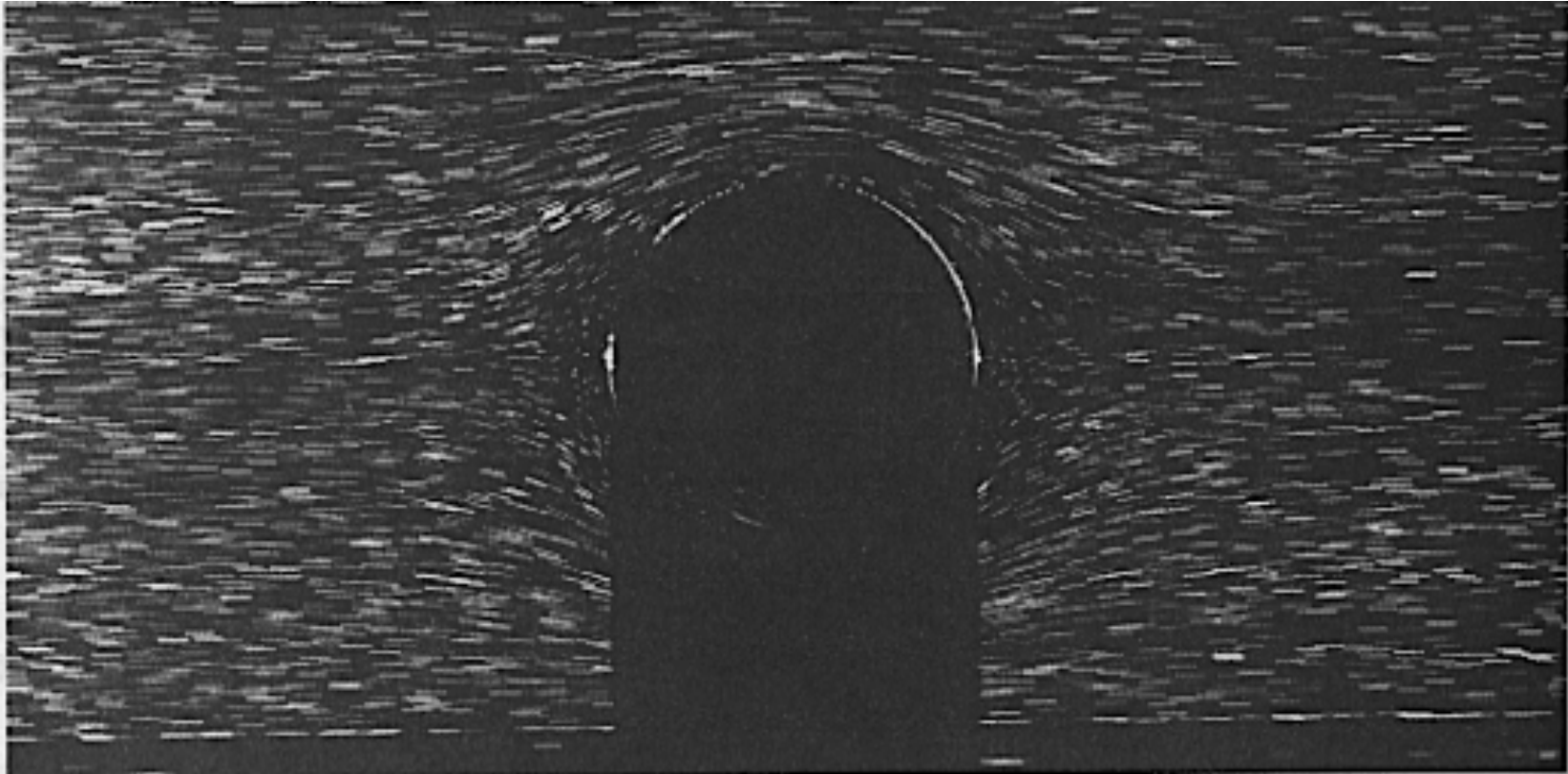
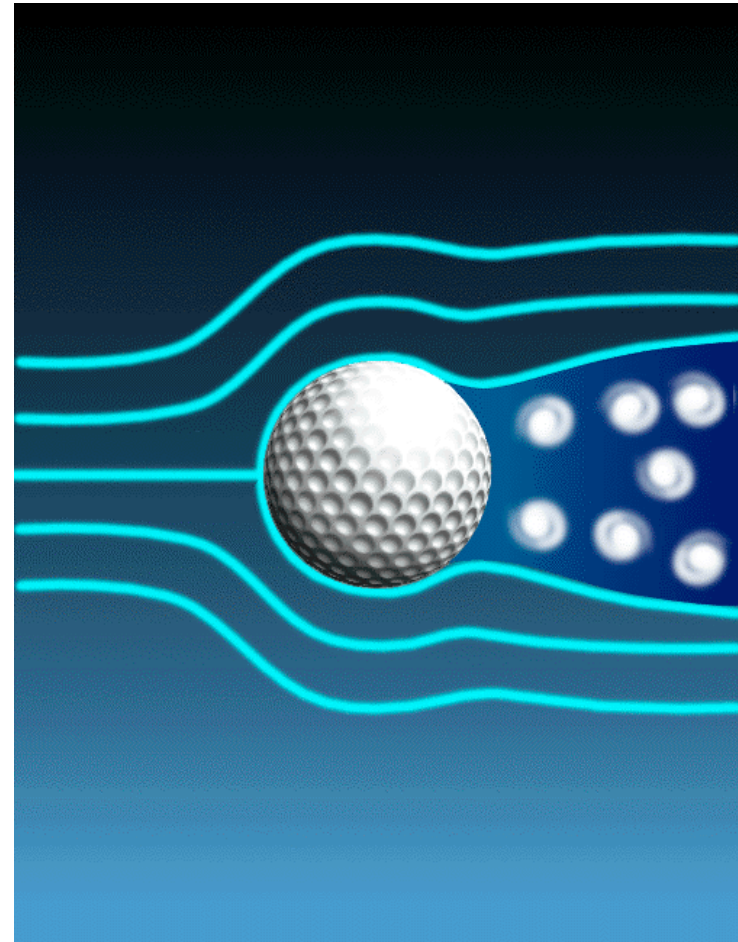
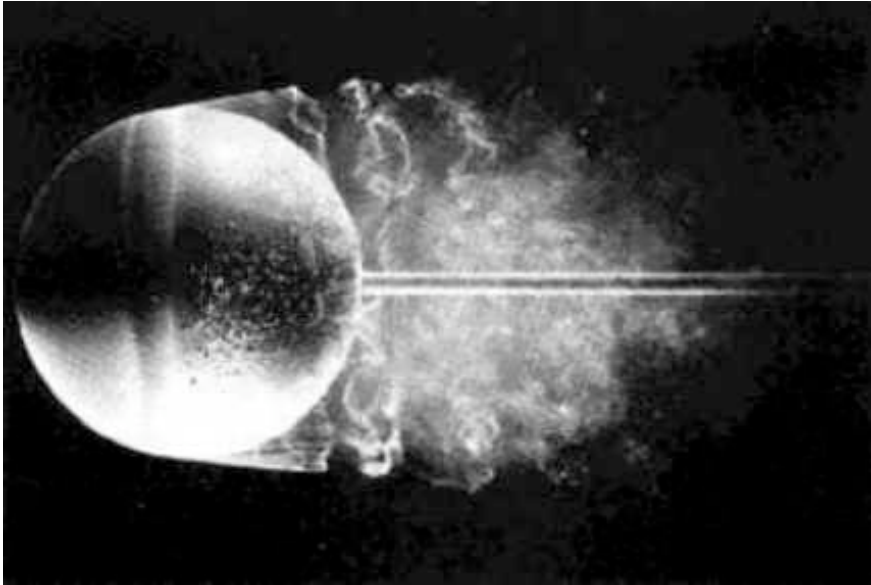


Laminar Flow

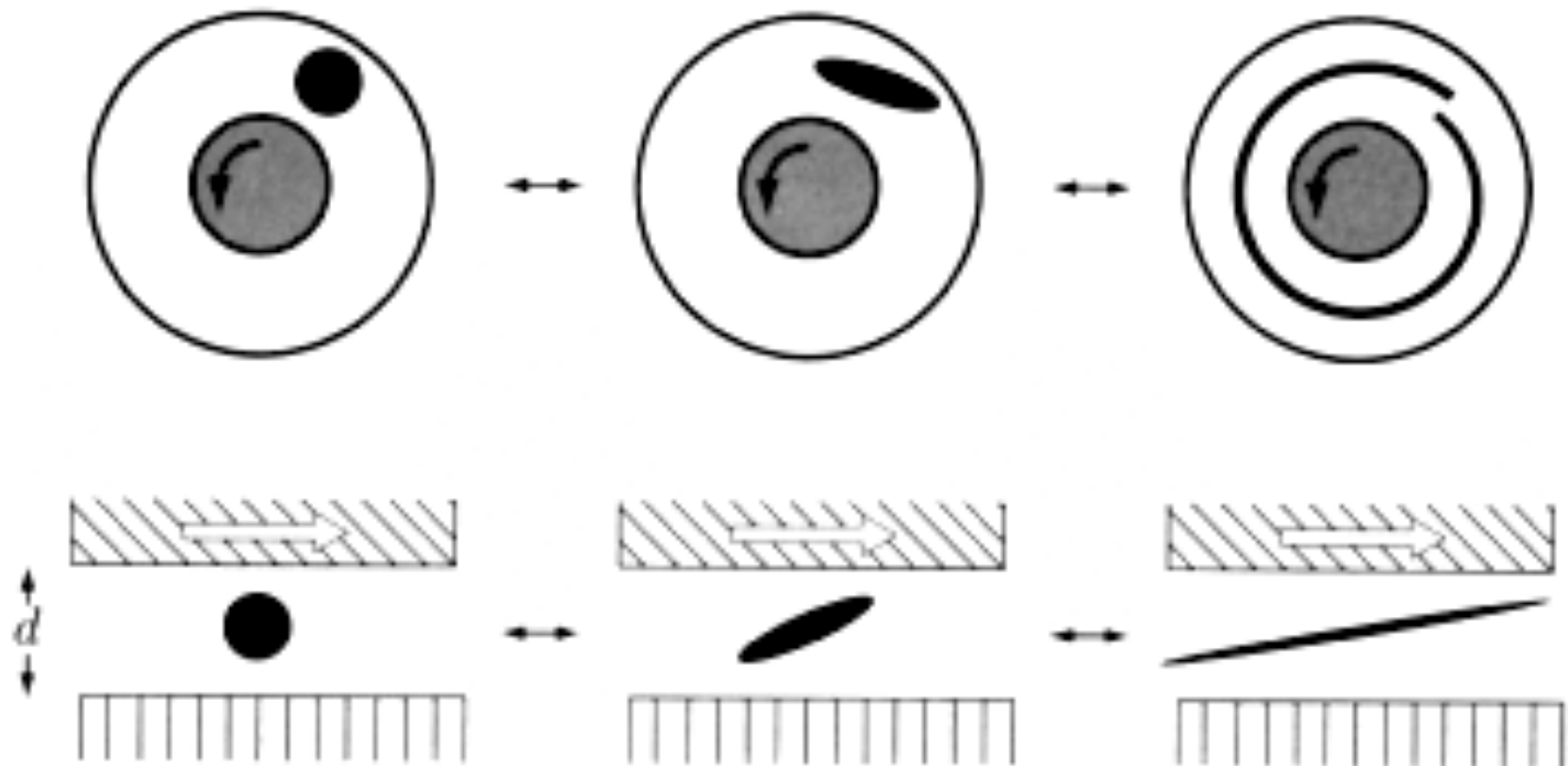


- Which direction is the flow?
- Particles don't collide with the sphere (can't catch the food ...).

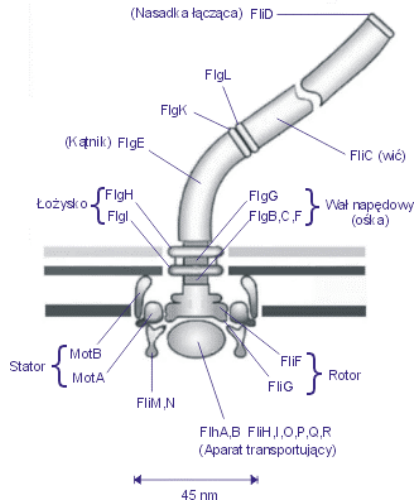
Turbulent Flow



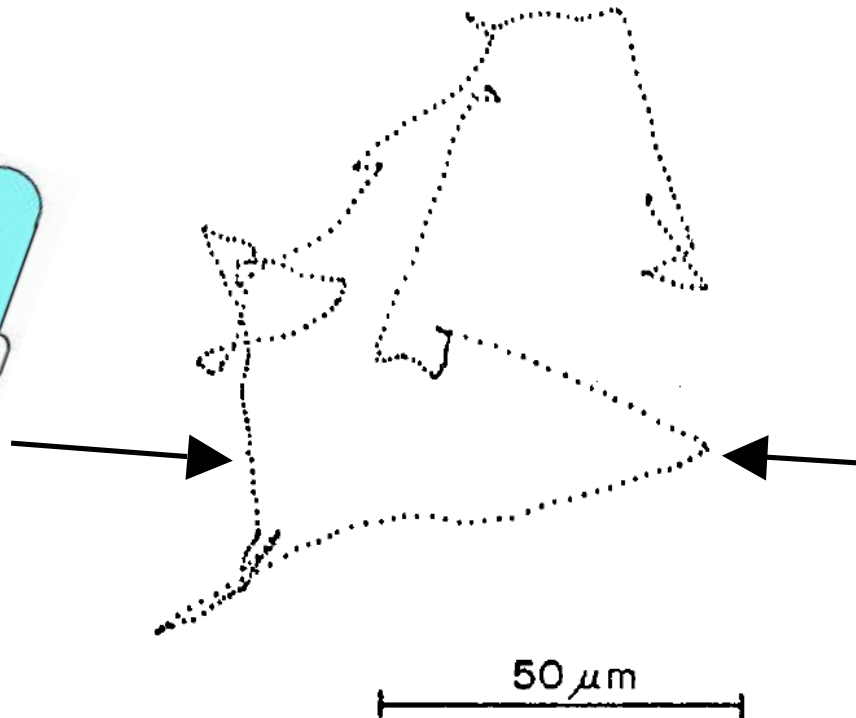
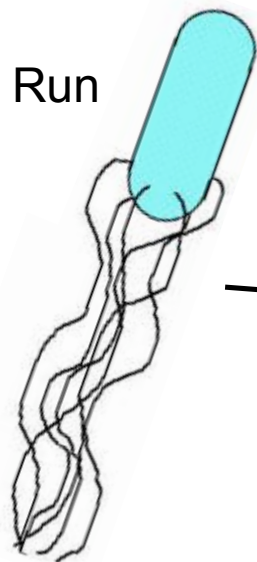
Time-reversible Laminar Flow



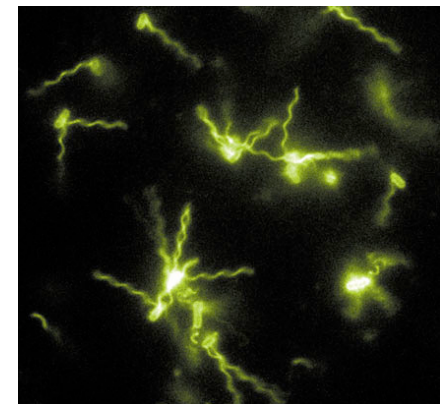
E. coli Chemotaxis



- Run – counterclockwise
- Tumble - clockwise



Tumble

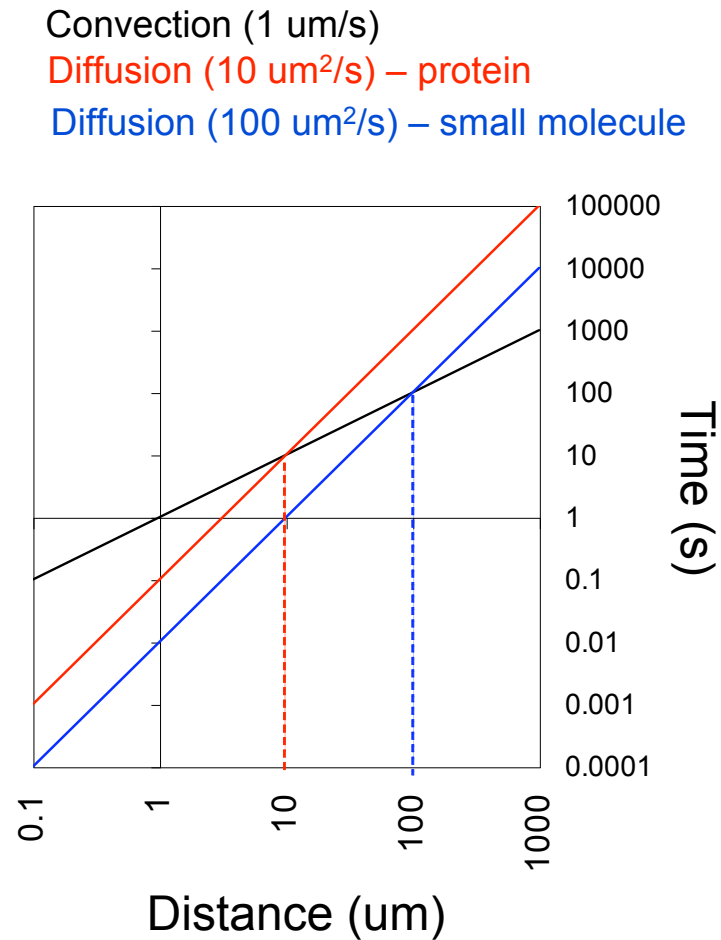


	MW, g/mol	D($\mu\text{m}^2/\text{s}$)	Diffusion time (s)	Pe
Oxygen	32	2000	2100	0.05
Glucose	180	200	523	0.50
Insulin	6,000	100	119	1.0
Antibody	150,000	60	69	1.67
	Diameter (μm)			
Virus	0.1	5	2,000	20
Bacterium	1	0.5	20,000	200
Cell	10	0.05	200,000	2000

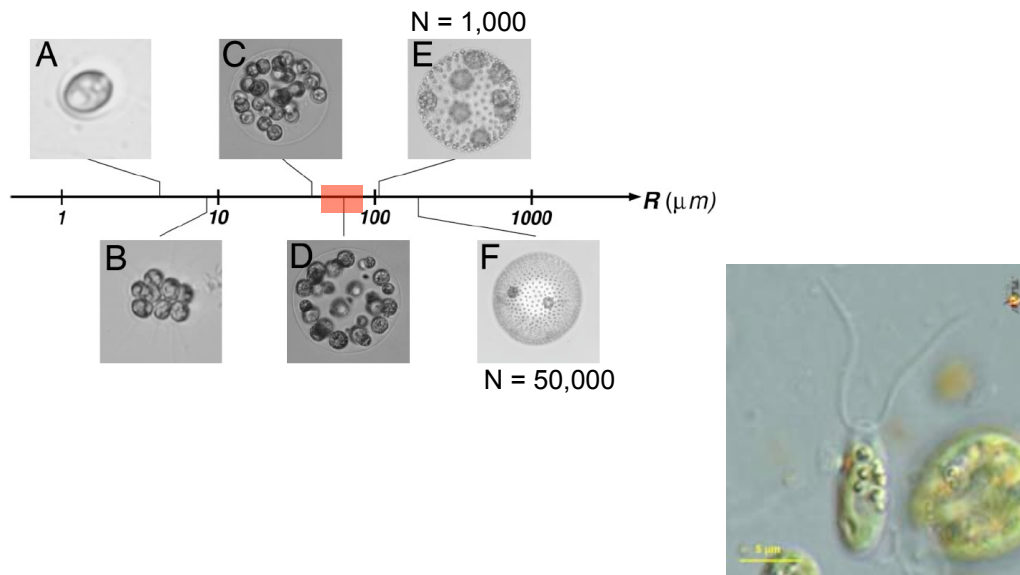
- For $L = 100 \mu\text{m}$ ($v = 1 \mu\text{m/s}$ - convection time is 100 s)

Diffusion versus Convection

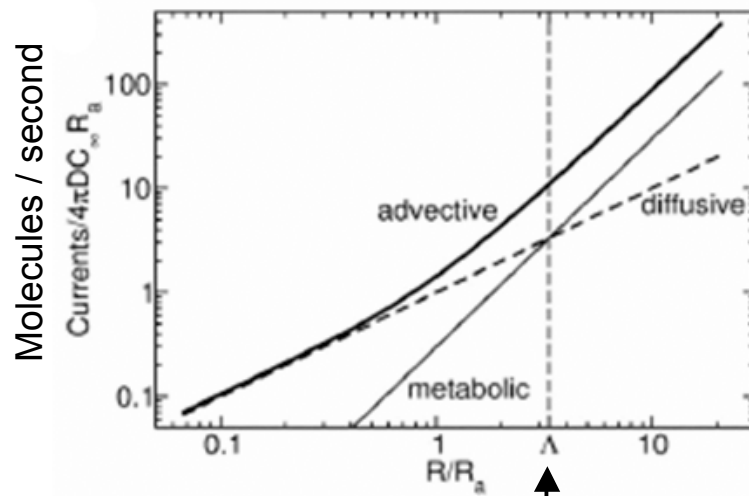
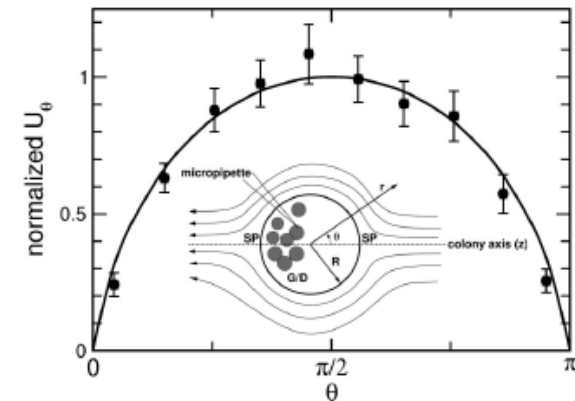
	Length scale (um)
Protein	0.01
Organelles	0.1
Bacterium	1
Eukaryote	10
Capillary spacing	100
Organs	100000
Body	1000000



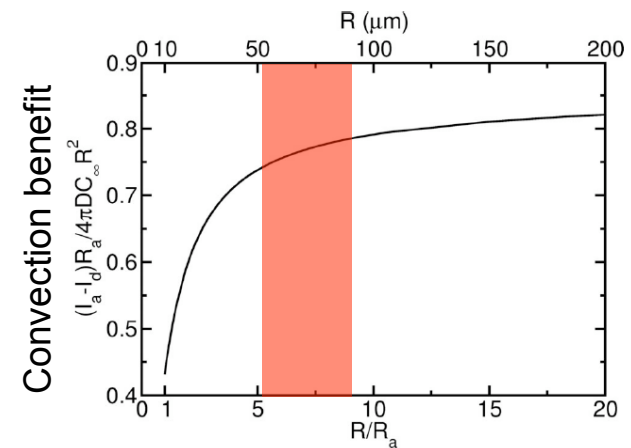
Multicellularity: Diffusion versus Convection



- *Volvox carteri*



For O_2 , $R = 50\text{-}200 \mu\text{m}$



(Short et al., PNAS, 103: 8315, 2007)