Red ball in vibrating box

See Lecture 3 diffusion experiment movie on course website.

\[ D = 0.2 \text{ cm}^2/\text{s} \]. Red ball diffuses \( L = 23 \text{ cm} \) along \( x \)-axis in roughly \( \frac{L^2}{2D} = 1323 \text{ s} \).
Water molecule [0.3 nm diameter] surrounded by water

\[ D \approx 2000 \ \mu m^2/s \]

0.25 ms

1 \ \mu m
Water molecule inside cell nucleus

\[ D \approx 200 \ \mu \text{m}^2/\text{s} \]

2.5 ms

1 \ \mu \text{m}
Protein [2 nm diameter] surrounded by water

\[ D \approx 100 \, \mu m^2/s \]

5 ms

1 \mu m
Protein inside cell

\[ D \approx 10 \, \mu m^2/s \]

50 ms

1 \, \mu m
Protein bound to membrane

\[ D \approx 0.1 - 1 \ \mu m^2/s \]

0.5 – 5 s

1 \mu m
Protein sliding along DNA

\[ D \approx 0.01 - 0.1 \, \mu m^2/s \]

5 - 50 s

1 \, \mu m
Protein inside cell: different cell sizes

Typical time to diffuse across:

1 µm bacterium: 0.05 s
Protein inside cell: different cell sizes

Typical time to diffuse across:
- $1 \mu m$ bacterium: $0.05$ s
- $10 \mu m$ human cell: $5$ s
Protein inside cell: different cell sizes

Typical time to diffuse across:

- $1 \mu m$ bacterium: 0.05 s
- $10 \mu m$ human cell: 5 s
- 3 m giraffe neck neuron: 14,000 yrs!!
Protein inside cell: different cell sizes

Typical time to diffuse across:

1 $\mu$m bacterium: 0.05 s
10 $\mu$m human cell: 5 s
3 m giraffe neck neuron: 14,000 yrs !!

Giraffes do not exist.
Life at larger scales is an exception rather than the rule

While the mechanisms of how large-scale life operates are fascinating, keep in mind they are a sideshow to the primarily unicellular, small-scale nature of life on earth:

numbers of cells on Earth:

- prokaryotes: $5 \times 10^{30}$
- plants: $2.4 \times 10^{28}$
- unicellular eukaryotes: $2.3 \times 10^{26}$
- animals: $1.3 \times 10^{26}$