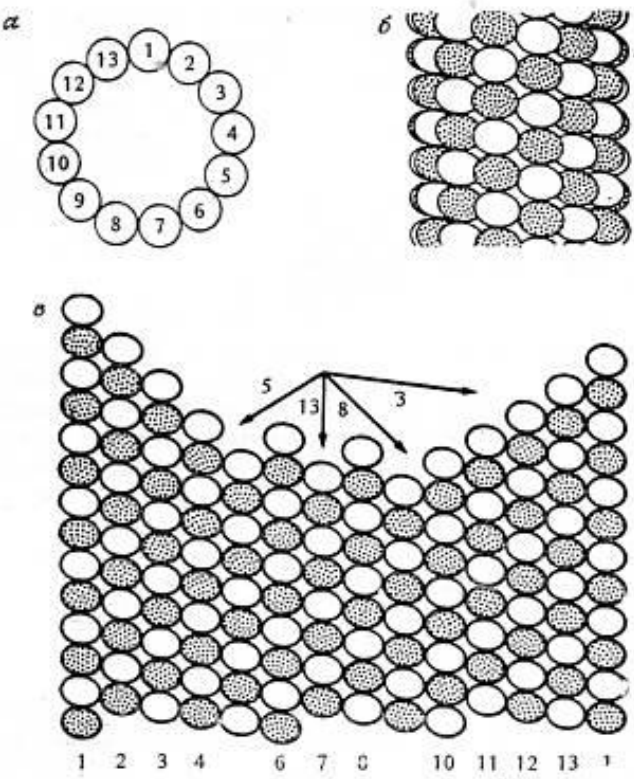
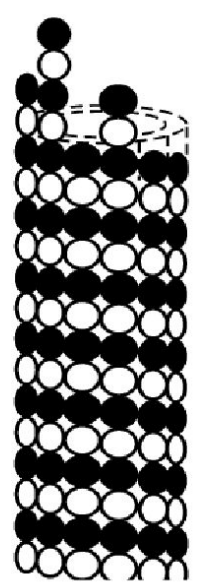


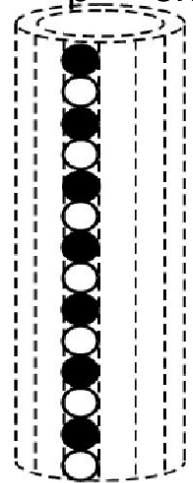
11. ОБЩИЕ АСПЕКТЫ МЕТАБОЛИЗМА



Growing microtubule

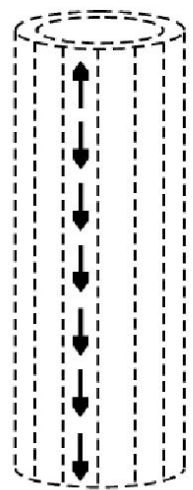


Proto-filament  $\beta$  + end

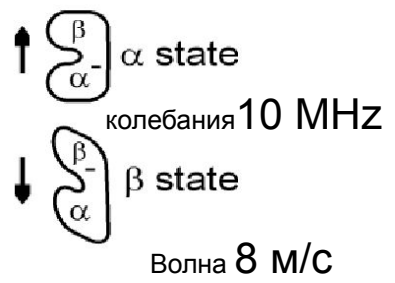


$\alpha$  - end

Dipole moments



Tubulin heterodimers



**Microtubules**

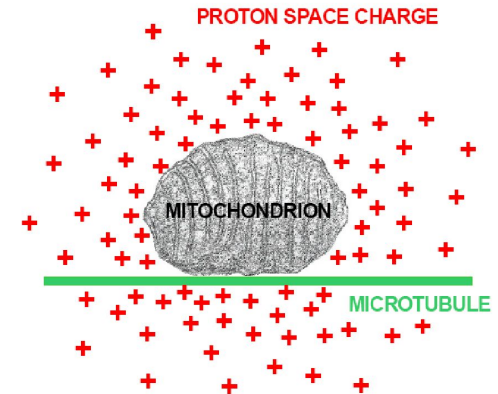
The electric dipole moment of a tubulin heterodimer is greater than 1000 Debye ( $10^{-26}$  Cm)

ПЛОТНОСТЬ ЭНЕРГИИ (МОЩНОСТИ), ЗАПАСЕННОЙ В МИКРОТРУБОЧКЕ В РЕЗУЛЬТАТЕ ГИДРОЛИЗА GTP:  $\sim 100 \text{ eV/c}/10 \text{ мкм} = 10^{-17} \text{ Вт}/10 \text{ мкм}$

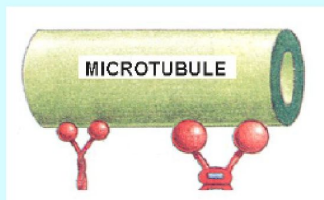
# ЭНЕРГИЗАЦИЯ МИКРОТРУБОЧЕК

## Источники энергии для мт:

1. За счет расщепления GTP: 0,074 eV / молекулу GTP,  
Или  $10^{-14}$  W/см длины мт;
2. За счет расщепления ATP моторными белками:  
 $\approx 4 \times 10^{-17}$  W
3. Поступление энергии от митохондрий:  $\approx 10^{-16} - 10^{-14}$  W на мт.



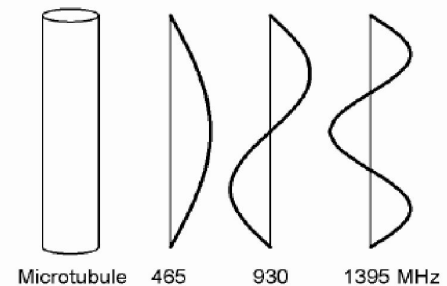
## Activity of motor proteins



Motor proteins  
moving along microtubules

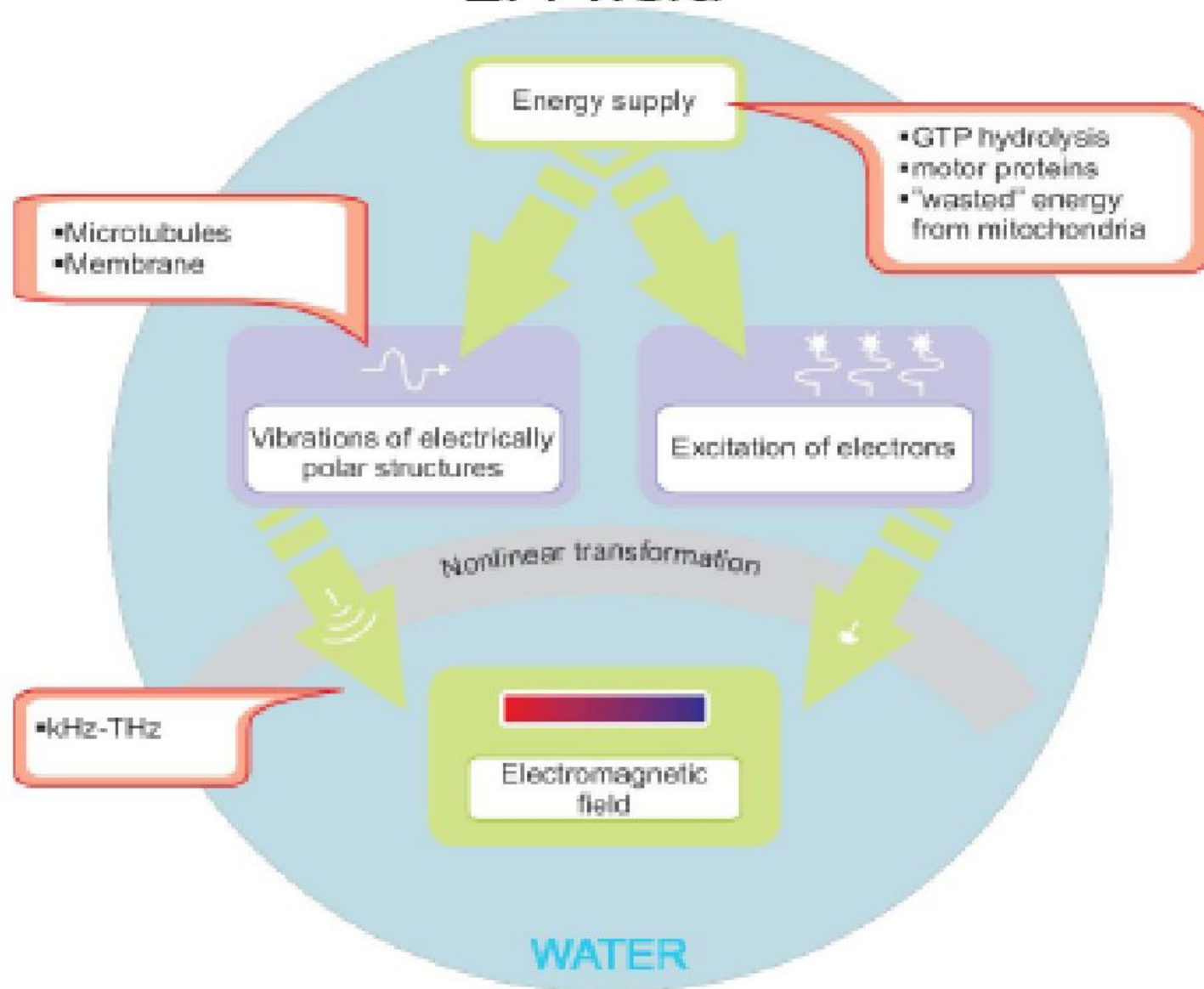
Concerted motor protein action supplies energy to vibration states (activation energy 58 kJ/mole). Metabolically driven nanomechanical process of vibrations.

Pelling A.E. et al.  
Local Nanomechanical  
Motion of the Cell Wall of  
*Saccharomyces cerevisiae*  
Science 305, 2004, 1147-  
1150

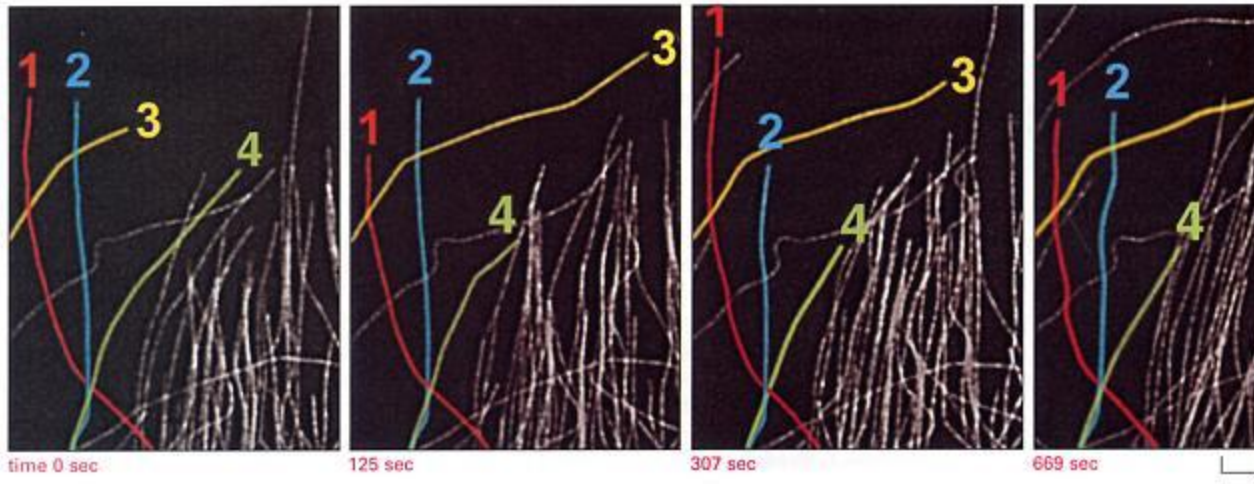


A schematic picture of longitudinal elastic resonant oscillations in a microtubule at the frequencies 465, 930, and 1395 MHz.

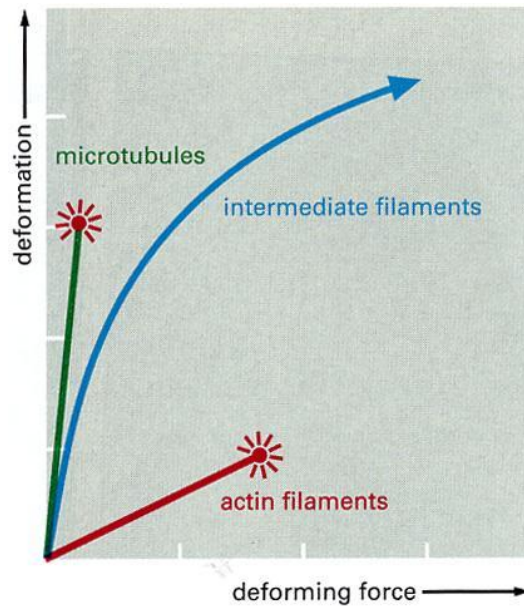
# Physical mechanism of generation of cellular EM field



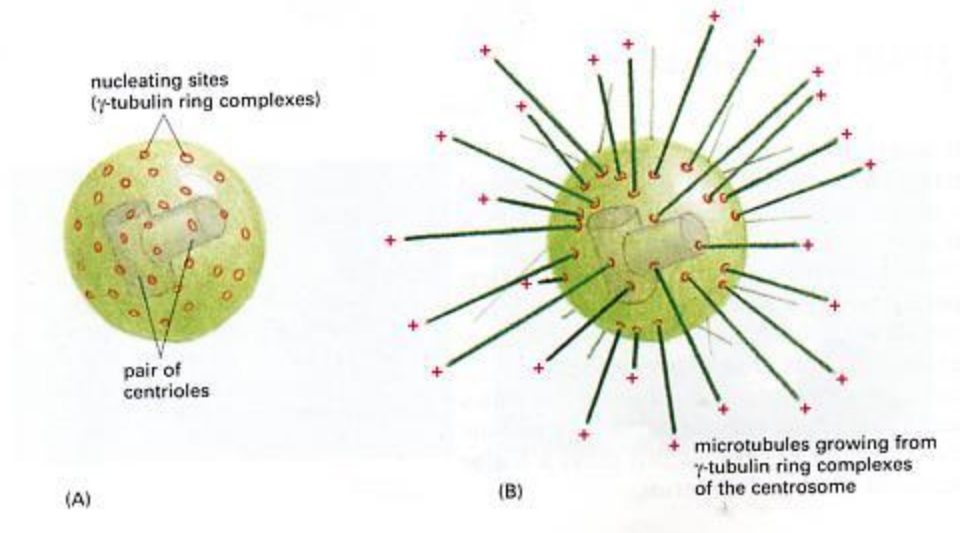
# Реология и динамическая нестабильность микротрубочек



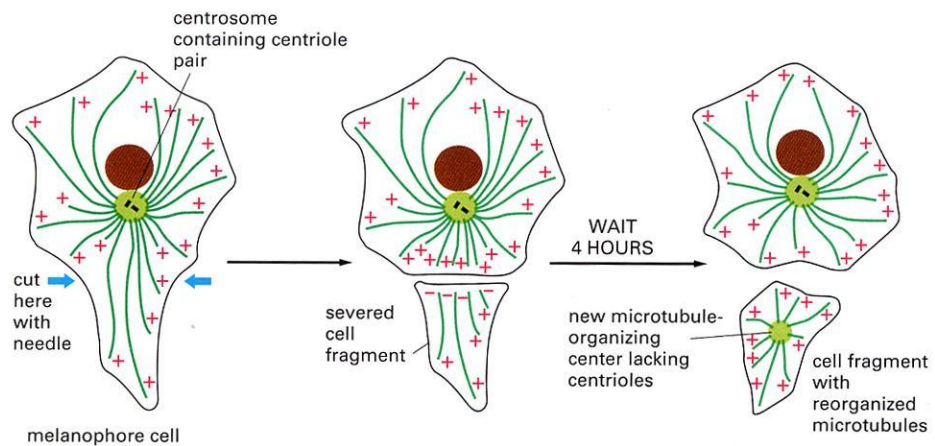
Микротрубочки сильно деформируются малыми силами



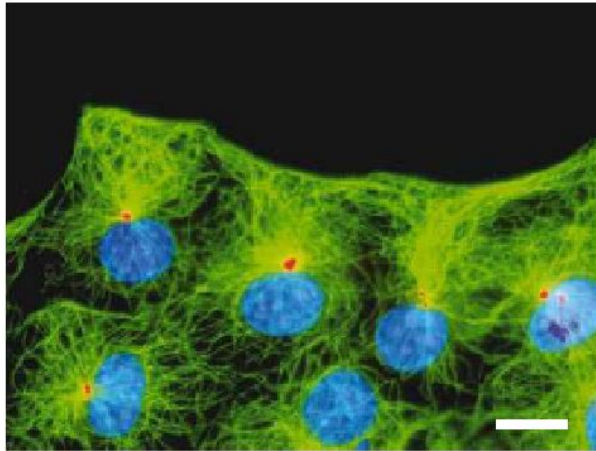
# ЦЕНТРЫ ОБРАЗОВАНИЯ МИКРОТРУБОЧЕК



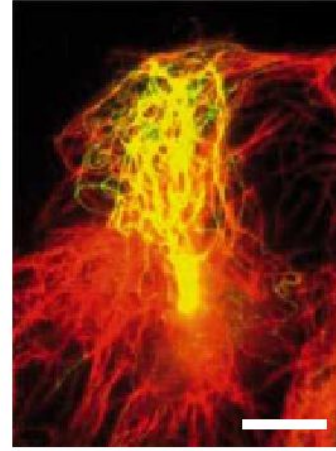
~ 20 микротрубочек / мин



a Centrosome orientation

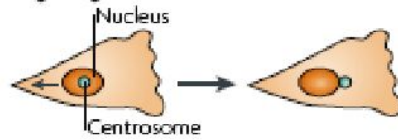


b Selective microtubule stabilization

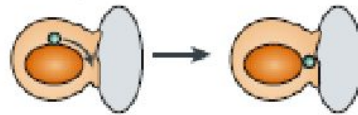


c

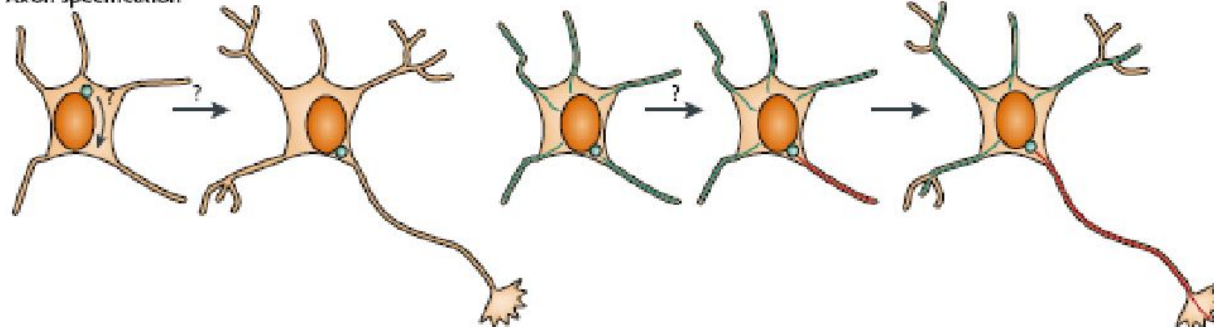
Migrating fibroblast



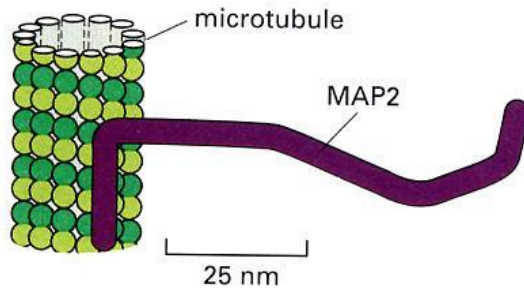
T cell-target interaction



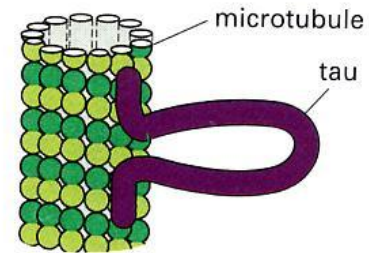
Axon specification



# БЕЛКИ, СВЯЗАННЫЕ С МИКРОТРУБОЧКАМИ



Рыхлая упаковка



плотная упаковка

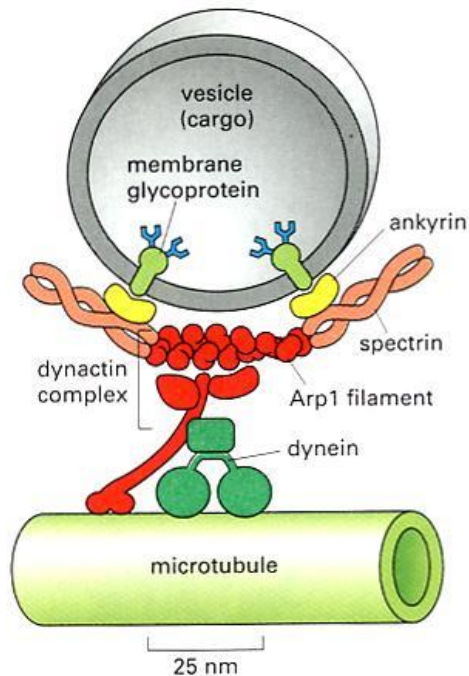
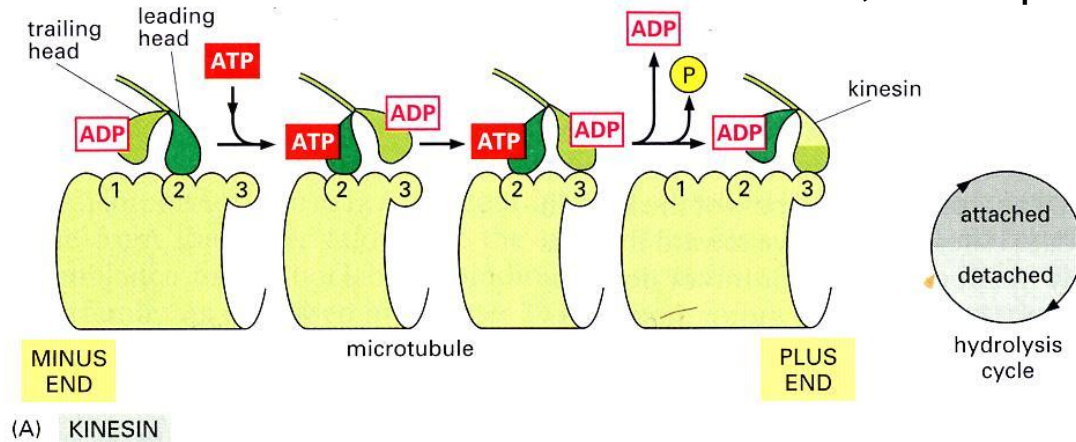
Катастрофин к + концу

Severing proteins (катанин) к « - » концу

# ДВИЖЕНИЕ КИНЕЗИНА И ДИНЕИНА ПО МИКРОТРУБОЧКЕ

## ОБЩЕПРИНЯТАЯ МОДЕЛЬ

0,02 – 2  $\mu\text{m/s}$



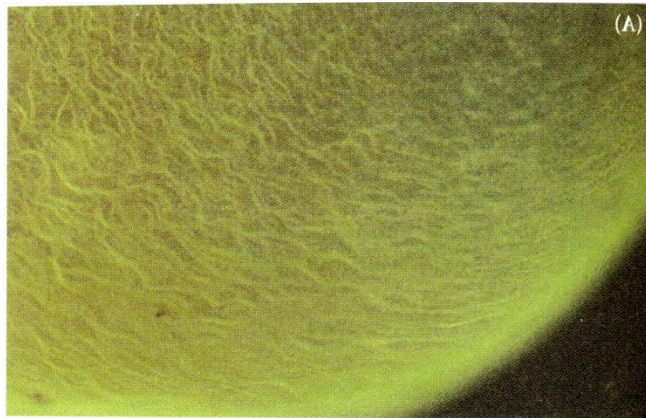
ПО POLLACK



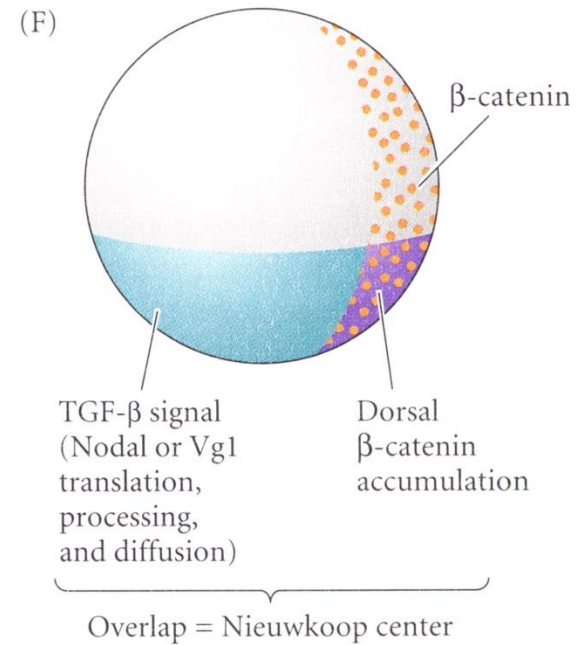
Figure 12.9. Mechanism of kinesin advance along the microtubule.



# НАКОПЛЕНИЕ $\beta$ -КАТЕНИНА В КЛЕТОЧНЫХ ЯДРАХ ДОРСАЛЬНОЙ СТОРОНЫ ЯЙЦЕКЛЕТКИ АМФИБИЙ В ХОДЕ ПОВОРОТА ОПЛОДОТВОРЕНИЯ

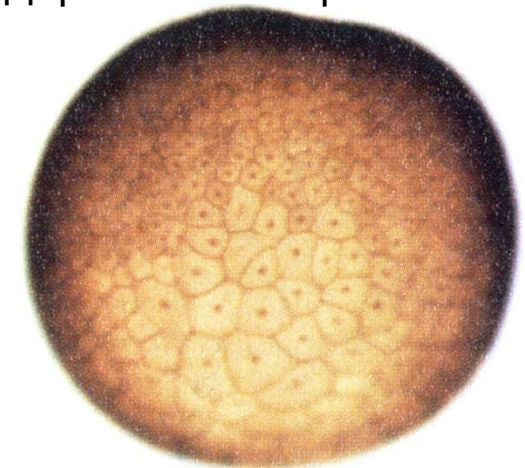
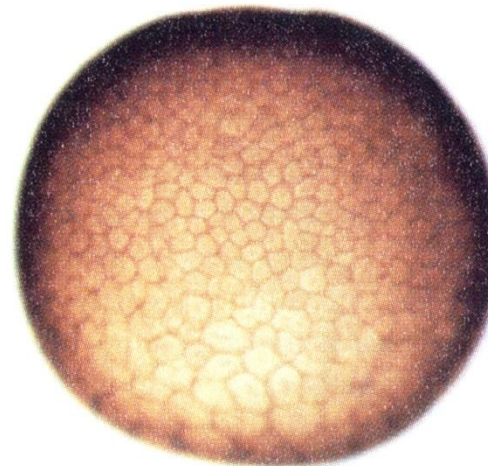


микротрубочки

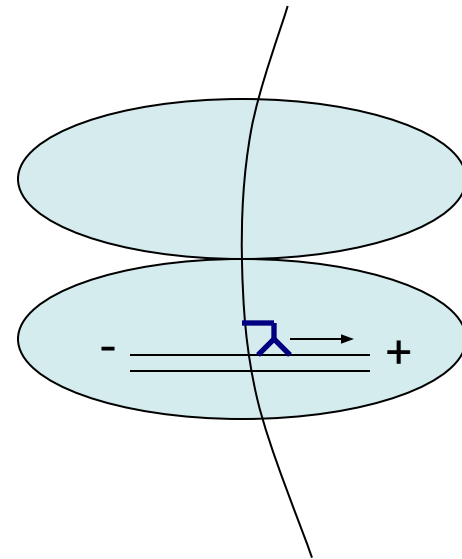
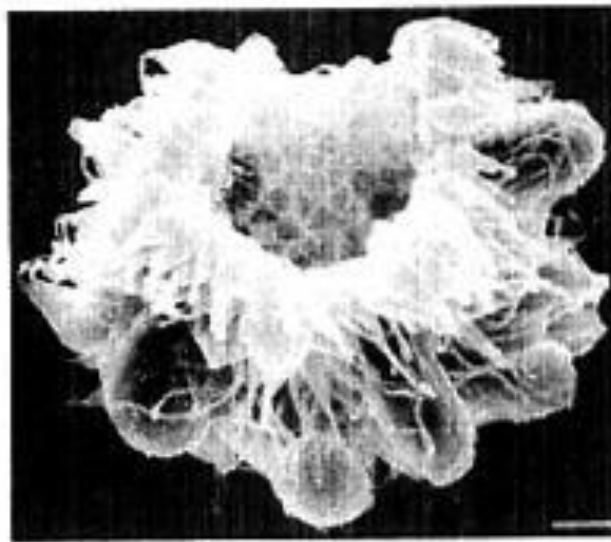
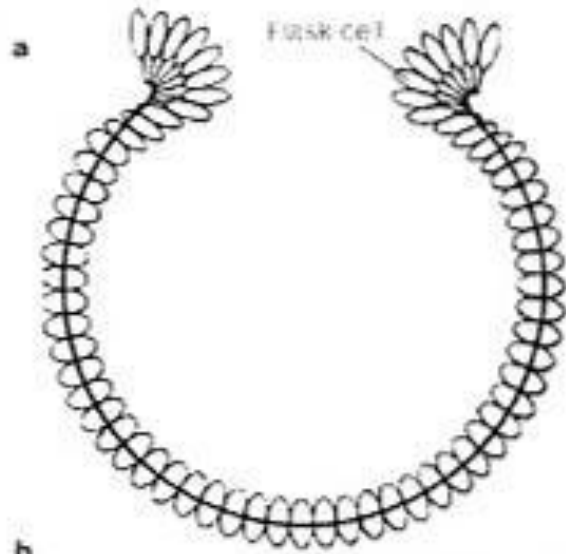


Вентральная сторона

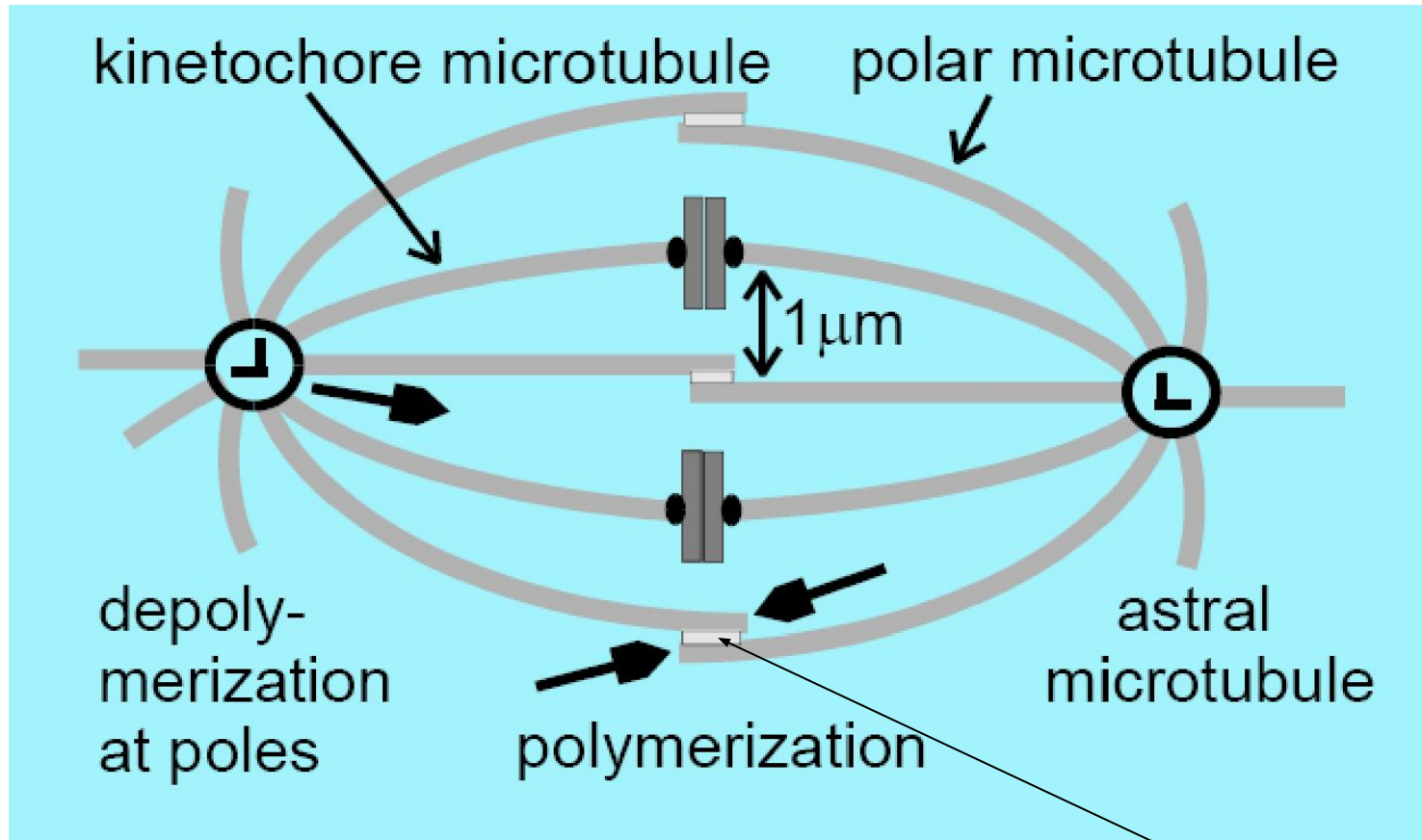
Дорсальная сторона



# Участие кинезина INV D в экскурвации волювокса

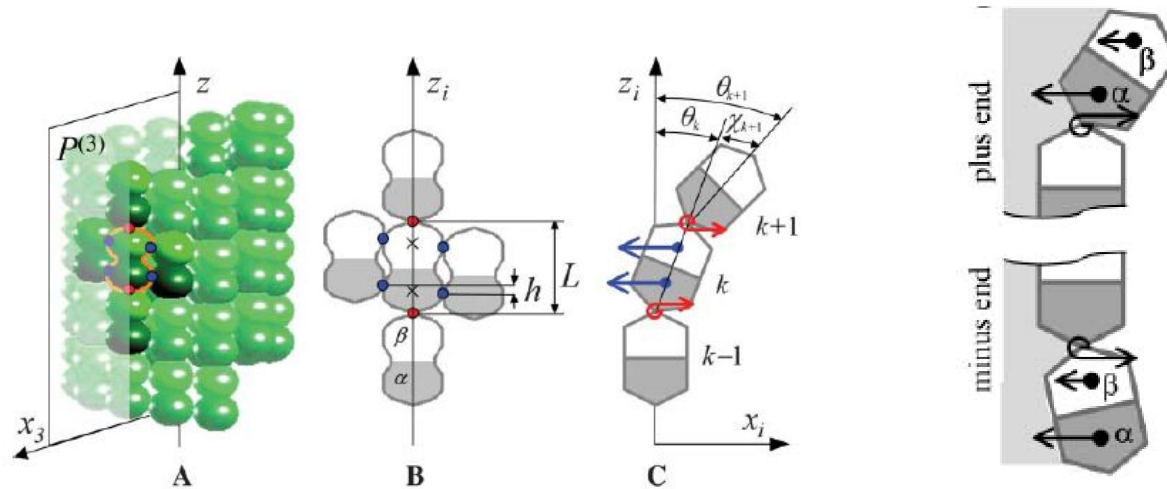


# МИКРОТРУБОЧКИ МИТОТИЧЕСКОГО ВЕРЕТЕНА



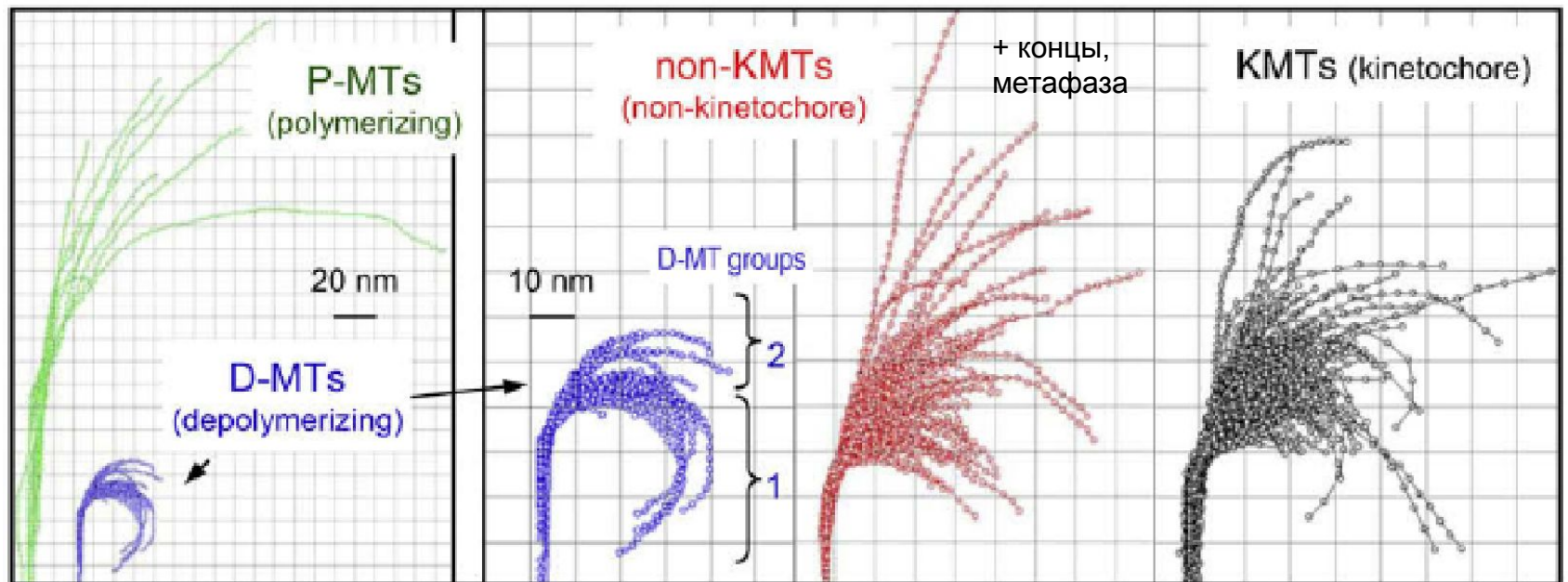
7 семейств кинезинов, в частности биполярный тетрамерный кинезин N

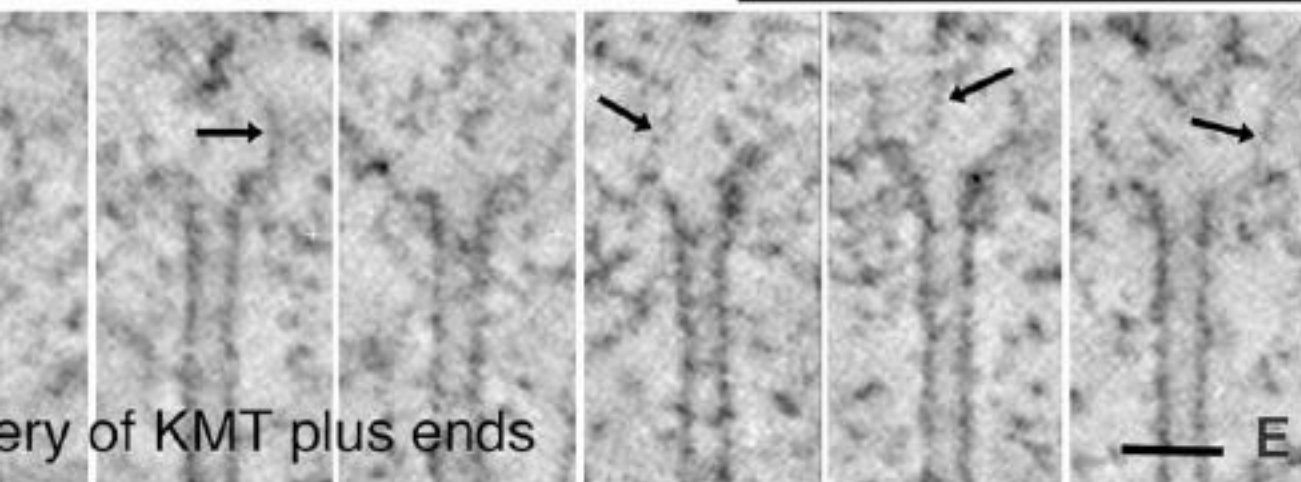
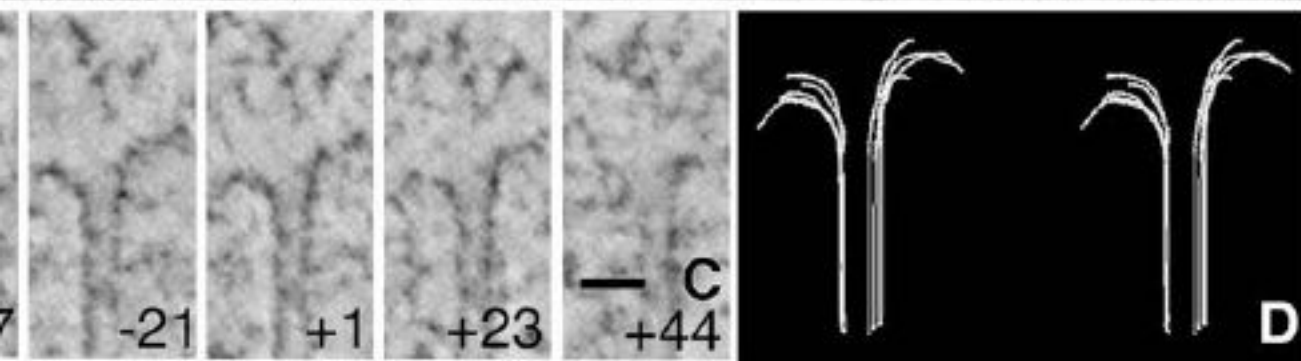
# ИЗГИБЫ ПРОТОФИЛАМЕНТ МИКРОТРУБОЧЕК



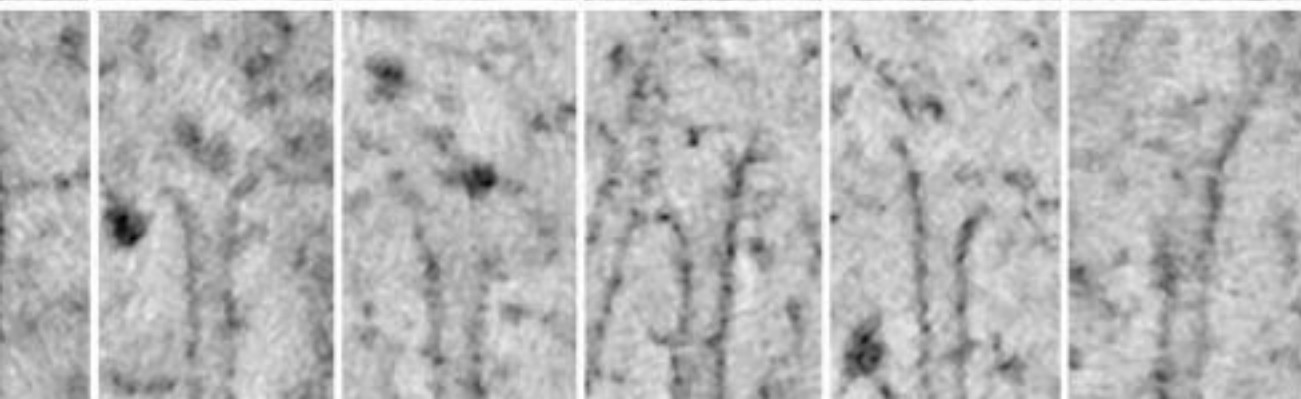
Тубулин in vitro

Случайная выборка из метафазных и анафазных МТ





Gallery of KMT plus ends



(A) Average of 15 consecutive tomographic slices showing a microtubule bundle with a total thickness  $\sim 30$  nm, analogous to a conventional thin section. Chromosome (C) and a chromosome (K) show characteristic staining. KMTs were identified as KMTs when they ended in close proximity to a chromosome. Bar =  $0.1 \mu\text{m}$ .

(B) KMTs from the same cell but seen in a slice cut parallel to their axes with the characteristic feature of IMOD. Arrow identifies a bundle, arrowhead indicates a fibril that runs from the chromatin. Bar =  $0.05 \mu\text{m}$ .

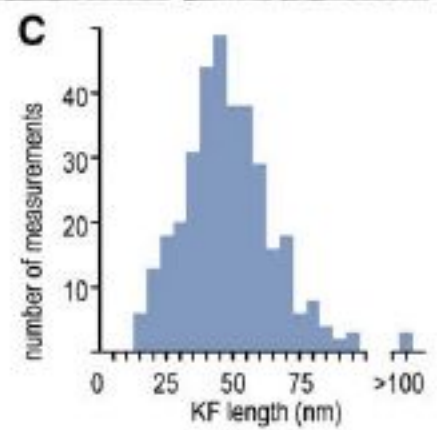
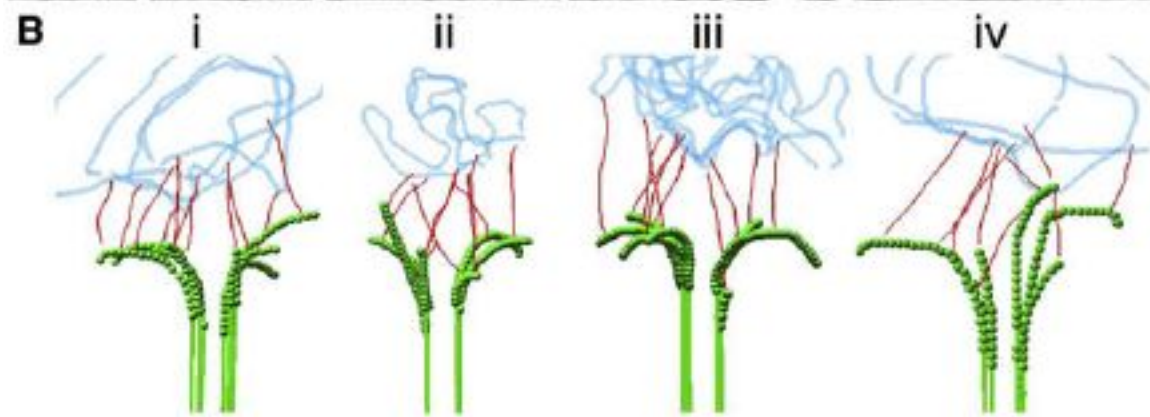
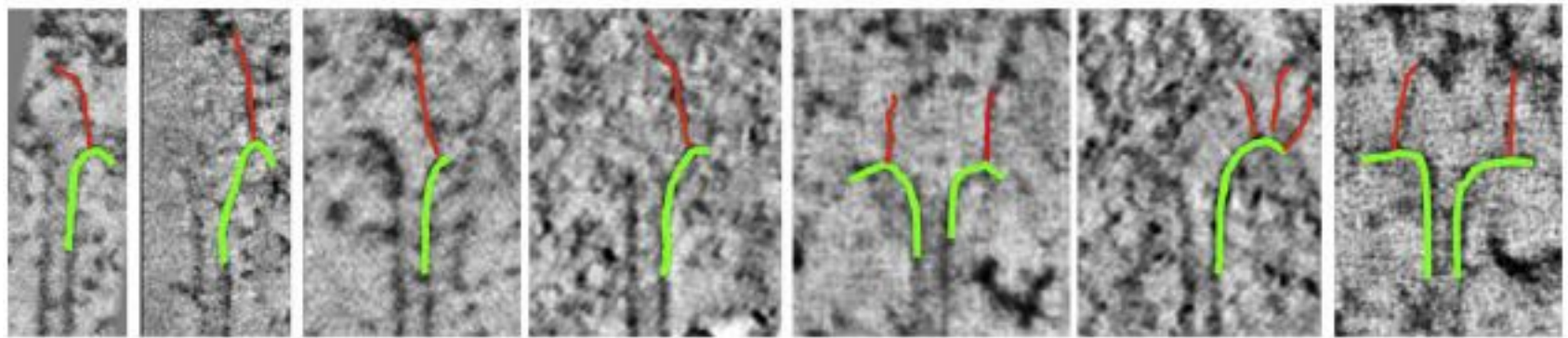
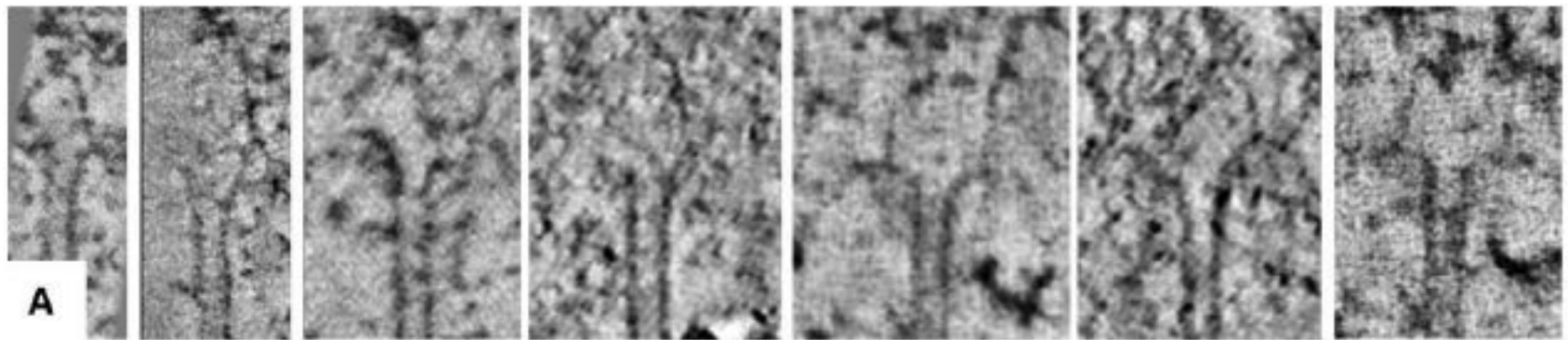
(C) Multiple image planes that contain the same microtubule but are oriented at the angles stated relative to the plane of section; PFs in each view differ in position and extent of flare. Bar =  $0.05 \mu\text{m}$ .

(D) Stereo pair of a 3D model of all the plus ends on the MT shown in Figure 1C. Use a stereo viewer for viewing.

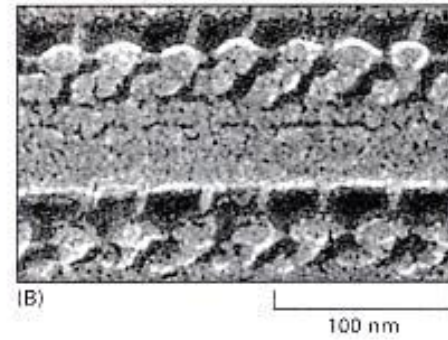
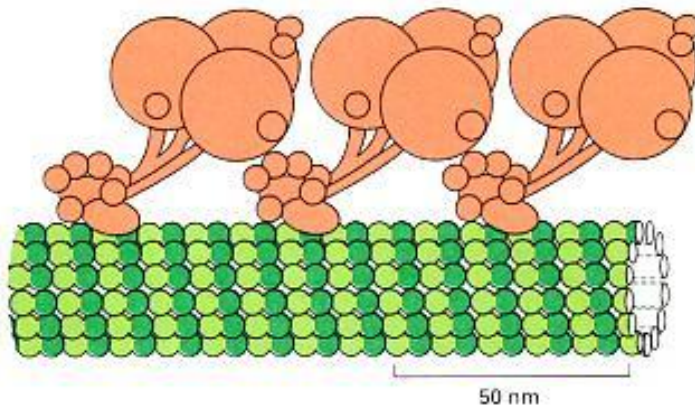
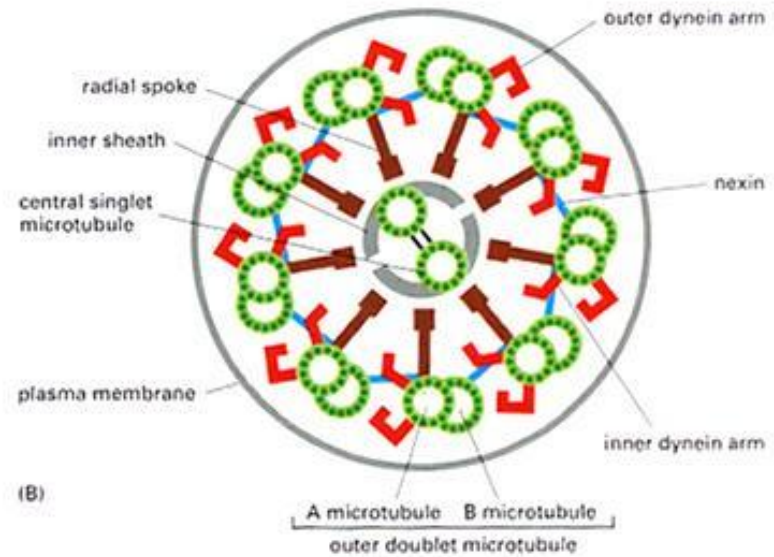
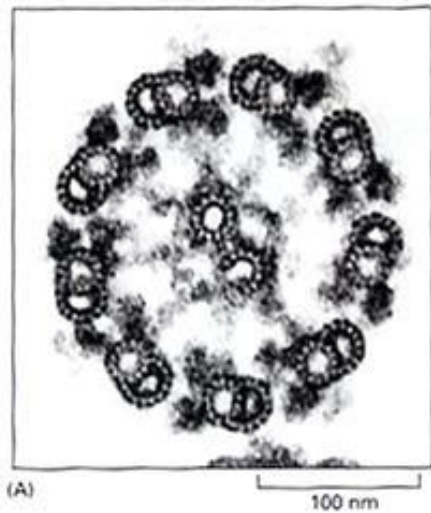
(E) Gallery of different KMT ends from the same cell. PF flare is variable; fibrillar material is associated with some PFs (arrows). Bar =  $0.05 \mu\text{m}$ .

(F) Gallery of non-KMT ends from the plus ends of a metaphase spindle; no chromosomes are nearby. Some MT ends are flared, others are not seen. Bar =  $0.05 \mu\text{m}$ .

depolymerizing when their length is constant on average, constant? Is KMT a simple reflection of dynamic stability in vitro, or do other factors affect

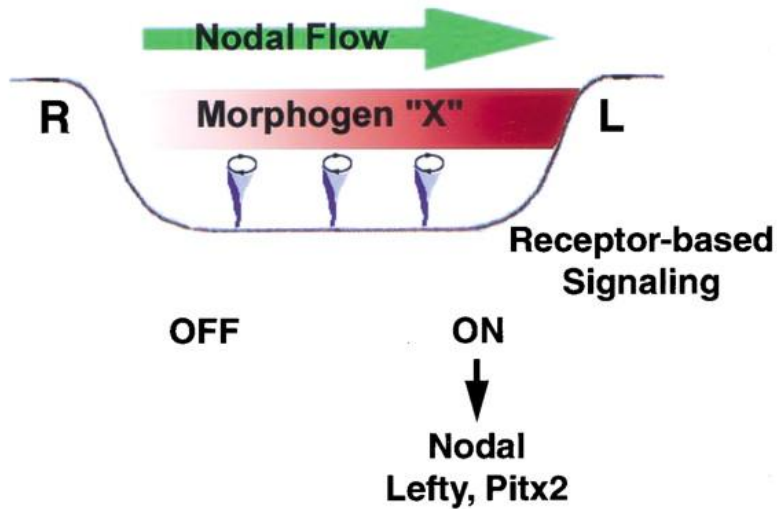


# СТРУКТУРА РЕСНИЧЕК

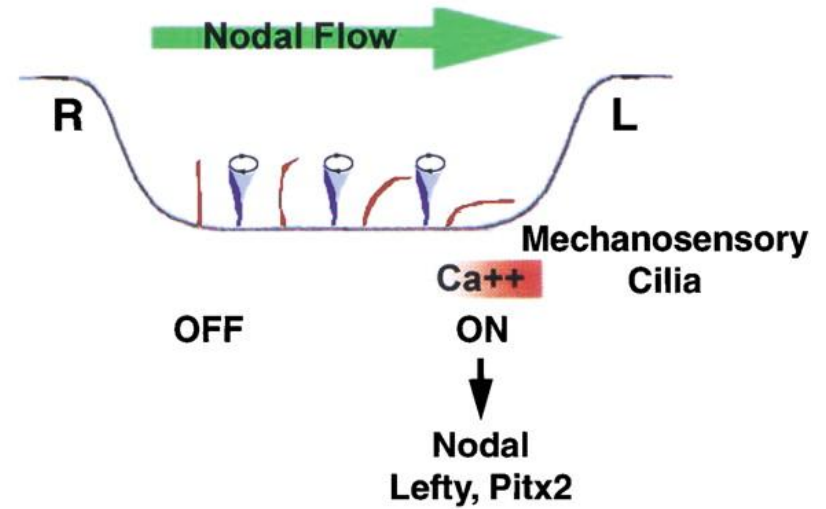


# РОЛЬ РЕСНИЧЕК В ФОРМИРОВАНИИ ЛЕВО-ПРАВОЙ ДИССИММЕТРИИ

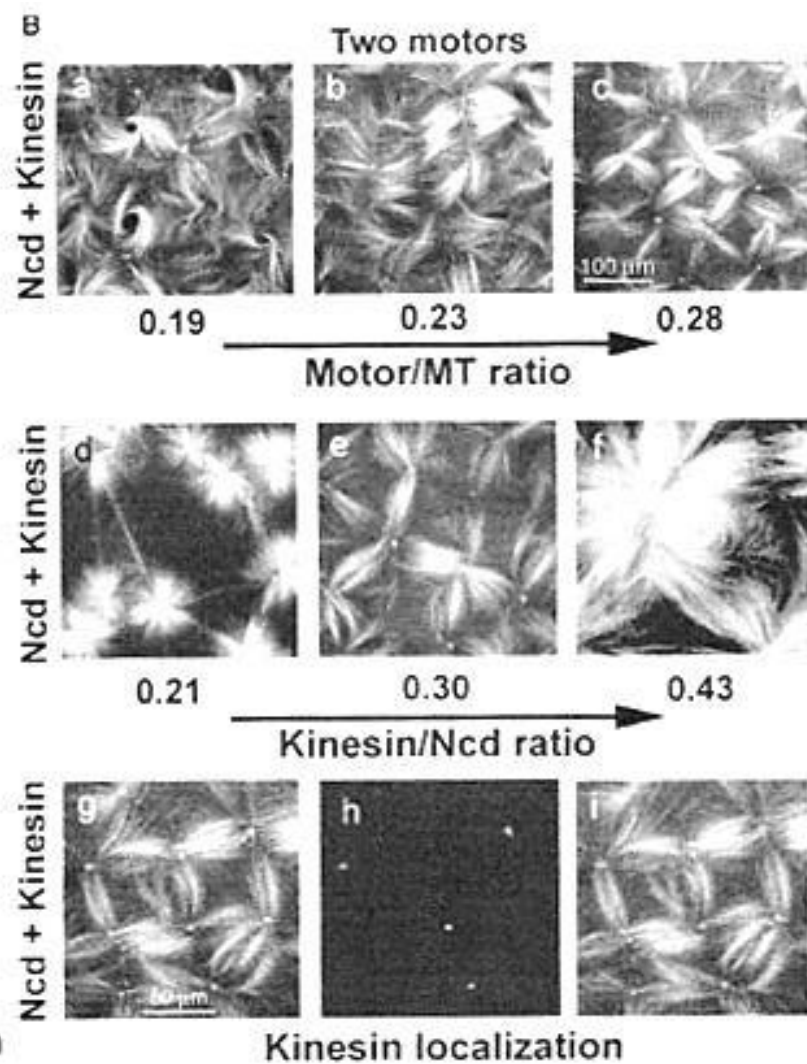
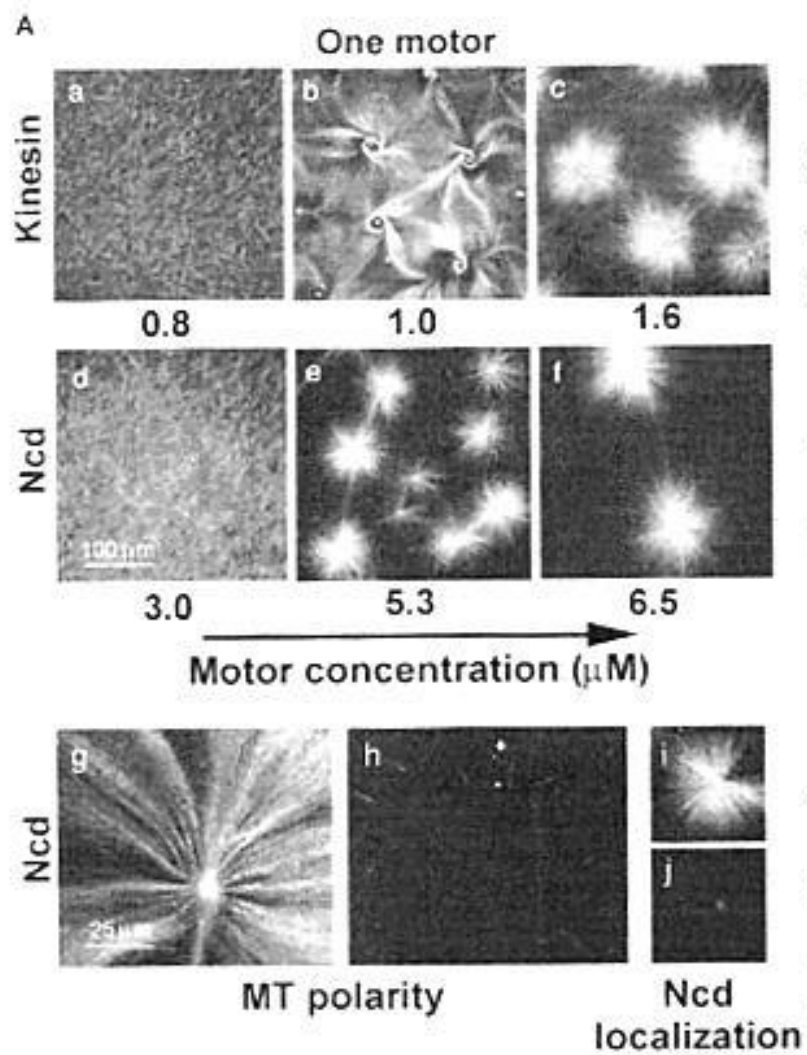
**A**



**B**

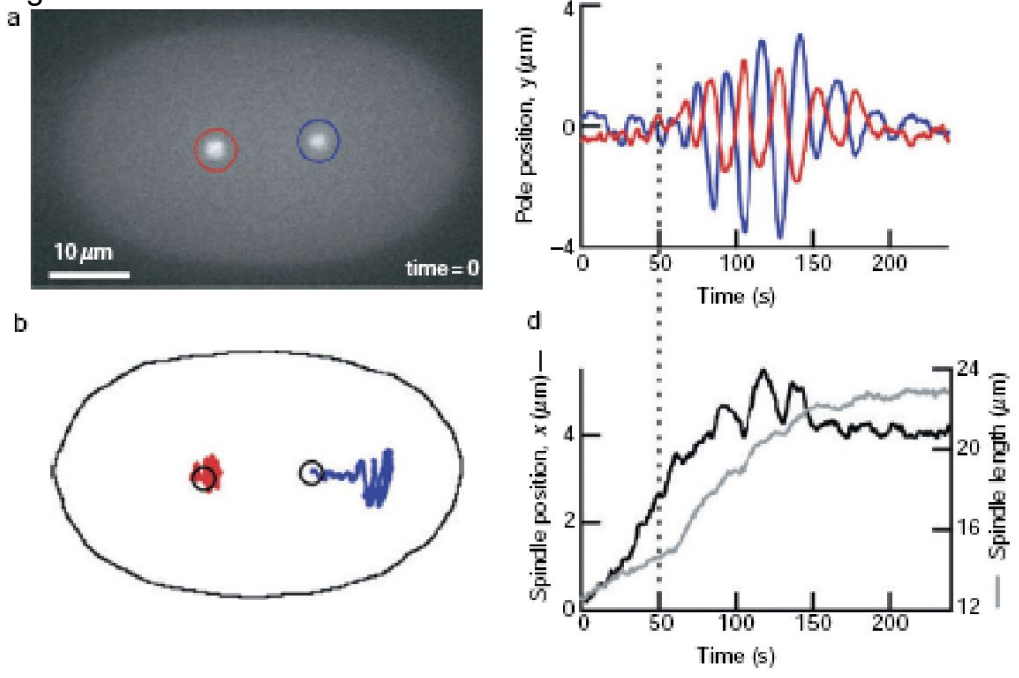




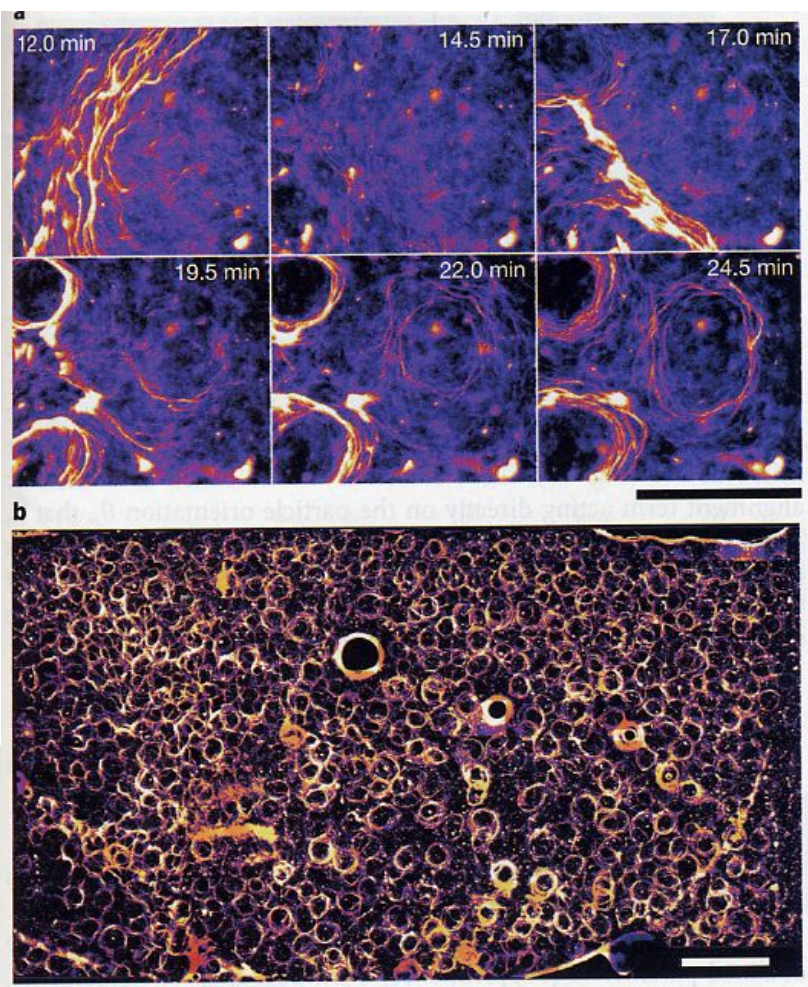


# КОЛЕБАНИЯ, ПОТОКИ И ВИХРИ МИКРОТРУБОЧЕК, СВЯЗАННЫХ С МОТОРАМИ

Колебания митотического веретена при первом делении дробления *C. elegans*

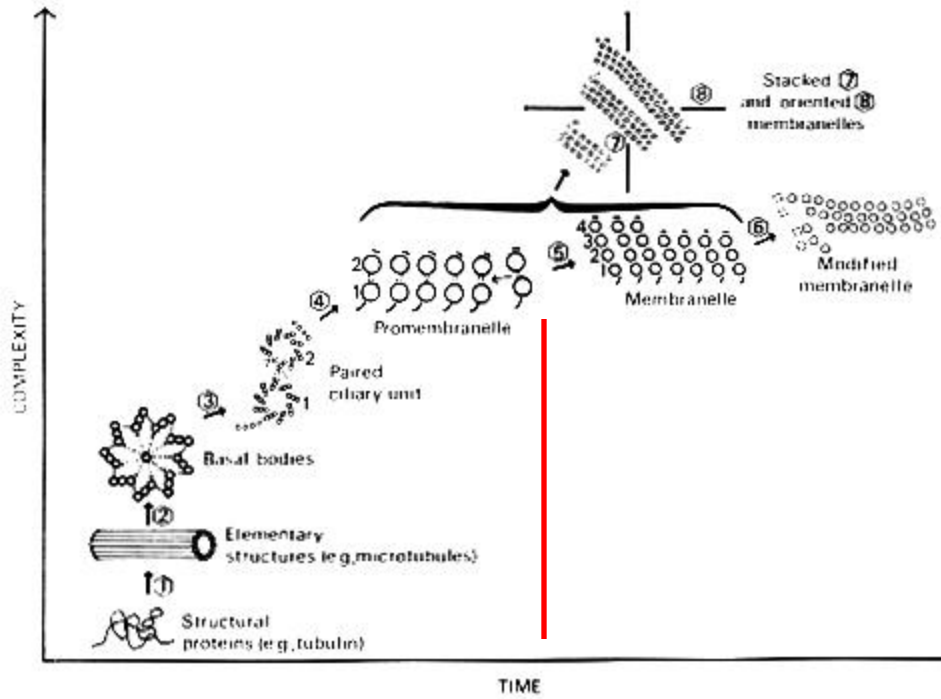


**Figure 1 | Active microtubule networks exhibit internally generated flows.** **a**, Schematic illustration of an extensile microtubule-kinesin bundle, the basic building block used for the assembly of active matter. Kinesin clusters exert inter-filament sliding forces, whereas depleting PEG polymers induce microtubule bundling. **b**, Two microtubule bundles merge and the resultant bundle immediately extends, eventually falling apart. Time interval, 5 s; scale bar, 15  $\mu\text{m}$ . **c**, In a percolating microtubule network, bundles constantly merge (red dashed lines), extend, buckle (green dashed lines), fracture, and self-heal to produce a robust and highly dynamic steady state. Time interval, 11.5 s; scale bar, 15  $\mu\text{m}$ . **d**, An active microtubule network viewed on a large scale. Arrows indicate local bundle velocity direction. Scale bar, 80  $\mu\text{m}$ .

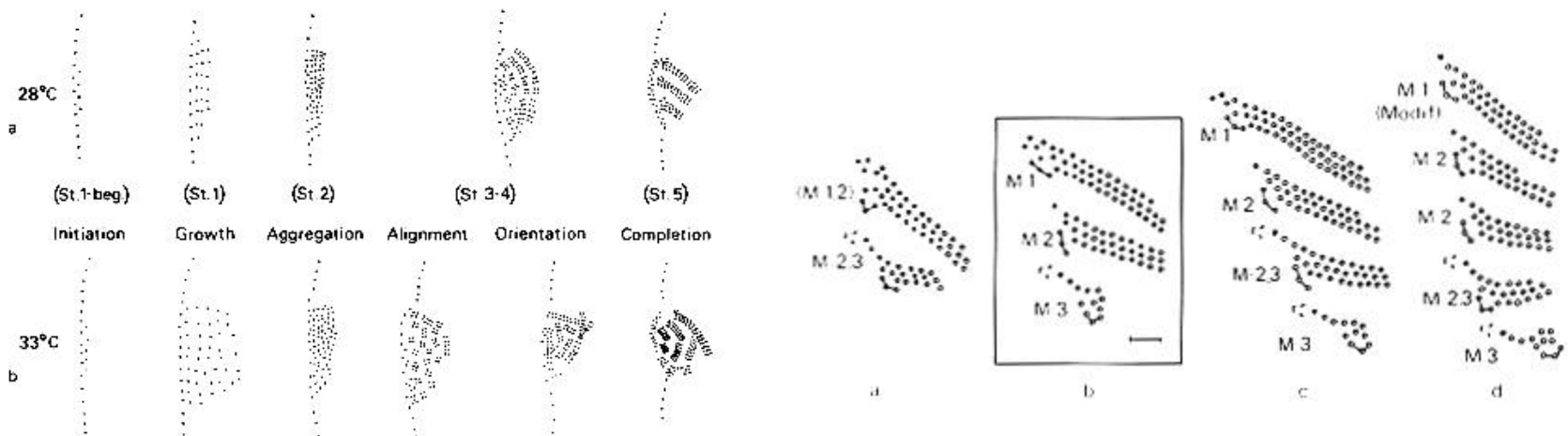


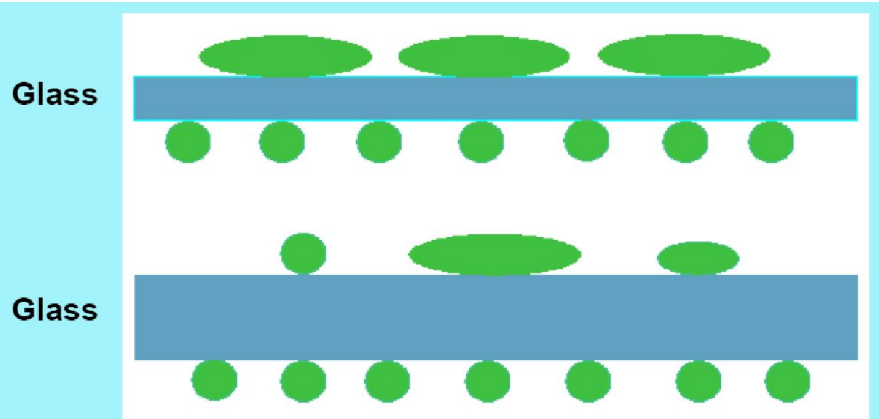
**Figure 1 | Emergence of vortices of microtubules.** False-color images. **a**, Formation process of vortex pattern: 0 min corresponds to the time of injection of ATP. Streams appeared around 5 min after this injection. At 12 min, streams started to meander. Vortices started to appear around 17 min, when meandering streams contacted one another. Once vortices had formed, they grew steadily (22 min). Scale bar, 500  $\mu\text{m}$ . **b**, Large-scale lattice of vortices. Vortices can be observed everywhere on the surface of the flow cell. Three air bubbles in the flow cell can be seen distinctively owing to their greater size and thicker edges. Scale bar, 2 mm.

# БАРЬЕР ФРАНКЕЛЯ: ПЕРЕХОД ОТ МОЛЕКУЛЯРНОЙ САМОСБОРКИ К МАКРОСКОПИЧЕСКОЙ РЕГУЛЯЦИИ

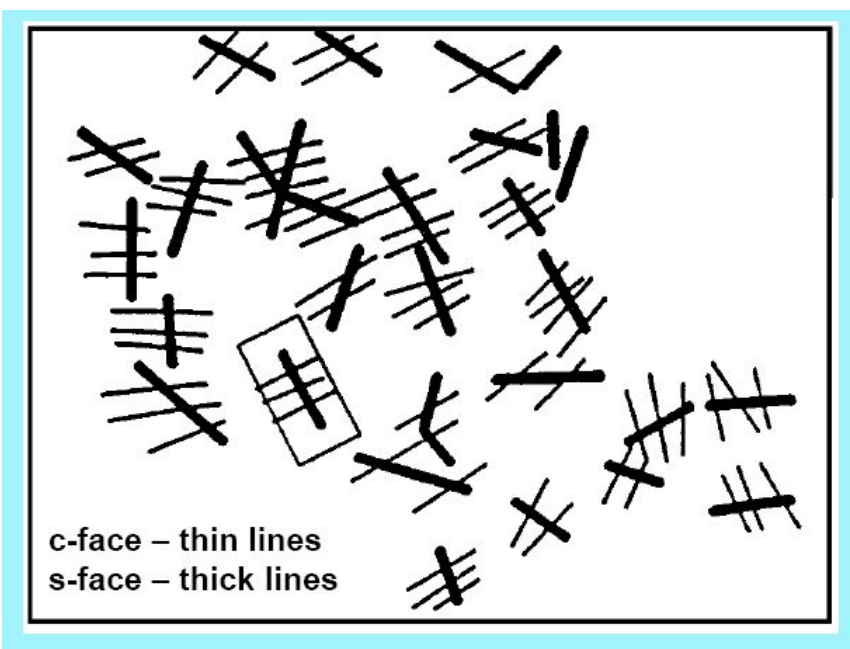


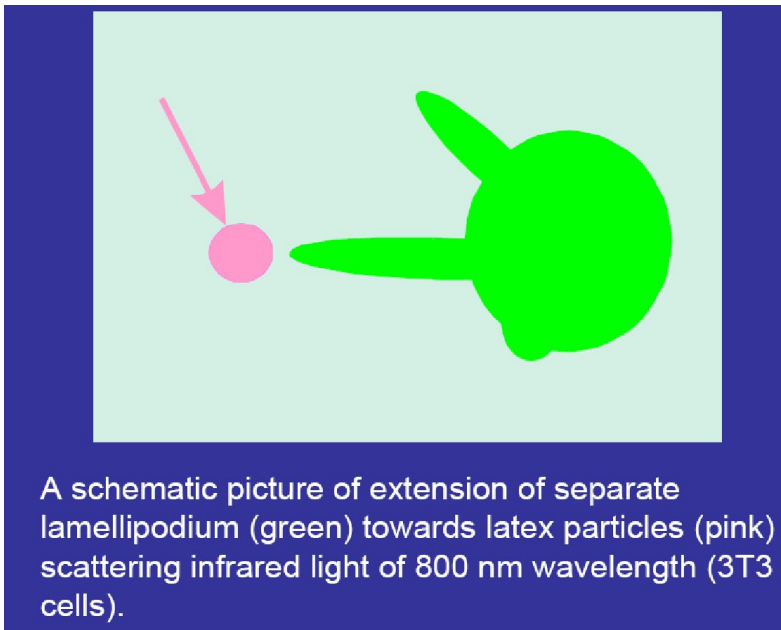
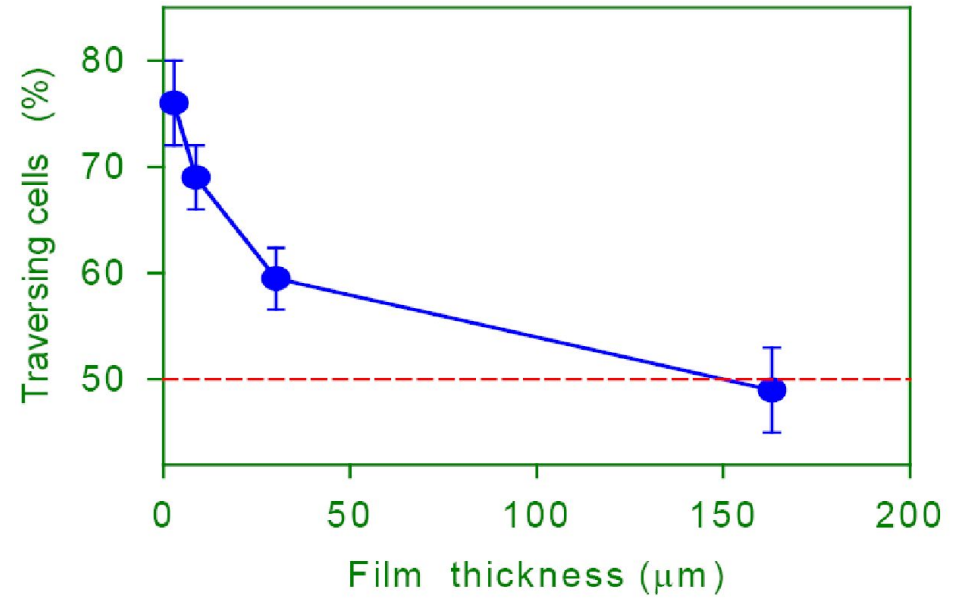
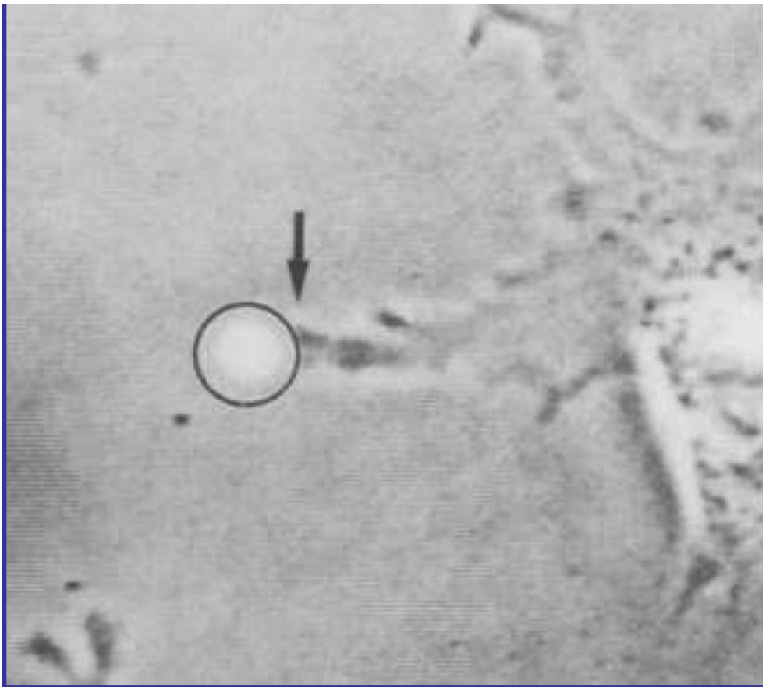
## РАЗДЕЛИМОСТЬ САМОСБОРКИ И РЕГУЛЯЦИИ ПОЛОЖЕНИЯ



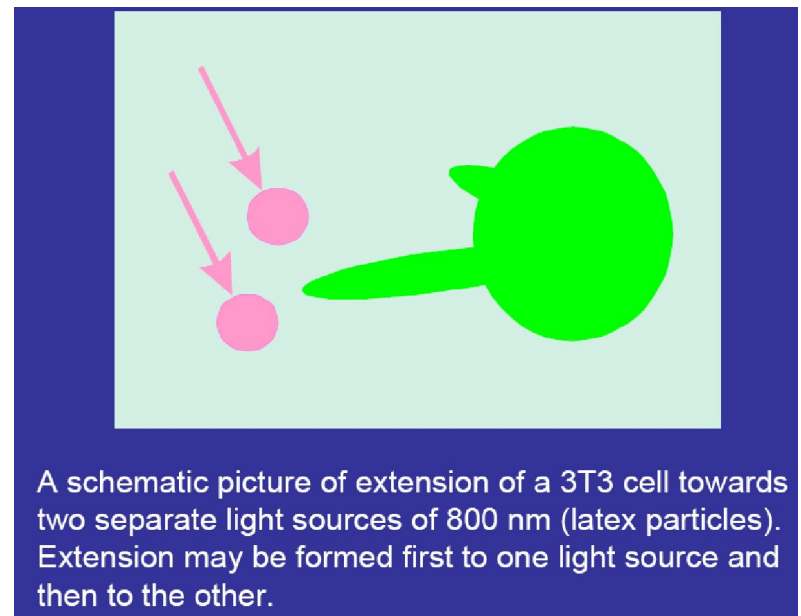


Electric oscillation field generated by living cells.  
Communication between BHK cells in the red or near  
infrared range (*Albrecht-Buehler G.*).





A schematic picture of extension of separate lamellipodium (green) towards latex particles (pink) scattering infrared light of 800 nm wavelength (3T3 cells).



A schematic picture of extension of a 3T3 cell towards two separate light sources of 800 nm (latex particles). Extension may be formed first to one light source and then to the other.