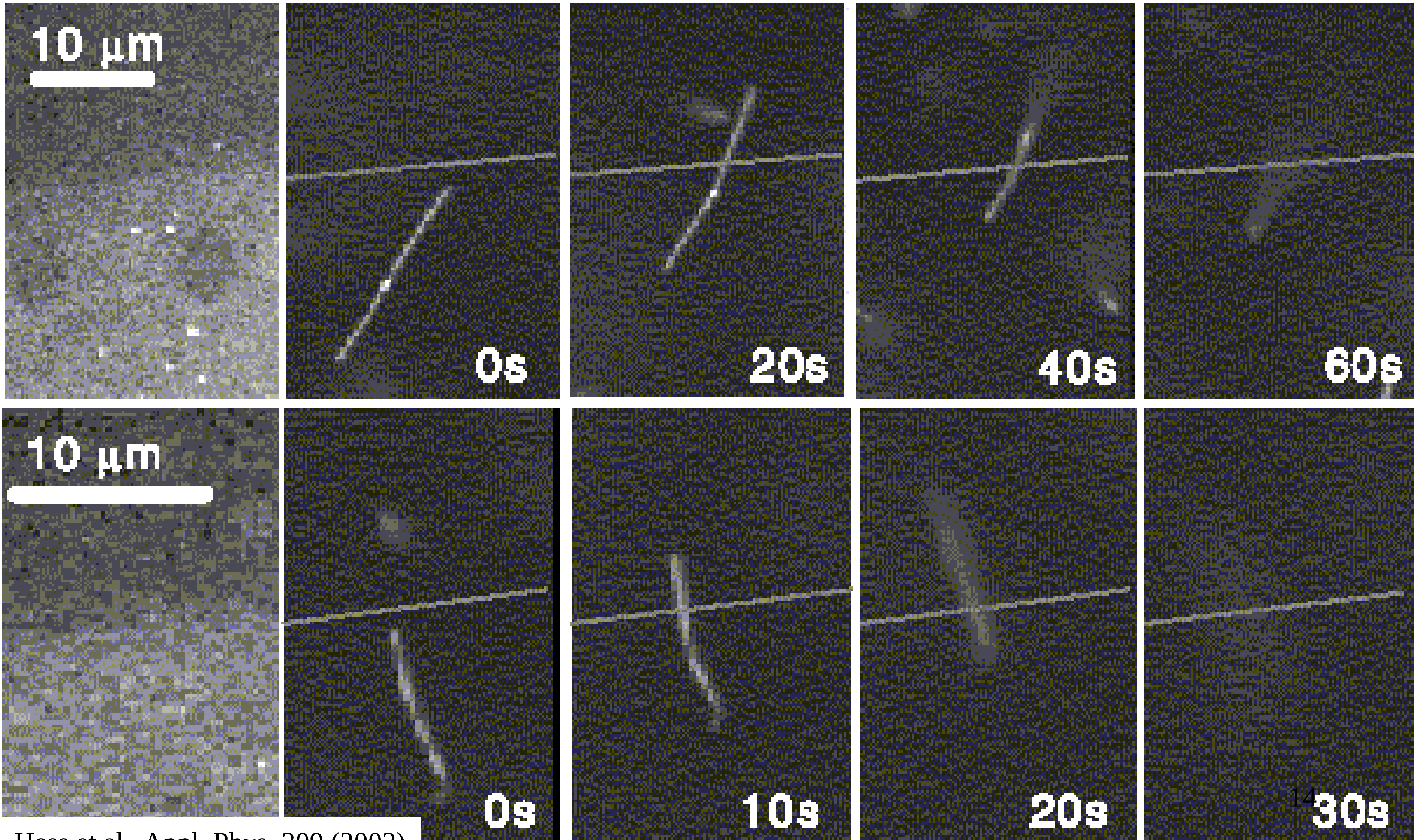
H. Hess and V. Vogel, Rev. Mol. Biotechnol. 67(2001)

Microtubules Moved in Tracks



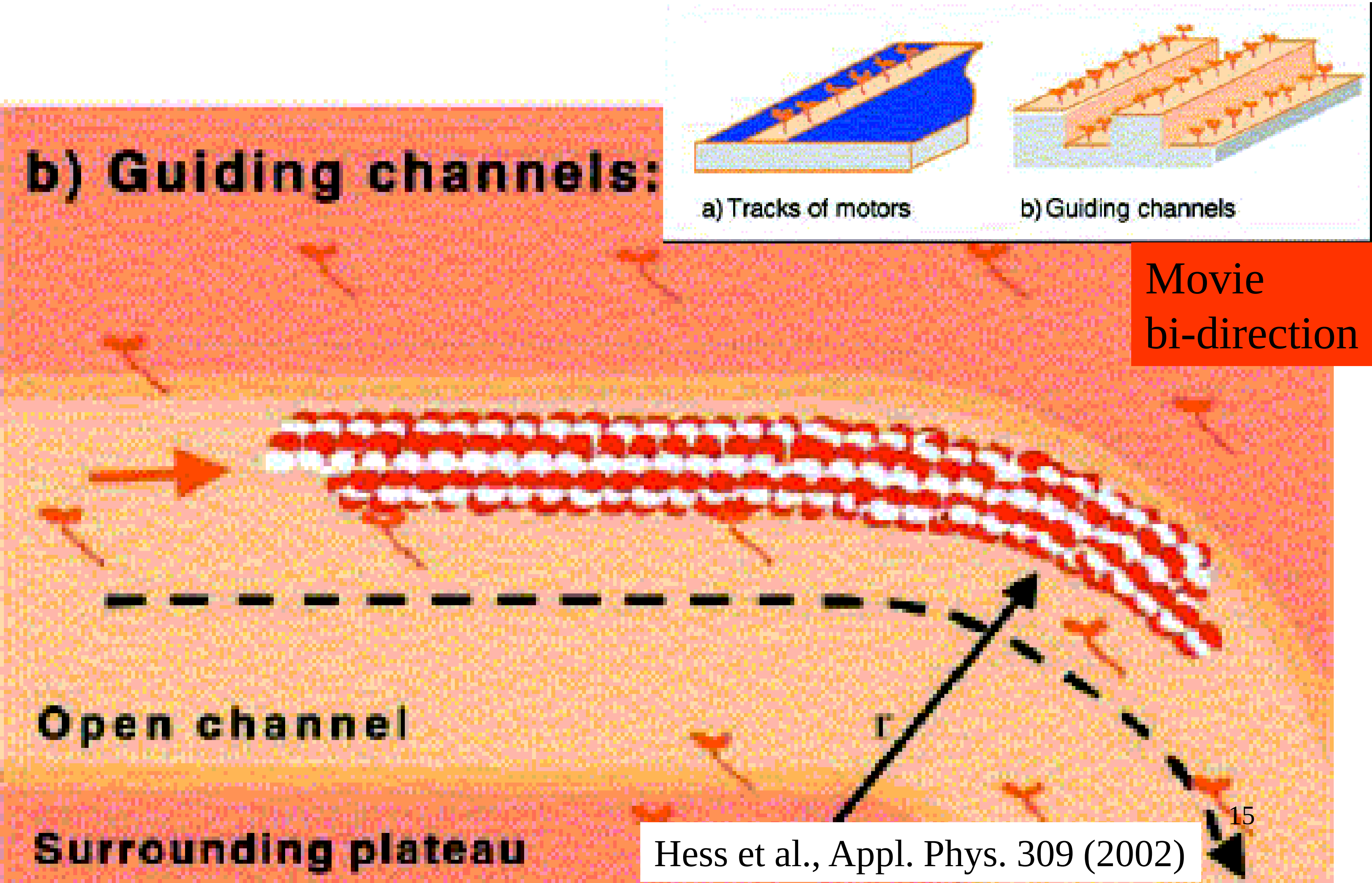
Hess et al., Appl. Phys. 309 (2002)

Microtubules Moved Out of a Track



Hess et al., Appl. Phys. 309 (2002)

Mechanical and Chemical Edges

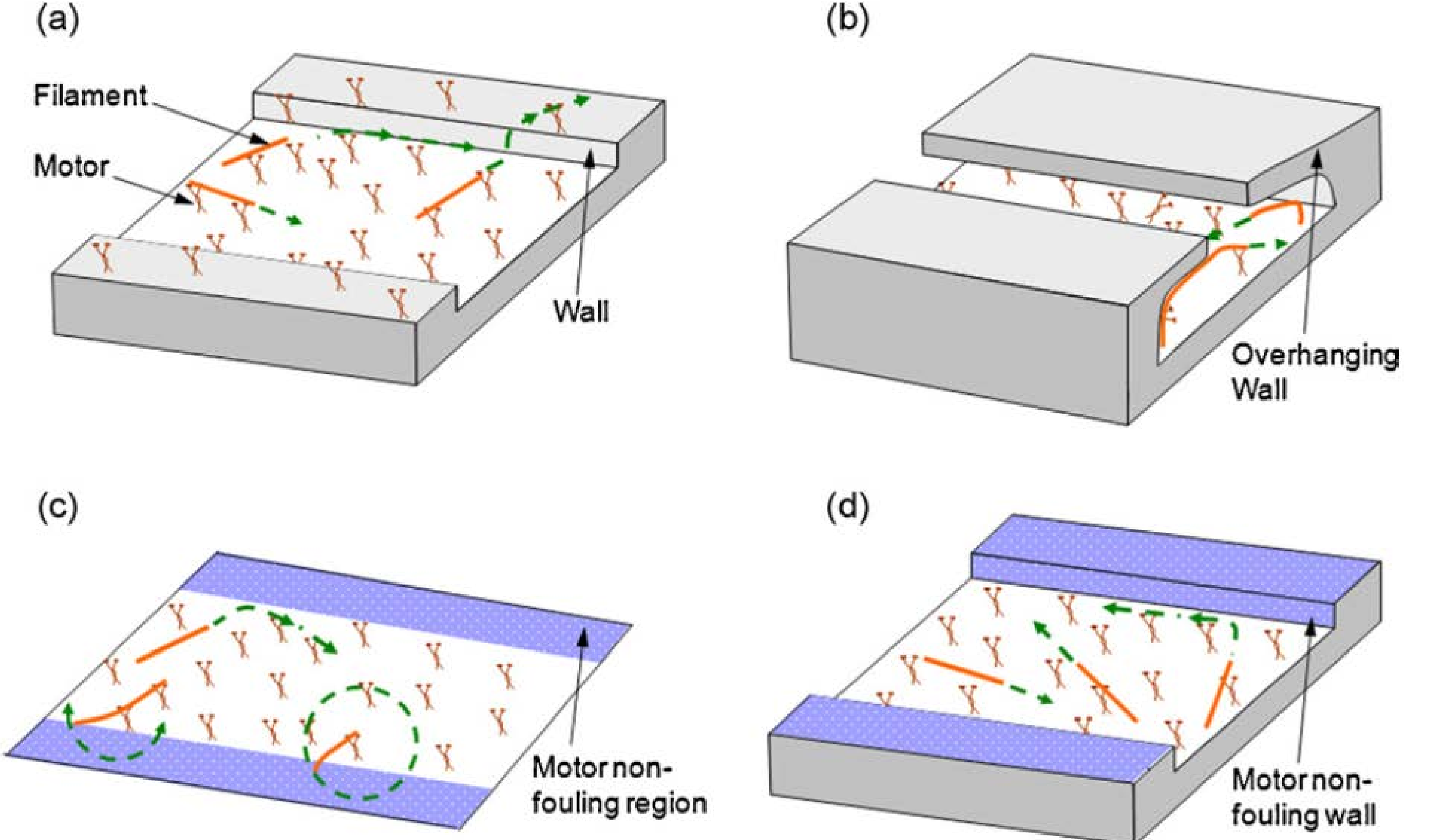


Movie
bi-direction

Hess et al., Appl. Phys. 309 (2002)

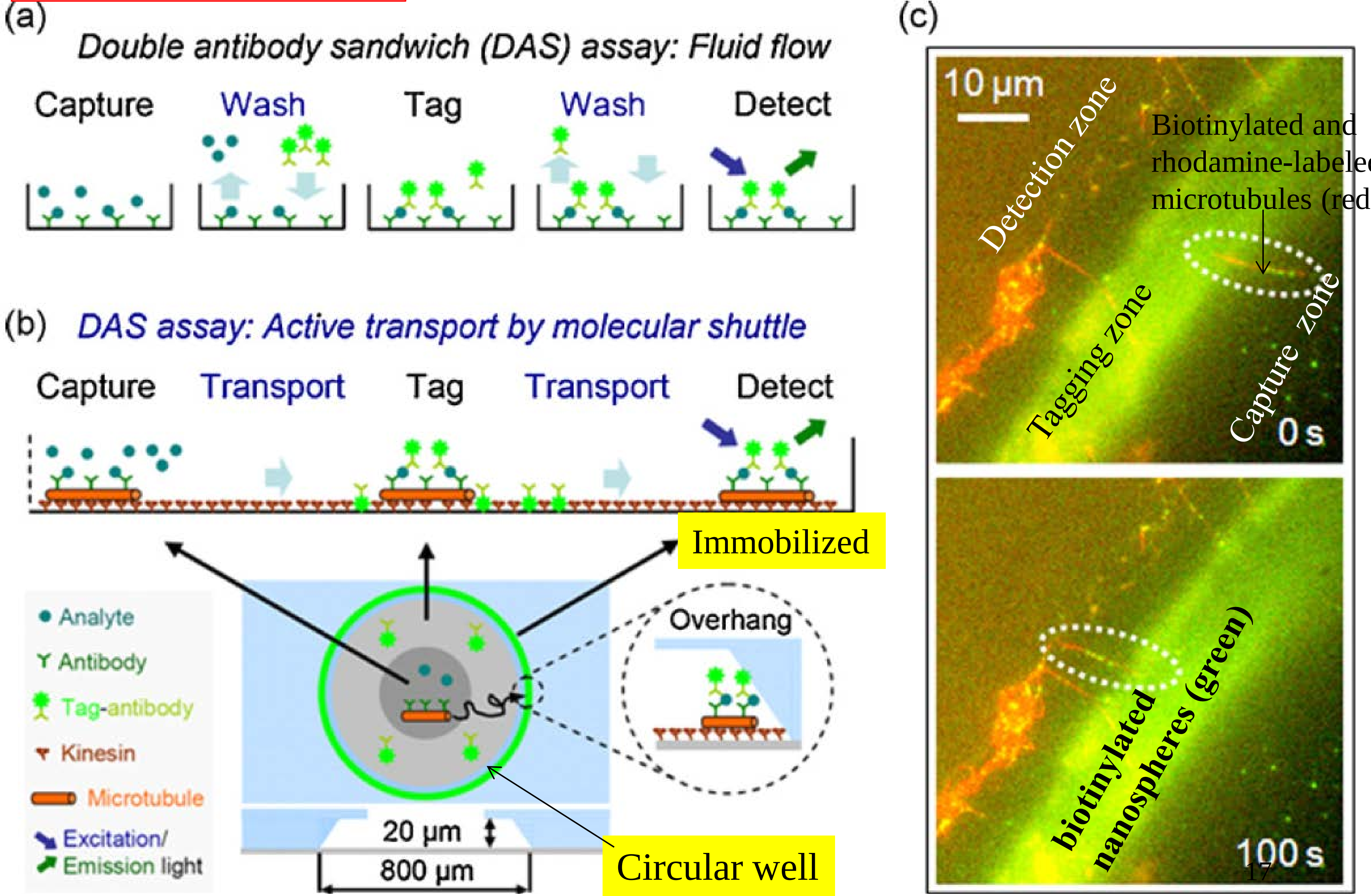
Guiding Approaches - 2010

Ashutosh Agarwala and Henry Hessb, Biomolecular motors at the intersection of nanotechnology and polymer science, Progress in Polymer Science 35 (2010) 252–277.



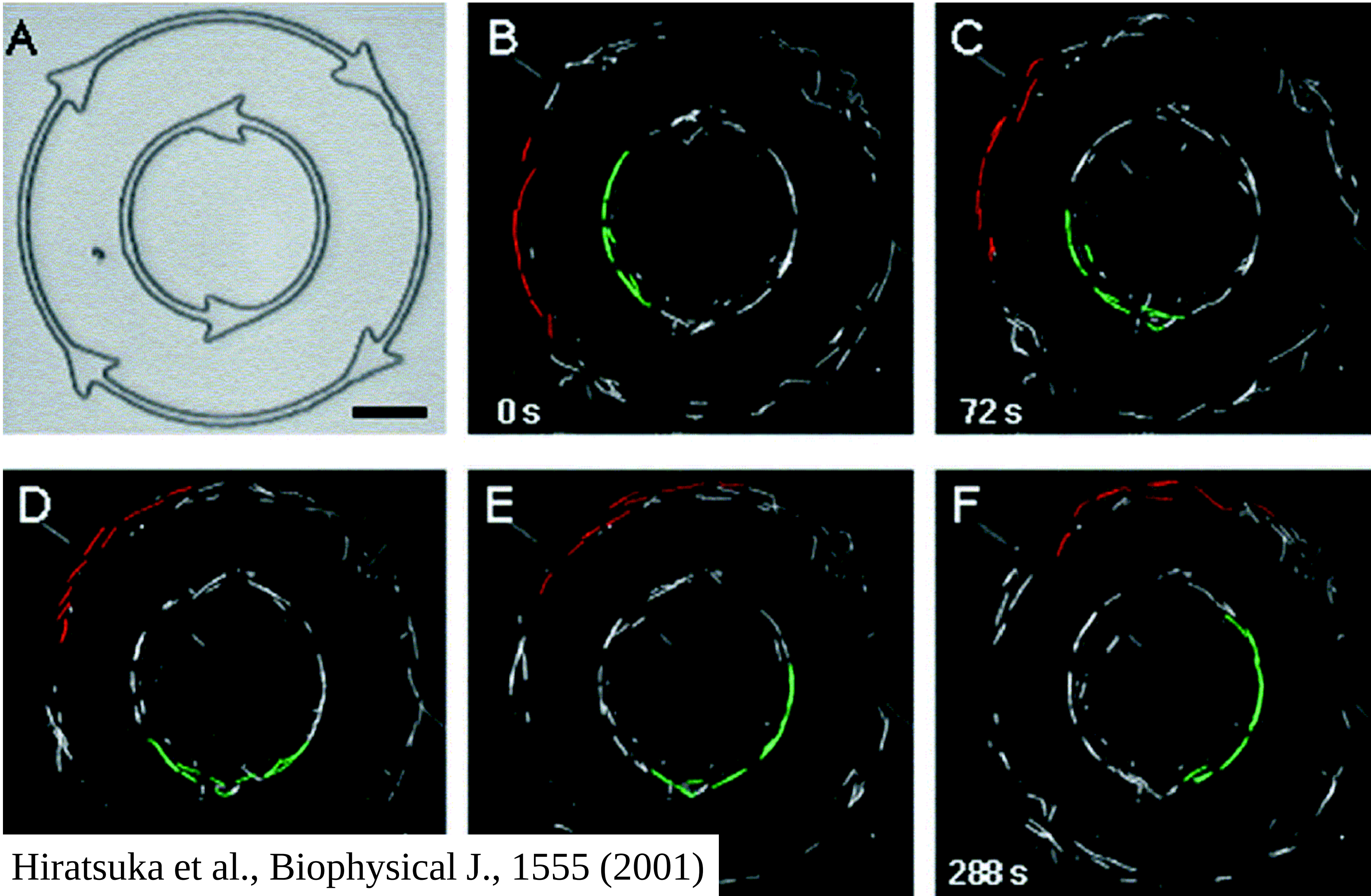
Agarwala and Hessb, Progress in Polymer Science 35 (2010) 252–277.

Smart dust biosensor



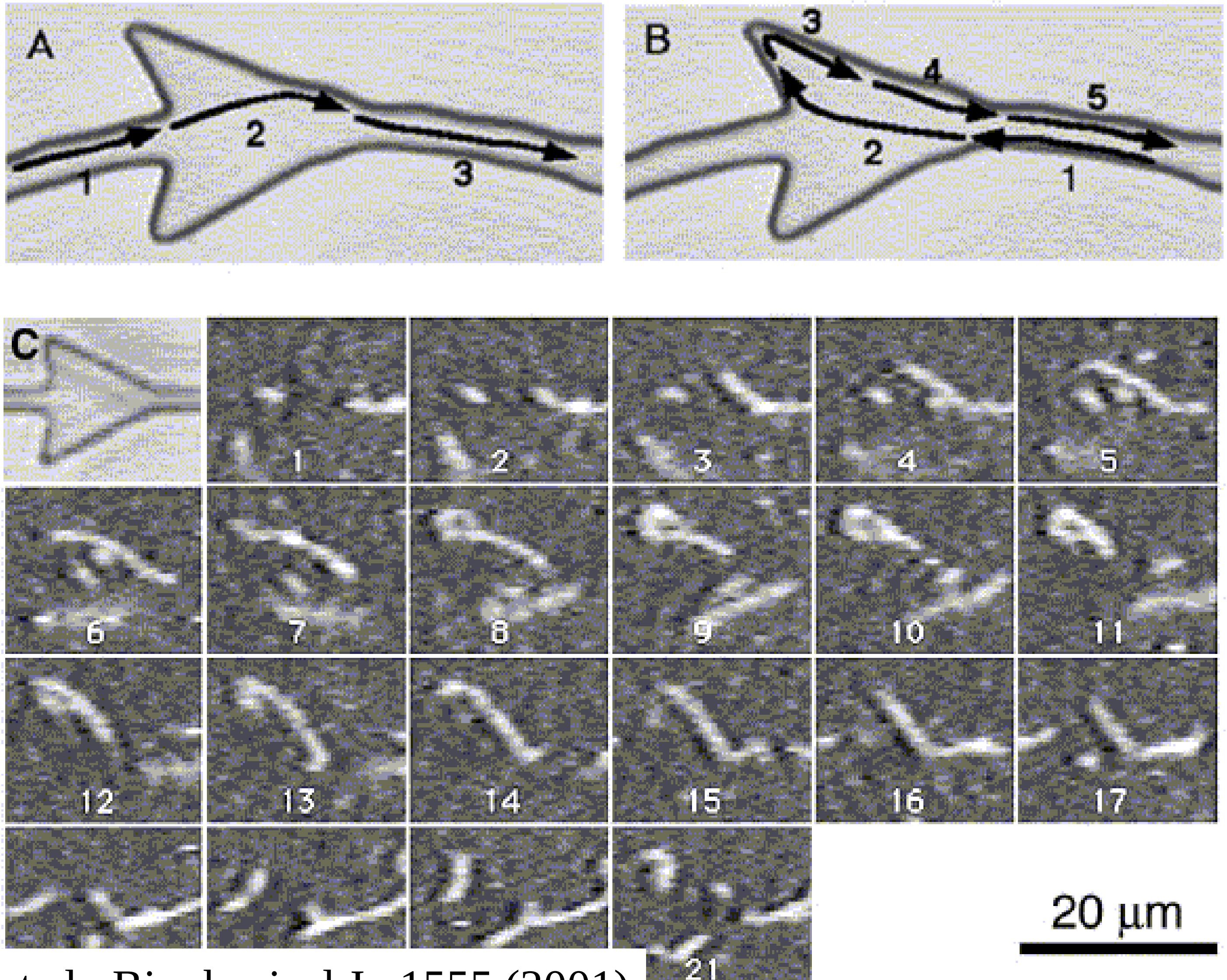
Uni-directional Movement

Movie



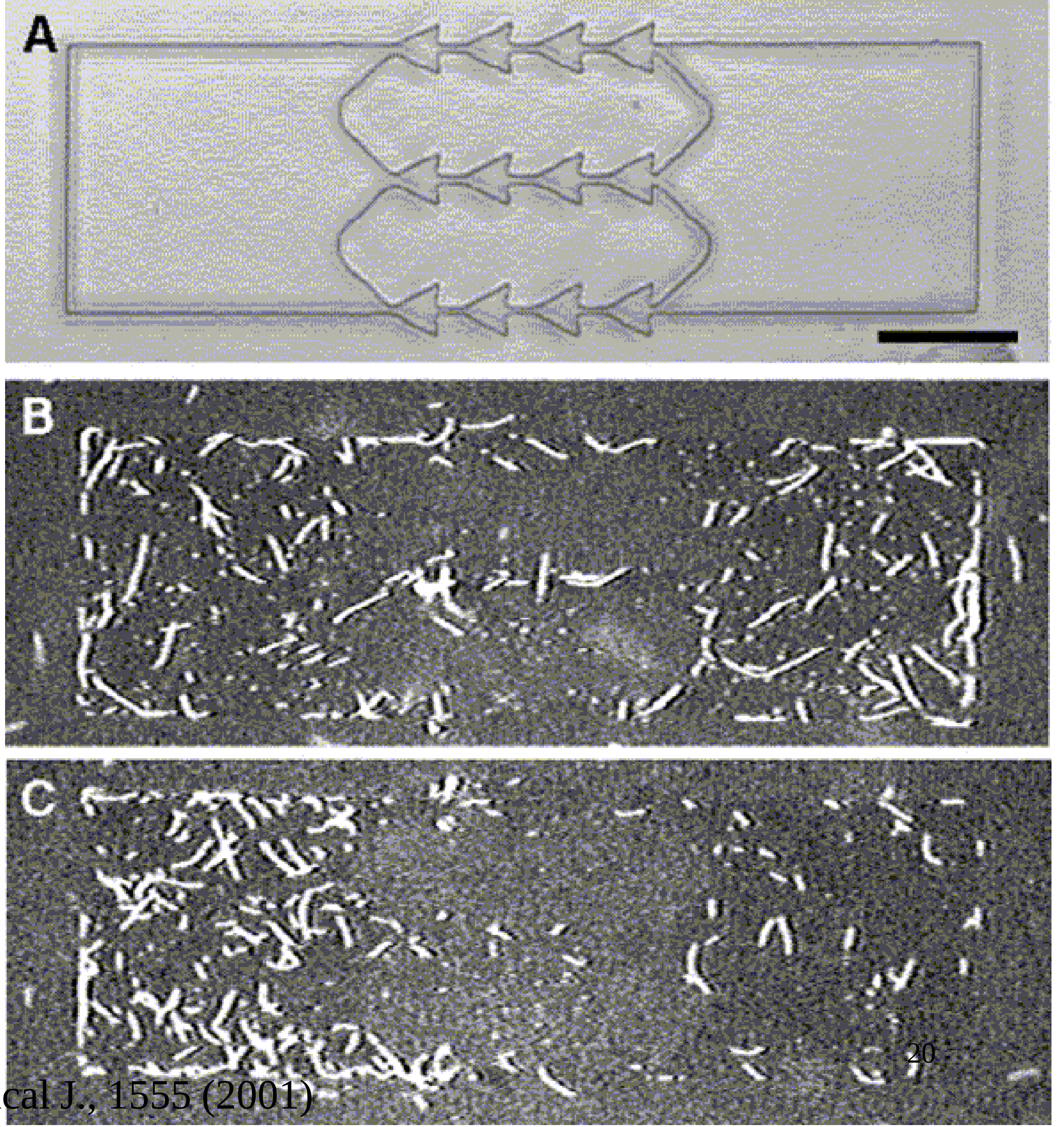
Hiratsuka et al., Biophysical J., 1555 (2001)

Inversion: Changing Direction



Hiratsuka et al., Biophysical J., 1555 (2001)

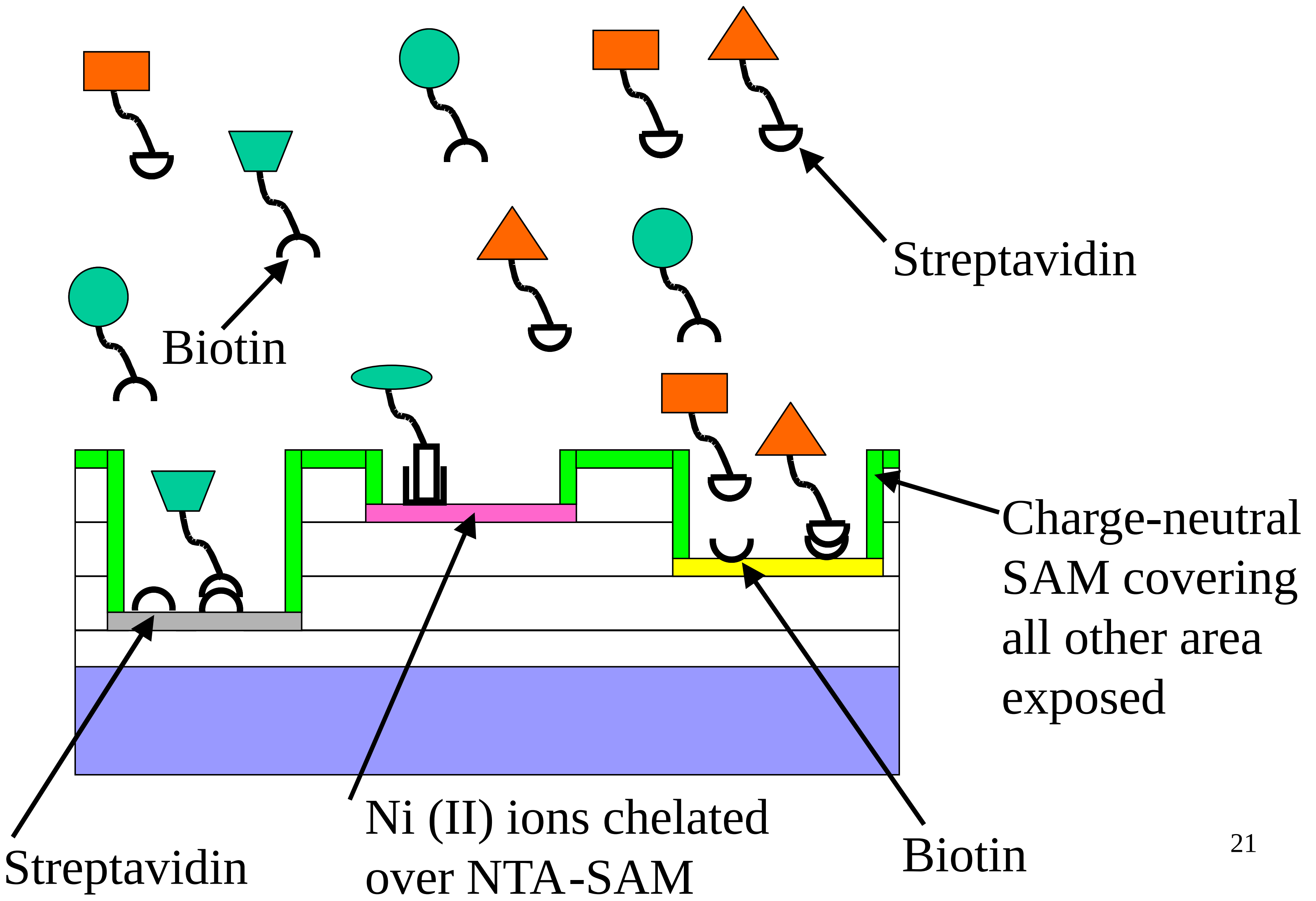
Microtubules Separation



Movie

Hiratsuka et al., Biophysical J., 1555 (2001)

Selective Kinesin Attachments



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- Control: Caged ATP
- Polymerization of protein chains

BIOMOLECULAR MOTOR-BASED CARGO TRANSPORTERS WITH LOADING/UNLOADING MECHANISMS ON A MICRO-PATTERNED DNA ARRAY

S. Hiyama1,2, S. Takeuchi3, R. Gojo3, T. Shima1, and K. Sutoh1

1Department of Life Sciences, The University of Tokyo, Japan

2Research Laboratories, NTT DoCoMo, Inc., Japan

3Institute of Industrial Science, The University of Tokyo, Japan

IEEE MEMS Conference, 2008

Figure 1: Mechanisms of cargo loading/transport/unloading

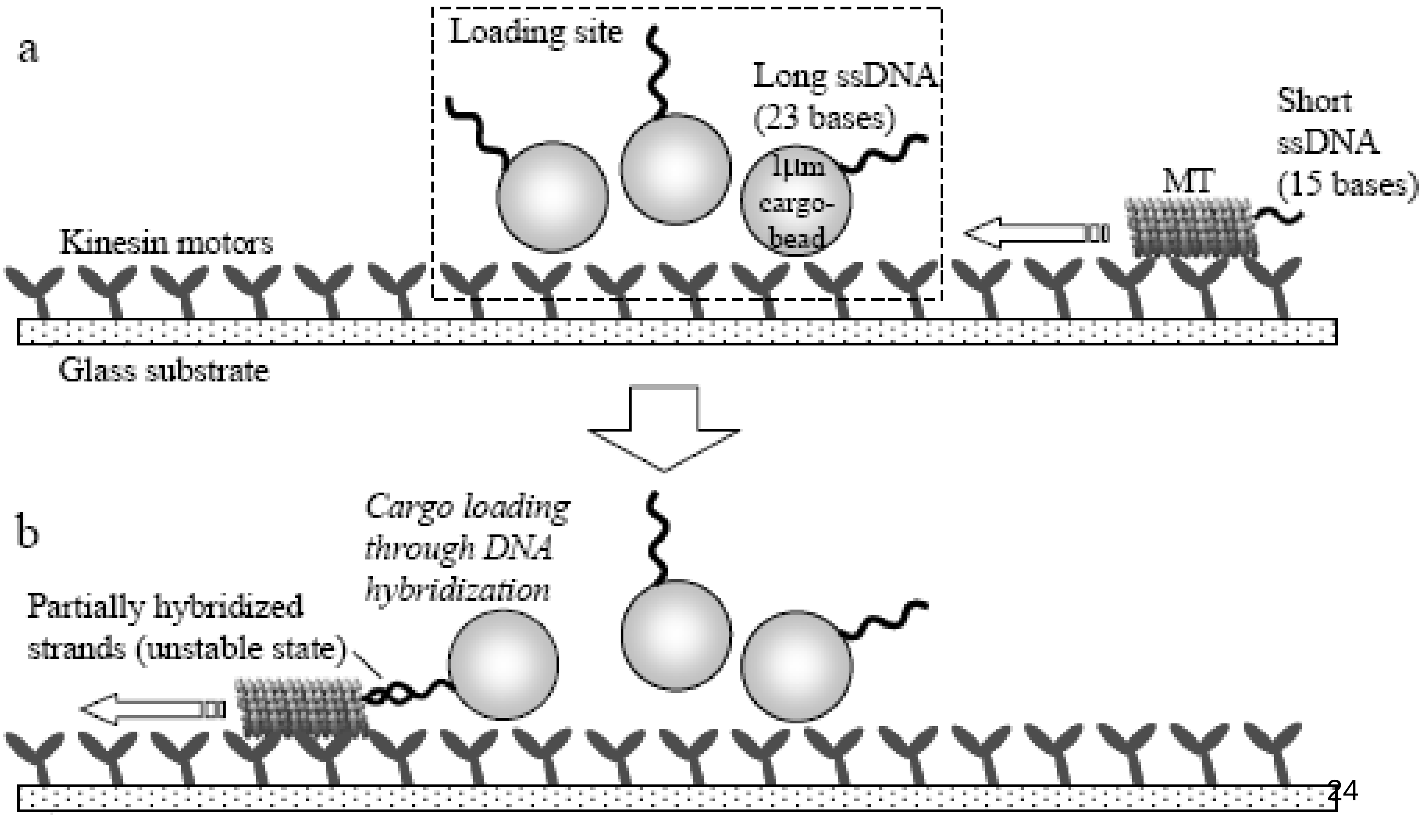
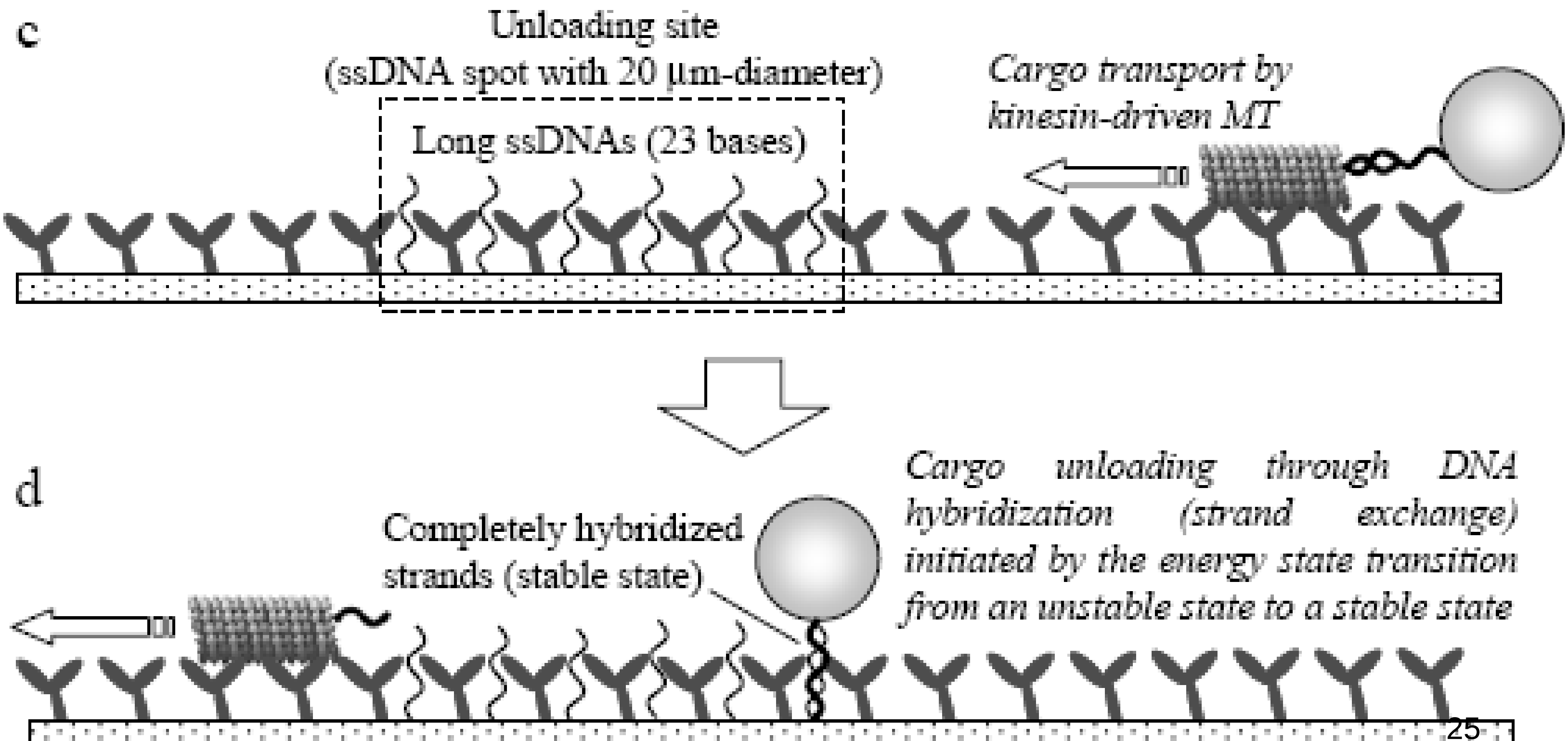


Figure 1: Mechanisms of cargo loading/transport/unloading



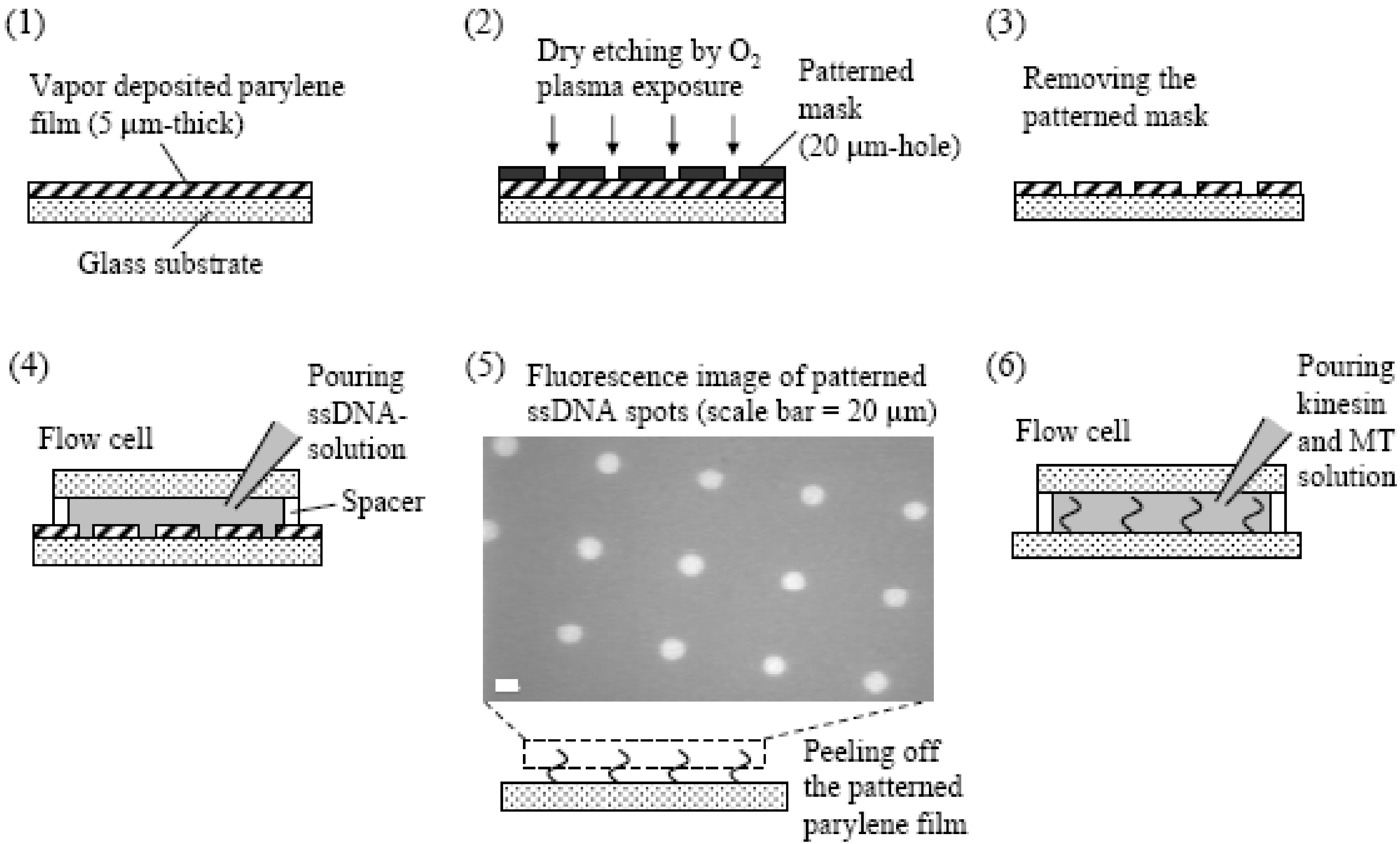
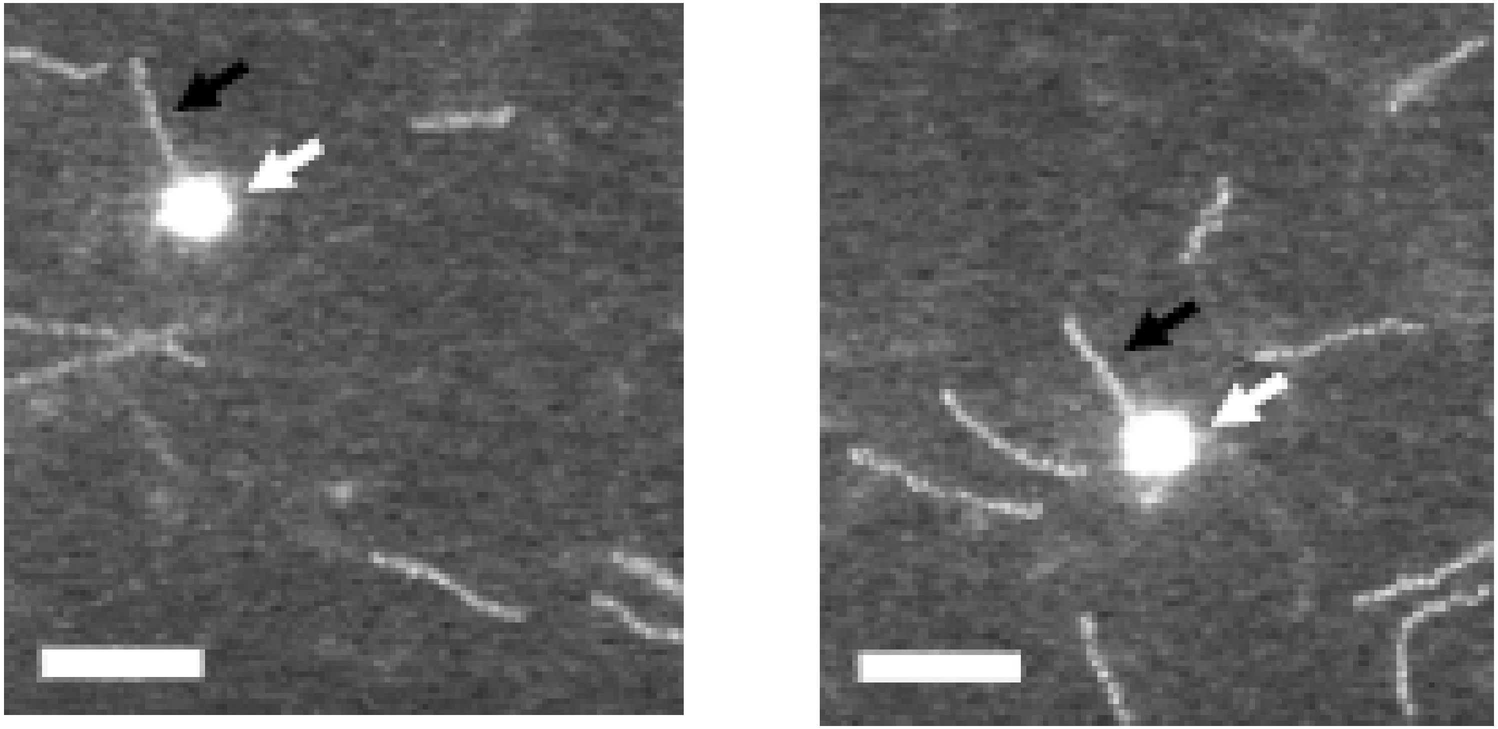


Figure 2: Preparation of a flow cell with micro-patterned ssDNA spots.



0 sec 16 sec

Figure 3: Time-lapsed fluorescence images of cargo transport by a single MT. The black and white arrows point to the gliding MT and the cargo-bead, respectively. The scale bars correspond to 3 μm.

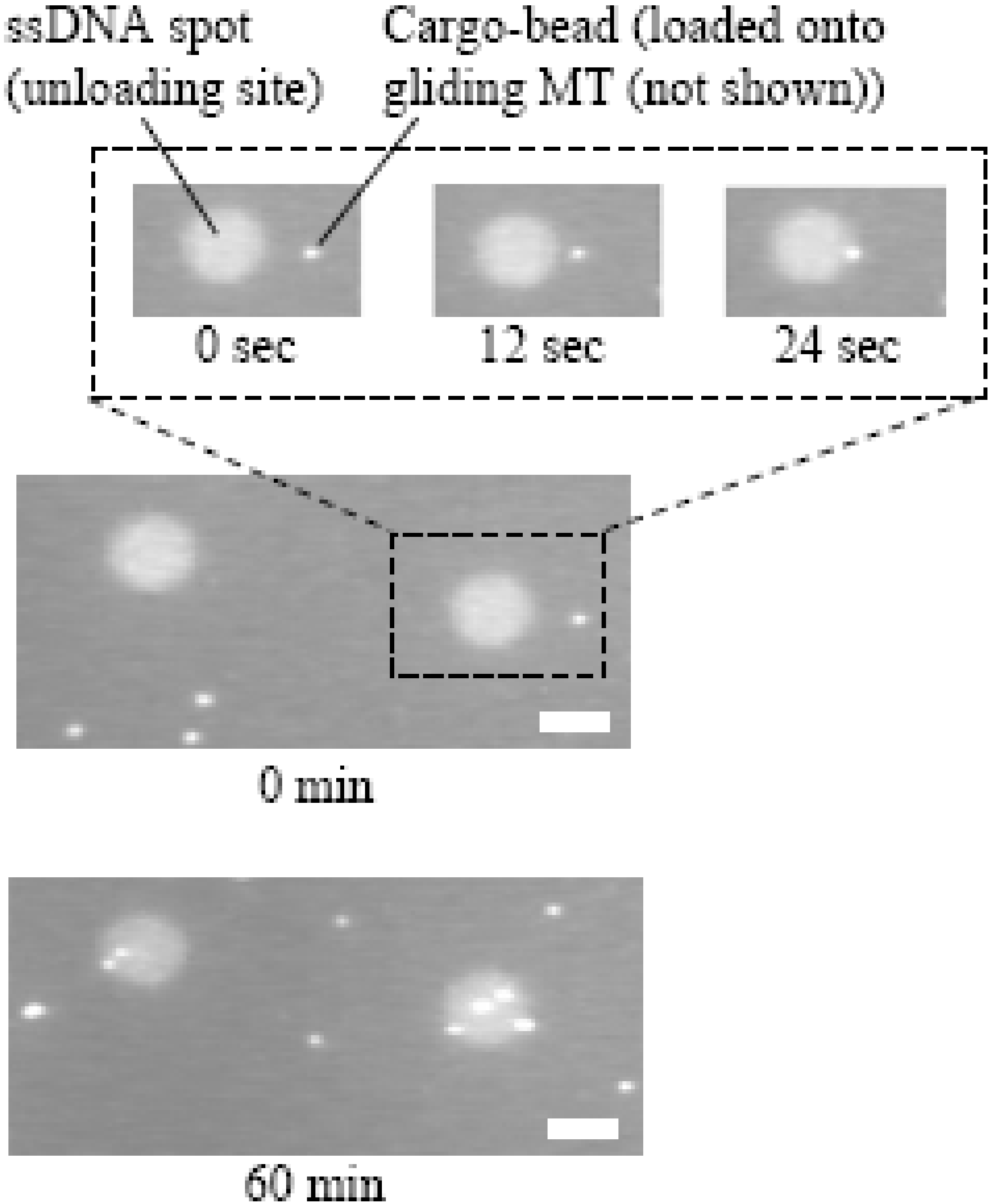


Figure 4: Time-lapsed fluorescence images of cargo-beads unloaded onto micro-patterned ssDNA spots. The scale bars correspond to 20 μm.

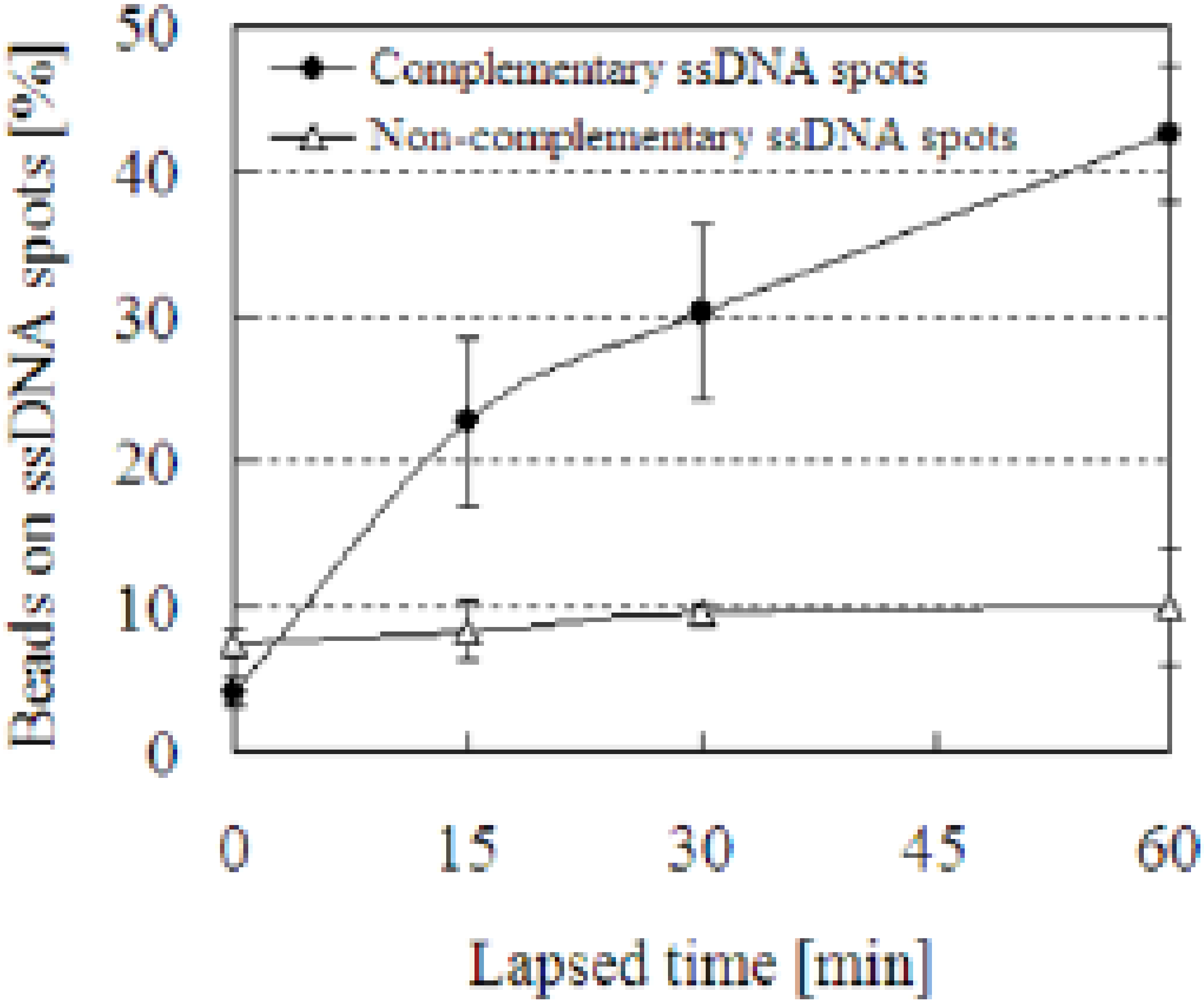
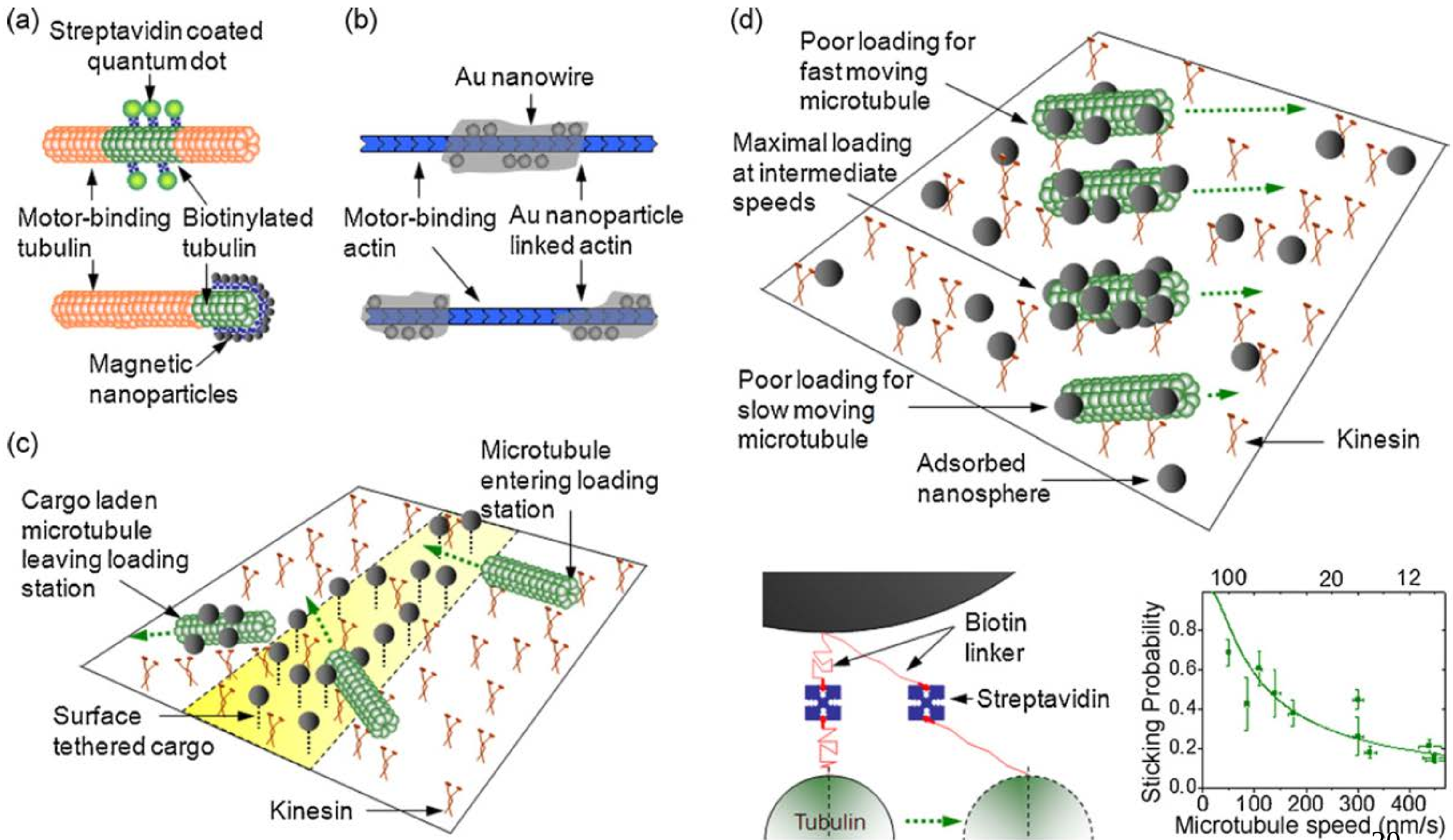


Figure 5: The rates of unloaded cargo-beads onto micro-patterned ssDNA spots.

Considerations for cargo loading onto kinesin driven microtubules

A. Agarwal, H. Hess / Progress in Polymer Science 35 (2010) 252–277



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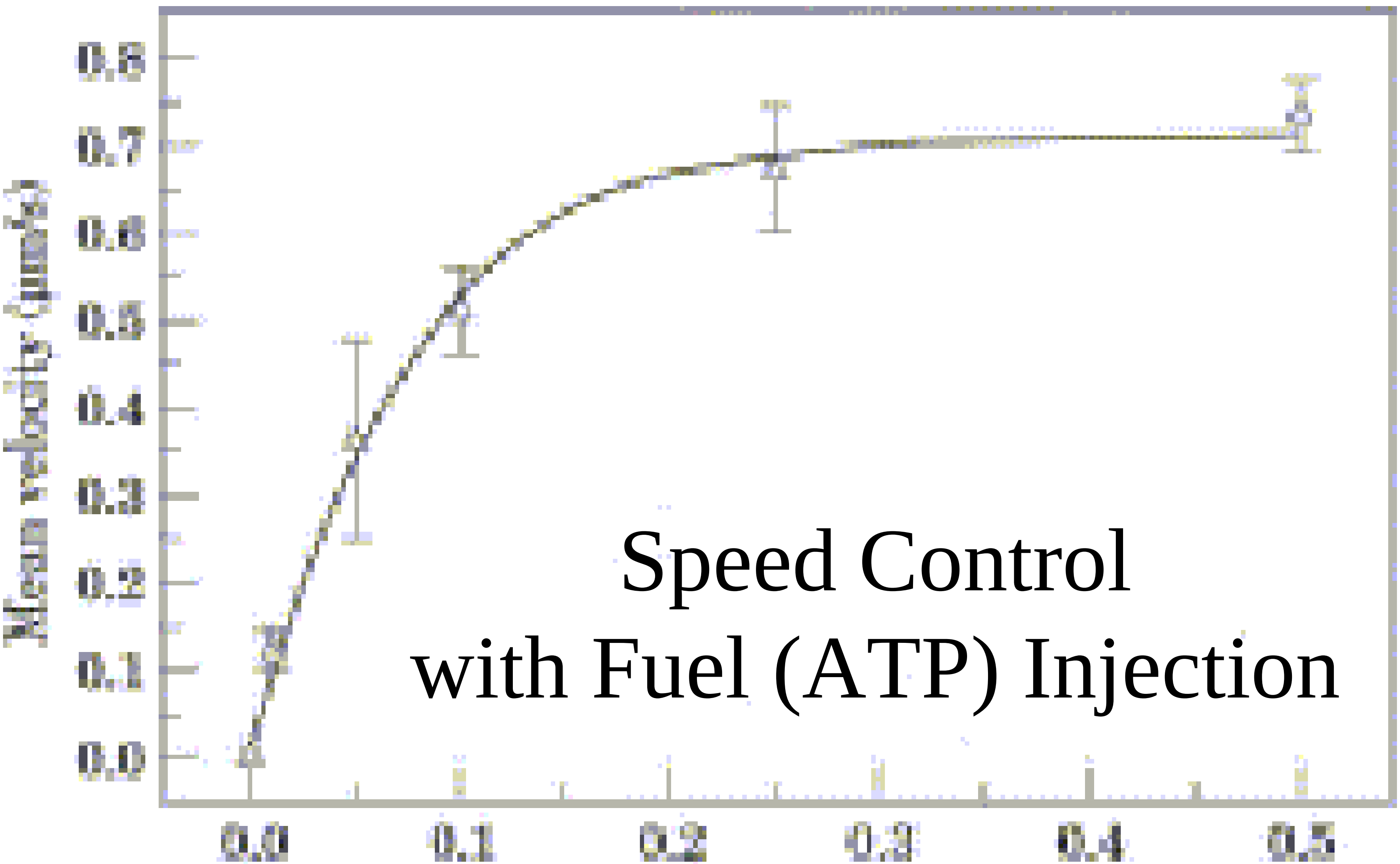
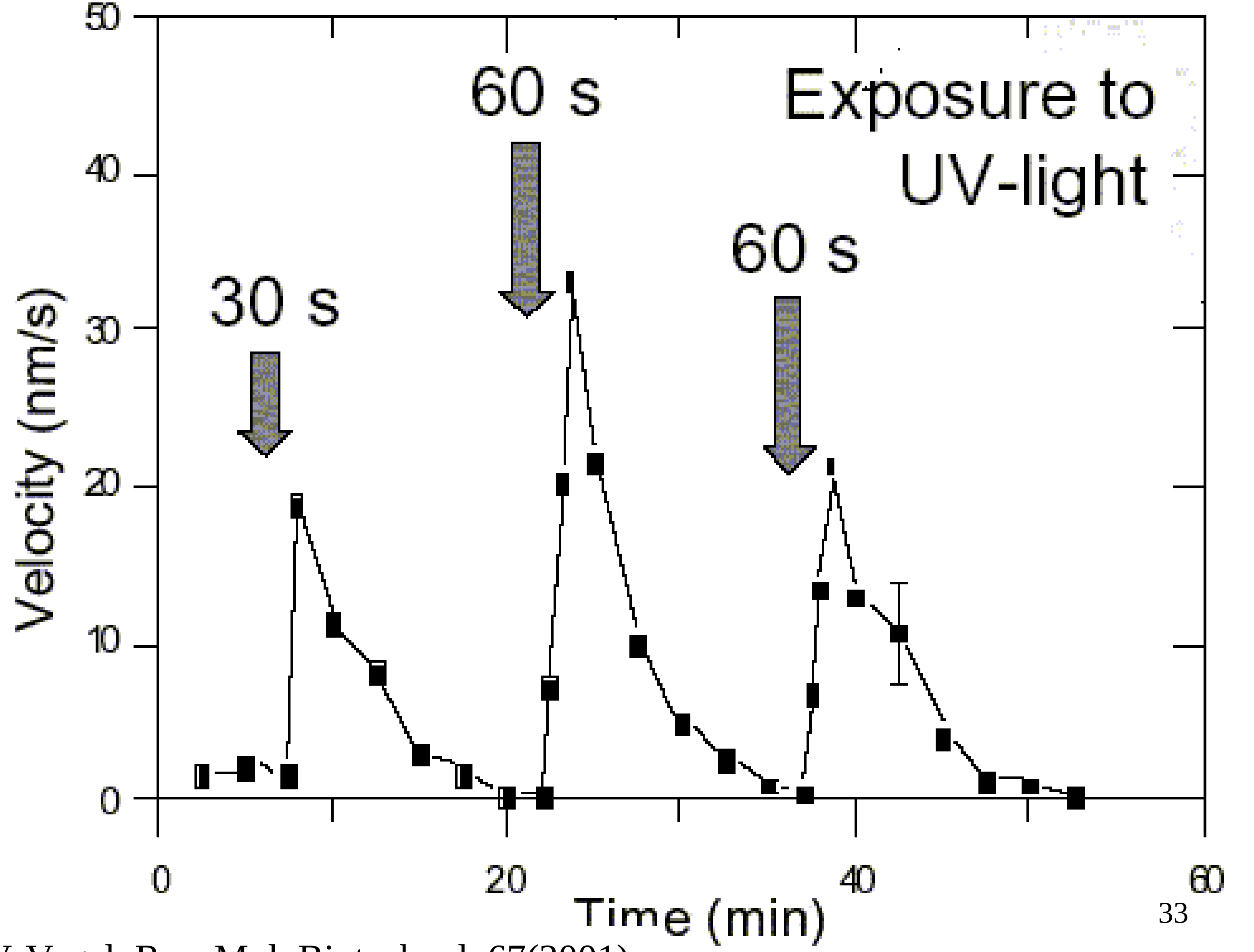
Speed Control with Fuel (ATP) Injection



H. Hess and V. Vogel, Rev. Mol. Biotechnol. 67(2001)

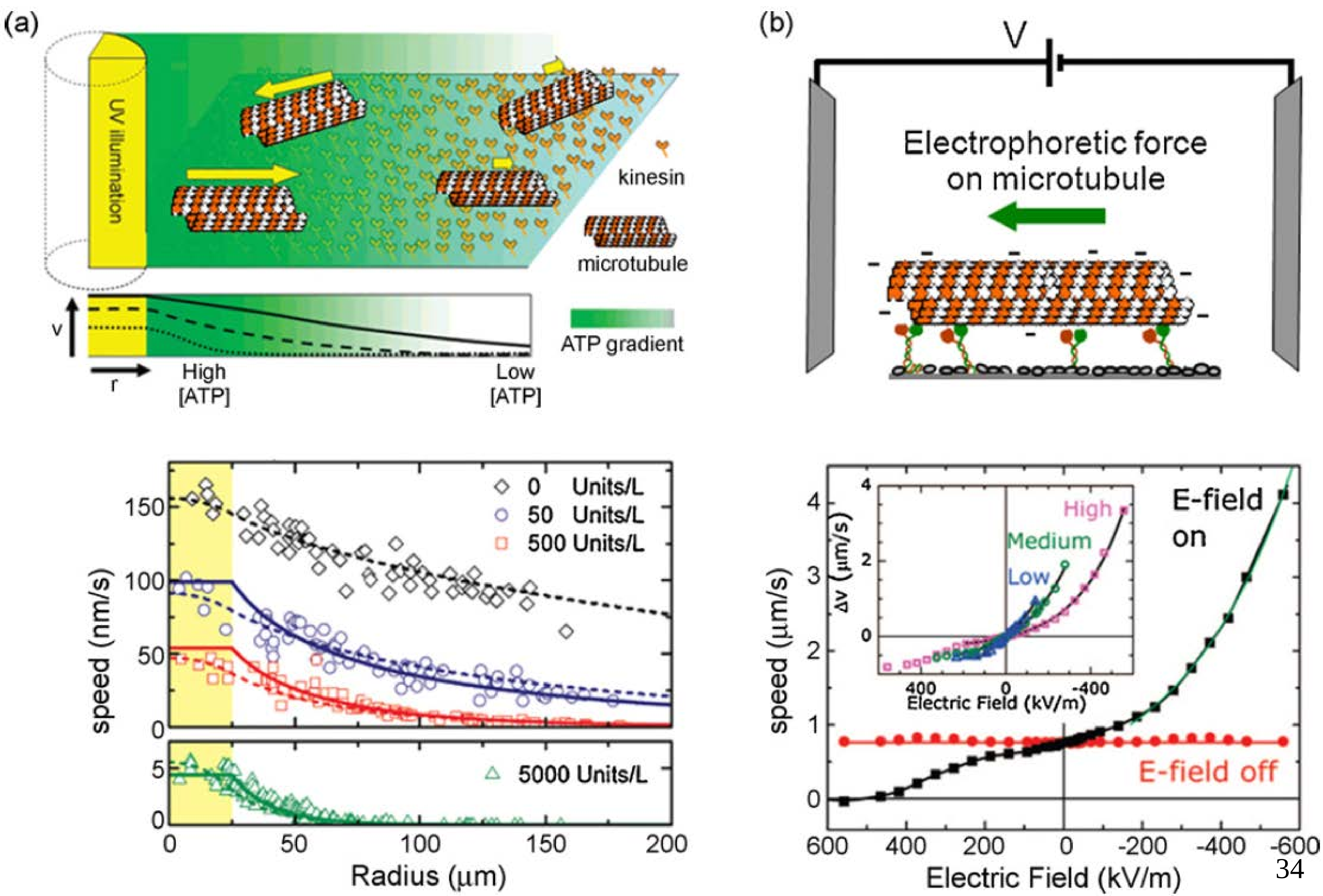
Caged ATP and ATP Consuming Enzymes (Acceleration and Deceleration)



H. Hess and V. Vogel, Rev. Mol. Biotechnol. 67(2001)

Control of molecular shuttles with light or electric field

A. Agarwal, H. Hess / Progress in Polymer Science 35 (2010) 252–277



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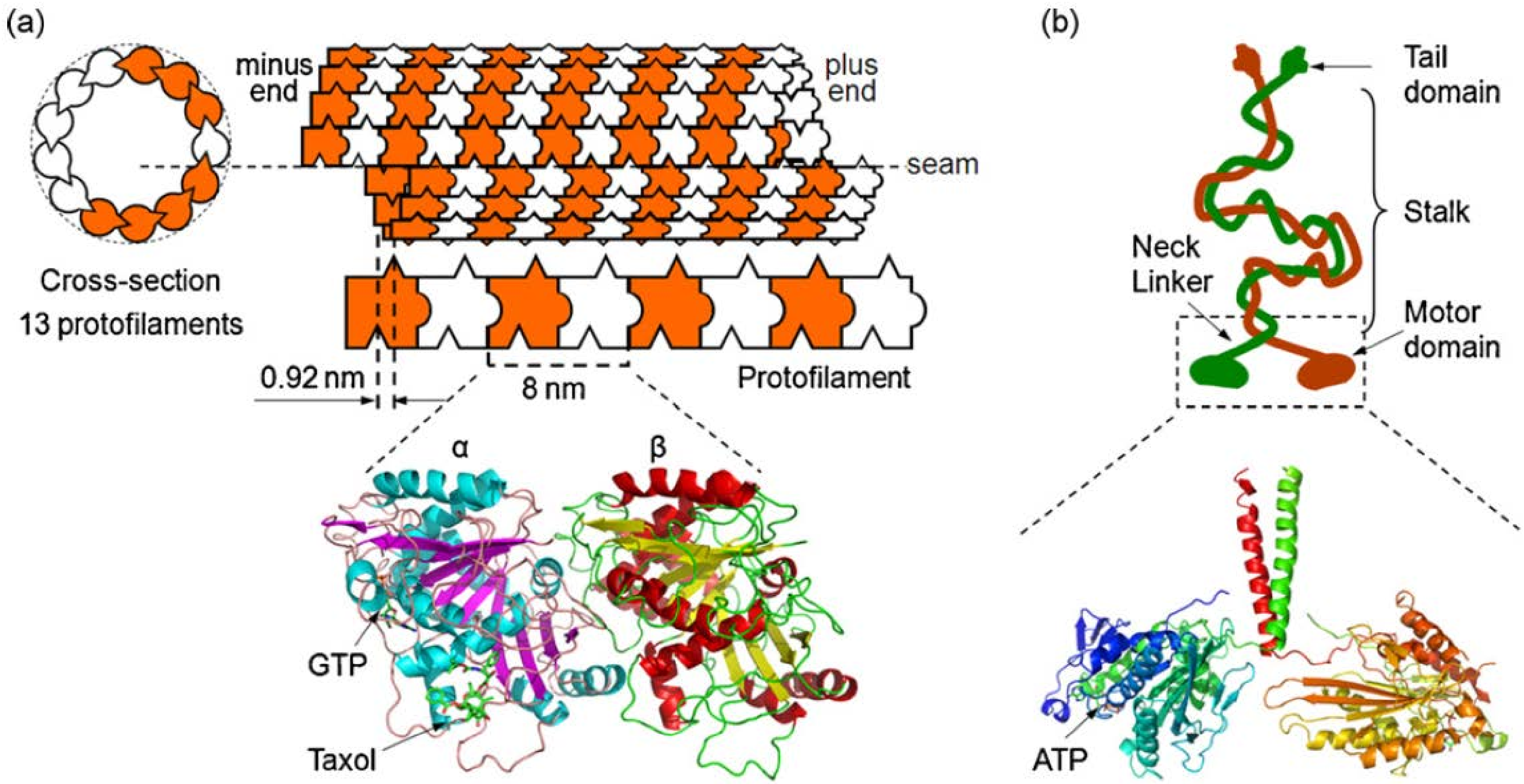
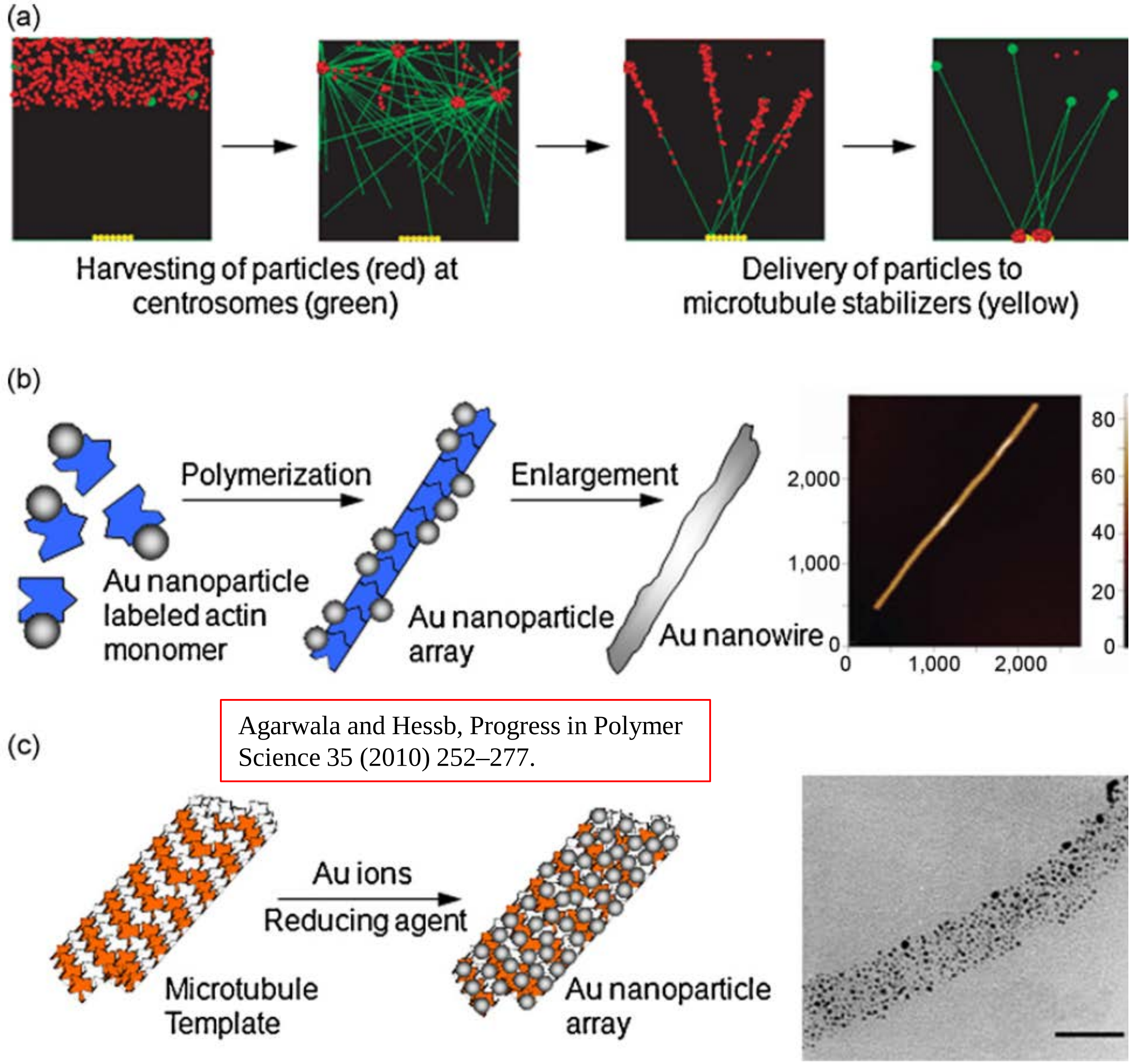
Microtubules → Polymerization of Protein Chains

Agarwala and Hessb, Progress in Polymer Science 35 (2010) 252–277.



Dynamic instability: stochastic switching between growing and shrinking phases



Agarwala and Hessb, Progress in Polymer Science 35 (2010) 252–277.

Regulated assembly and disassembly of microtubules can generate pulling and pushing forces. Other examples:

a) Strategies to sort, pattern, harvest, and deliver nanoparticles have been evaluated.

b) Fabrication of gold nanowires using actin filaments as templates via polymerization of gold-labeled actin monomers and subsequent metallization.

c) Microtubules have been used as templates to nucleate and grow nanoparticles from metal ion solutions in presence of reducing agents.

Summary

- Bio-molecular motors
  - Rotary motors: ATP Synthase
  - Linear motors: myosin and kinesin
  - Efficiencies > 50% in room temperature
- Molecular Shuttles
  - Kinesin and microtubules
- Guiding channels
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