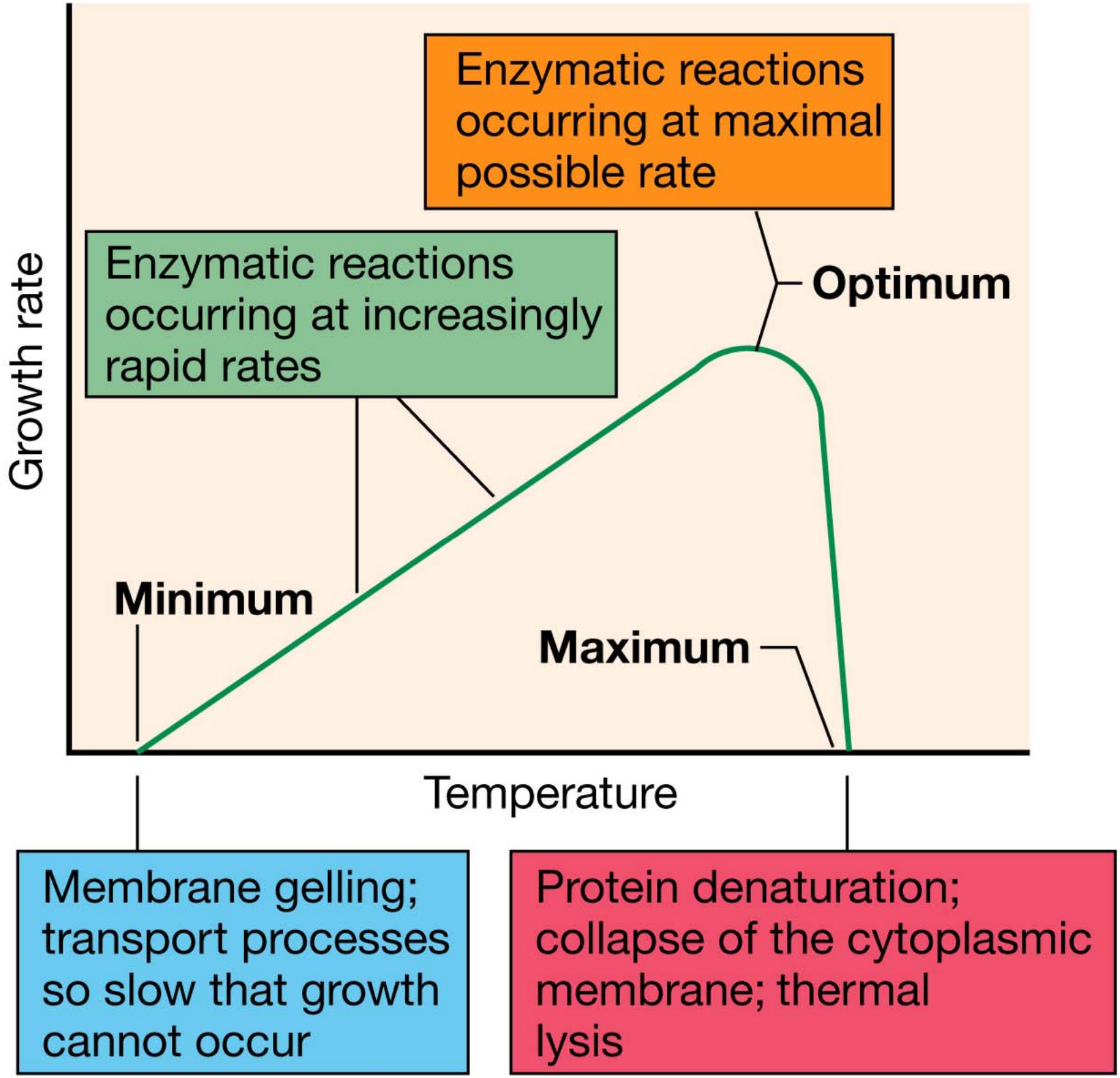
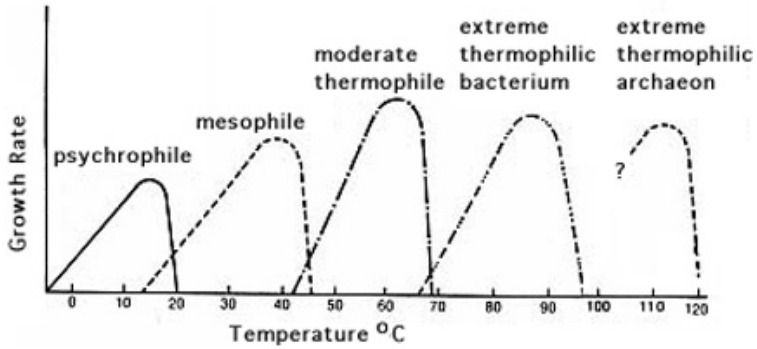
Microbial Growth

Environmental Forcing Functions:

- Temperature: Psychrophile, Mesophile, Thermophile, & Hyperthermophile
  Cardinal Temps: Min*, Max, & Optimal*
  Q_{10} Rule: 10°C rise will double the growth rate*

- Pressure: Barophiles (Most are also psychrophiles!)
  Found only in the deep ocean.....so far


Enzymatic reactions occurring at maximal possible rate
Enzymatic reactions occurring at increasingly rapid rates
Optimum
Growth rate
Minimum
Maximum
Temperature
Membrane gelling; transport processes so slow that growth cannot occur
Protein denaturation; collapse of the cytoplasmic membrane; thermal lysis


psychrophile
mesophile
moderate thermophile
extreme thermophilic bacterium
extreme thermophilic archaeon
?
Growth Rate
0 10 20 30 40 50 60 70 80 90 100 110 120
Temperature °C

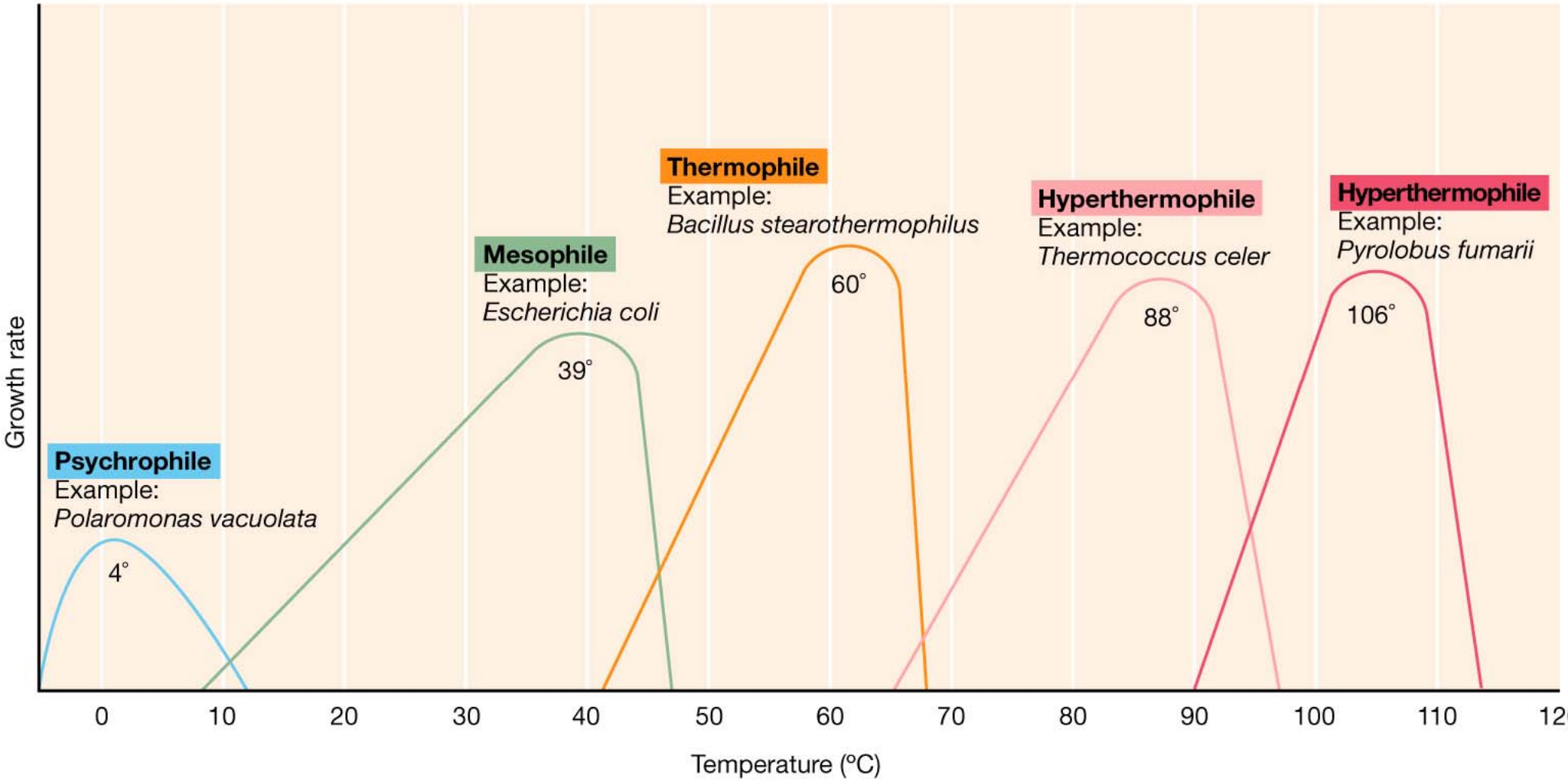
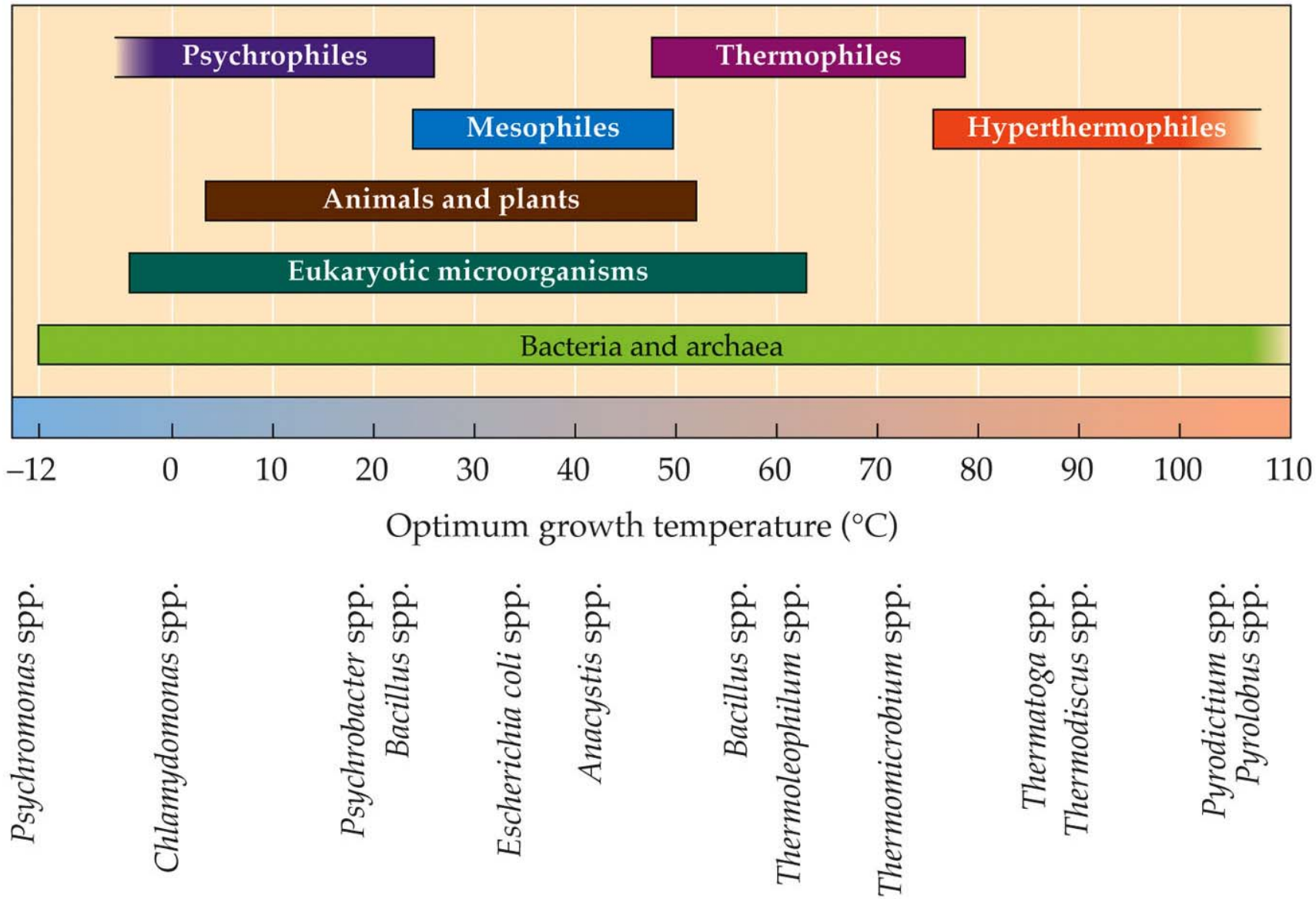
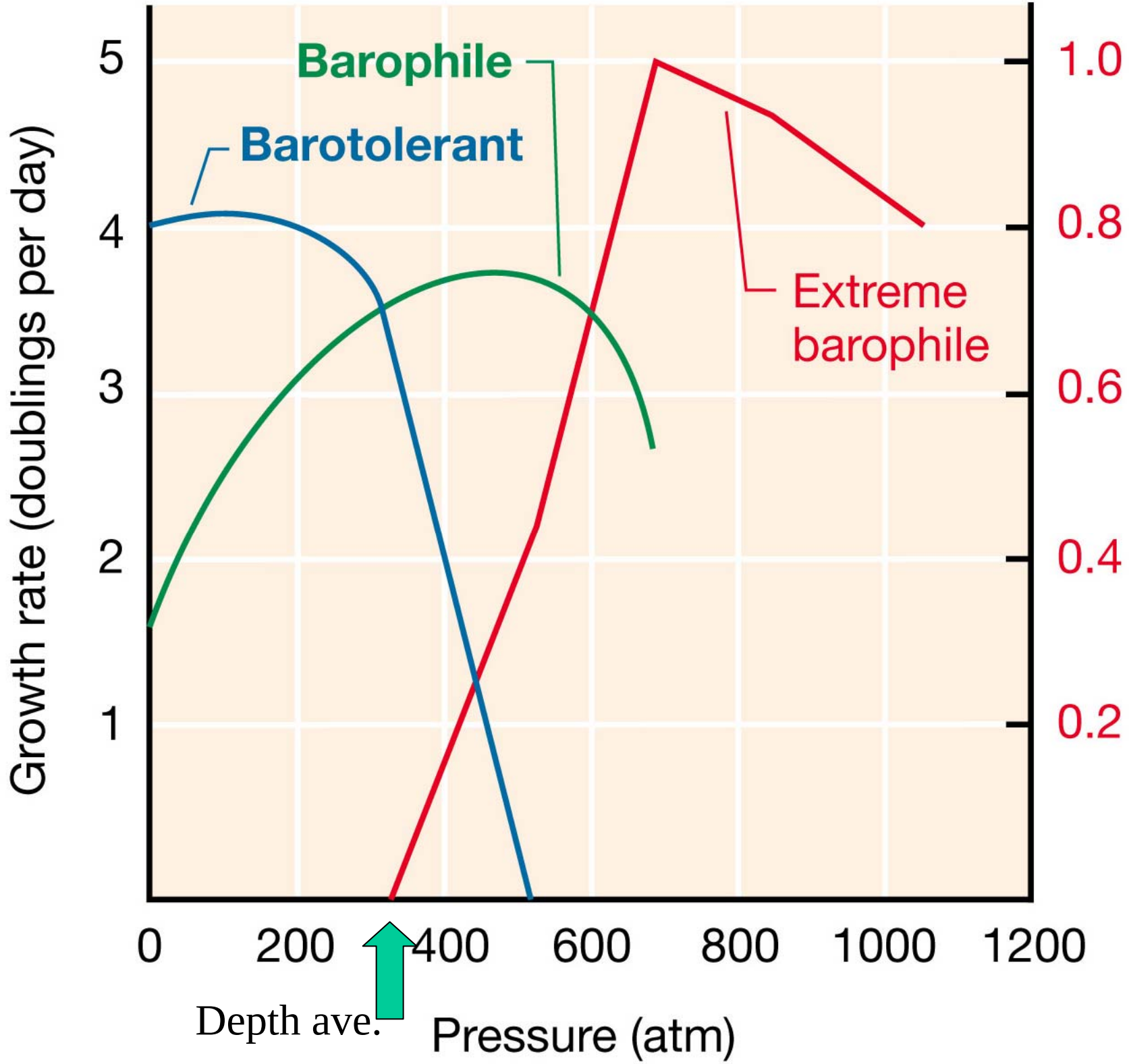

Psychrophile
Example:
Polaromonas vacuolata
4°
Mesophile
Example:
Escherichia coli
39°
Thermophile
Example:
Bacillus stearothermophilus
60°
Hyperthermophile
Example:
Thermococcus celer
88°
Hyperthermophile
Example:
Pyrolobus fumarii
106°
Growth rate
0 10 20 30 40 50 60 70 80 90 100 110 120
Temperature (°C)

Table 6.3 Temperature ranges for growth of *Bacteria* and *Archaea*

Species	Range (°C)
Psychrophiles	
Cytophaga psychrophila	4–20
Bacillus insolitus	<0–25
Aquaspirillum psychrophilum	2–26
Mesophiles	
Escherichia coli	10–40
Lactobacillus lactis	18–42
Bacillus subtilis	22–40
Pseudomonas fluorescens	4–40
Thermophiles	
Bacillus thermoleovorans	42–75
Thermoleophilum album	45–70
Thermus aquaticus	40–79
Chloroflexus aurantiacus	45–70
Hyperthermophiles (*Archaea*)	
Hyperthermus butylicus	85–108
Methanothermus fervidus	65–97
Pyrodictium occultum	80–110
Thermococcus celer	70–95

Growth temperature ranges for various life forms



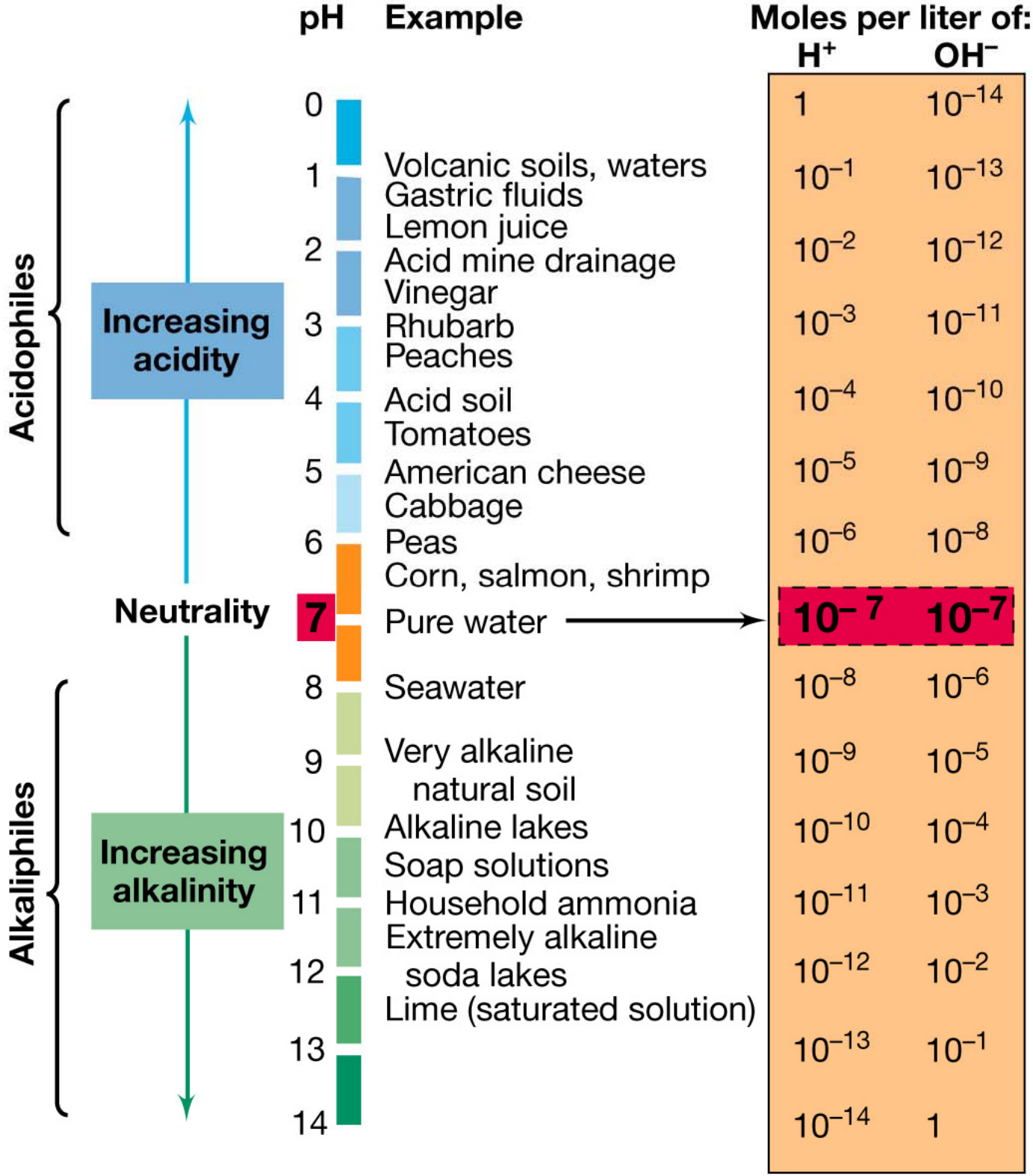

Barophile
Barotolerant
Extreme barophile
Growth rate (doublings per day)
5
4
3
2
1
1.0
0.8
0.6
0.4
0.2
0
200
400
600
800
1000
1200
Depth ave.
Pressure (atm)

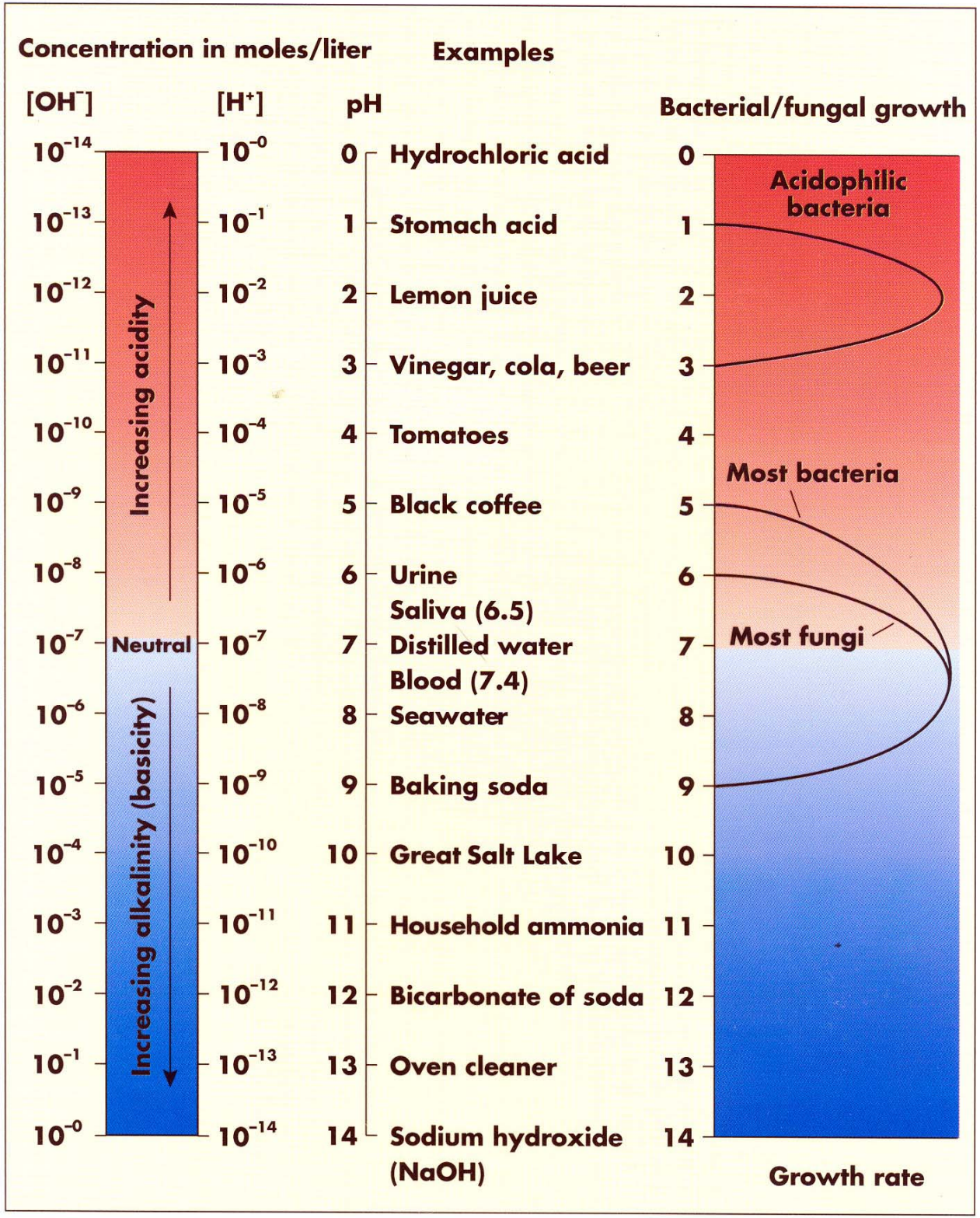
Microbial Growth

Environmental Forcing Functions:

- pH: acidophiles & alkaliphiles
  cytoplasm still near neutral

- eH: available electron donors & terminal electron acceptors
  affects the chemistry of the environment


pH
Example
Moles per liter of:
H+
OH−
Acidophiles
Increasing acidity
Neutrality
Alkaliphiles
Increasing alkalinity
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Volcanic soils, waters
Gastric fluids
Lemon juice
Acid mine drainage
Vinegar
Rhubarb
Peaches
Acid soil
Tomatoes
American cheese
Cabbage
Peas
Corn, salmon, shrimp
Pure water
Seawater
Very alkaline natural soil
Alkaline lakes
Soap solutions
Household ammonia
Extremely alkaline soda lakes
Lime (saturated solution)
1 10−14
10−1 10−13
10−2 10−12
10−3 10−11
10−4 10−10
10−5 10−9
10−6 10−8
10−7 10−7
10−8 10−6
10−9 10−5
10−10 10−4
10−11 10−3
10−12 10−2
10−13 10−1
10−14 1


Concentration in moles/liter
Examples
[OH⁻]
[H⁺]
pH
Bacterial/fungal growth
10⁻¹⁴
10⁻¹³
10⁻¹²
10⁻¹¹
10⁻¹⁰
10⁻⁹
10⁻⁸
10⁻⁷
10⁻⁶
10⁻⁵
10⁻⁴
10⁻³
10⁻²
10⁻¹
10⁻⁰
10⁻⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
10⁻¹³
10⁻¹⁴
Increasing acidity
Neutral
Increasing alkalinity (basicity)
0 Hydrochloric acid
1 Stomach acid
2 Lemon juice
3 Vinegar, cola, beer
4 Tomatoes
5 Black coffee
6 Urine
Saliva (6.5)
7 Distilled water
Blood (7.4)
8 Seawater
9 Baking soda
10 Great Salt Lake
11 Household ammonia
12 Bicarbonate of soda
13 Oven cleaner
14 Sodium hydroxide (NaOH)
Acidophilic bacteria
Most bacteria
Most fungi
Growth rate

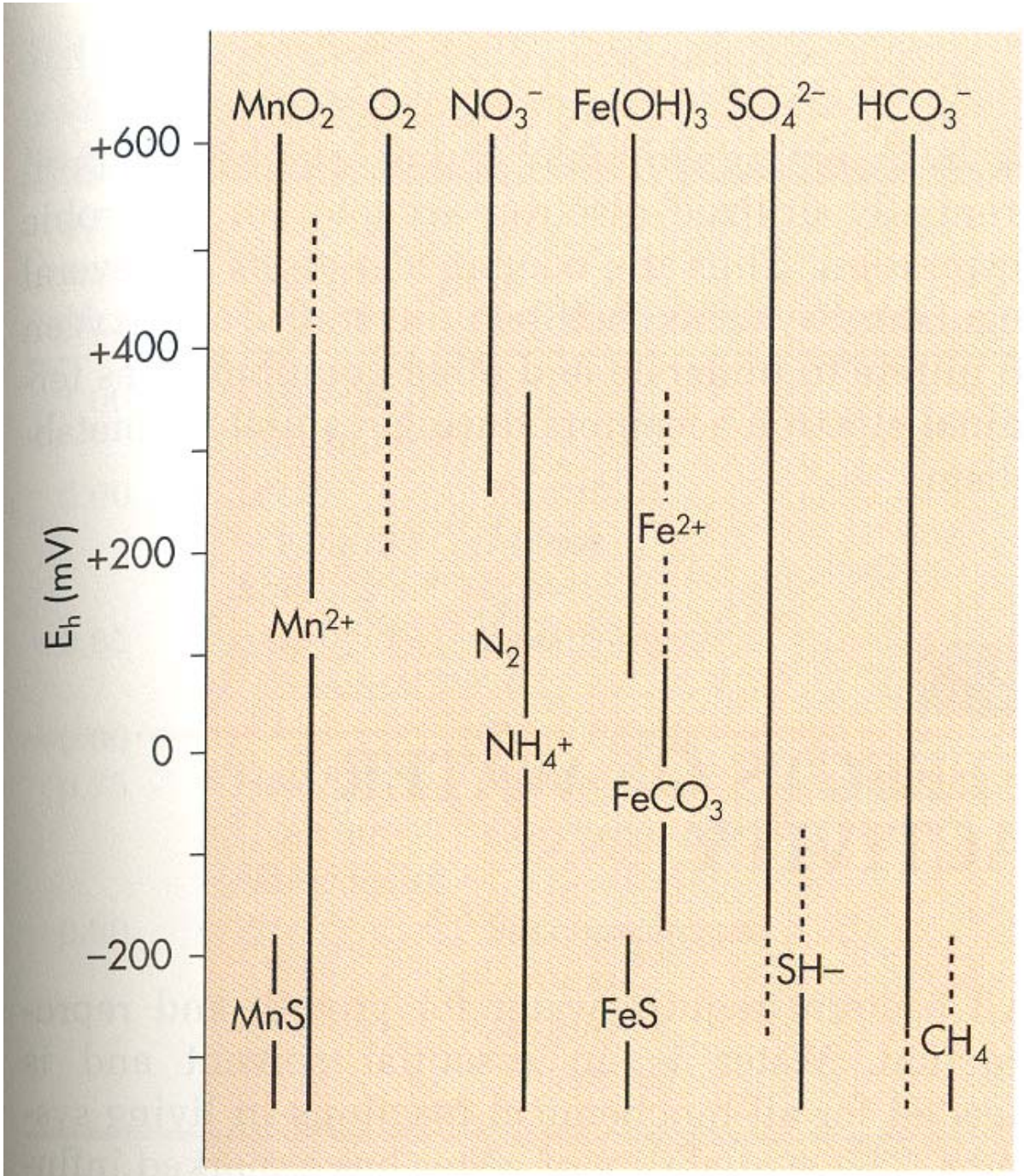
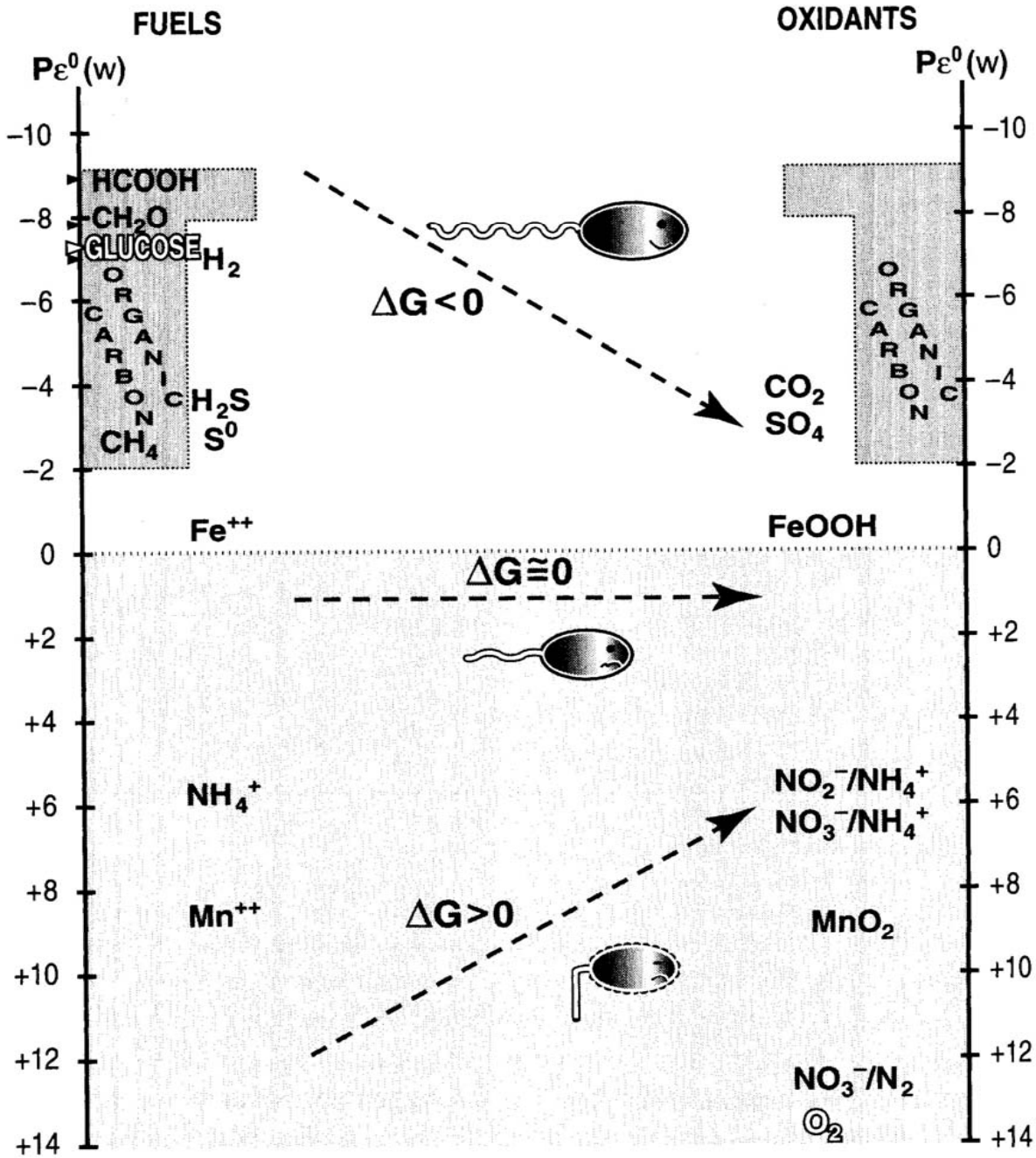


Fig. 9-26 E_h Values. Ranges of E_h values for various substances. In complex systems the reduction potential is influenced by the strongest oxidant, or reductant, in that system.

Thermodynamics: The Chemical Fuels and Oxidants of Life

e- source



e- sink

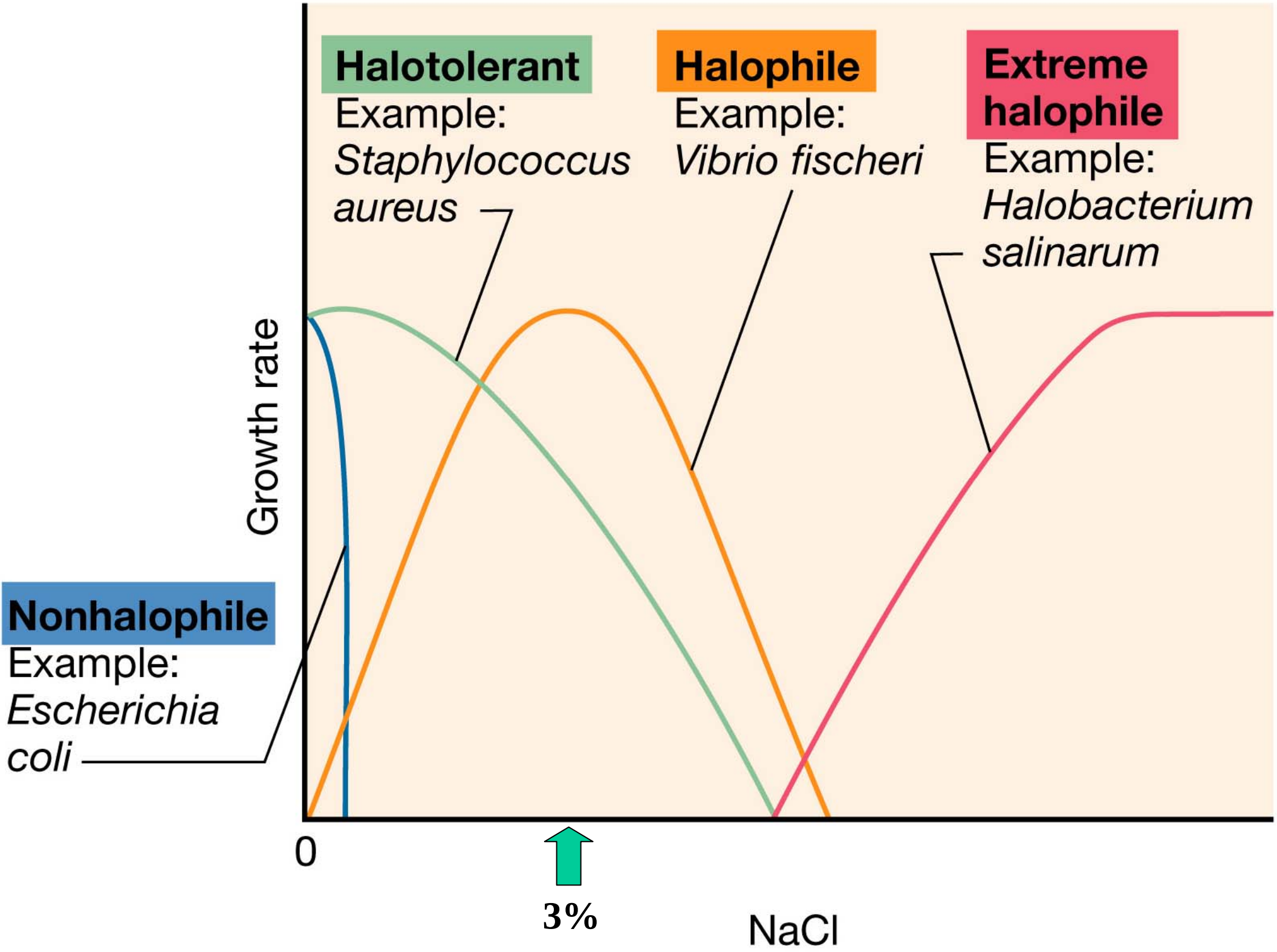
Microbial Growth

Environmental Forcing Functions:

- Salt: Halophiles
  Compatible solutes: amino acid derivatives (e.g., proline & glycine)

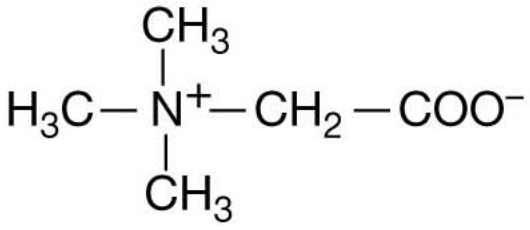
- Water Activity: Xerophiles (live in very dry habitats)
  All microbes are **osmotrophs**, must use organic material in solution!

- Oxygen Usage: aerobe, facultative (an)aerobe, microaerophile, obligate anaerobe
  DeTox enzymes: Catalase, Peroxidase, SOD

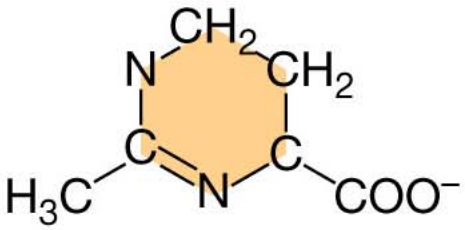

Halotolerant
Example:
Staphylococcus aureus
Halophile
Example:
Vibrio fischeri
Extreme halophile
Example:
Halobacterium salinarum
Nonhalophile
Example:
Escherichia coli
Growth rate
0
3%
NaCl

1. Amino acid–type solutes:

Glycine betaine

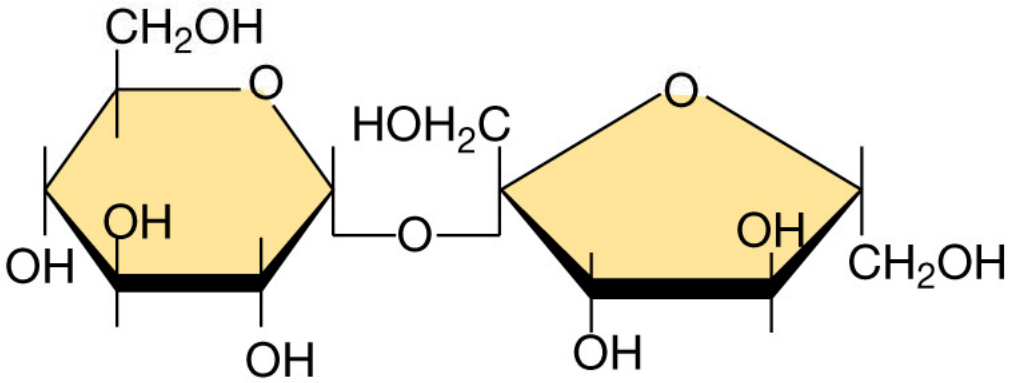


Ectoine

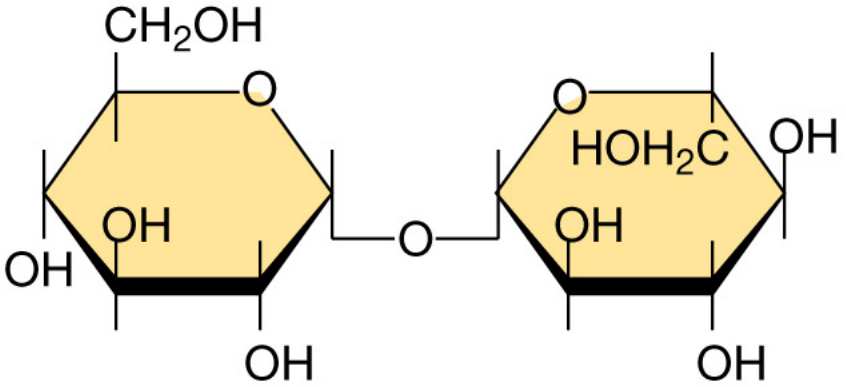


2. Carbohydrate-type solutes:

Sucrose



Trehalose

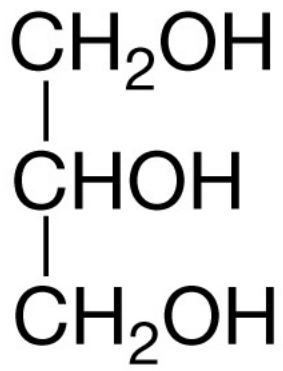


Compatible solutes

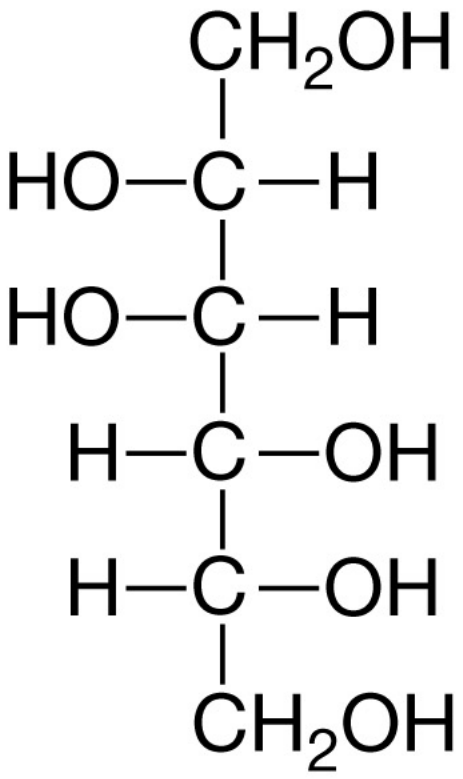
3. Alcohol-type solutes:

Compatible solutes

Glycerol



Mannitol



4. Other:

Dimethylsulfoniopropionate:

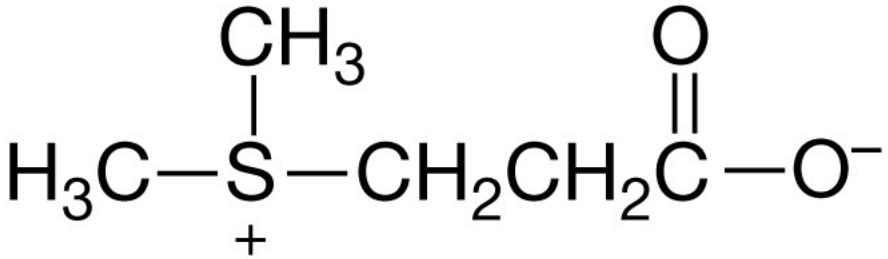
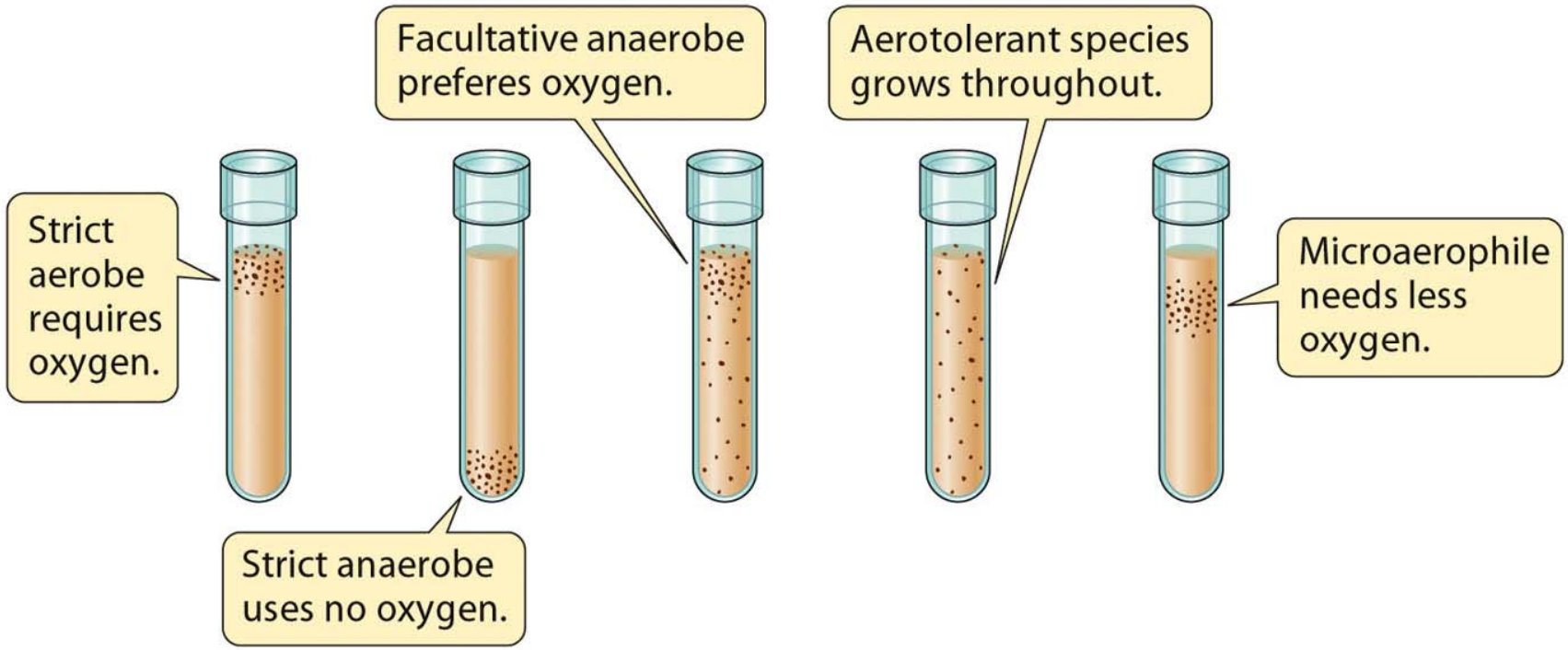


Table 6.4 Tolerance of selected *Bacteria* and *Archaea* for decreased water activity a_w

Type	Organisms	a_w
Nonhalophiles	*Aquaspirillum* and *Caulobacter*	1.00
Marine forms	Pseudomonads and *Alteromonas*	0.98
Moderate halophiles	*Vibrio* species and gram-positive cocci	0.91
Extreme halophiles	*Halobacterium* and *Halococcus*	0.75

Response of bacterial growth to oxygen availability



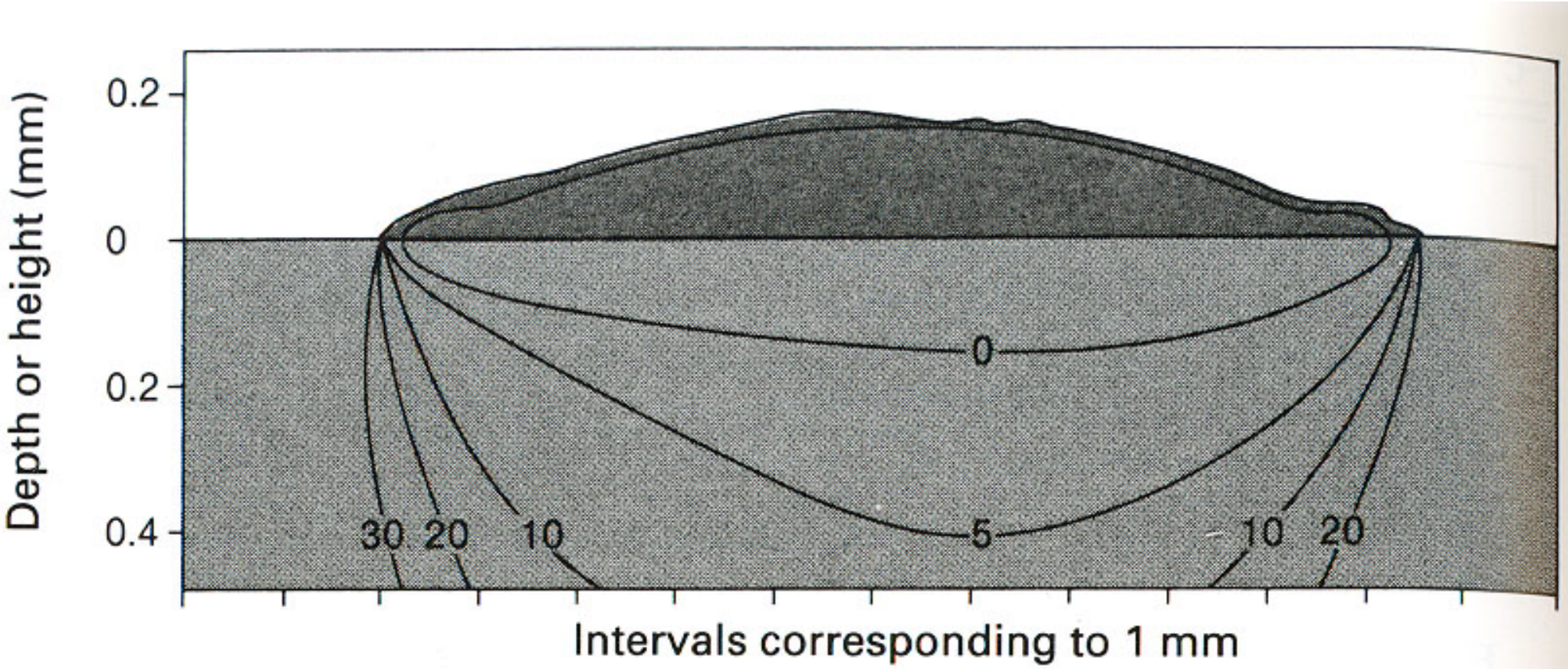


Fig. 6.3. *Oxygen distribution under and inside a colony of* Escherichia coli *after growth on complex agar.*

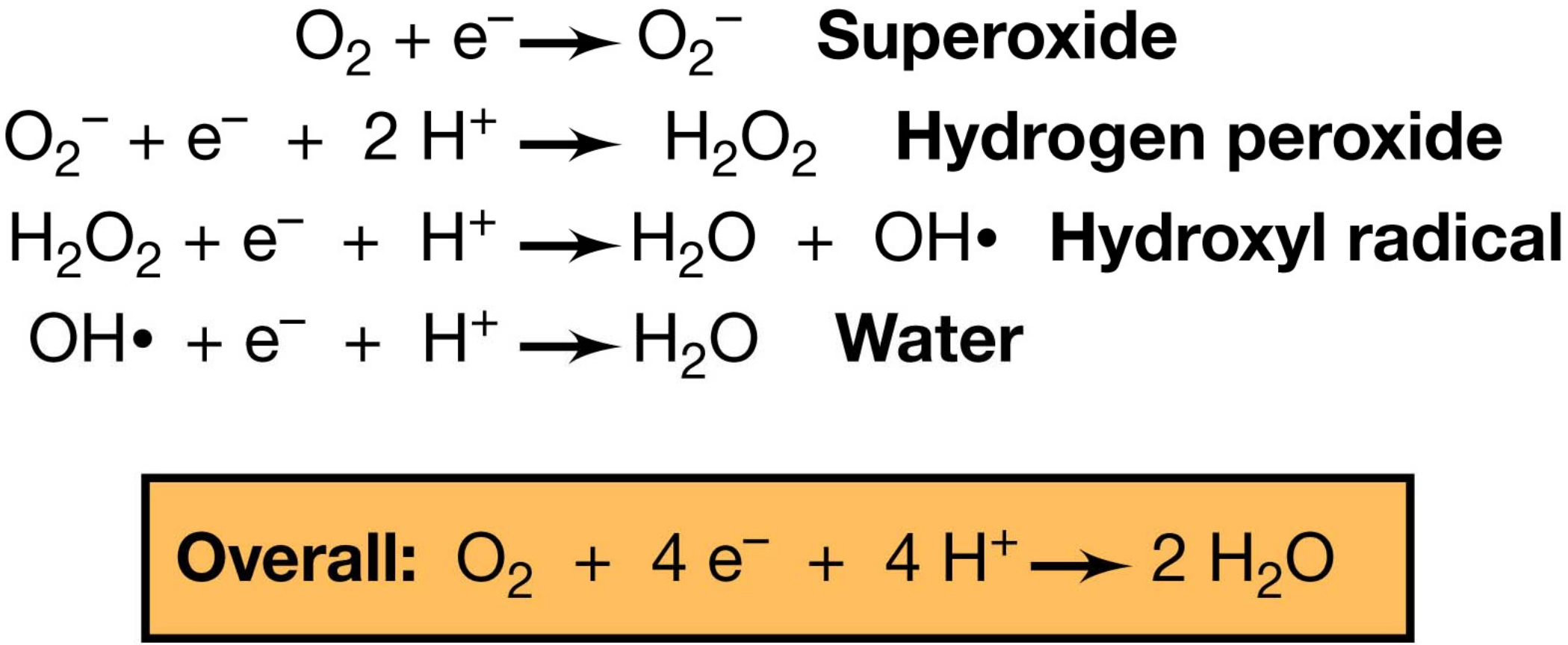
Deborah O. Jung and M. T. Madigan

(a)

Table 9-5 Electronic States of Oxygen

Form	Formula	Simplified Electronic Structure	Spin of Outer Electrons
Triplet oxygen (normal atmospheric form)	$^3O_2$	$\dot{O}—\dot{O}$	↑ ↑
Singlet oxygen	$^1O_2$	$\dot{O}—\dot{O}$	↓↑ ○
			↑ ↓
Superoxide free radical	O_2^-	$\ddot{O}—\dot{O}$	↓↑ ↑
Peroxide	O_2^{2-}	$\ddot{O}—\ddot{O}$	↓↑ ↓↑

Nasty!



4 electron reduction of O_2 to water

Table 9-6 Bacterial Enzymes that Protect the Cell Against Toxic Forms of Oxygen

Microorganism	Catalase	Superoxide Dismutase
Aerobe	+	+
Facultative anaerobe	+	+
Microaerophile	−	+
Obligate anaerobe	−	−

(a) Catalase:

$$H_2O_2 + H_2O_2 \rightarrow 2\ H_2O + O_2$$

(b) Peroxidase:

$$H_2O_2 + NADH + H^+ \rightarrow 2\ H_2O + NAD^+$$

(c) Superoxide dismutase:

$$O_2^- + O_2^- + 2\ H^+ \rightarrow H_2O_2 + O_2$$

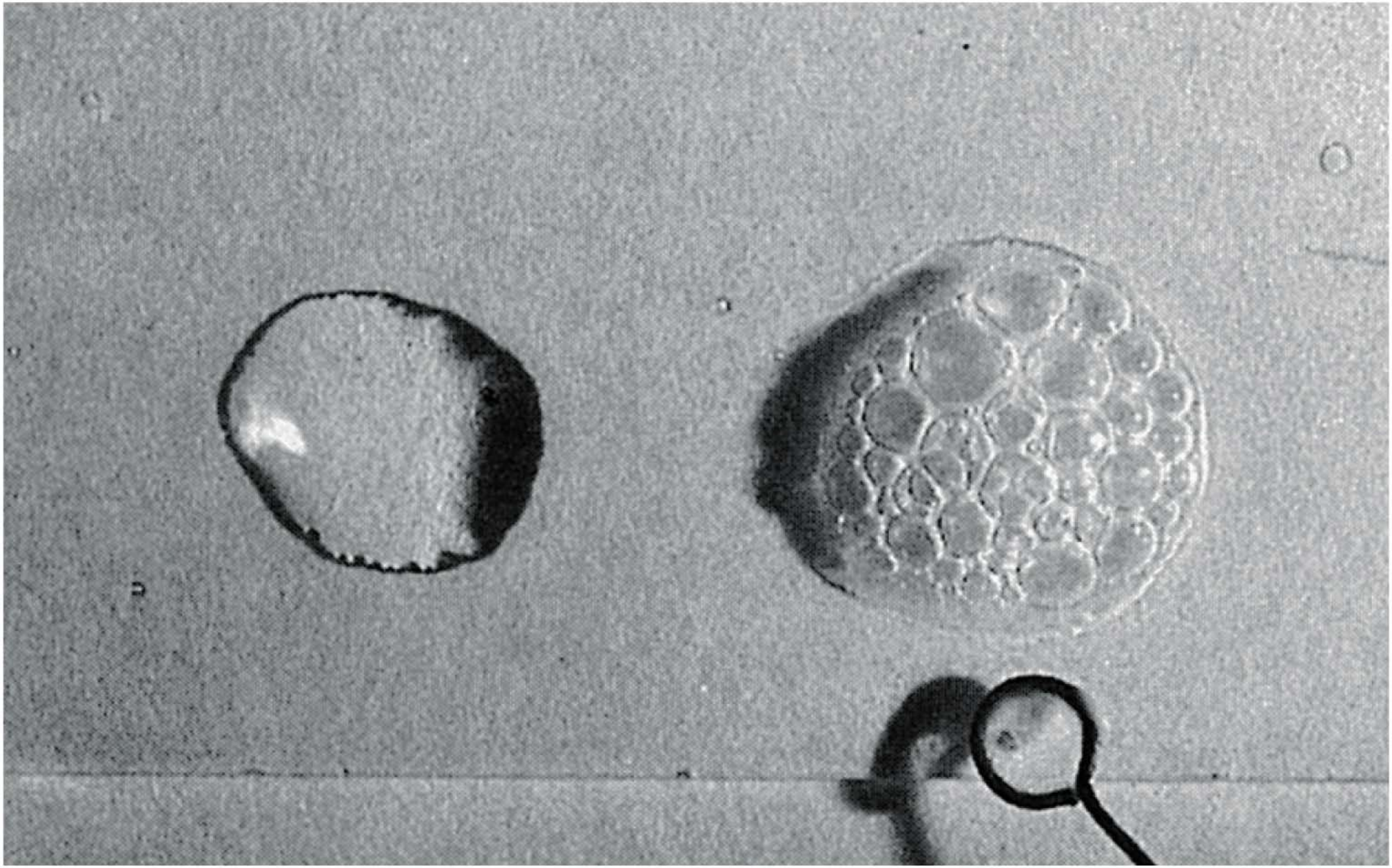
(d) Superoxide dismutase/catalase in combination:

$$4\ O_2^- + 4\ H^+ \rightarrow 2\ H_2O + 3\ O_2$$

(e) Superoxide reductase:

$$O_2^- + 2\ H^+ + \text{cyt } c_{\text{reduced}} \rightarrow H_2O_2 + \text{cyt } c_{\text{oxidized}}$$

Catalase Test



T. D. Brock

Cytochrome Oxidase Test

An important diagnostic indicator for the identification of *Pseudomonas* and *Neisseria* spp.