1. **Pick up** Name Folder

- Pick up name folder and set it up at seat.

2. **Sit** with your lab group.

- laptops almost closed (avoid distracting)

3. **Clicker** Attendance

- Launch your Top Hat, and get ready to click.

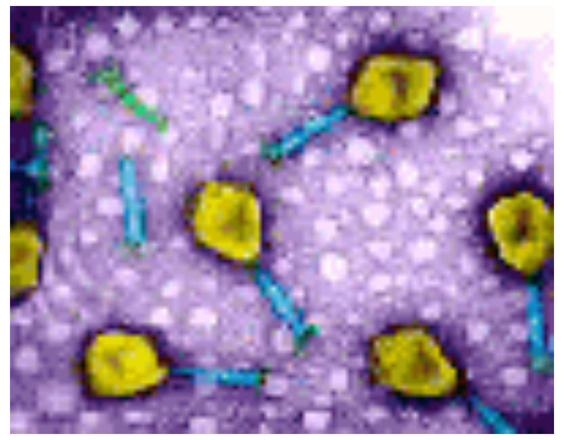
. Laptops closed (unless TopHat)

(open if need 4 TopHat, don't distract others)

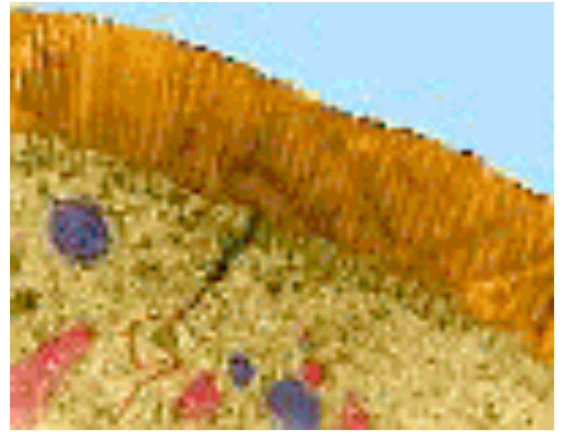
Announcements

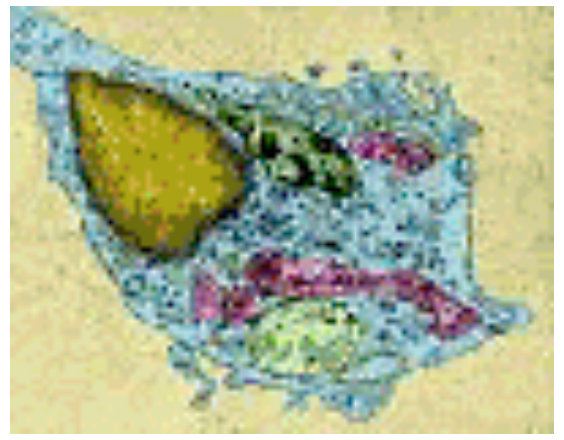
1. **You need to have completed Hazardous waste training and bring Certificate to enter lab today**



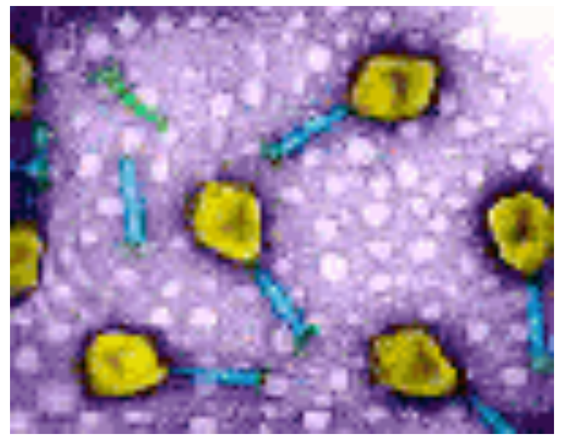


See *different*

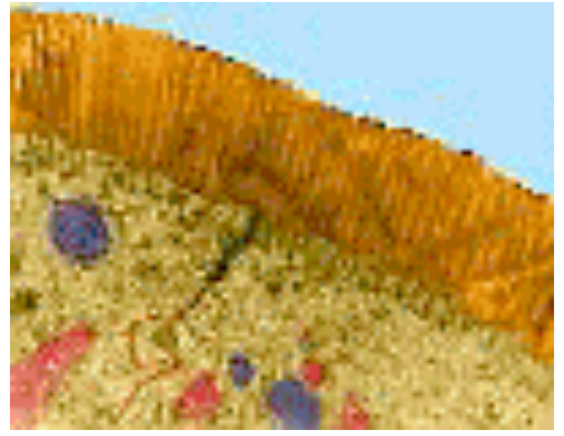


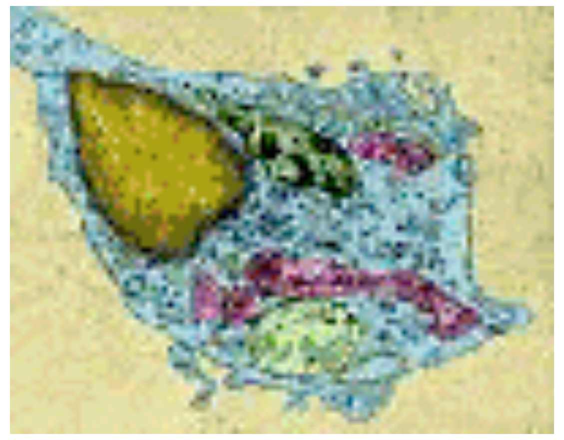






(the “verbal” final)





The verbal final


incoming photon
Stroma (pH8)
incoming photon
NADP$_{ox}$
OH$^-$
OH$^-$
OH$^-$
OH$^-$
OH$^-$
OH$^-$
OH$^-$
OH$^-$
NAD$_{re}$
Q
PQ
P680
2e$^-$
2e$^-$
2e$^-$
P700
2e$^-$
Cyt f
PC
Fd
2e$^-$
FAD
FeS
Z
PQ
2e$^-$
2H$^+$
2H$^+$
H+
H$^+$
PHOTOSYSTEM II
PHOTOSYSTEM I
H$_2$O
$\frac{1}{2}$O$_2$
Thylakoid interior (pH4)


OH⁻
OH
OH
PQ
PQ
2e⁻
2e⁻
Cyt f
PC
P700
Fd
FeS
2H⁺
H⁺
Electron transfer
Primary electron acceptor
Photon
Reaction-center chlorophyll
ransfer
f energy
Antenna pigment molecules
Photosystem

The verbal final

4.4 Can non-living objects harvest and store energy?

- Context: Life consumes energy, and the first cells would need an abiotic way to harvest and store energy.
- Major theme: The origin of living systems occurred by natural processes, and life continues to evolve within a changing environment; organisms can be linked by lines of descent from common ancestry.
- Bottom line: Nonliving vesicles can accumulate energy in the form of a pH gradient.

Biology Learning Objectives

- Use evidence to support the scientific understanding that life evolved from abiotic forces and phenomenon.
- Discuss how vesicles can grow, compete, *and store energy*.
- Illustrate how abiotic structures exhibit dynamic and competitive behaviors.

In Section 4.2, you saw RNA molecules function as RNA polymerases. In Section 4.3, you saw RNA molecules become entrapped inside abiotic vesicles and produce osmotic pressure to out-compete relaxed vesicles for lipids. Life also requires energy, and so far you have not seen any data indicating that these primitive cells could harvest or store energy. Is it possible for primitive, abiotic cells to store energy in an abiotic world? Could growing vesicles sequester energy that could be used to do work at a later time? You will analyze published data that will help you determine if energy storage is possible in an abiotic world.

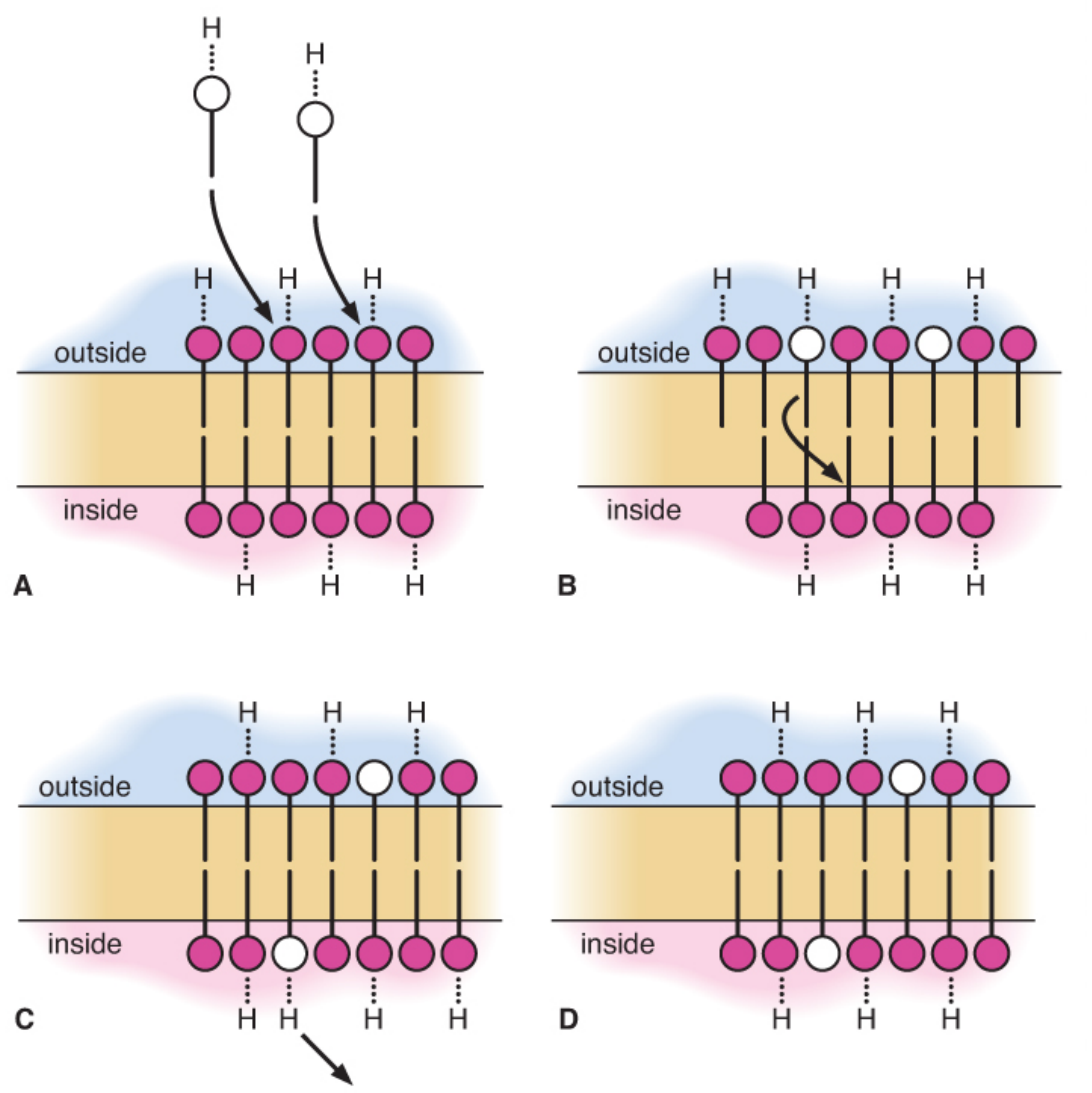


Figure 4.16 Proposed mechanism for accumulation of a pH gradient inside the vesicle lumen. The process proceeds from **(A)** through **(D)** over time to gradually accumulate H^+ ions inside vesicles, which lowers internal pH. Lipids can flip from one side of the bilayer to the other. From Chen and Jack W. Szostak. 2004a. Figure 2. Irene A. Chen and Jack W. Szostak. 2004a. Membrane growth can generate a transmembrane pH gradient in fatty acid vesicles. PNAS. 101 (21): 7965 – 7970. Copyright (2004) National Academy of Sciences, U.S.A.

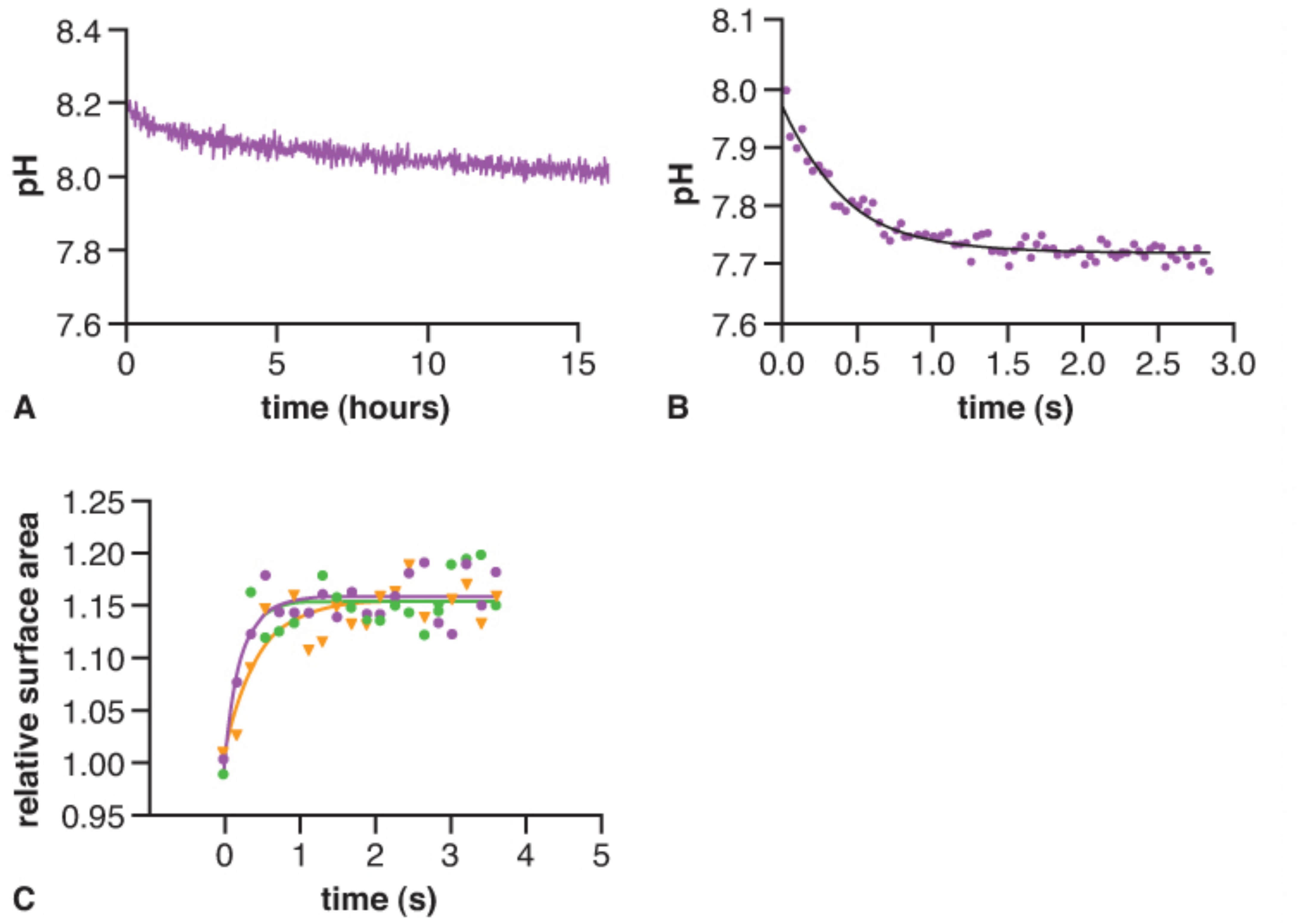


Figure 4.17 Vesicle pH after adding micelles. **A,** pH drops quickly at first, and then slowly. **B,** Reduced pH immediately after adding micelles. **C,** Change of surface area for vesicles in **B.** Three trials are shown with each line representing an exponential curve fit. From Chen and Jack W. Szostak. 2004a. Figure 3. Irene A. Chen and Jack W. Szostak. 2004a. Membrane growth can generate a transmembrane pH gradient in fatty acid vesicles. PNAS. 101 (21): 7965 – 7970. Copyright (2004) National Academy of Sciences, U.S.A.

So a drawing of the mechanism is the WHAT?

Hypothesis

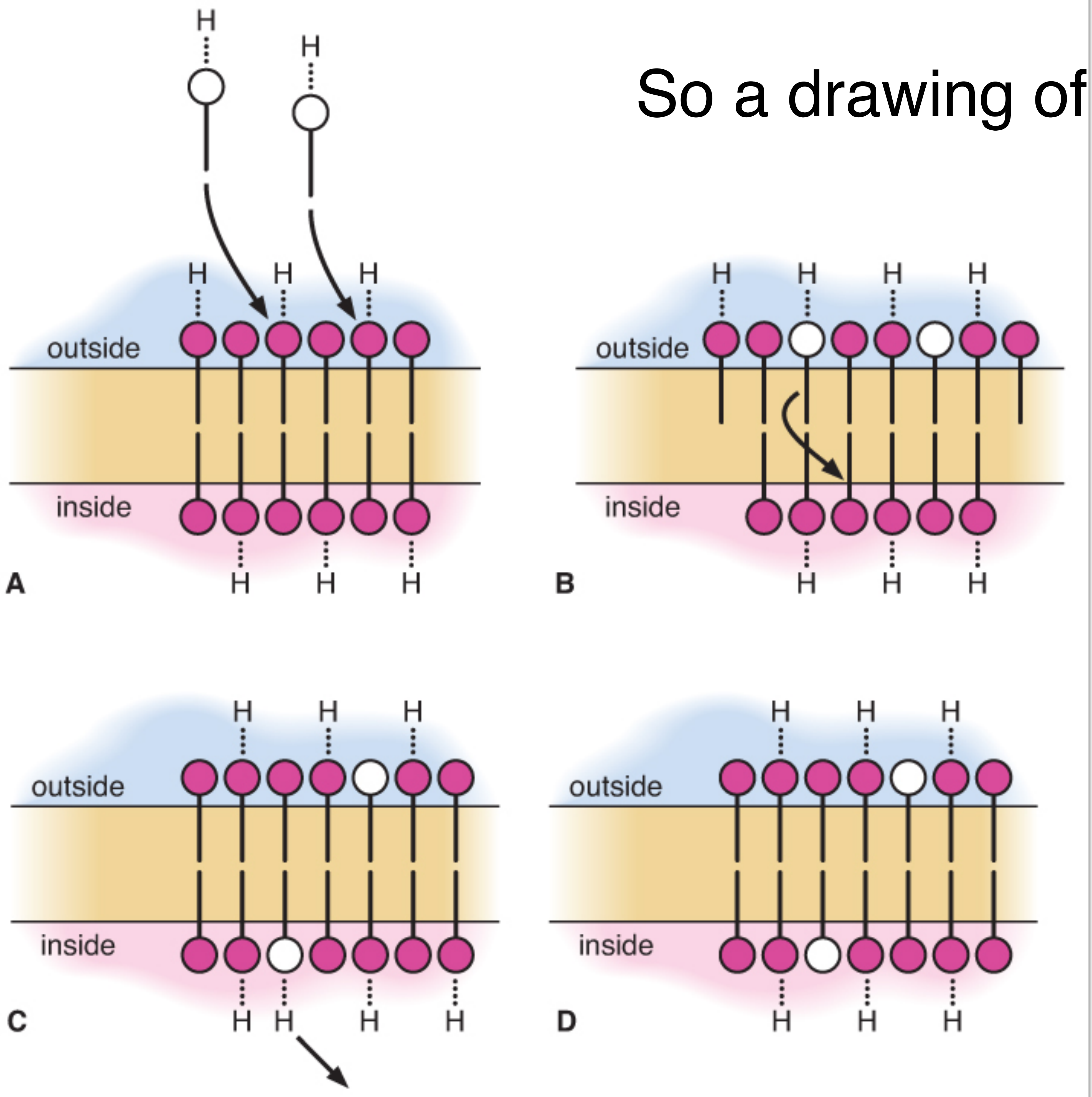
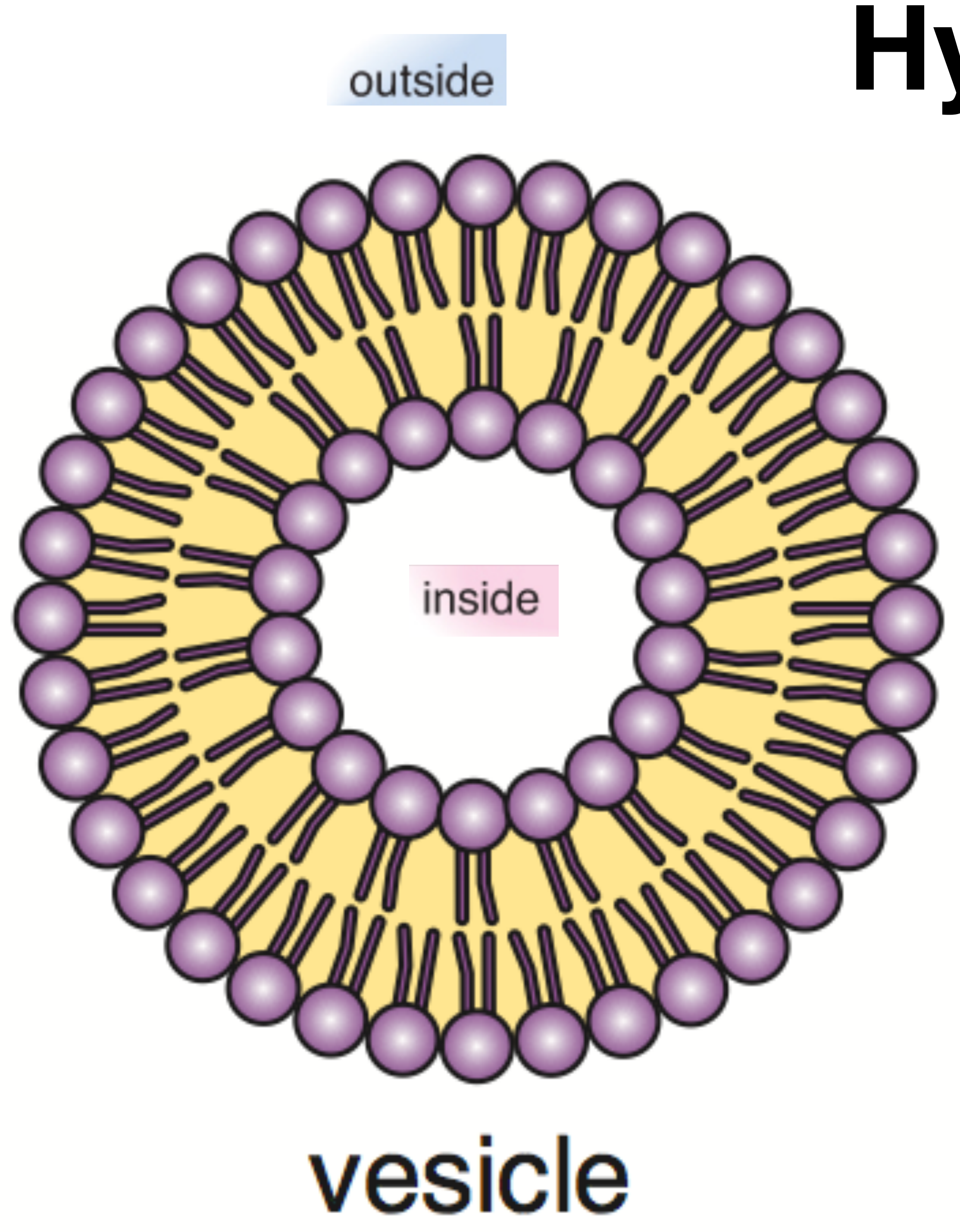
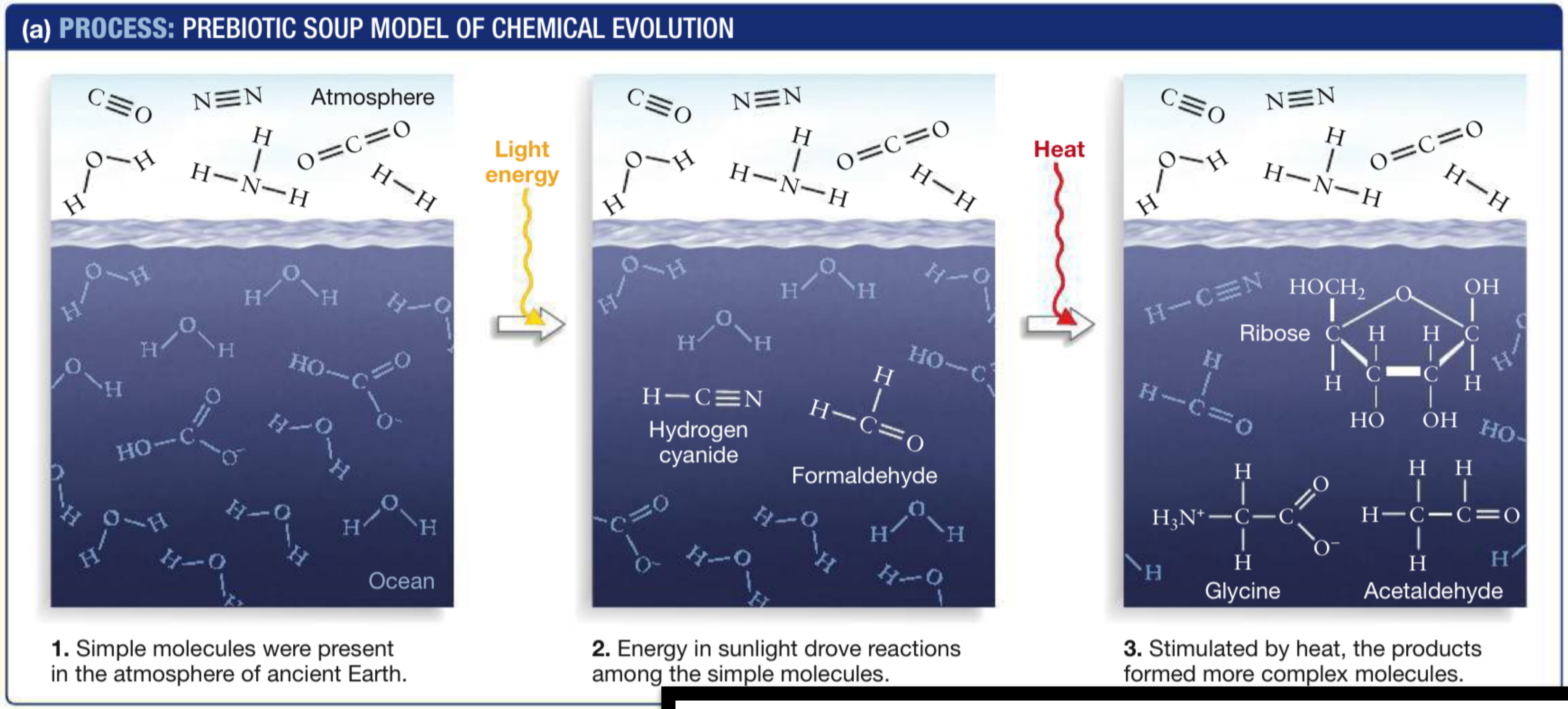
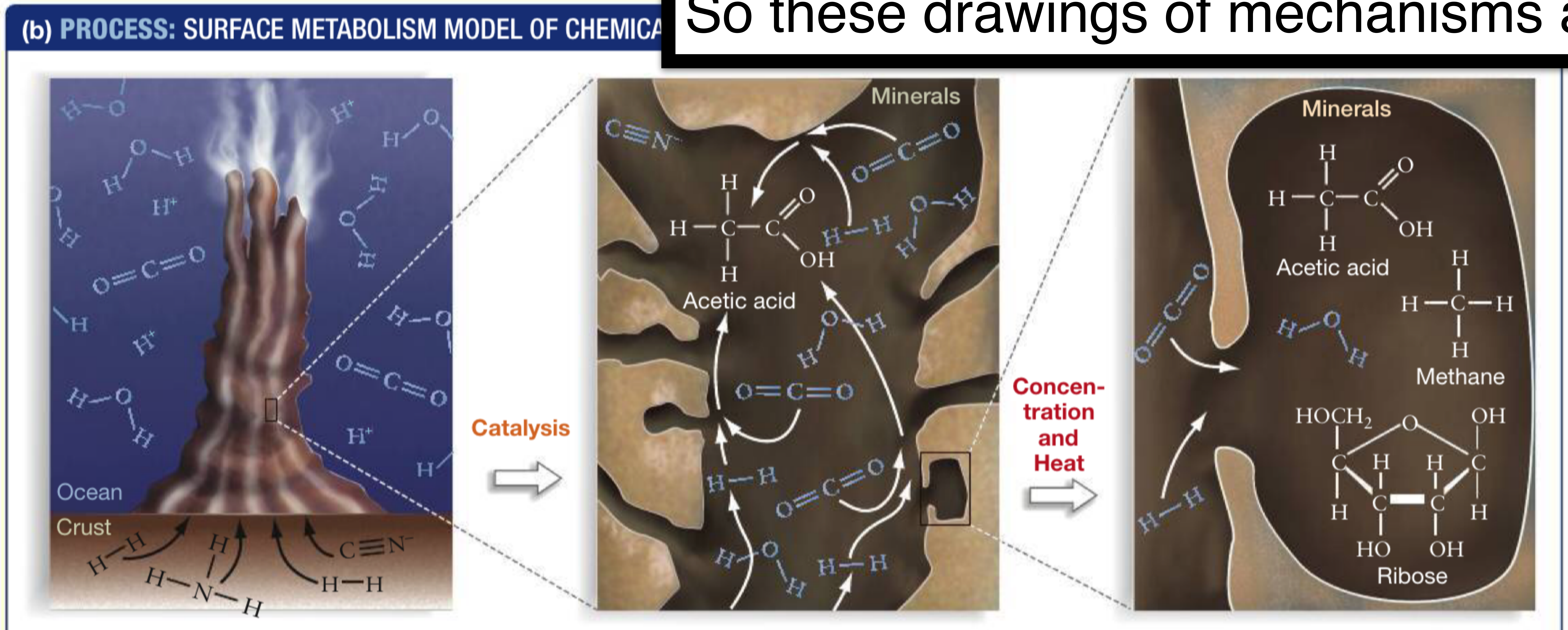


Figure 4.16 Proposed mechanism for accumulation of a pH gradient inside the vesicle lumen. The process proceeds from **(A)** through **(D)** over time to gradually accumulate H^+ ions inside vesicles, which lowers internal pH. Lipids can flip from one side of the bilayer to the other. From Chen and Jack W. Szostak. 2004a. Figure 2. Irene A. Chen and Jack W. Szostak. 2004a. Membrane growth can generate a transmembrane pH gradient in fatty acid vesicles. PNAS. 101 (21): 7965 – 7970. Copyright (2004) National Academy of Sciences, U.S.A.



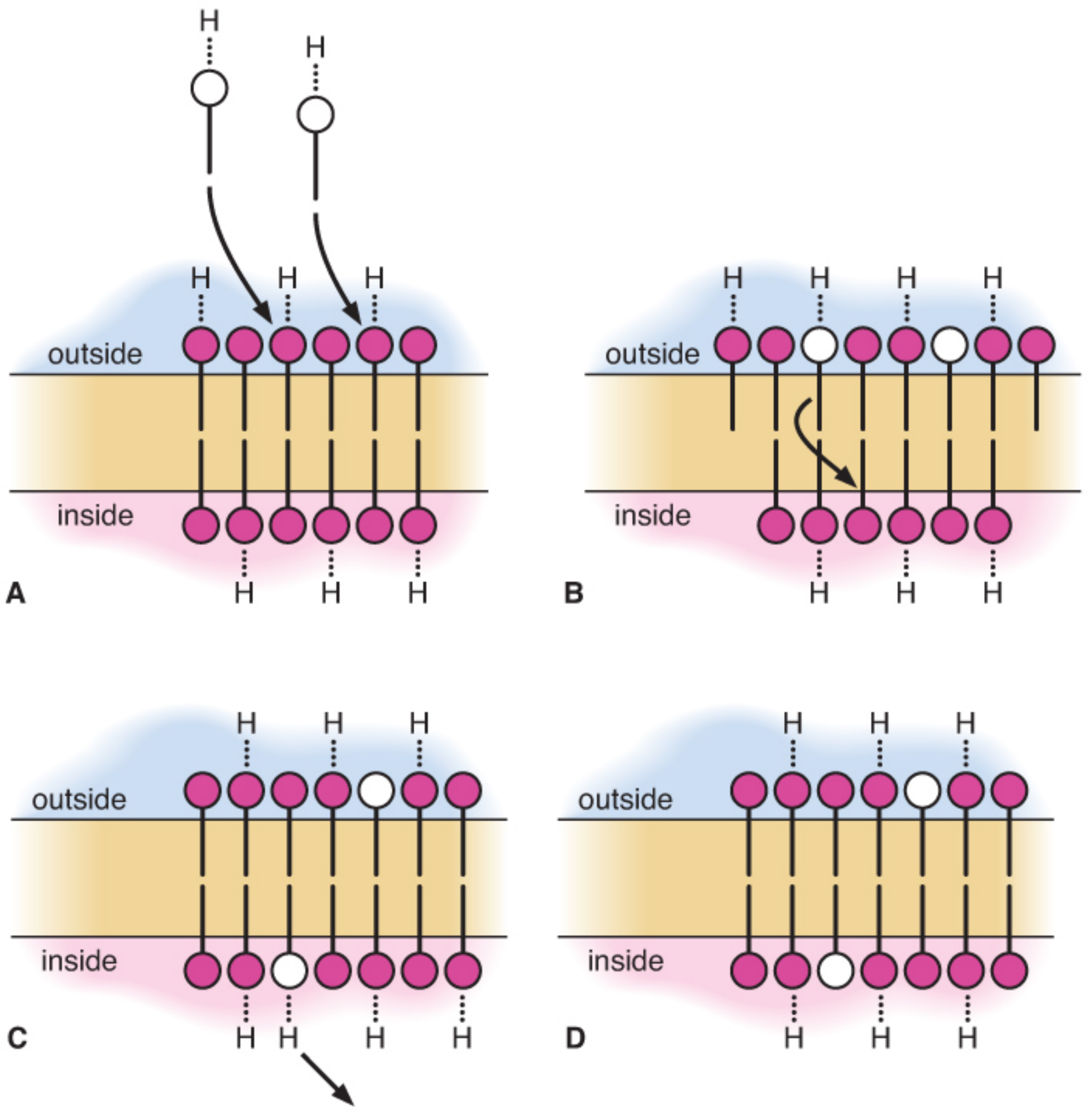


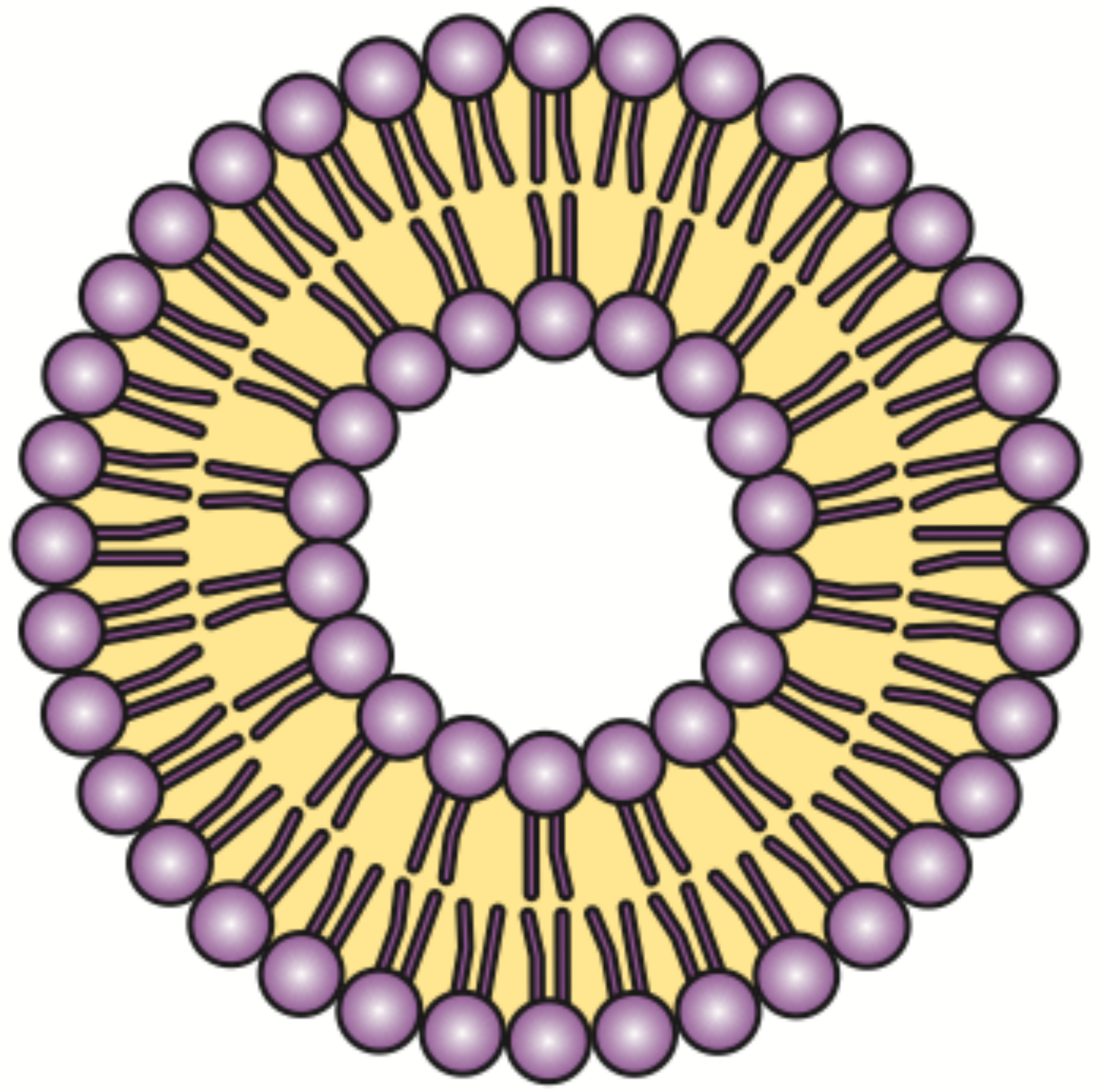
Hypothesis



So these drawings of mechanisms are the WHAT?

Hypothesis

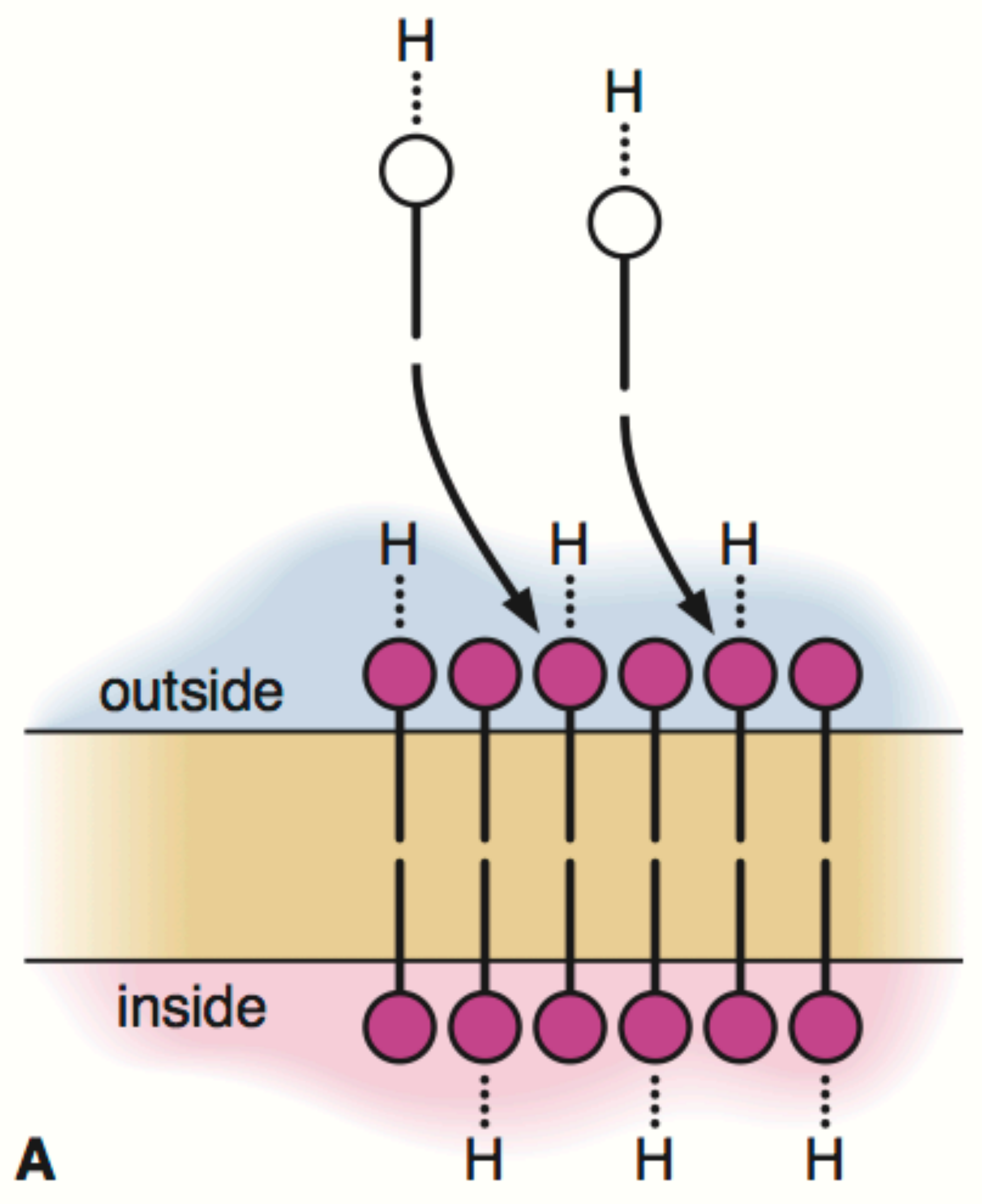




vesicle

Figure 4.16 Proposed mechanism for accumulation of a pH gradient inside the vesicle lumen. The process proceeds from **(A)** through **(D)** over time to gradually accumulate H^+ ions inside vesicles, which lowers internal pH. Lipids can flip from one side of the bilayer to the other. From Chen and Jack W. Szostak. 2004a. Figure 2. Irene A. Chen and Jack W. Szostak. 2004a. Membrane growth can generate a transmembrane pH gradient in fatty acid vesicles. PNAS. 101 (21): 7965 – 7970. Copyright (2004) National Academy of Sciences, U.S.A.

Model of pH Gradient Production



new lipids fuse with outer layer

Fig. 4.16

modified from Chen and Jack W. Szostak. 2004a

Model of pH Gradient Production

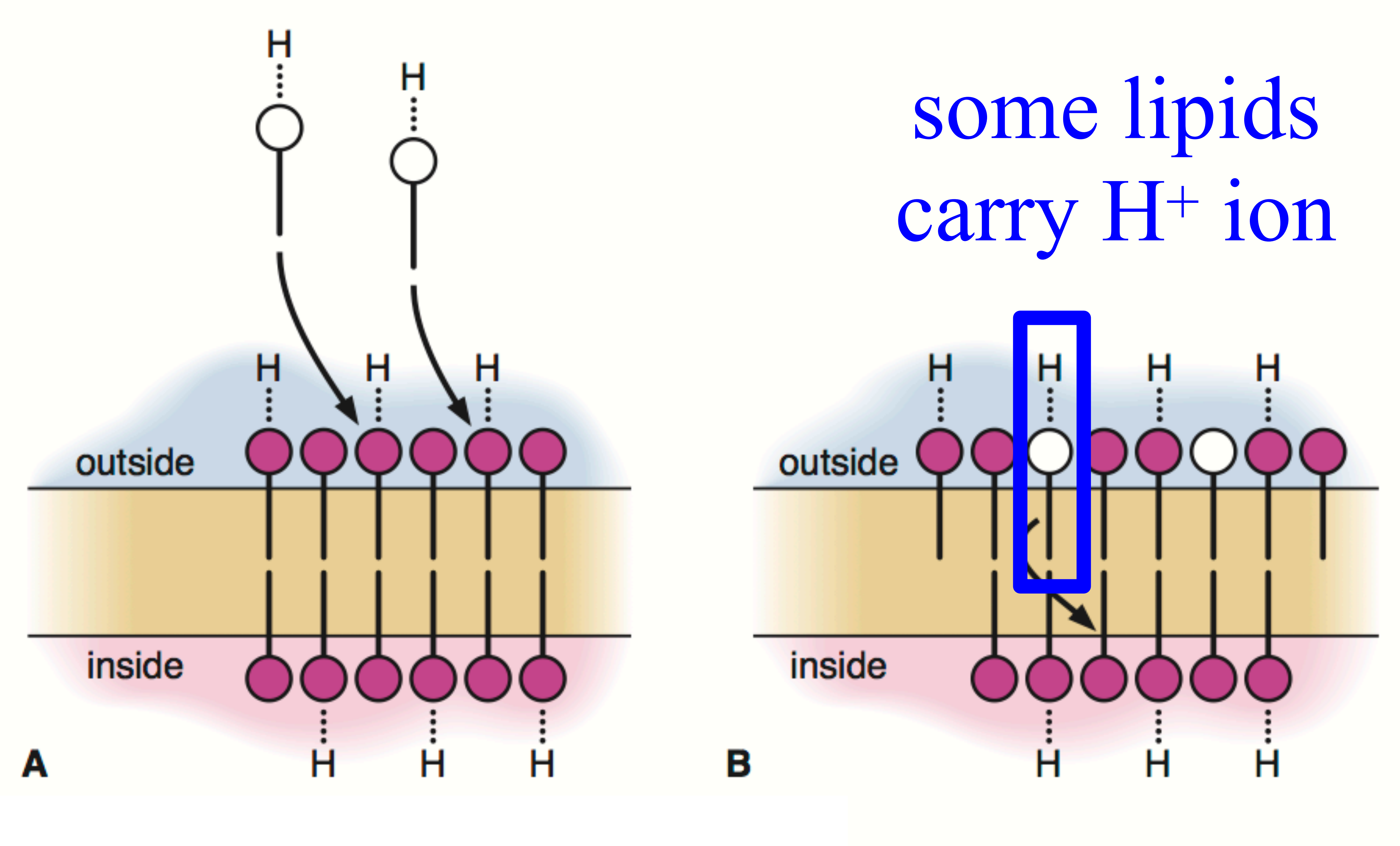
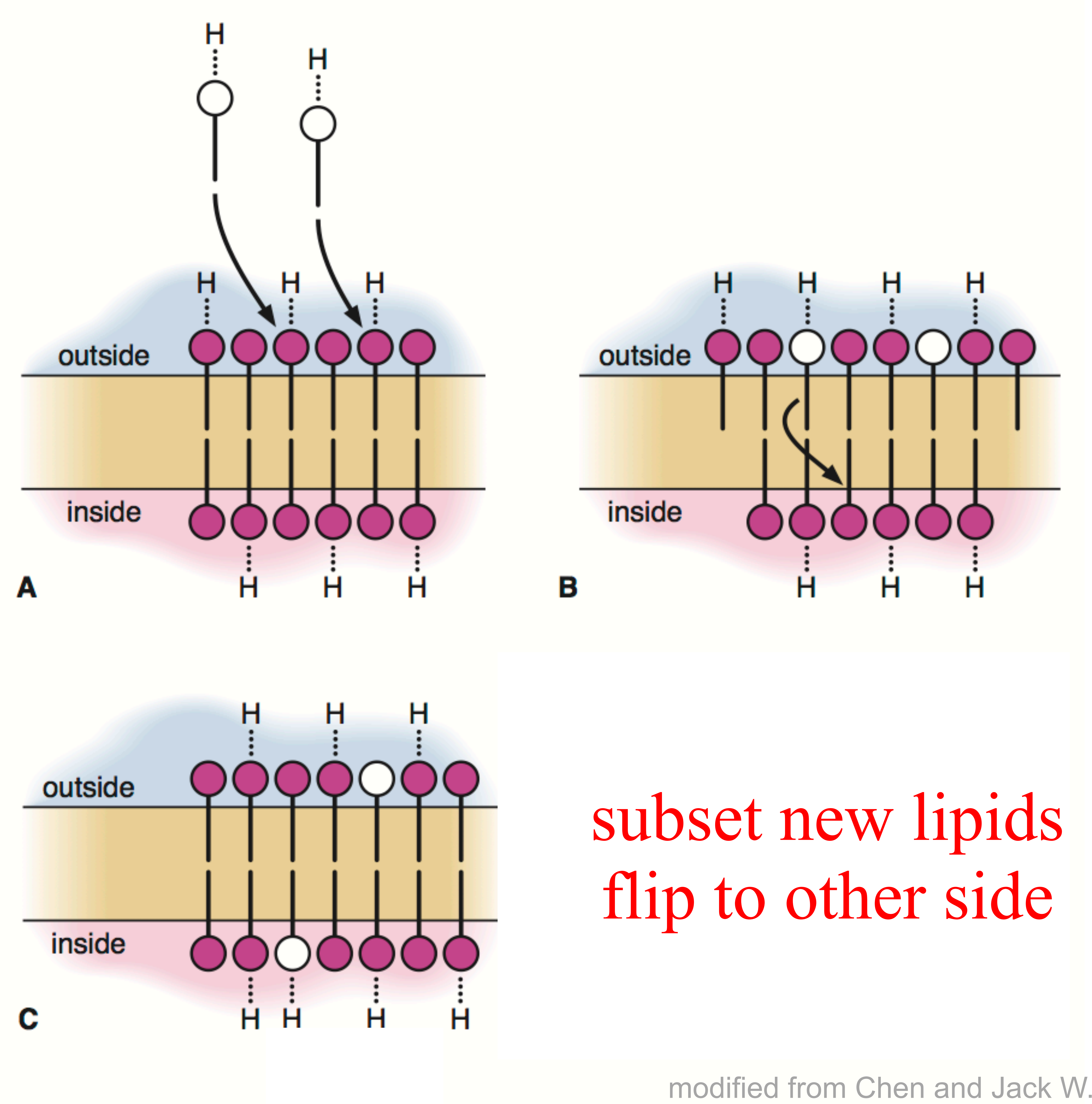


Fig. 4.16

modified from Chen and Jack W. Szostak. 2004a

Model of pH Gradient Production

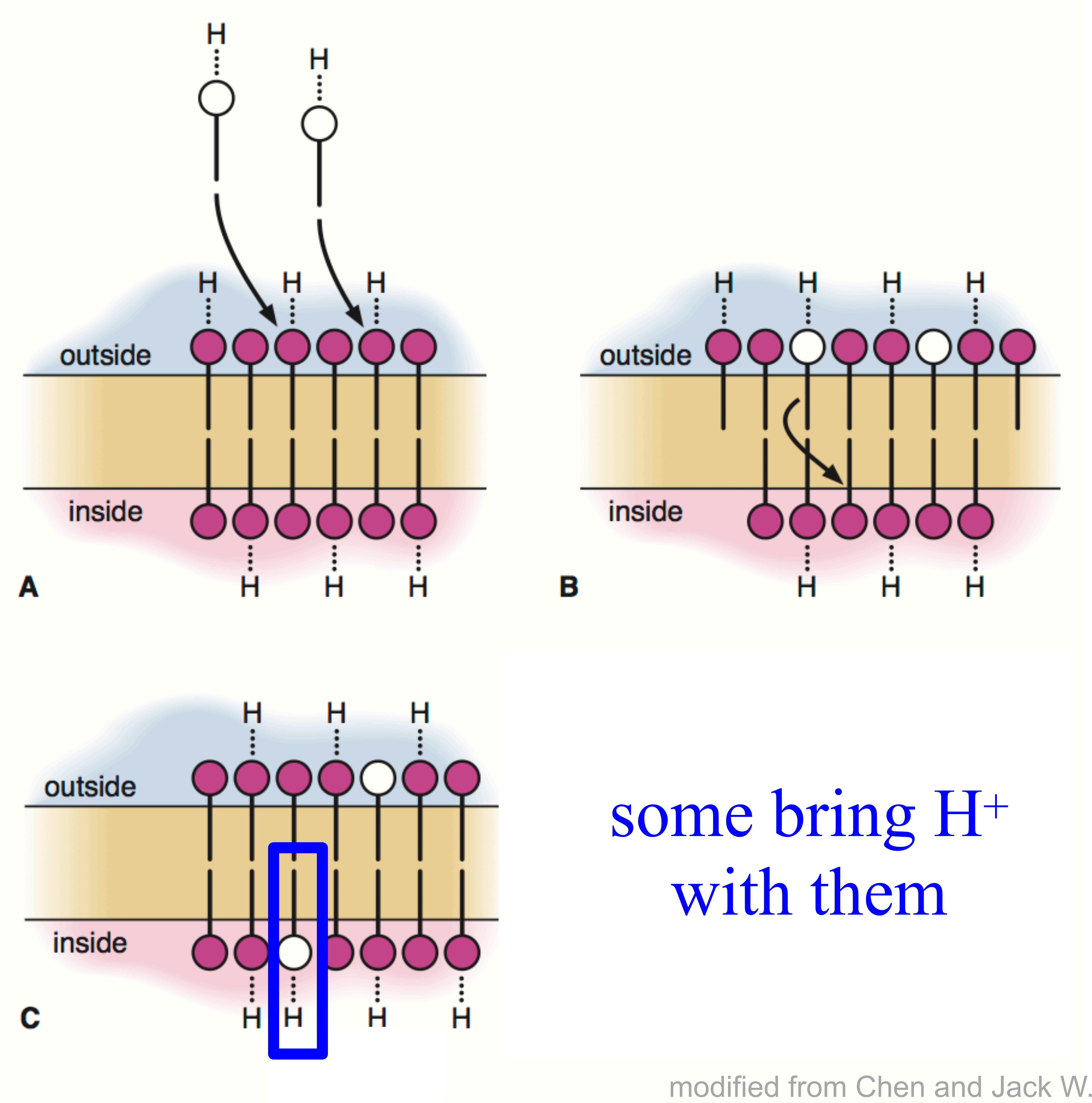


subset new lipids
flip to other side

Fig. 4.16

modified from Chen and Jack W. Szostak. 2004a

Model of pH Gradient Production

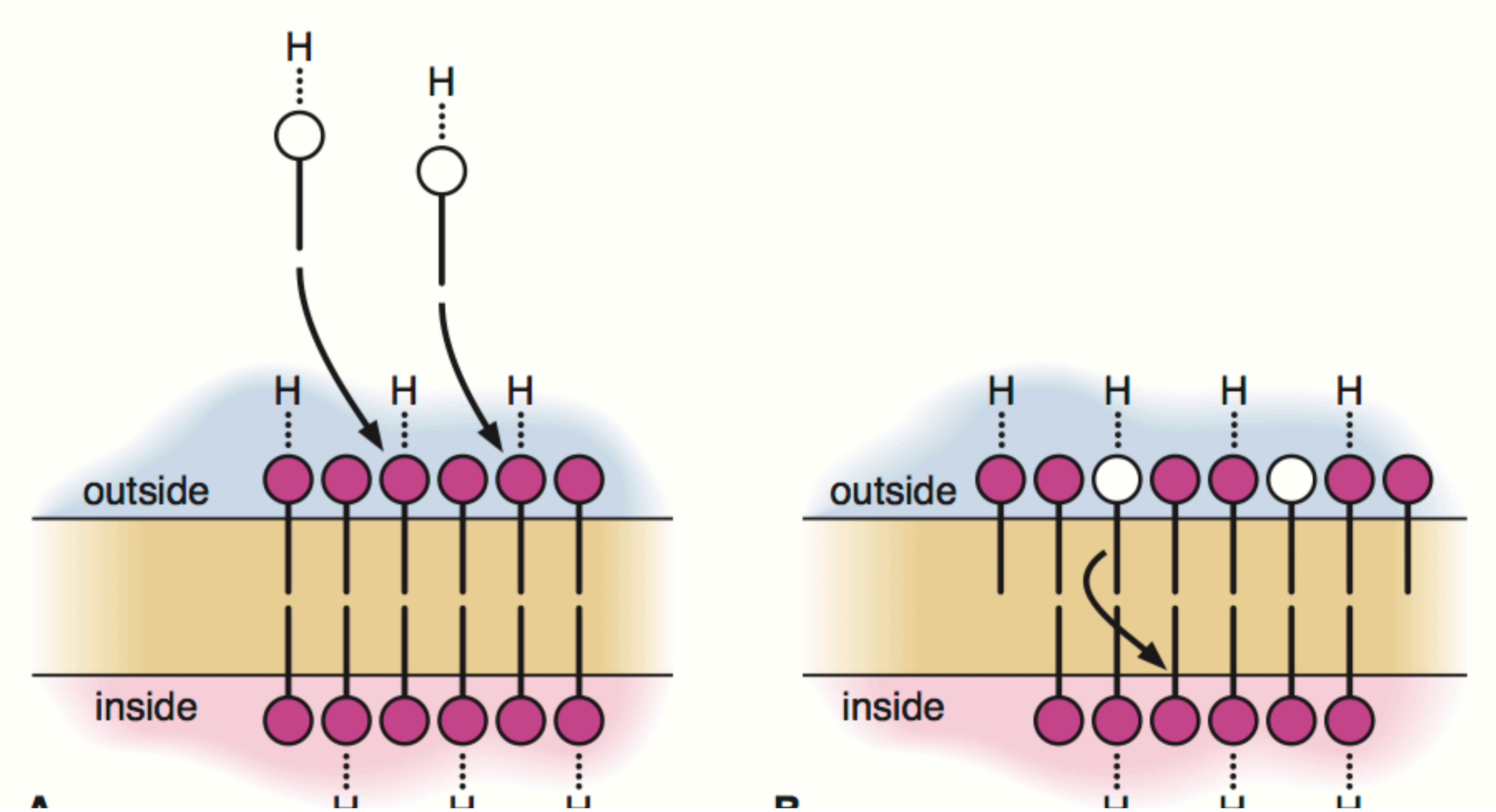


some bring H^+
with them

Fig. 4.16

modified from Chen and Jack W. Szostak. 2004a

Model of pH Gradient Production



subset of new charges diffuse inside vesicle

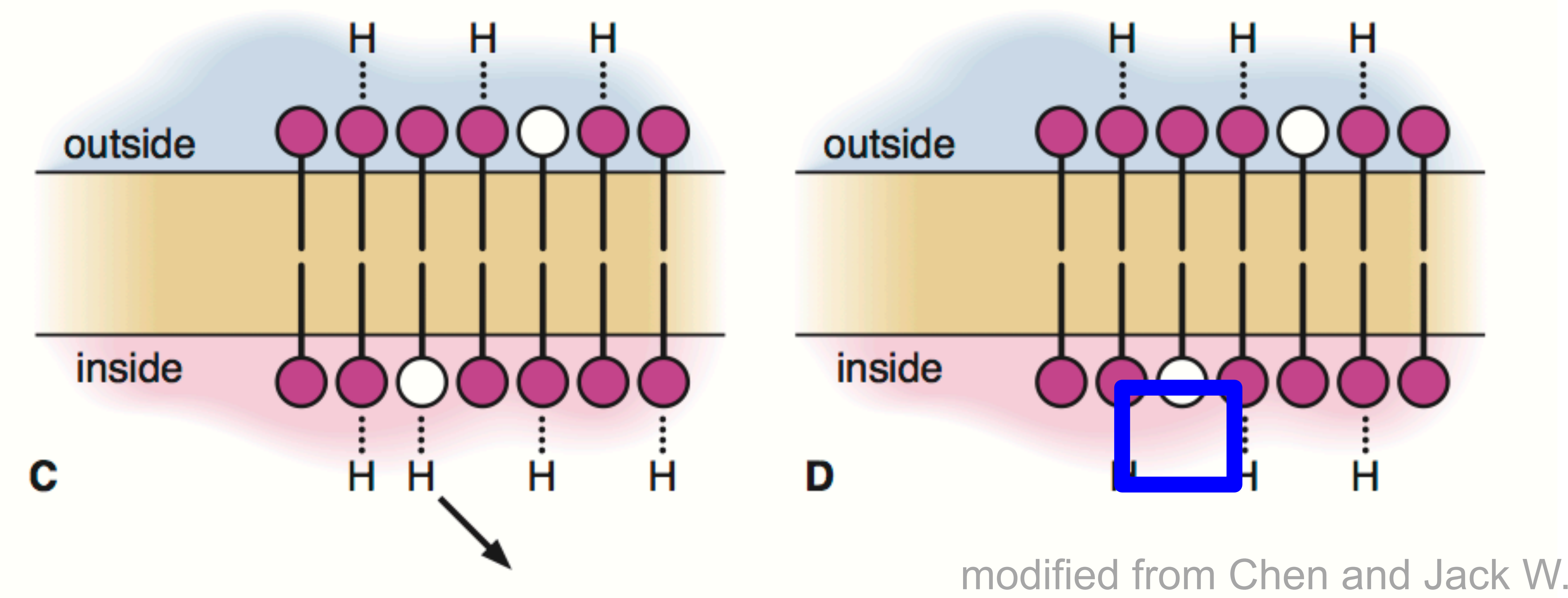
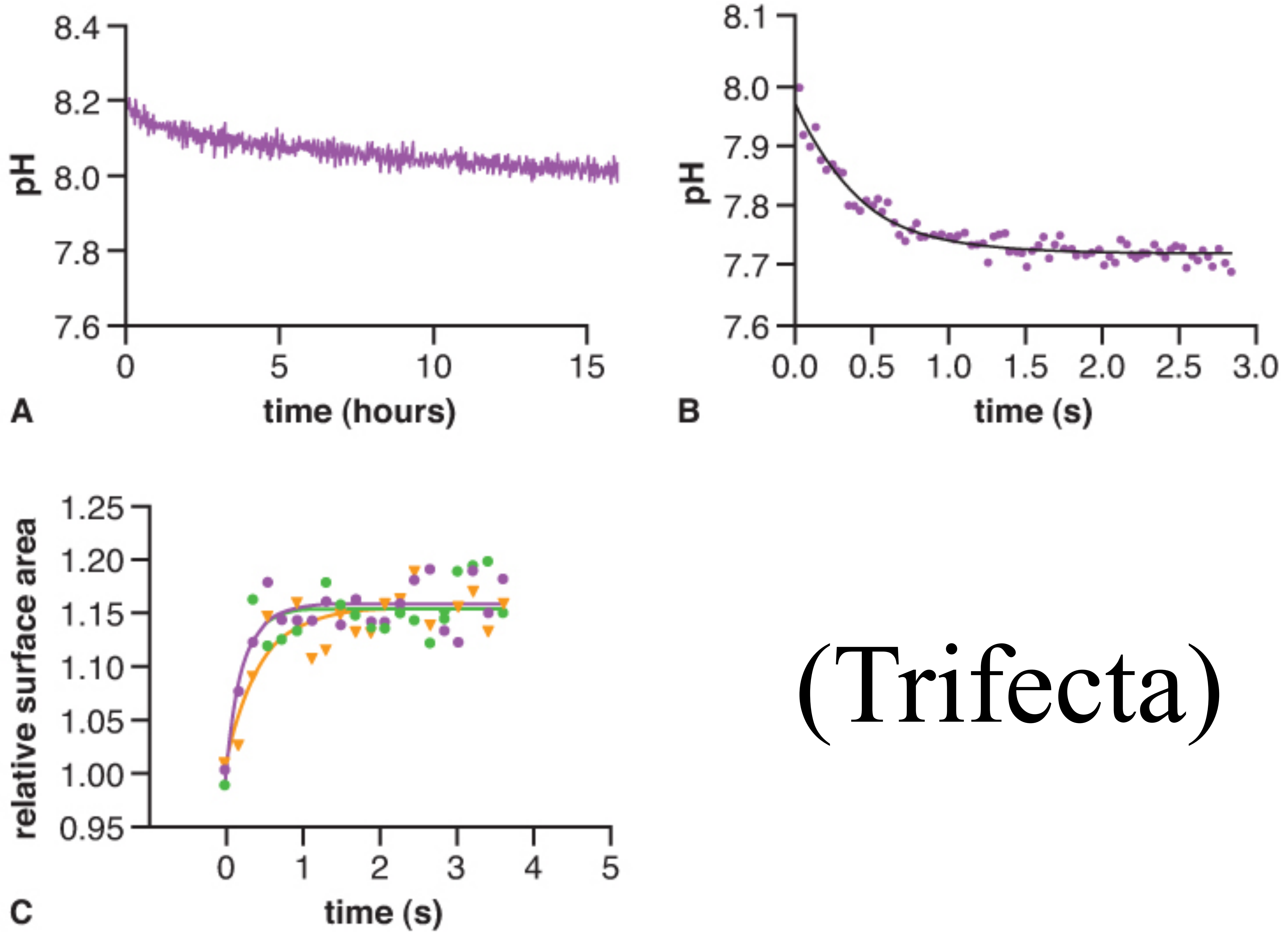


Fig. 4.16

modified from Chen and Jack W. Szostak. 2004a



(Trifecta)

Figure 4.17 Vesicle pH after adding micelles. **A,** pH drops quickly at first, and then slowly. **B,** Reduced pH immediately after adding micelles. **C,** Change of surface area for vesicles in **B.** Three trials are shown with each line representing an exponential curve fit. From Chen and Jack W. Szostak. 2004a. Figure 3. Irene A. Chen and Jack W. Szostak. 2004a. Membrane growth can generate a transmembrane pH gradient in fatty acid vesicles. PNAS. 101 (21): 7965 – 7970. Copyright (2004) National Academy of Sciences, U.S.A.

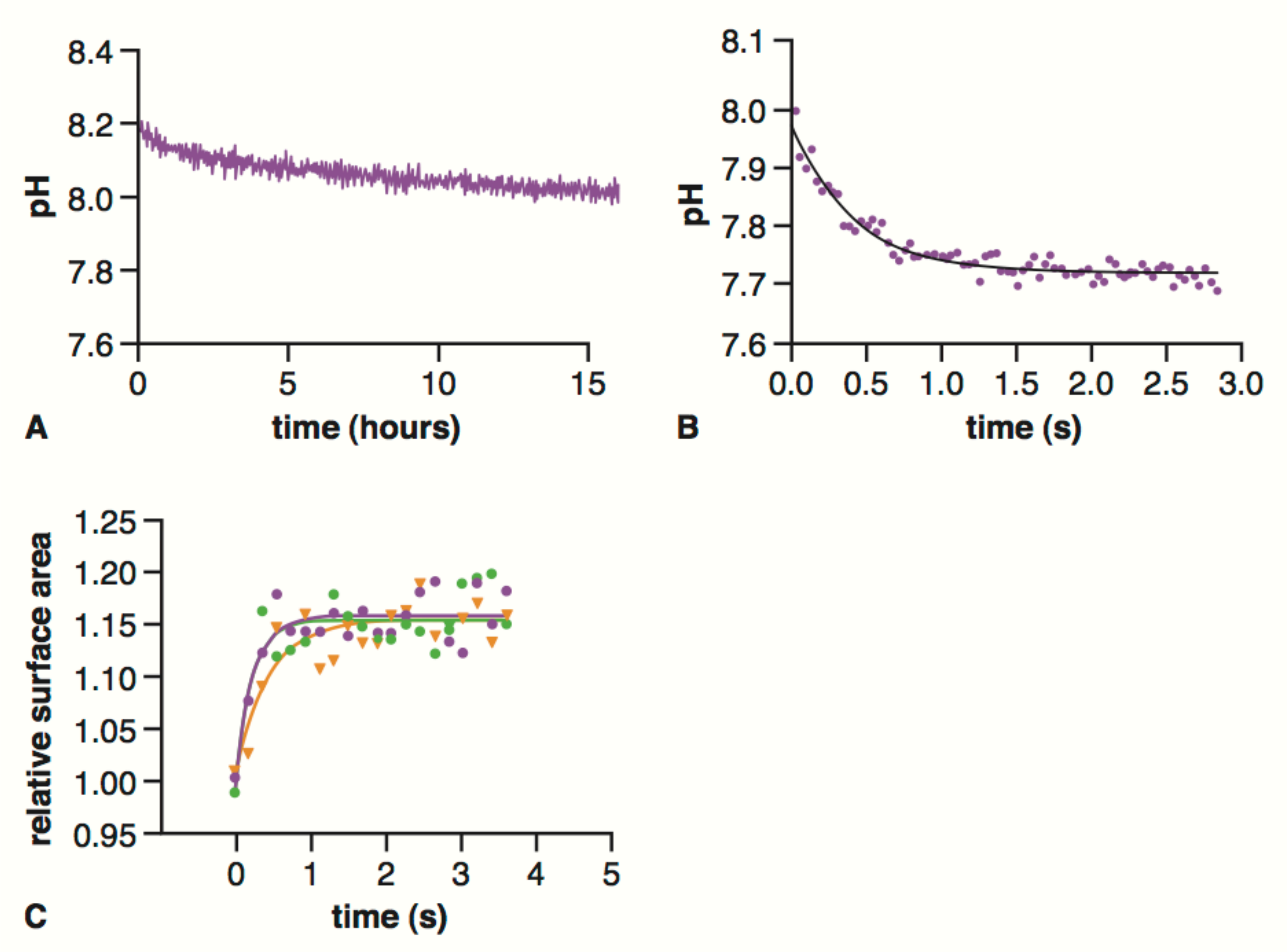
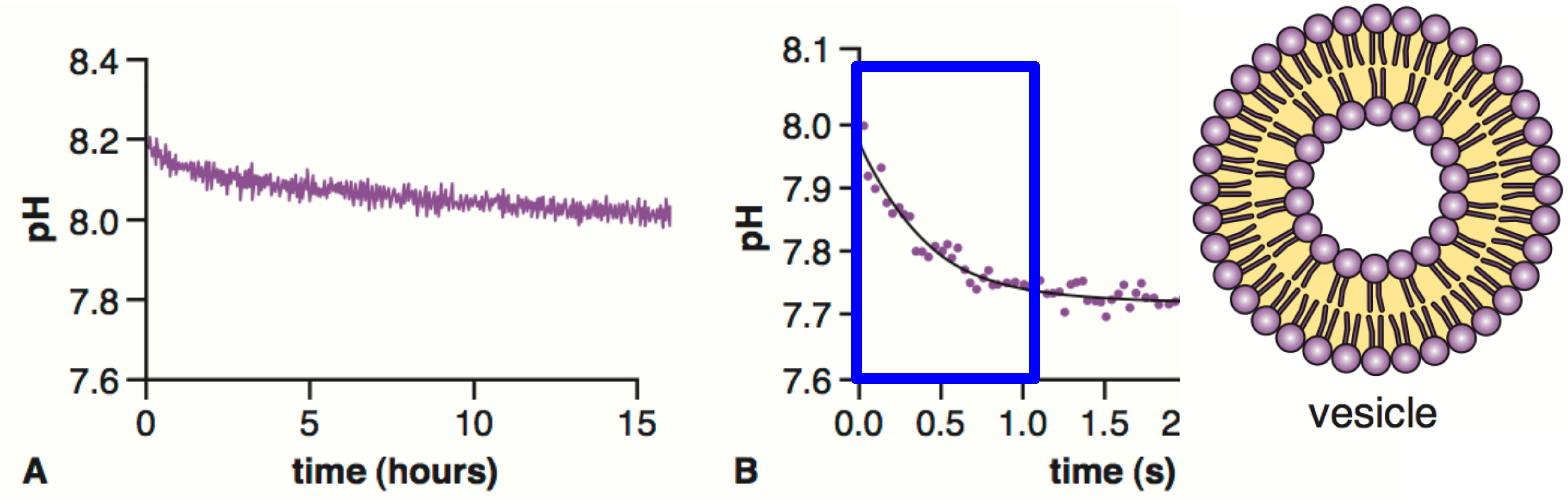
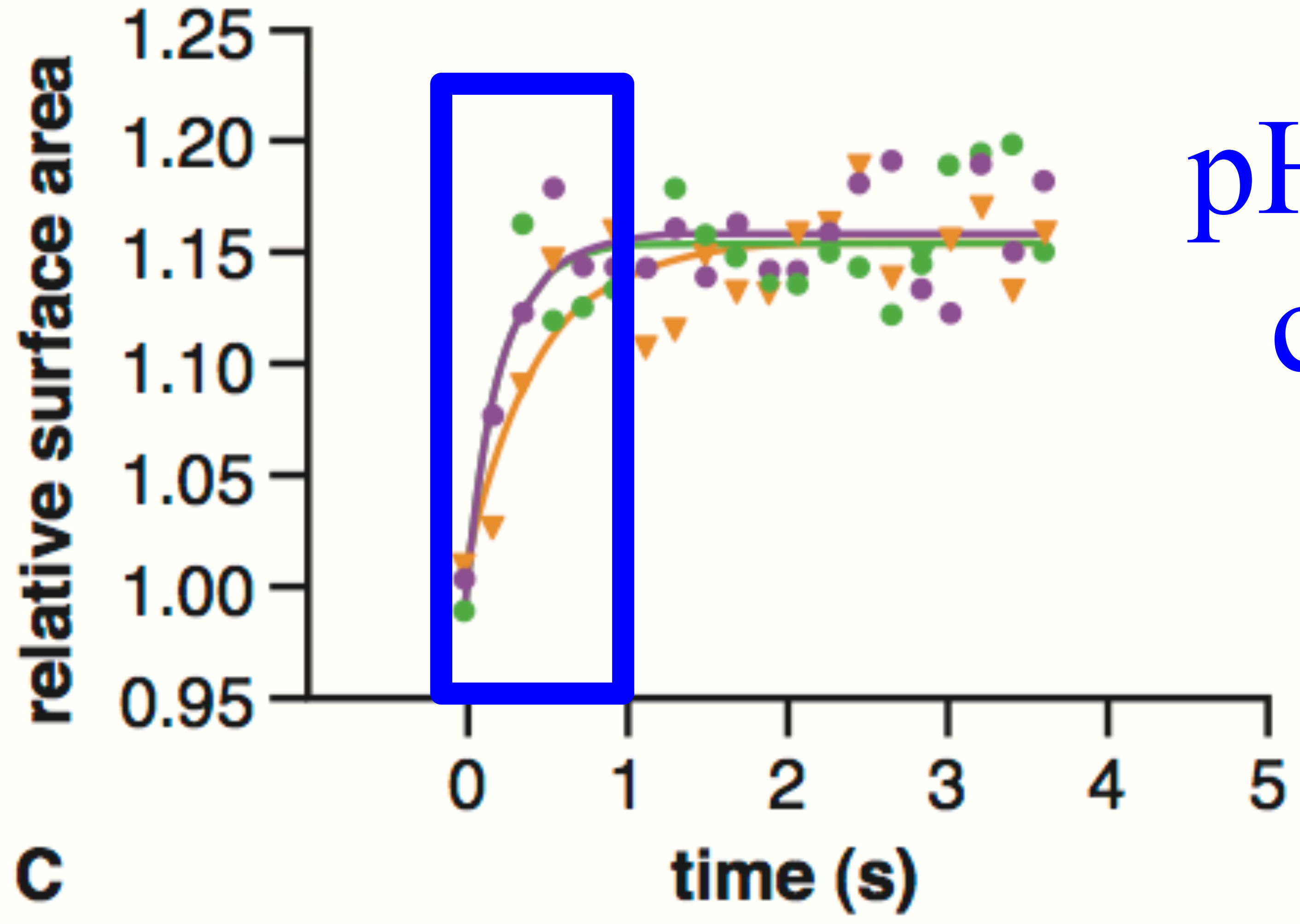


Fig. 4.17

modified from Chen and Jack W. Szostak. 2004a





pH and surface area changes on same time scale

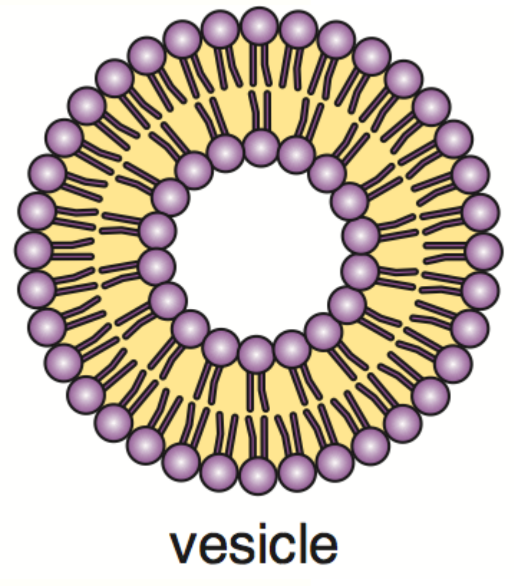
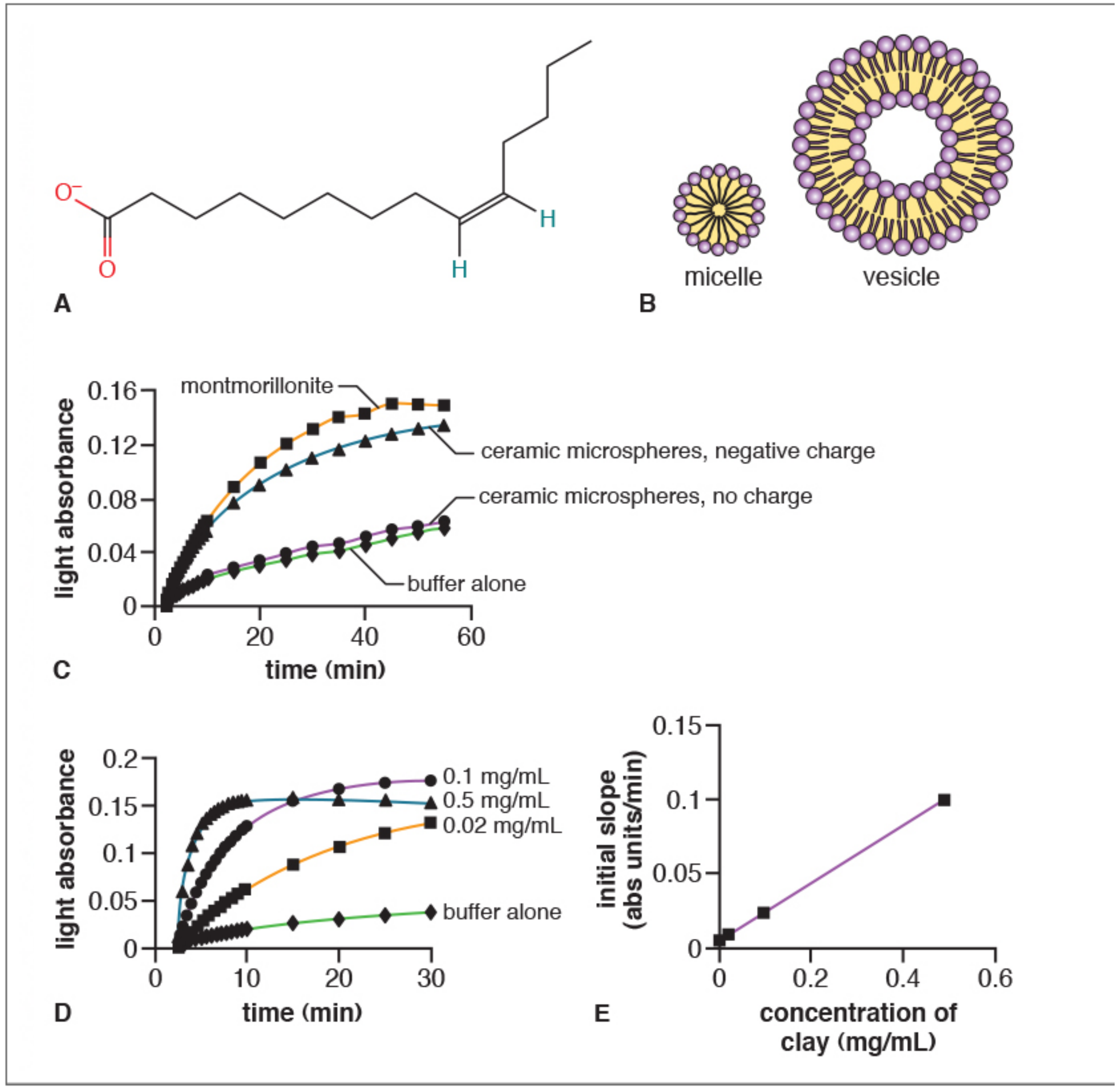
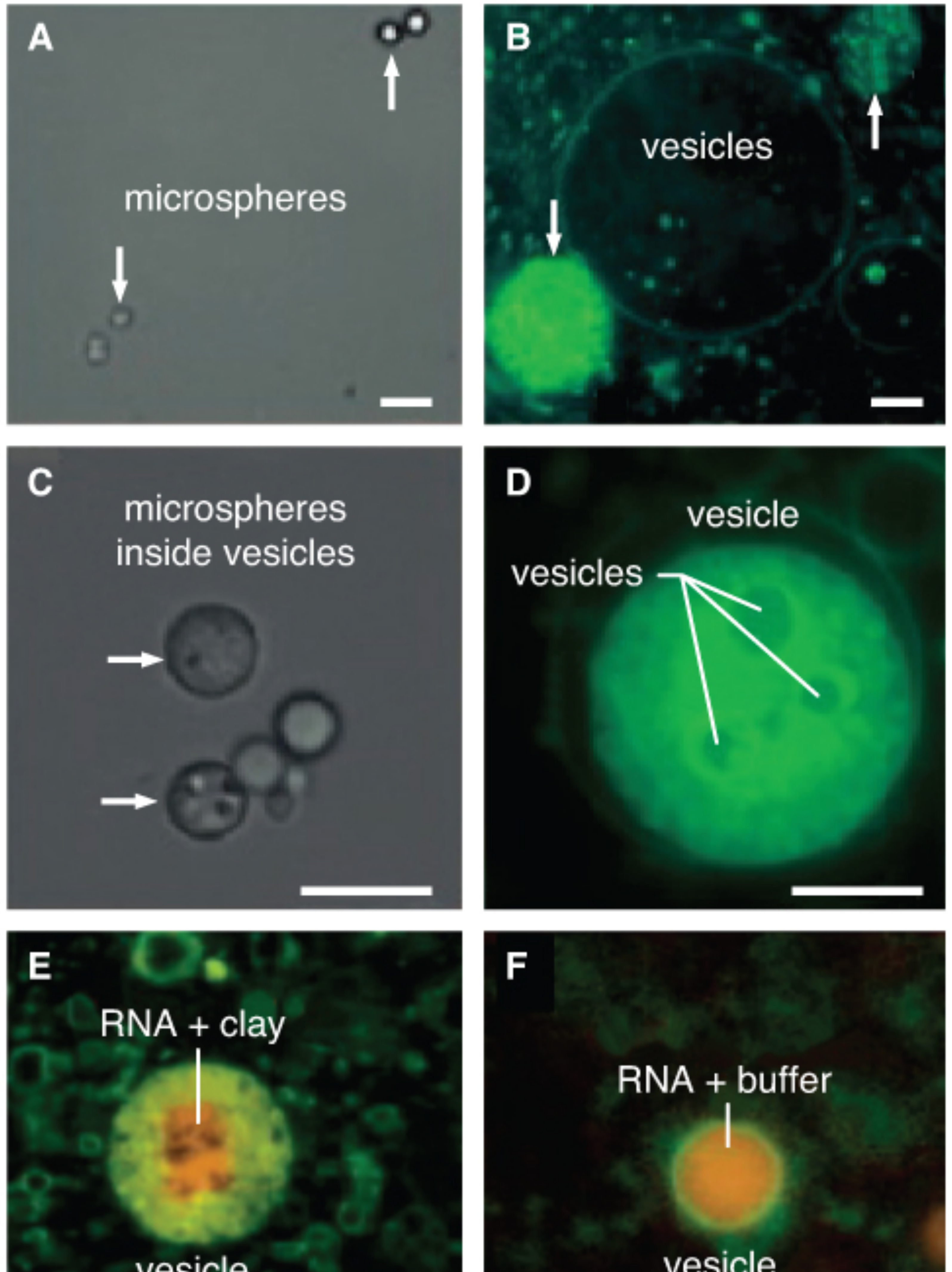


Fig. 4.17

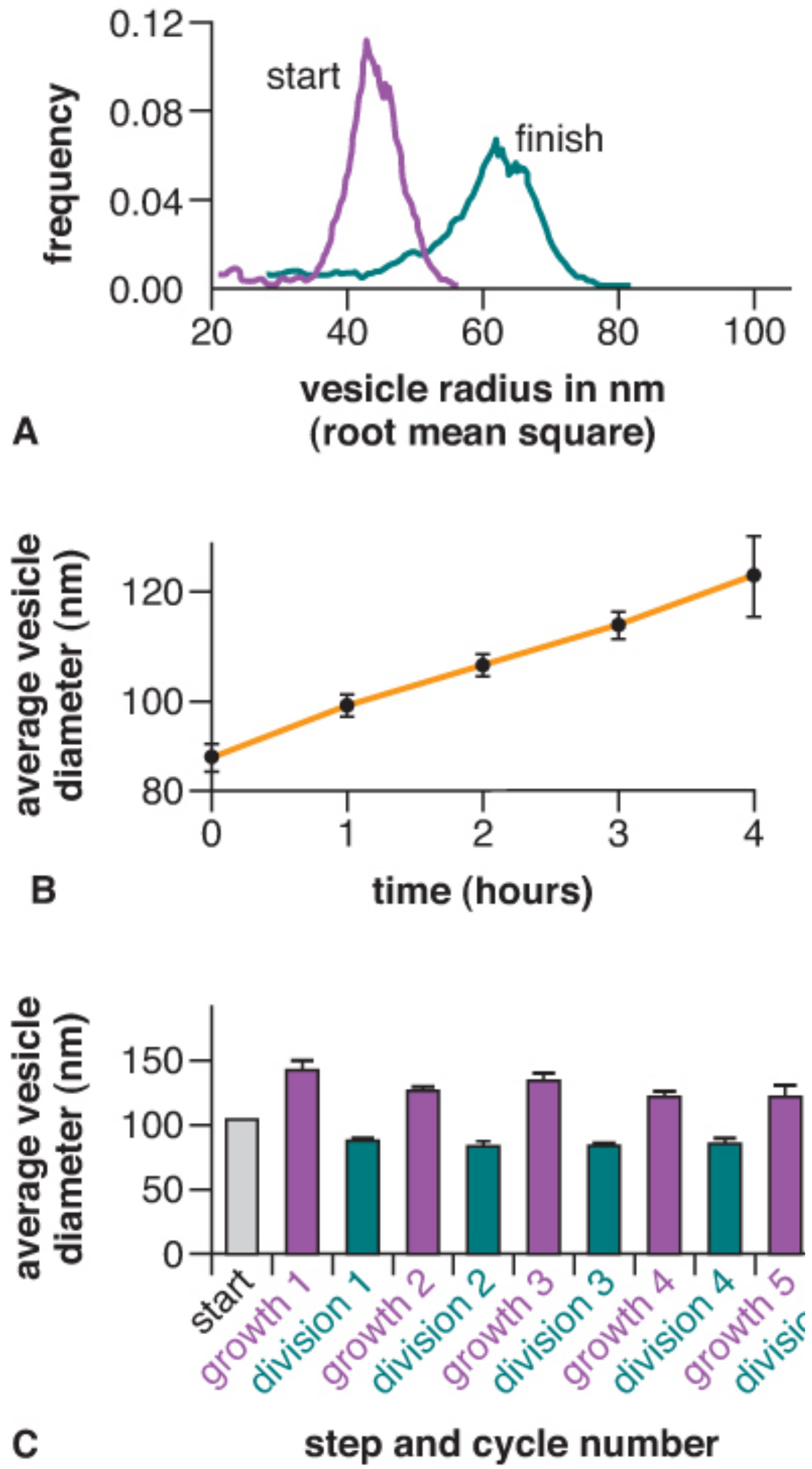
modified from Chen and Jack W. Szostak. 2004a

Clay: lipids can gather together and form abiotic “cells” with RNA inside





Growth, Reproduction, Storage of energy (H+s)



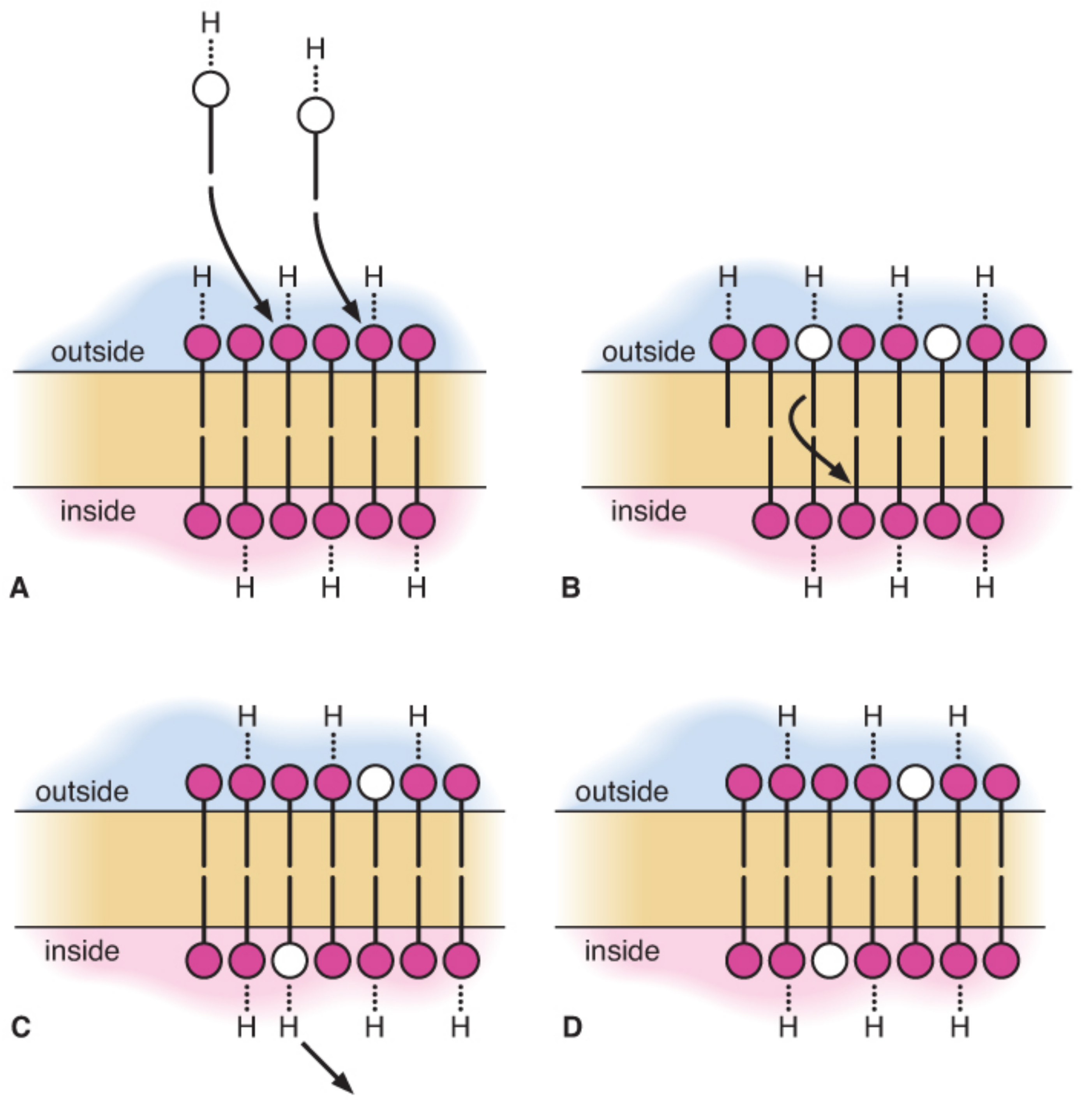
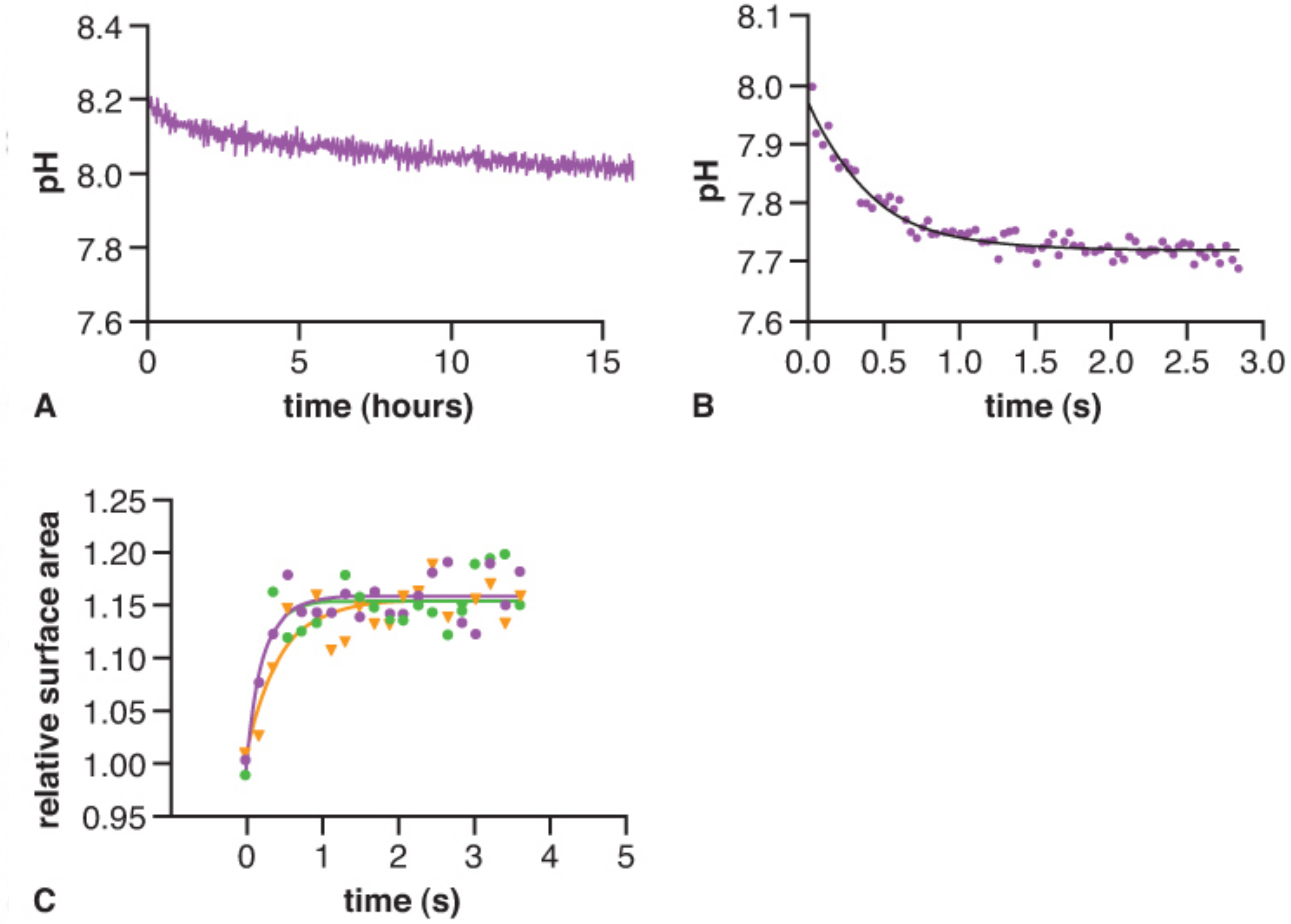


Figure 4.16 Proposed mechanism for accumulation of a pH gradient inside the vesicle lumen. The process proceeds from **(A)** through **(D)** over time to gradually accumulate H^+ ions inside vesicles, which lowers internal pH. Lipids can flip from one side of the bilayer to the other. From Chen and Jack W. Szostak. 2004a. Figure 2. Irene A. Chen and Jack W. Szostak. 2004a. Membrane growth can generate a transmembrane pH gradient in fatty acid vesicles. PNAS. 101 (21): 7965 – 7970. Copyright (2004) National Academy of Sciences, U.S.A.



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cycles with 10 pools per cycle [K. Burgess, A. I. Liaw, and N. Wang. *J. Med. Chem.* **37**, 2985 (1994)].
31. An impurity in the LCMS chromatogram, which was ^{1}H NMR-silent and had an isotope pattern in its mass spectrum consistent with an osmium-containing substance, was not included in calculating the purity of product **8**.
32. We gratefully acknowledge M. Narovlyansky for providing macrobeads **1**; Q. Liao, P. Wang, and J. Dudek for HRMS analysis; J. Raggio, L. Castro, and J. Tallarico for providing encoding reagents and for cleaving and analyzing chemical tags; Y.-K. Kim for helpful discussions regarding the transformation of **3** → **4**; and M. Kanan for thoughtful review of this manuscript. Supported by the NIGMS and the NCI. S.L.S. is an Investigator at the Howard Hughes Medical Institute at Harvard. M.D.B. is an HHMI predoctoral fellow, and E.M.B. is an HHMI undergraduate fellow.

Supporting Online Material
www.sciencemag.org/cgi/content/full/302/5645/613/DC1
Materials and Methods
Tables S1 to S7

31 July 2003; accepted 22 September 2003

Experimental Models of Primitive Cellular Compartments: Encapsulation, Growth, and Division

Martin M. Hanczyc,* Shelly M. Fujikawa,* Jack W. Szostak†

The clay montmorillonite is known to catalyze the polymerization of RNA from activated ribonucleotides. Here we report that montmorillonite accelerates the spontaneous conversion of fatty acid micelles into vesicles. Clay particles often become encapsulated in these vesicles, thus providing a pathway for the prebiotic encapsulation of catalytically active surfaces within membrane vesicles. In addition, RNA adsorbed to clay can be encapsulated within vesicles. Once formed, such vesicles can grow by incorporating fatty acid supplied as micelles and can divide without dilution of their contents by extrusion through small pores. These processes mediate vesicle replication through cycles of growth and division. The formation, growth, and division of the earliest cells may have ... eral particles and inputs

The bilayer membranes that surround all present-day cells and act as boundaries are thought to have originated in the spontaneous self-assembly of amphiphilic molecules into membrane vesicles (*1–5*). Simple amphiphilic molecules have been found in meteorites

fatty alcohol mixtures with carbon chain lengths as short as 9 can form vesicles capable of retaining ionic fluorescent dyes, DNA, and proteins (*4*).

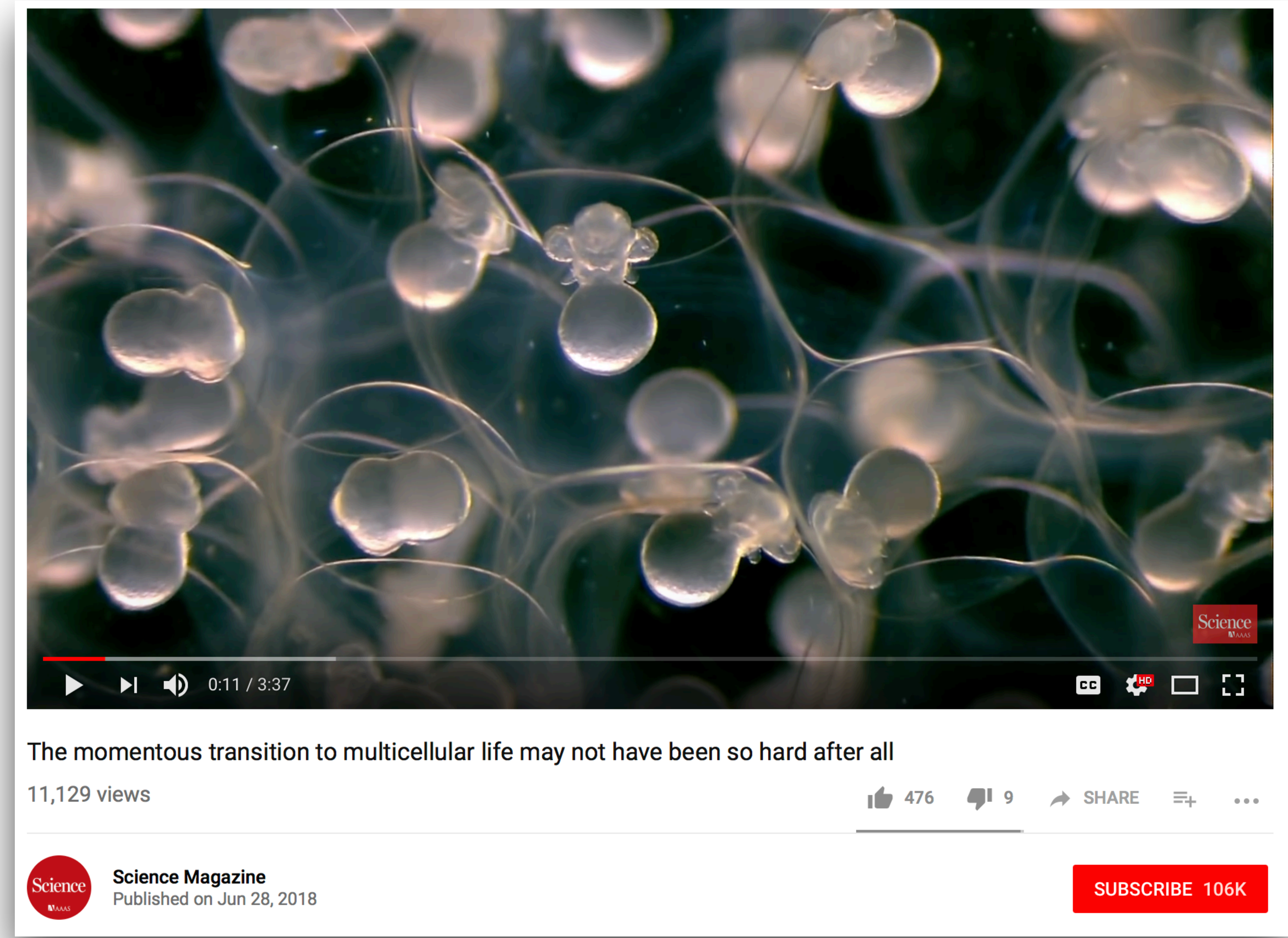
Vesicles consisting of simple amphiphilic molecules could have existed under plausible

of the vesicle. Furthermore, compartmentalization of replicating nucleic acids (or some other form of localization) is required to enable Darwinian evolution by preventing the random mixing of genetic polymers, thus coupling genotype and phenotype (*13*). If primordial nucleic acids assembled on mineral surfaces (*14–17*), the question arises as to how they eventually came to reside within membrane vesicles. Although dissociation from the mineral surface followed by encapsulation within newly forming vesicles (perhaps in a different location under different environmental conditions) is certainly a possibility, a direct route would be more satisfying and perhaps more efficient. The unexpected interaction between mineral surfaces and membrane-forming amphiphiles described here could provide such a pathway.

In the course of exploring the autocatalytic assembly of myristoleate (C14) vesicles from myristoleate micelles (*18*), we examined the effect of other negatively charged surfaces on vesicle assembly. We found that the addition of small quantities of montmorillonite to the reaction mixture resulted in an increase in the initial rate of the vesicle assembly reaction by a factor of 100 (*19*) (Fig.

If it looks like a cell, and acts like a cell…?

- Lipids can form through abiotic mechanisms.
- Abiotic vesicles can form spontaneously.
- Abiotic vesicles can trap RNA inside them.
- RNA ribozymes can polymerize RNA molecules.
- Abiotic vesicles can grow by consuming additional lipids.
- Abiotic vesicles can compete against each other for lipids.
- Abiotic vesicles can divide and leak their RNA cargo with each division.
- Abiotic vesicles with RNA inside can outcompete vesicles lacking RNA inside.



https://youtu.be/hjTdbWblhxw

3min

What is our next question of EvoLife?

How did mitochondria and chloroplasts originate?

Biology Learning Objective

- Assemble evidence that demonstrates the evolutionary origin of mitochondria and chloroplasts.

Week 3

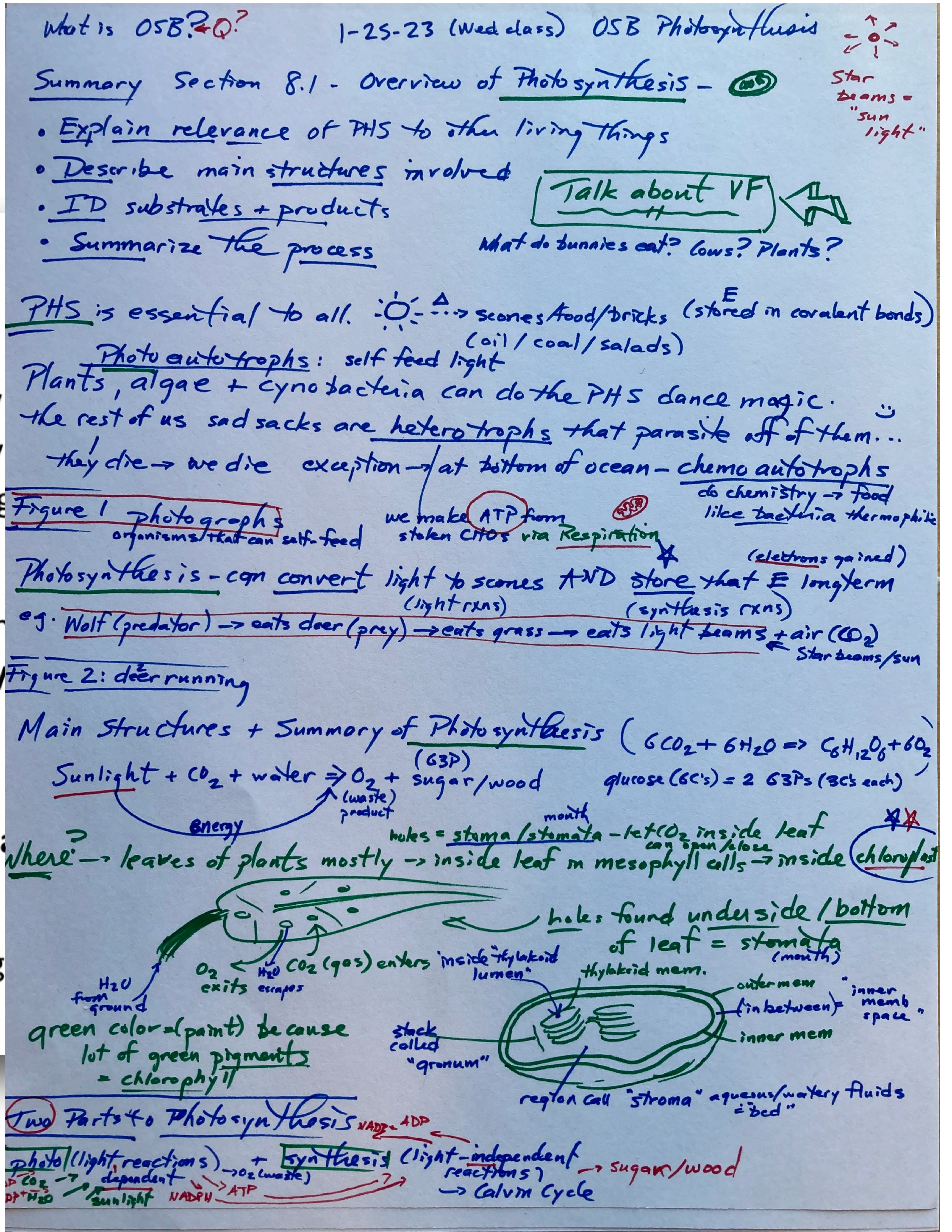
(Preparing for) **Wednesday's lecture:**

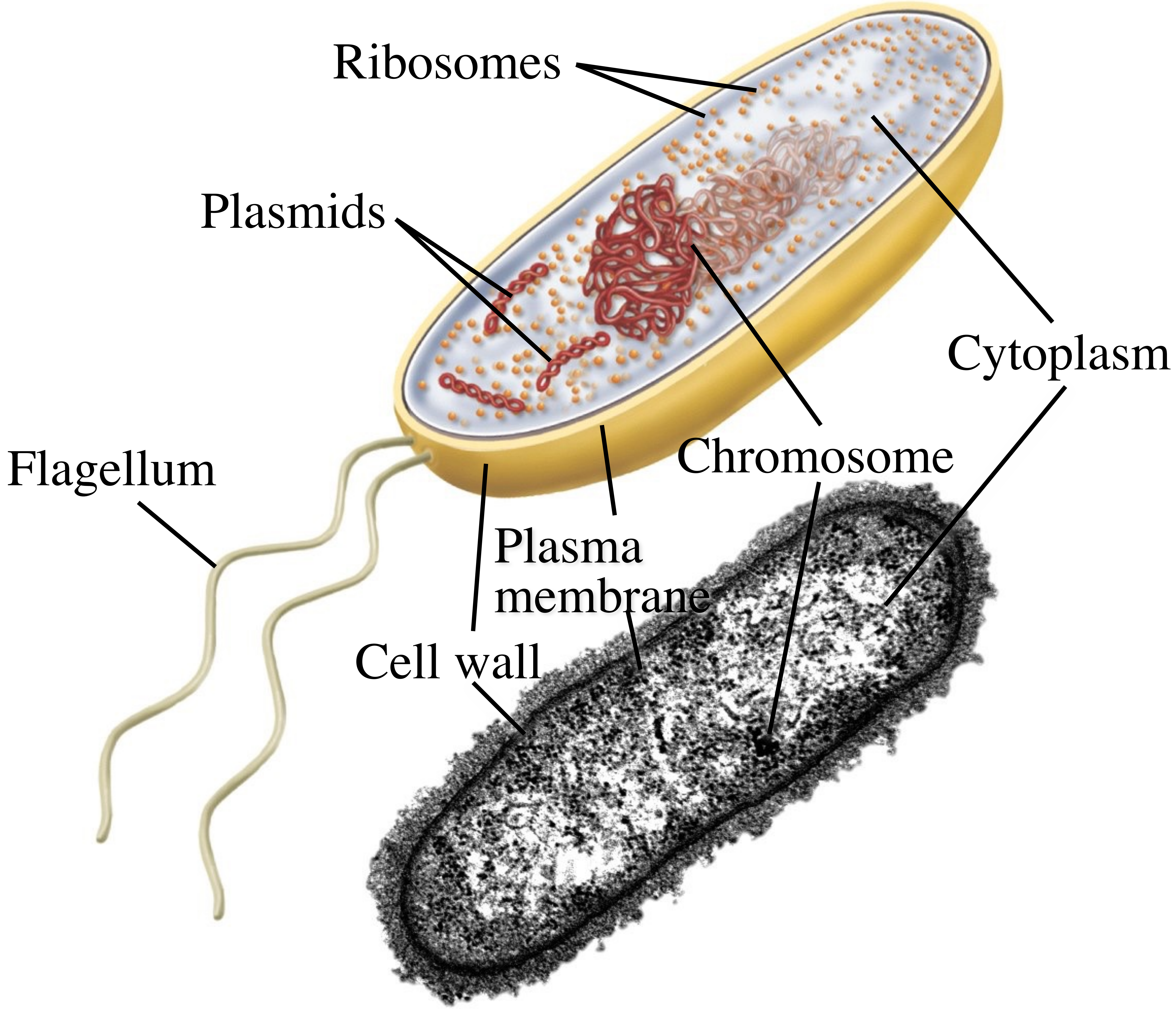
Budgeting homework time (60 min): In the Chapter **Photosynthesis (OSB)**
has quite a few figures. This should take 8 minutes if you just read it. But w
pause to review figures and take good notes, this assignment should take y
Give yourself at least 10 more minutes to google and read about Lynn Marg

1. _______ **For Wednesday's lecture, first google** "Lynn Margulis" to fir
notes on, the *endosymbiotic hypothesis*. Then in the chapter **Photosy**
8.1 "Overview of Photosynthesis" and take handwritten notes.

2. _______ (Tip): **Prepare to explain (aloud) the anatomy of a chloropl**

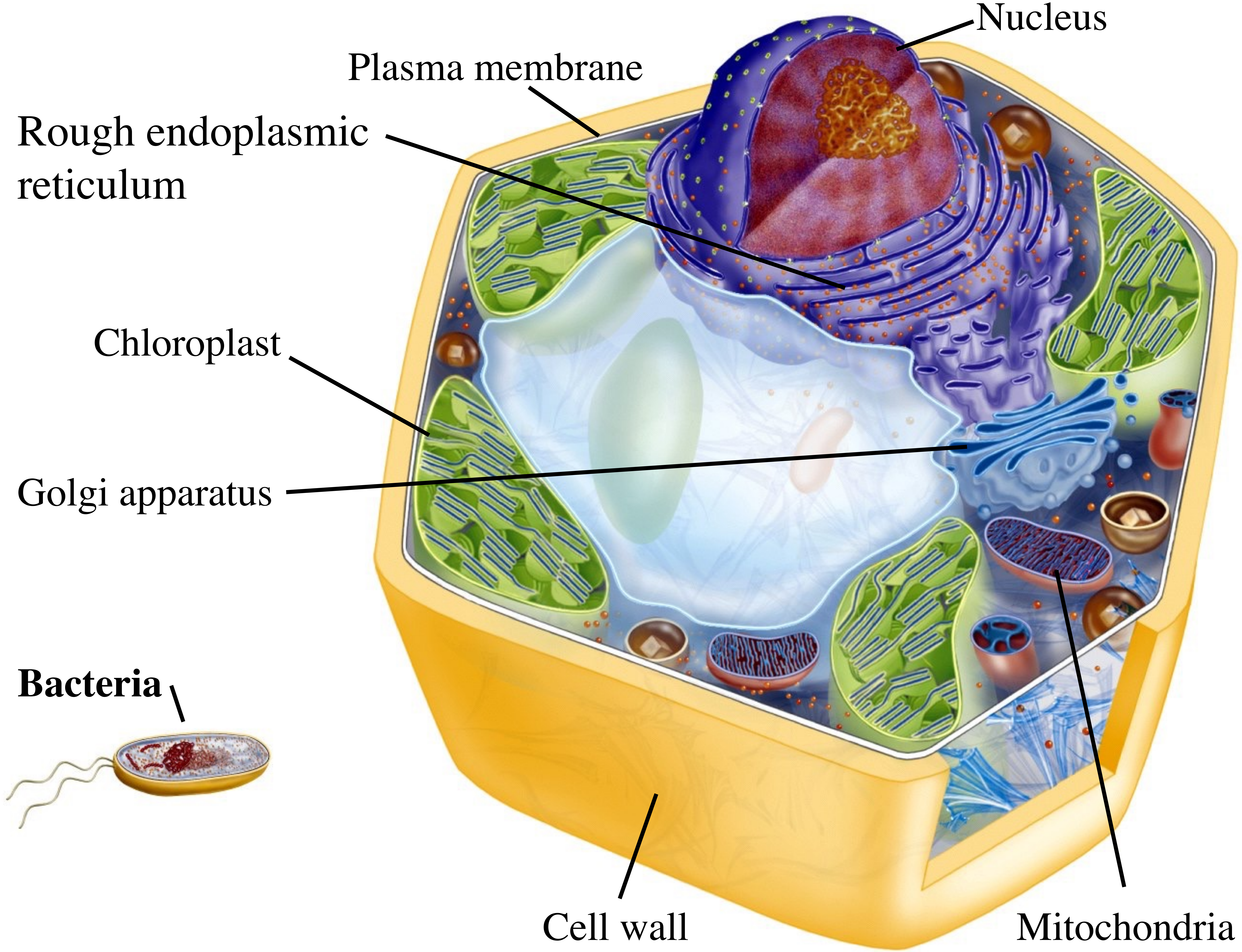
3. _______ **Advanced**: Take a peek at section 8.2, in particular study Fig
process in class.

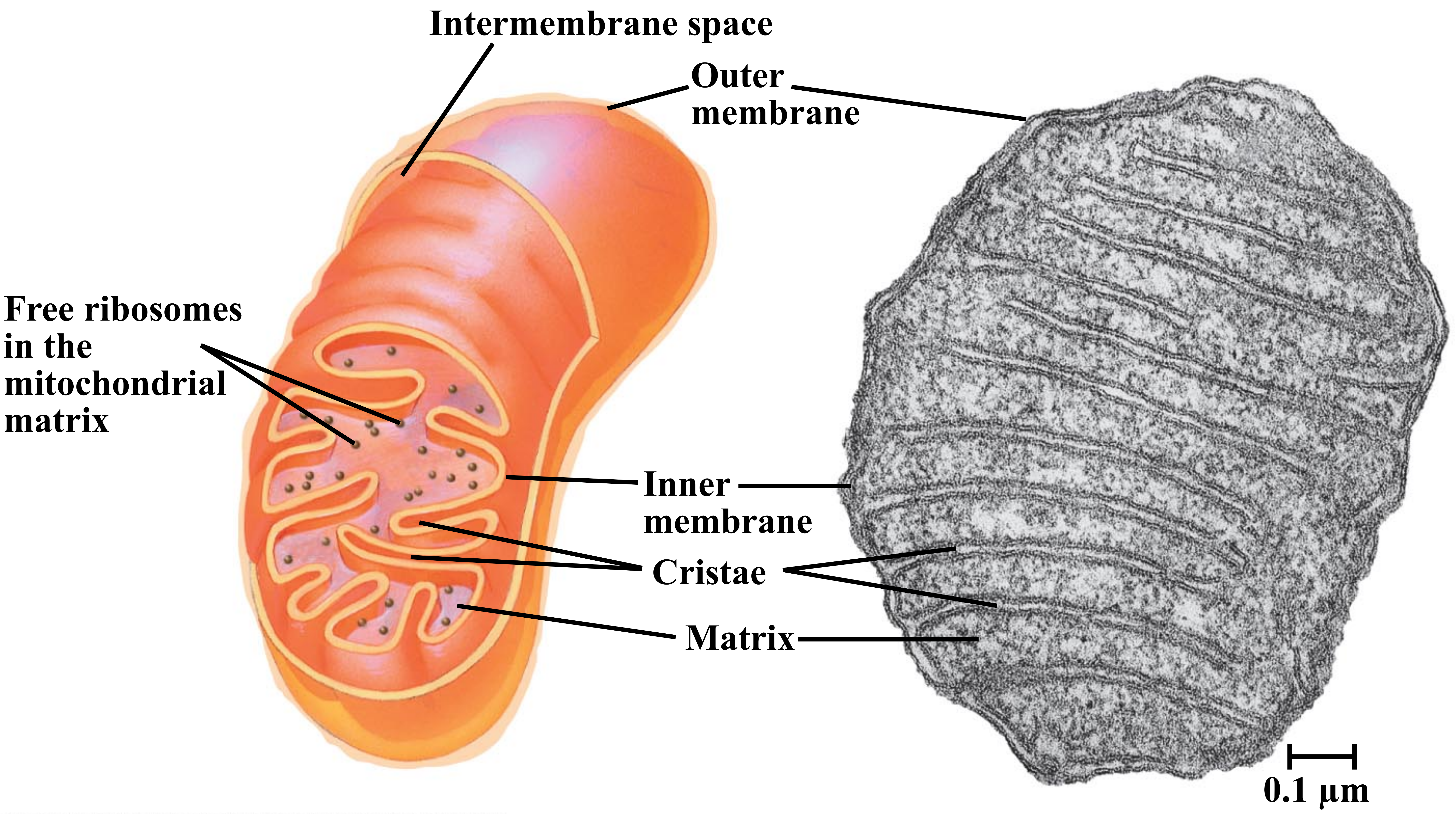




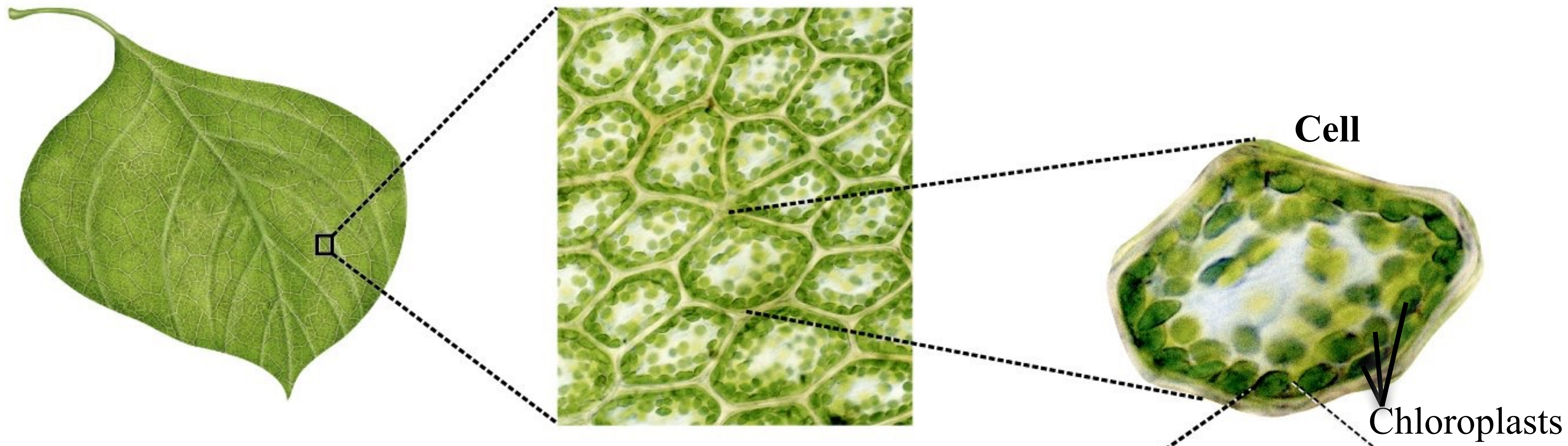
So what does a bacteria cell have?

What eukaryotic cell has that prok. doesn't?

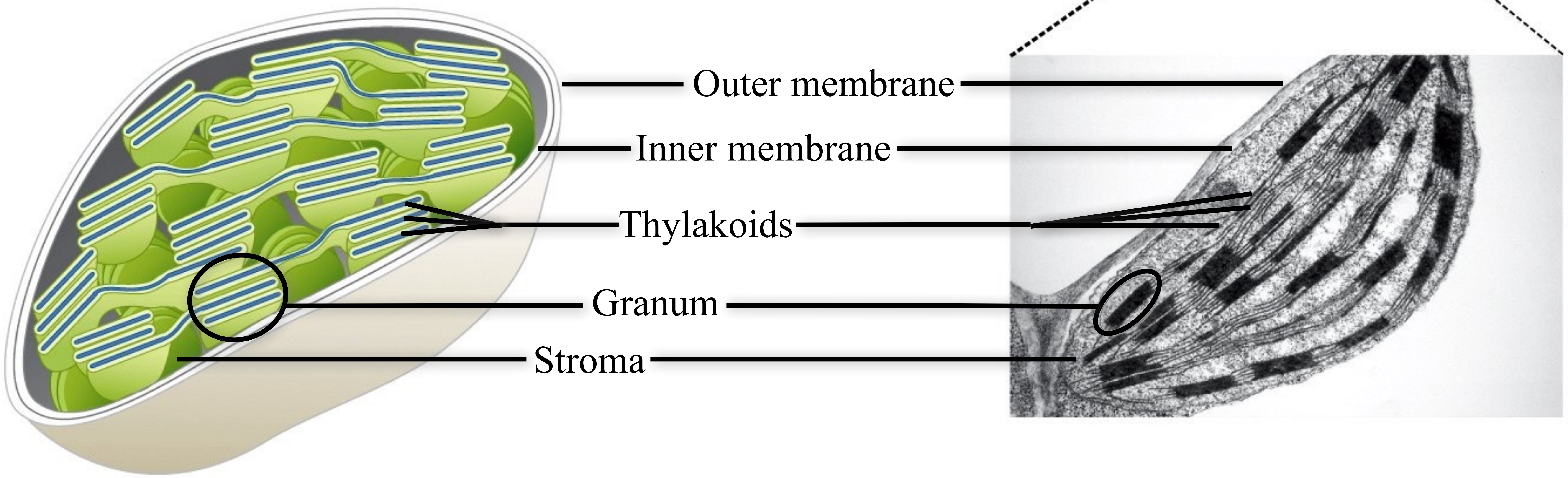


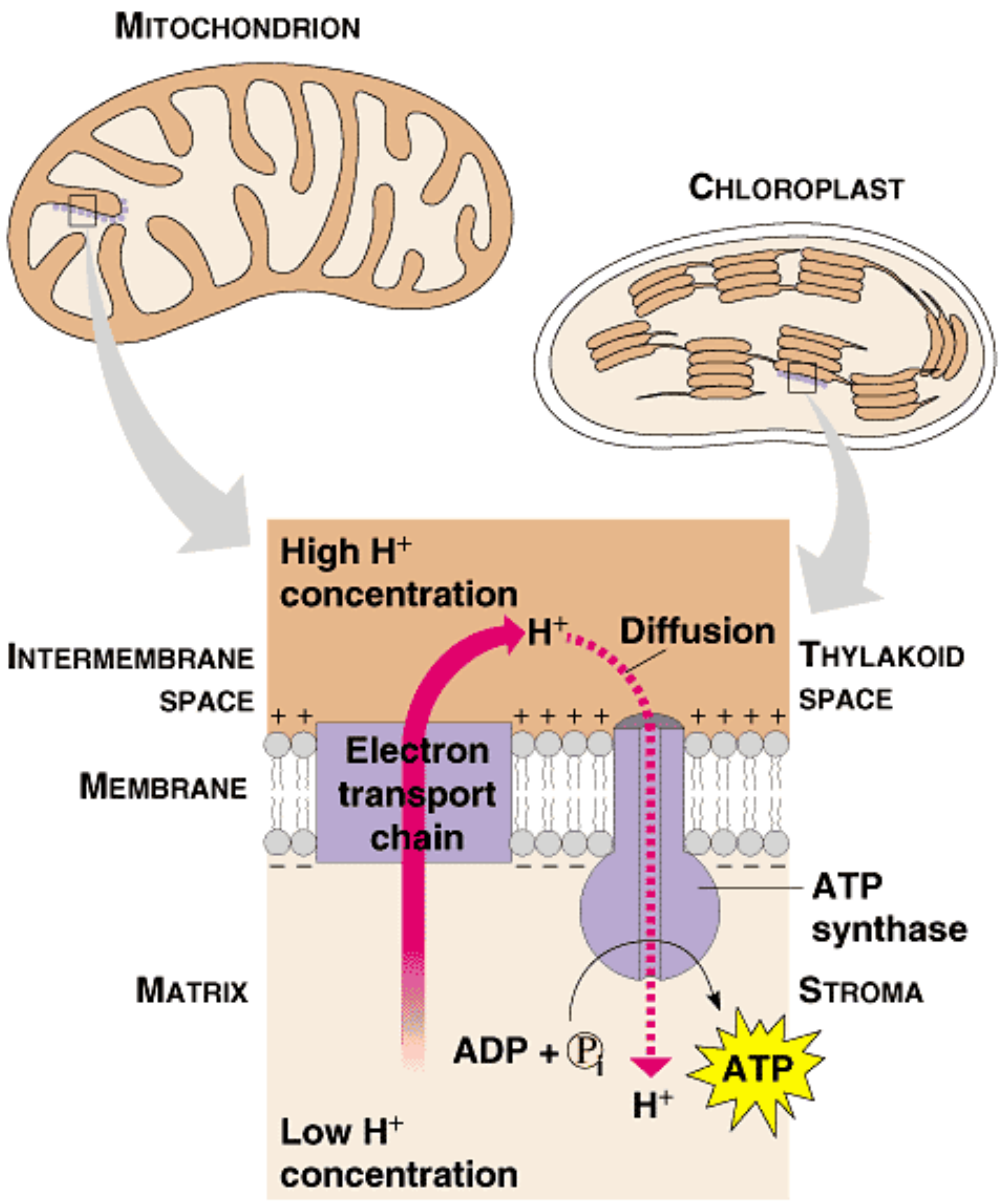

Intermembrane space
Outer membrane
Free ribosomes in the mitochondrial matrix
Inner membrane
Cristae
Matrix
0.1 µm

Leaves contain millions of chloroplasts.



Chloroplasts are highly structured, membrane-rich organelles.



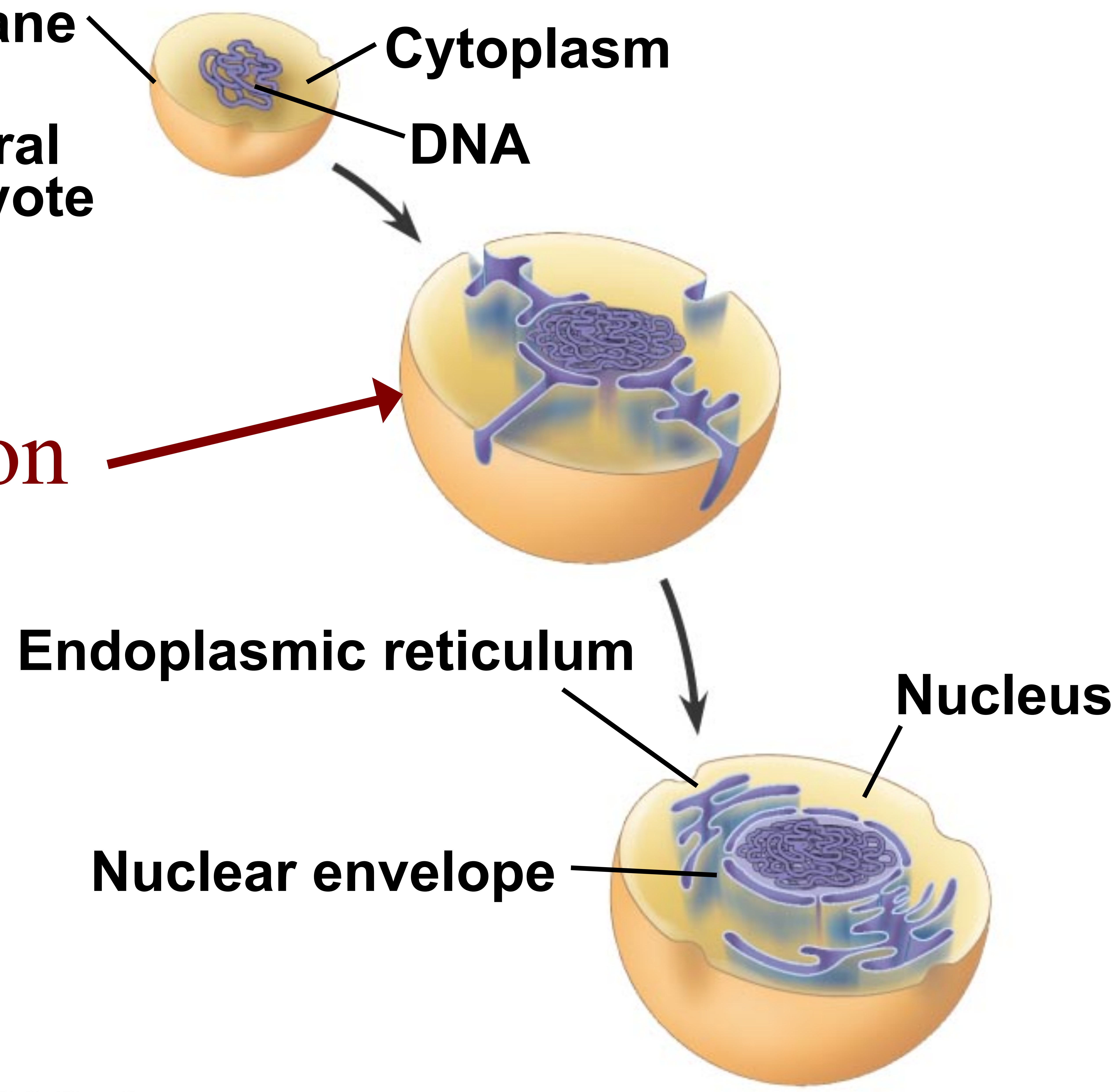

MITOCHONDRION
CHLOROPLAST
High H+ concentration
H+
Diffusion
INTERMEMBRANE SPACE
THYLAKOID SPACE
MEMBRANE
Electron transport chain
ATP synthase
MATRIX
STROMA
ADP + Ⓟi
ATP
H+
Low H+ concentration

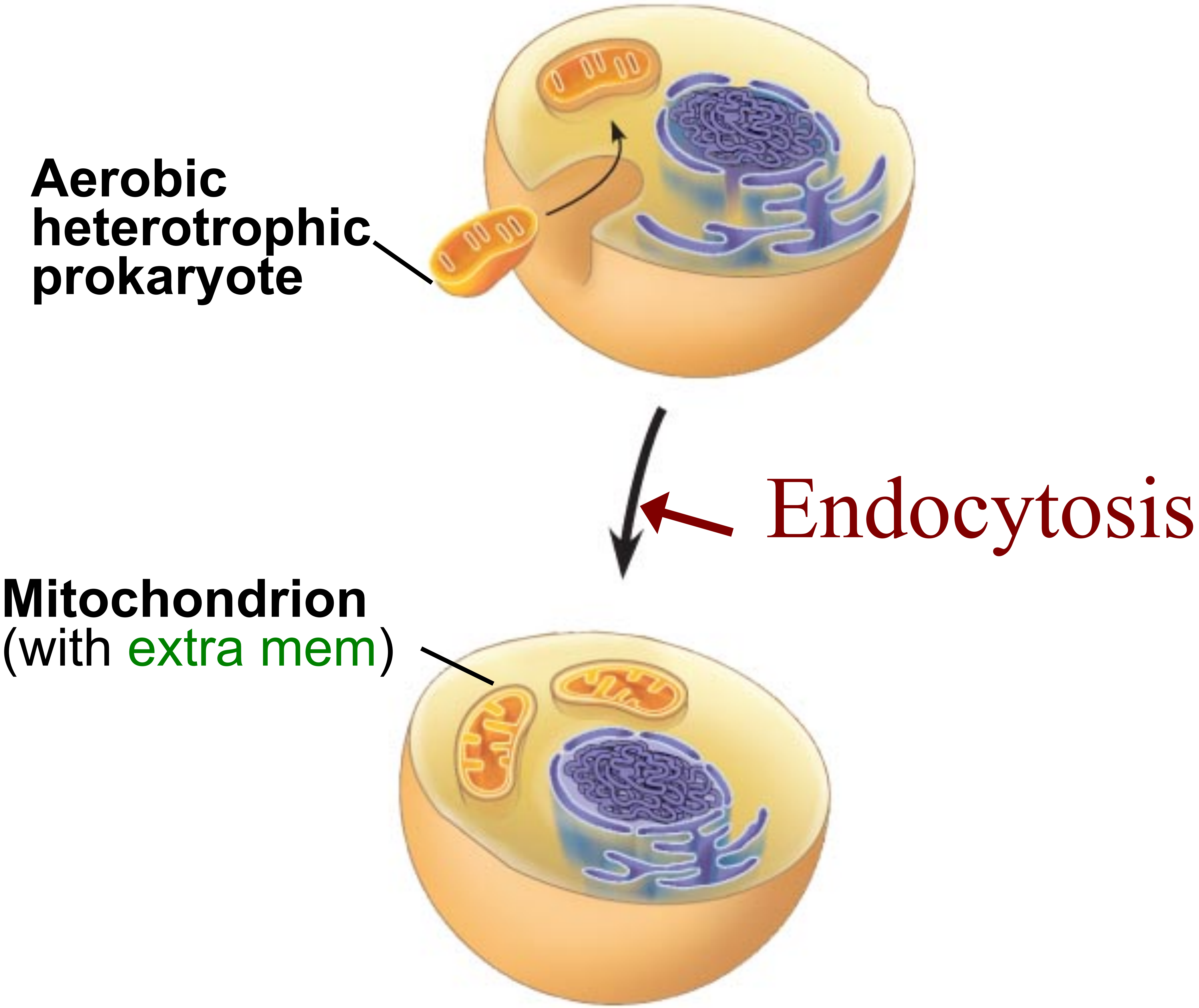
So where did my organelles come from?

What does ***endosymbiosis*** suggest is the evolutionary origin of the chloroplast?

Lynn Margulis as a young woman.

a. nuclear envelope
b. invagination of membrane
c. golgi apparatus
d. endocytosis of bacterium
e. infection of virus


Plasma membrane
Cytoplasm
DNA
Ancestral prokaryote
Invagination
Endoplasmic reticulum
Nucleus
Nuclear envelope


Aerobic heterotrophic prokaryote
Endocytosis
Mitochondrion
(with extra mem)

How do chloroplasts function?
(a deep dive into one organelle)

Biology Learning Objective

- Build knowledge of the processes used by chloroplasts when functioning (photosynthesis).
- How do photons that depart the sun and strike the earth get converted to chemical energy (ATP, CHO) that is the source of all life.

The Light-Dependent Reactions of Photosynthesis

Summary: By the end of this section, you will be able to:

- Explain how plants absorb energy from sunlight
- Describe short and long wavelengths of light
- Describe how and where photosynthesis takes place within a plant

How can light be used to make food? When a person turns on a lamp, electrical energy becomes light energy. Like all other forms of kinetic energy, light can travel, change form, and be harnessed to do work. In the case of photosynthesis, light energy is converted into chemical energy, which photoautotrophs use to build carbohydrate molecules (**Figure 1**). However, autotrophs only use a few specific components of sunlight.

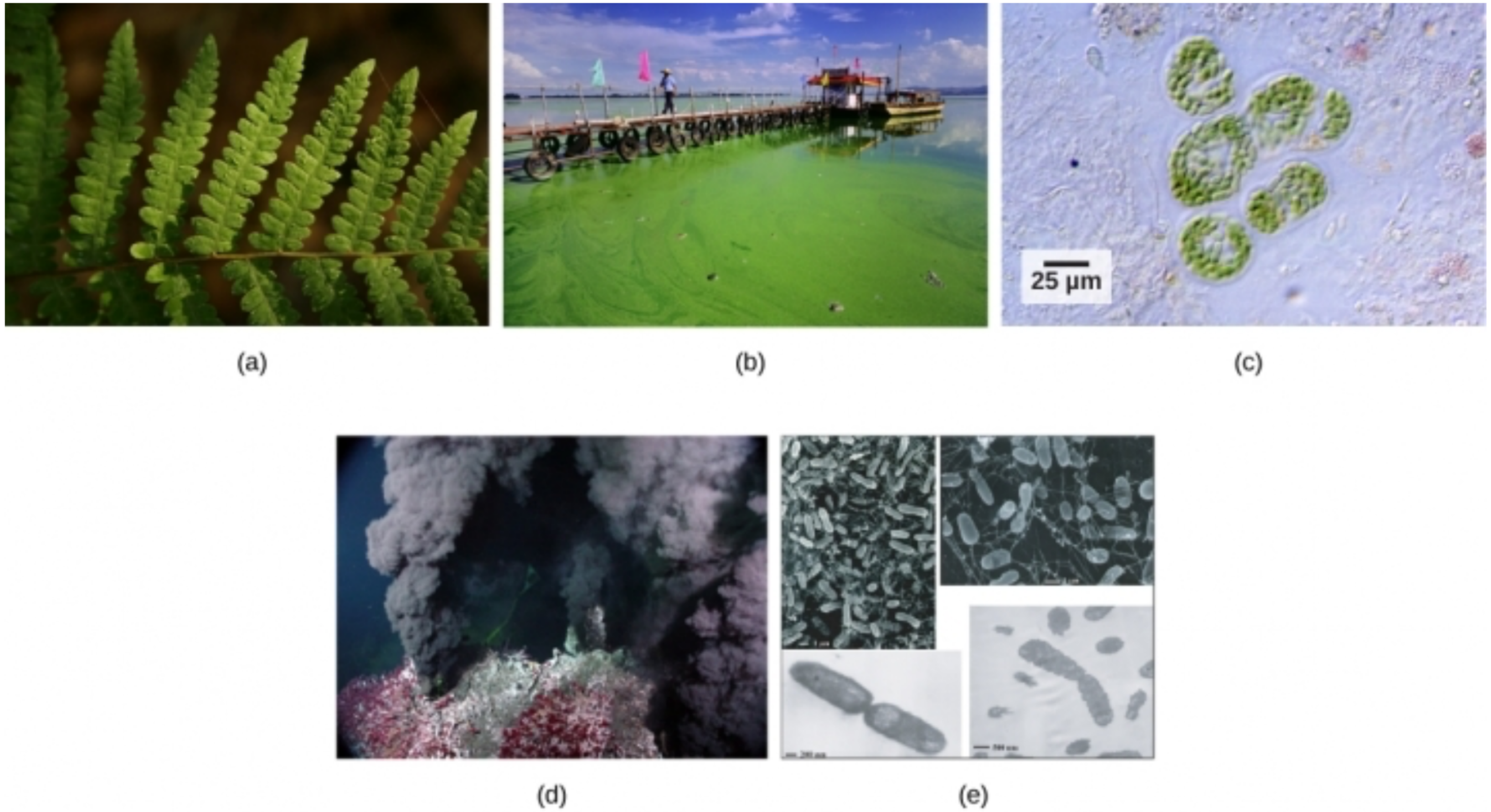
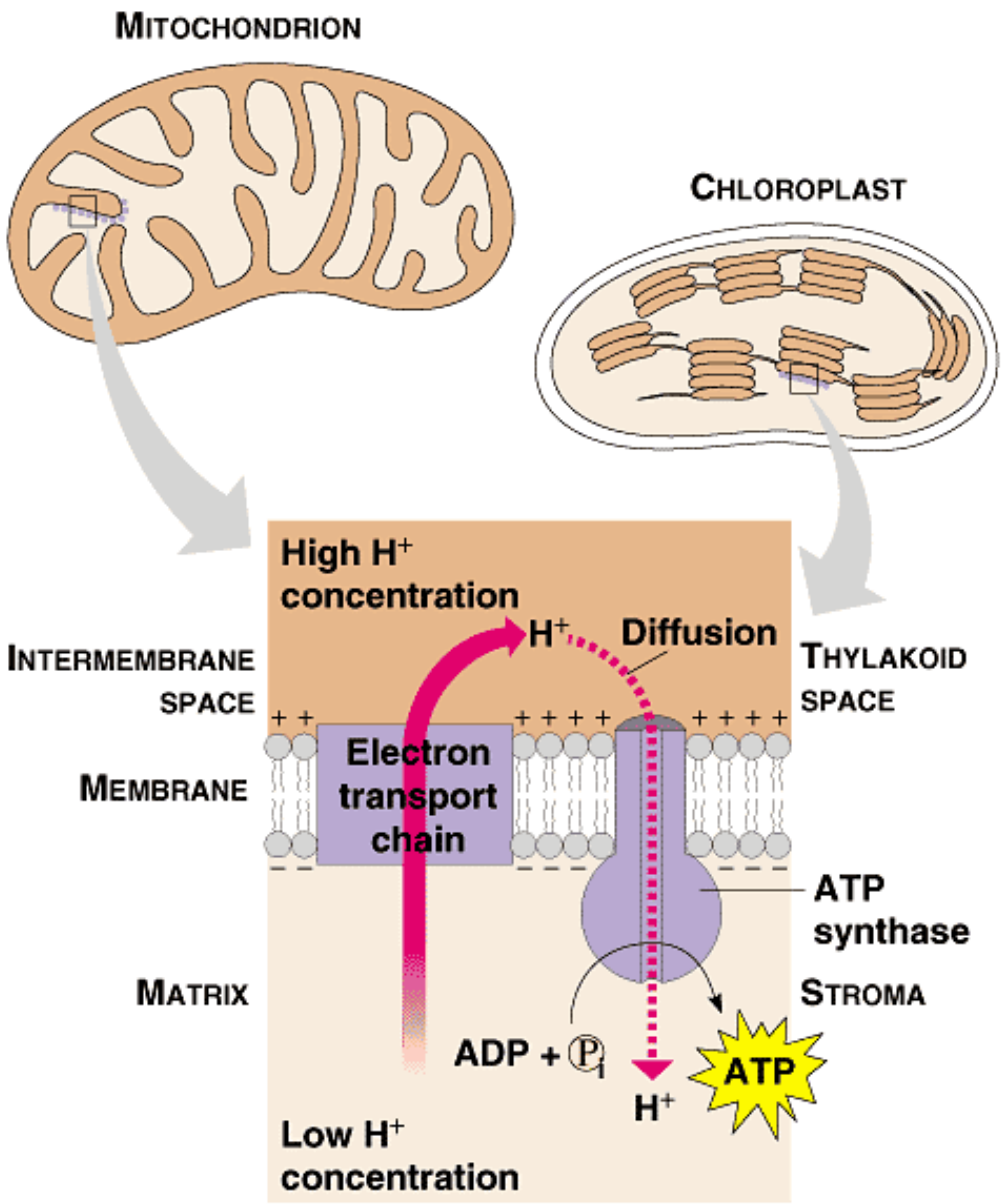
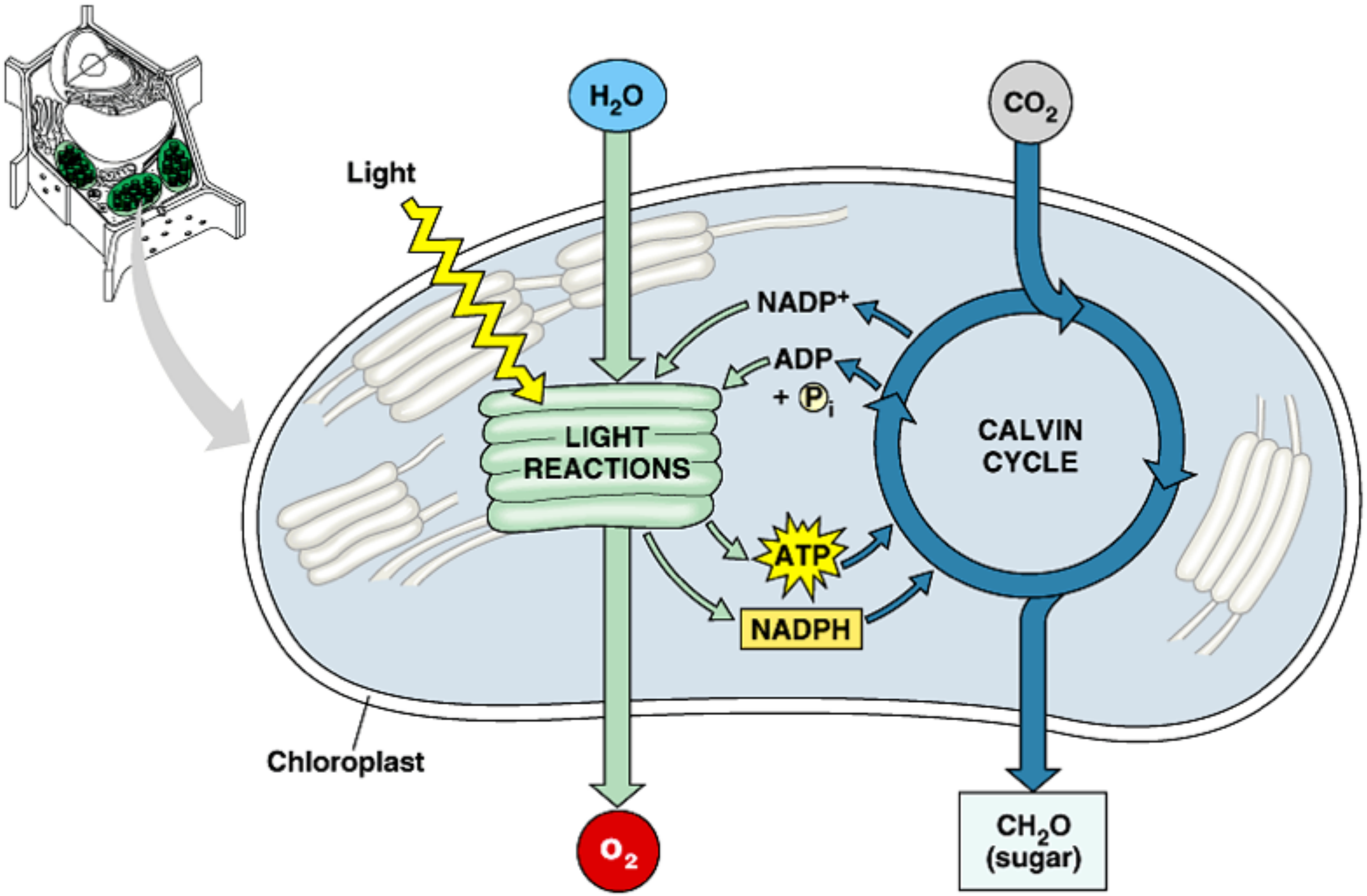


Figure 1: Photoautotrophs including (a) plants, (b) algae, and (c) cyanobacteria synthesize their organic compounds via photosynthesis using sunlight as an energy source. Cyanobacteria and planktonic algae can grow over enormous areas in water, at times completely covering the surface. In a (d) deep sea vent, chemoautotrophs, such as these (e) thermophilic bacteria, capture energy from inorganic compounds to produce organic compounds. The ecosystem surrounding the vents has a diverse array of animals, such as tubeworms, crustaceans, and octopi that derive energy from the bacteria. (credit a: modification of work by Steve Hillebrand, U.S. Fish and Wildlife


incoming photon
Stroma (pH8)
incoming photon
NADP$_{ox}$
2H$^+$
OH$^-$
OH$^-$
OH$^-$
OH$^-$
OH$^-$
OH$^-$
OH$^-$
NAD$_{re}$
OH$^-$
Q
PQ
P680
2e$^-$
Z
2e$^-$
2e$^-$
Cyt f
PC
2e$^-$
PQ
P700
2e$^-$
2e$^-$
Fd
FAD
FeS
2H$^+$
H$^+$
H$^+$
2H$^+$
PHOTOSYSTEM II
H$^+$
PHOTOSYSTEM I
H$^+$
H$_2$O
$\frac{1}{2}$O$_2$
H$^+$
H$^+$
Thylakoid interior (pH4)
H$^+$

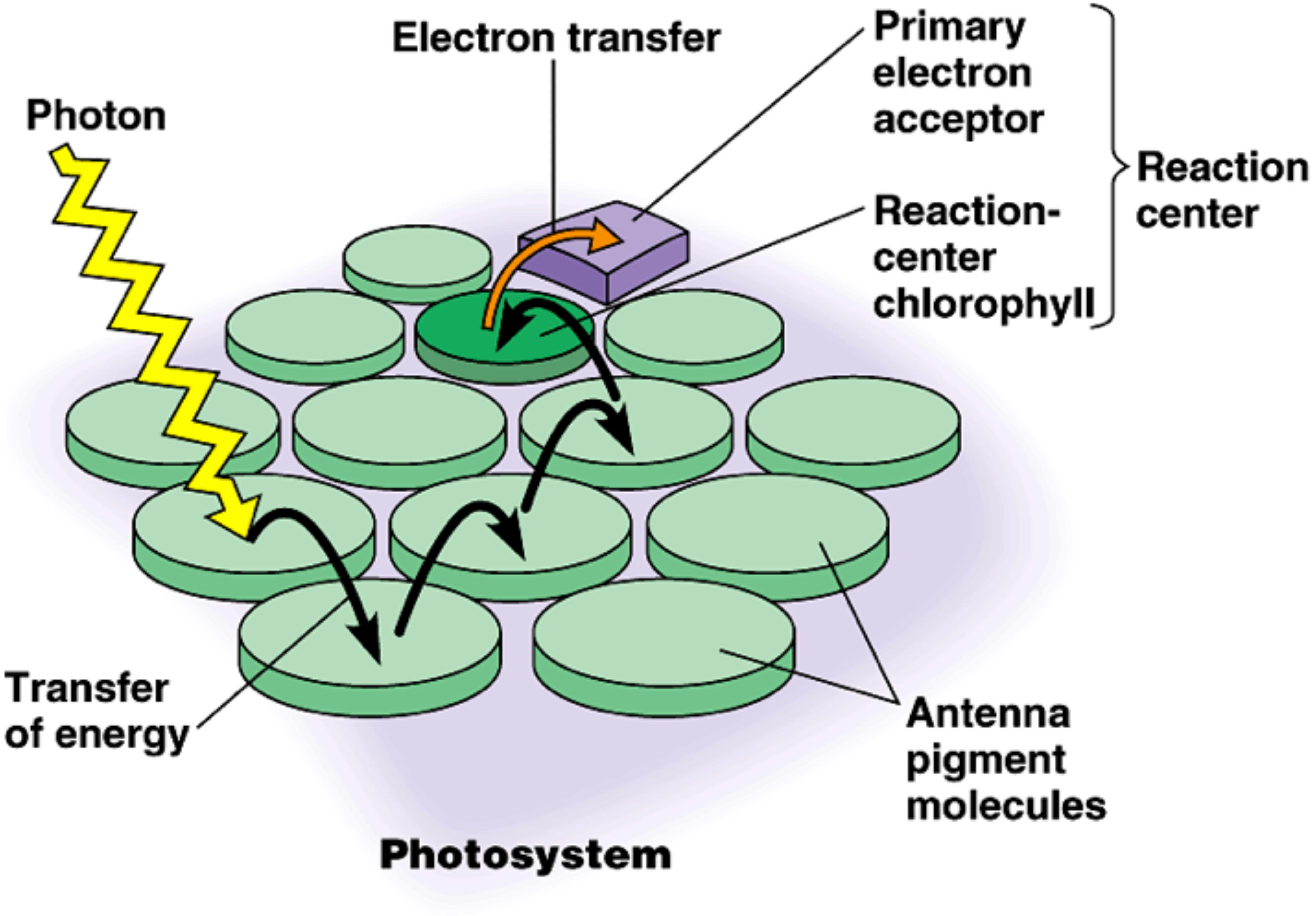


MITOCHONDRION
CHLOROPLAST
High H+ concentration
H+
Diffusion
INTERMEMBRANE SPACE
THYLAKOID SPACE
MEMBRANE
Electron transport chain
ATP synthase
MATRIX
STROMA
ADP + Ⓟi
ATP
H+
Low H+ concentration



Light
H_2O
CO_2
$NADP^+$
ADP
+ P_i
LIGHT REACTIONS
CALVIN CYCLE
ATP
NADPH
Chloroplast
O_2
CH_2O (sugar)

photon
OH⁻
OH⁻
OH⁻
OH⁻
OH⁻
OH⁻
NAD$_{re}$
PQ
PQ
Cyt f
PC
P700
Fd
FAD
FeS
CF
2e⁻
2e⁻
2e⁻
2e⁻
2e⁻
2H⁺
H⁺
H⁺
TOSYSTEM II
PHOTOSYSTEM I


Electron transfer
Primary electron acceptor
Reaction center
Photon
Reaction-center chlorophyll
Transfer of energy
Antenna pigment molecules
Photosystem

When Light Is Absorbed, Electrons Enter an Excited State

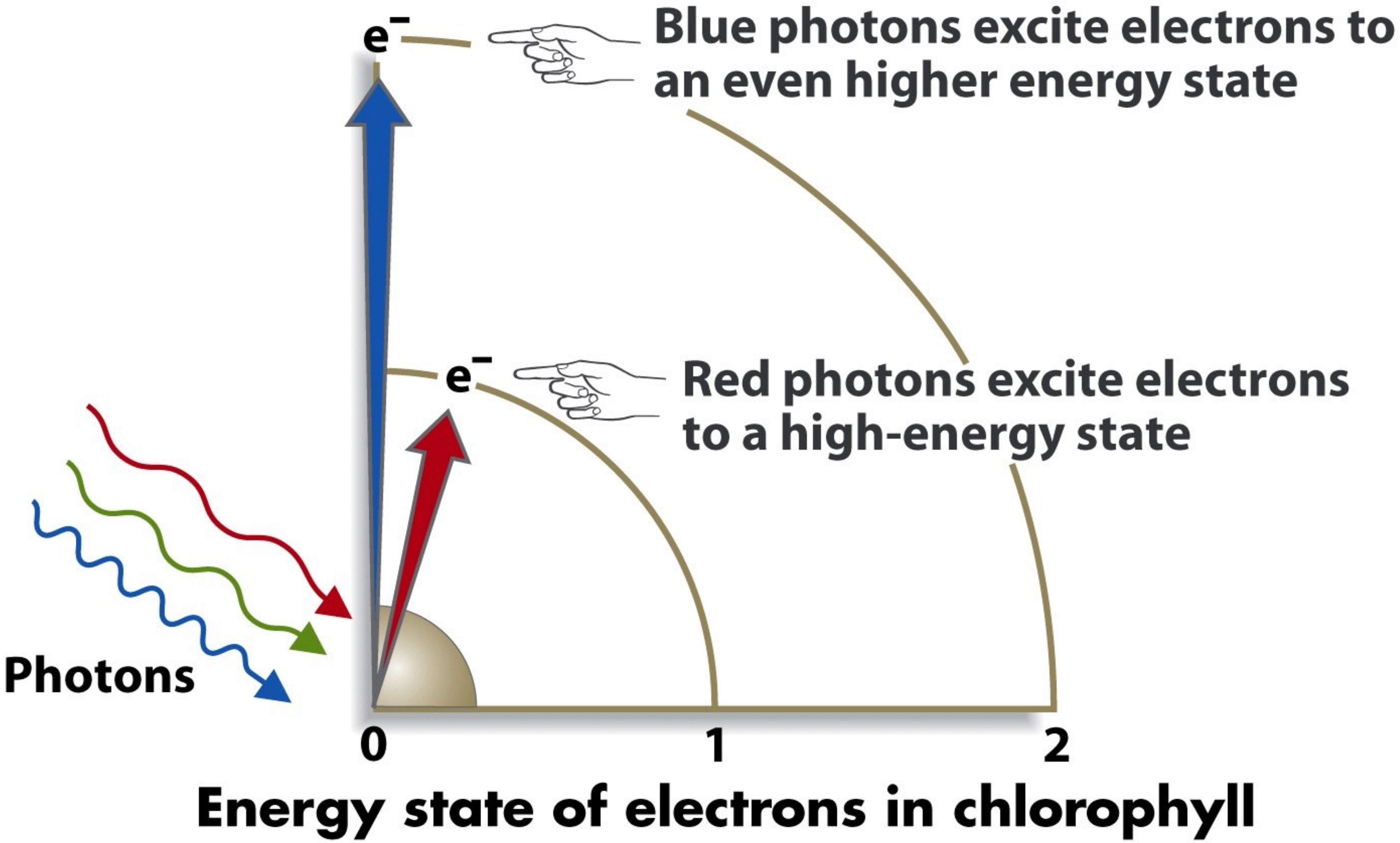


Figure 10-9 Biological Science, 2/e

Time to capture photons (photosystem football)