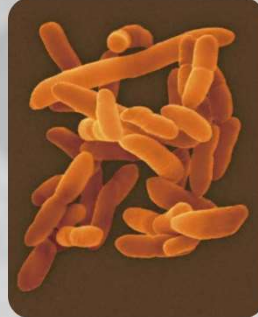
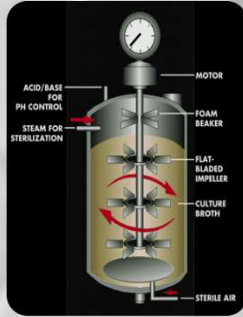


Fermentation Microbiology I

UE. Industrial fermentations



Pr. H. Ouled Haddar

Université de Jijel

H. Ouled Haddar

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Program

1. Reminder : microbial culture, microbial growth, microbial metabolism
2. Industrial microorganisms : isolation, selection, screening and properties
3. Culture media in industrial bioprocessing : carbon source, nitrogen, energy..
4. Production improvement : process engineering, optimization, strain improvement (genetic engineering)
5. Immobilized cells process : methods, applications
6. Industrial bioprocessing : batch, fed-batch, continuous bioreactors

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Self-directed projects

Students are asked to prepare and present (15 to 20 min) orally a self-directed project on one of the following topics:

- Extremophiles (thermophilic/psychrophilic, ..) in industrial microbiology (IM)
- Microalgae/*Bacillus* species/Actinomycetes/Yeasts/ Fungi, in IM
- Omics and IM
- Solid State Fermentation (SSF)
- Phage infection and control in IM
- Biofilms and bioprocessing
- Precision fermentations
- Culture collections

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Guidelines

- Bibliographic review – recent articles (reviews or originals), no copy-paste
- Introduction – with alphabetical citations
- Written report (body)– structured, with references
- Conclusion – include your personal critical opinion
- Reference list – complete and consistent
- Figures/Tables – with captions and references
- Formatting – 10 to 15 pages, Times New Roman 12, line spacing 1.5,
- PowerPoint presentation – 15–20 minutes

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Google Scholar biofilm industrial fermentation

Articles Environ 116 000 résultats (0,14 s)

Date indifférente
Depuis 2025
Depuis 2024
Depuis 2021
Période spécifique...

Trier par pertinence
Trier par date

Toutes les langues
Recherche dans les pages en Français

Tous les types
Articles de revue

☐ inclure les brevets
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☒ Créer l'alerte

Current and future trends for **biofilm** reactors for **fermentation** processes
D Ercan, A Demirci - Critical reviews in biotechnology, 2015 - Taylor & Francis
... properties of a **biofilm** matrix to run the **biofilm** reactor at optimum ... of **biofilm** formation;
properties of a **biofilm** matrix and their roles in the **biofilm** formation; factors that improve the **biofilm** ...
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Multispecies **biofilms** in **fermentation**: **Biofilm** formation, microbial interactions, and communication [PDF] researchgate.net
S Yao, L Hao, R Zhou, Y Jin, J Huang... - ... reviews in food science ..., 2022 - Wiley Online Library
... Here, in this review, we focus on multispecies **biofilms** in **fermentation**. More attention ... **biofilm**
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Biofilm application in the microbial biochemicals production process
Y Jiang, Y Liu, X Zhang, H Gao, L Mou, M Wu... - Biotechnology ..., 2021 - Elsevier
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microbial fermentation biofilm reactors formation immobilized fermentation

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Google Scholar biofilm industrial fermentation

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ISO 690 JIANG, Yujia, LIU, Yansong, ZHANG, Xiaoyu, et al. Biofilm application in the microbial biochemicals production process. *Biotechnology Advances*, 2021, vol. 48, p. 107724.

MLA Jiang, Yujia, et al. "Biofilm application in the microbial biochemicals production process." *Biotechnology Advances* 48 (2021): 107724.

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Laboratory sessions (21h)

- Lab 1: Culture medium preparation (2.5h)
- Lab 2: Isolation and primary screening of protease-producing sporulating bacteria (2.5h)
- Lab 3: Quantitative screening of protease-producing sporulating bacteria (4h)
- Lab 4: Effect of carbon source/pH/temperature on protease production by *Bacillus* sp. (2.5h)
- Lab 5: Bacterial cell immobilization (2.5h)
- Lab 6: Protease production by immobilized cells of *Bacillus* sp. in a continuous system (4h)
- Lab 7: Solid state fermentation (SSF) (3h)

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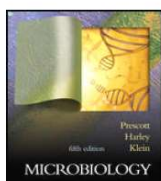
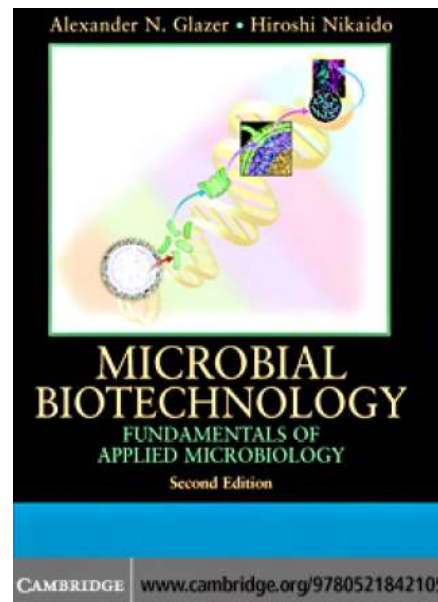
Modern Industrial Microbiology and Biotechnology

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Department of Biological Sciences
Clemson University, Clemson
South Carolina
USA



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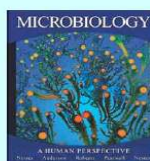


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Microbiology: A Human Perspective

4th edition

Eugene W. Nester, University of Washington
Denise G. Anderson, University of Washington
C. Evans Roberts, Jr., University of Washington
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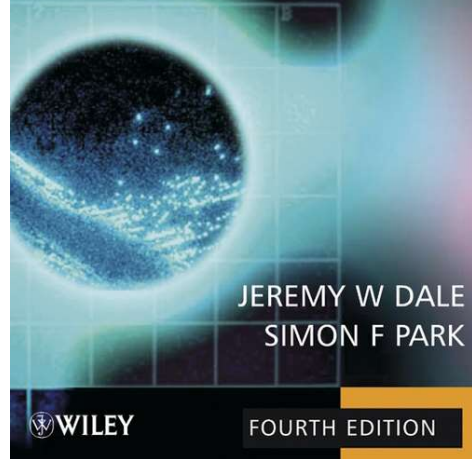
Fermentation Microbiology and Biotechnology



Third Edition
Edited by
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Molecular Genetics OF BACTERIA



JEREMY W DALE
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FOURTH EDITION

Fermentations

Principales applications industrielles

par **Paul BADUEL**

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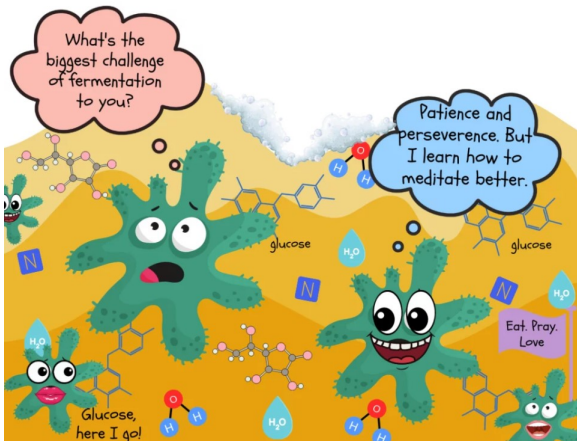
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General informations

What is a bioprocess?

Bioprocess = Set of methods and techniques that use biological systems for the production of goods and services

POV: In the ocean of culture broth on one fermentation day...



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The art of making microorganisms work in industry

The use of living organisms and their metabolites by industry

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Examples

- ✓ **Fermented food production:** marinades, sauerkraut, cheese, yogurt
- ✓ **Winemaking:** wines, beers, spirits
- ✓ **Production of pharmaceutical products:** antibiotics, vitamins, vaccines, antibodies...
- ✓ **Valorization of industrial and agricultural by-products:** molasses, whey..
- ✓ **Conversion into high added value products:** organic acids, polymers, biogas
- ✓ **Biological treatment:** wastewater, air, contaminated soil, domestic waste

Most bioprocesses are based on fermentation technology

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Fermentation = process allowing the production of a substance or biomass of cells on a large scale using the cultivation of a microorganism, in the presence or absence of air

understand biotechnology

biochemistry, microbiology, cell and molecular biology, chemistry, computer science...

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History

Sumerians and Babylonians Neolithic (6000 BC)

Egyptians

Roman "fermentare" = to boil

Greeks

Late 16th century

Between 12th and 18th century

wine

bread, wine..

Antonie Van Leeuwenhoek

Acetic acid fermentation (1650)



FIGURE 1.1 Bread making as depicted on the wall of an ancient Egyptian tomb dated c. 1400 BC. (Reprinted with the kind permission of the Fitzwilliam Museum, Cambridge, England.)

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Pasteur 1850
Late 19th century
Weismann 1912-1914
Fleming 1929
Insulin 1982

alcoholic and lactic acid fermentation
Baker's yeast
Acetone butanol
Penicillin



FIGURE 1.2 Grape treading and wine making as depicted on the walls of Nakhte's tomb, Thebes, c. 1400 BC. (Reprinted with the kind permission of AKG, London, England/Erich Lessing.)

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Chapter I: Reminder: culture, growth of microorganisms and microbial metabolism

Introduction

The growth of bacteria depends not only on a suitable physical environment, but also on a permanent source of chemical compounds used in nutrition.

The cell needs to synthesize all of the cellular structural components such as **lipid membranes, cell walls**, etc.

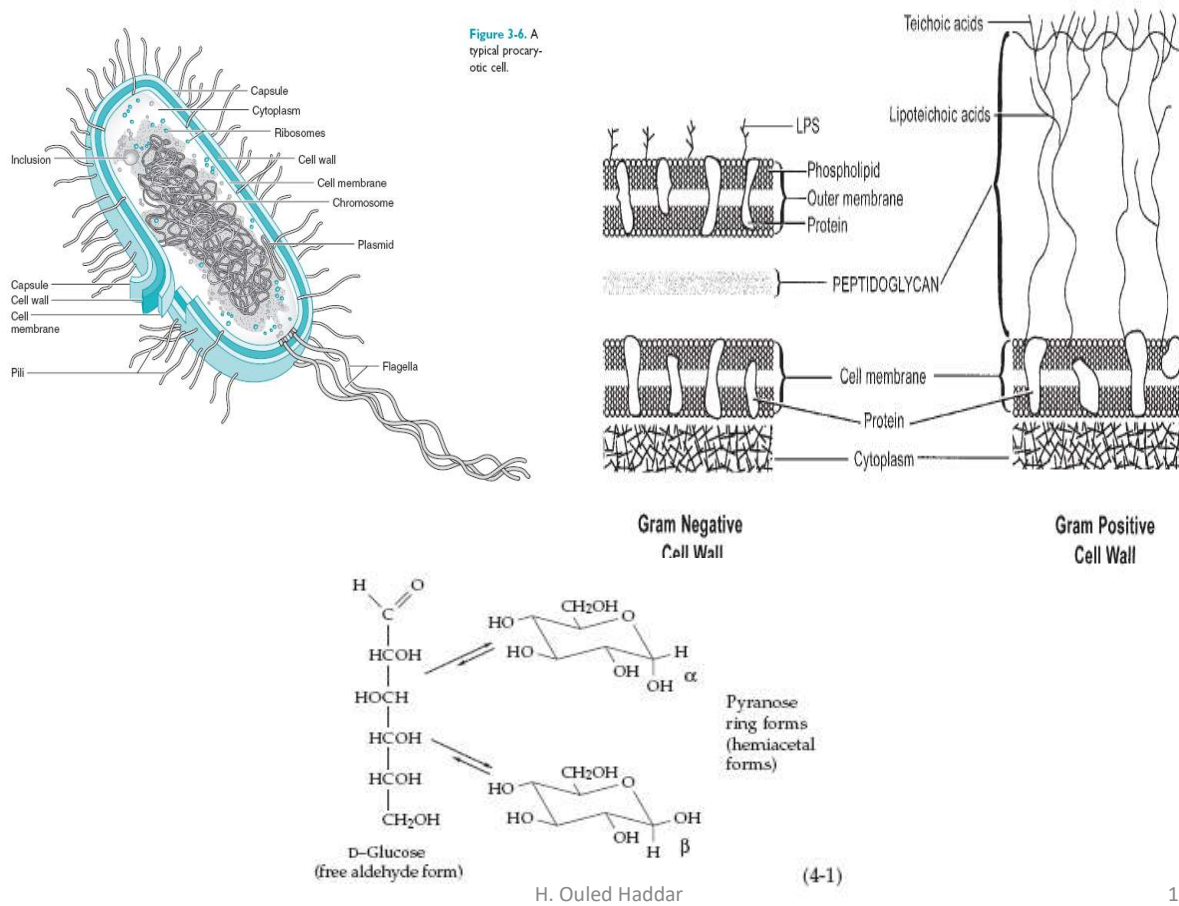
These components are synthesized from less complex molecules which are structural units such as **amino acids** and **nucleotides**.

On the other hand, each of these structural units is composed of a variety of chemical elements such as **carbon** and **nitrogen**.

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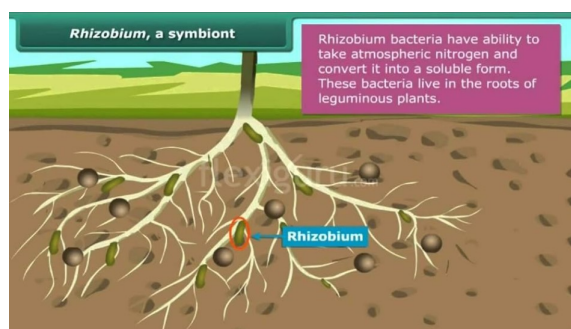
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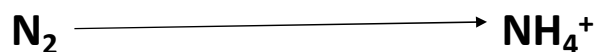
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What makes the world of prokaryotes different from other life forms is their remarkable ability to utilize different sources of these elements.

Example: They are the only ones who can use atmospheric nitrogen (N_2) as a nitrogen source.



Rhizobium



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II-Energy

According to the laws of thermodynamics, cells do not create energy but they **transform** that present in the universe into a form that can be used by the cell. Bacteria use two methods to obtain energy: that from **photosynthesis** and that released by **chemical reactions**.

Phototrophic organisms: consume solar energy to synthesize organic compounds such as glucose. (synthesis of ATP from ADP and inorganic phosphate).

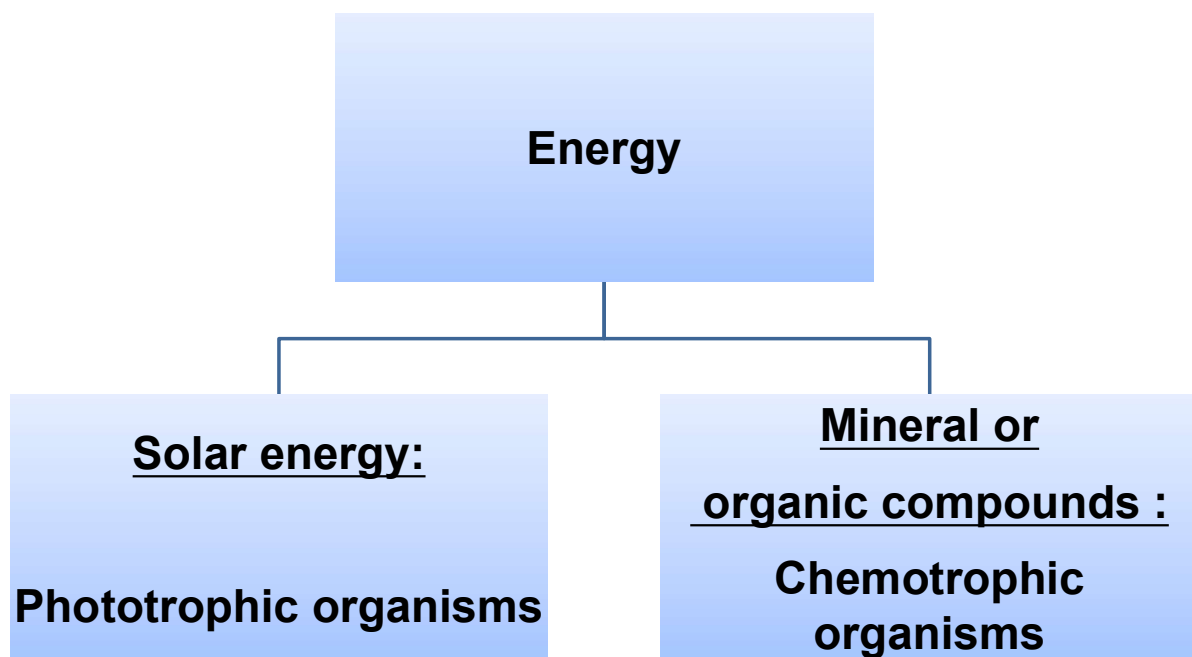
Chemotrophic organisms: obtain their energy from mineral or organic compounds. They use electron donors and acceptors (mineral element: chemolithotrophic bacteria; organic element: chemoorganotrophic bacteria). The energy released from chemical bonds is used.

Most microorganisms are **chemotrophs**.

Energetic chemical reactions are essentially redox reactions.

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Table 4.4 Energy and Carbon Sources Used by Different Groups of Prokaryotes

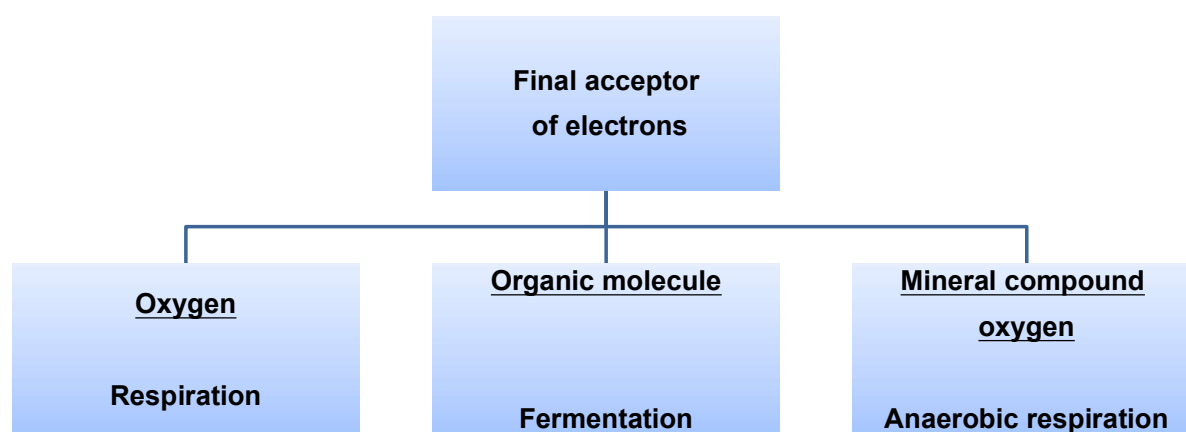
Type	Energy Source	Carbon Source
Photoautotroph	Sunlight	CO ₂
Photoheterotroph	Sunlight	Organic compounds
Chemolithoautotroph	Inorganic chemicals (H ₂ , NH ₃ , NO ₂ ⁻ , Fe ²⁺ , H ₂ S)	CO ₂
Chemoorganoheterotroph	Organic compounds (sugars, amino acids, etc.)	Organic compounds

TABLE 1.2 Principal modes of metabolism

Type	Prokaryotes	Eukaryotes
Chemoautotrophs	+	none
Chemoheterotrophs	+	+ ("animals," fungi)
Photoautotrophs	+	+ ("plants")
Photoheterotrophs	+	none

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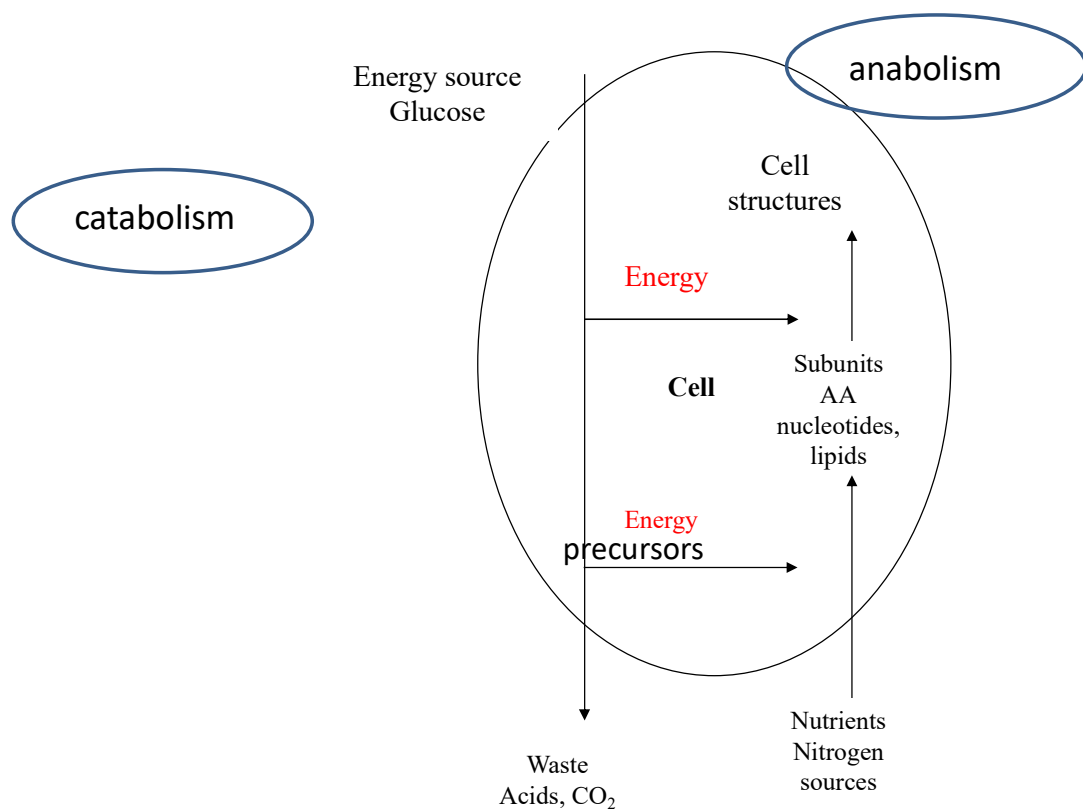
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TABLE 7-2 DIFFERENCES BETWEEN CATABOLISM AND ANABOLISM

Catabolism	Anabolism
All the catabolic reactions in a cell	All the anabolic reactions in a cell
Catabolic reactions release energy	Anabolic reactions require energy
Catabolic reactions involve the breaking of bonds; whenever chemical bonds are broken, energy is released	Anabolic reactions involve the creation of bonds; it takes energy to create chemical bonds
Larger molecules are broken down into smaller molecules (sometimes referred to as degradative reactions)	Smaller molecules are bonded together to create larger molecules (sometimes referred to as biosynthetic reactions)

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**Figure 1. The relationship between catabolism and anabolism.**

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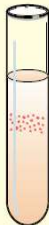
Table 6.8 Metabolism of Chemolithotrophs

Common Name of Organism	Source of Energy	Oxidation Reaction (Energy Yielding)	Important Features of Group	Common Genera in Group
Hydrogen bacteria	H ₂ gas	$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$	Can also use simple organic compounds for energy	<i>Hydrogenomonas</i>
Sulfur bacteria (non-photosynthetic)	H ₂ S	$H_2S + \frac{1}{2} O_2 \rightarrow H_2O + S$ $S + 1\frac{1}{2} O_2 + H_2O \rightarrow H_2SO_4$	Some organisms of this group can live at a pH of less than 1	<i>Thiobacillus</i> <i>Beggiatoa</i> <i>Thiothrix</i>
Iron bacteria	Reduced iron (Fe ²⁺)	$2 Fe^{2+} + \frac{1}{2} O_2 + H_2O \rightarrow 2 Fe^{3+} + 2 OH^-$	Iron oxide present in the sheaths of these bacteria	<i>Sphaerotilus</i> <i>Gallionella</i>
Nitrifying bacteria	NH ₃	$NH_3 + 1\frac{1}{2} O_2 \rightarrow HNO_2 + H_2O$	Important in nitrogen cycle	<i>Nitrosomonas</i>
	HNO ₂	$HNO_2 + \frac{1}{2} O_2 \rightarrow HNO_3$	Important in nitrogen cycle	<i>Nitrobacter</i>

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Table 4.2 Oxygen (O₂) Requirements of Prokaryotes

Obligate aerobe	Facultative anaerobe	Obligate anaerobe	Microaerophile	Aerotolerant
				
Enzymes in Cells for O₂ Detoxification Catalase: $2H_2O_2 \rightarrow 2H_2O + O_2$ Superoxide dismutase: $2O_2^- + 2H^+ \rightarrow O_2 + H_2O_2$	Catalase, superoxide dismutase	Neither catalase nor superoxide dismutase in most	Small amounts of catalase and superoxide dismutase	Superoxide dismutase

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Table 4.1 Environmental Factors that Influence Microbial Growth

Environmental Factor/ Descriptive Terms	Characteristics
Temperature	Thermostability appears to be due to protein structure.
Psychrophile	Optimum temperature between -5°C and 15°C .
Psychrotroph	Optimum temperature between 20°C and 30°C , but grows well at lower temperatures.
Mesophile	Optimum temperature between 25°C and 45°C .
Thermophile	Optimum temperature between 45°C and 70°C .
Hyperthermophile	Optimum temperature between 70°C and 110°C .
Oxygen (O_2) Availability	Oxygen (O_2) requirement/tolerance reflects the organism's energy-converting mechanisms (aerobic respiration, anaerobic respiration, and fermentation) and its ability to detoxify O_2 derivatives.
Obligate aerobe	Requires O_2 .
Obligate anaerobe	Cannot multiply in the presence of O_2 .
Facultative anaerobe	Grows best if O_2 is present, but can also grow without it.
Microaerophile	Requires small amounts of O_2 , but higher concentrations are inhibitory.
Aerotolerant anaerobe (obligate fermenter)	Indifferent to O_2 .
pH	Prokaryotes that live in pH extremes appear to maintain a near neutral internal pH by pumping protons out of the cell.
Neutrophile	Multiplies in the range of pH 5 to 8.
Acidophile	Grows optimally at a pH below 5.5.
Alkalophile	Grows optimally at a pH above 8.5.
Water Availability	Prokaryotes that can grow in high solute solutions increase their internal solute concentration by either pumping ions into the cell or synthesizing certain small organic compounds.
Osmotolerant	Can grow in relatively high salt solutions, up to approximately 10% NaCl.
Halophile	Requires high levels of sodium chloride.

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Industrial products from primary metabolism

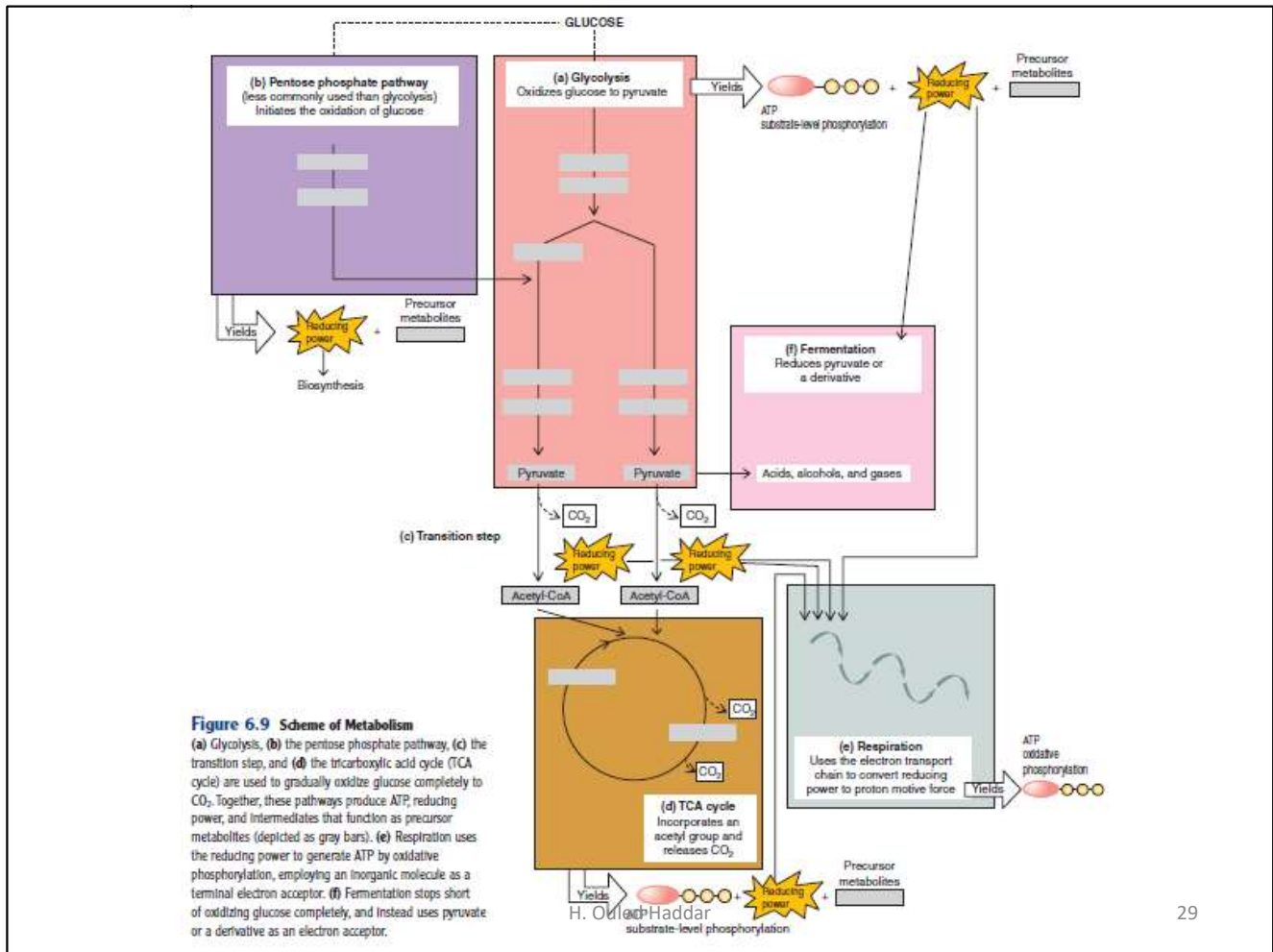
- **Catabolic products**

EMP, PP, ED, fermentation

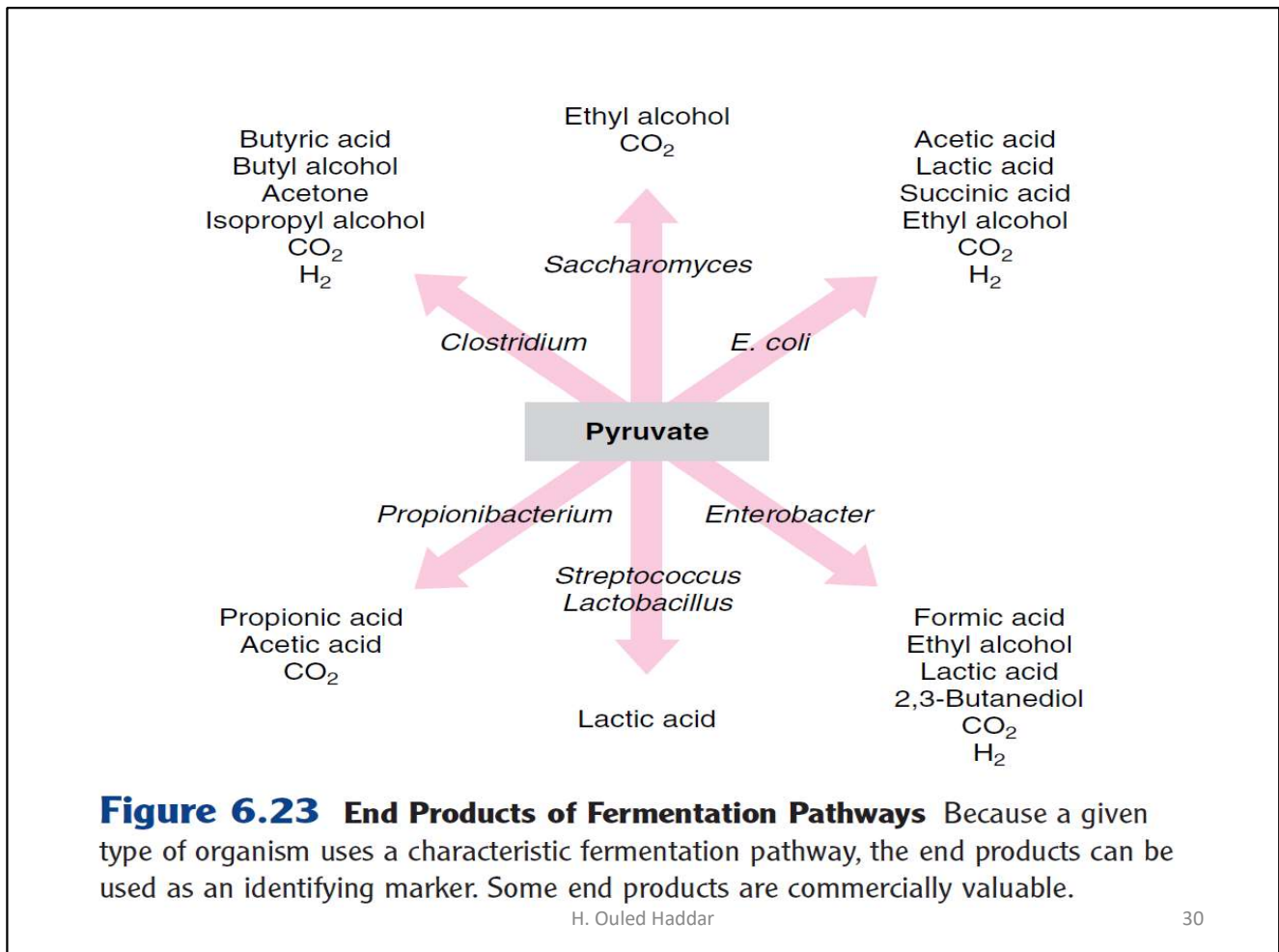
ethanol, acetic acid, 2, 3-butanediol, butanol, acetone,
lactic acid...

- **Anabolic products**

Amino acids, enzymes, citric acid, nucleic acids.



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Table 5.1 Some industrial products resulting from primary metabolism

<i>Anabolic Products</i>	<i>Catabolic Products</i>
1. Enzymes	1. Ethanol and ethanol-containing products, e.g. wines
2. Amino acids	2. Butanol
3. Vitamins	3. Acetone
4. Polysaccharides	4. Lactic acid
5. Yeast cells	5. Acetic acid (vinegar)
6. Single cell protein	
7. Nucleic acids	
8. Citric acid	

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Industrial products from secondary metabolism

a. Products deriving from the intact structure of glucose:

Some families of antibiotics, namely: aminoglycosides (streptomycin produced by *Streptomyces griseus*, gentamicin by *Micromonospora purpurea*),

b. Products derived from nucleosides:

Antibiotics from the nucleoside family (Blasticidin S by *Streptomyces griseochromogenes* used in agriculture)

Found in actinomycetes and fungi.

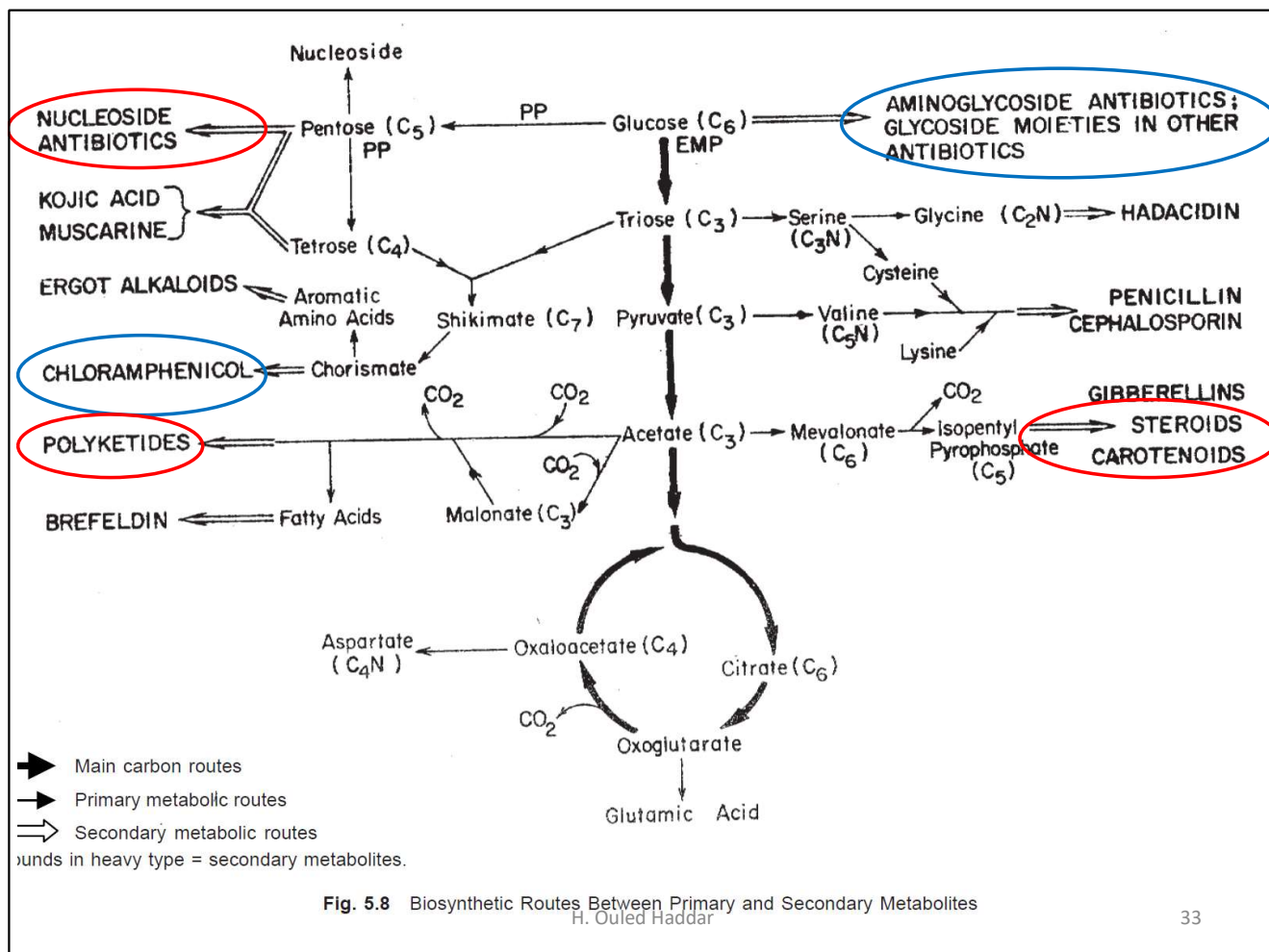
c. Products deriving from the Shikimate-Chorismate pathway:

Antibiotics (chloramphenicol from *Streptomyces venezuelae*, novobiocin from *Streptomyces niveus*, etc.)

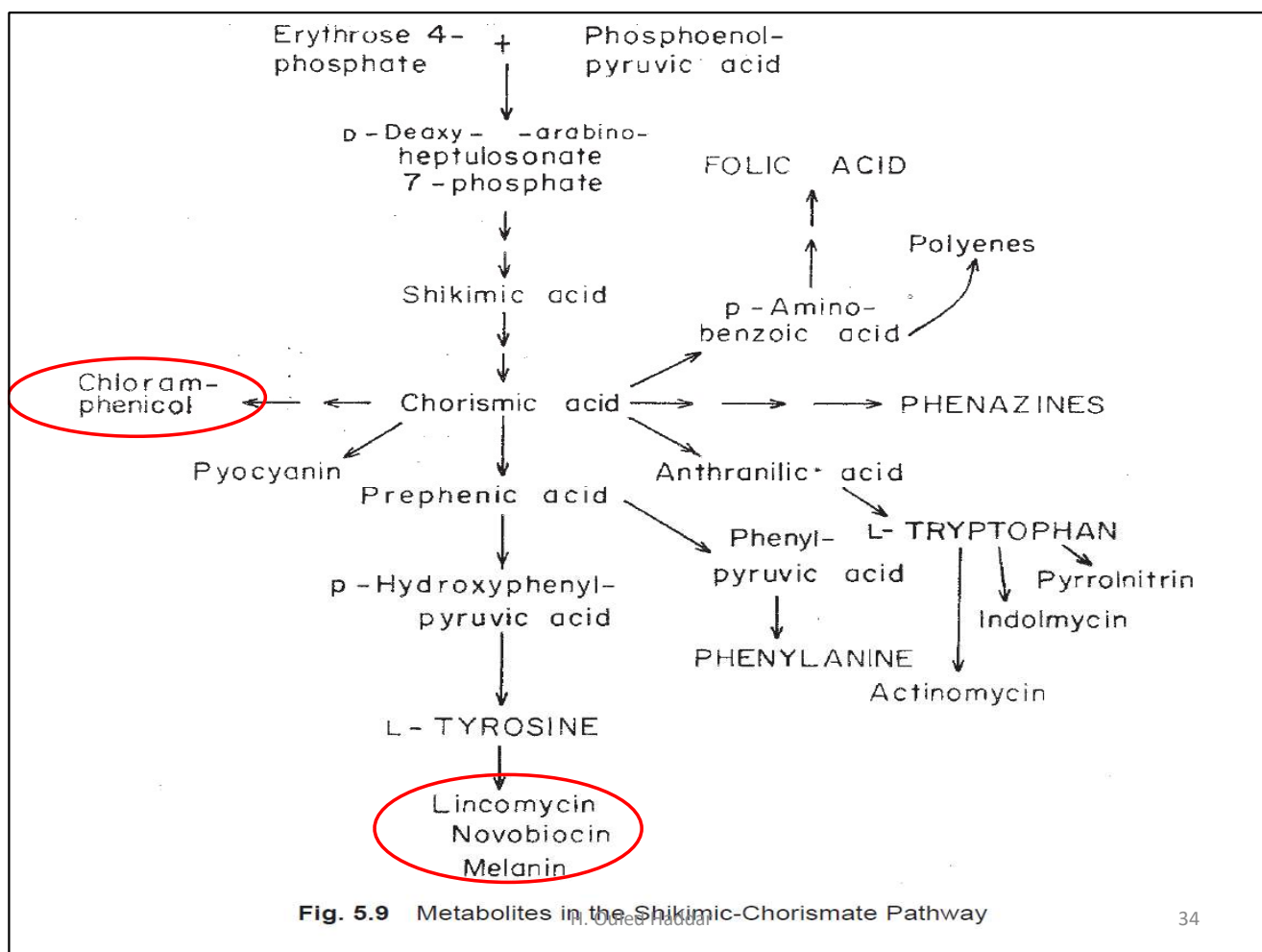
Bacteria and actinomycetes, rare in fungi,

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d. Products derived from the polyketide pathway

They constitute one of the major classes of secondary metabolites of bacteria, fungi and plants.

Their biosynthesis presents similarities with that of fatty acids: they are synthesized by a succession of condensation steps of acetyl or malonyl groups.

The enzyme complexes that catalyze these reactions are polyketide synthetases. There are several types: triketides, tetraketides, pentaketides, etc.

Macrolide antibiotics (erythromycin from *Streptomyces erythraeus*)

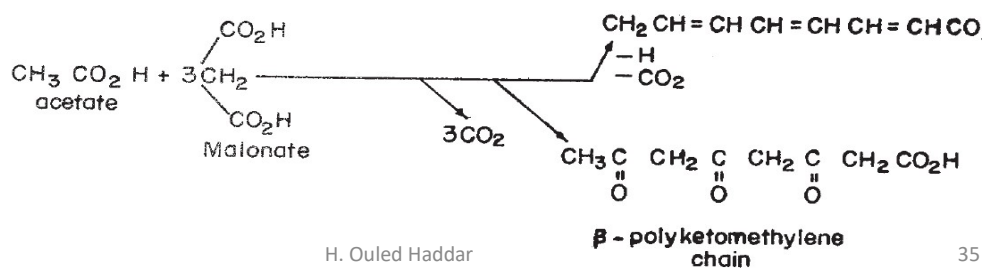


Fig. 5.10 Formation of Polyketides

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e. Synthesis of terpenes and steroids

Two pathways exist:

- Mevalonate pathway**

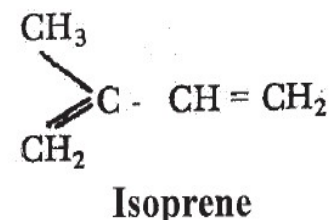
Found in mammals, plants, fungi and some bacteria

Acetate → mevalonic acid → isoprene

-Condensation

-Cyclization

-Edit



- Methylerythritol phosphate (MEP) pathway**

Naphtherpine, menaquinone of actinomycetes

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f. compounds derived from amino acids

- Metabolites formed from one amino acid



Glycine

Hadacidin

Penicillium frequentans

- ✓ Ibotenic acid (Amanita factor C, a neurotoxic agent) by *Amanita muscaria*
- ✓ Ergot alkaloids by *Claviceps purpureae* for therapeutic use, synthesized from tryptophan,
- ✓ Cycloserine, an antibiotic from the oxazolidinone family of *Streptomyces garyphalus*

- Metabolites formed from two amino acids

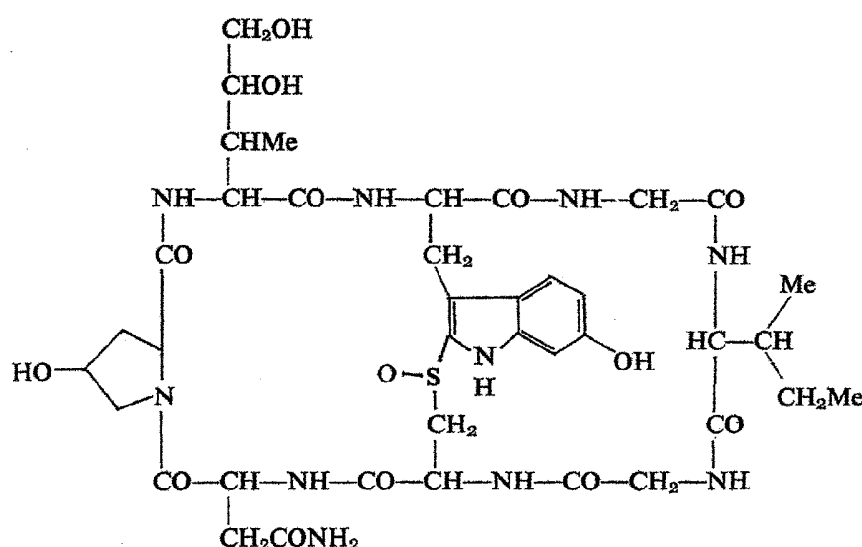
Glutathione by *Trichoderma*, *Aspergillus*, an anti-inflammatory drug

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- Metabolites formed from more than two amino acids

Toxins (*Amanita* sp, *Aspergillus* spp), polypeptide antibiotics, bacitracin (*Bacillus*)



Amanitin specific inhibitor of RNA polymerase

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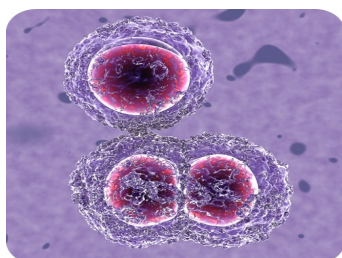
Table 5.2 Some industrial products of microbial secondary metabolism

Product	Organism	Use/Importance
<i>Antibiotics</i>		
Penicillin	<i>Penicillium chrysogenum</i>	Clinical use
Streptomycin	<i>Streptomyces griseus</i>	Clinical use
<i>Anti-tumor Agents</i>		
Actinomycin	<i>Streptomyces antibioticus</i>	Clinical use
Bleomycin	<i>Streptomyces verticillus</i>	Clinical use
<i>Toxins</i>		
Aflatoxin	<i>Aspergillus flavus</i>	Food toxin
Amanitine	<i>Amanita</i> sp	Food toxin
<i>Alkaloids</i>		
Ergot alkaloids	<i>Claviceps purpurea</i>	Pharmaceutical
<i>Miscellaneous</i>		
Gibberellic acid	<i>Gibberella fujikuroi</i>	Plant growth hormone
Kojic acid	<i>Aspergillus flavus</i>	Food flavor
Muscarine	<i>Clitocybe rivalosa</i>	Pharmaceutical
Patulin	<i>Penicillium urticae</i>	Anti-microbial agent

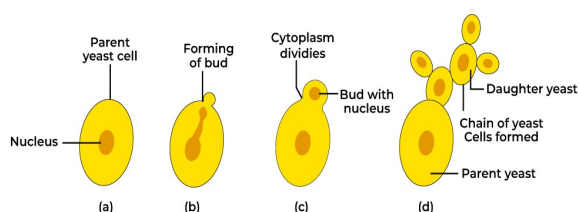
Bacterial Growth

Growth can be defined as an increase in cellular constituents, it results in an increase in the number of cells when MOs multiply by fission or budding. In this case the cells enlarge and divide to give two daughter cells of relatively equal size.

Growth also occurs when the cells simply become longer or larger



Budding in Yeast



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Methods for Measuring Bacterial Growth

Method	Characteristics and Limitations
Direct Cell Counts	Used to determine total number of cells; can be used for those bacteria that cannot be cultured.
Direct microscopic count	Rapid, but at least 10^7 cells/ml must be present to be effectively counted. Counts include living and dead cells.
Cell-counting instruments	Coulter counters and flow cytometers count total cells in dilute solutions. Flow cytometers can also be used to count organisms to which fluorescent dyes or tags have been attached.
Viable Cell Counts	Used to determine the number of viable bacteria in a sample, but only includes those that can grow in given conditions. Requires an incubation period of approximately 24 hours or longer. Selective and differential media can be used to enumerate specific species of bacteria.
Plate count	Time-consuming but technically simple method that does not require sophisticated equipment. Generally used only if the sample has at least 10^2 cells/ml.
Membrane filtration	Concentrates bacteria by filtration before they are plated; thus can be used to count cells in dilute environments.
Most probable number	Statistical estimation of likely cell number; it is not a precise measurement. Can be used to estimate numbers of bacteria in relatively dilute solutions.
Measuring Biomass	Biomass can be correlated to cell number.
Turbidity	Very rapid method; used routinely. A one-time correlation with plate counts is required in order to use turbidity for determining cell number.
Total weight	Tedious and time-consuming; however, it is one of the best methods for measuring the growth of filamentous microorganisms.
Chemical constituents	Uses chemical means to determine the amount of a given element, usually nitrogen. Not routinely used.
Measuring Cell Products	Methods are rapid but must be correlated to cell number. Frequently used to detect growth, but not routinely used for quantitation.
Acid	Titration can be used to quantify acid production. A pH indicator is often used to detect growth.
Gases	Carbon dioxide can be detected by using a molecule that fluoresces when the medium becomes slightly more acidic. Gases can be trapped in an inverted Durham tube in a tube of broth.
ATP	Firefly luciferase catalyzes light-emitting reaction when ATP is present.

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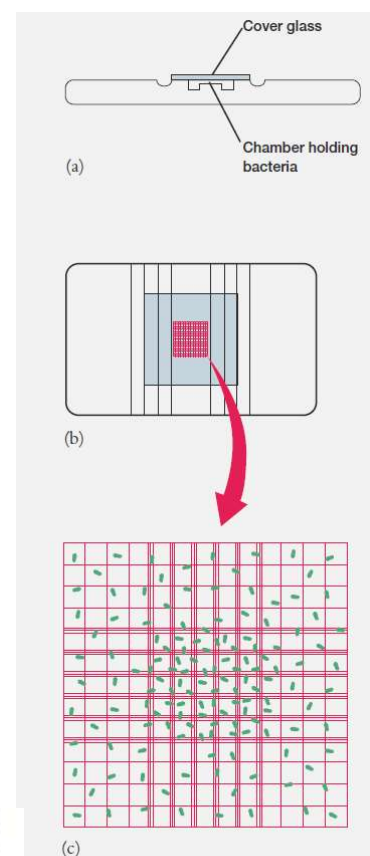
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Counting chambers:

Hemocytometer

Malassez counting chamber

Petrof-Hauser counting chamber



$$\text{bacteria/cm}^3 = (28 \text{ bacteria}) (25 \text{ squares}) (50) (10^3) = 3.5 \times 10^7$$

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The Petroff-Hauser Counting Chamber.

Coulter counter

This device counts automatically particles or cells suspended in an electrolyte solution:

It is a cylindrical tube perforated with a micro-orifice on either side of which are placed two electrodes connected to an electric current generator.

When a cell passes through the orifice, it displaces a volume of the conductive solution which is equal to its own volume, producing a momentary increase in resistance. Above a certain threshold, this resistance results in a pulse which is recorded by an electric meter.

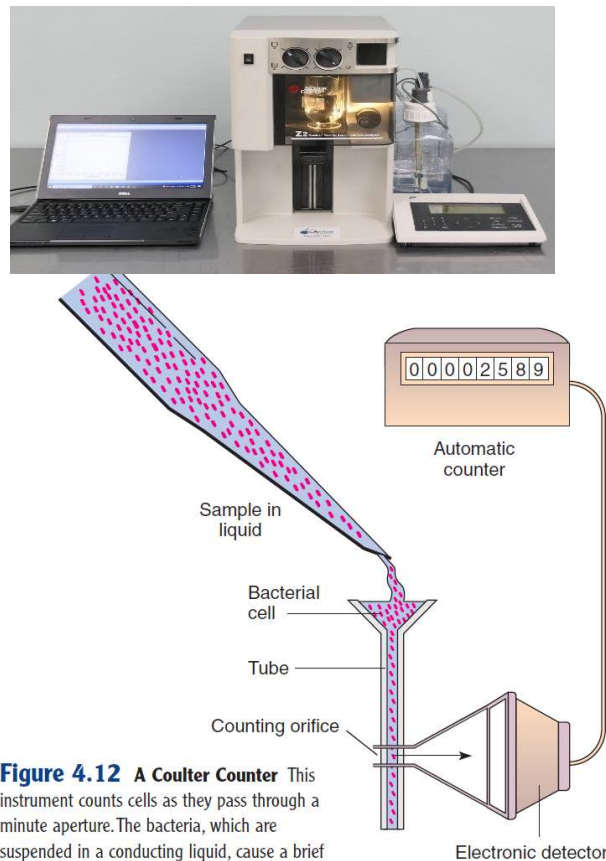


Figure 4.12 A Coulter Counter This instrument counts cells as they pass through a minute aperture. The bacteria, which are suspended in a conducting liquid, cause a brief change in resistance as they pass by the counter.

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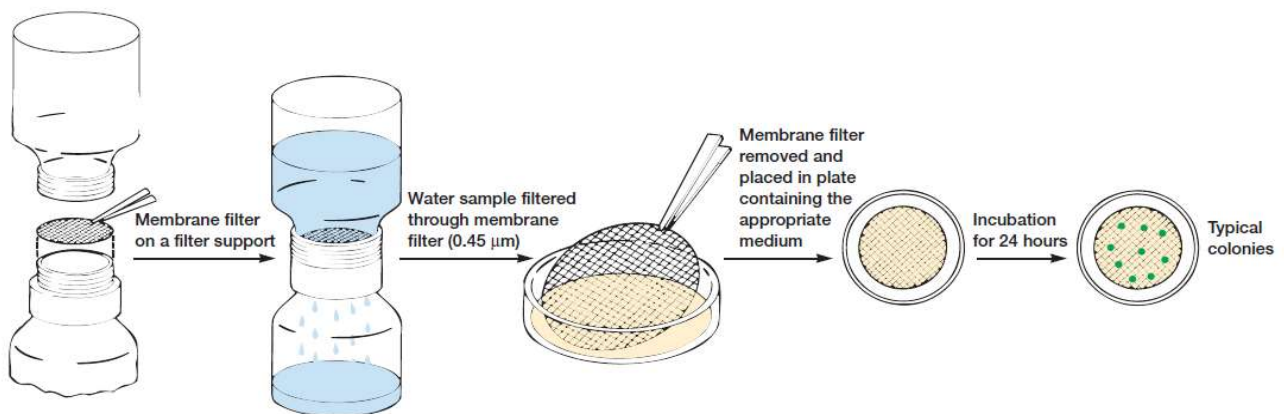
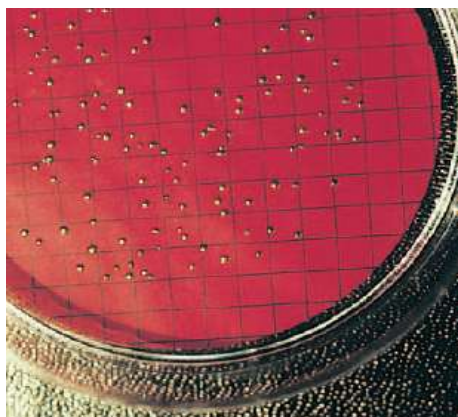


Figure 6.6 The Membrane Filtration Procedure. Membranes with different pore sizes are used to trap different microorganisms. Incubation times for membranes also vary with the medium and microorganism.



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a)

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2 µm

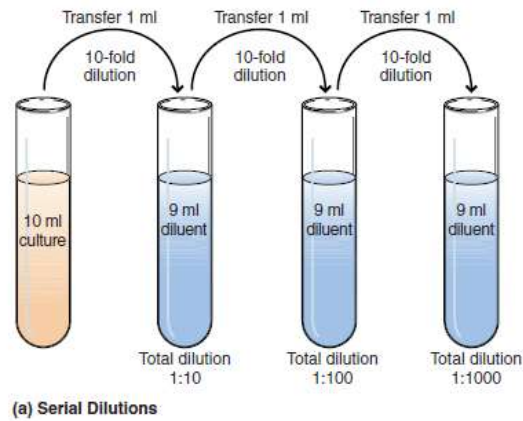
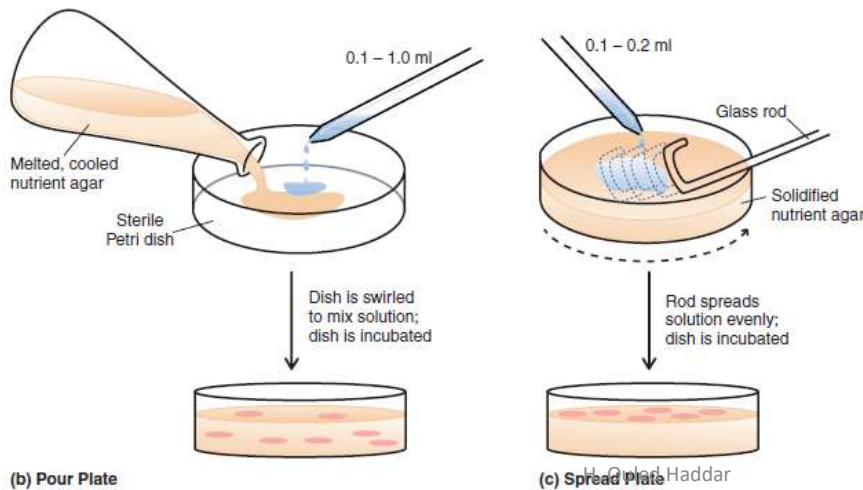


Figure 4.13 Plate Counts (a) A sample is first diluted in 10-fold increments. (b) In the pour-plate method, 0.1–1.0 ml of a dilution is transferred to a sterile Petri dish and overlaid with melted, cooled nutrient agar. When the agar hardens, the plate is incubated and distinguishable colonies form on the surface and within the agar. (c) In the spread-plate method, 0.1–0.2 ml of a dilution is spread on a hardened agar plate with a sterile glass rod. After incubation, distinguishable colonies form only on the surface of the agar.



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Determination of dry weight

Microorganisms are harvested by centrifugation or by membrane filtration (generally porosity of 1 to 5 μm).

Washed carefully using an appropriate buffer (NaCl 0.9%)

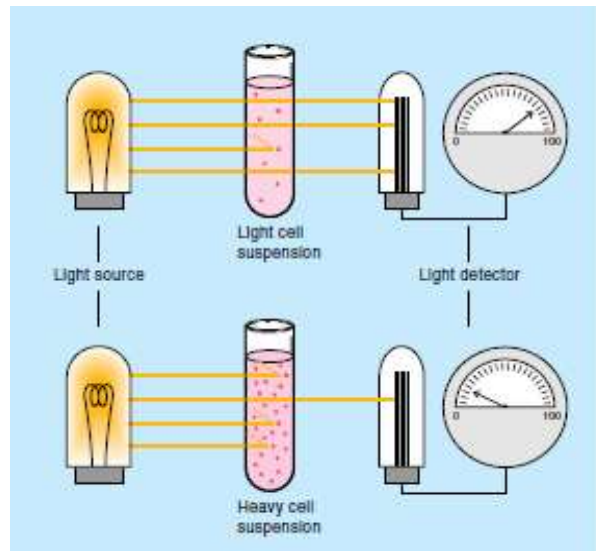
The pellet or filter is dried at 100–110°C

After cooling, it is weighed.

The weight is expressed in g of DM/L



(a)



(b)

Figure 4.16 Measuring Turbidity with a Spectrophotometer (a) The cloudiness, or turbidity, of the liquid in the tube on the left is proportional to the concentration of cells. (b) The percentage of light that reaches the detector is inversely proportional to the optical density. To use turbidity to estimate cell number, a one-time experiment must be done to determine the correlation between cell concentration and optical density of a culture.

Turbidity measurement

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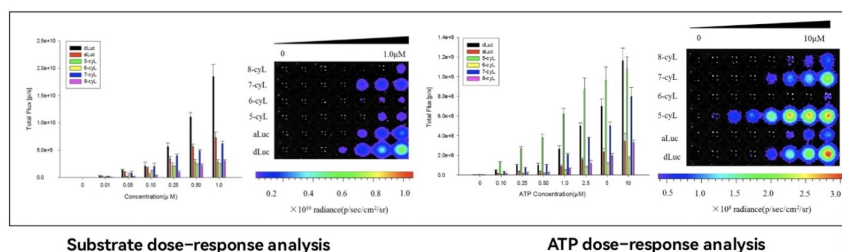
Measurement of cellular constituents and products

- Cellular nitrogen (Kjeldal or Bradford)



- ATP, FAD, FMN (bioluminescence)

In Vitro Bioluminescence Assay



Substrate dose-response analysis

ATP dose-response analysis

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The growth curve

When MOs are cultured in a liquid medium, they usually grow in a closed medium called “**batch culture**” or “**discontinuous**”, they are incubated in a closed flask containing a single lot (batch) of medium.

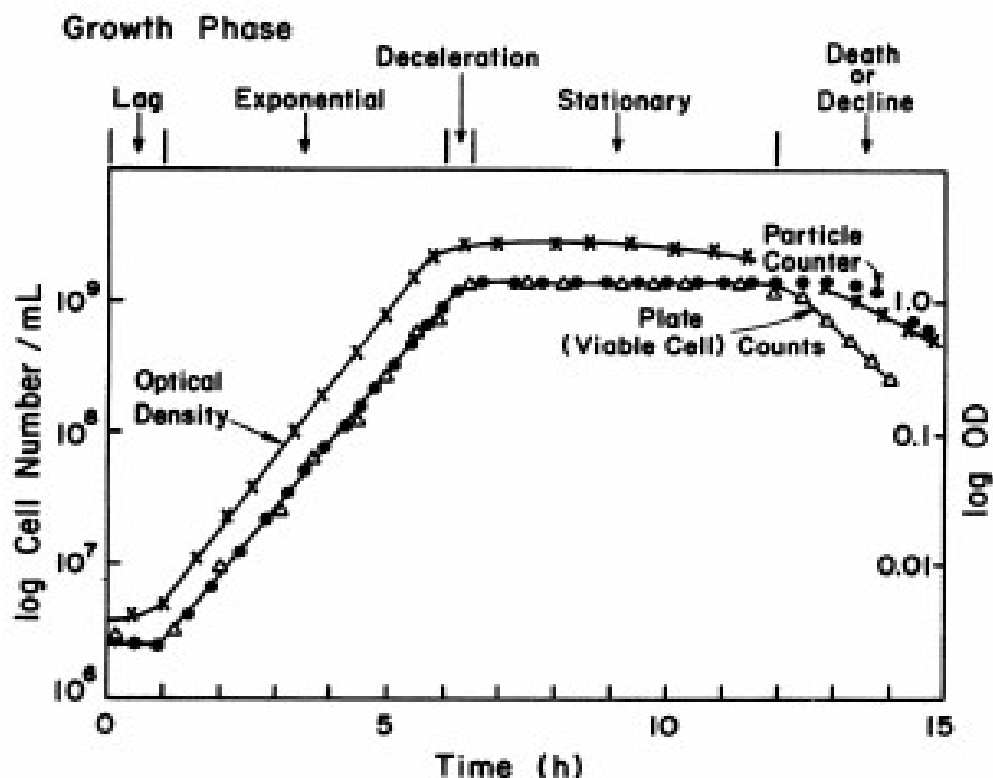
Since there is no supply of fresh medium during incubation, the quantity of nutrients decreases and the concentration of waste increases.

Growth is graphed as the log of cell number versus incubation time

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Bacterial growth is a dynamic phenomenon that has six phases represented schematically in the following figure.

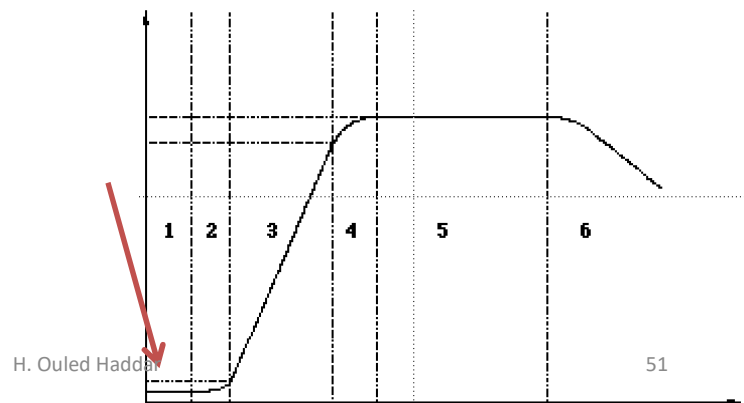


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Phase 1: latent phase (lag phase): Growth rate is null, bacteria become adapted to the environment and started synthesis of new cellular components necessary for growth.

This phase is important for different reasons:

1. The cells can be old and devoid of ATP, cofactors, ribosomes, etc.
2. The environment may be different from that in which the MO previously grew (they will need to synthesize new enzymes).
3. MOs can be damaged, so they require repair time



- The duration of this phase varies:
- **Long**, if the inoculum comes from an aged or cooled culture, or if the medium has a different composition from that of the inoculum preparation medium
- **Short**, when a young culture in the growth phase is transferred to a medium of the same composition

$$N_t = N_0$$

$$\text{growth rate } \mu = 0$$

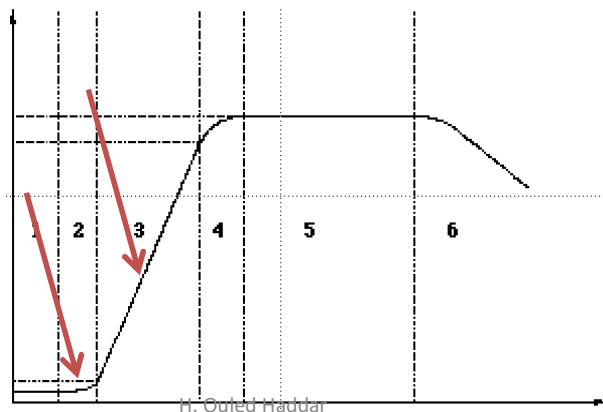
Phase 2: acceleration phase here there is an increase in growth velocity,

Phase 3: exponential growth phase:

Cell division time is short

Growth rate is constant and maximum $\mu = \max$

The population is almost uniform (Same biochemical and physiological properties)



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Main parameters of growth action

- The temperature

Three types of growth curves exist: Mesophilic, thermophilic and psychrophilic

MO	Temperature (° C)	μ (h ⁻¹)	generation time (h)
<i>E. coli</i>	40	3.3	0.21
	18	0.5	1.38
<i>Bacillus subtilis</i>	40	1.6	0.43
<i>Clostridium botulinum</i>	37	1.19	0.58
<i>Mycobacterium tuberculosis</i>	37	0.057	12
<i>Rhodospirillum rubrum</i>	25	0.15-0.13	4.6-5.3
<i>S. cerevisiae</i>	30	0.35	2

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- The pH

Species	minimal pH	optimal pH	maximmal pH
<i>Bacillus</i>	5-6	6.8-7.5	9.5-11
<i>Clostridium perfringens</i>	5.5	6-7.6	8.5
<i>E. coli</i>	4.3	6-8	9
<i>Lactobacillus</i>	4-4.5	5.5-6	7
Yeasts	1.5-3.5	4-6.5	8-8.5
Molds	1.5-3.5	4.5-6.8	8-11
<i>Thiobacillus</i>	0	3-5	7

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- The Aw

When Aw decreases, the growth slows down.

- The substrate

The specific growth rate of a bacterial species depends closely on the environment in which it is cultivated.

for *E. coli*:

Medium	μ
Synthetic citrated medium	0.3
Nutrient broth	2

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The growth mathematics

N_0 = The initial number of cells

N_t = The population at time t

n = the number of generations in time t

Time	Number of divisions	2^n	population ($N_0 \times 2^n$)	$\log N_t$
0	0	1	1	0.00
20	1	2	2	0.301
40	2	4	4	0.602
60	3	8	8	0.903
80	4	16	16	1.204
100	5	32	32	1.505
120	6	64	64	1.806

The growth rate of a batch culture can be expressed in terms of the average growth rate constant (k or μ) = the number of generations per unit time (h)

$$\mu = \frac{n}{t} = \frac{\log N_t - \log N_0}{\log 2 \times t} \quad \text{with } N_t = 2N_0$$

Average generation time = cell division time

$$g = \frac{1}{\mu}$$

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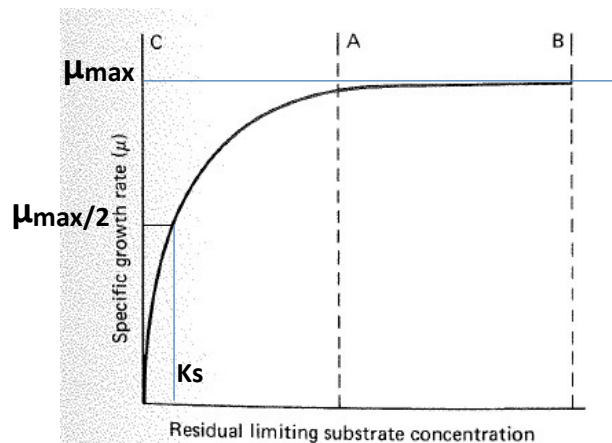


FIG. 2.3. The effect of residual limiting substrate concentration on the specific growth rate of a hypothetical bacterium.

$$\mu = \mu_{\max} s / (K_s + s)$$

$\mu_{\max}$: maximum specific growth rate (rate) (h^{-1})

S : substrate concentration

K_s : Monod's constant

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Table 6.1

Approximate generation times for several organisms growing in media optimal for growth.

Species	Generation Time
<i>Escherichia coli</i>	20 min
<i>Bacillus subtilis</i>	28 min
<i>Staphylococcus aureus</i>	30 min
<i>Pseudomonas aeruginosa</i>	35 min
<i>Thermus aquaticus</i>	50 min
<i>Thermoproteus tenax</i>	1 hr 40min
<i>Rhodobacter sphaeroides</i>	2 hr 20 min
<i>Sulfolobus acidocaldarius</i>	4 hr
<i>Thermoleophilum album</i>	6 hr
<i>Thermophilum pendens</i>	10 hr
<i>Mycobacterium tuberculosis</i>	13 hr 20 min

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Phase 4 : deceleration phase: the growth rate decreases, there is depletion of nutrients from the culture medium and accumulation of wastes,

Phase 5 : stationary phase:

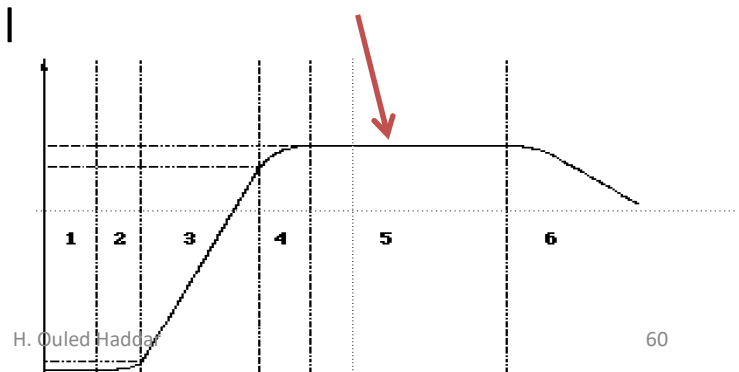
The reproduction stops due to a limiting factor in the environment (oxygen, source of C, etc.), or the accumulation of toxic waste (lactic acid, etc.)

the growth rate is null

the division rate equals the autolysis rate,

Bacteria reach 10^9 Cells/ml

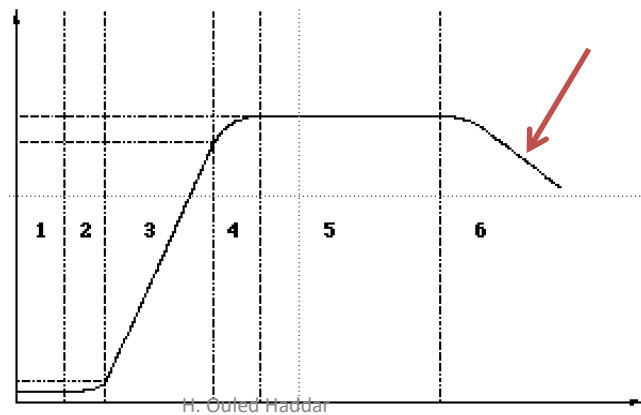
Algae 10^6 Cells/ml



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Phase 6 : decline phase: resources are depleted, waste accumulates and the number of bacteria decreases, this phase is complex, in some cases, and during a drastic reduction in the population, the mortality rate increases giving rise to a survival of some resistant cells.



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Diauxic growth

In a synthetic medium containing a mixture of two carbon substrates, an abnormal two-phase curve is observed as if two growths were succeeding one another. This phenomenon is described by Monod under the name **diauxie**.

G1: glucose, sucrose, fructose, mannose

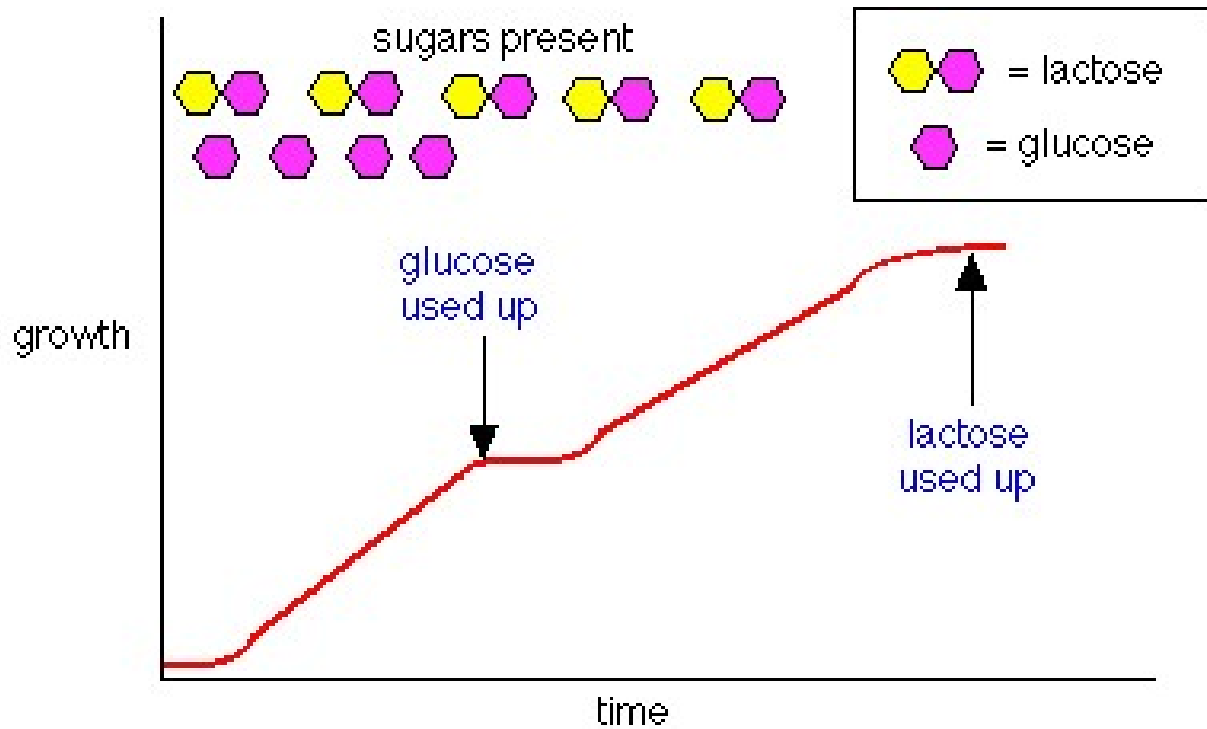
G2: maltose, sorbitol, arabinose, inositol

Only G1+G2 mixtures will give a diauxie phenomenon.

Triauxia phenomena have been also described, particularly with the glucose-glycerol-sorbitol mixture.

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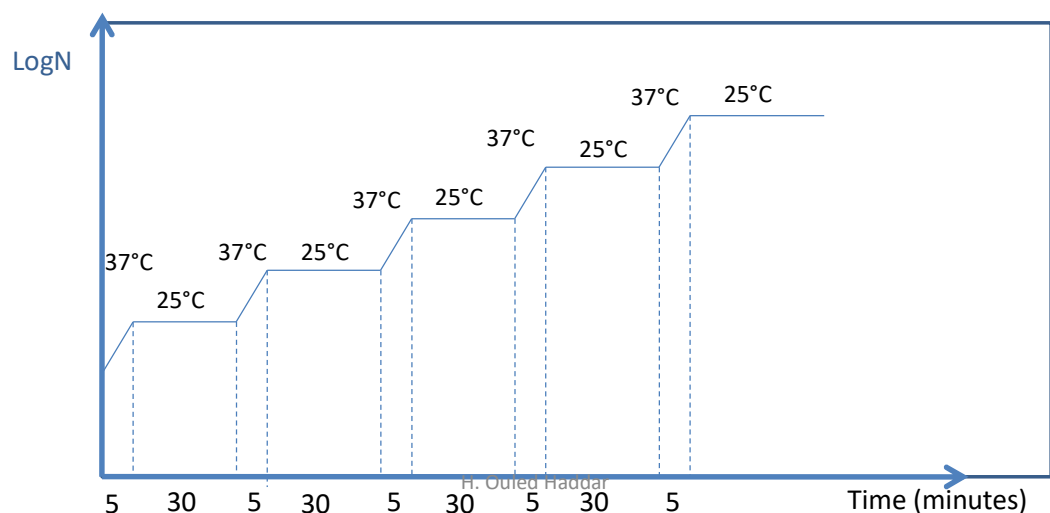


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Synchronous growth

- By selective filtration
- By thermal shock (shift up/shift down)
- Starvation



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