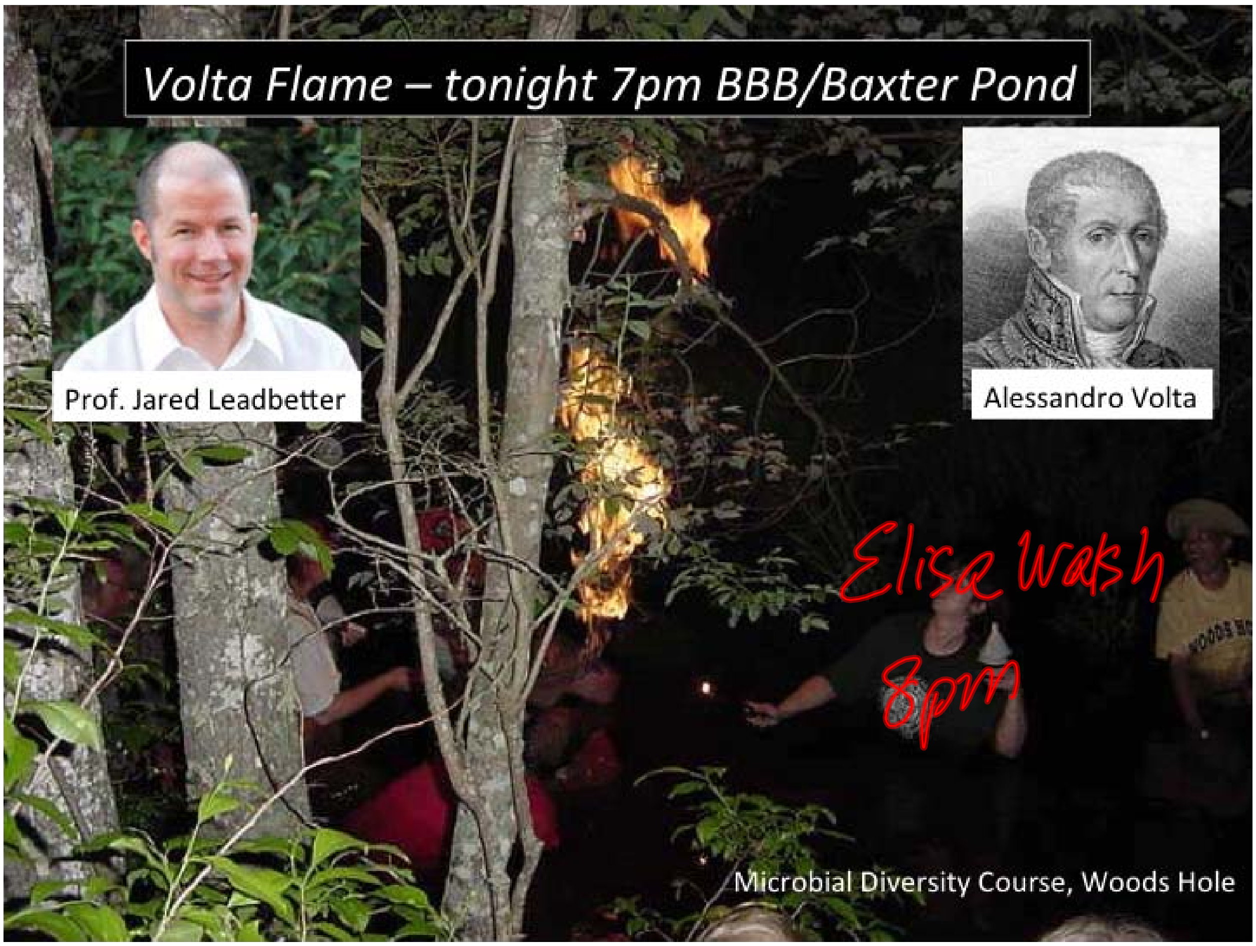
April 05, 2012



What percentage of the class has methanogens in their gut?

~25%

Methanogenesis reaction

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

e^- acceptor $\quad$ e^- donor

Outline for today

<u>Part 1</u>
- Introduction to different cell types
- Cell composition
- Cell dynamics/ transport
- Compartmentalization

iClicker Q1, short break

<u>Part 2</u>
- The eukaryotic cell
  - Features and consequences
  - Origin
- Multicellularity
  - Where and when it occurs (all domains)
  - Molecular basis

iClicker Q2

Introduction to different cell types

norm pace

Bacteria, Archaea, Eucaryotes

B A

E

Prokaryotes

1 µm

B, A

compact

10 µm

E

compartmentalized

[vs. Viruses, Prions, Viroids]

<u>Structural/functional v. chemical similarity</u>

→ antibiotics!

Basic principles: what does a cell need?

Functional goal	Components
• Reproduction (make copies)	*nucleic acids*
• Ability to move (get good stuff, avoid bad)	*flagella, pili, slime (proteins, EPS)*
• Transportation network (get things in/out)	*protein channels*
• Ability to harvest energy	*small molecules, membranes (battery)*
• Ability to defend itself	*small molecules, cell wall/membrane*
• Emergency preparedness (repair damage)	*proteins*
• Separate the inside from outside	*membranes*

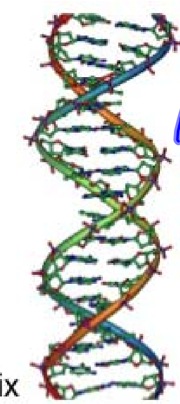
Building blocks – **Nucleic acids**

Function: DNA (information storage), RNA (information transfer, catalysis, synthesis, regulation)

Polymers of nucleotides joined by sugar and phosphate backbones

* DNA = deoxyribonucleic acid (A pairs with T, C pairs with G)

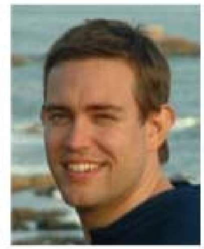
* RNA = ribonucleic acid (A pairs with U, C pairs with G)



H-bonds connecting base pairs

DNA double helix

tRNA



P. Rothemund
(BE, CS)

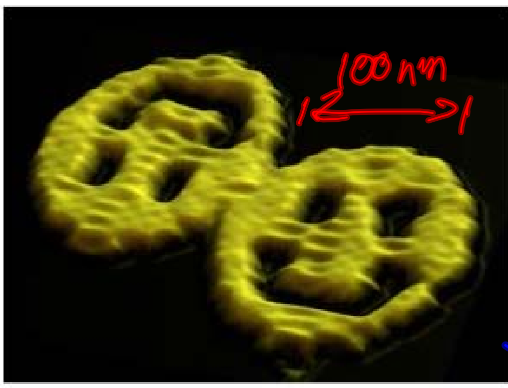
Building blocks – **Nucleic acids**

NOT RANDOM

Energetic significance of base pairing facilitates programming

Highly computation → molecular programming

DNA Origami



Giant DNA complexes imaged with AFM

- ~14,000 DNA base
  - ↳ 7,000 " (single strand) → M13 virus
  - \+
  - 7,000 → shorter (250) strands
    - ↳ each ~30 bp

Rothemund, Folding DNA to create nanoscale shapes and patterns, *Nature* (2006)
See TED talk posted online!

I ♥ Bi1

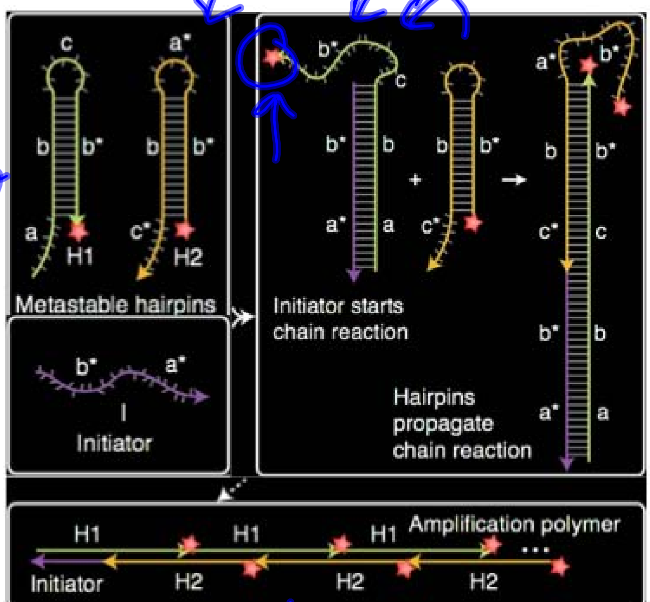
RNA

Building blocks – **Nucleic acids**

physical modeling
comput. simul.
Dynamics

Example: Detection of specific RNAs

RNA detect

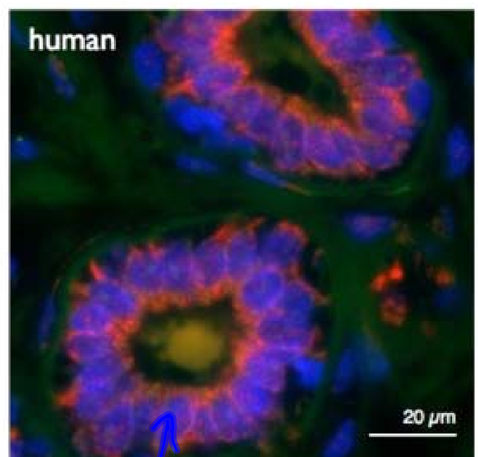


HCR = hybrid. chain reaction

Dirks and Pierce, *Proc Natl Acad Sci USA*, 2004

N. Pierce (BE, ACM)

ACM 95!



transcript = RNA

Building blocks – **Nucleic acids**

J. Barton CCE Chair

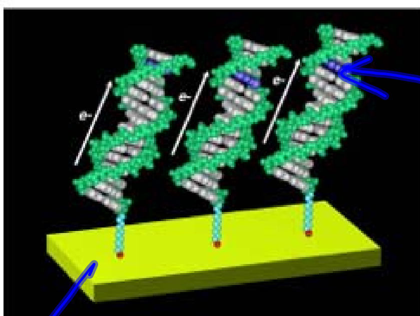
DNA conduct e^-

↳ apply to detect mismatches

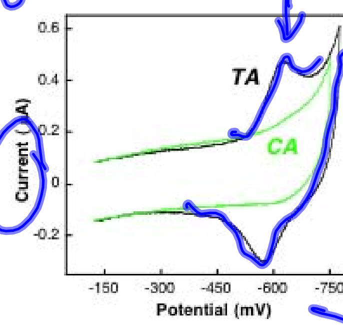
Redox

SH-5'ATTATATTAAT CG
TAATATAATTA GC

SH-5'ATTATATTAAT CG
TAATACAATTA GC



Redox active molecule e^-



electrode

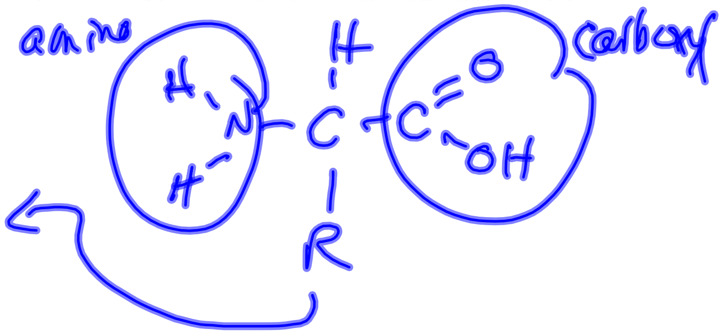
Cyclic voltam.

→ Hyp: mech to detect & repair DNA damage

Kelley, S.O.; Jackson, N.M.; Hill, M.G.; Barton, J.K. *ACI* **38,** 941 (1999).

Building blocks – **Proteins**

Function: make things, move things around, provide structure, regulate, protect and repair



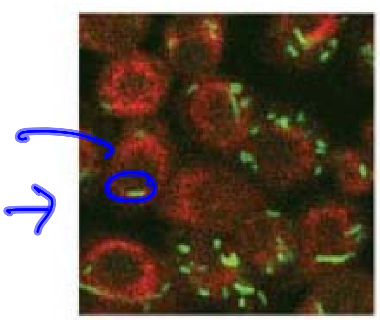
20 aa

+ or −

unch.

hydroph.

-special case → methione

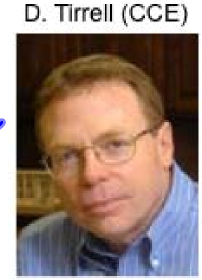


Can we engineer new properties?

azide,

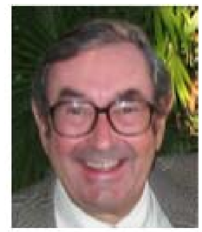
fluor

D. Tirrell (CCE)



JT Ngo *et al* (2009) Cell selective metabolic labeling of proteins, *Nat Chem Bio*

Building blocks – **Proteins**



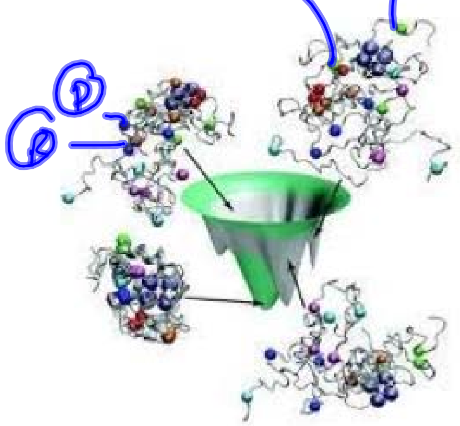
H. Gray (CCE)

"Levinthal's Paradox":
Consider a small protein (polypeptide) comprised of 100 aa
Assume each aa can take on 2 different conformations (2^{100})

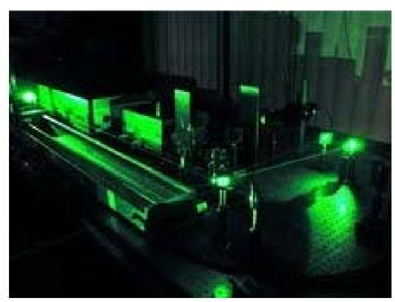
D ⟷ A FRET

Landscape

ps-time



Pascher et al. *Science* **1996**, *271*: 1558
Levinthal, *J. Chim. Phy.* **1968**, *65*: 44



532 Nd:YAG laser

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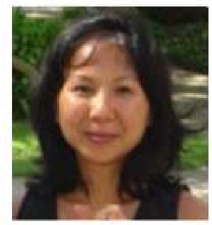
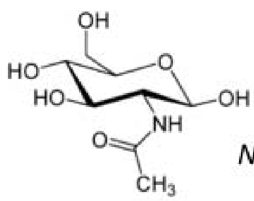
Building blocks – **Carbohydrates, Lipids**

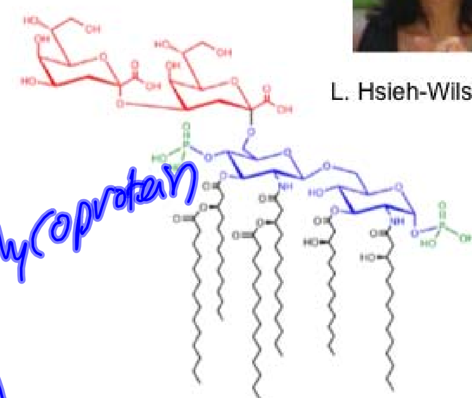
Function: separate inside from outside



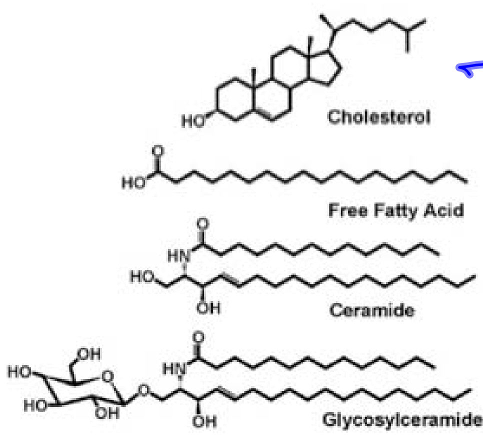
L. Hsieh-Wilson (CCE)

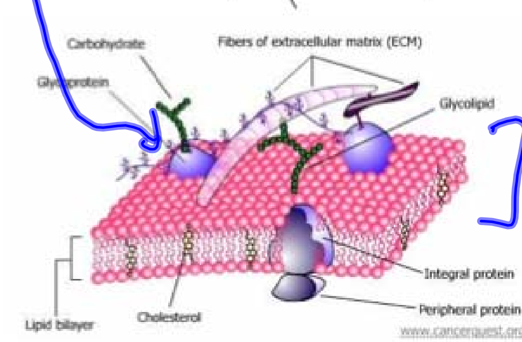


N-acetylglucosamine)



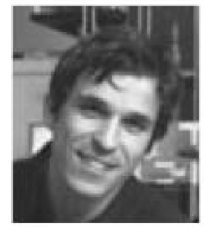
glycoprotein



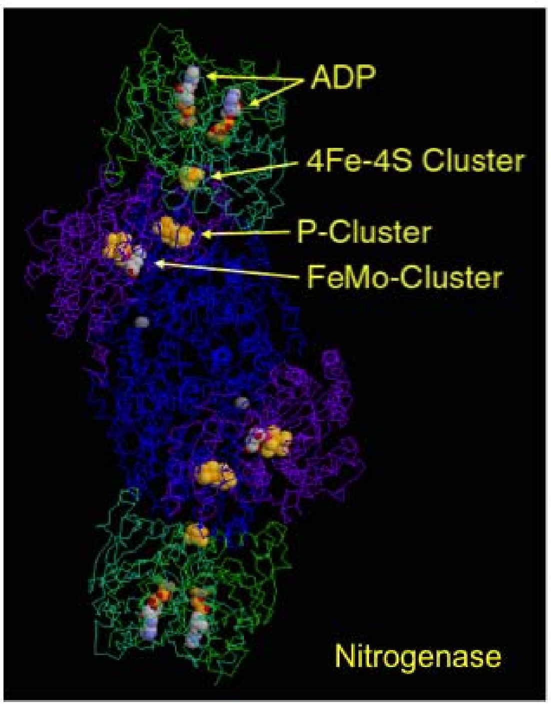


membrane

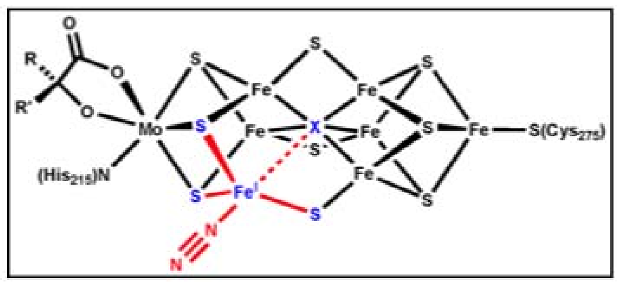
Building blocks – **metal cofactors** (function: catalysis)



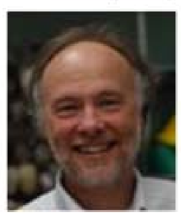
J. Peters (CCE)



The FeMo cofactor



D. Rees (CCE)



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General Bacterial cell biology

Trans. Elec. Microp

- Compact genome

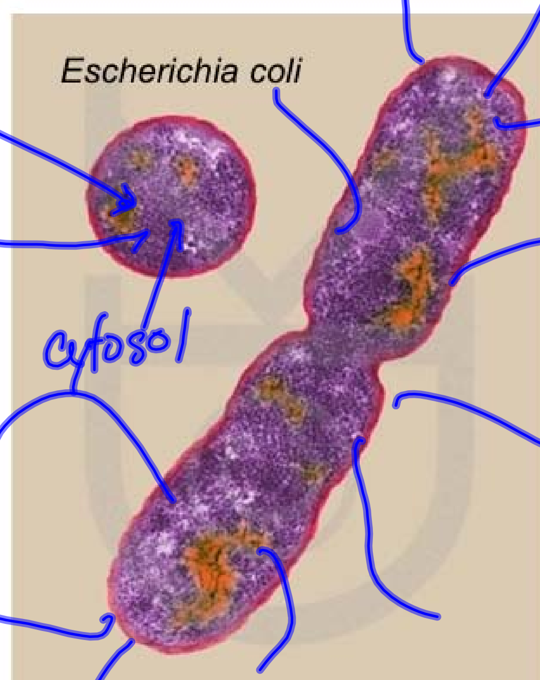
nucleoid

- Ribosomes
- Envelope

cytosol

- Metabolicaly Diverse

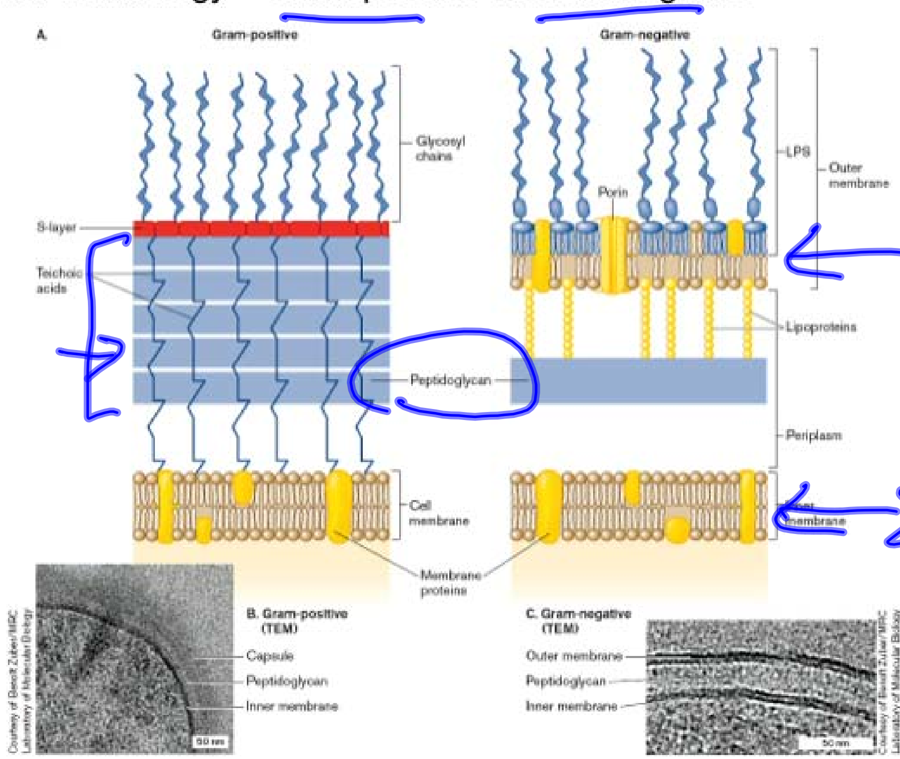
Flagellum



www.DennisKunkel.com

Bacterial cell biology – Gram positive v. Gram negative

cell wall



OM

IM

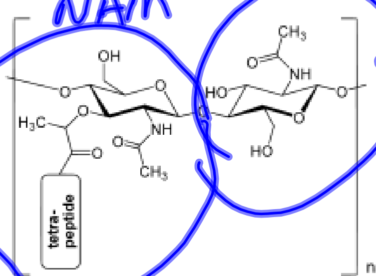
Bacterial cell biology –peptidoglycan cell wall

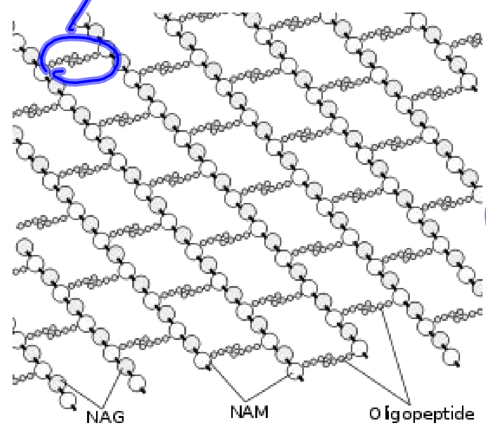
peptides
Proteins

N-acetylglucosamine (GlcNAc or NAG) +
N-acetylmuramic acid (MurNAc or NAM)

NAG

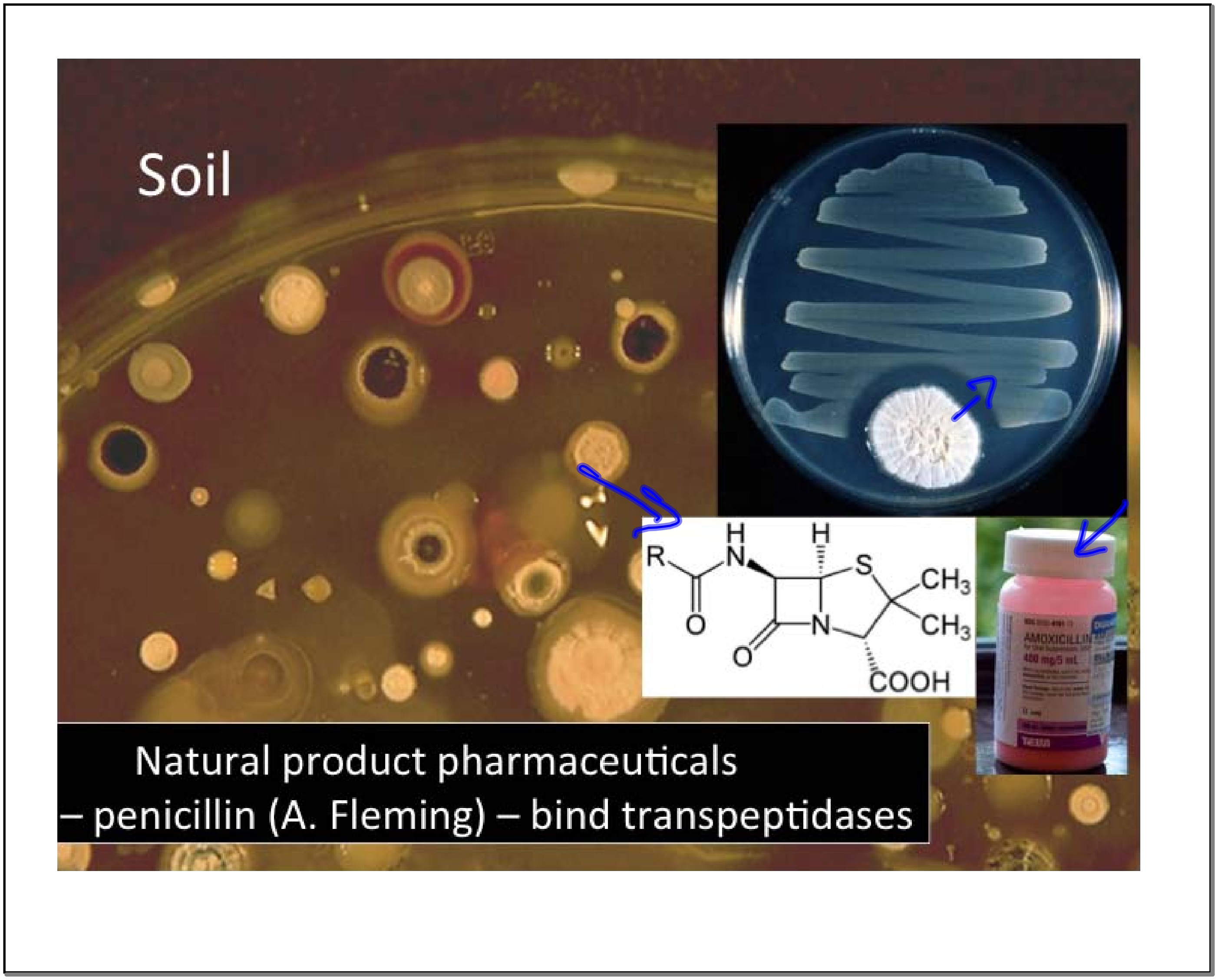
NAM





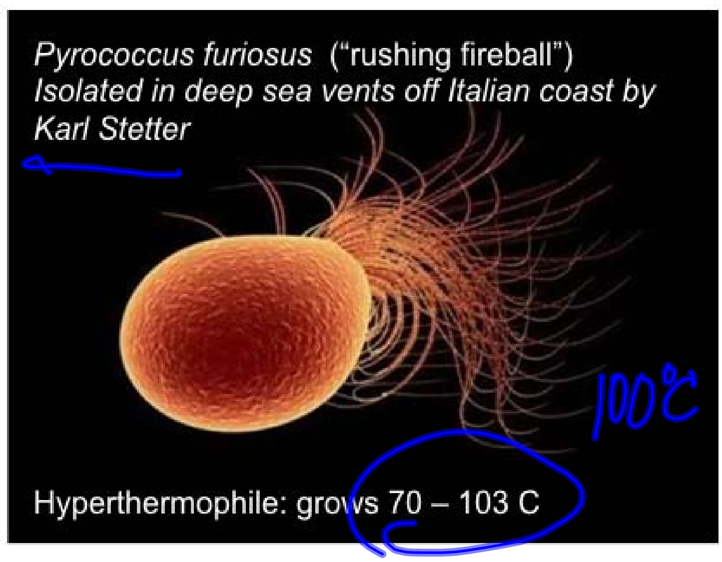
Transpeptidases (*i.e.* Penicillin binding proteins) catalyze joining of strands

PBP


Soil
R
H
N
H
S
CH3
CH3
O
O
N
COOH
AMOXICILLIN
400 mg/5 mL
Natural product pharmaceuticals
– penicillin (A. Fleming) – bind transpeptidases

General Archaeal cell biology

- Compact genome
- Abund ribosomes
- Cell Envelope
  ↳ chem.



Archaeal cell biology—cell membrane

phospholipids

1.) isoprene chains

2.) ether linkage

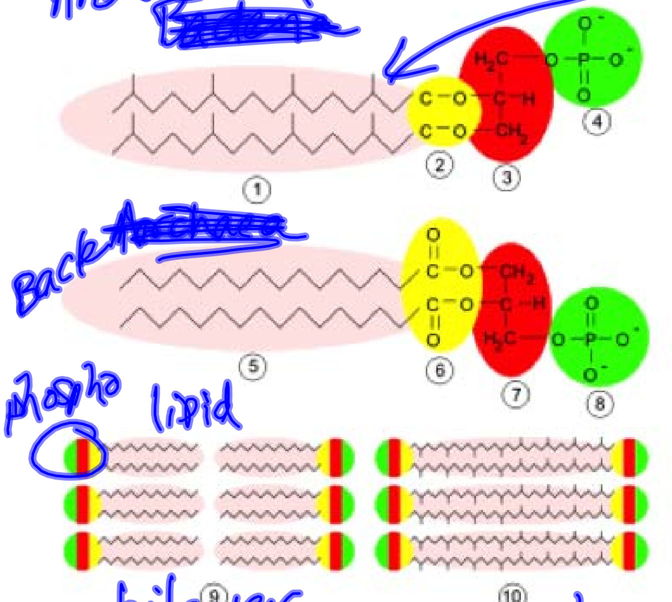
5.) fatty acids

6.) ester

tougher ↑temp

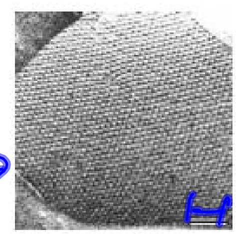
Archae ~~Bacteria~~

Back ~~Archaea~~



→ ↑ rigidity heat tol.

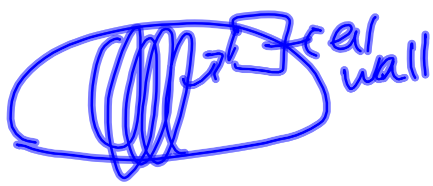
cell wall = S-layer (crystalline layer of proteins/glycoproteins)
(also in some Gm+ bacteria)



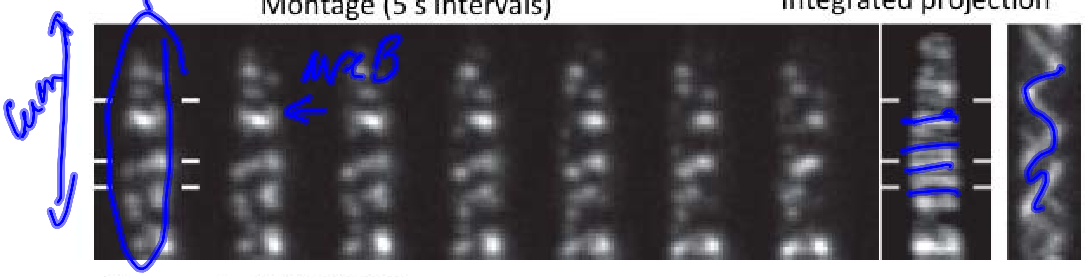
Cell dynamics: targeted movement of proteins within cells

Example: Dynamic MreB movement (peptidoglygan biosynthesis) in *Bacillus subtilis*

→ actin-like protein (in euks → mech. supp, motility, muscle contract, cargo trans)



B. subtilis



Garner *et al.* (2011) *Science*
Dominguez-Escobar *et al.* (2011) *Science*

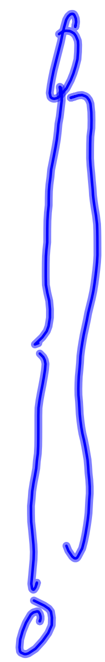
Can cells transport things by diffusion alone?

$t = \frac{x^2}{D}$ Diffusion (protein) = $10\ \mu m^2/s$

E. coli vs. Sensor neuron

$t_{E.coli} = \frac{(1\mu m)^2}{10\mu m^2/s} = 10^{-1} s$

$\boxed{= 0.1 \text{ sec}}$



$1m = 10^6 \mu m$

$t_{neuron} = \frac{(10^6 \mu m)^2}{10 \mu m^2/s} = 10^{11} s$

= 10,000 years!

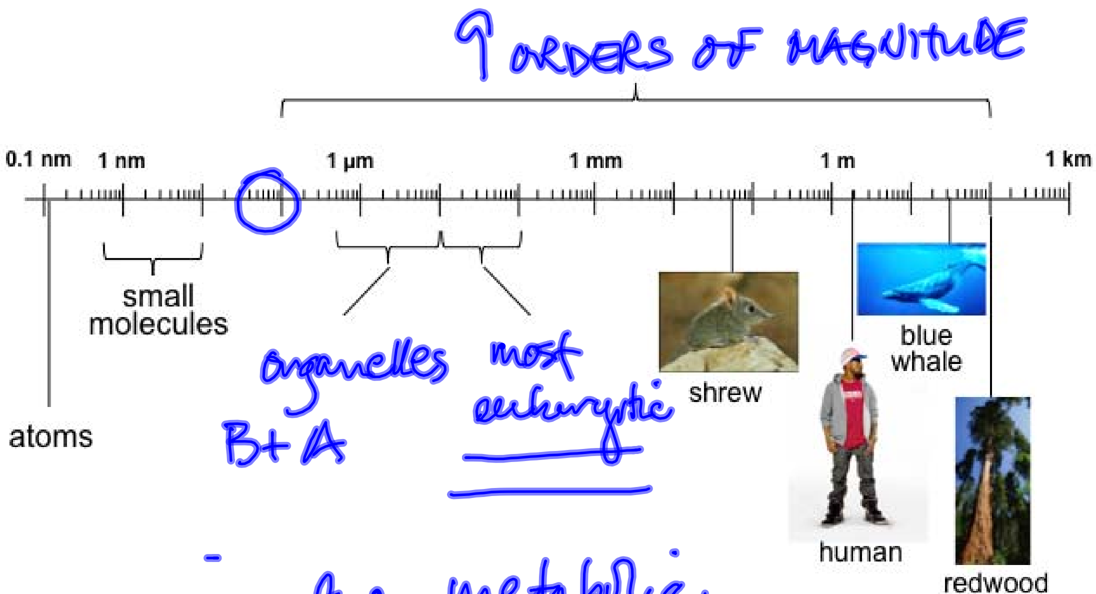
Compartmentalization

Homework

Mank

Key concepts for today – Part 2:

1. THE EUKARYOTIC CELL
2. MULTICELLULARITY

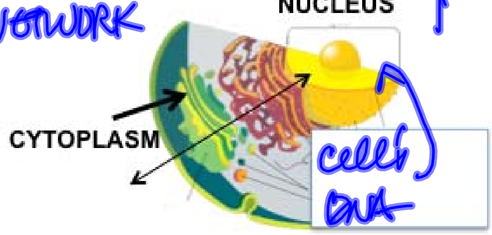


impact on metabolic rate

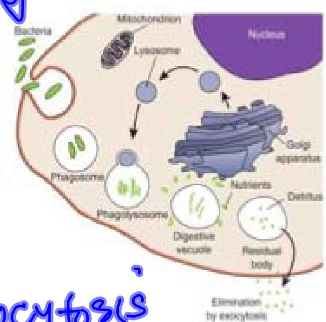
The Eukaryotic Cell

ABUNDANT MEMBRANE NETWORK

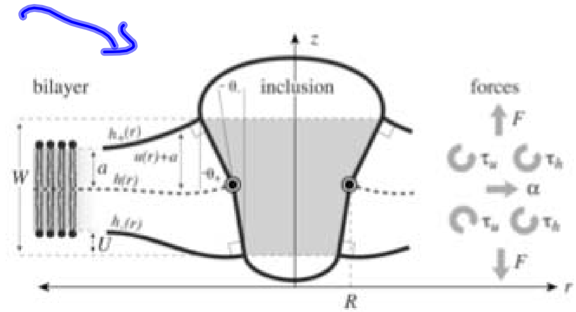
USU 1 (RBC, & CELLS)



cells DNA



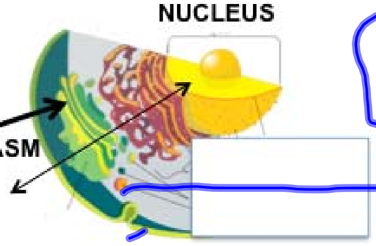
phagocytosis



Rob Phillips – Applied Physics

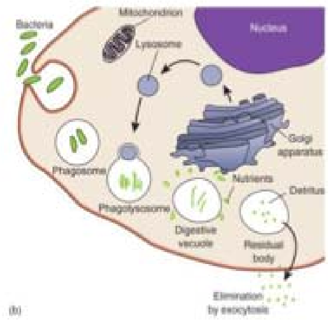
The Eukaryotic Cell

NUCLEUS

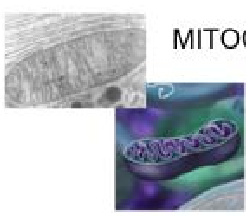


CYTOPLASM

Single-layer membrane network

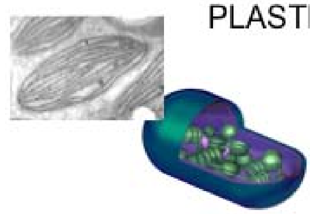


DOUBLE MEMBRANE, NUCLEIC ACIDS (lack histones)
BACTERIA-SPECIFIC PROTEINS



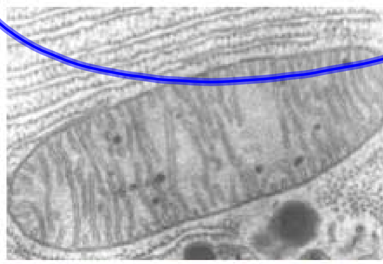
MITOCHONDRIA

PLASTIDS

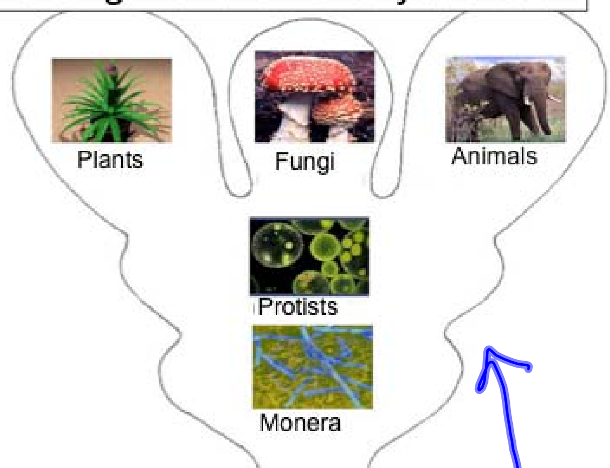


BACTERIAL?

Endosymbiosis Theory of the Origin of the Eukaryotic Cell



Lynn Margulis 1938-2011

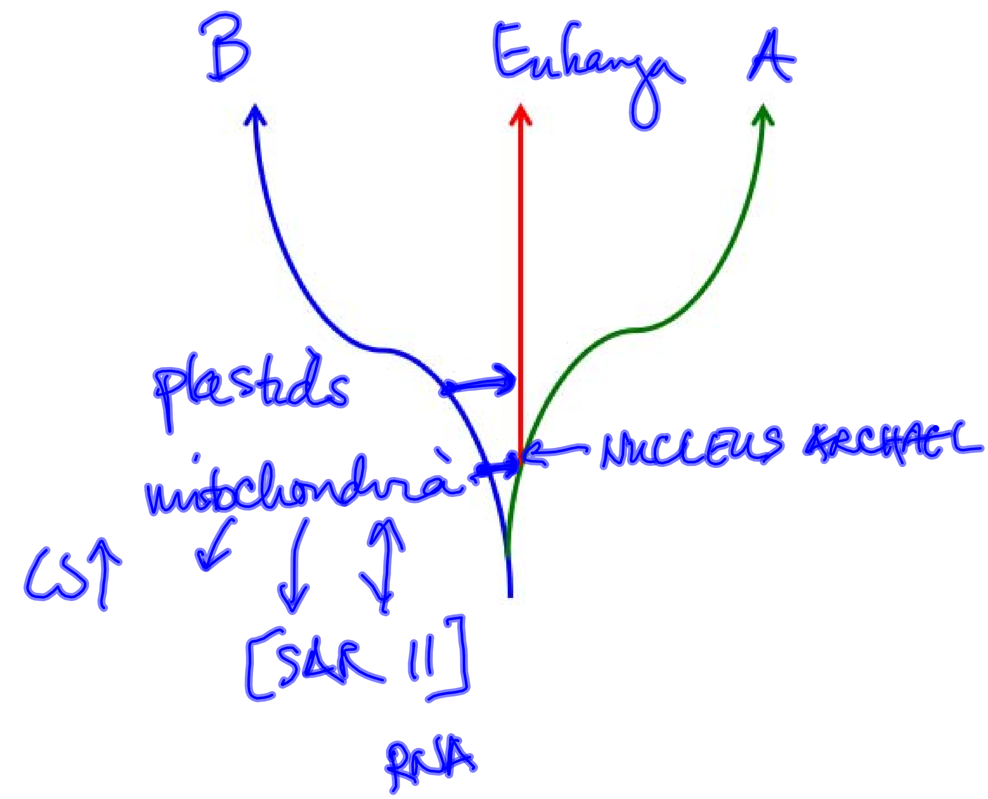


Five Kingdom Model

L SAGAN (1967)

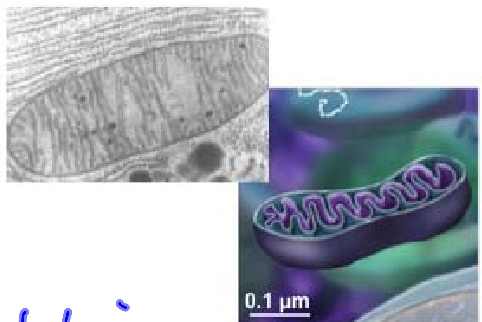
1960 - 2000

ENDOSYMBIOSIS - LIVES ON


B
Eukarya
A
plastids
NUCLEUS ARCHAEL
mitochondria
CS
[SAR 11]
RNA

The Eukaryotic Cell

The mitochondrion:



0 - 100,000 (eggs)

2 - 1° Functions

1. oxidative phosphorylation

   organic C + $\boxed{O_2}$ → CO_2 + H_2O

   terminal e^- acceptor

2. BIOSYNTHESIS OF Fe-S CLUSTERS

   only essential function of mitochondrion

   A. - e^- transfer (-500 to +300)

   B. cofactors

   C. sense environment

MATERNALLY INHERITED -

EVE

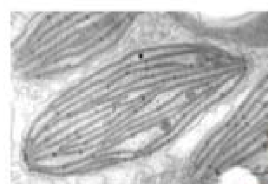
IN PLANTS/ALGAE

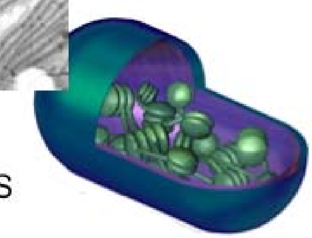
1. LEAVES – photosynthesis
2. ROOT – STORE STARCH
3. FLOWER – COLOR

CHLOROPLAST

$\boxed{C}O_2 + \boxed{H_2}O \xrightarrow{h\nu}$ ORGANIC C + O_2

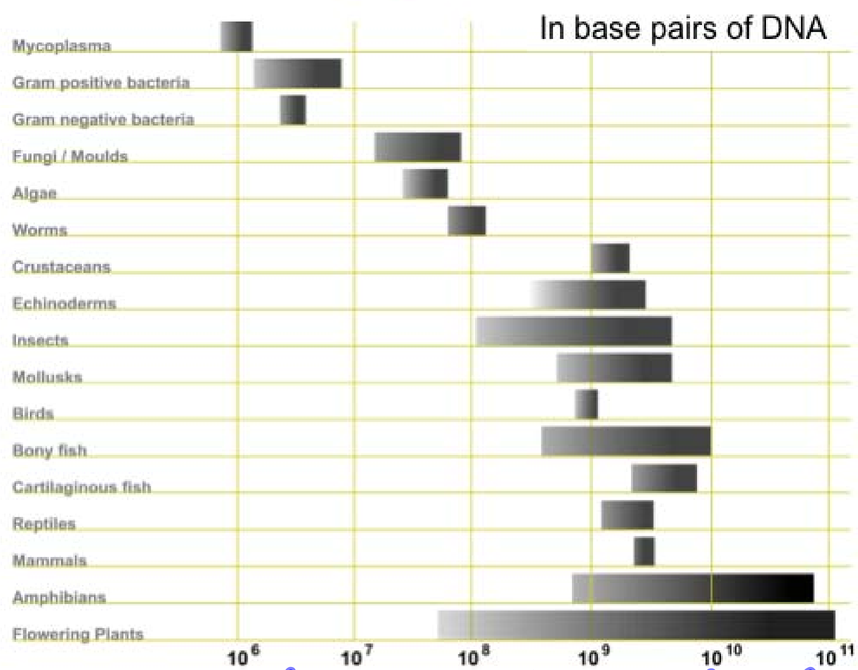
unlike B/A





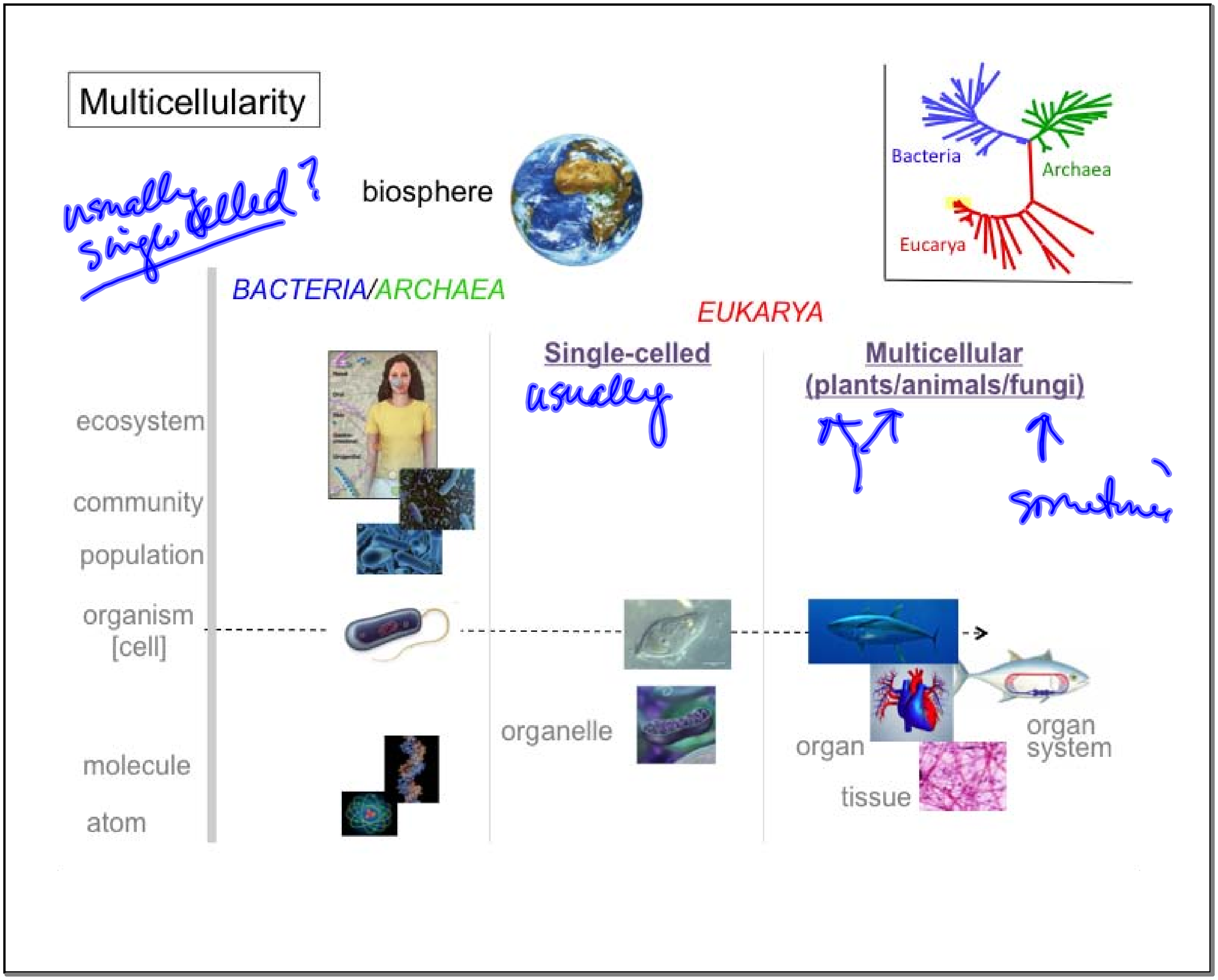
PLASTIDS

Eukaryotic cells have larger genome sizes



smallest
160 kb

Largest genome - amoeba 670 Gbp
humans - 3,2 Gbp
lungfish - 130 Gbp


Multicellularity
usually single celled?
biosphere
Bacteria
Archaea
Eucarya
BACTERIA/ARCHAEA
EUKARYA
Single-celled
usually
Multicellular
(plants/animals/fungi)
sometimes
ecosystem
community
population
organism
[cell]
molecule
atom
organelle
organ
organ system
tissue

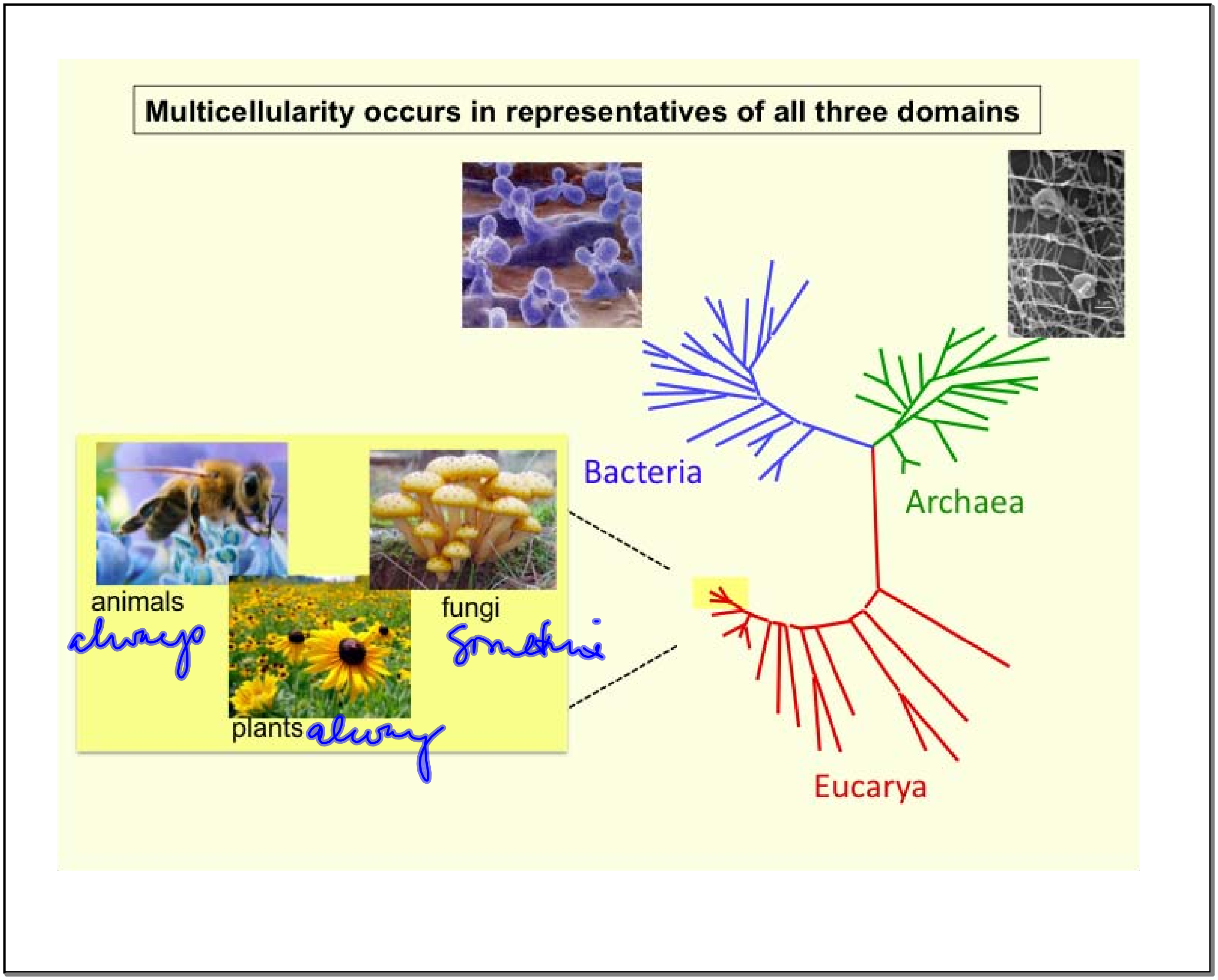
Multicellularity

groups of cells & +/- differentiation

Arises
1) cell aggregation
2) lack of separation in division

ω is greater w/ m-c if selection
favor cooperativity

$\omega \downarrow$ conflict


Multicellularity occurs in representatives of all three domains
Bacteria
Archaea
Eucarya
animals
always
fungi
sometimes
plants
always

Difference in number of cell types:

Bacteria - 2-3 cell types
fungi - 7-9 cells "
Plants + Animals 10s → 100s

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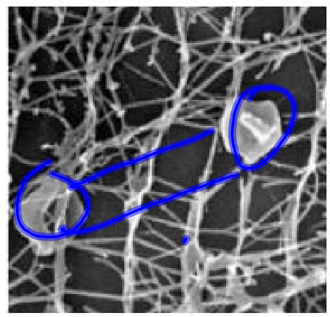
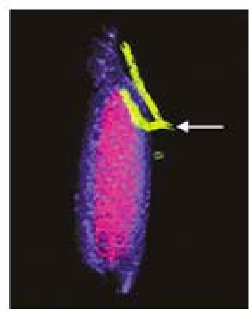
Multicellular Archaea

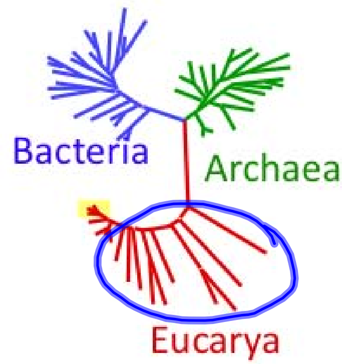


3000m
~100°C
Pyrodictium



MULTICELLULAR PROTIST

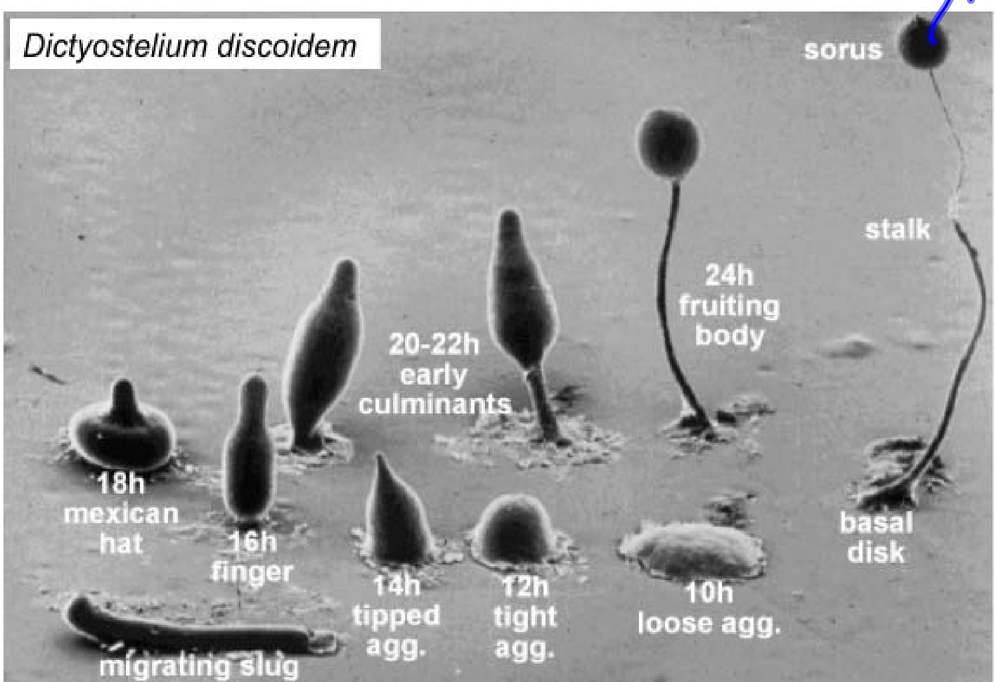
Dictyostelium discoideum



MOVIE

cAMP

April 05, 2012

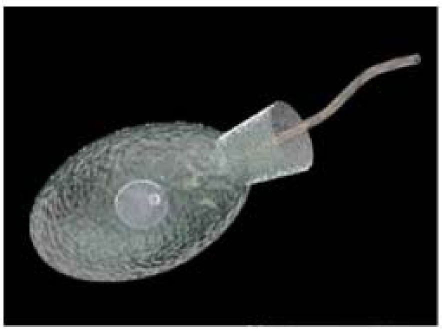


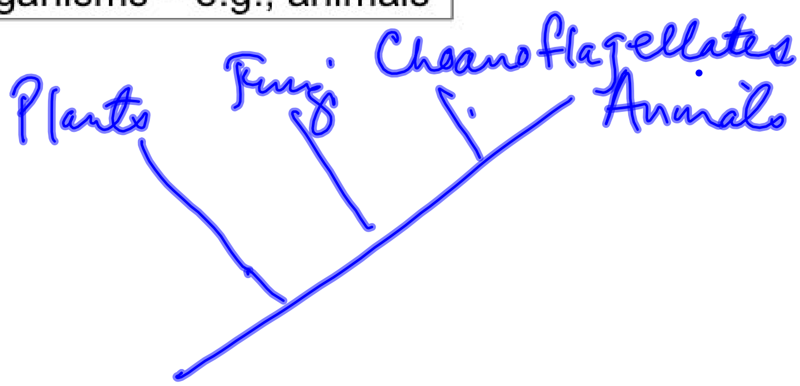
differentiation; division of labor
self-sacrifice

Where in the hierarchy? What emergent properties?

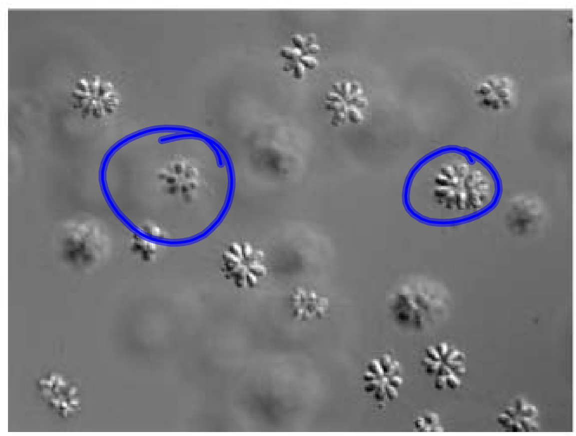
biosphere
ecosystem
community
population
organ system
organ
tissue
cell
organelle
molecule
atom

Obligately multicellular organisms – e.g., animals





bacteria →
sphingolipid (rare)



What pre-adapted the choanoflagellates to respond?

cells-cell adhesion
intercellular
signaling

Ca^{++} cadherin