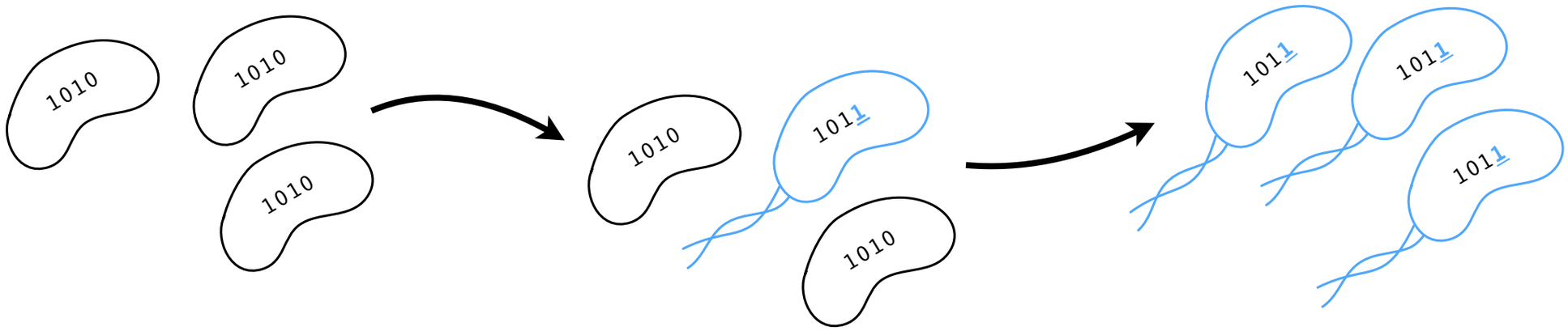
APPHYS 205 // BIO 126/226:

Introduction to Biophysics



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)

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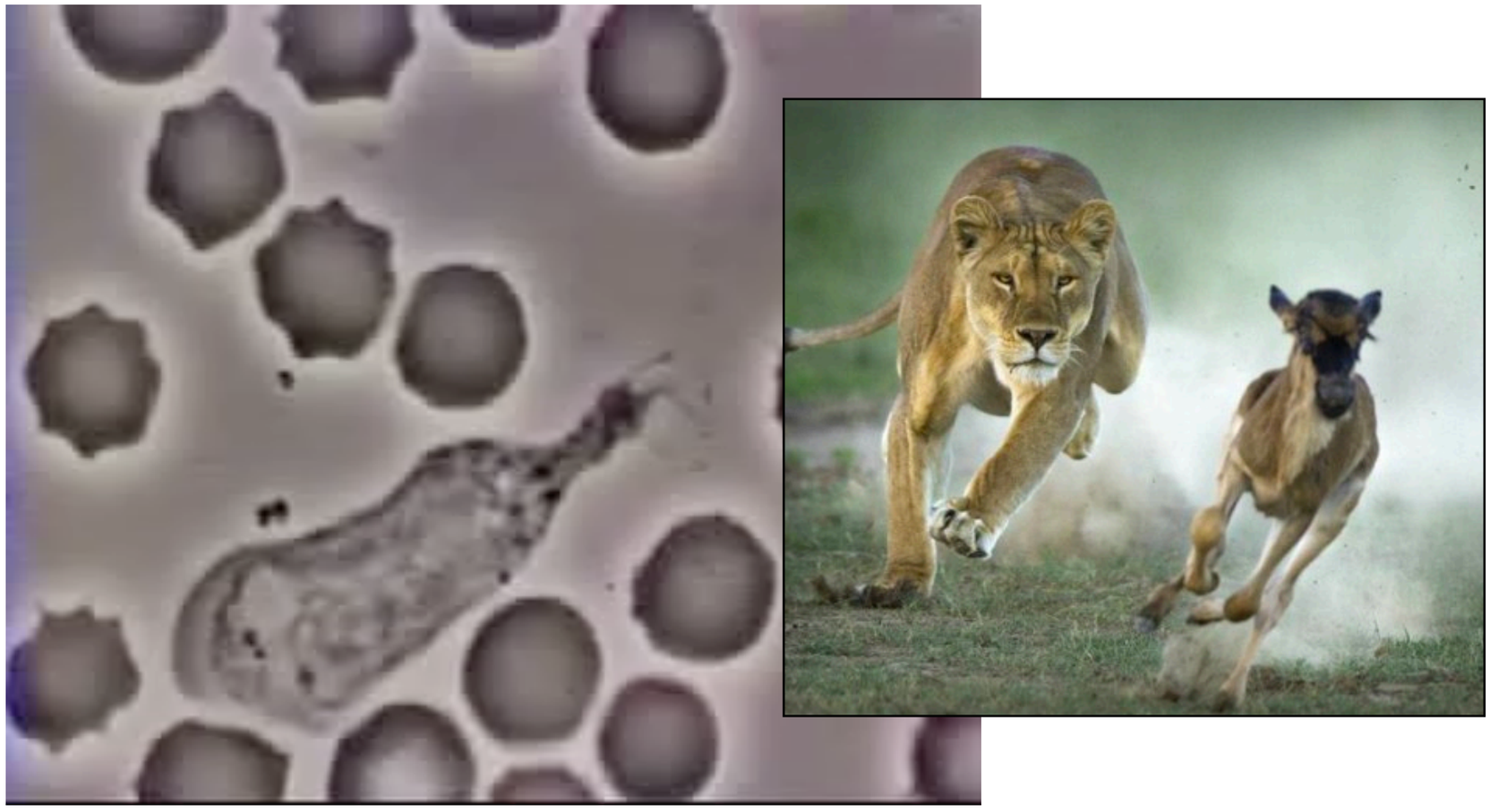

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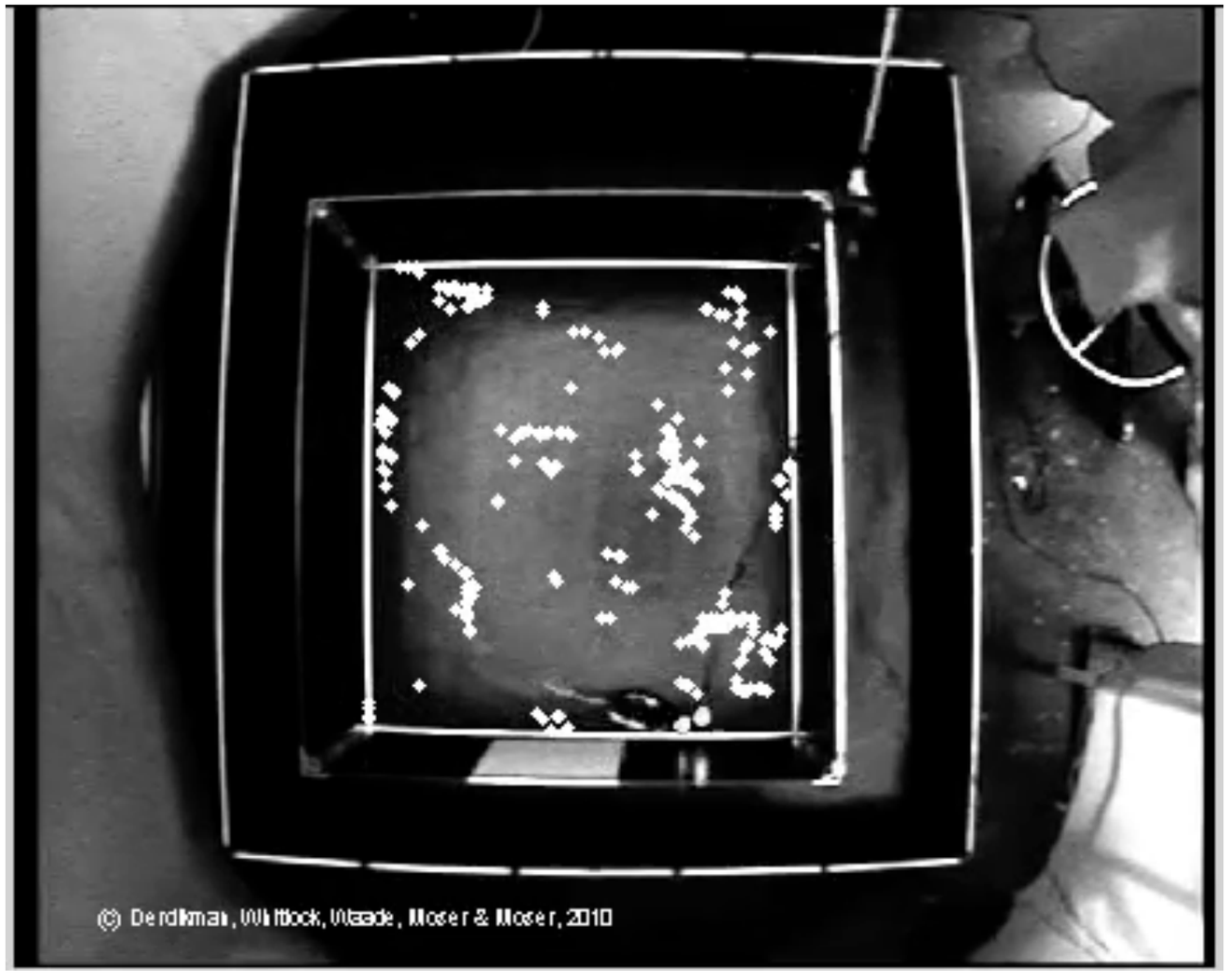

e.g. firing pattern of a single "grid neuron" in a rat moving within a box (credit: Derdikman, Whitlock, Waade, Moser & Moser

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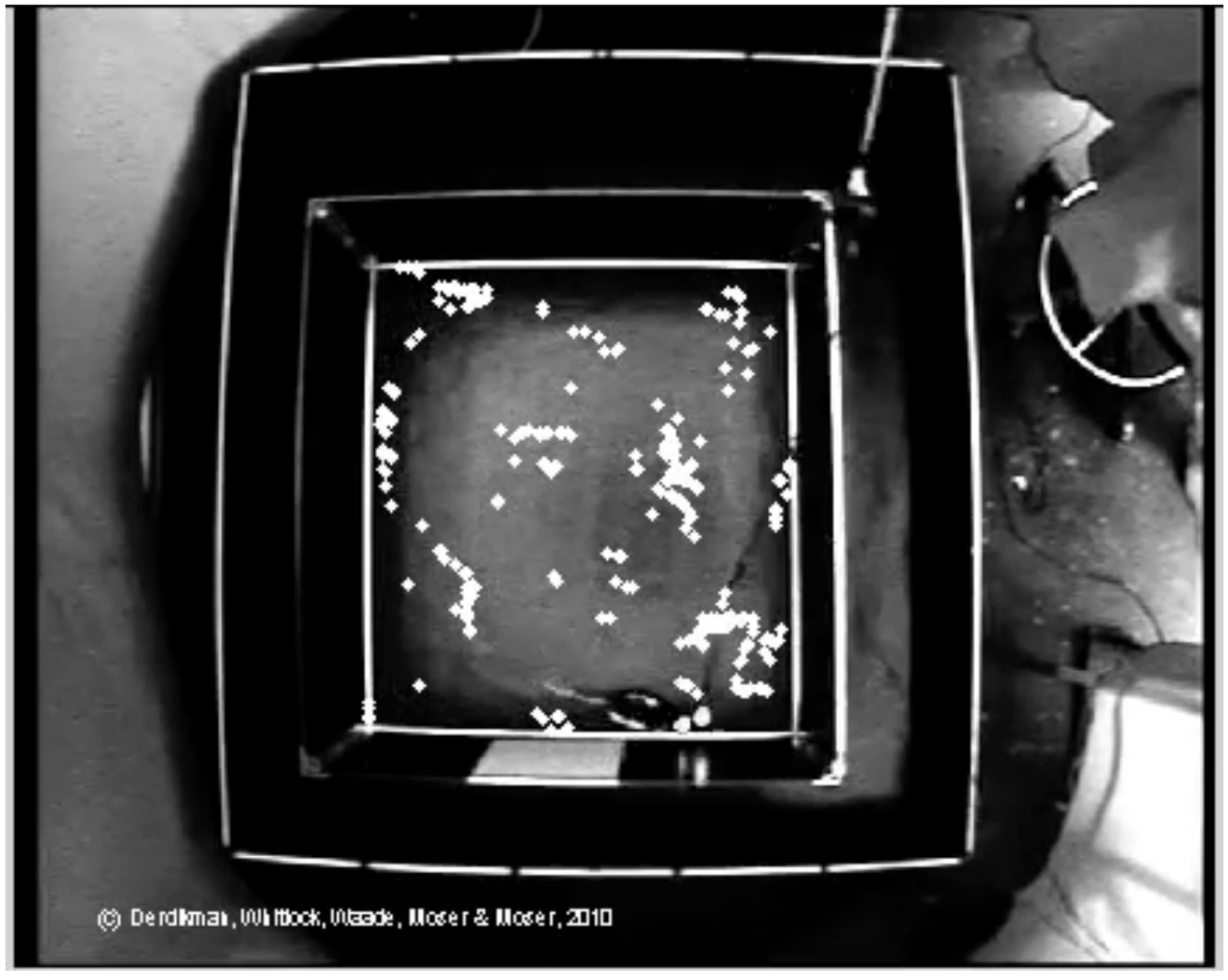

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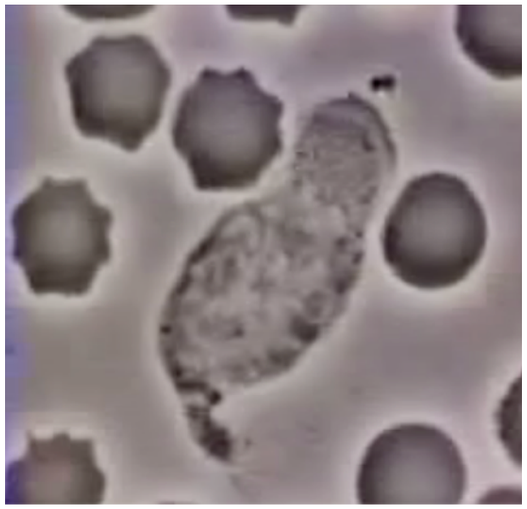
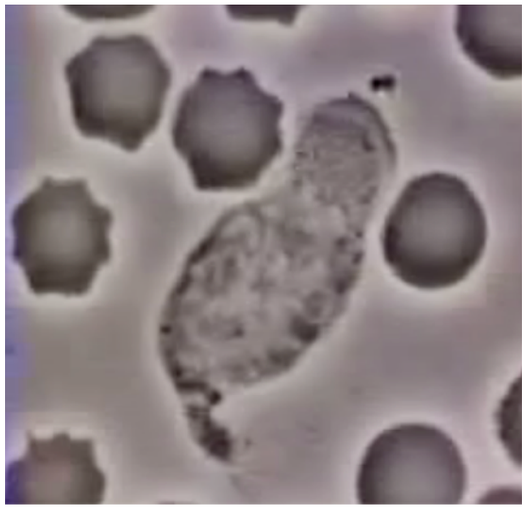


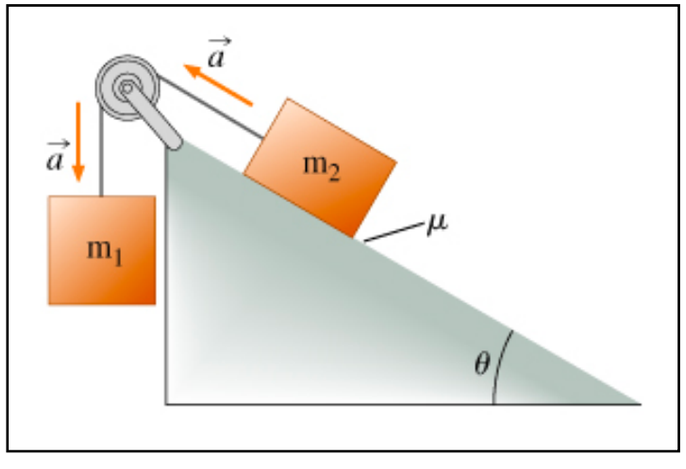
…but physics imposes strong constraints!

Biology generates exquisitely complex behavior from simple chemical building blocks

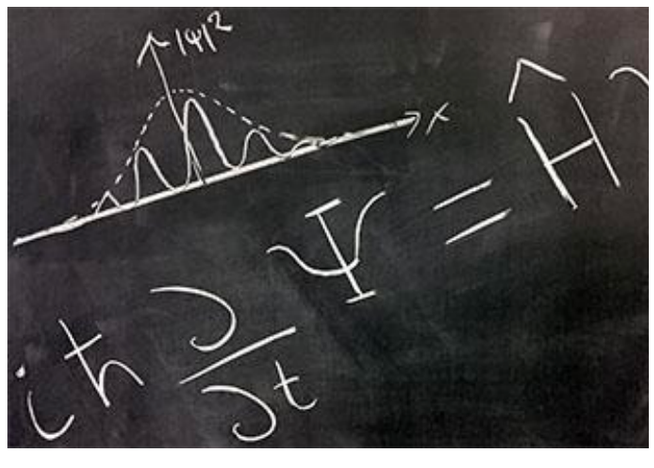


…but physics imposes strong constraints!

Can be different from our "usual" physical intuition:

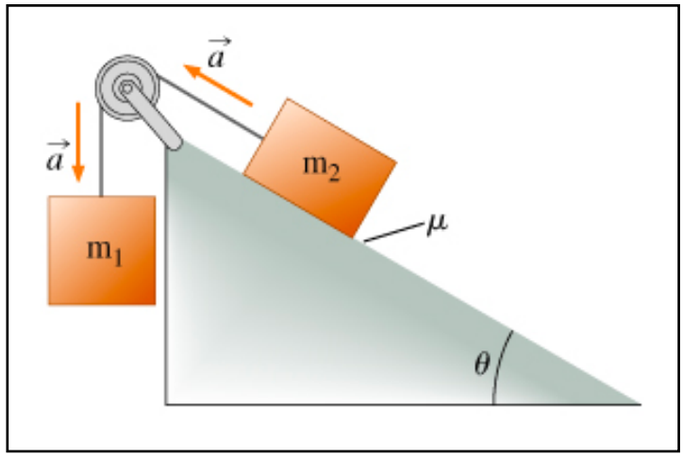


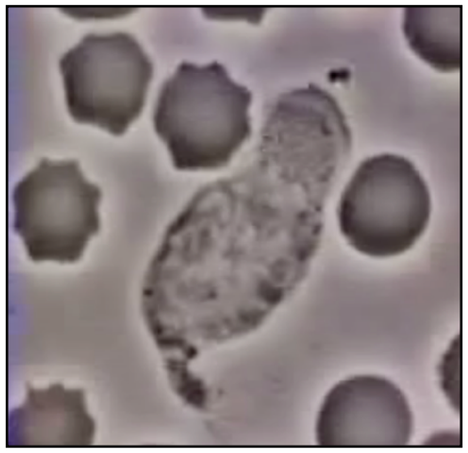
Physics of everyday objects

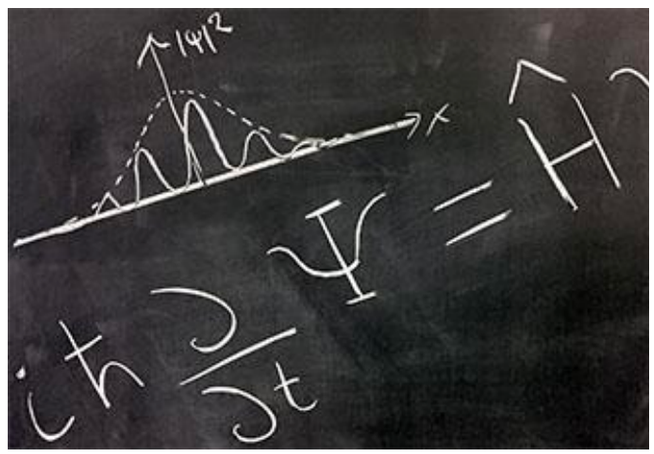


Quantum mechanics

Biology generates exquisitely complex behavior
…but physics imposes strong constraints





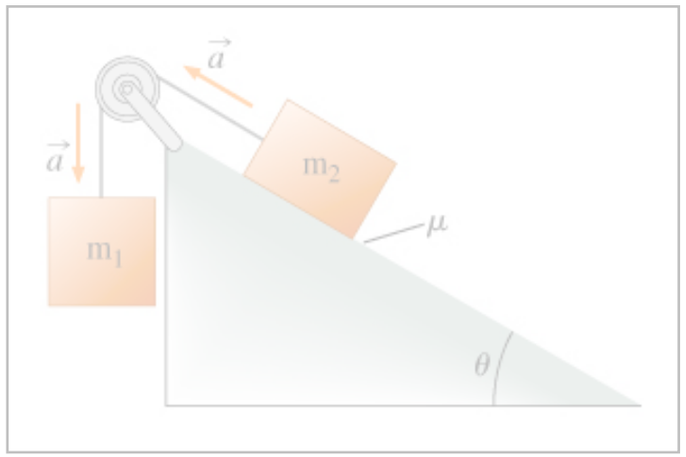


Physics of everyday objects | ***Biophysics*** | *Quantum mechanics*

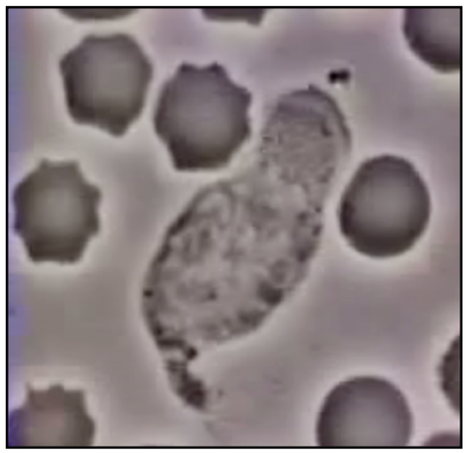
↓

interesting new physics emerges at these <u>cellular</u> scales

Biology generates exquisitely complex behavior
…but physics imposes strong constraints



Physics of everyday objects



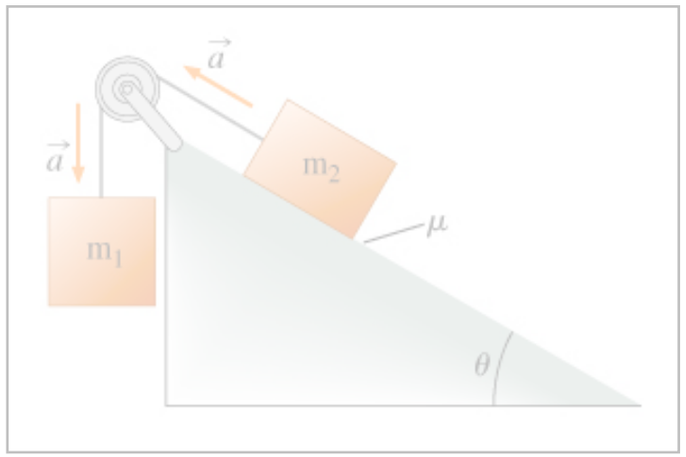
Biophysics

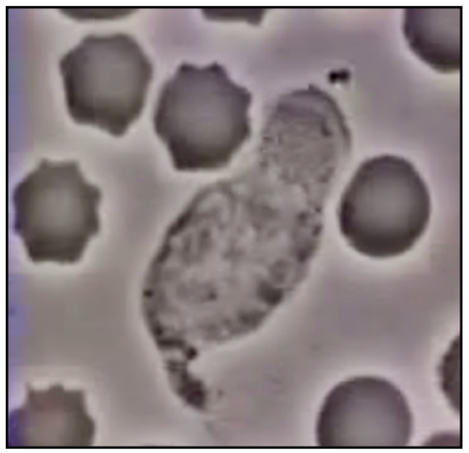
Quantum mechanics

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



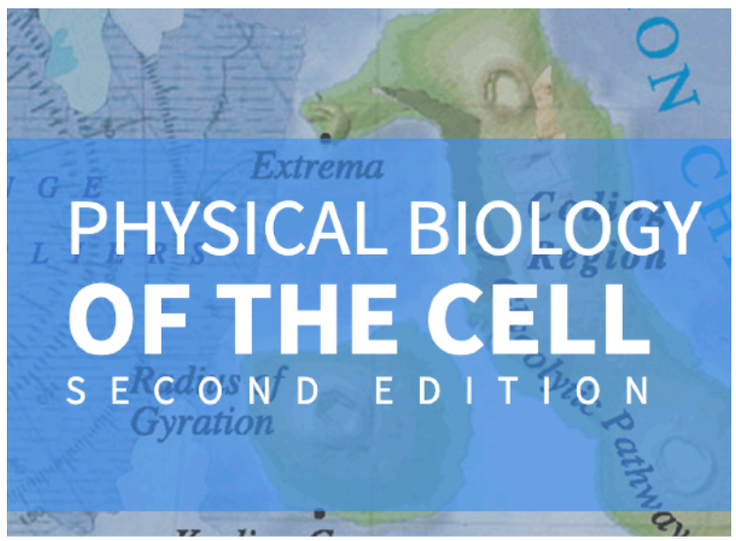


Physics of everyday objects | ***Biophysics*** | *Quantum mechanics*

Major themes:

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

"biology by the numbers"

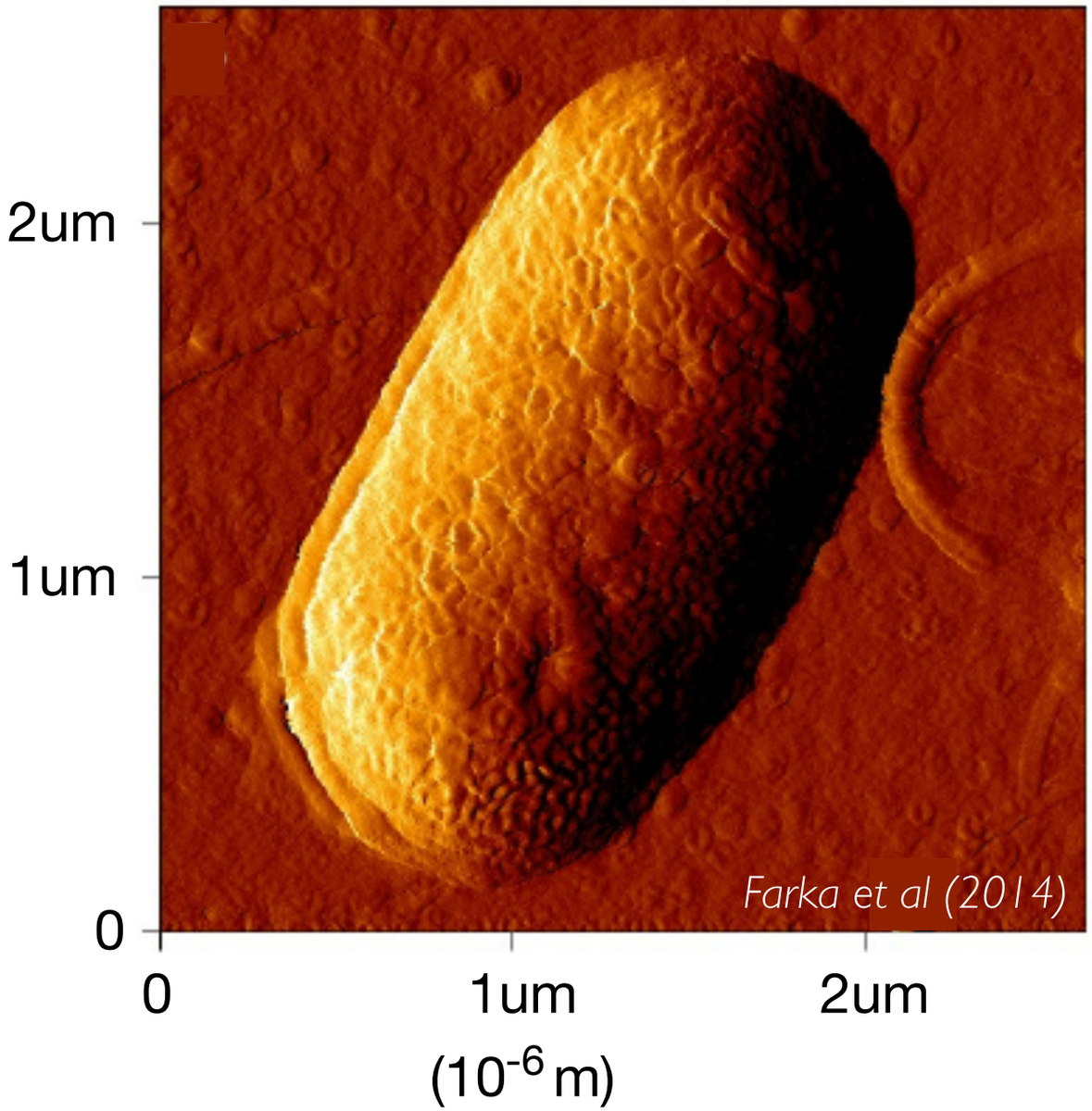


Phillips, Kondev, Theriot, & Garcia

Today:

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

E. Coli will be our standard ruler

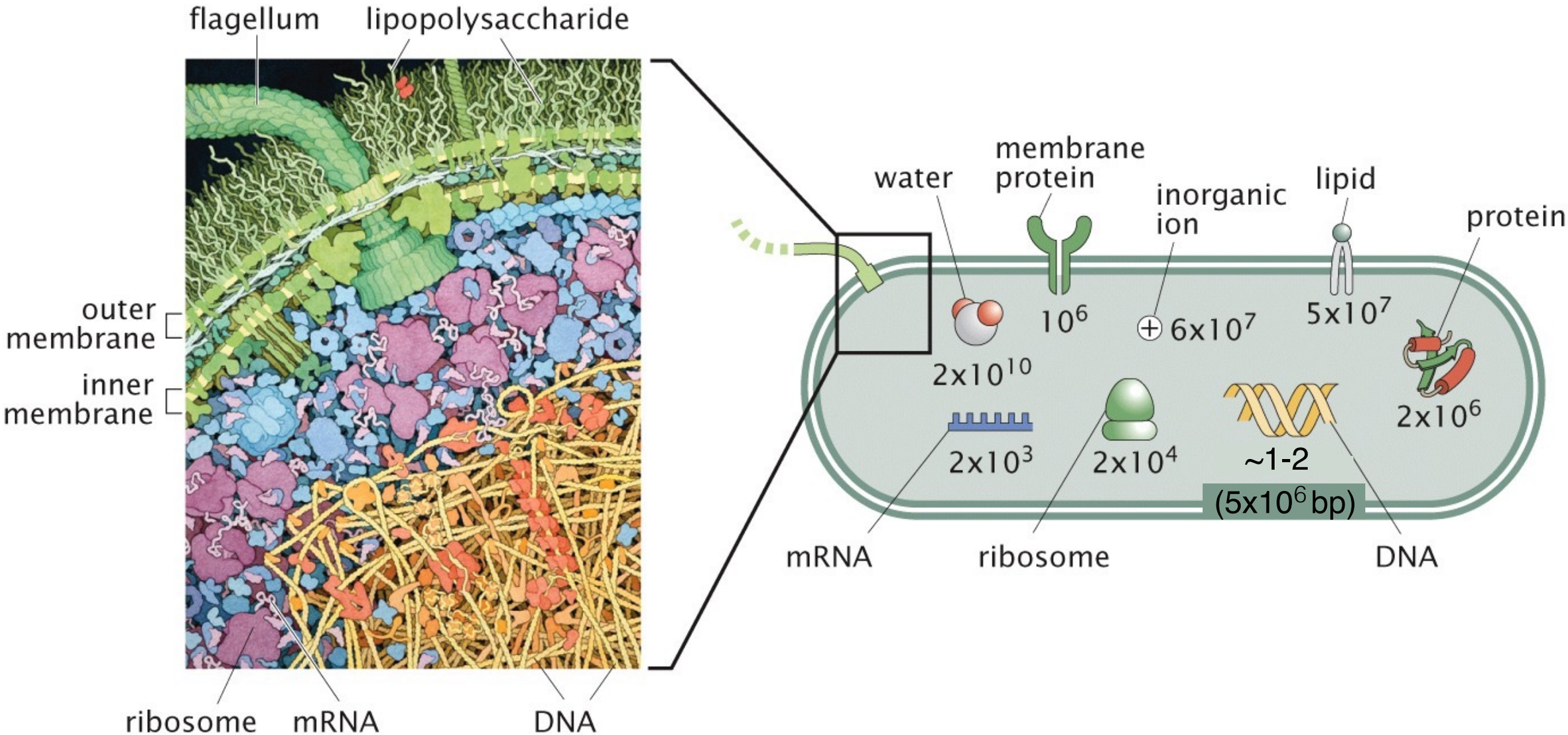


→ Volume: ~10^{-15} L

Mass: ~10^{-12} g

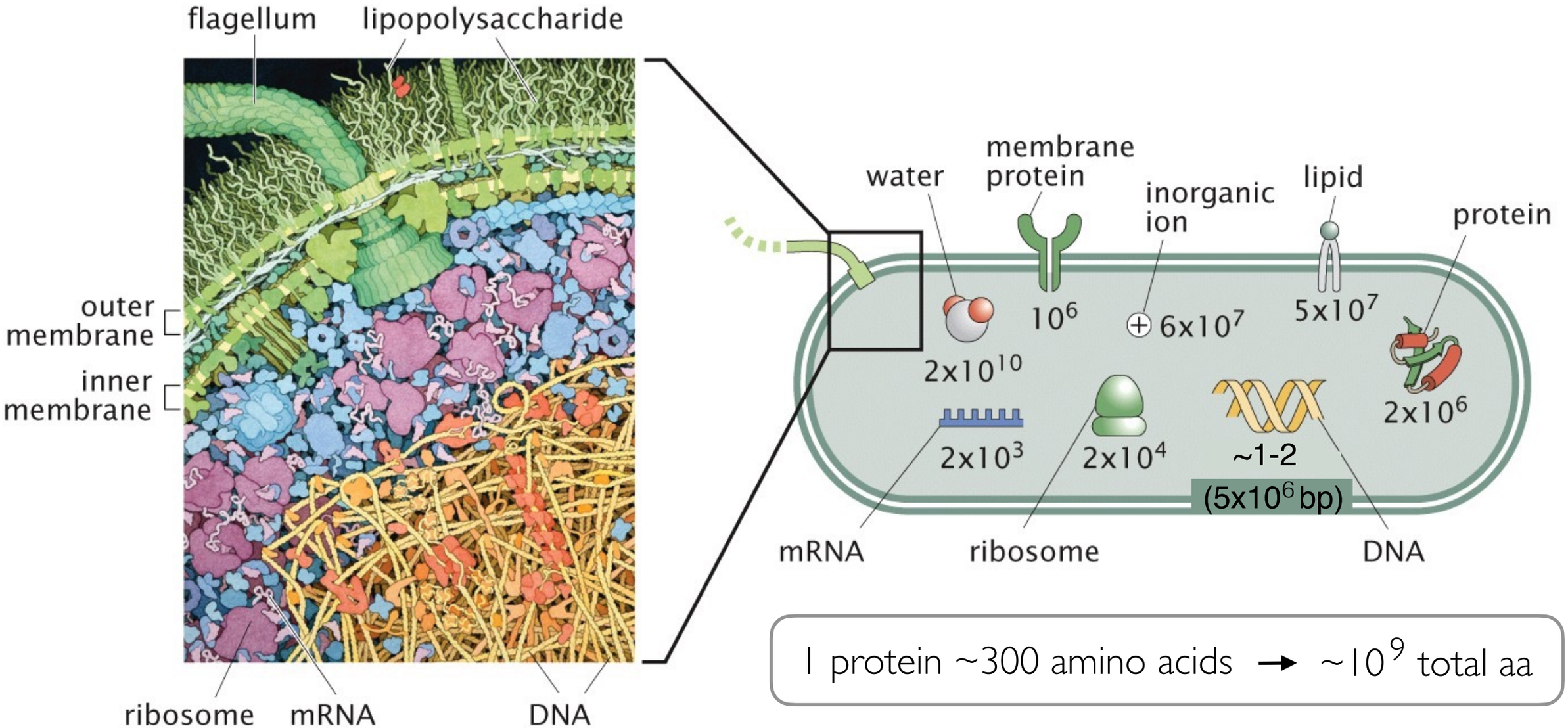
(assuming density ~ water)

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



DNA —transcription (*RNA polymerase*)→ ***mRNA*** —translation (*ribosome*)→ ***Protein (amino acids)*** → ***Growth***

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



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

DNA —transcription (*RNA polymerase*)→ ***mRNA*** —translation (*ribosome*)→ ***Protein (amino acids)*** → ***Growth***

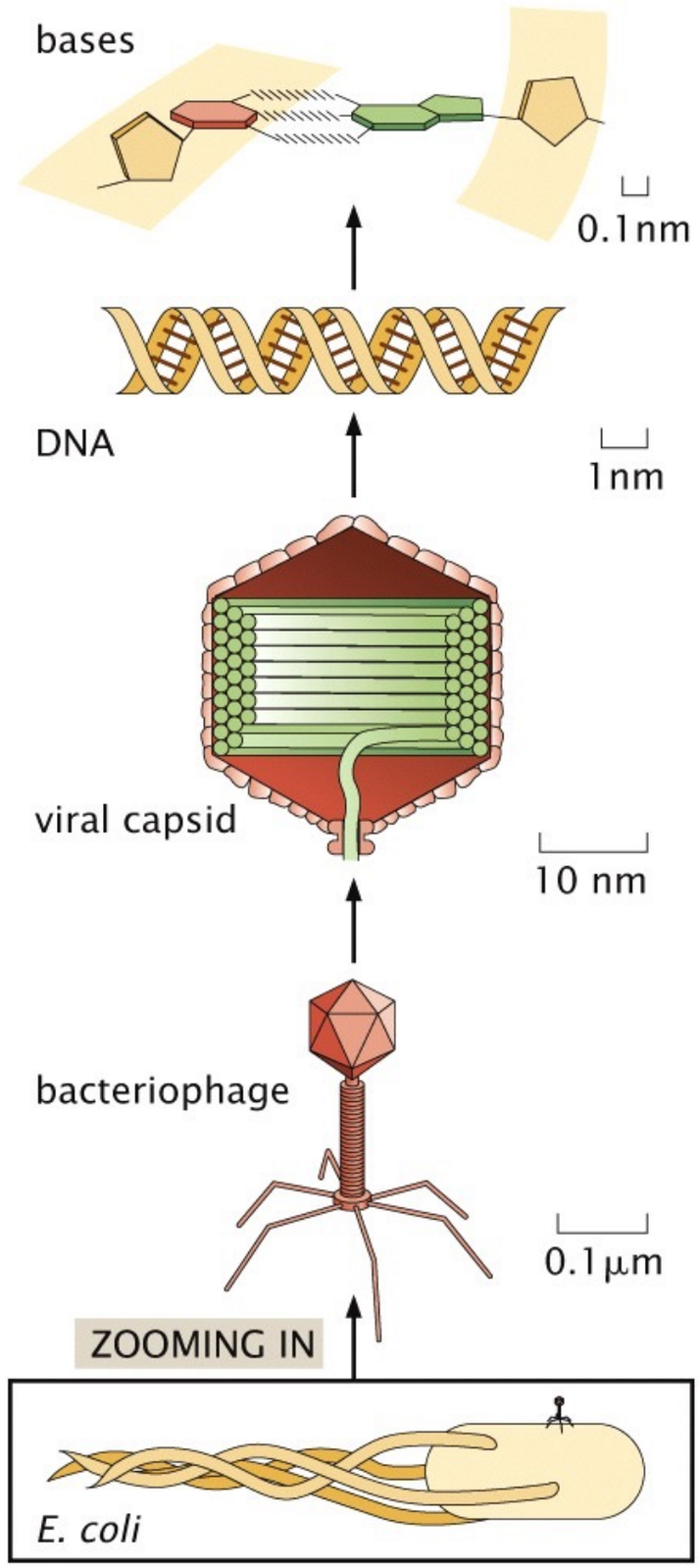
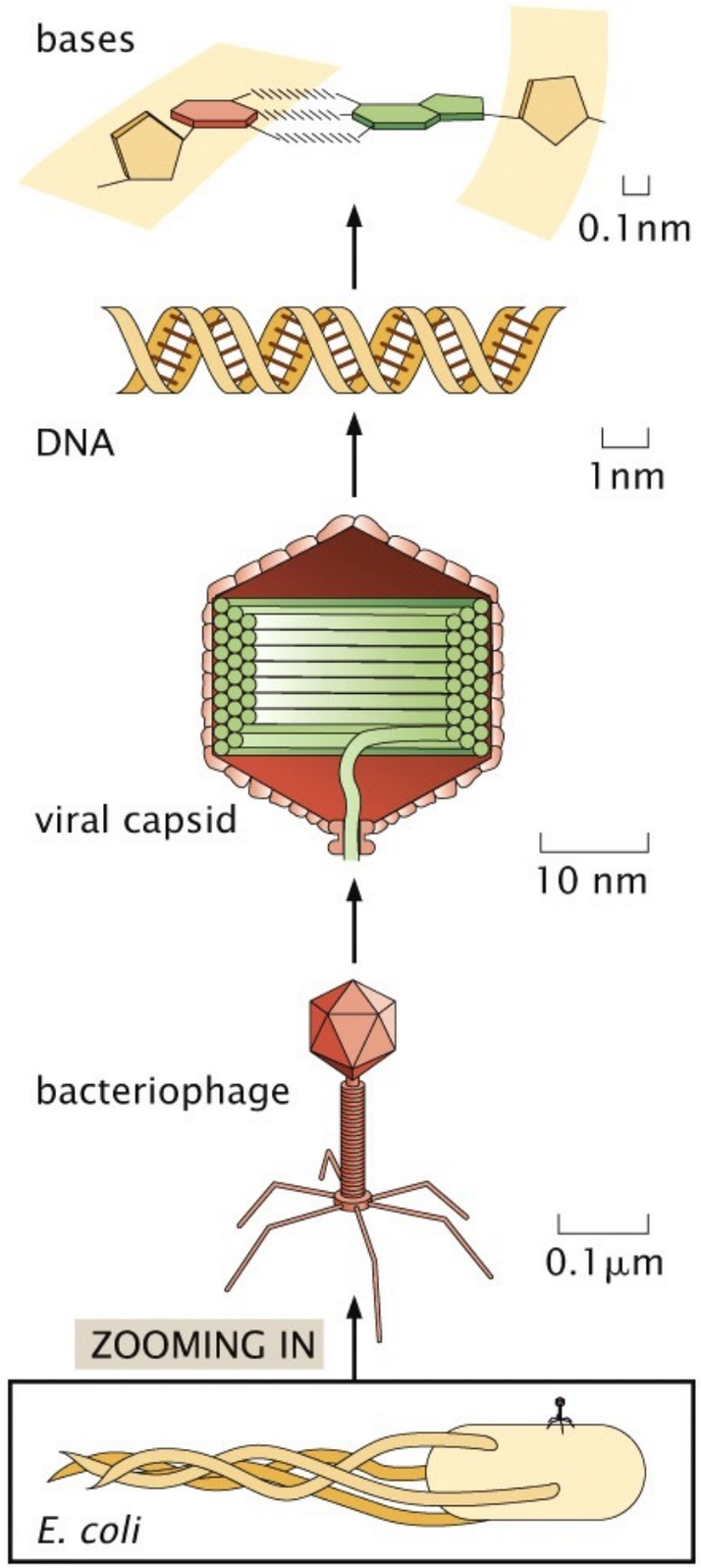


Figure 2.15 (part 1 of 2) Physical Biology of the Cell, 2ed. (© Garland Science 2013)



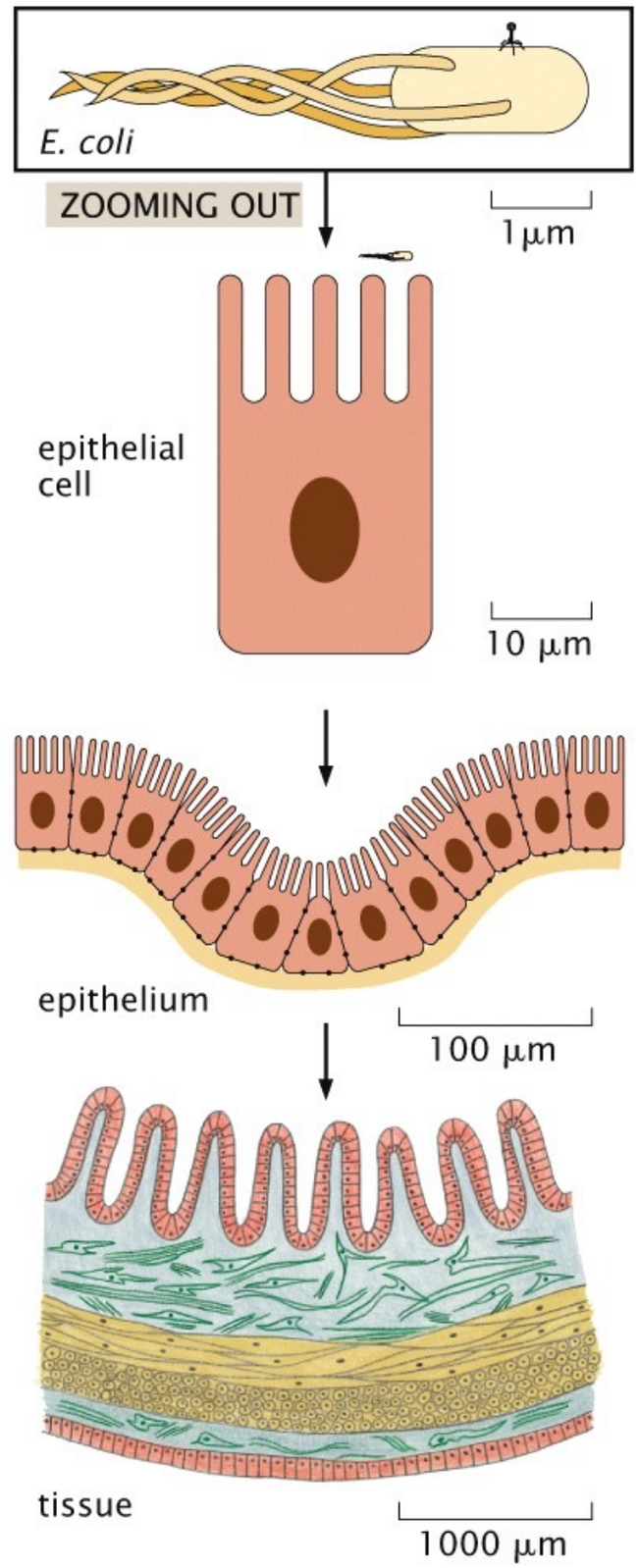
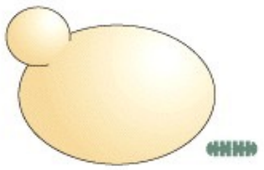


Figure 2.15 (part 1 of 2) Physical Biology of the Cell, 2ed. (© Garland Science 2013)

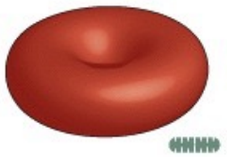
Human cells have a huge diversity of structure and function

Fibroblast

Budding yeast

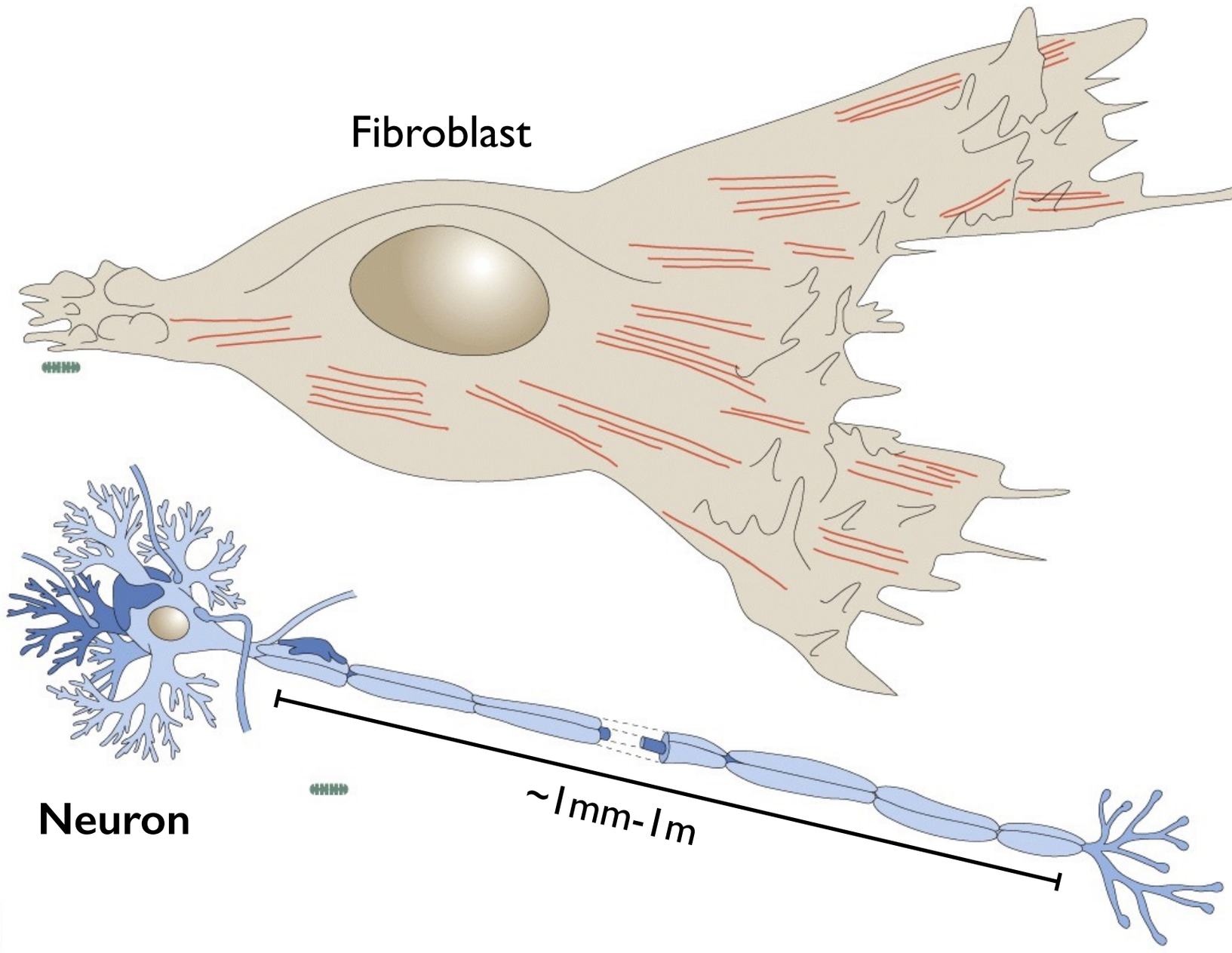


E. coli



Red blood cell

~5um



Neuron

Biological processes occur over a huge range of timescales

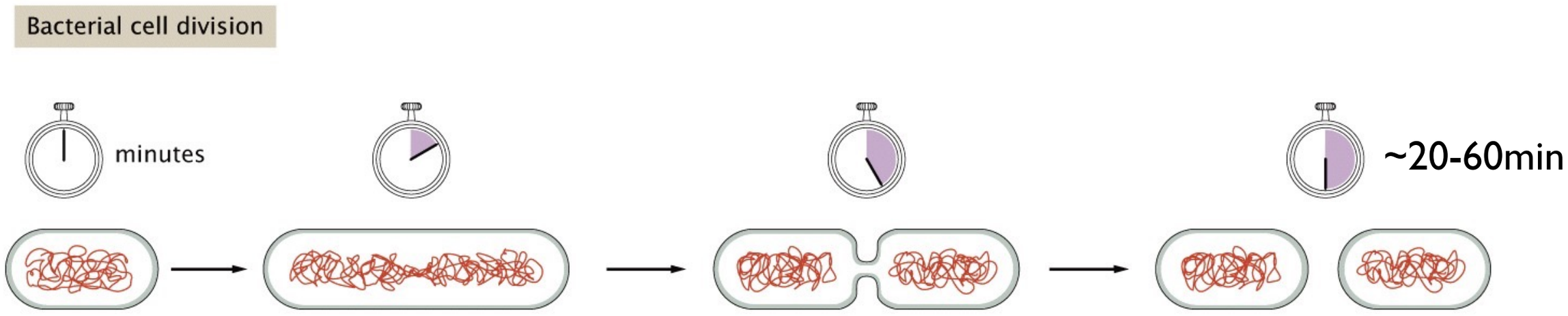


Figure 3.2c Physical Biology of the Cell, 2ed. (© Garland Science 2013)

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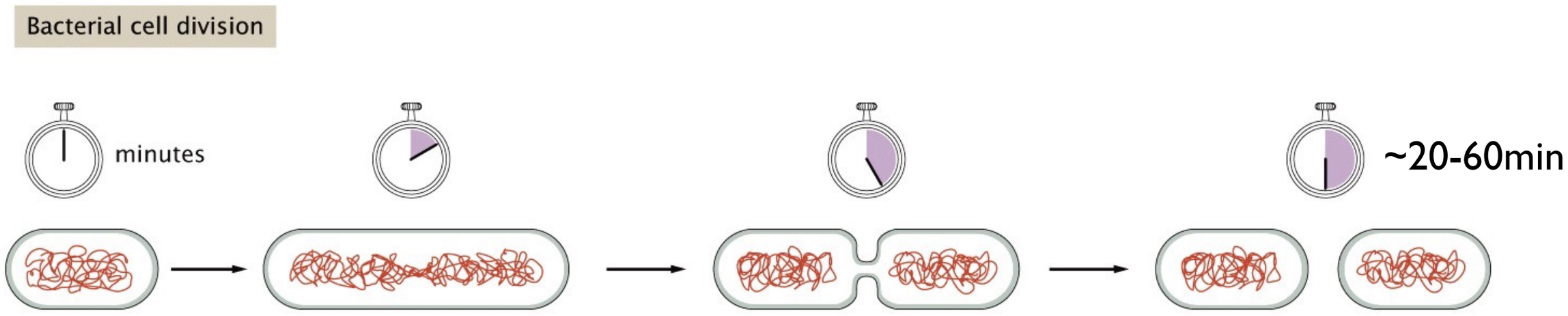

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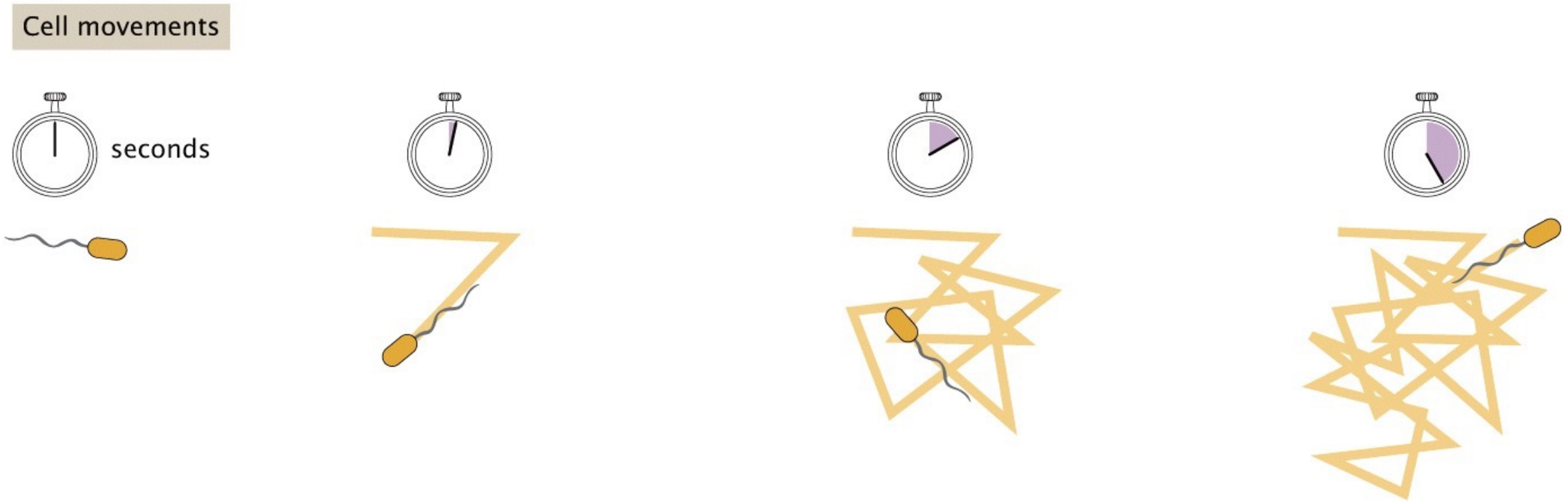

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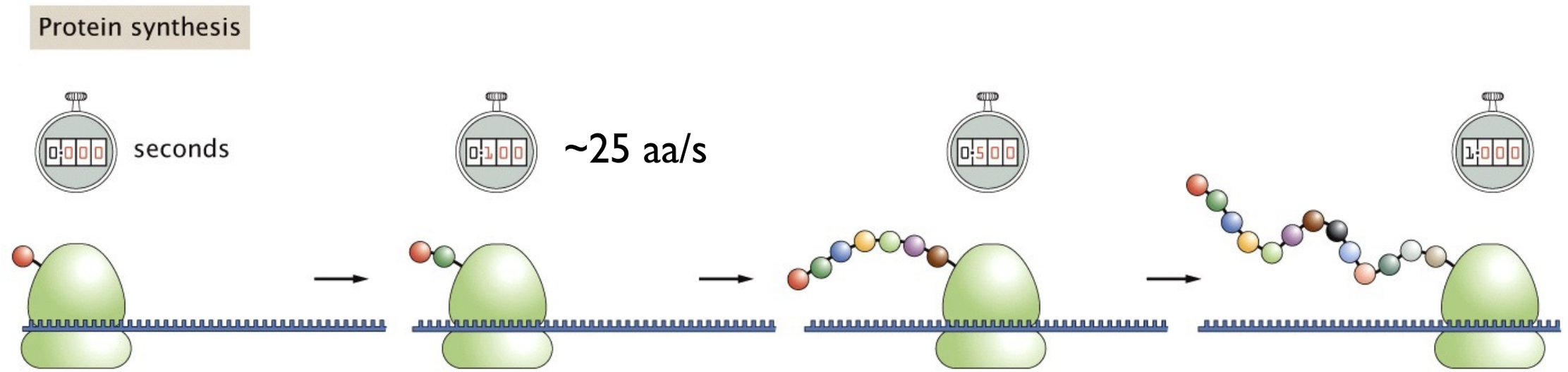

Figure 3.2e Physical Biology of the Cell, 2ed. (© Garland Science 2013)

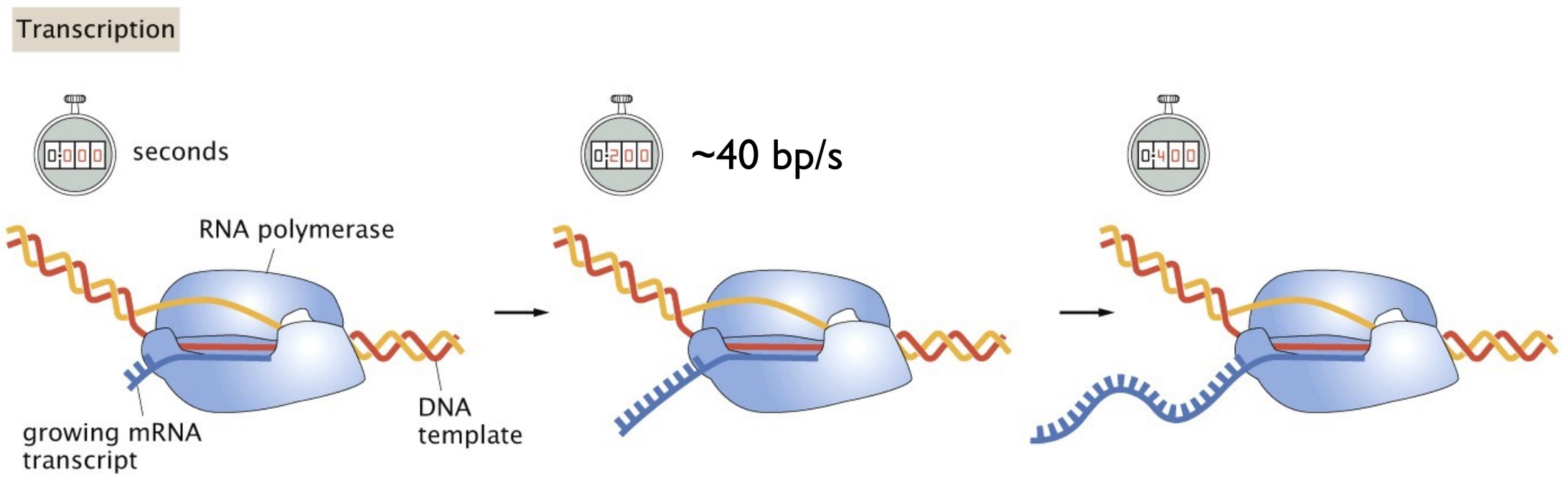

Figure 3.2f Physical Biology of the Cell, 2ed. (© Garland Science 2013)

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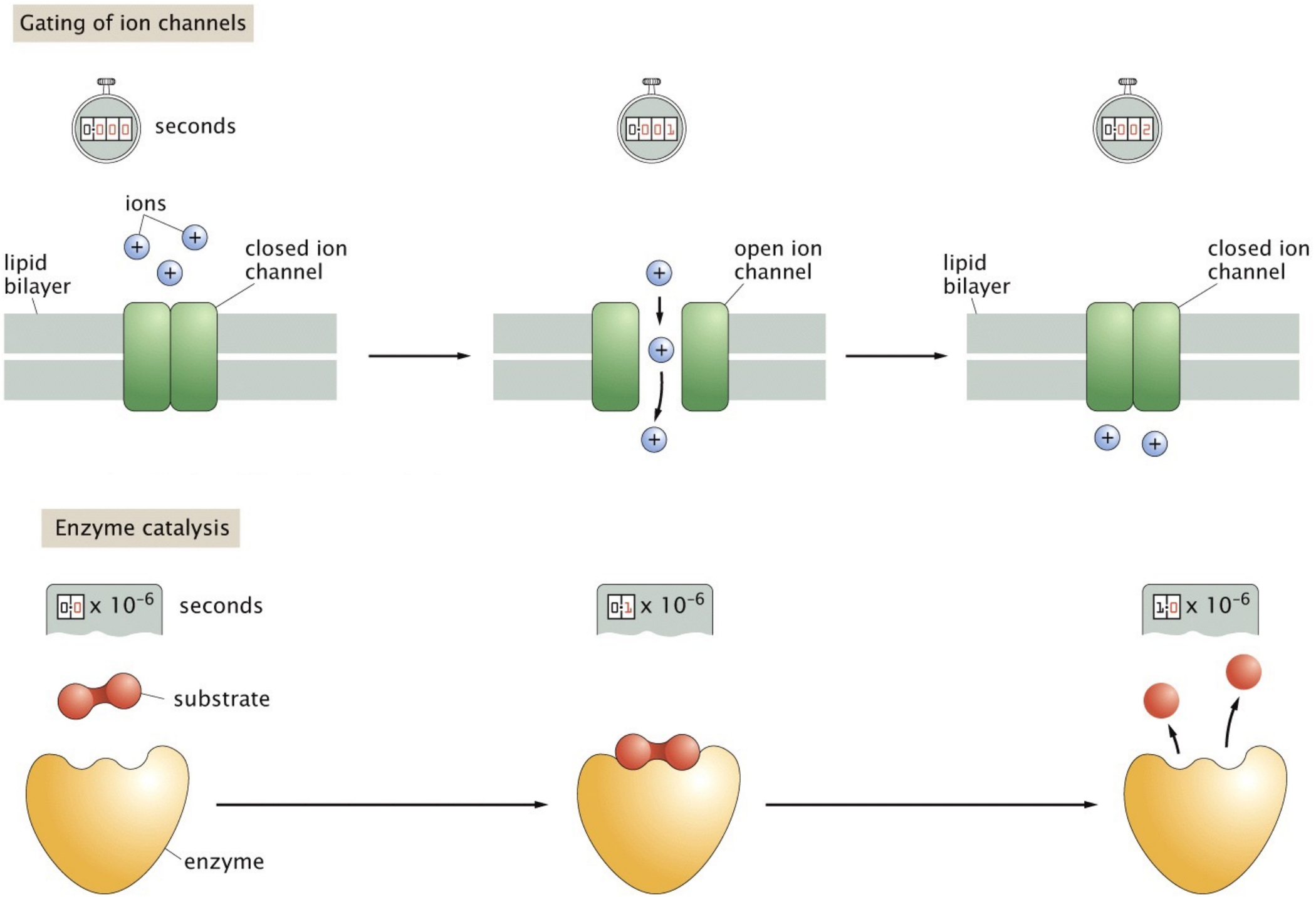
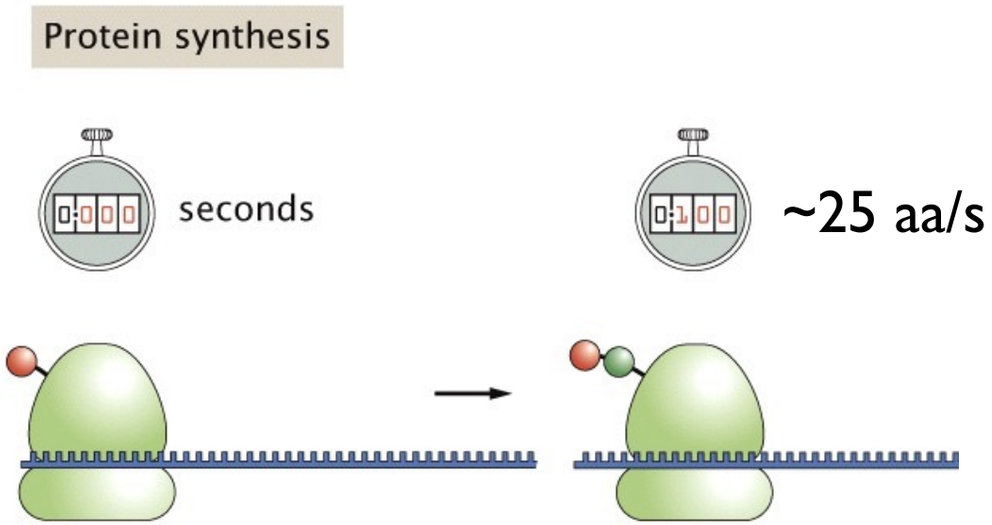


Figure 3.2h Physical Biology of the Cell, 2ed. (© Garland Science 2013)

What can we learn from these numbers?



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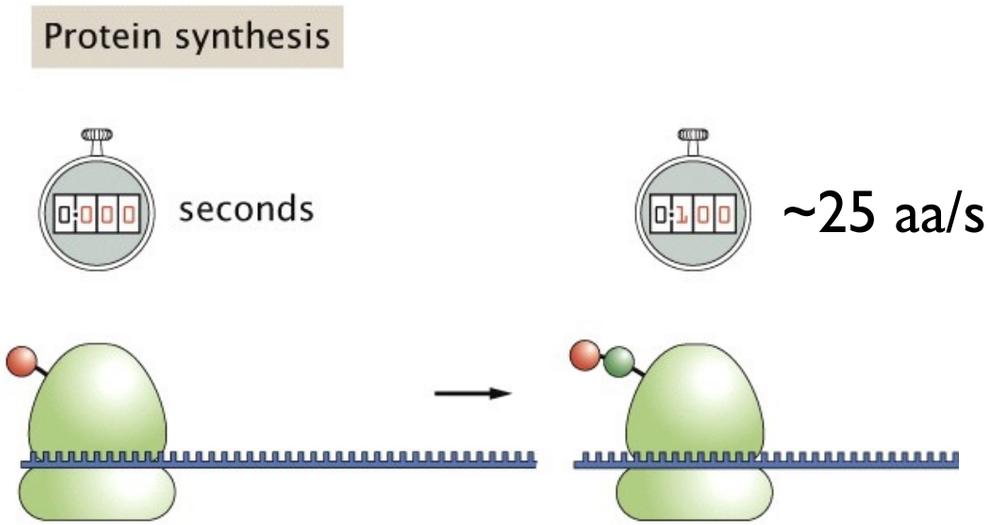
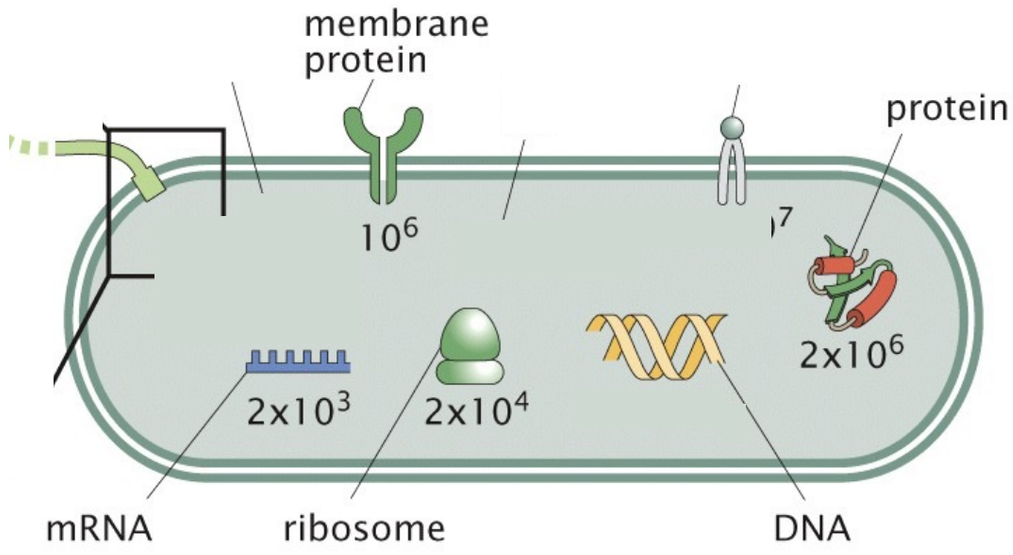


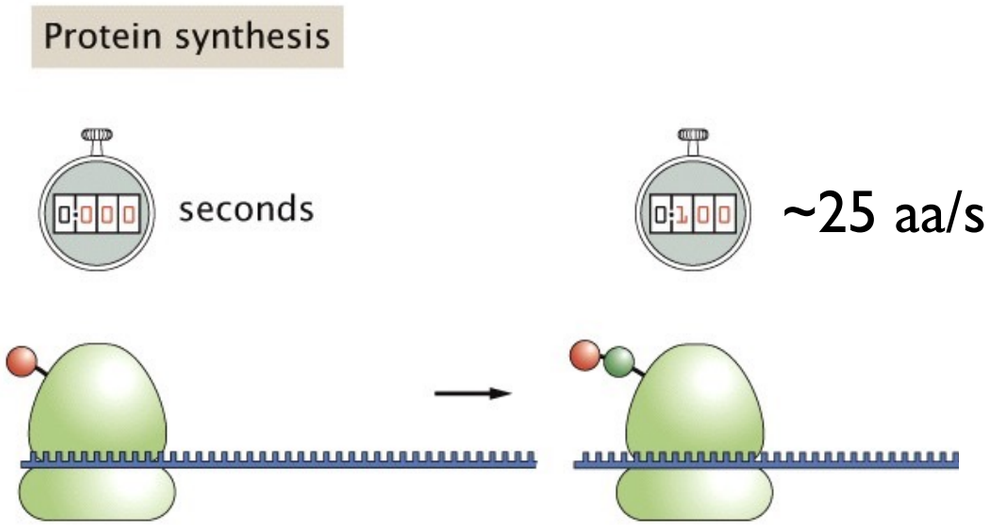
~25 aa/s

+



~300 aa / protein → ~10^9 aa / cell

What can we learn from these numbers?



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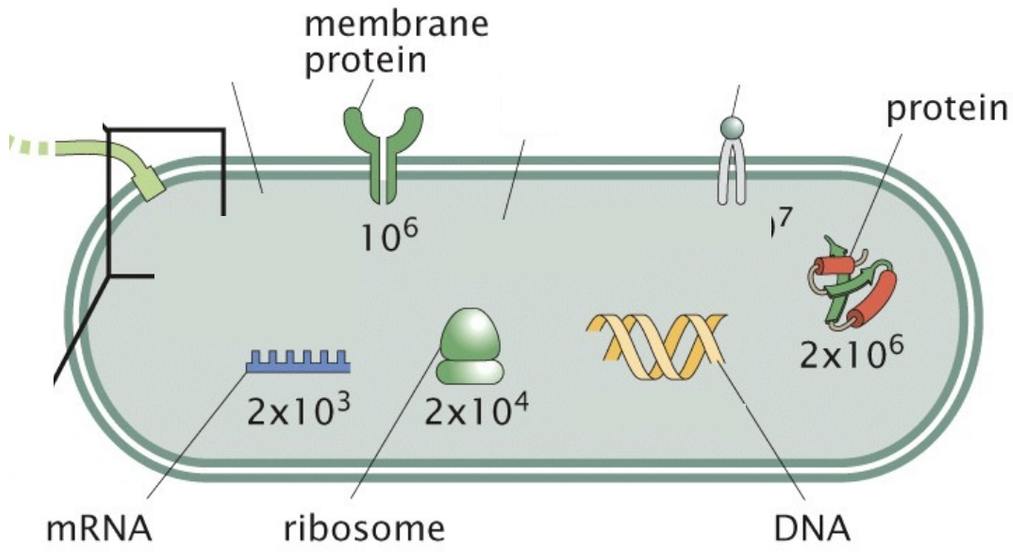

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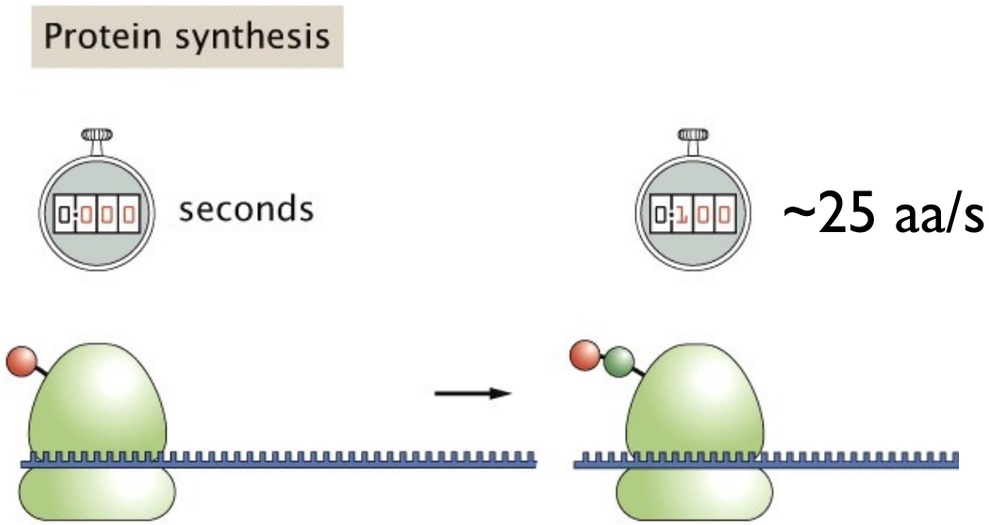
Minimum replication time = ~10^9 aa

What can we learn from these numbers?



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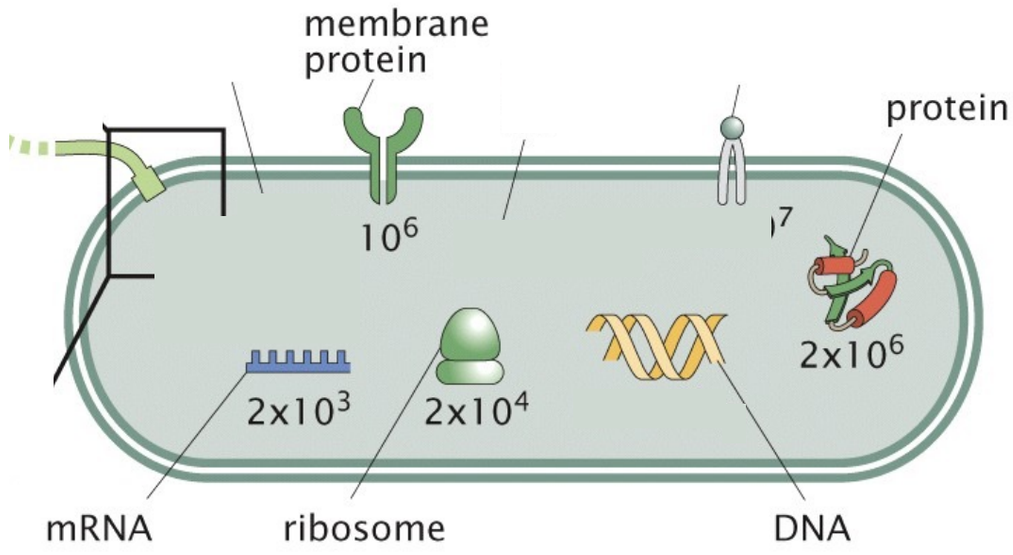

~300 aa / protein → ~10^9 aa / cell

Minimum replication time = ~10^9 aa / ~25 aa / s **x** ~2×10^4 ribosomes

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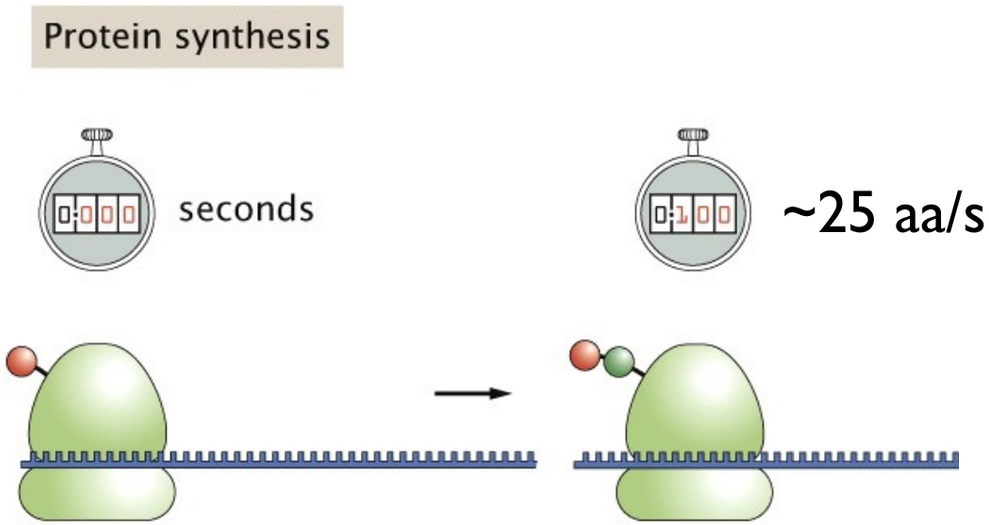

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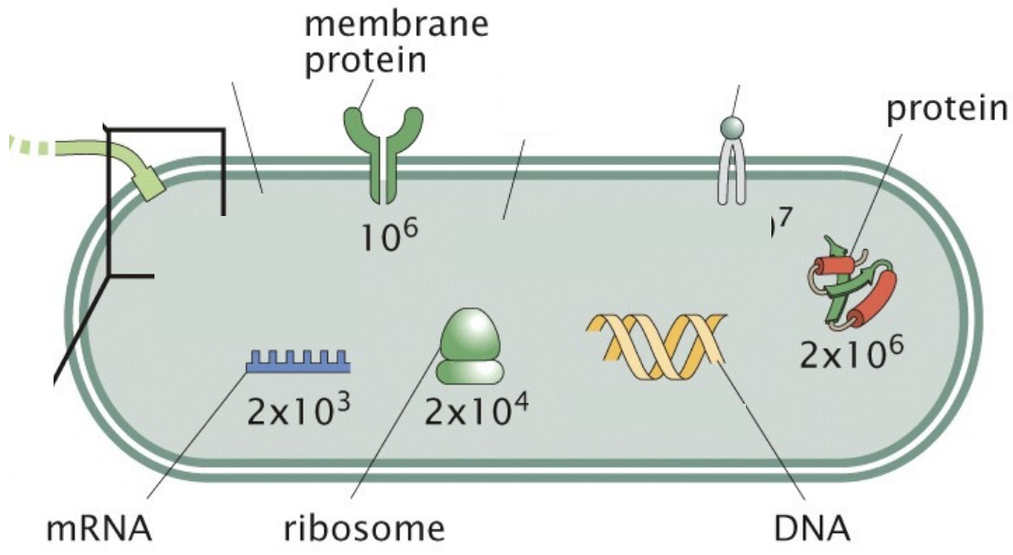

~300 aa / protein → ~10^9 aa / cell

Minimum replication time = ~10^9 aa / ~25 aa / s x ~$2 x10^4$ ribosomes = ~30 mins!

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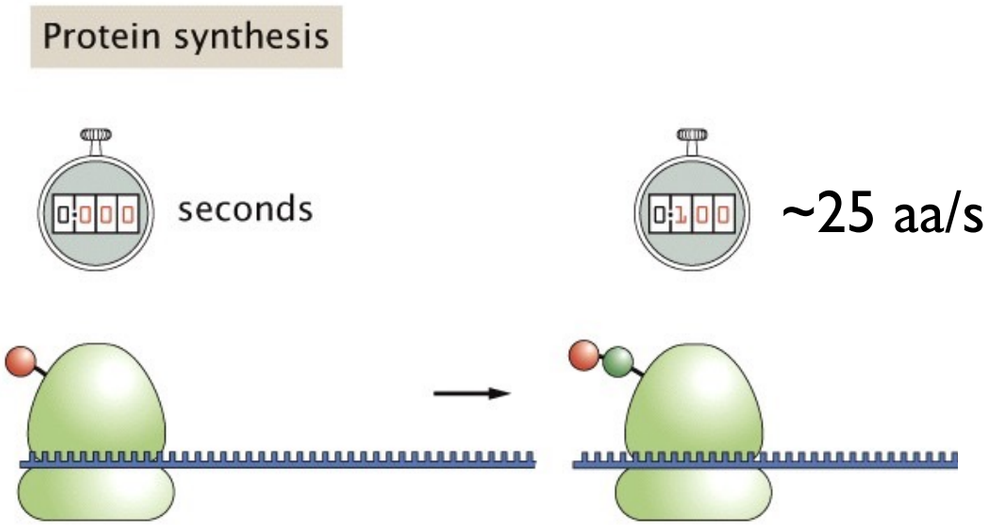

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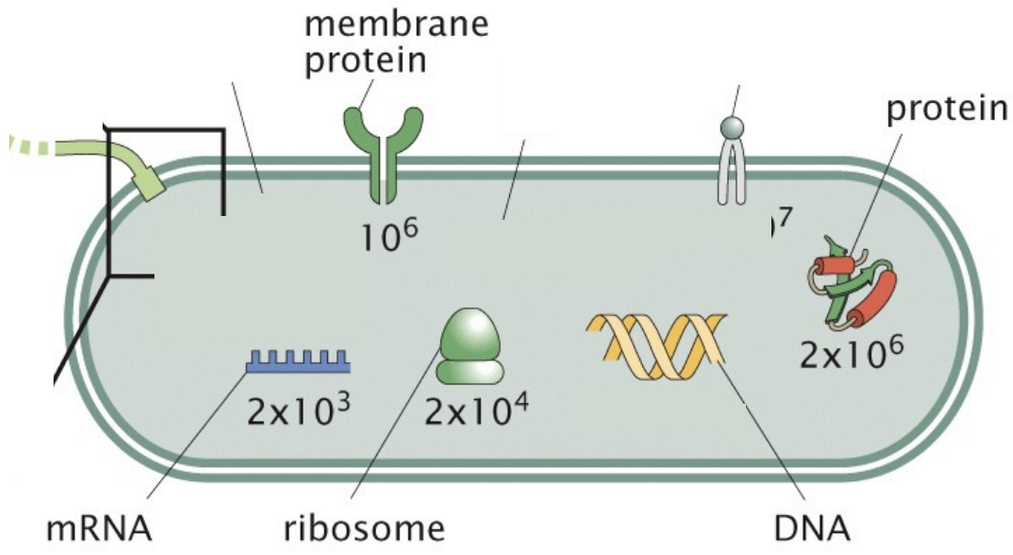

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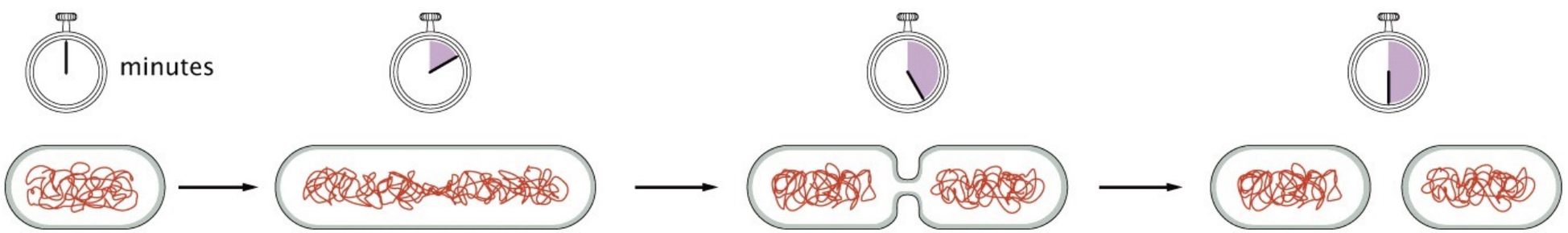

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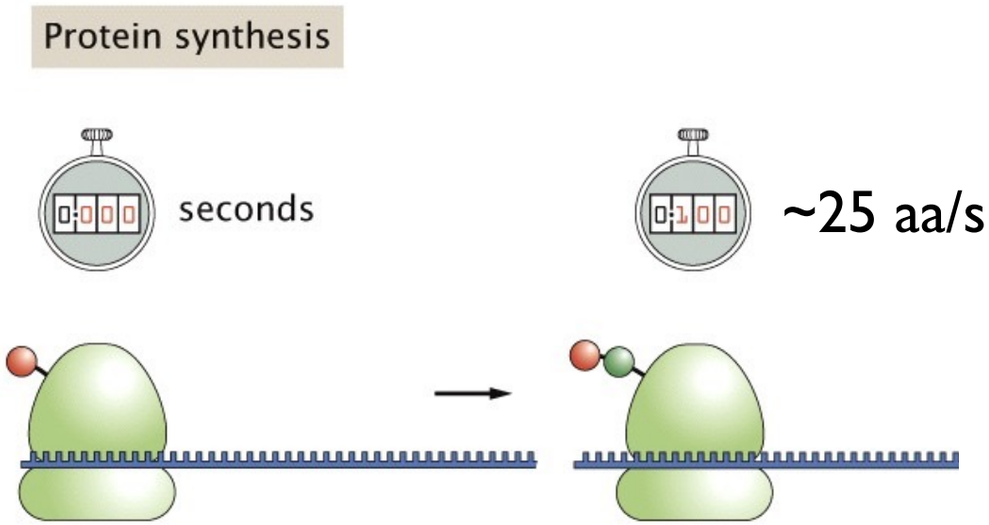

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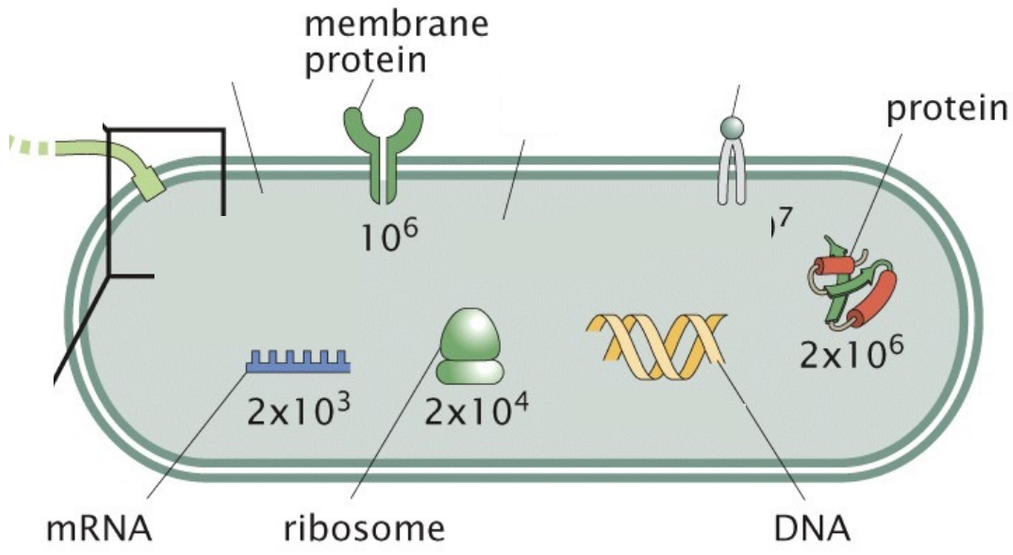

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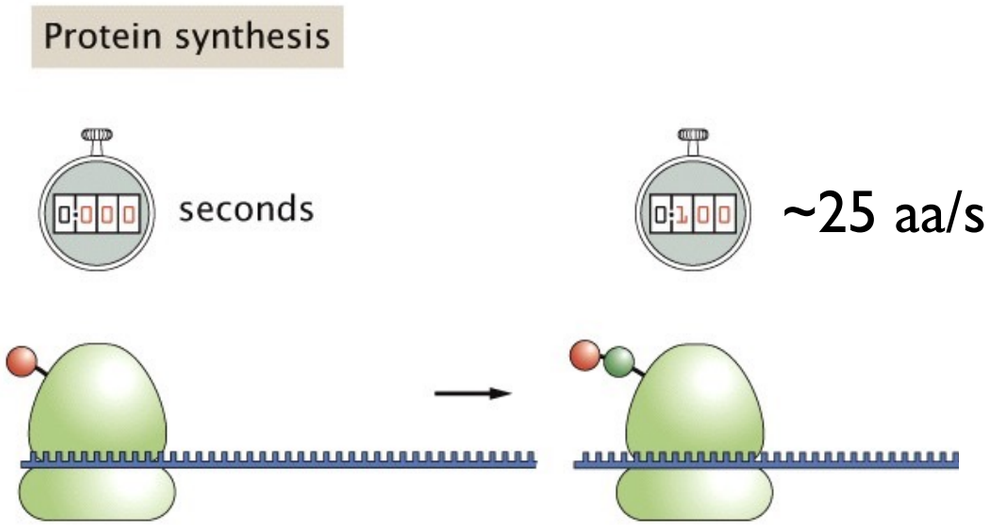
→ ~10s per protein

(~20s / mRNA)

What can we learn from these numbers?



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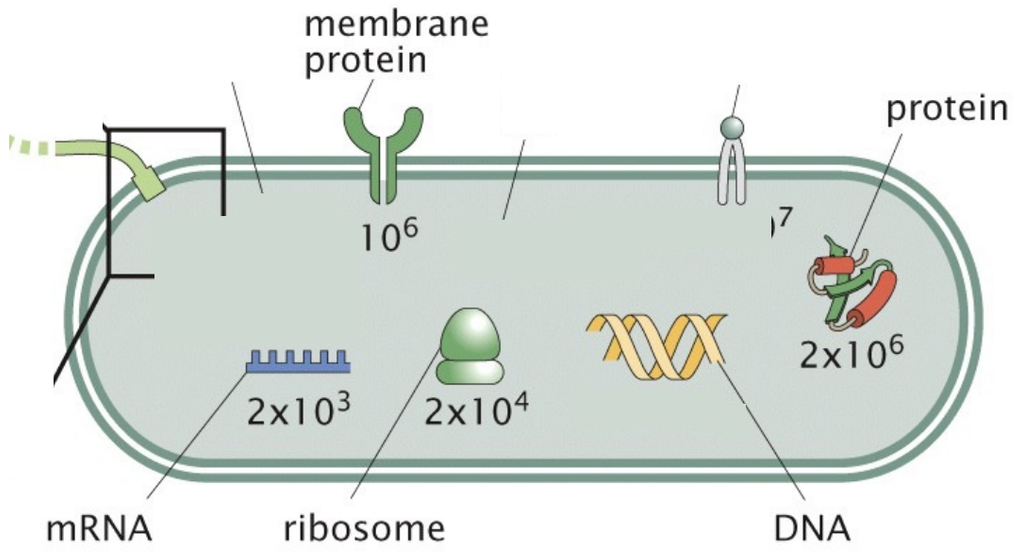

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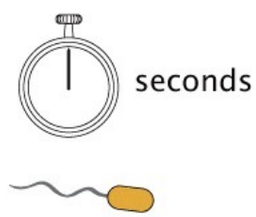


How can we count absolute # of molecules per cell?

One way: *fluctuations during division*

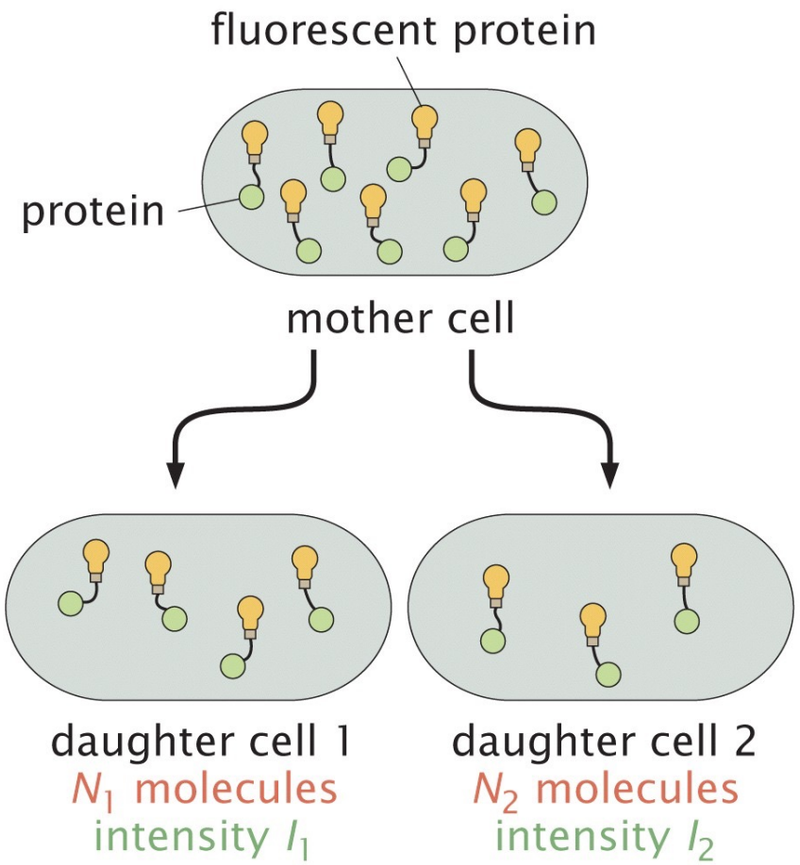
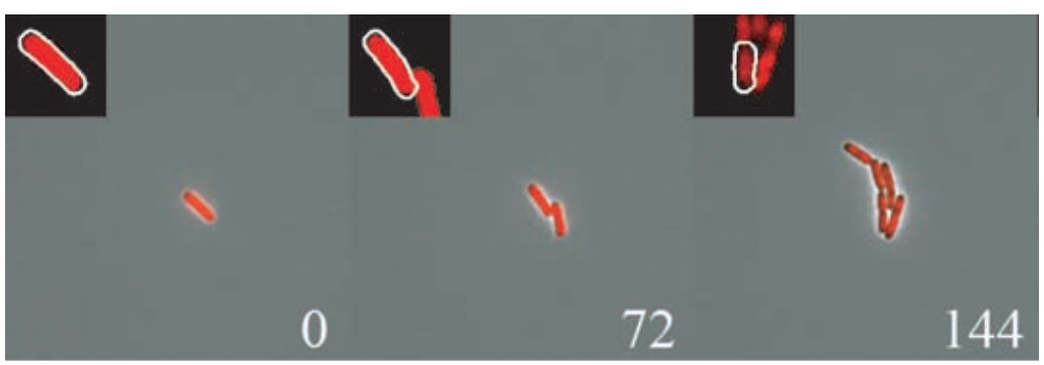


Figure 2.10a Physical Biology of the Cell, 2ed. (© Garland Science 2013)

Each molecule flips a coin:

$$\Pr[N_1 = k] = \binom{N}{k} \left(\frac{1}{2}\right)^k \left(1 - \frac{1}{2}\right)^{N-k}$$

"binomial distribution"



Rosenfeld et al, Science 2005

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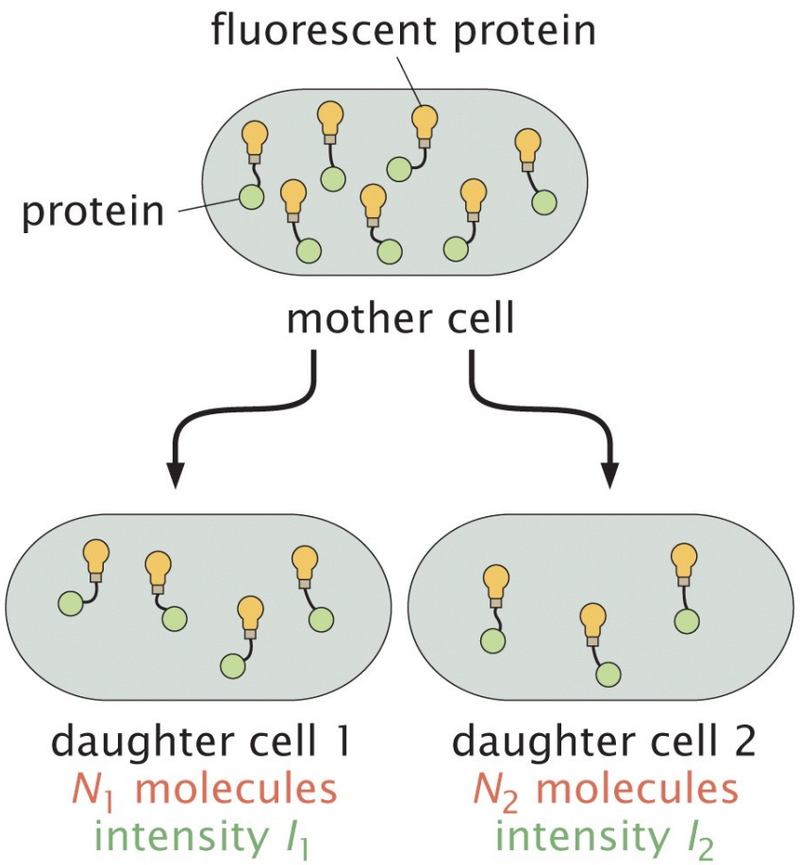


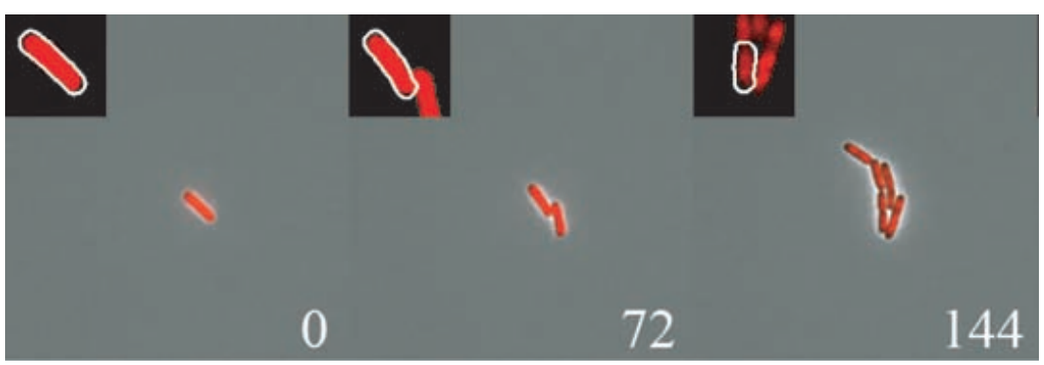
Figure 2.10a Physical Biology of the Cell, 2ed. (© Garland Science 2013)

Each molecule flips a coin:

$$\Pr[N_1 = k] = \binom{N}{k} \left(\frac{1}{2}\right)^k \left(1 - \frac{1}{2}\right)^{N-k}$$

"binomial distribution"

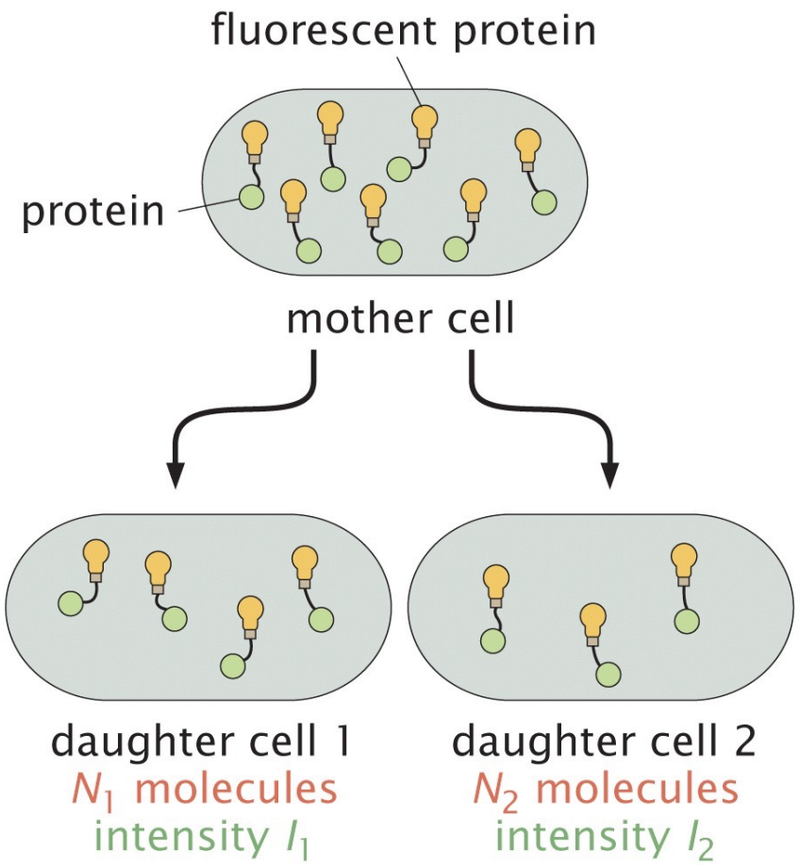
Average: $\langle N_1 \rangle \equiv \overline{N}_1 = N/2$



Rosenfeld et al, Science 2005

How can we count absolute # of molecules per cell?

One way: *fluctuations during division*



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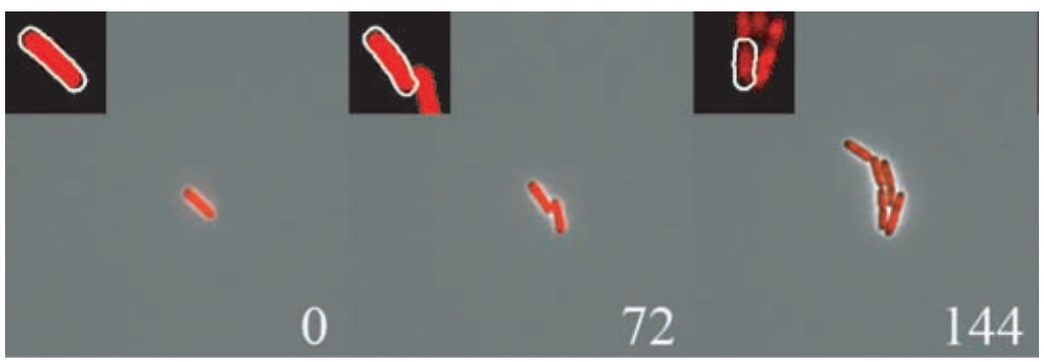

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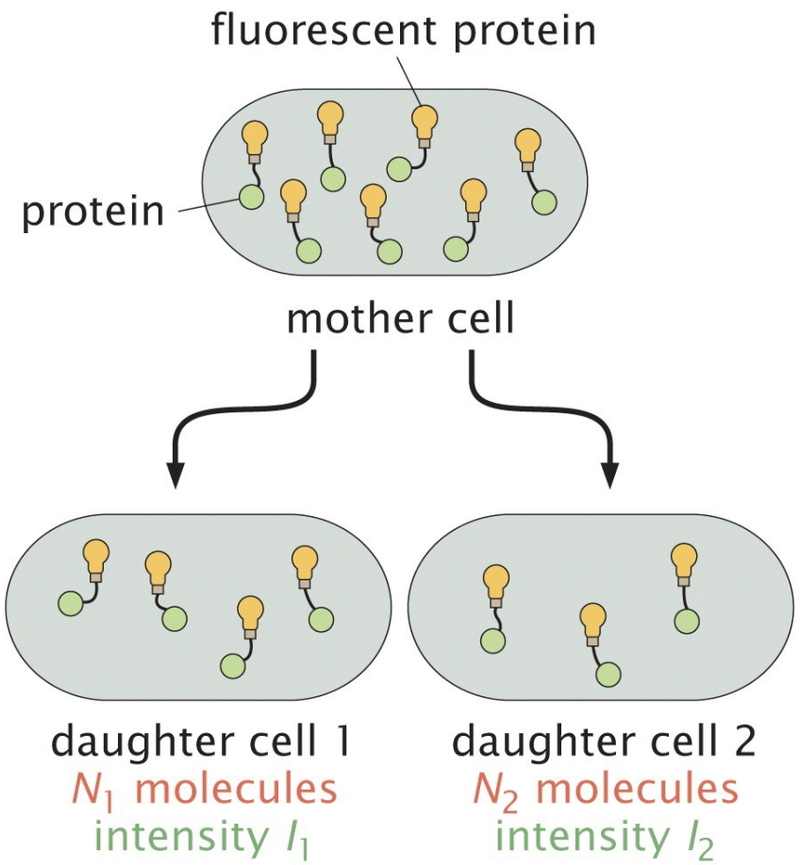

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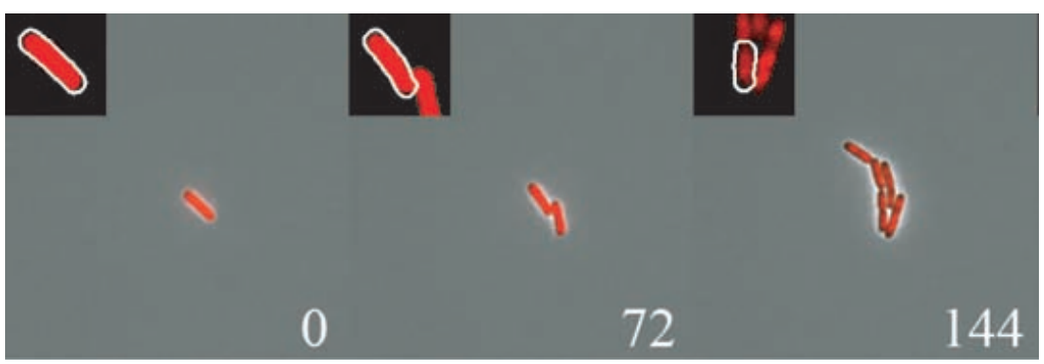

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$$\left\langle \left(\frac{\delta I}{I}\right)^2 \right\rangle = \left\langle \left(\frac{\delta N}{N}\right)^2 \right\rangle = \frac{1}{N}$$

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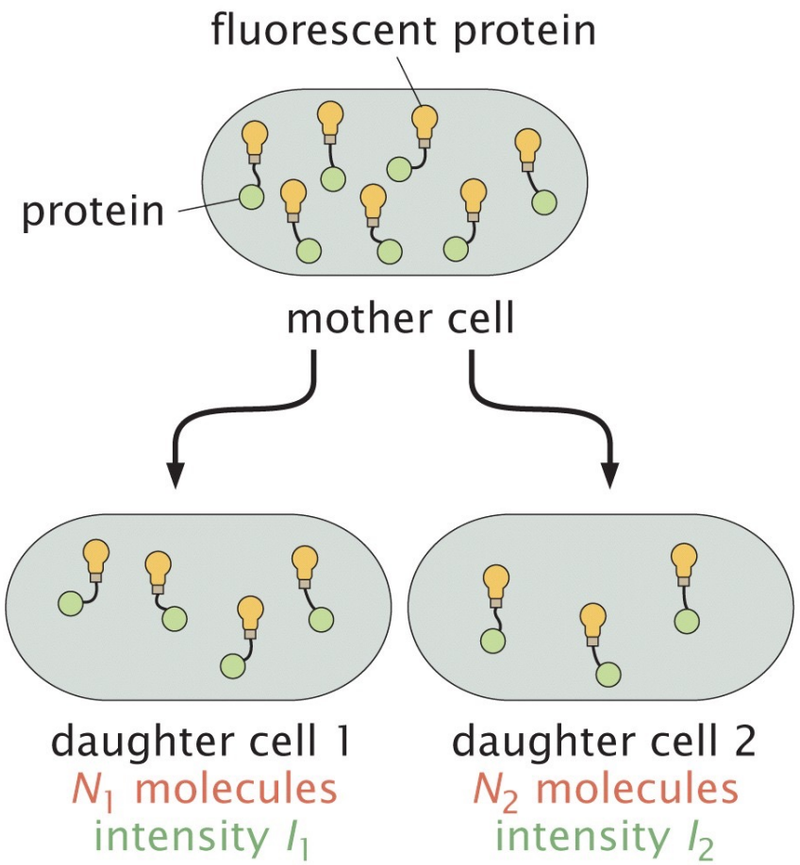

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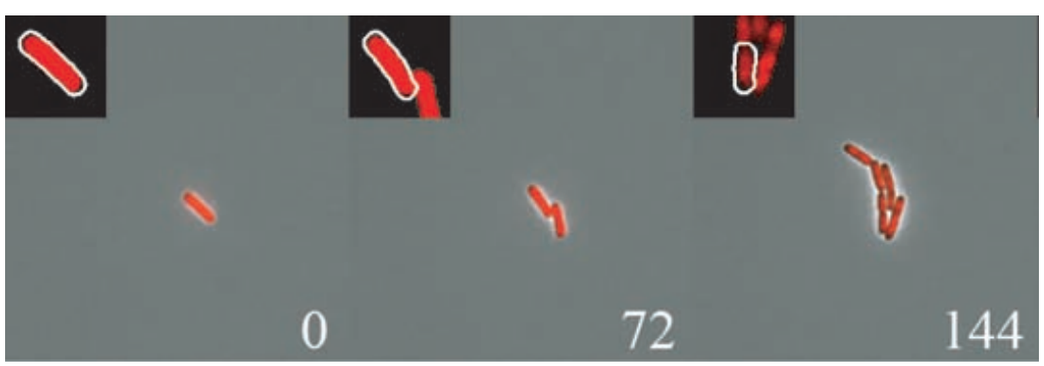
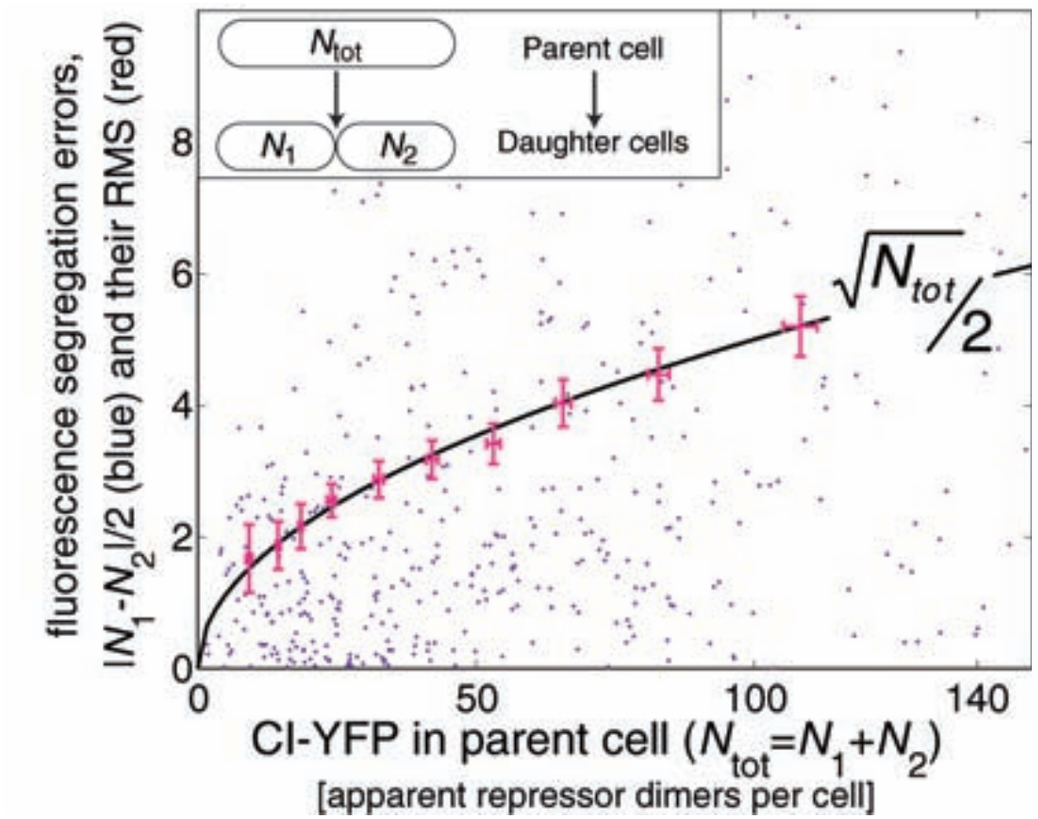


Rosenfeld et al, Science 2005



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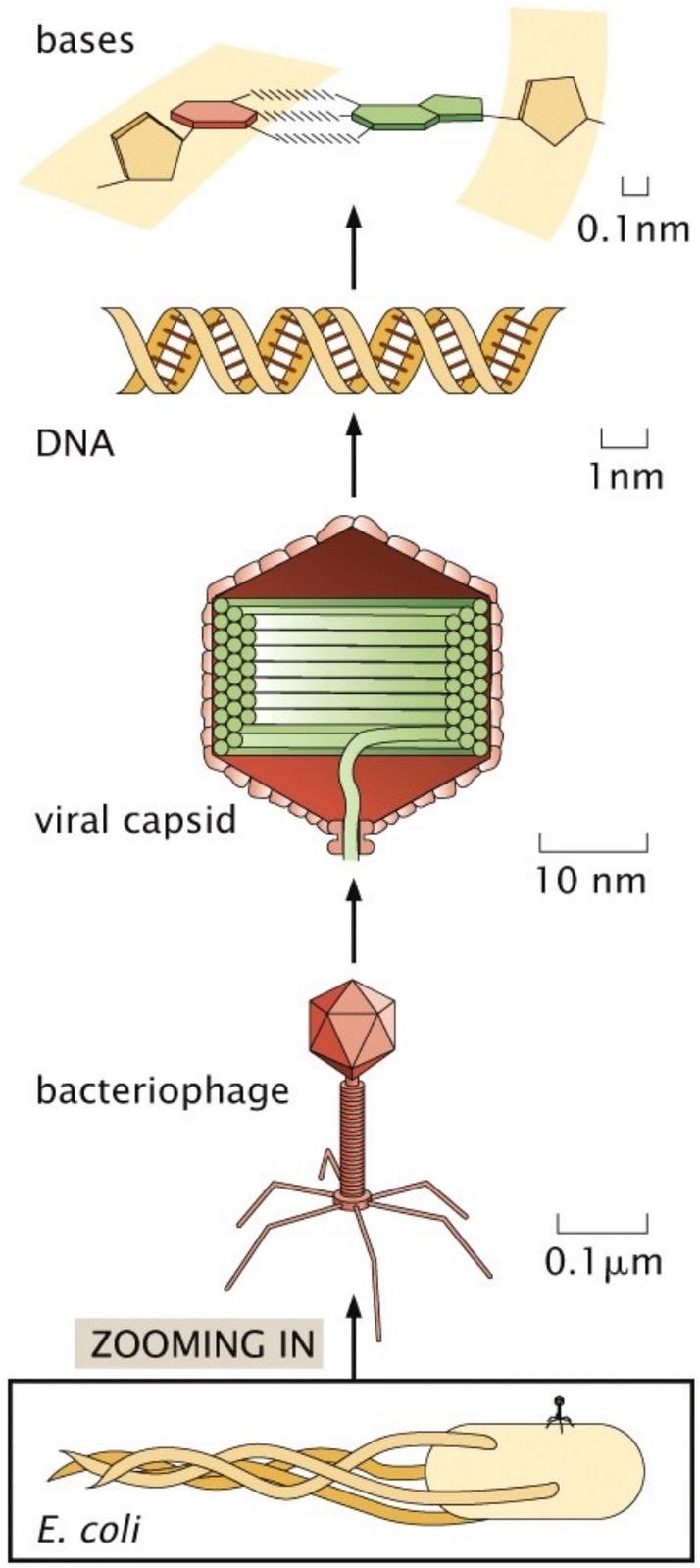

Figure 2.15 (part 1 of 2) Physical Biology of the Cell, 2ed. (© Garland Science 2013)

Next time:

Introduction to

Statistical Mechanics