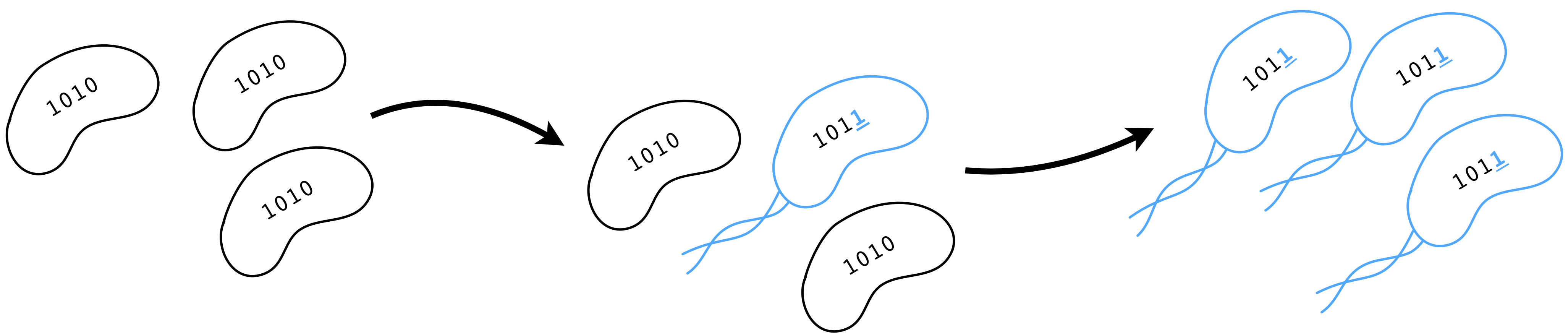
APPHYS 205 // BIO 126/226:

Introduction to Biophysics



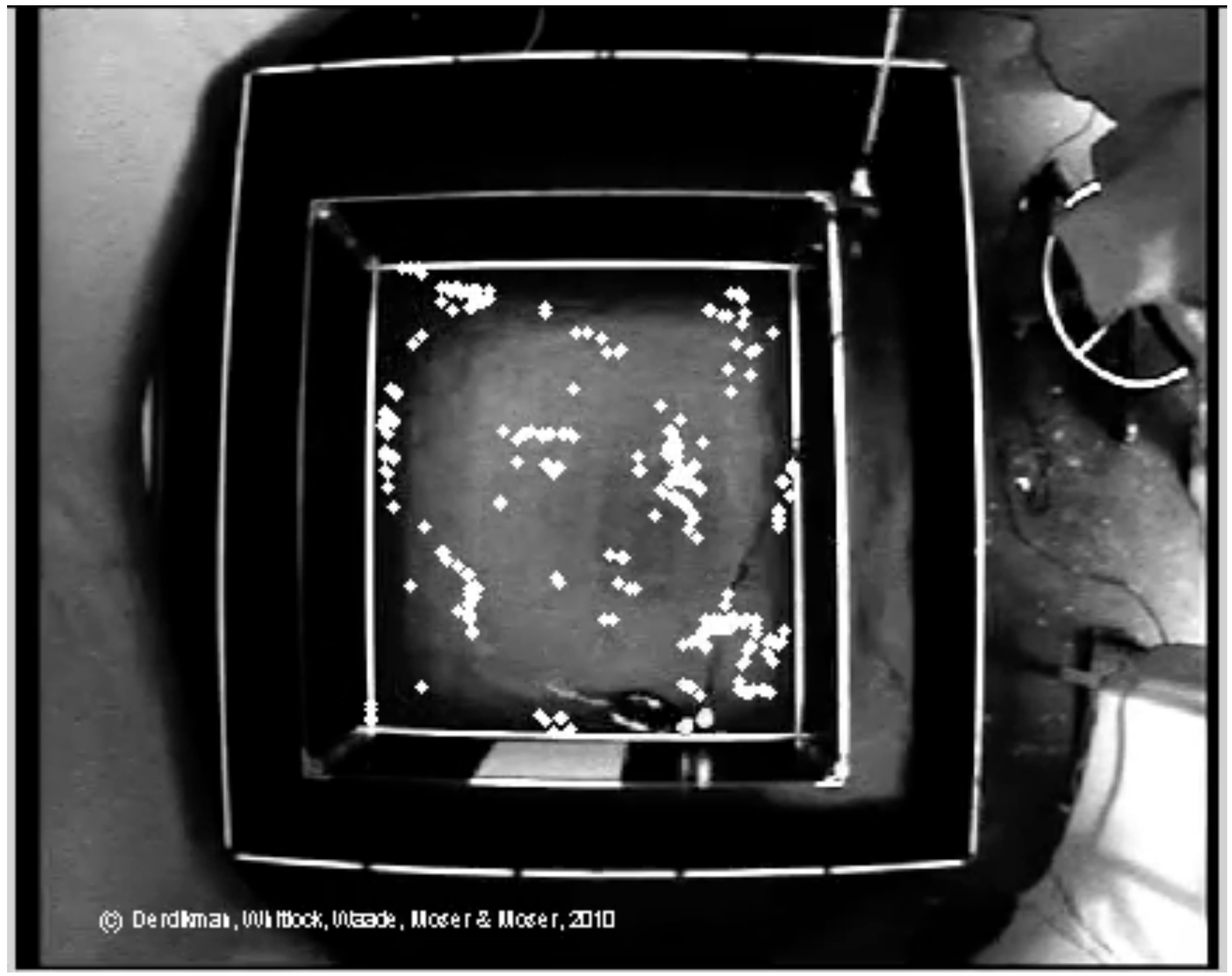
Winter 2025

Biology generates exquisitely complex behavior from simple chemical building blocks

e.g. a human white blood cell "chasing" an S. aureus bacterium (credit: David Rogers)

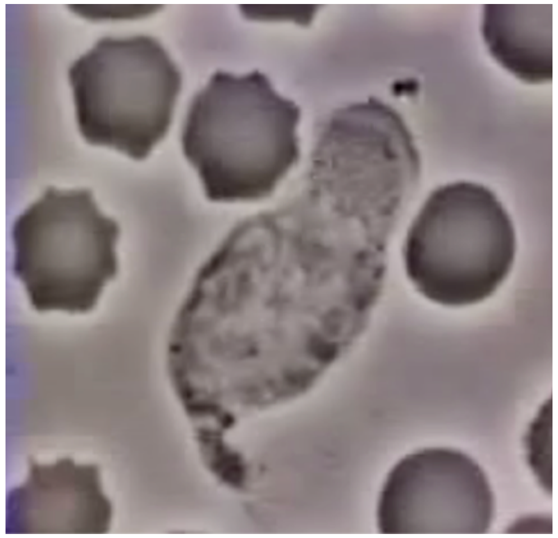
⟶ **will discuss more in Lectures B7 & B8 (Chemotaxis)**

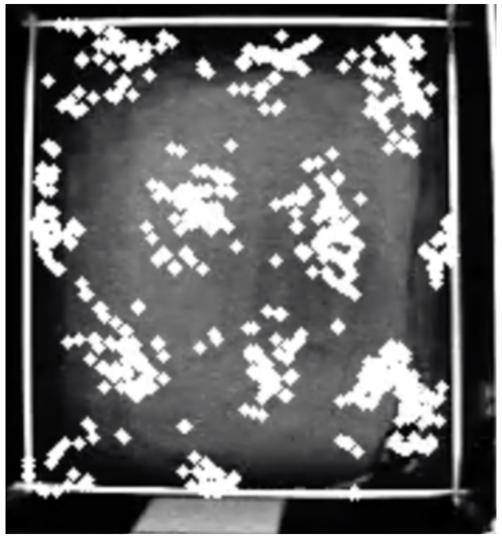
Biology generates exquisitely complex behavior from simple chemical building blocks



e.g. firing pattern of a single "grid neuron" in a rat moving within a box (credit: Derdikman, Whitlock, Waade, Moser & Moser)

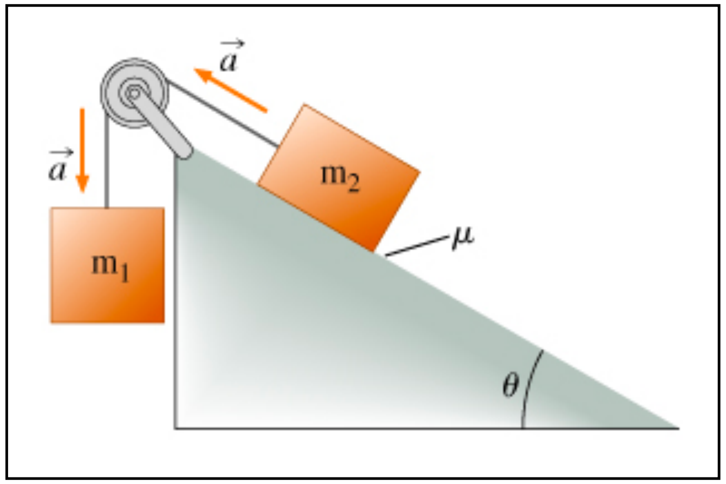
Biology generates exquisitely complex behavior from simple chemical building blocks



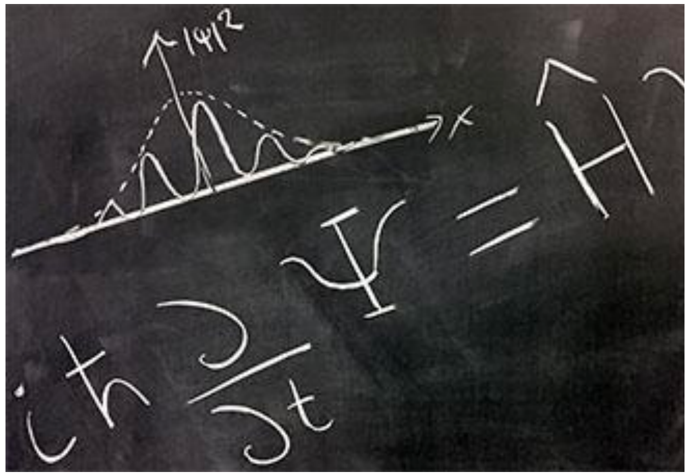


…but physics imposes strong constraints!

Can be different from our "usual" physical intuition:

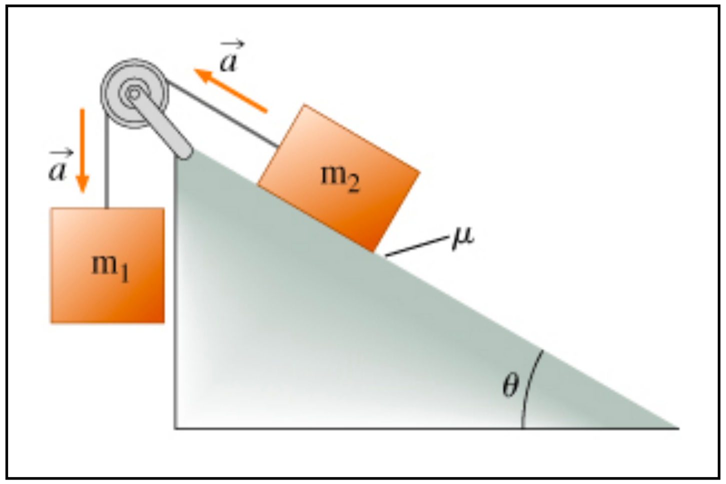


Physics of everyday objects

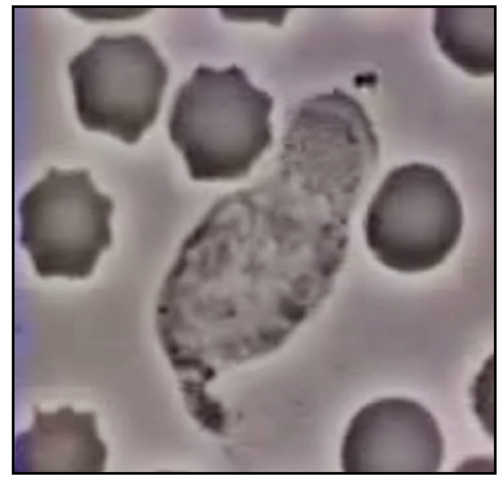


Quantum mechanics

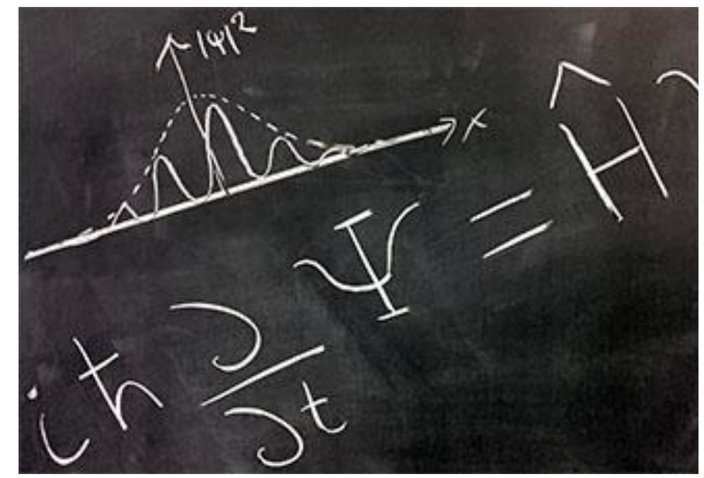
Biology generates exquisitely complex behavior …but physics imposes strong constraints



Physics of everyday objects



Biophysics

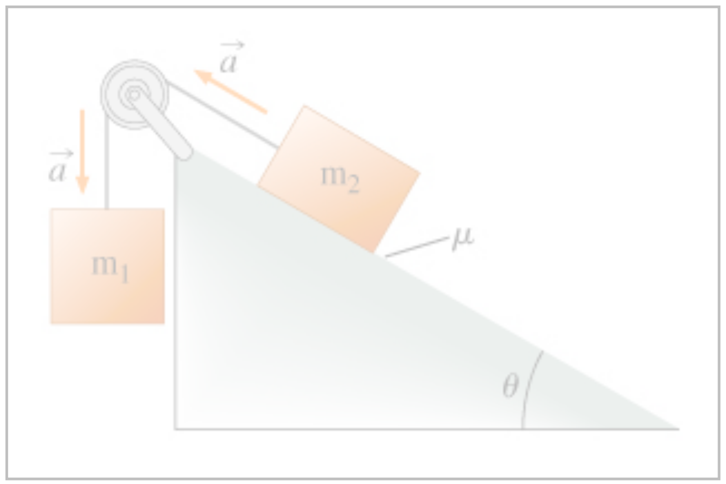


Quantum mechanics

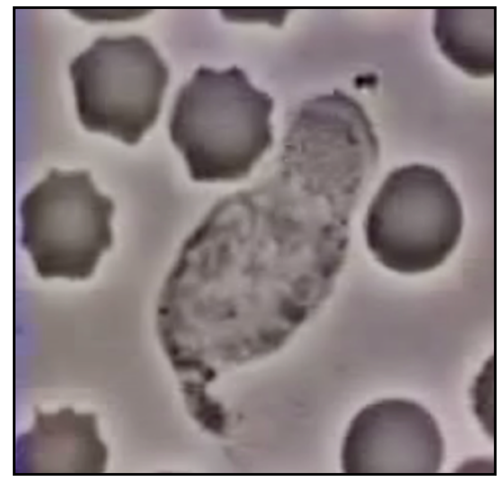
↓

interesting new physics emerges at these cellular scales

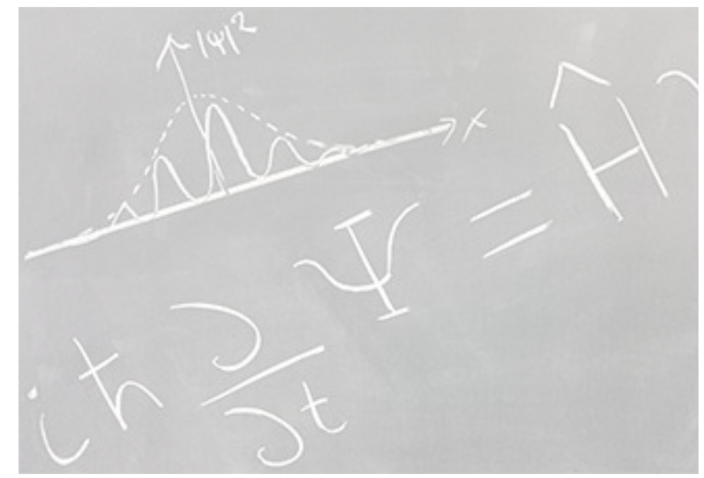
Biology generates exquisitely complex behavior …but physics imposes strong constraints



Physics of everyday objects



Biophysics

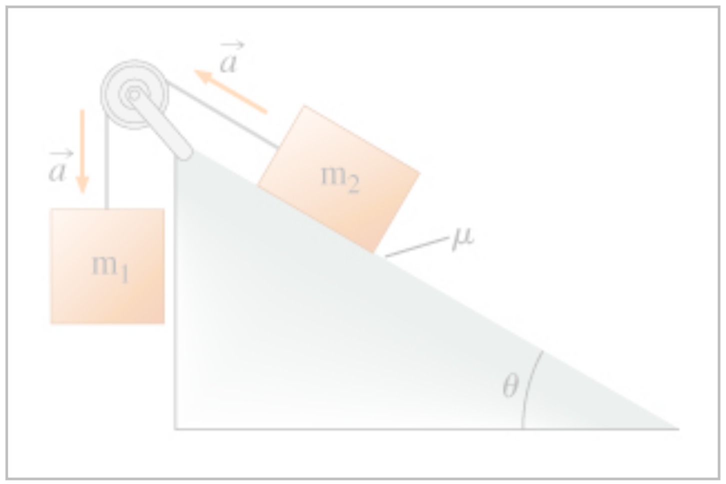


Quantum mechanics

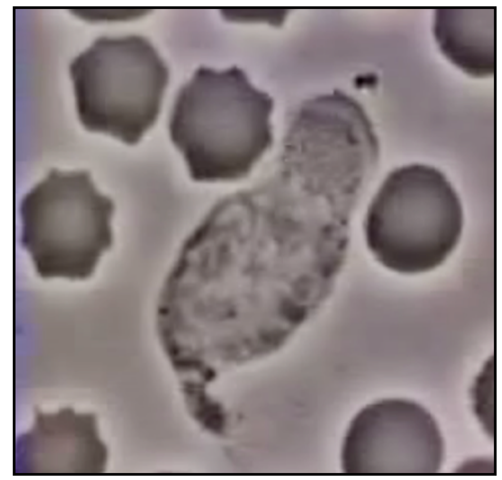
Major themes:

- *Thermal fluctuations (*statistical mechanics*)*
- *Constant jostling of particles in solution (*diffusion*)*
- *Finite # molecules per cell (*counting noise*)*

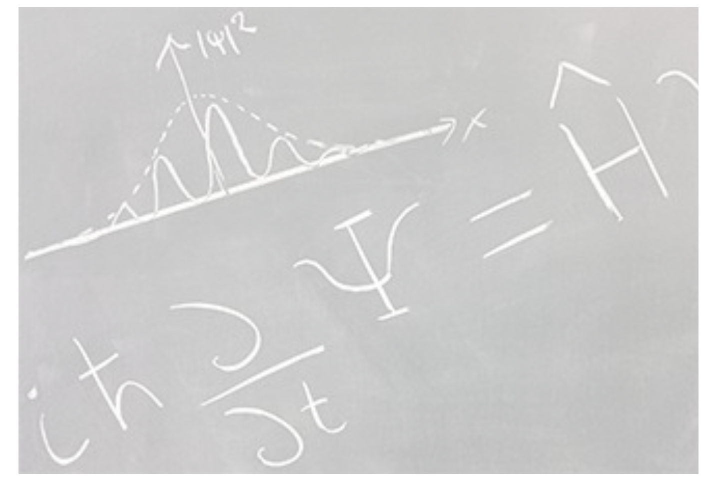
Biology generates exquisitely complex behavior …but physics imposes strong constraints



Physics of everyday objects



Biophysics

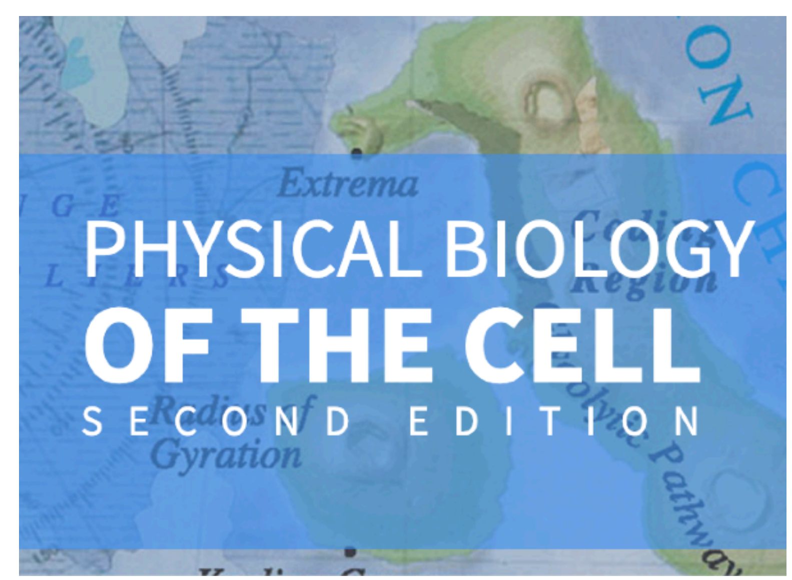


Quantum mechanics

Major themes:

- *Quantitative reasoning & order-of-magnitude estimation*

"biology by the numbers"



Phillips, Kondev, Theriot, & Garcia

Today:

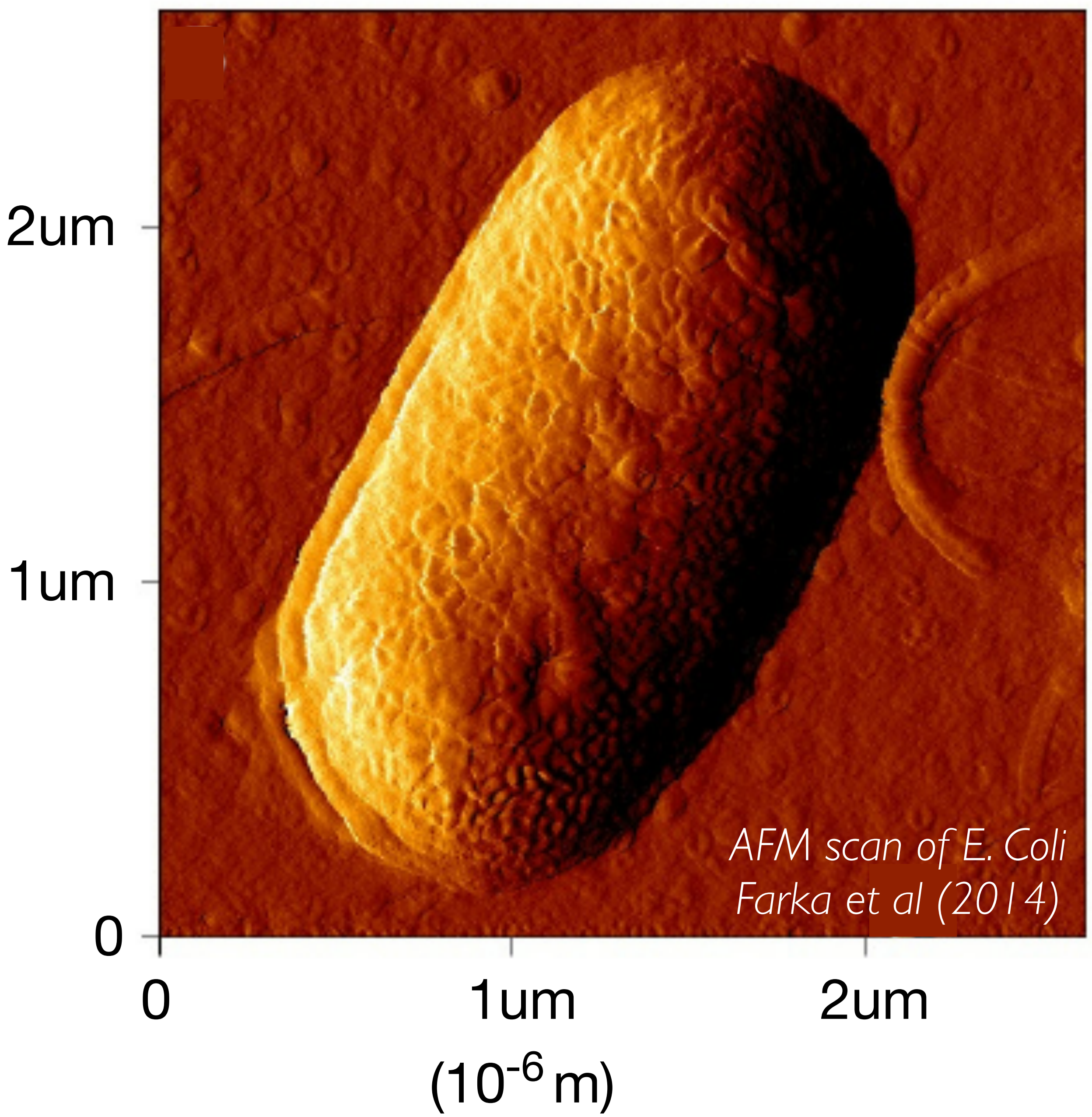
tour of basic length, time,
& abundance scales in biology

Why?

- #s impose strong constraints on what physical processes are relevant
- "trying to explain ***why*** #s have the magnitudes they do often ends up being an engine of discovery."

— *Cell Biology by the Numbers* (Milo & Phillips) http://book.bionumbers.org/

E. Coli will be our standard ruler



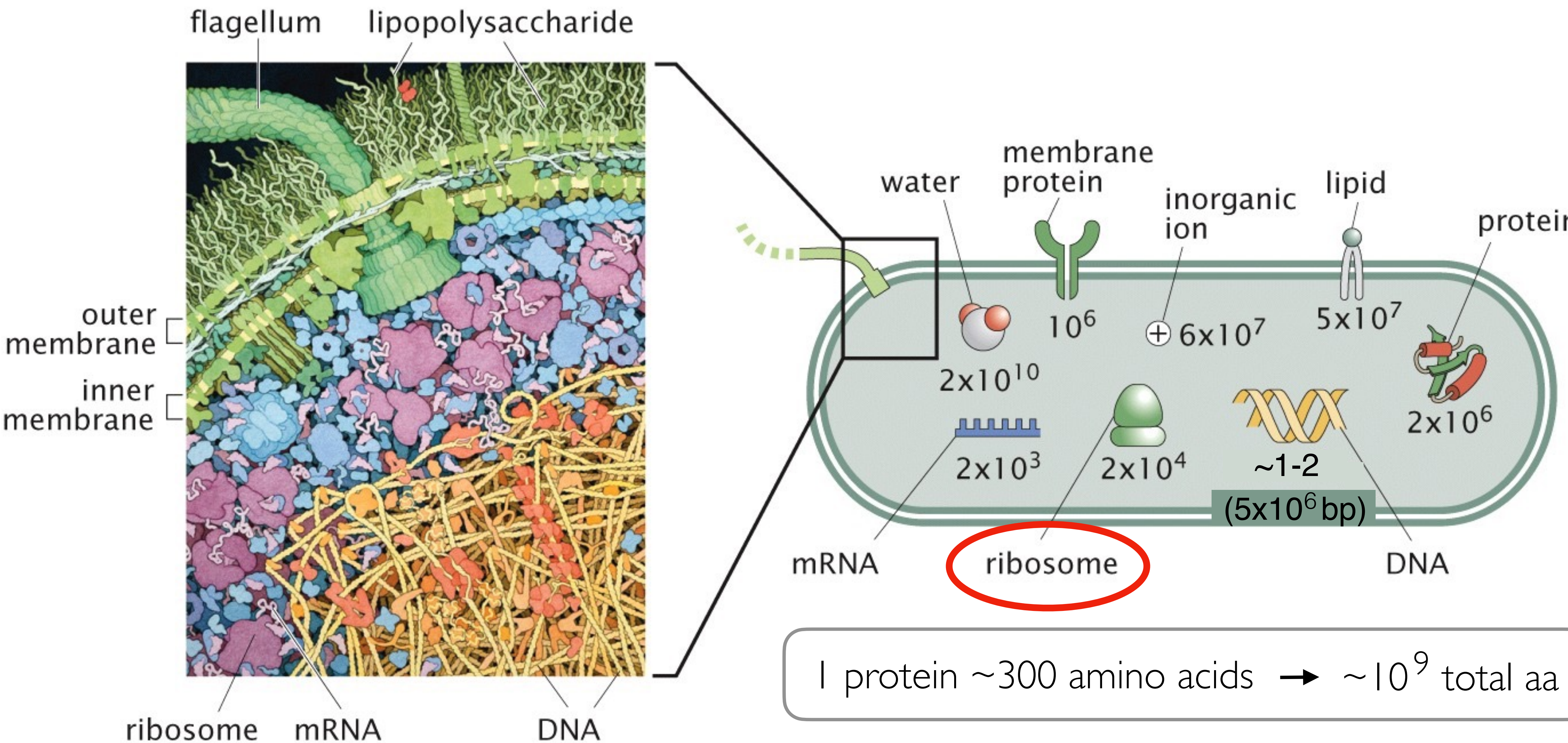
AFM scan of E. Coli
Farka et al (2014)

→ Volume: $\sim(1\text{um})^3 = 10^{-15}$ L

Mass ~ (10^{-15} L) (1g/ml) = 10^{-12} g

(assuming density ~ water)

Taking the molecular census of an *E. Coli* cell



1 protein ~300 amino acids → ~10^9 total aa

DNA $\xrightarrow[\text{(RNA polymerase)}]{\text{transcription}}$ ***mRNA*** $\xrightarrow[\text{(ribosome)}]{\text{translation}}$ ***Protein (amino acids)*** → ***Growth***

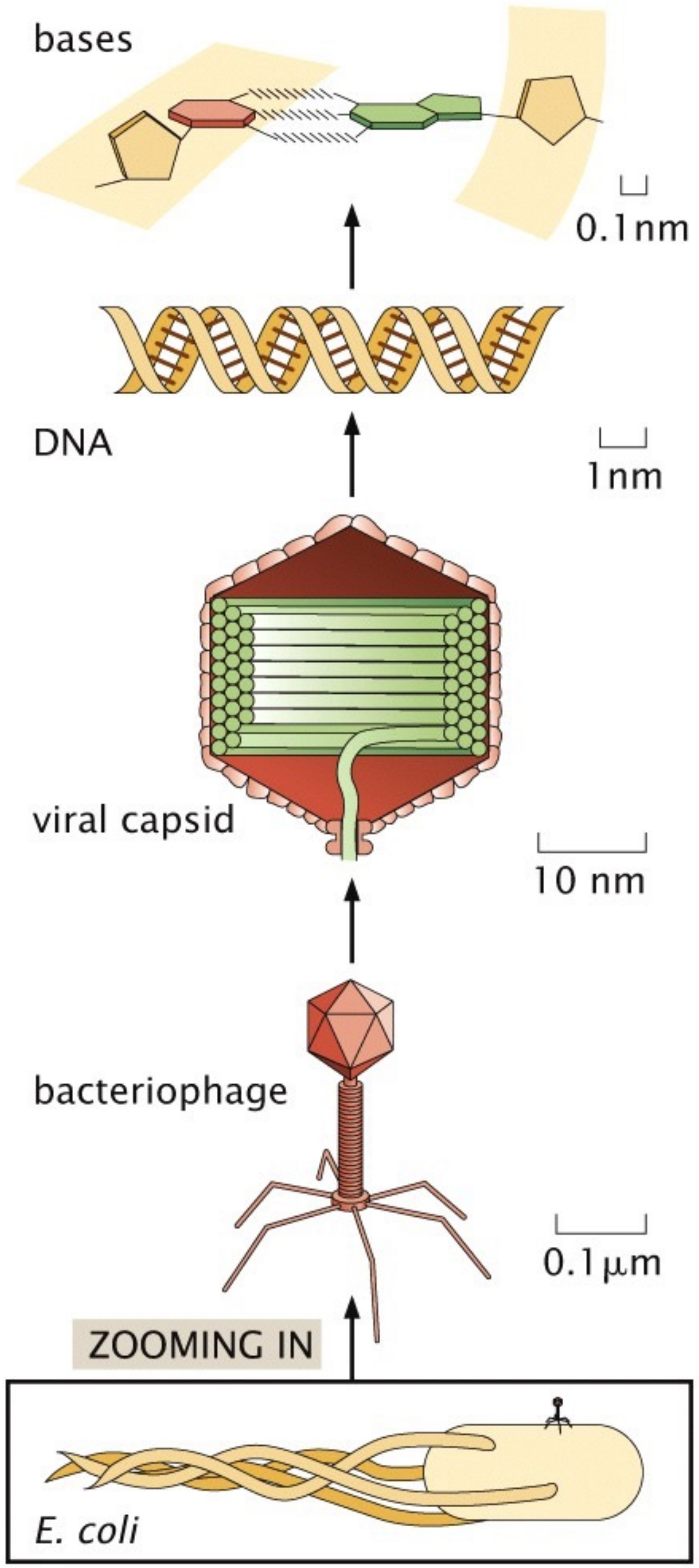


Figure 2.15 (part 1 of 2) Physical Biology of the Cell, 2ed. (© Garland Science 2013)

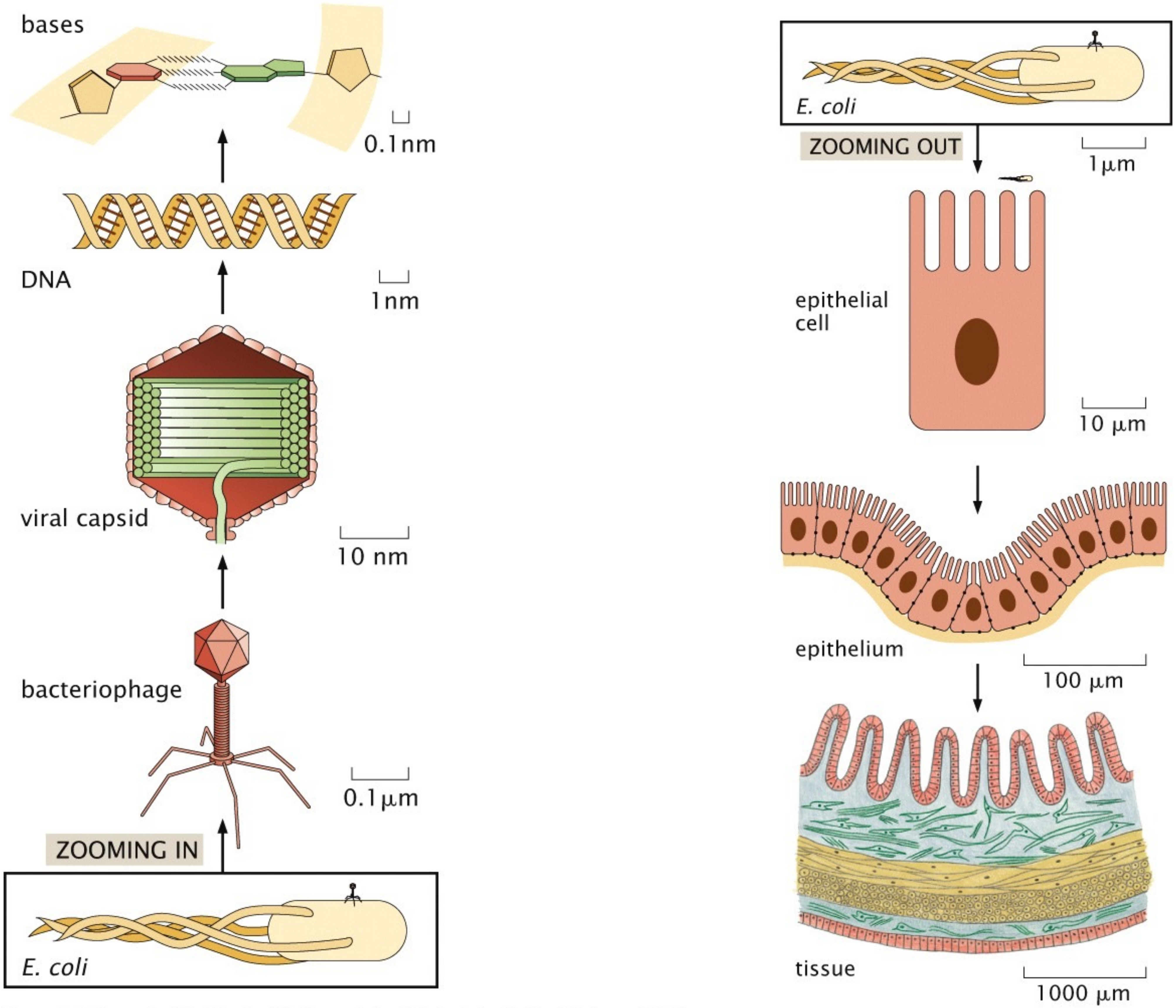
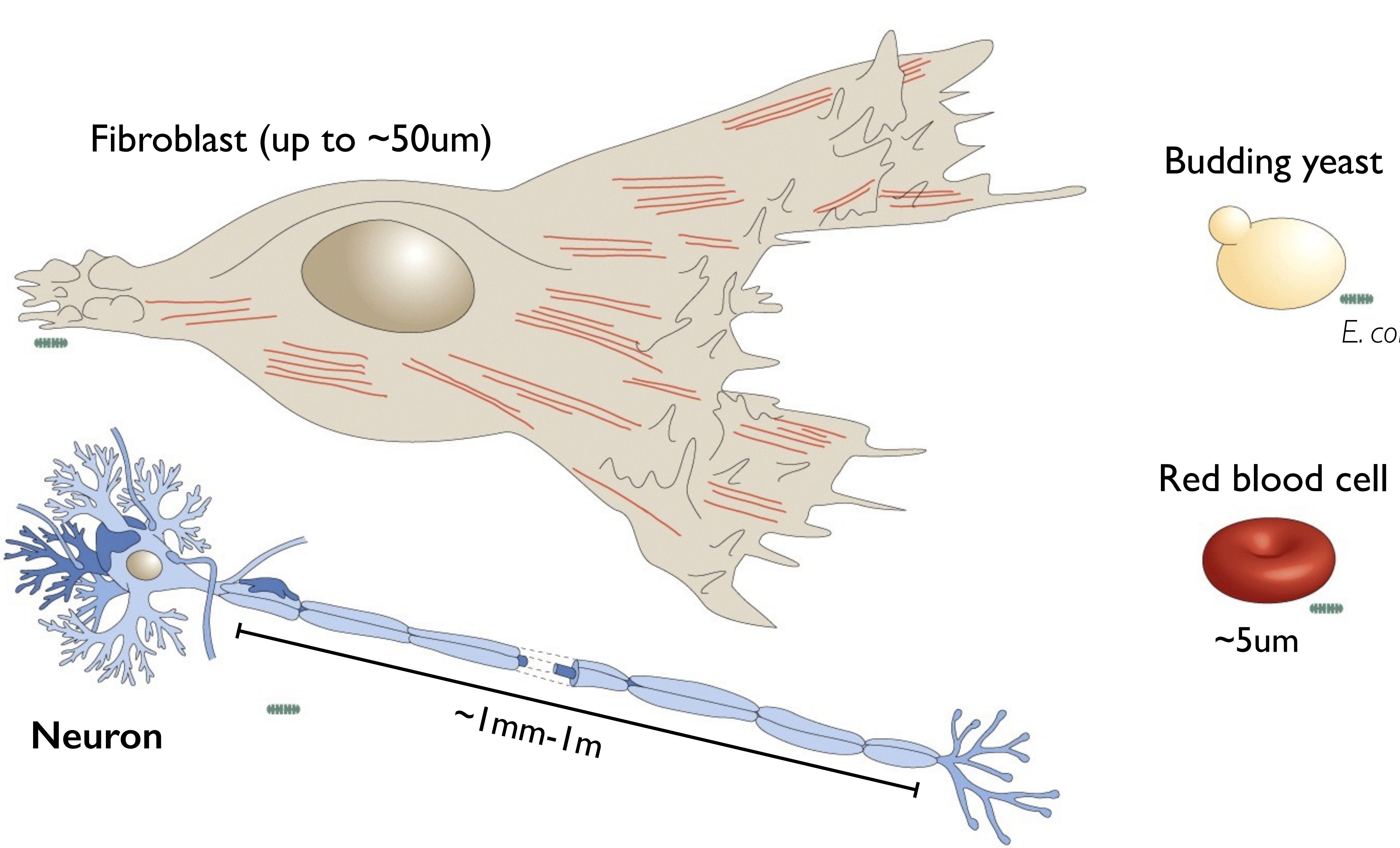


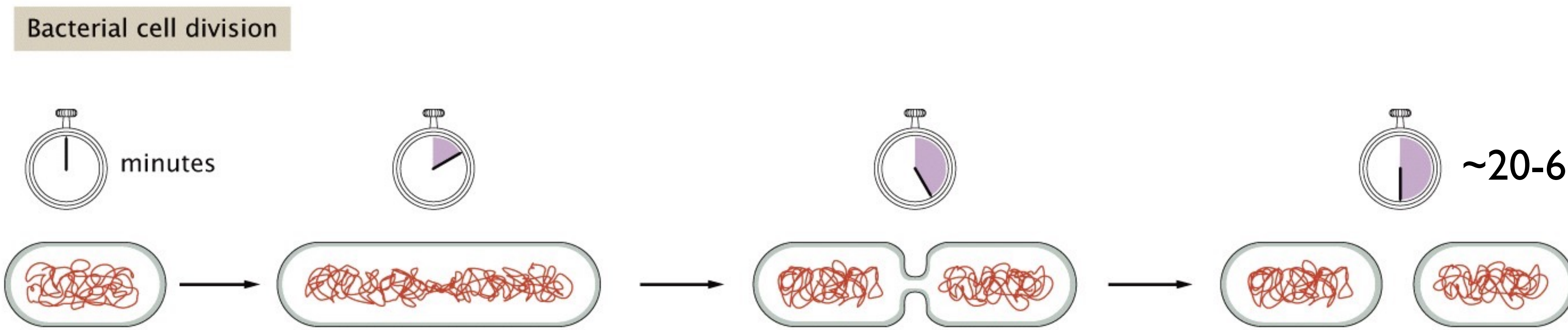
Figure 2.15 (part 1 of 2) Physical Biology of the Cell, 2ed. (© Garland Science 2013)

Human cells have a huge diversity of structure and function



→ Implications for intra-cellular communication (Lectures B5 & B7)

Biological processes occur over a huge range of timescales



~20-60min

Figure 3.2c Physical Biology of the Cell, 2ed. (© Garland Science 2013)

Biological processes occur over a huge range of timescales

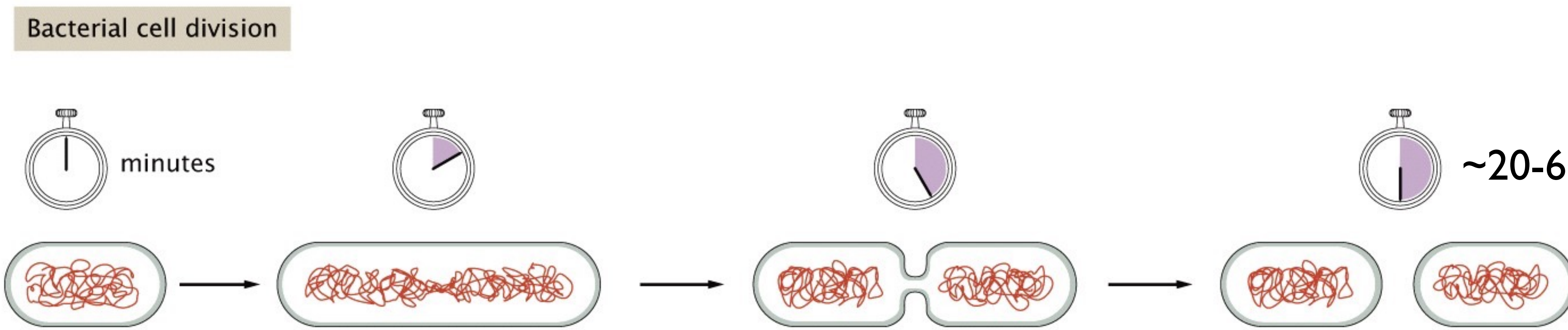


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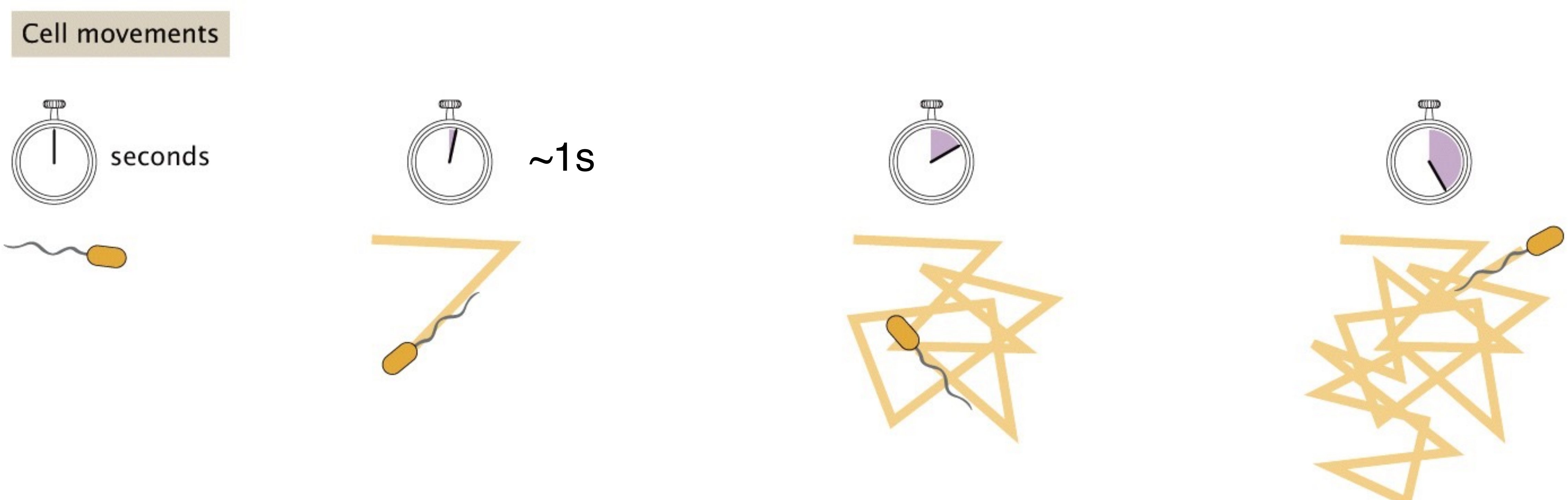
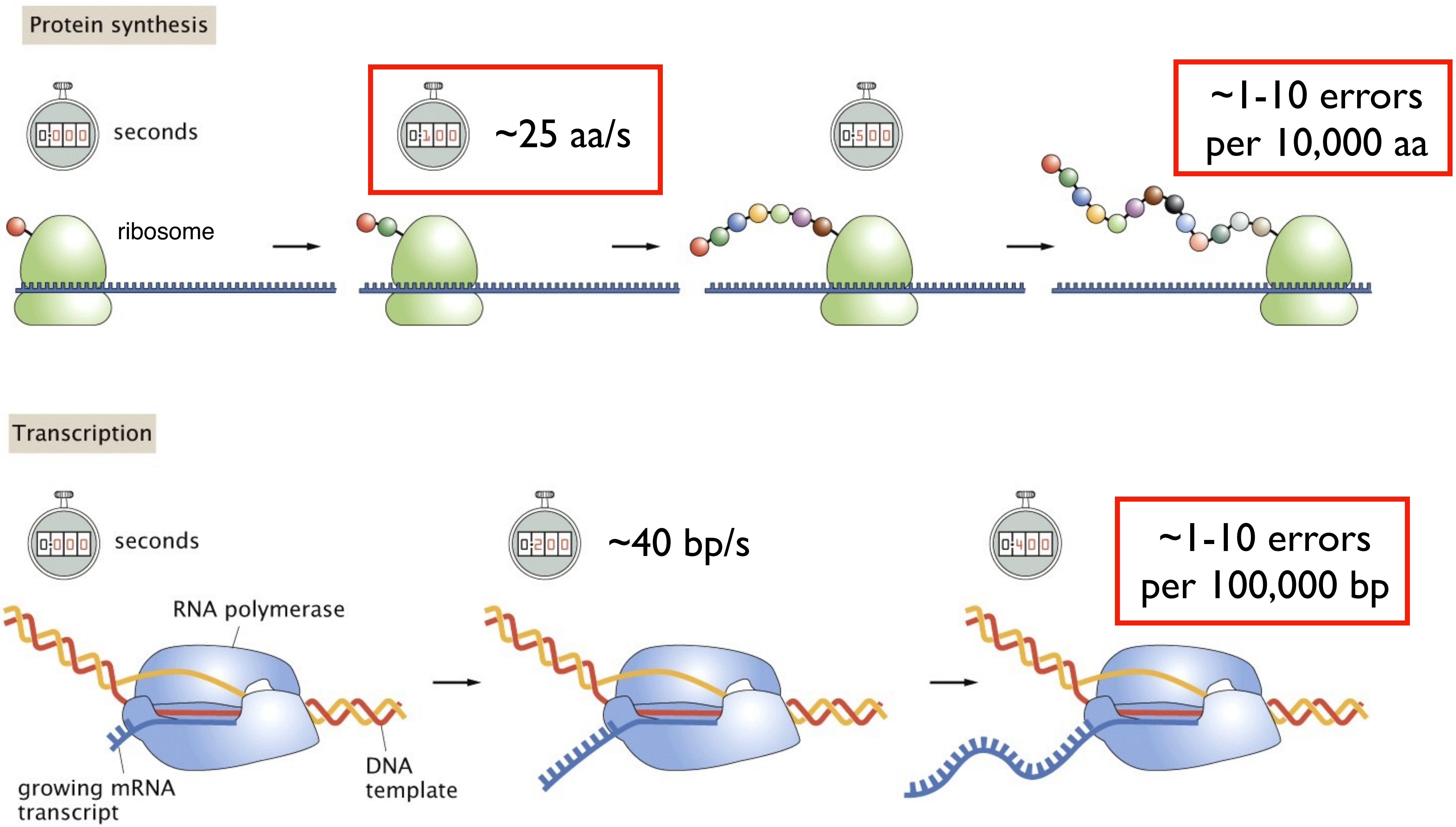
Figure 3.2c Physical Biology of the Cell, 2ed. (© Garland Science 2013)



~1s

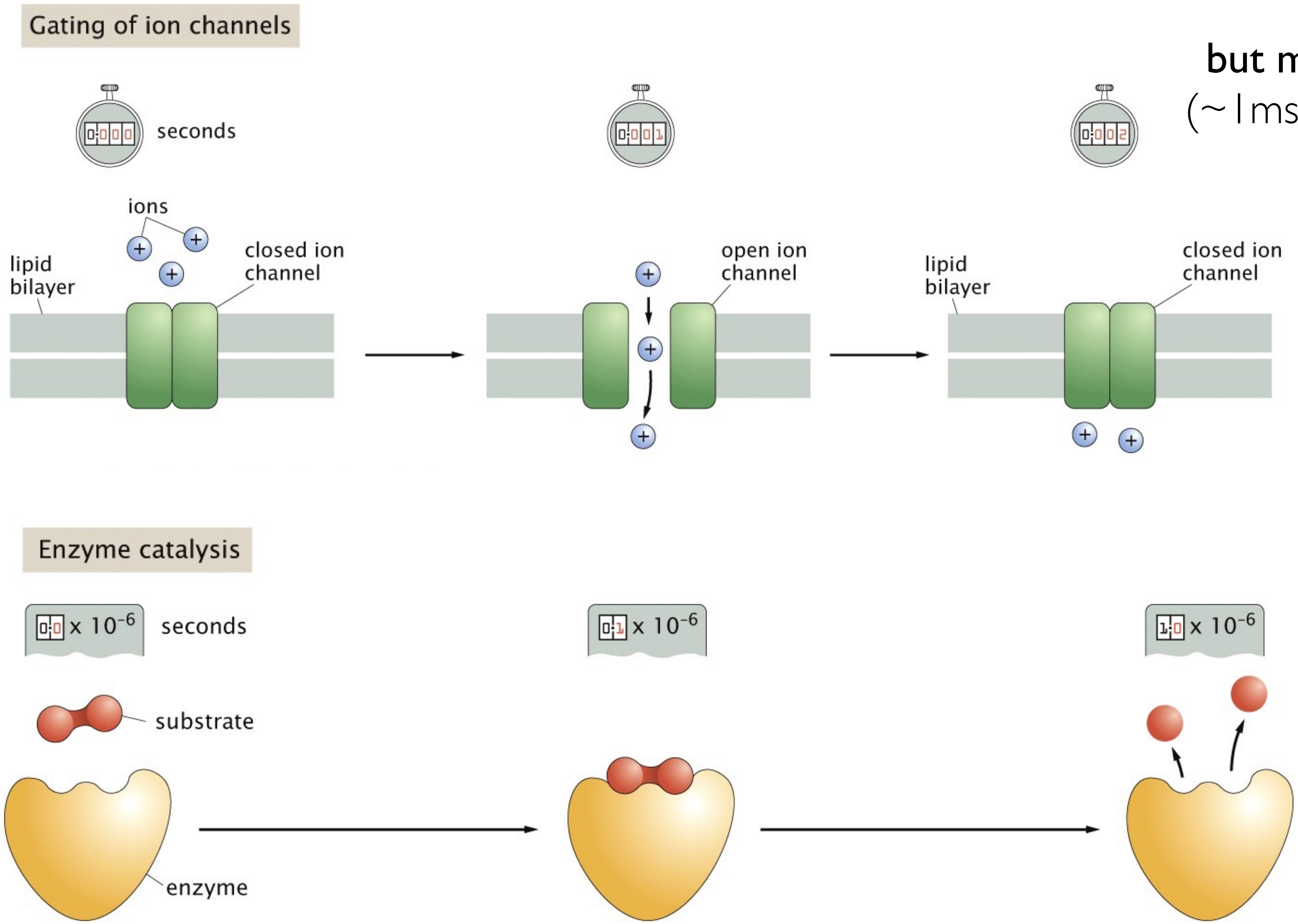
⟶ **will explore in detail in Lectures B7 & B8 (Chemotaxis)**

Biological processes occur over a huge range of timescales



→ Lectures B9 & B10: How do these machines achieve such low error rates?
(& how could _evolution_ make them better?)

Biological processes occur over a huge range of timescales

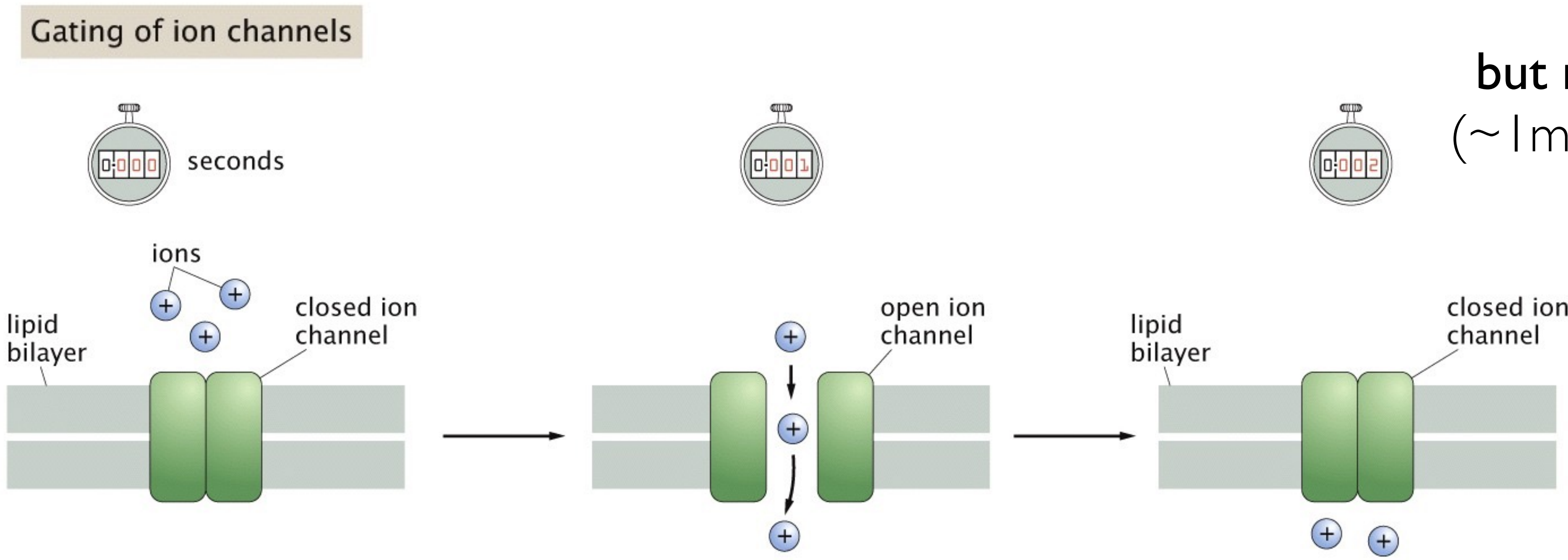


but many still slow!
(~1ms-1s, Lecture B7)

(fastest)

(Floor ~ characteristic QM timescale, h/kT ~ 10^{-12} s)

Biological processes occur over a huge range of timescales



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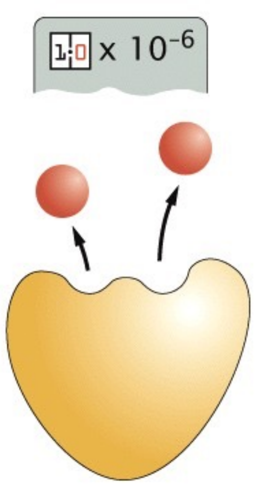


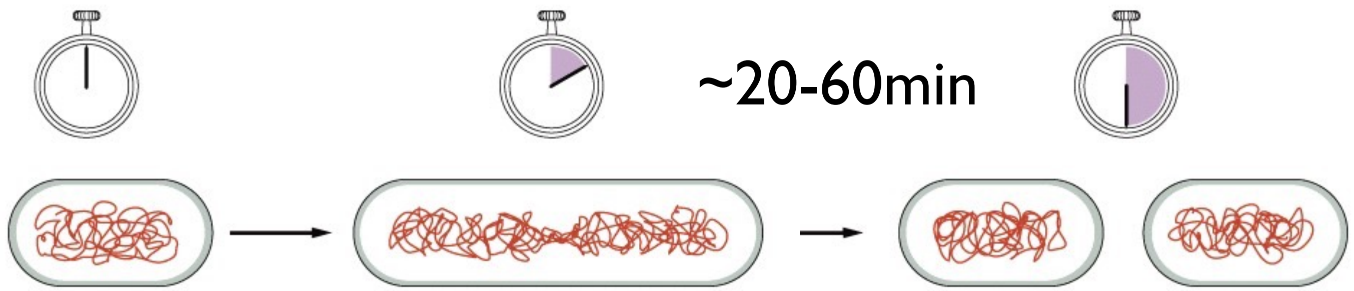
(fastest)

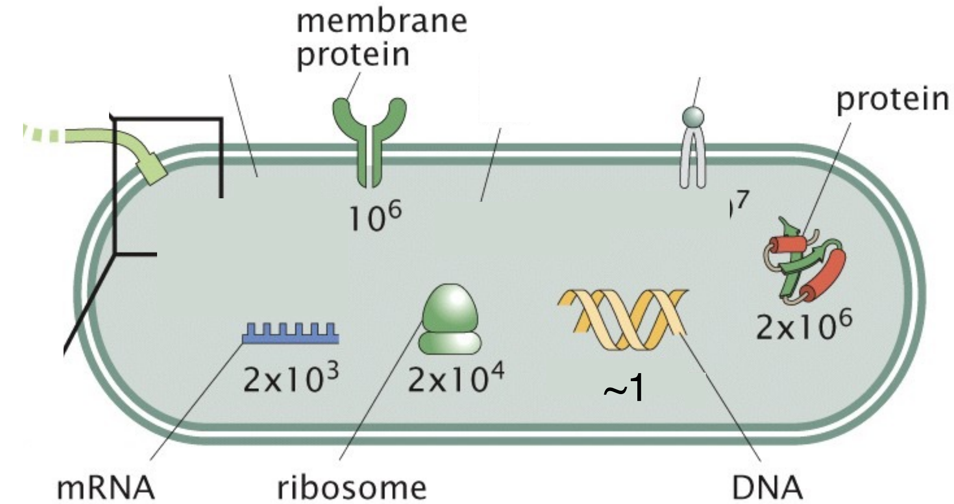
Goal:

Understand ***physical processes*** that set timescales, & how they influence ***design*** of cells & organisms.

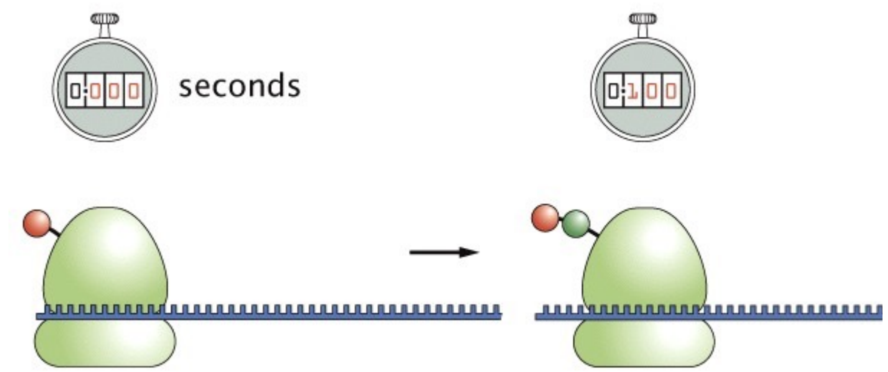
(Floor ~ characteristic QM timescale, h/kT ~ 10^{-12} s)

Example: what can we learn from these numbers?





Protein synthesis ~25 aa/s



E. coli replication time $\geq$ Time required for ribosomes to synthesize all proteins for new cell

$$\approx \frac{(\sim 3\times10^{6}\ \text{proteins})\ (\sim 300\ \text{aa/protein})}{(\sim 25\ \text{aa/s})\ (\sim 2\times10^{4}\ \text{ribosomes})}$$

$\approx$ 30 mins!

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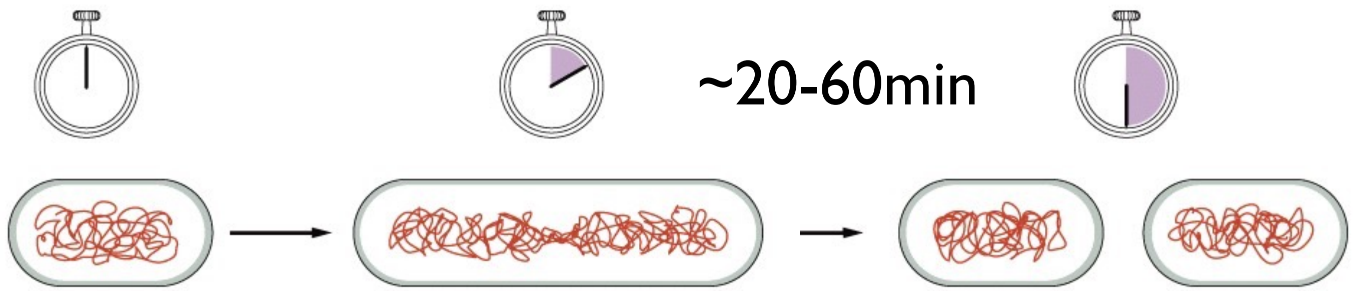

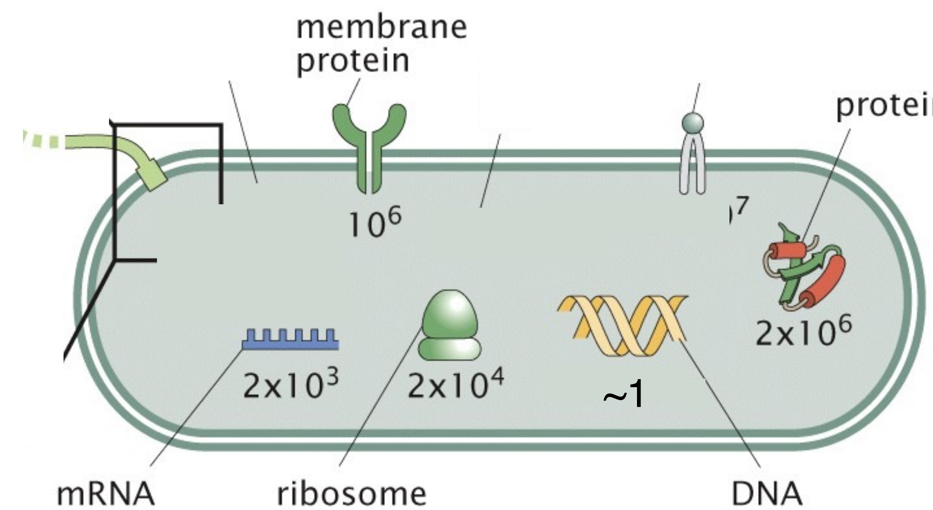

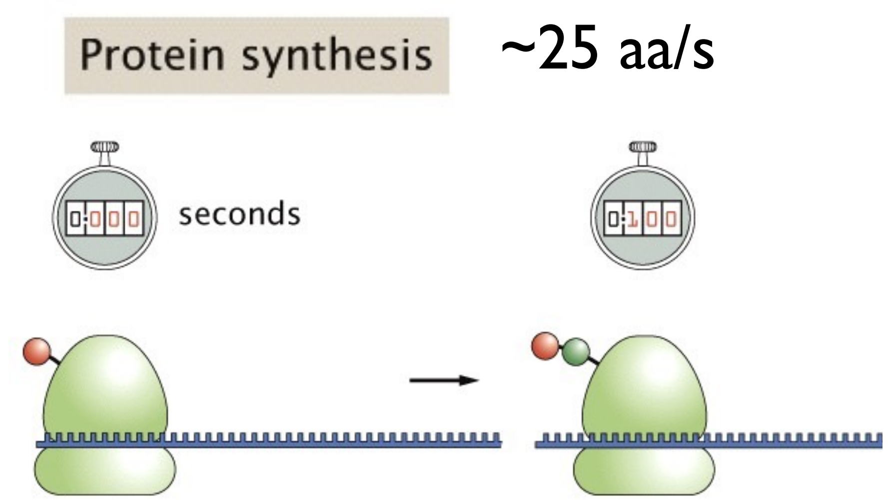

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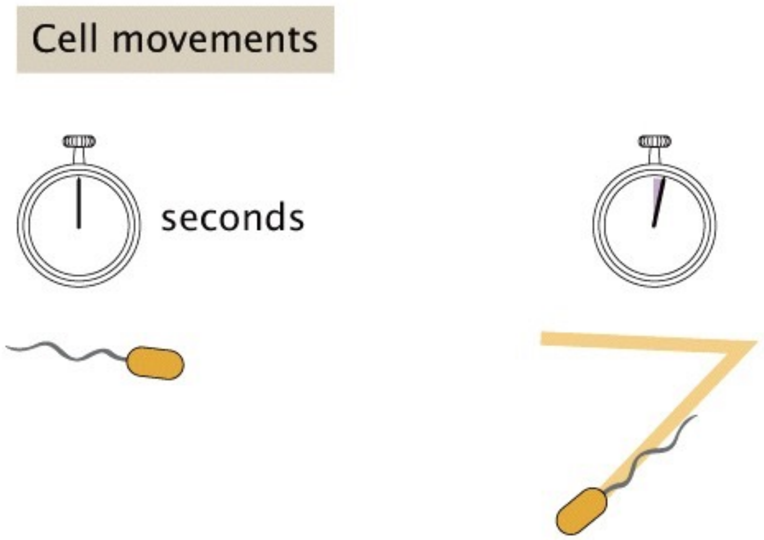
$\approx$ 30 mins!

E. coli replication time $\geq$ Time required for DNAp to copy entire genome $\approx \frac{1 \times (\sim 4\times10^{6}\ \text{bp})}{(\sim 1000\ \text{bp/s}) \times 1} \approx$ 1 hr (too long!)

Solution: E. Coli starts copying *next* genome before first one finishes!

Challenge Question:

How long does it take a cell to transcribe and translate a single protein?



What does this tell us about the mechanisms responsible for regulating these cell movements?

Next time:

Introduction to
Statistical Mechanics