

Taxonomy

You will learn:

- Why is taxonomy important
- Methods for identification of microorganisms
- Correlation between taxonomy & evolution



Taxon = group
onomy ≈ distribution

More info: Bergey's Manual:

<http://link.springer.com/book/10.1007%2F0-387-28021-9>

Taxa = groups

WHY TAXONOMY?

- **Classification**
 - Arrangements in groups (taxa)
 - **Nomenclature**
 - Assigning names to taxa
 - **Identification**
 - Determination of taxon to which an isolate belongs
- (most practical part of taxonomy)

MAKING SENSE OF NATURE

PERIODIC TABLE OF THE ELEMENTS

<http://www.ktf-split.hr/periodni/en/>

GROUP	PERIODIC TABLE OF THE ELEMENTS																18						
PERIOD	1	2		3-10										11-12		13	14	15	16	17	18		
	IA	IIA		IIIB-VIIB										VIII		IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18					
1	1.0079 H HYDROGEN															10.811 B BORON	12.011 C CARBON	14.007 N NITROGEN	15.999 O OXYGEN	18.998 F FLUORINE	20.180 Ne NEON		
2	6.941 Li LITHIUM	9.0122 Be BERYLLIUM													26.982 Al ALUMINIUM	28.086 Si SILICON	30.974 P PHOSPHORUS	32.065 S SULPHUR	35.453 Cl CHLORINE	39.948 Ar ARGON			
3	22.990 Na SODIUM	24.305 Mg MAGNESIUM													69.723 Ga GALLIUM	72.64 Ge GERMANIUM	74.922 As ARSENIC	78.96 Se SELENIUM	79.904 Br BROMINE	83.80 Kr KRYPTON			
4	39.098 K POTASSIUM	40.078 Ca CALCIUM	44.956 Sc SCANDIUM	47.867 Ti TITANIUM	50.942 V VANADIUM	51.996 Cr CHROMIUM	54.938 Mn MANGANESE	55.845 Fe IRON	58.933 Co COBALT	58.693 Ni NICKEL	63.546 Cu COPPER	65.39 Zn ZINC	69.723 Ga GALLIUM	72.64 Ge GERMANIUM	74.922 As ARSENIC	78.96 Se SELENIUM	79.904 Br BROMINE	83.80 Kr KRYPTON					
5	85.468 Rb RUBIDIUM	87.62 Sr STRONTIUM	88.906 Y YTTRIUM	91.224 Zr ZIRCONIUM	92.906 Nb NIObIUM	95.94 Mo MOLYBDENUM	(98) Tc TECHNETIUM	101.07 Ru RUTHENIUM	102.91 Rh RHODIUM	106.42 Pd PALLADIUM	107.87 Ag SILVER	112.41 Cd CADMIUM	114.82 In INDIUM	118.71 Sn TIN	121.76 Sb ANTIMONY	127.60 Te TELLURIUM	126.90 I IODINE	131.29 Xe XENON					
6	132.91 Cs CAESIUM	137.33 Ba BARIUM	57-71 La-Lu Lanthanide	178.49 Hf HAFNIUM	180.95 Ta TANTALUM	183.84 W TUNGSTEN	186.21 Re RHENIUM	190.23 Os OSMIUM	192.22 Ir IRIDIUM	195.08 Pt PLATINUM	196.97 Au GOLD	200.59 Hg MERCURY	204.38 Tl THALLIUM	207.2 Pb LEAD	208.98 Bi BISMUTH	(209) Po POLONIUM	(210) At ASTATINE	(222) Rn RADON					
7	(223) Fr FRANCIUM	(226) Ra RADIUM	89-103 Ac-Lr Actinide	(261) Rf RUTHERFORDIUM	(262) Db DUBNIUM	(266) Sg SEABORGIUM	(264) Bh BOHRNIUM	(277) Hs HASSIUM	(268) Mt MEITNERIUM	(281) Uun UNUNNIUM	(272) Uuu UNUNUNIUM	(285) Uub UNUNBIUM		(289) Uuq UNUNQUADIUM									

RELATIVE ATOMIC MASS (A)

GROUP IUPAC

GROUP CAS

ATOMIC NUMBER

SYMBOL

ELEMENT NAME

- Metal
- Semimetal
- Nonmetal
- 1 Alkali metal
- 2 Alkaline earth metal
- Transition metals
- Lanthanide
- Actinide
- 16 Chalcogens element
- 17 Halogens element
- 18 Noble gas

STANDARD STATE (25 °C; 101 kPa)

Ne - gas Fe - solid
Ga - liquid Tc - synthetic

Question 1:
Why did we group them in a systematic way?

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36	63 151.96 Eu EUROPIUM	64 157.25 Gd GADOLINIUM	65 158.93 Tb TERBIUM	66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.04 Yb YTTERIUM	71 174.97 Lu LUTETIUM
44	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM

Founding father of taxonomy: Carl von Linné (1707 – 1778)

Born 1707 Stenbrohult, Småland

1727 Un of Lund (medicine)

1728 Un of Uppsala (botany)

1731 Lapland excursion

1735 Un of Harderwijk (medical degree)

1735 Un of Leiden

Systema Naturae, 1st Edition

1738 Sweden – Stockholm

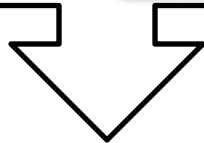

1741 Professor at Un of Uppsala

Died 1778



Some important developments

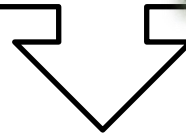
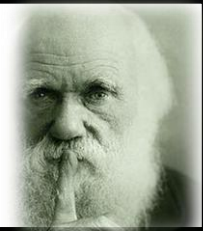
Linnaeus
1735



**Natural
classification**

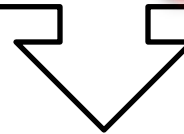

**Plants
Animals**

C Darwin
1859



**Phylogenetic
classification**

C Woese
1977



**Modern
Phylogeny**

**Microorganisms
Macroorganisms**

Classification

- **Natural** - anatomical characteristics
- **Phenetic** - phenotypic characteristics
- **Genotypic** - genetic characteristics
- **Phylogenetic** - evolutionary links

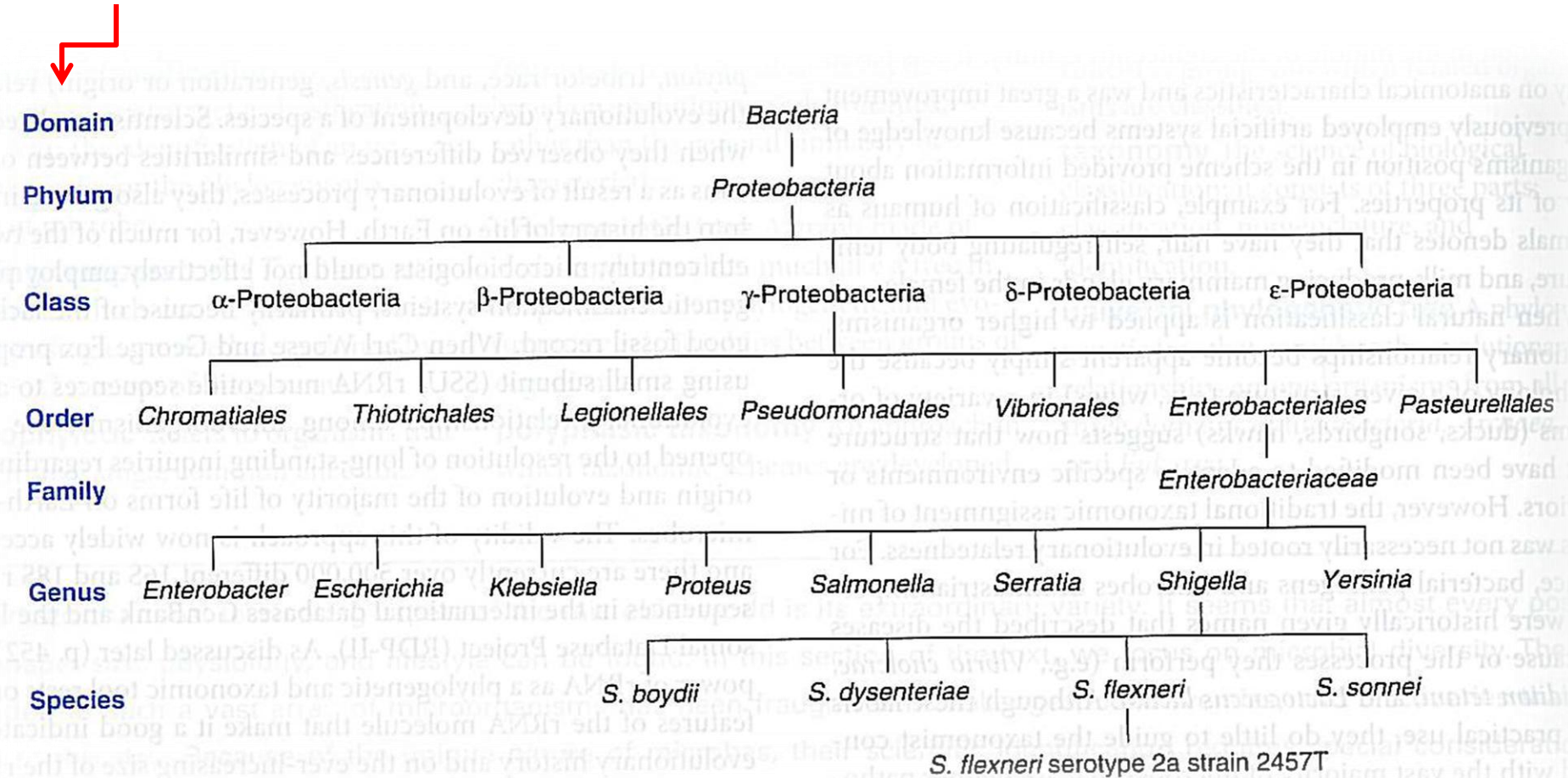
Polyphasic taxonomy

- Incorporates information from genetic, phenotypic and phylogenetic analysis
- Used for determining the genus* and species of a newly discovered (micro-)organism

*genus – well defined group of one or more species that is clearly separate from other genera

Classification: Hierarchical arrangement

Taxonomic ranks



Microbiologist use binomial system of Linné: genus & species

Question 2

Living in the 1970s....

Without molecular techniques

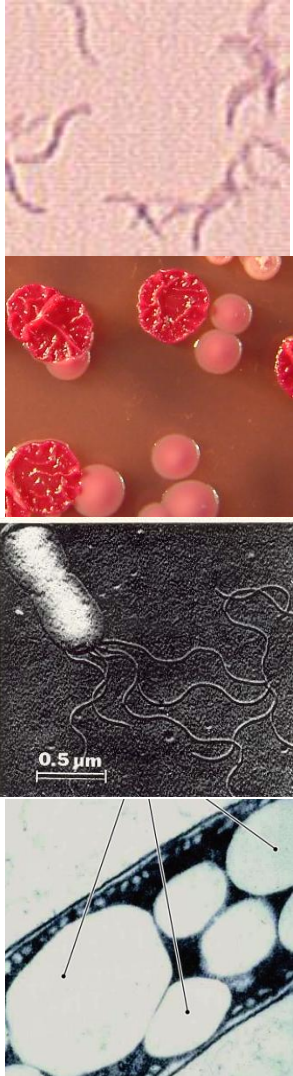
Which techniques would you have used to classify a microorganism?

Which properties of the microorganisms were considered then?

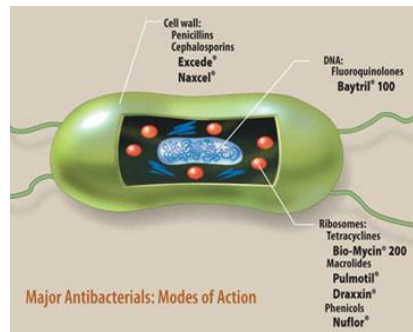
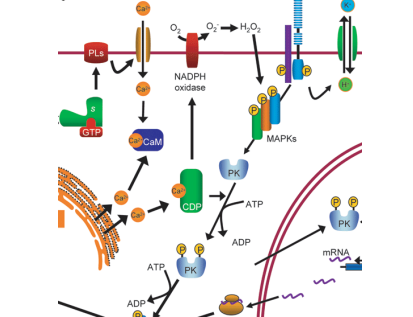
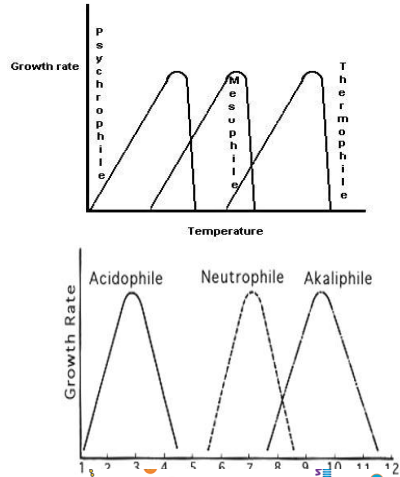
Answer: several examples

Classical methods!

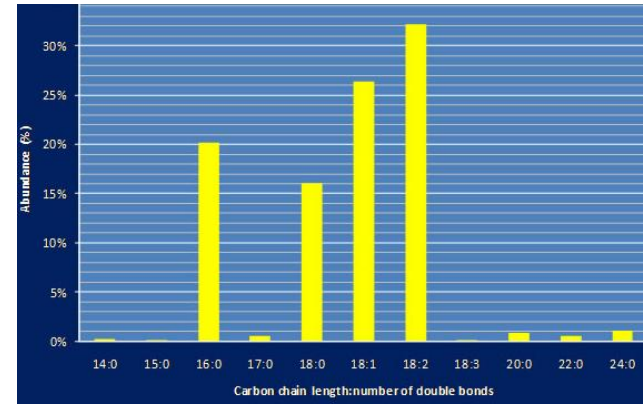
Morphology



Physiology



Biochemistry



Ecology

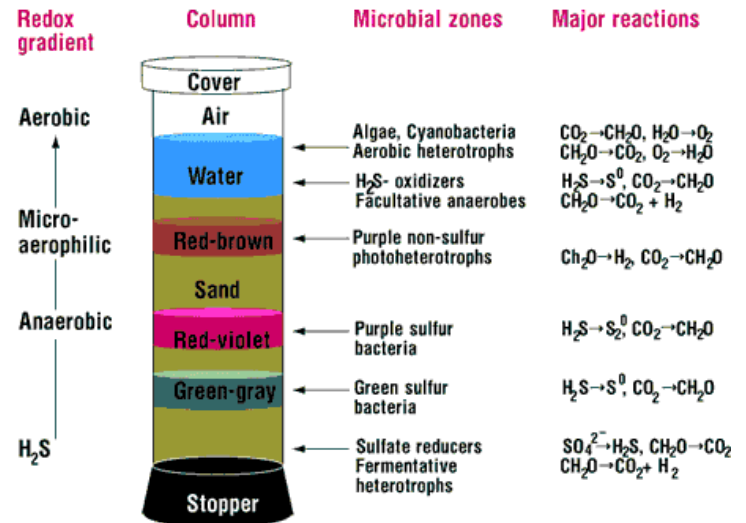


Table 19.10 Some Characteristic Differences between Gram-Negative and Gram-Positive Bacteria

Property	Gram-Negative Bacteria	Gram-Positive Bacteria	Mycoplasmas
Cell wall	Gram-negative type wall with inner 2–7 nm peptidoglycan layer and outer membrane (7–8 nm thick) of lipid, protein, and lipopolysaccharide. (There may be a third outermost layer of protein.)	Gram-positive type wall with a homogeneous, thick cell wall (20–80 nm) composed mainly of peptidoglycan. Other polysaccharides and teichoic acids may be present.	Lack a cell wall and peptidoglycan precursors; enclosed by a plasma membrane
Cell shape	Spheres, ovals, straight or curved rods, helices or filaments; some have sheaths or capsules.	Spheres, rods, or filaments; may show true branching	Pleomorphic in shape; may be filamentous, can form branches
Reproduction	Binary fission, sometimes budding	Binary fission, filamentous forms grow by tip extension	Budding, fragmentation, and/or binary fission
Metabolism	Phototrophic, chemolithoautotrophic, or chemoorganoheterotrophic	Usually chemoorganoheterotrophic, a few phototrophic	Chemoorganoheterotrophic; most require cholesterol and long-chain fatty acids for growth.
Motility	Motile or nonmotile. Flagella placement can be varied—polar, lophotrichous, peritrichous. Motility may also result from the use of axial filaments (spirochetes) or gliding motility.	Most often nonmotile; have peritrichous flagella when motile	Usually nonmotile
Appendages	Can produce several types of appendages—pili and fimbriae, prosthecae, stalks	Usually lack appendages (may have spores on hyphae)	Lack appendages
Endospores	Cannot form endospores	Some groups	Cannot form endospores

Outcome of Classical methods

Methods for identification

Classical

See previous slides

Molecular

GC content

DNA-DNA hybridization

Amino acid sequencing

16R rRNA sequencing

Genomic fingerprinting

Genome sequencing

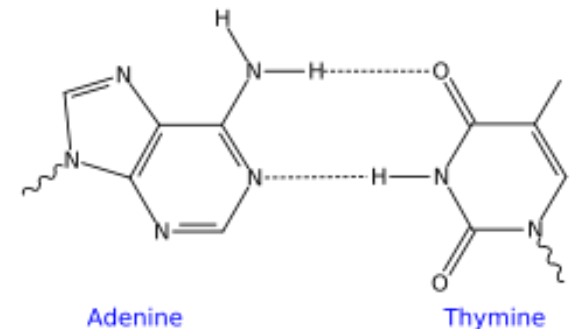
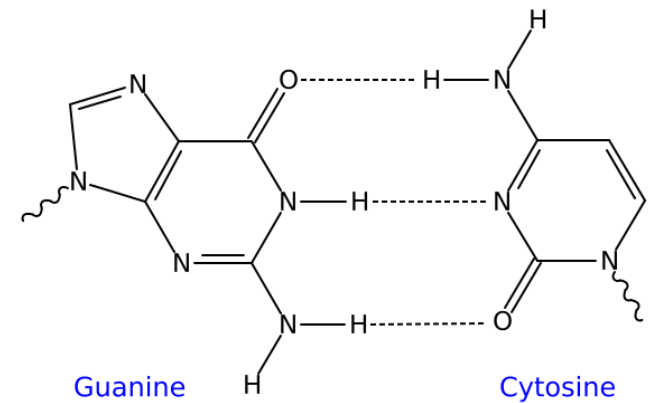
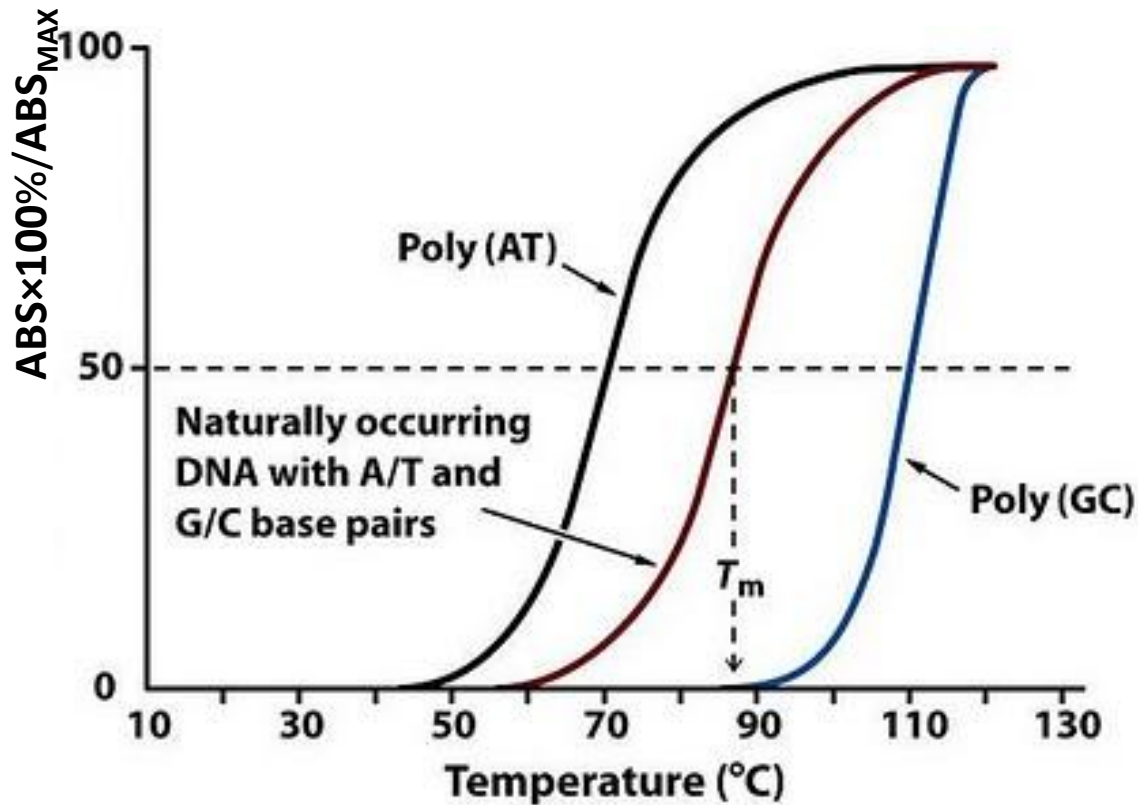
Relative taxonomic resolution

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Family	Genus	Species	Subspecies	Strain
Genome sequencing				
16S rDNA sequencing				
Mol% G+C				
DNA-DNA hybridization				
Multilocus sequence typing				
Whole cell protein profiling				
Genomic fingerprinting				

GC Content (nucleic acid base composition)

Question 3: Why T_m Poly(AT) < T_m poly(GC)?



Absorption at 260 nm (UV)

Principle DNA DNA hybridisation

Measure of sequence homology

common procedure:

- Bind nonradioactive DNA to nitrocellulose filter
- Incubate filter with radioactive single-stranded DNA
- Measure amount of radioactive DNA attached to filter

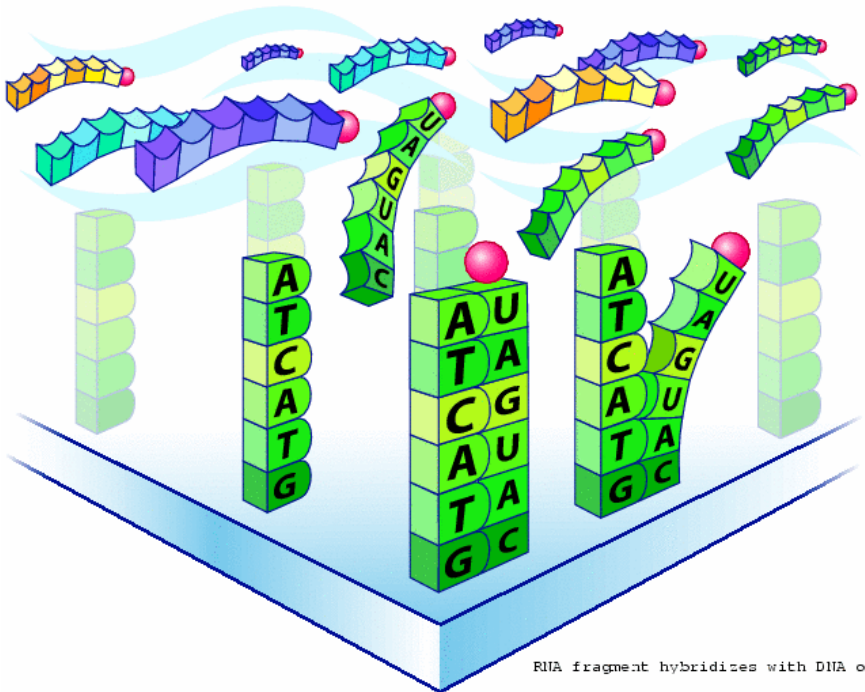
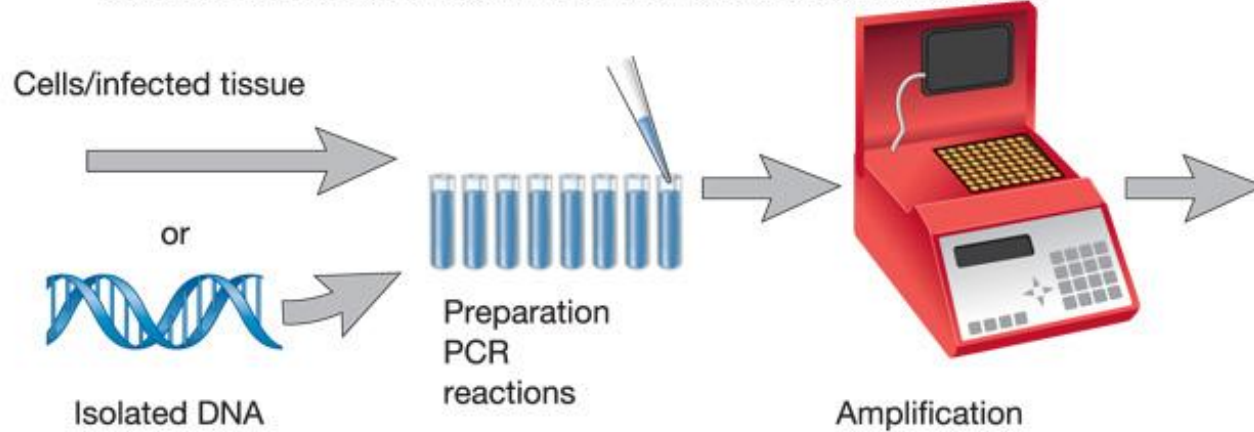


Table 17.4 Comparison of *Neisseria* Species by DNA Hybridization Experiments

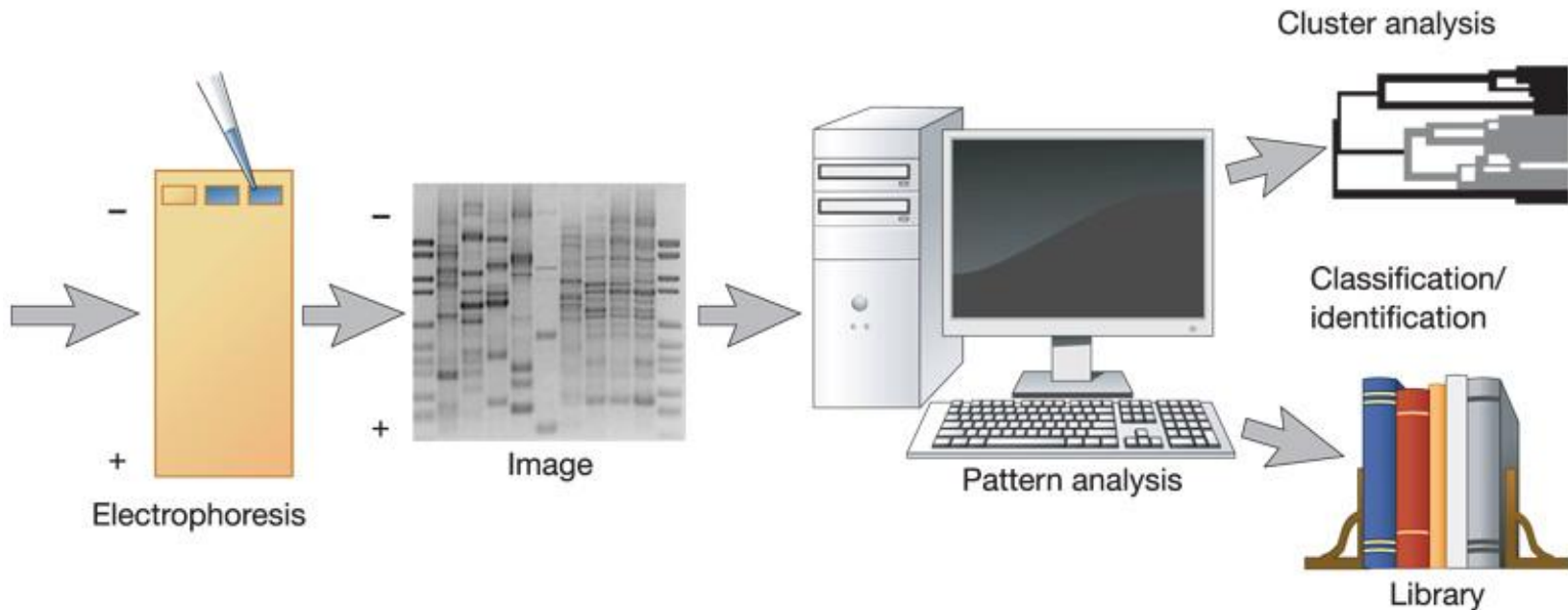
Membrane-Attached DNA ^a	Percent Homology ^b
<i>Neisseria meningitidis</i>	100
<i>N. gonorrhoeae</i>	78
<i>N. sicca</i>	45
<i>N. flava</i>	35

Principle of genomic fingerprinting

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Add Specific primers for Repetitive Nucleotide Sequences



PhD student improves police DNA analysis

29 April 2011



Statens kriminaltekniska
laboratorium - SKL

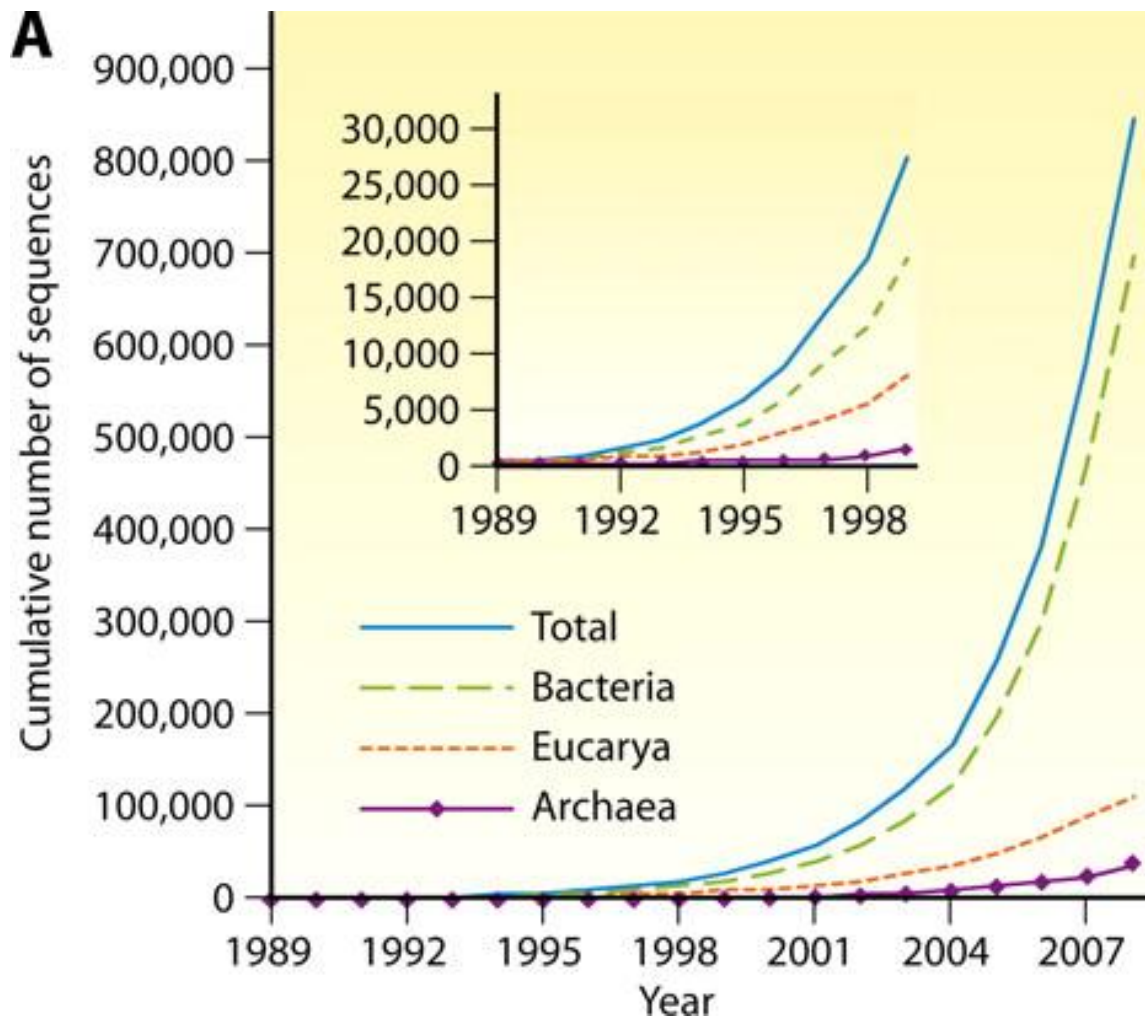
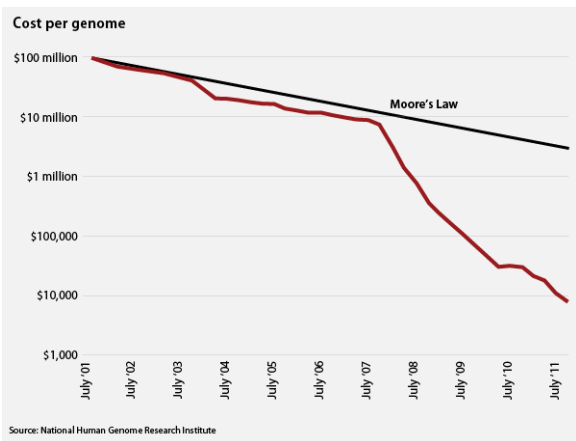


The police have begun using an improved method of DNA analysis, developed by **Johannes Hedman**, a doctoral student at **Applied Microbiology**. Together with the Swedish National Laboratory of Forensic Science, **SKL**, he has created a new enzyme combination that makes DNA profiles from crime scene samples clearer. This raises the chances of linking the perpetrator to the crime when there is little genetic material and the sample is dirty – which is often the case.

Whole genome sequencing

Technique becomes:

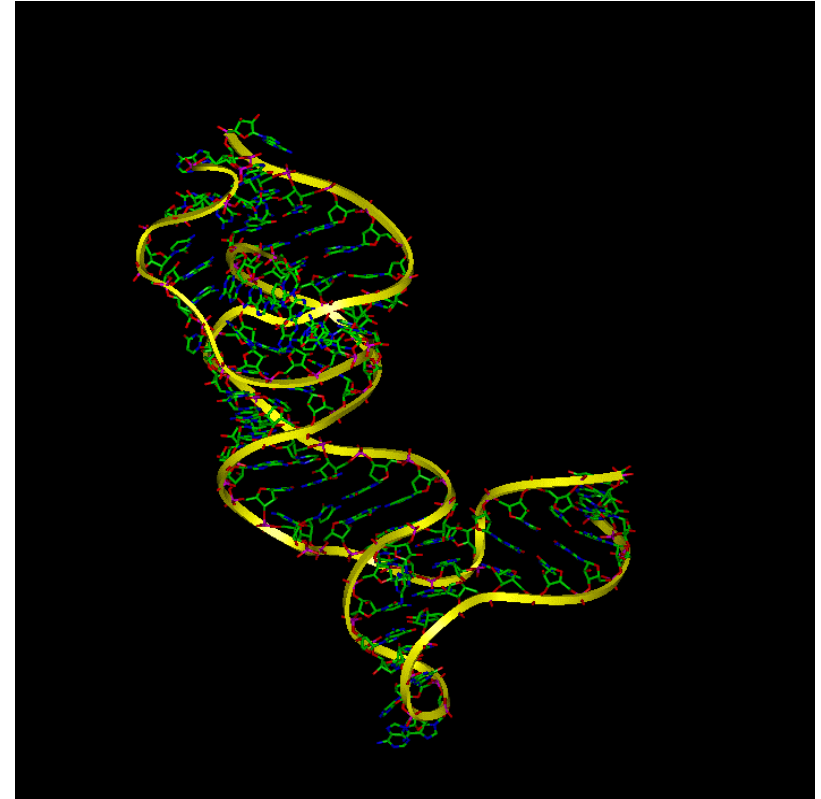
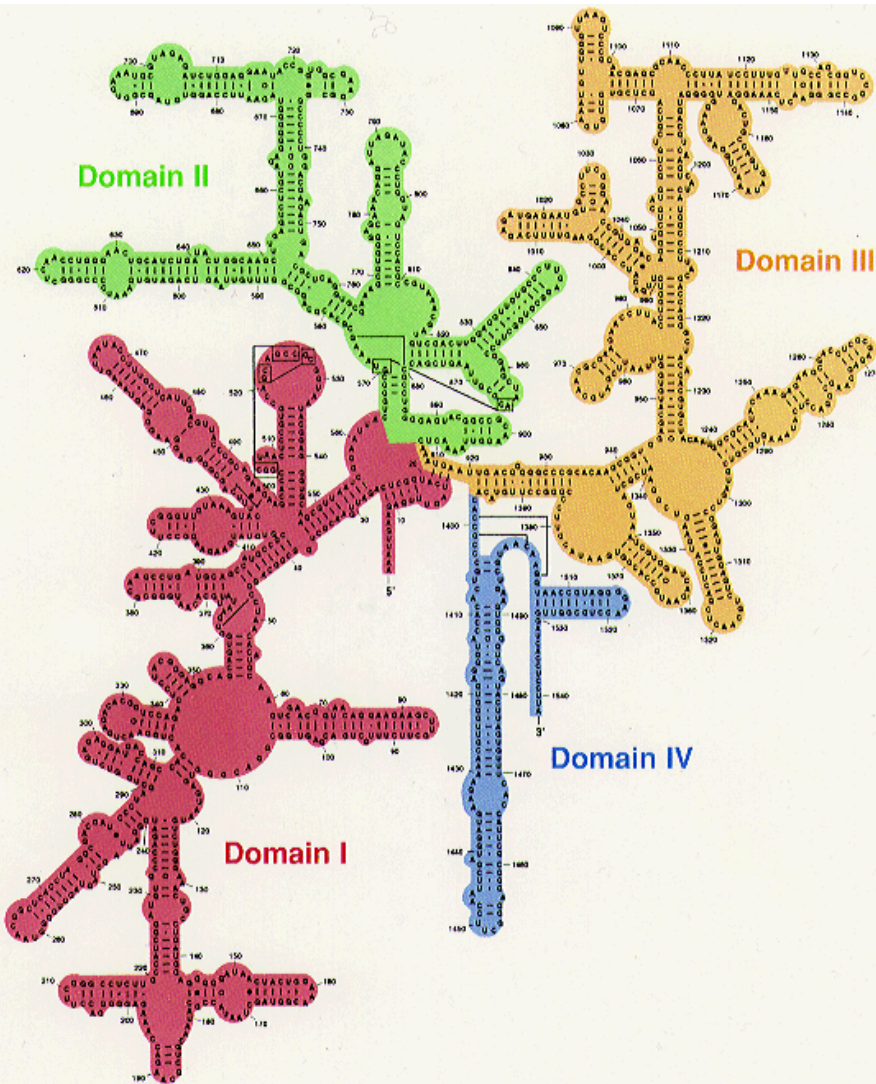
- Cheaper
- Easier
- Scaled down:
 - Lab bench size



Pace (2009) Microbiol Mol Biol Rev 73:565-576

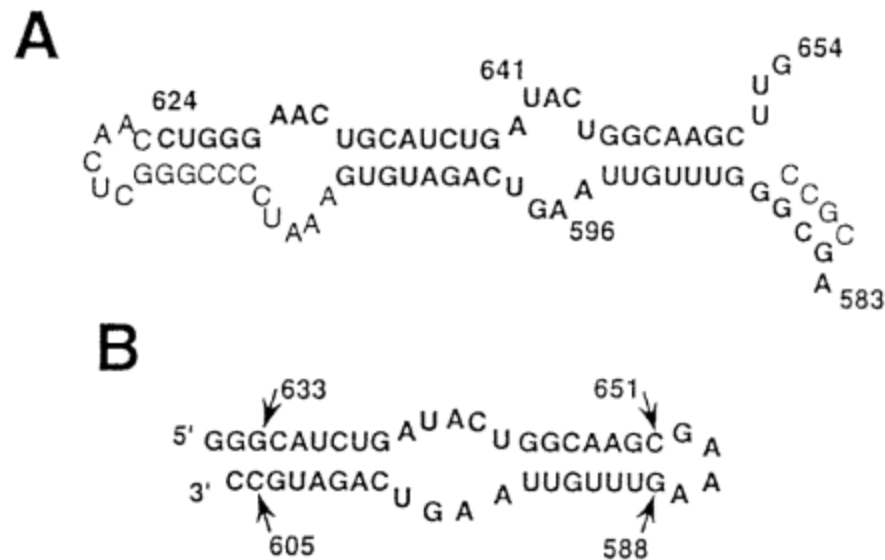
Sequencing 16S rRNA for prokaryotic phylogenetic tree

2D & 3D forms



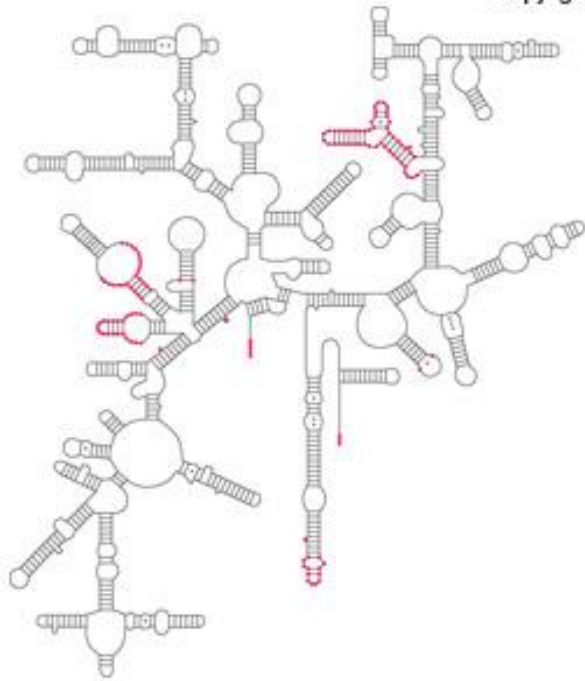
16S rRNA fluctuates during equilibrium as simulated here

Question 4: how does the RNA form stems and loops?



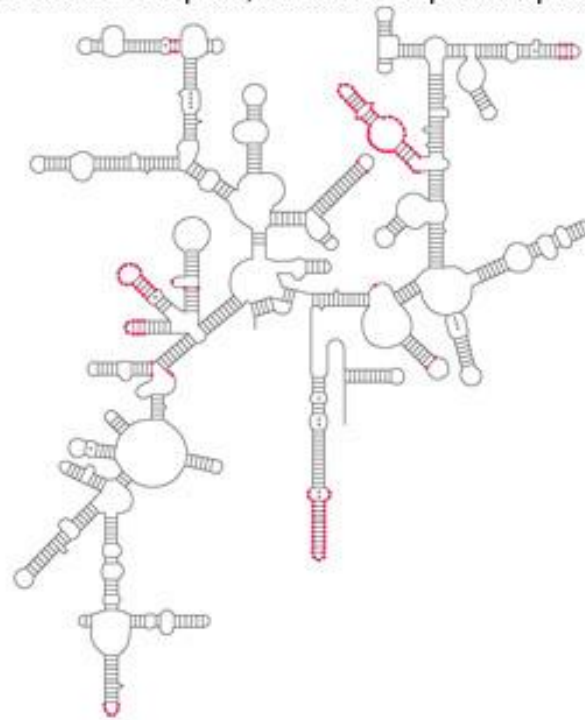
16S rRNA & 18S rRNA

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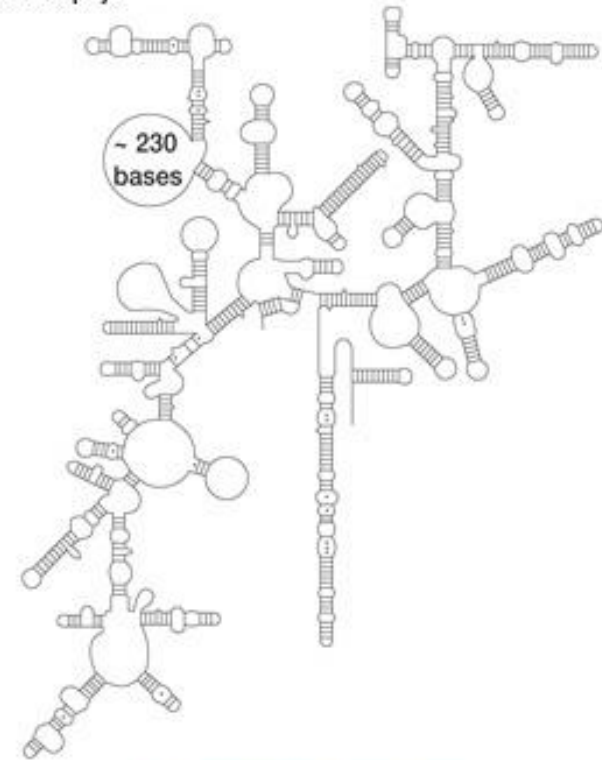
Escherichia coli

Bacterium



Methanococcus vannielii

Archea



Saccharomyces cerevisiae

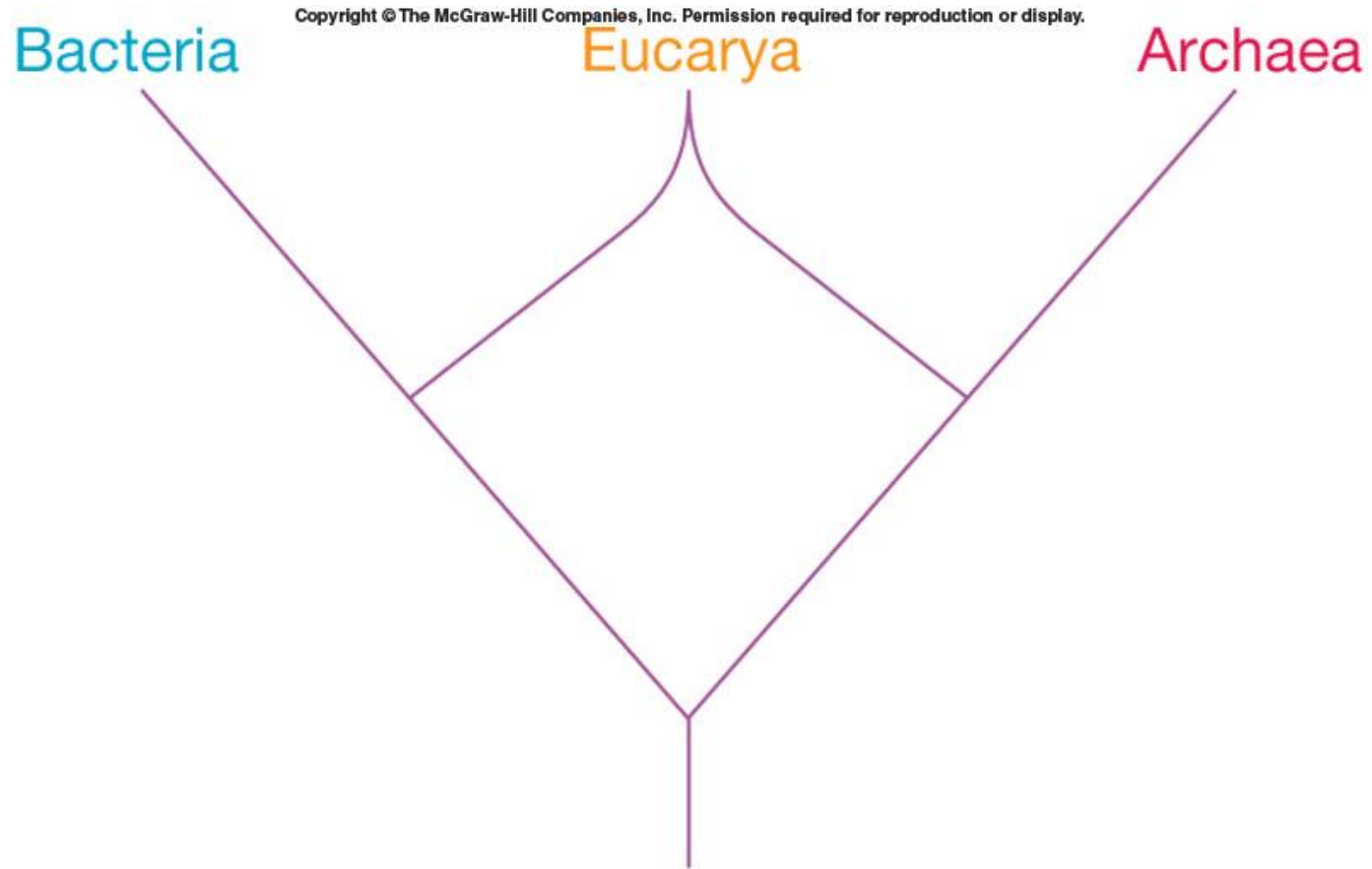
Eukaryote

Table 19.1 Comparison of *Bacteria*, *Archaea*, and *Eucarya*

Property	<i>Bacteria</i>	<i>Archaea</i>	<i>Eucarya</i>
Membrane-Enclosed Nucleus with Nucleolus	Absent	Absent	Present
Complex Internal Membranous Organelles	Absent	Absent	Present
Cell Wall	Almost always have peptidoglycan containing muramic acid	Variety of types, no muramic acid	No muramic acid
Membrane Lipid	Have ester-linked, straight-chained fatty acids	Have ether-linked, branched aliphatic chains	Have ester-linked, straight-chained fatty acids
Gas Vesicles	Present	Present	Absent
Transfer RNA	Thymine present in most tRNAs <i>N</i> -formylmethionine carried by initiator tRNA	No thymine in T or T ϕ C arm of tRNA Methionine carried by initiator tRNA	Thymine present Methionine carried by initiator tRNA
Polycistronic mRNA	Present	Present	Absent
mRNA Introns	Absent	Absent	Present
mRNA Splicing, Capping, and Poly A Tailing	Absent	Absent	Present
Ribosomes			
Size	70S	70S	80S (cytoplasmic ribosomes)
Elongation factor 2 reaction with diphtheria toxin	Does not react	Reacts	Reacts
Sensitivity to chloramphenicol and kanamycin	Sensitive	Insensitive	Insensitive
Sensitivity to anisomycin	Insensitive	Sensitive	Sensitive
DNA-Dependent RNA Polymerase			
Number of enzymes	One	One	Three
Structure	Simple subunit pattern (6 subunits)	Complex subunit pattern similar to eucaryotic enzymes (8–12 subunits)	Complex subunit pattern (12–14 subunits)
Rifampicin sensitivity	Sensitive	Insensitive	Insensitive
Polymerase II Type Promoters	Absent	Present	Present
Metabolism			
Similar ATPase	No	Yes	Yes
Methanogenesis	Absent	Present	Absent
Nitrogen fixation	Present	Present	Absent
Chlorophyll-based photosynthesis	Present	Absent	Present*
Chemolithotrophy	Present	Present	Absent

*Present in chloroplasts of bacterial origin.

A favoured phylogenetic tree of the 3 Domains

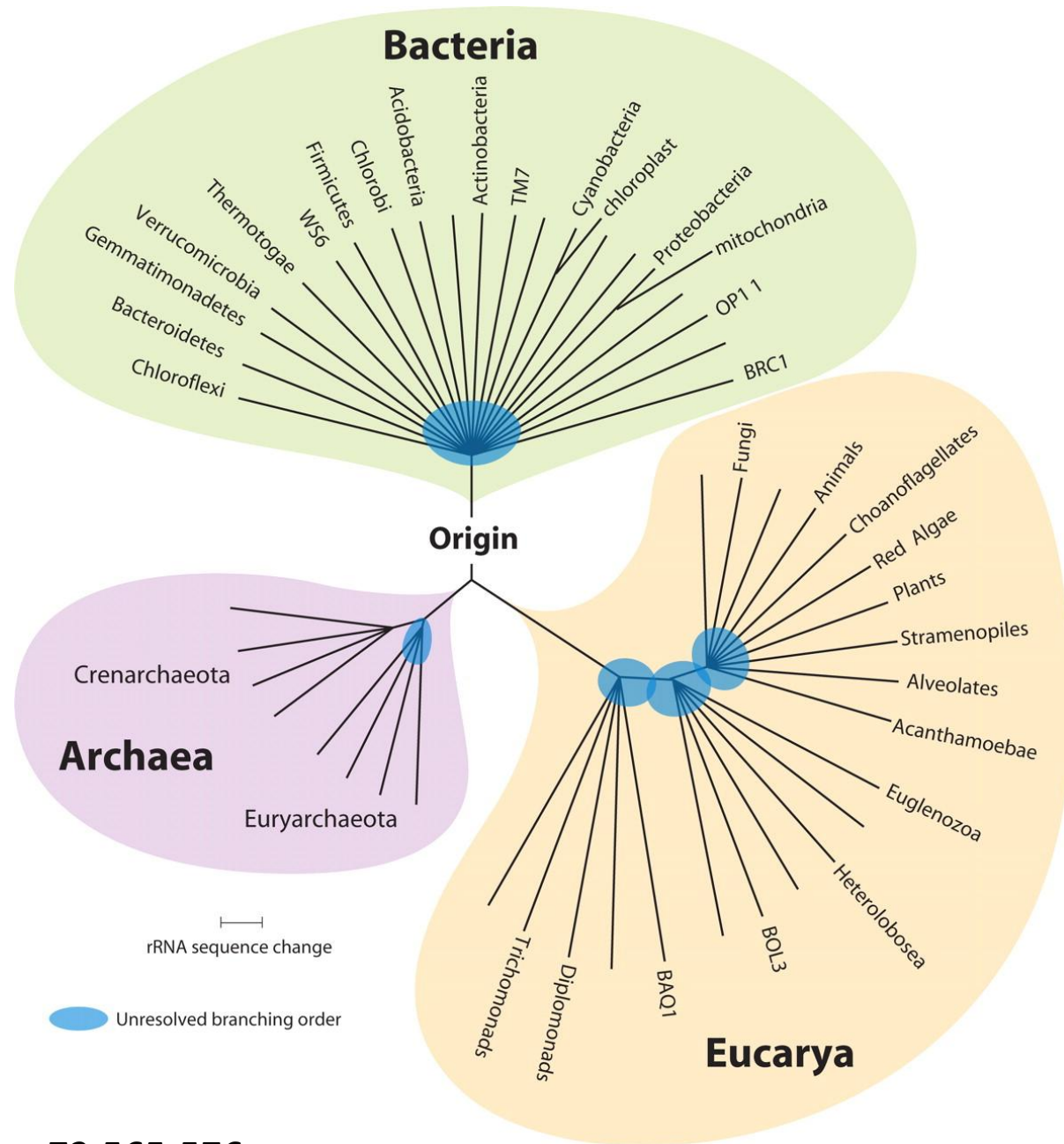


Woese 1977

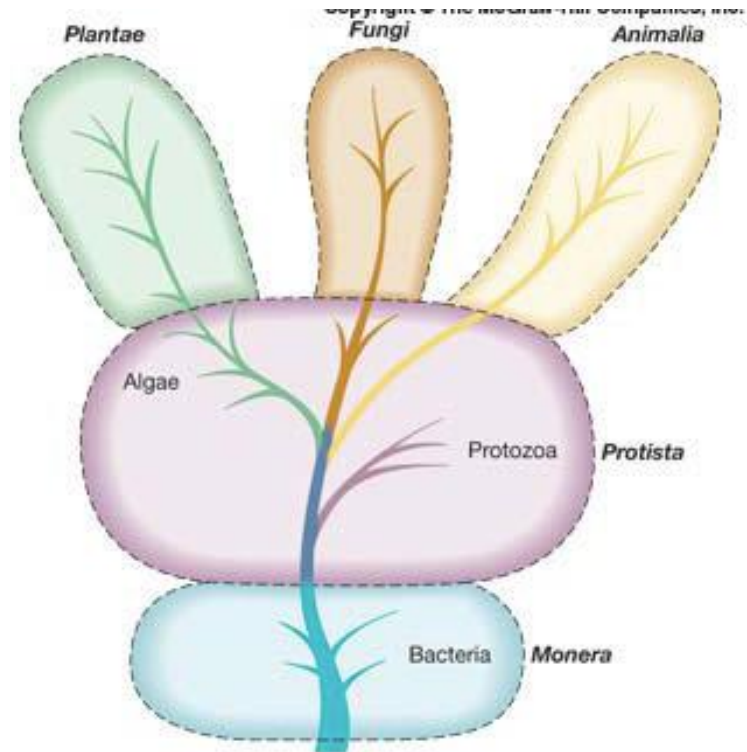
3 Domains of life

Microbiologist point of view 😊

Question 5:
What does the biologist not like in this picture?

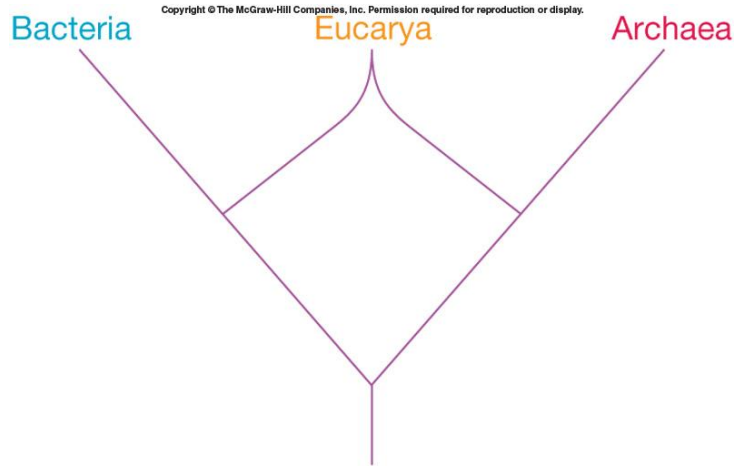


Suggested: Kingdoms of life

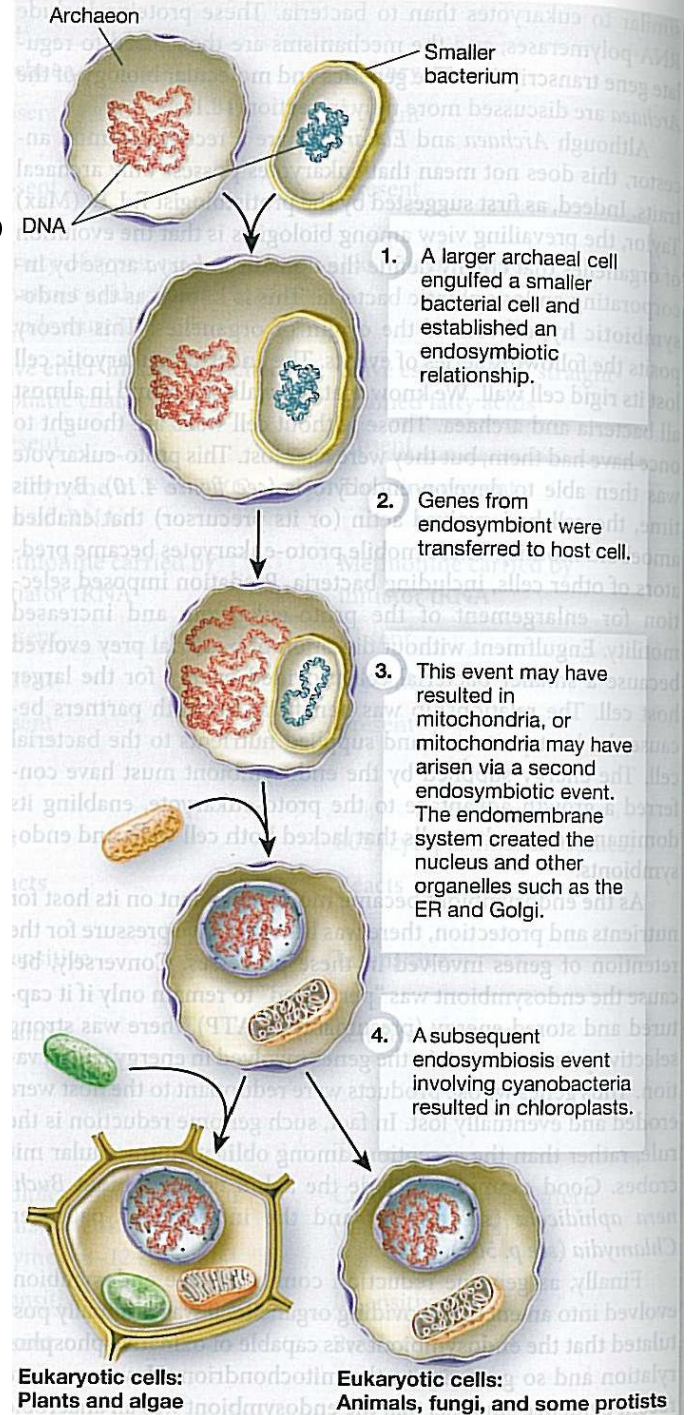


Biologists point of view

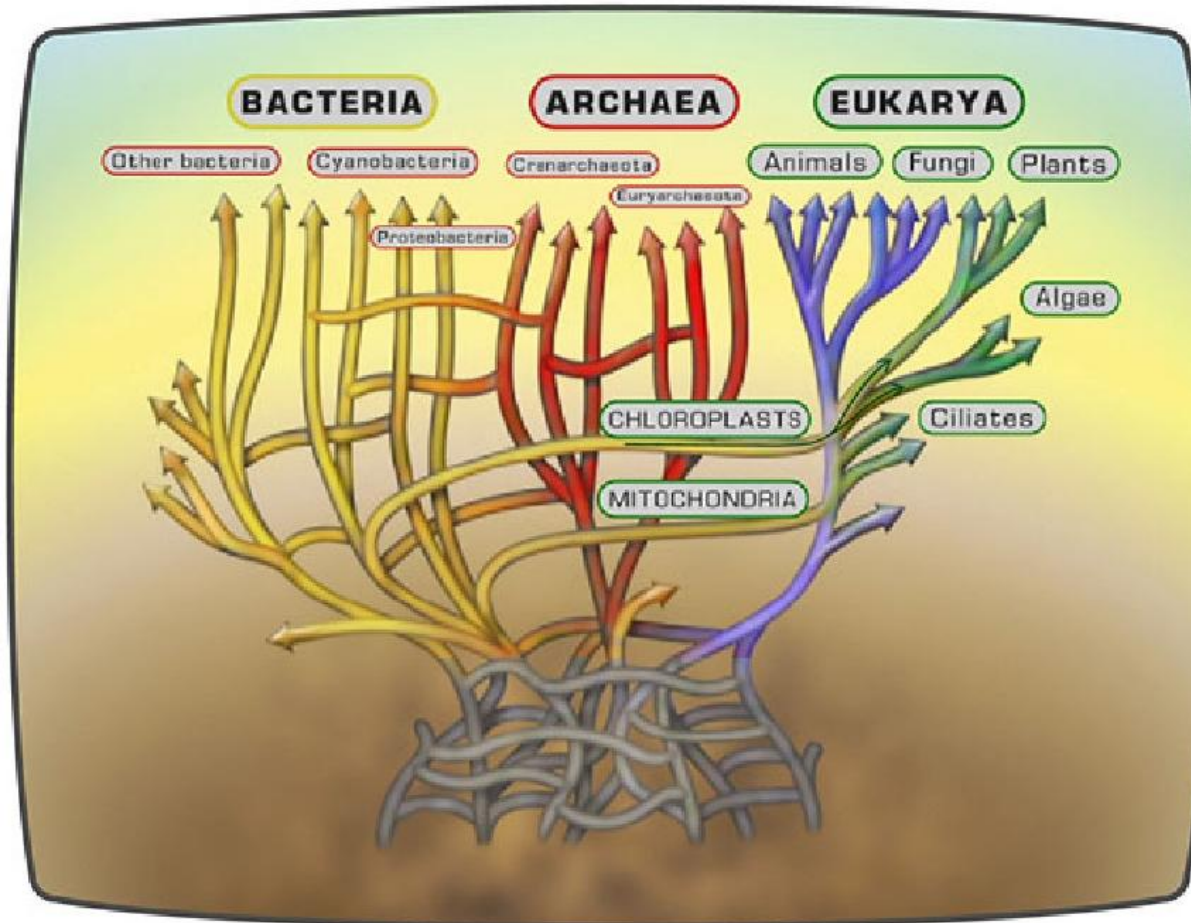
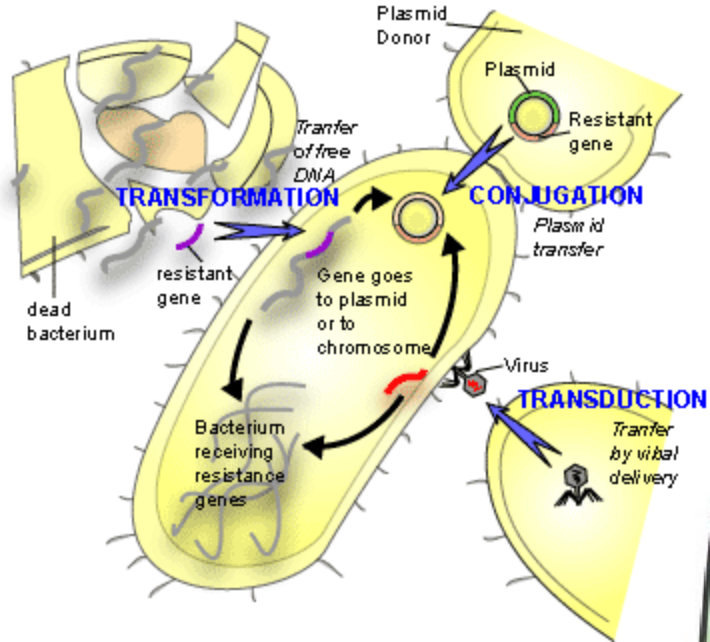
From prokaryotic endosymbionts to eukaryotes



Lynn Margulis 1970
endosymbiosis



Lateral gene transfer



Taxonomy mindmap

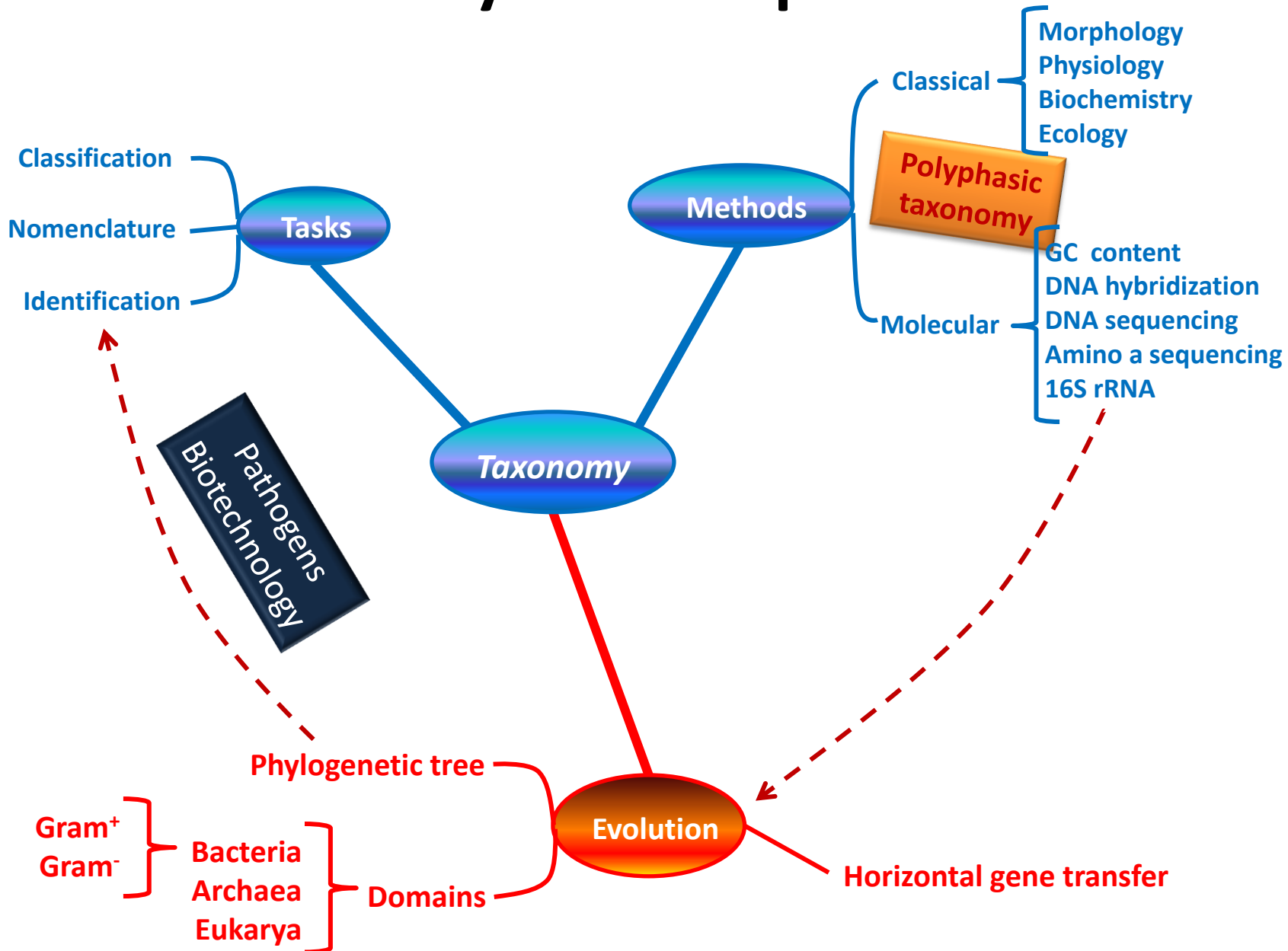
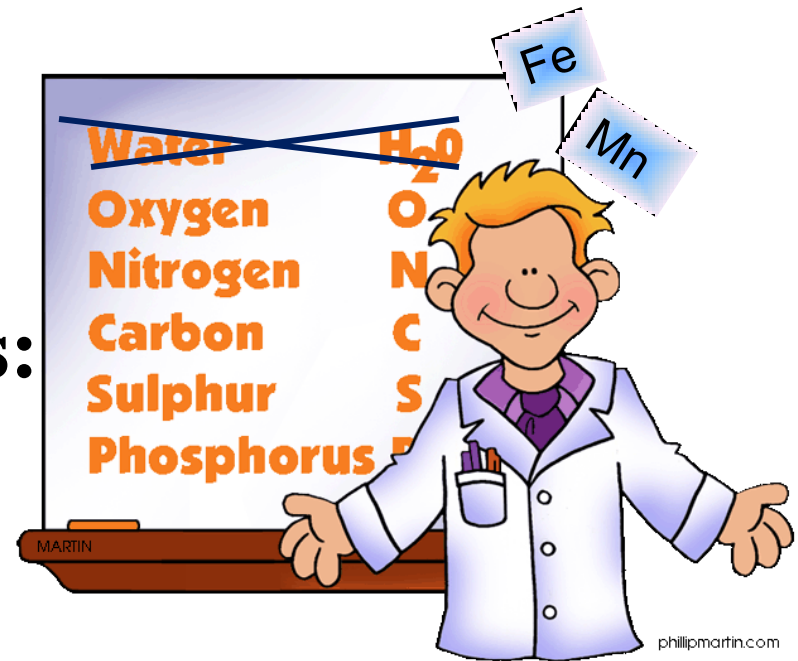


Table 19.6 Representative G + C Content of Microorganisms

Organism	Percent G + C	Organism	Percent G + C	Organism	Percent G + C
Bacteria		<i>Rhodospirillum</i>	62–66	<i>Peridinium triquetrum</i>	53
<i>Actinomyces</i>	59–73	<i>Rickettsia</i>	29–33	<i>Physarum polycephalum</i>	38–42
<i>Anabaena</i>	39–44	<i>Salmonella</i>	50–53	<i>Plasmodium berghei</i>	41
<i>Bacillus</i>	32–62	<i>Spirillum</i>	38	<i>Scenedesmus</i>	52–64
<i>Bacteroides</i>	28–61	<i>Spirochaeta</i>	51–65	<i>Spirogyra</i>	39
<i>Bdellovibrio</i>	49.5–51	<i>Staphylococcus</i>	30–38	<i>Stentor polymorphus</i>	45
<i>Caulobacter</i>	62–65	<i>Streptococcus</i>	33–44	<i>Tetrahymena</i>	19–33
<i>Chlamydia</i>	41–44	<i>Streptomyces</i>	69–73	<i>Trichomonas</i>	29–34
<i>Chlorobium</i>	49–58	<i>Sulfolobus</i>	31–37	<i>Trypanosoma</i>	45–59
<i>Chromatium</i>	48–70	<i>Thermoplasma</i>	46	<i>Volvox carteri</i>	50
<i>Clostridium</i>	21–54	<i>Thiobacillus</i>	52–68		
<i>Cytophaga</i>	33–42	<i>Treponema</i>	25–53	Fungi	
<i>Deinococcus</i>	62–70			<i>Agaricus bisporus</i>	44
<i>Escherichia</i>	48–59	Protists		<i>Amanita muscaria</i>	57
<i>Halobacterium</i>	66–68	<i>Acanthamoeba castellanii</i>	56–58	<i>Aspergillus niger</i>	52
<i>Hyphomicrobium</i>	59–67	<i>Acetabularia mediterranea</i>	37–53	<i>Blastocladiella emersonii</i>	66
<i>Methanobacterium</i>	32–50	<i>Amoeba proteus</i>	66	<i>Candida albicans</i>	33–35
<i>Micrococcus</i>	64–75	<i>Chlamydomonas</i>	60–68	<i>Claviceps purpurea</i>	53
<i>Mycobacterium</i>	62–70	<i>Chlorella</i>	43–79	<i>Coprinus lagopus</i>	52–53
<i>Mycoplasma</i>	23–40	<i>Cyclotella cryptica</i>	41	<i>Fomes fraxineus</i>	56
<i>Myxococcus</i>	68–71	<i>Dictyostelium</i>	22–25	<i>Mucor rouxii</i>	38
<i>Neisseria</i>	48–56	<i>Euglena gracilis</i>	46–55	<i>Neurospora crassa</i>	52–54
<i>Nitrobacter</i>	59–62	<i>Lycogala</i>	42	<i>Penicillium notatum</i>	52
<i>Oscillatoria</i>	40–50	<i>Nitella</i>	49	<i>Polyporus palustris</i>	56
<i>Prochloron</i>	41	<i>Nitzschia angularis</i>	47	<i>Rhizopus nigricans</i>	47
<i>Proteus</i>	38–41	<i>Ochromonas danica</i>	48	<i>Saccharomyces cerevisiae</i>	36–42
<i>Pseudomonas</i>	58–69	<i>Paramecium</i> spp.	29–39	<i>Saprolegnia parasitica</i>	61

BIOGEOCHEMICAL CYCLES & MINERALISATION

a) Elemental cycles:

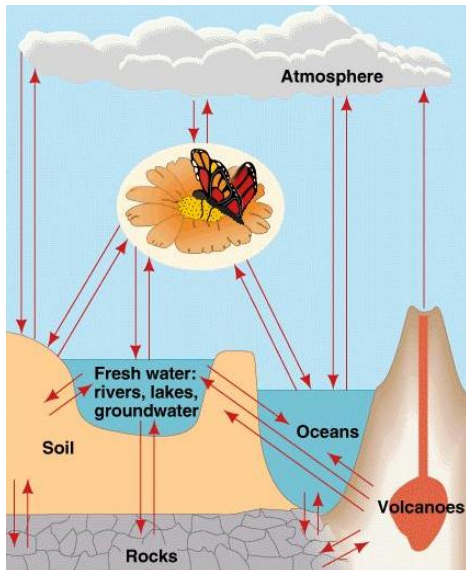
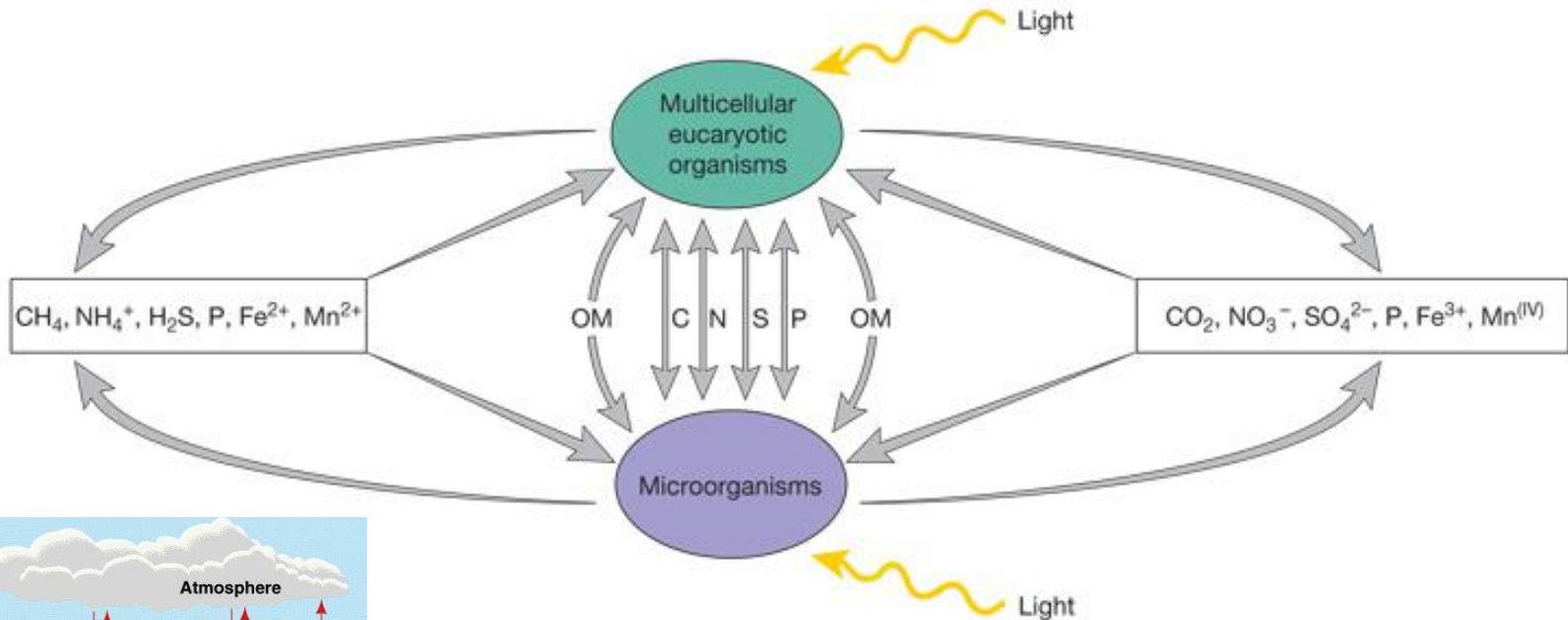


Biomass substitute for oil

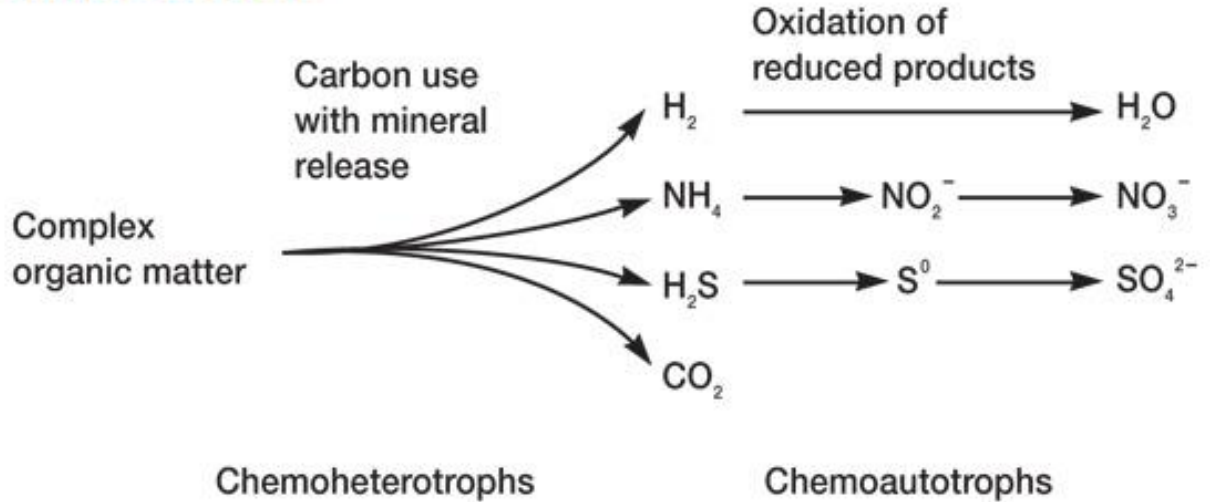
Macrobiogeochemistry

Reduced forms

Oxidized forms



Question 1: Where do you expect
- The reduced forms to be produced?
- The oxidized forms to be produced?



Anaerobic carbon use

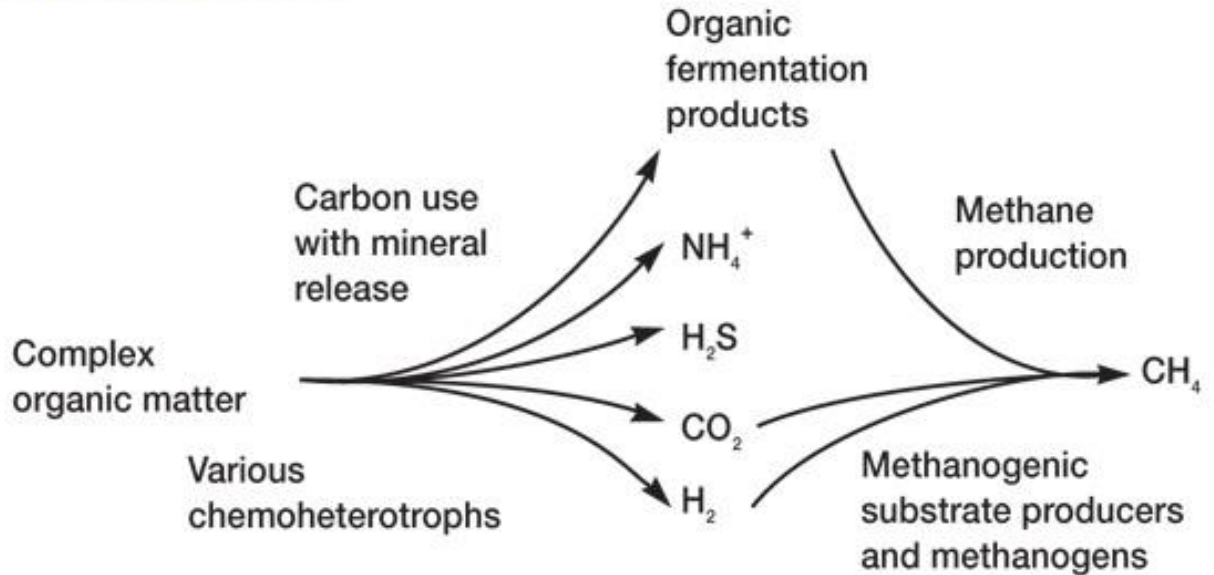


Fig. 27.3
Influence of oxygen on degradation of organic matter.

Table 5.1**Sources of Carbon, Energy, and Electrons****Carbon Sources**

Autotrophs	CO ₂ sole or principal biosynthetic carbon source
Heterotrophs	Reduced, preformed, organic molecules from other organisms

Energy Sources

Phototrophs	Light
Chemotrophs	Oxidation of organic or inorganic compounds

Electron Sources

Lithotrophs	Reduced inorganic molecules
Organotrophs	Organic molecules

Question 2: What is a
-Photolithoautotroph? Give an example
- Chemoorganoheterotroph? Give an example

Table 5.2 Major Nutritional Types of Microorganisms

Nutritional Type	Carbon Source	Energy Source	Electron Source	Representative Microorganisms
Photolithoautotrophy (photolithotrophic autotrophy)	CO ₂	Light	Inorganic e ⁻ donor	Purple and green sulfur bacteria, cyanobacteria
Photoorganoheterotrophy (photoorganotrophic heterotrophy)	Organic carbon, but CO ₂ may also be used	Light	Organic e ⁻ donor	Purple nonsulfur bacteria, green nonsulfur bacteria
Chemolithoautotrophy (chemolithotrophic autotrophy)	CO ₂	Inorganic chemicals	Inorganic e ⁻ donor	Sulfur-oxidizing bacteria, hydrogen-oxidizing bacteria, methanogens, nitrifying bacteria, iron-oxidizing bacteria
Chemolithoheterotrophy or mixotrophy (chemolithotrophic heterotrophy)	Organic carbon, but CO ₂ may also be used	Inorganic chemicals	Inorganic e ⁻ donor	Some sulfur-oxidizing bacteria (e.g., <i>Beggiatoa</i>)
Chemoorganoheterotrophy (chemoorganotrophic heterotrophy)	Organic carbon	Organic chemicals often same as C source	Organic e ⁻ donor, often same as C source	Most nonphotosynthetic microbes, including most pathogens, fungi, many protists, and many archaea

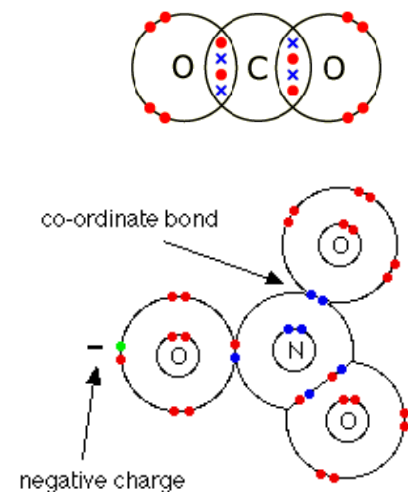
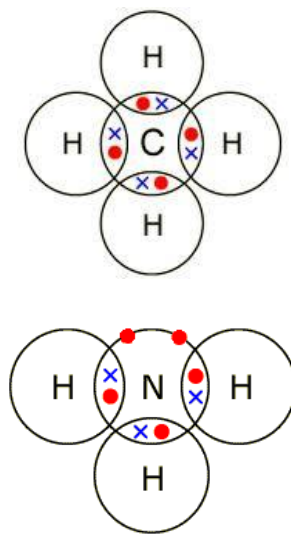
Table 27.1

The Major Forms of Carbon, Nitrogen, Sulfur, and Iron Important in Biogeochemical Cycling

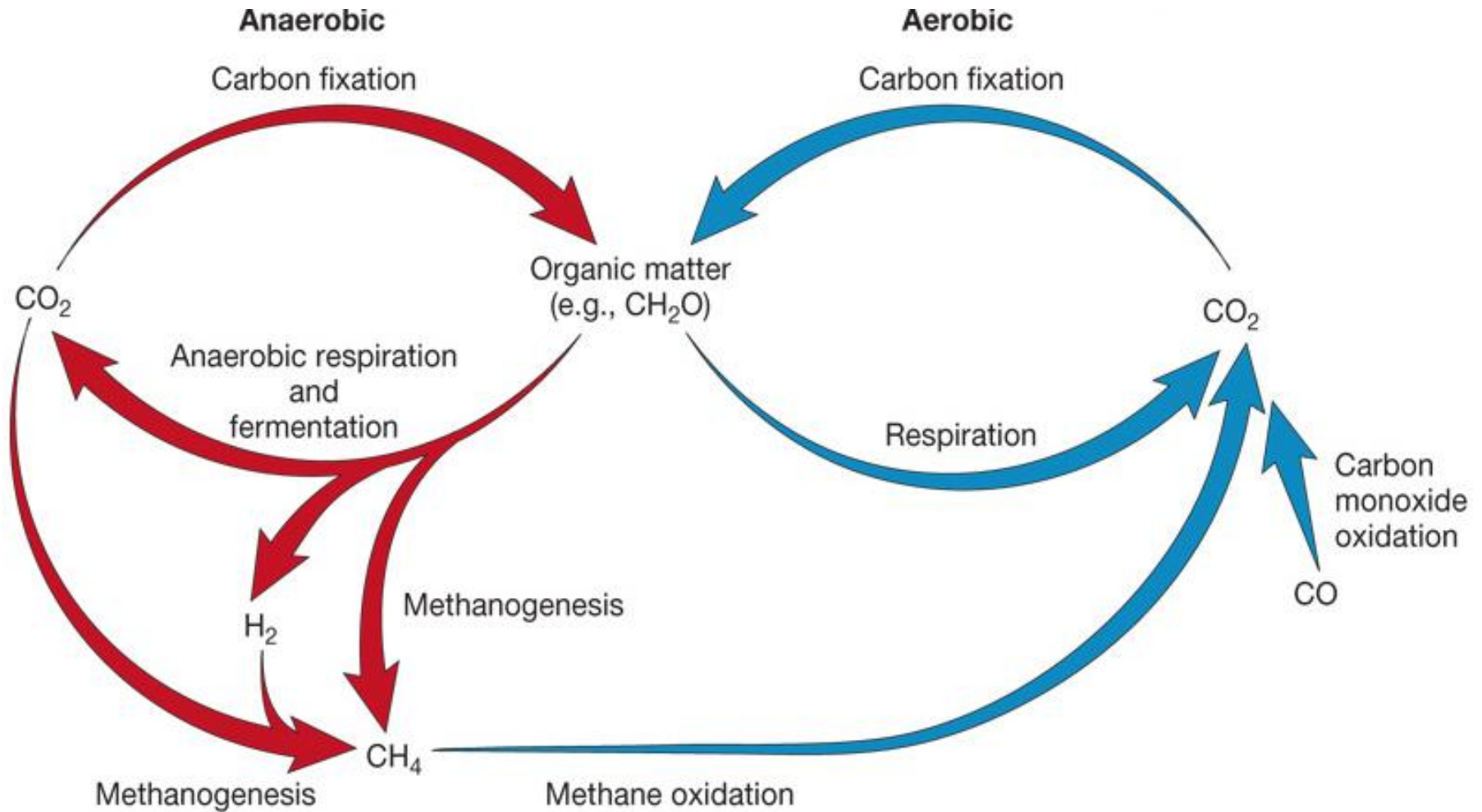
Major Forms and Valences

Cycle	Significant Gaseous Component Present?	Reduced Forms	Intermediate Oxidation State Forms			Oxidized Forms
C	Yes	Methane: CH ₄ (-4)	Carbon monoxide CO (+2)			CO ₂ (+4)
N	Yes	Ammonium: NH ₄ ⁺ , organic N (-3)	Nitrogen gas: N ₂ (0)	Nitrous oxide: N ₂ O (+1)	Nitrite: NO ₂ ⁻ (+3)	Nitrate: NO ₃ ⁻ (+5)
S	Yes	Hydrogen sulfide: H ₂ S, SH groups in organic matter (-2)	Elemental sulfur: S ⁰ (0)	Thiosulfate: S ₂ O ₃ ²⁻ (+2)	Sulfite: SO ₃ ²⁻ (+4)	Sulfate: SO ₄ ²⁻ (+6)
Fe	No	Ferrous iron: Fe ²⁺ (+2)				Ferric Iron: Fe ³⁺ (+3)

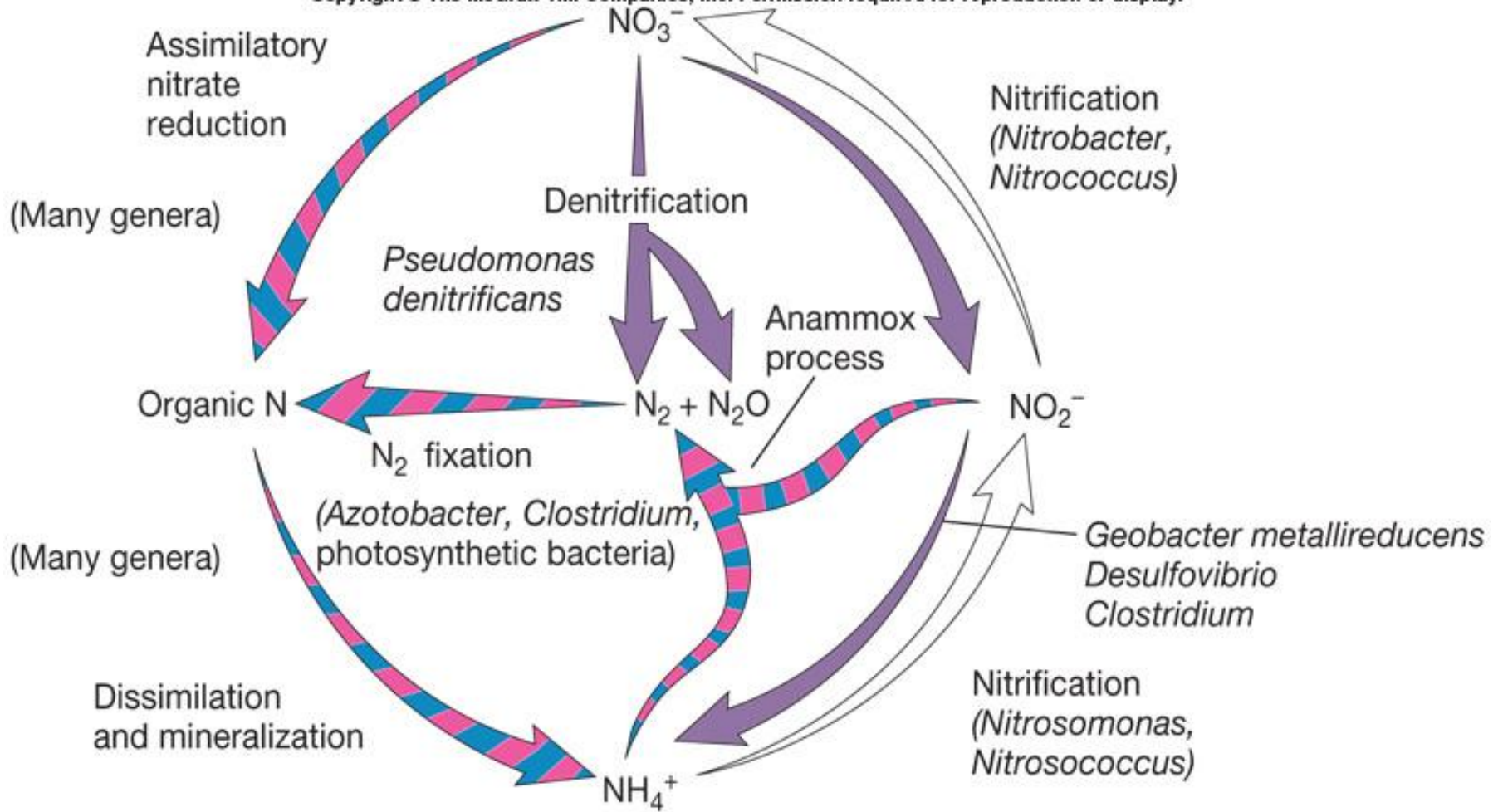
Note: The carbon, nitrogen, and sulfur cycles have significant gaseous components, and these are described as gaseous nutrient cycles. The iron cycle does not have a gaseous component, and this is described as a sedimentary nutrient cycle. Major reduced, intermediate oxidation state, and oxidized forms are noted, together with valences.



Carbon cycle

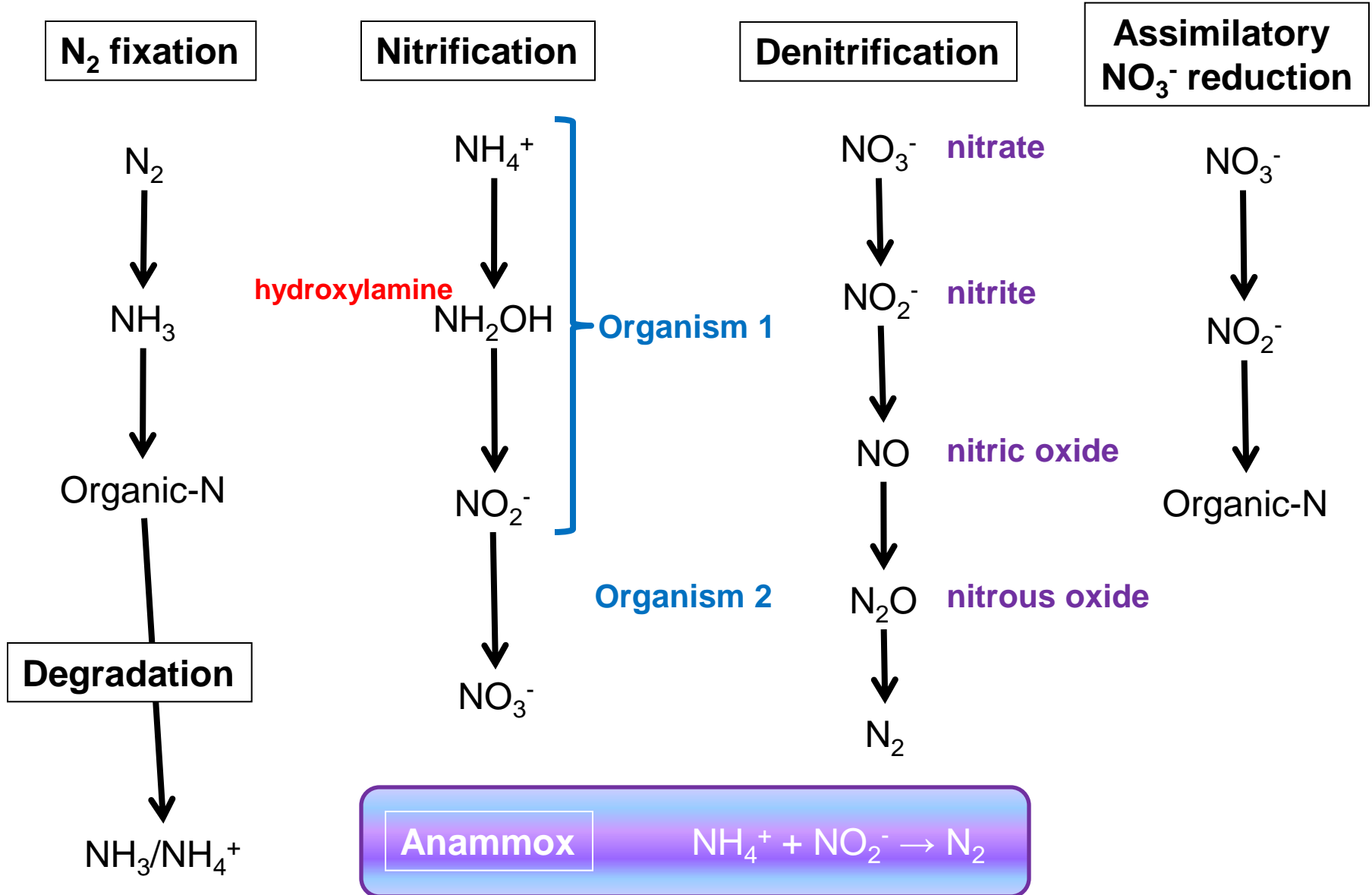


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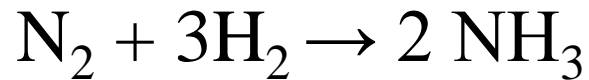
Nitrogen cycle

Nitrogen reactions more detailed



Nodules on the roots of Legume plant

Rhizobium species live in the nodules to fix N_2 . Dead rhizobia are N-source for plant to synthesize amino acids.



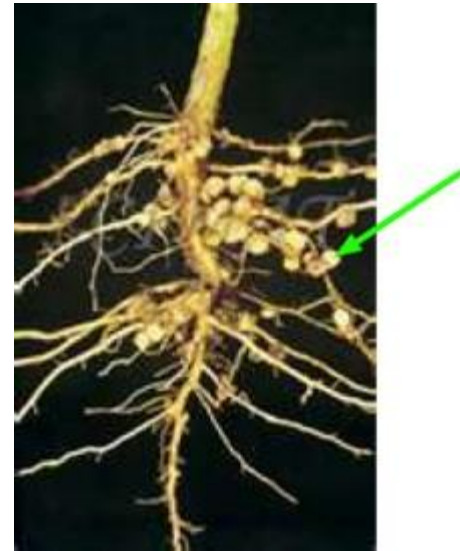
Nitrogenase, ATP, Mo, Fe

$165 \cdot 10^6$ ton N/yr

Haber-Bosch process:

$40 \cdot 10^6$ ton N/yr

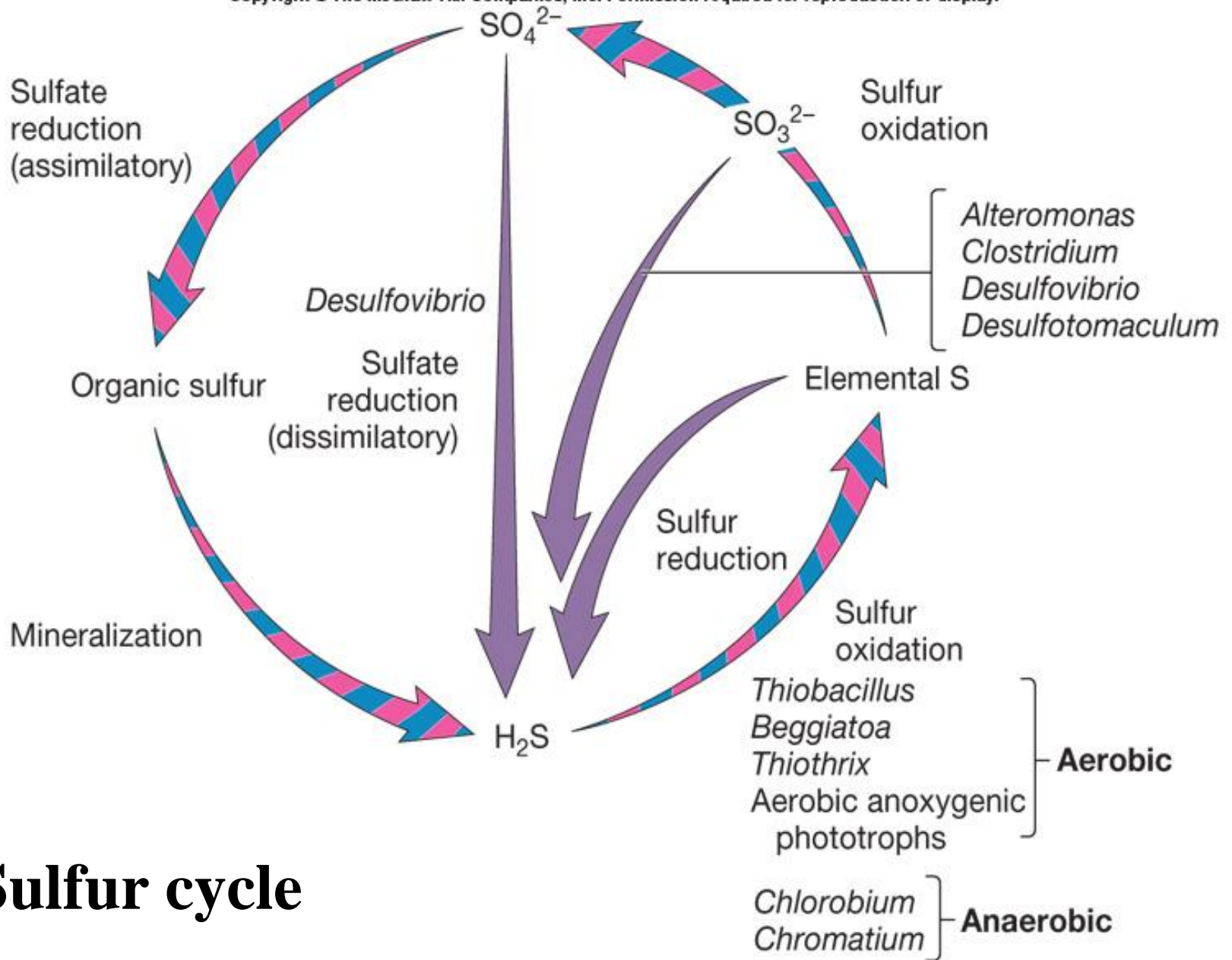
(400-450°C, 200 atm)



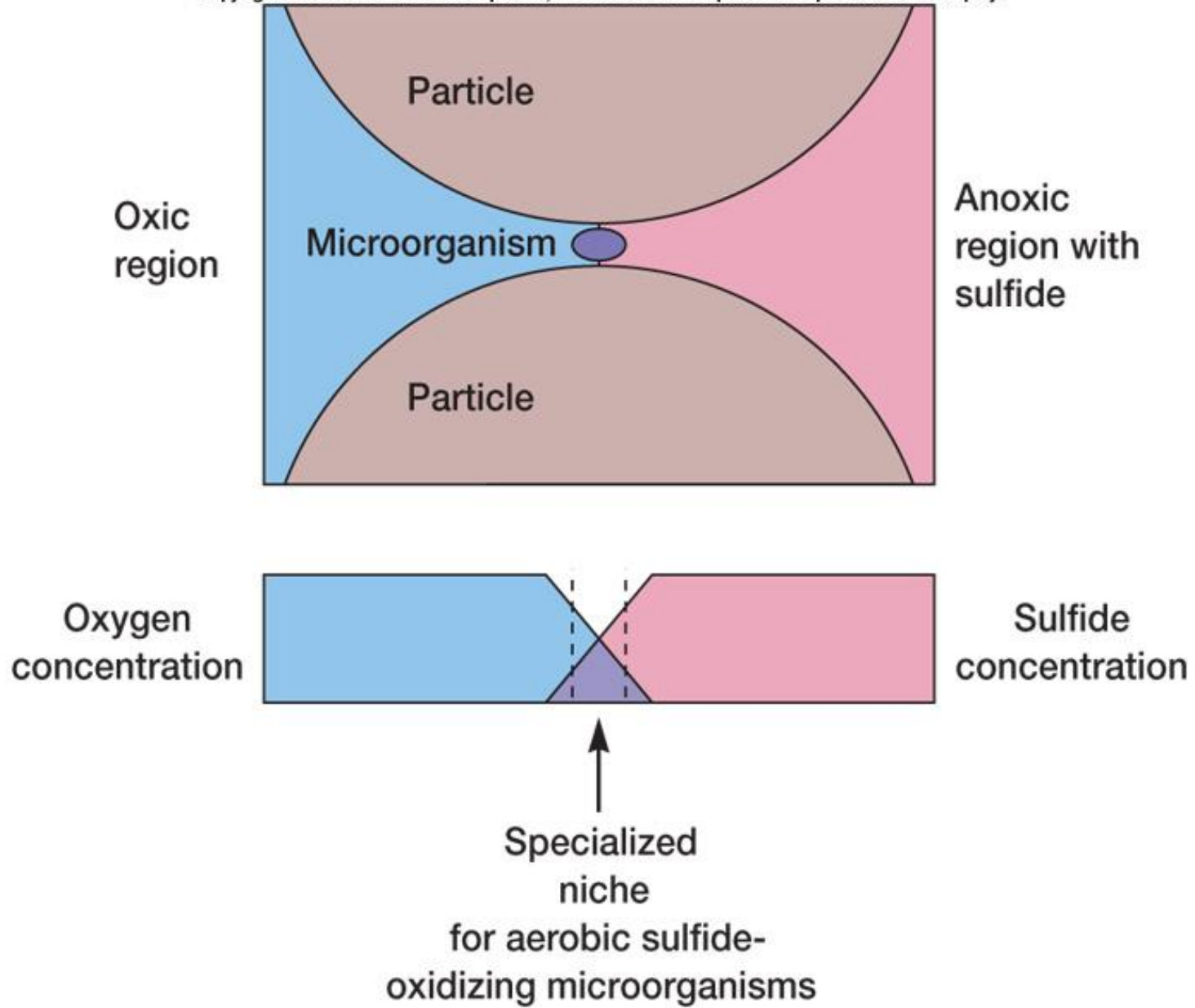
Biological nitrogen fixation

• Symbiotic	kg N/ha·yr
<i>Rhizobium</i>	20 – 500
clover, sojabeans, pea, luzern	
<i>Actinomycefer</i>	40 – 500
alder, buckthorn, myrtle, avens	
• Non-symbiotic	
<i>Azotobacter, Clostridium</i>	0.2
Bluegreen algae	10 - 20

Question 4: How come there is more N fixed via symbiotic relationships?



Sulfur cycle



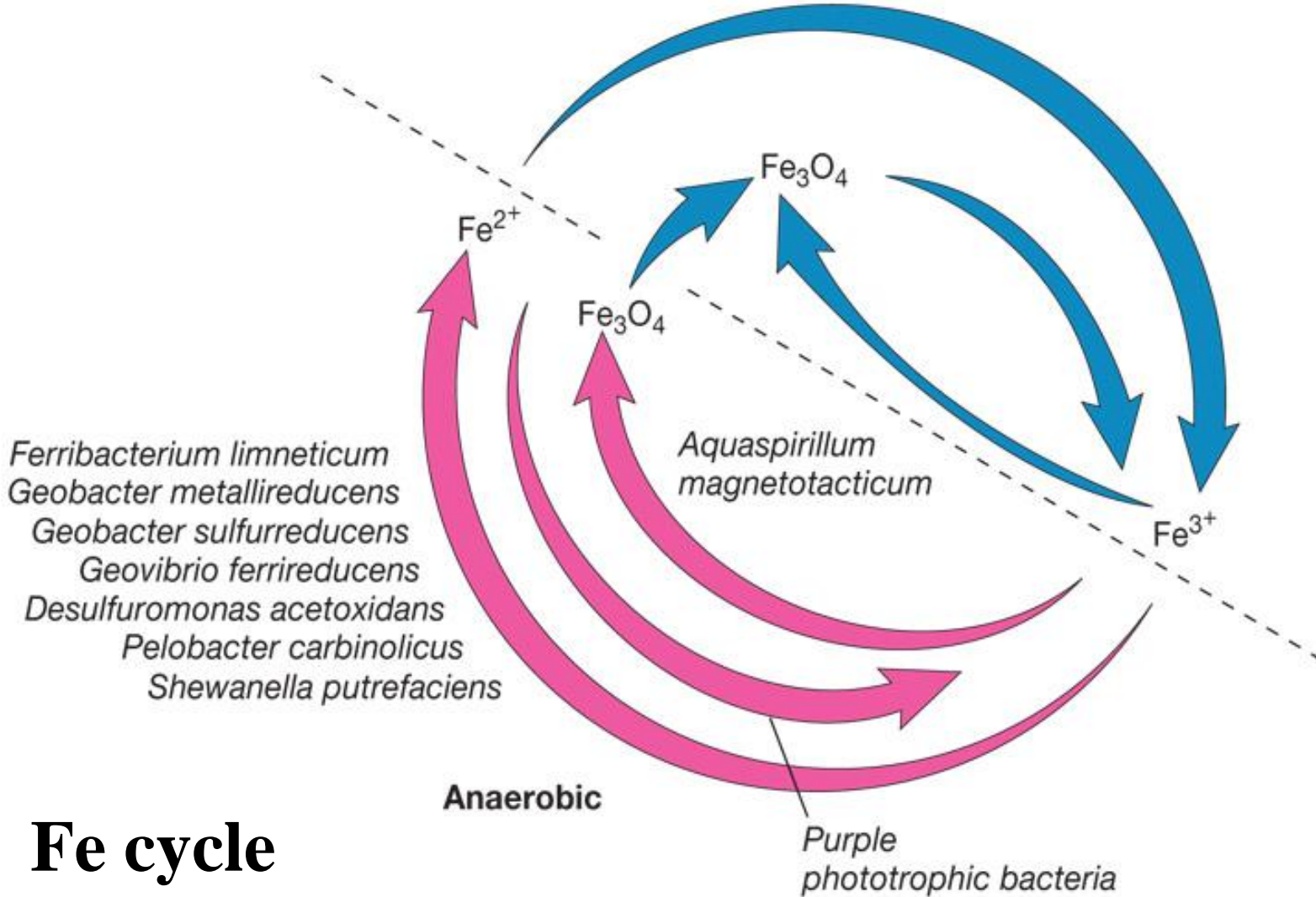
Microenvironments

Aerobic

Neutral pH = *Gallionella* spp.

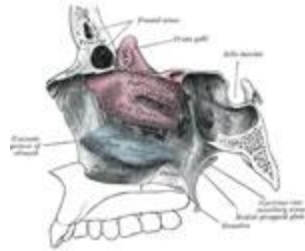
Acidic = *Leptospirillum*, *Thiobacillus ferrooxidans*

Acidic, thermophilic = *Sulfolobus* spp.

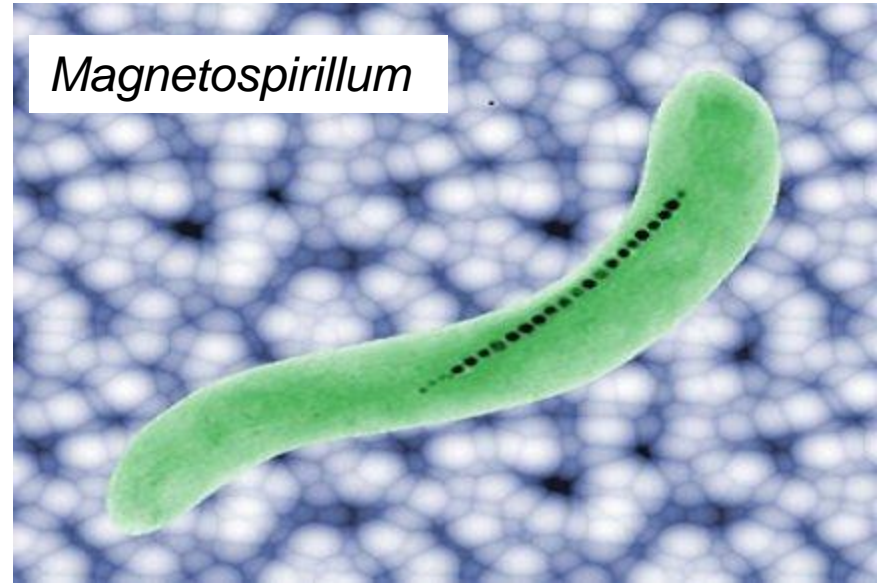


Fe cycle

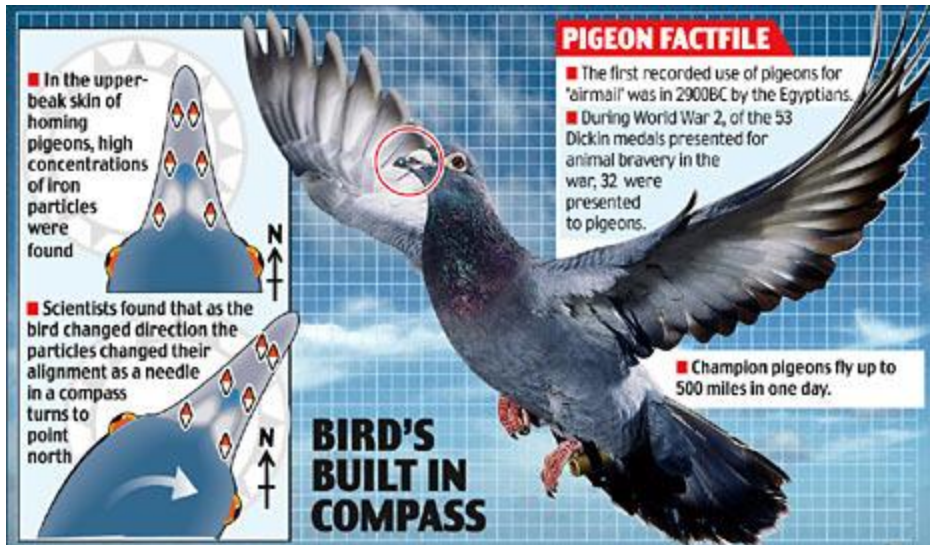
Magnetite: wonderful stuff!



Humans



Magnetospirillum



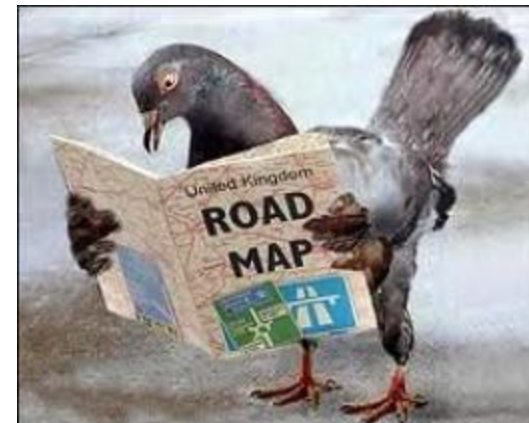
PIGEON FACTFILE

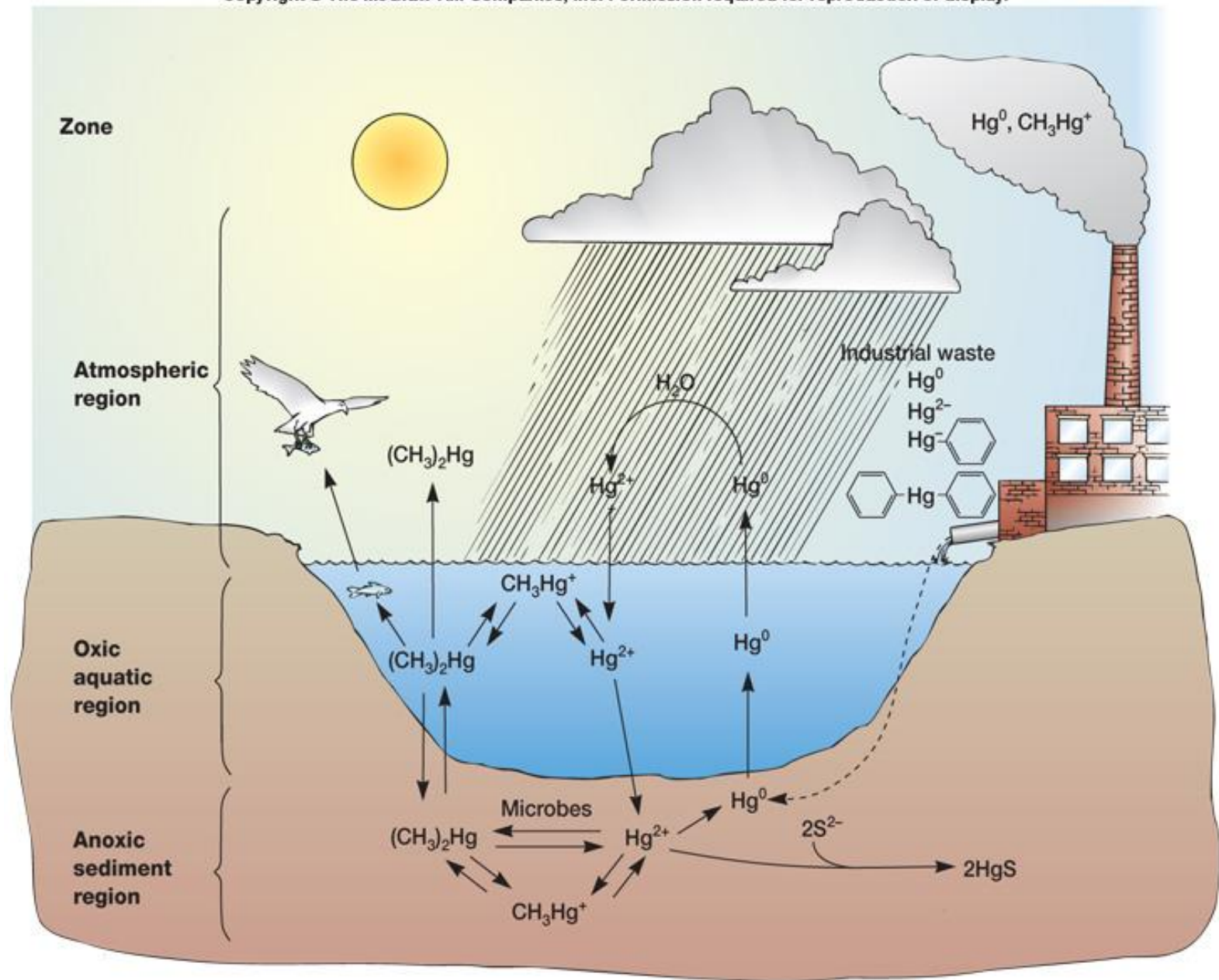
- The first recorded use of pigeons for "airmail" was in 2900BC by the Egyptians.
- During World War 2, of the 53 Dickin medals presented for animal bravery in the war, 32 were presented to pigeons.
- Champion pigeons fly up to 500 miles in one day.

BIRD'S BUILT IN COMPASS

- In the upper-beak skin of homing pigeons, high concentrations of iron particles were found
- Scientists found that as the bird changed direction the particles changed their alignment as a needle in a compass turns to point north

That's why you never see this:





The Mercury cycle

The
Economist

Don't blame China

PAGE 65

The Democrats' economic ideas

PAGE 25

Iran's last chance

PAGE 32

A SURVEY OF CORPORATE LEADERSHIP

PAGE 50

OCTOBER 2 2003 \$4.50

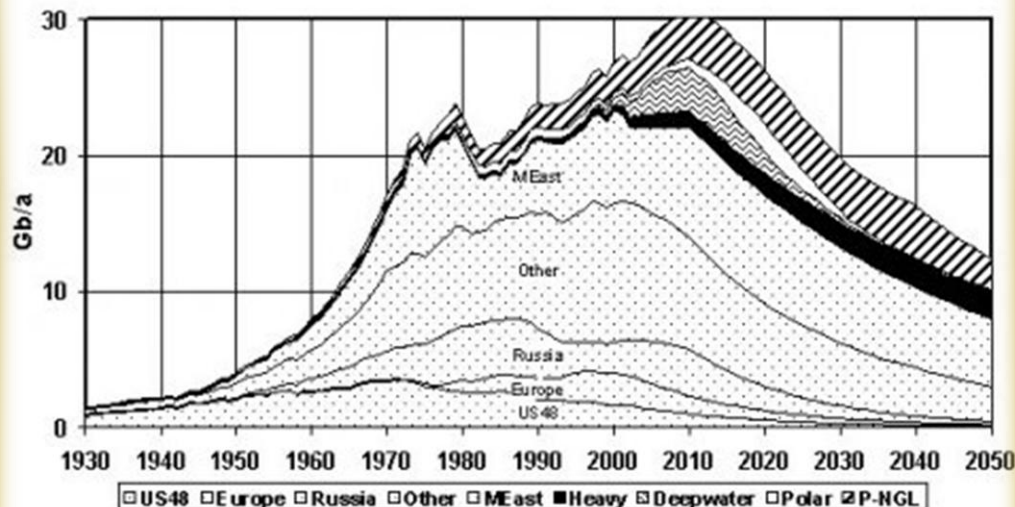
www.economist.com

The end of the Oil Age



Argentina \$4.50 Brazil \$4.50 Canada \$4.50 Chile \$4.50 Colombia \$4.50 Costa Rica \$4.50 Denmark \$4.50 France \$4.50 Germany \$4.50 Greece \$4.50 Hong Kong \$4.50 India \$4.50 Italy \$4.50 Japan \$4.50 Korea \$4.50 Mexico \$4.50 New Zealand \$4.50 Norway \$4.50 Pakistan \$4.50 Peru \$4.50 Philippines \$4.50 Portugal \$4.50 Singapore \$4.50 South Africa \$4.50 Spain \$4.50 Sweden \$4.50 Switzerland \$4.50 Taiwan \$4.50 Thailand \$4.50 United Kingdom \$4.50 USA \$4.50

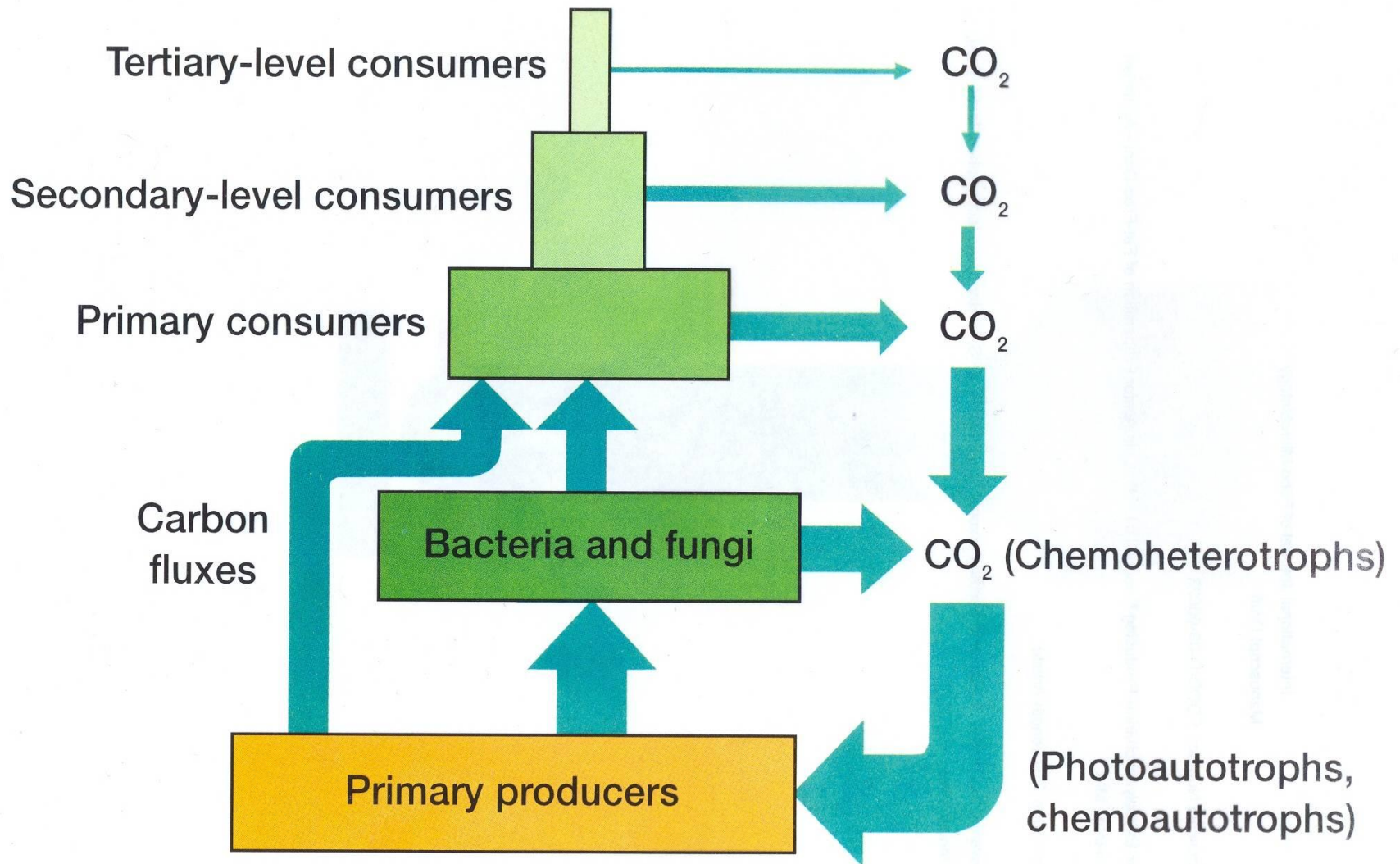
Oil & Natural Gas Liquids 2003 Base Case Scenario



From the ASPO Newsletter; graph developed by Colin Campbell.

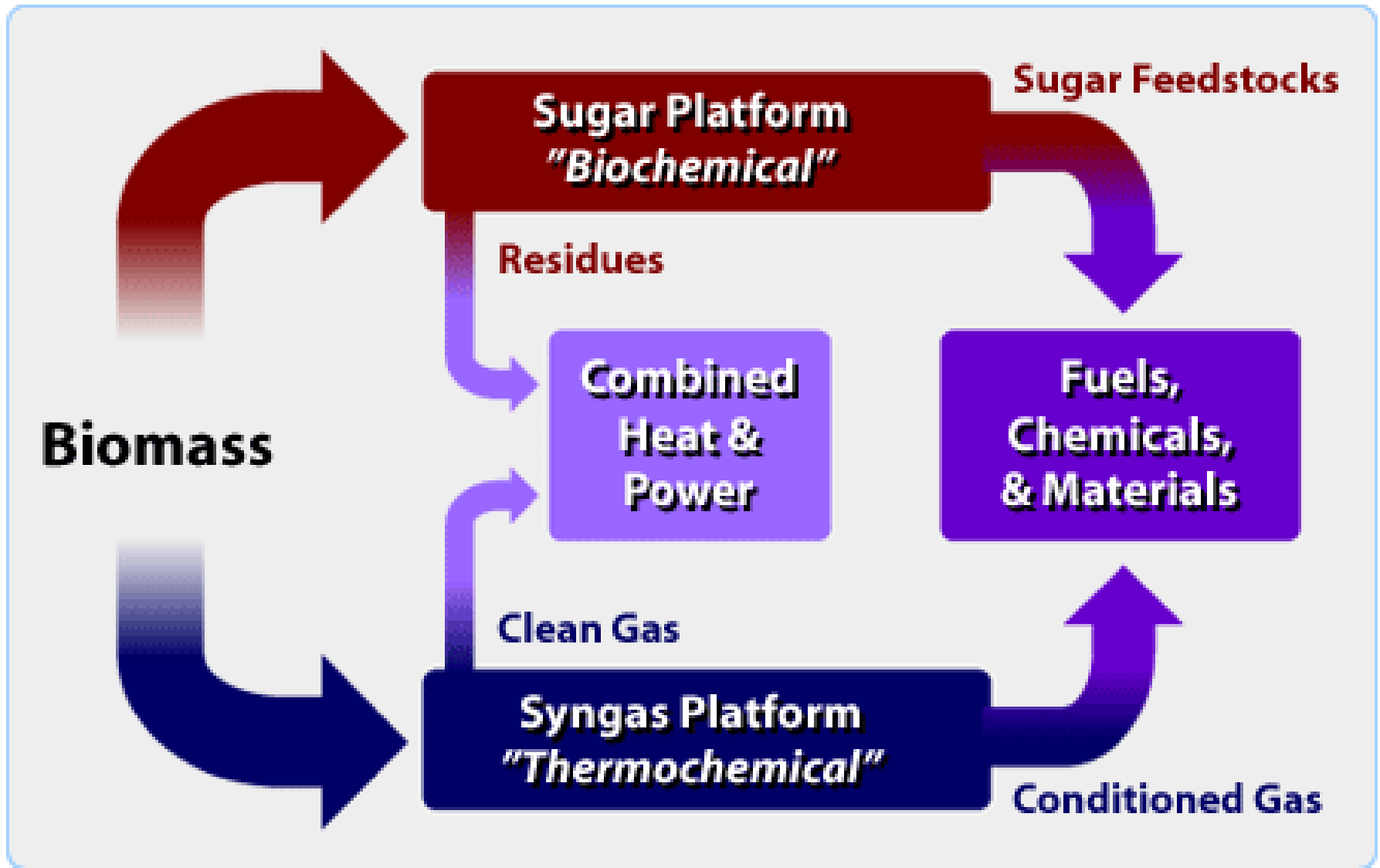
<http://www.asponews.org/>

Role of microorganisms in flow of organic carbon and CO₂



Q 4: Where can we tap organic carbon for replacing oil?

Biorefinery Concept



Biogeochemical cycle mindmap

