Volta Flame – tonight 7pm BBB/Baxter Pond

Prof. Jared Leadbetter

Alessandro Volta

Elise Wash
8pm

Microbial Diversity Course, Woods Hole
What percentage of the class has methanogens in their gut?

\[ \sim 25\% \]

Methanogenesis reaction

\[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \]

\[ \uparrow \text{e- donor} \quad \uparrow \text{i- acceptor} \]
Outline for today

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

*iClicker Q1, short break*

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

*iClicker Q2*
Introduction to different cell types

Bacteria, Archaea, Eucaryotes

$B \neq A$ (Protists)

$E \sim \text{compact}$

$\sim \text{vs. Viruses, Prions, Viroids}$

Structural/functional vs. chemical similarity

$\rightarrow \text{antibiotics!}$
**Basic principles:** what does a cell need?

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

→

P. Rothemund
(BE, CS)

See TED talk posted online!

I ♥ BiZ
Building blocks – Nucleic acids

Example: Detection of specific RNAs

Dirks and Pierce, Proc Natl Acad Sci USA, 2004
Building blocks – **Nucleic acids**

DNA conduct e⁻

⇒ apply to detect mismatches

SH-5 ATATTTAAT CG
TAATTAATAA GC

SH-5 ATATTTAAT CG
TAATAATTAAC GC

<table>
<thead>
<tr>
<th>electrode</th>
</tr>
</thead>
</table>

Redox

active molecule

⇒ hyp: mech to detect & repair DNA damage

Cyclic voltam.

Building blocks – Proteins

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

Can we engineer new properties?

D. Tirrell (CCE)

Building blocks – **Proteins**

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


532 Nd:YAG laser
Building blocks – **Carbohydrates, Lipids**

Function: separate inside from outside
Building blocks – **metal cofactors** (function: catalysis)

The FeMo cofactor

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ADP

4Fe-4S Cluster

P-Cluster

FeMo-Cluster

Nitrogenase

J. Peters (CCE)

D. Rees (CCE)
General Bacterial cell biology

- Compact genome
- Ribosomes
- Envelope
- Metabolically diverse
  - Flagellum
  - Cytosol

Trans. Elec. Micro

Escherichia coli

www.DennisKunkel.com
Bacterial cell biology – Gram positive v. Gram negative

A. Gram-positive
- S-layer
- Teichoic acids
- Cell wall
- Membrane proteins
- Cell membrane

B. Gram-positive (TEM)
- Capsule
- Peptidoglycan
- Inner membrane

C. Gram-negative (TEM)
- LPS
- Outer membrane
- Peptidoglycan
- Inner membrane

Cell wall
OM
IM
Bacterial cell biology – peptidoglycan cell wall

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

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

Natural product pharmaceuticals
- penicillin (A. Fleming) – bind transpeptidases
General Archaeal cell biology

- Compact genome
- Abundant ribosomes
- Cell envelope

*Pyrococcus furiosus* ("rushing fireball")
Isolated in deep sea vents off Italian coast by Karl Stetter

Hyperthermophile: grows 70 – 103°C
Archaeal cell biology—cell membrane

- Phospholipids
  - Isoprene chains
  - Ether linkage

- Fatty acids
- Ester

- Tougher at higher temp

- Phospho lipid

- Bilayer
- Monolayer

- 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 (peptidoglycan biosynthesis) in *Bacillus subtilis*

Montage (5 s intervals)  Integrated projection

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)** = \(10 \, \mu m^2/s\)

\[ \text{calc.} \quad \frac{1}{1 \mu m} \]

\[ t_{\text{calc.}} = \frac{(1 \mu m)^2}{10 \mu m^2/s} = 10^{-1} \, s \]

\[ = 0.1 \, \text{sec} \]

\[ \text{Sensor neuron} \]

\[ t_{\text{neuron}} = \frac{(10^6 \mu m)^2}{10 \mu m^2/s} = \frac{10^9}{10^{-1}} \, s \]

\[ = 10^8 \, \text{s} \]

\[ \approx 10,000 \, \text{years}^{-1} \]
Compartmentalization

Homework

Manik
Key concepts for today – Part 2:

1. THE EUKARYOTIC CELL
2. MULTICELLULARITY
9 orders of magnitude

- small molecules
- organelles most eukaryotic
  B + A

Impact on metabolic rate

- human
- redwood
- blue whale
- shrew
The Eukaryotic Cell

ABUNDANT MEMBRANE NETWORK

NUCLEUS

CYTOPLASM

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

Five Kingdom Model


Endosymbiosis - Lives on
The Eukaryotic Cell

The mitochondrion:

- 0 - 100,000 (eggs)
- 2 - 10 mitochondria

1. Oxidative phosphorylation
   \[ \text{organic } C + \left[ \text{O}_2 \right] \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]
   terminal e- acceptor

2. Biosynthesis of Fe-S Clusters
   only essential function of mitochondria
   a. e- transfer (-500 mV + 300)
   b. cofactors
   c. sense environment

MATERNALLY INHERITED-
   EVE
In plants/algae:

1. Leaves - Photosynthesis
2. Root - Store starch
3. Flower - Color

Chloroplasts:

$\text{CO}_2 + \text{H}_2\text{O} \xrightarrow{\text{hv}} \text{organic C} + \text{O}_2$

Unlike B/A

PLASTIDS
Eukaryotic cells have larger genome sizes

In base pairs of DNA

Smallest: 160 kb

Largest genome:
- Amoeba: 670 Gbp
- Humans: 3, 2 Gbp
- Lungfish: 130 Gbp
Multicellularity

usually single-celled?

BACTERIA/ARCHAEA

EUKARYA

Single-celled

usually

Multicellular (plants/animals/fungi)

ecosystem
community
population
organism [cell]
molecule
atom

biosphere

organ
organ system

organ

organ

organ

organ system

organ

organ system
Multicellularity

Groups of cells +/- differentiation.

Assi:
1) cell aggregation
2) lack of separation in division

W is greater w/ m-c F selection favor cooperation
and conflict
Multicellularity occurs in representatives of all three domains.
Difference in number of cell types:

Bacteria - 2-3 cell types
Fungi - 7-9 cell types
Plants & Animals 10s \(\rightarrow\) 100s
Multicellular Archaea

3000 m
~ 100°C
Pyrodictium
MULTICELLULAR PROTIST

Dictyostelium discoideum

MOVIE

CAMP
*Dictyostelium discoideum*

- migrating slug
- 18h mexican hat
- 16h finger
- 20-22h early culminants
- 14h tipped agg.
- 12h tight agg.
- 10h loose agg.
- 24h fruiting body
- stalk
- basal disk
- sorus

*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 $\rightarrow$ sphingolipid (rare)
What pre-adapted the choanoflagellates to respond?

Cells-cell adhesion

Cell-cell adhesion

Cell-cell adhesion

Cell-cell adhesion

Café cadherin

Intercellular signaling