AN OVERVIEW OF BACTERIAL METABOLISM

Growth Requirements: Cells need genetic information as well as raw materials (macro- & micro-nutrients), and must generate energy and reducing power as well as manufacturing cellular components.

a) Coding Capacity. *E. coli* has sufficient DNA to code for about 3000 genes. Roughly 1500 of these have been identified and somewhat over 1000 different proteins have been observed by 2 dimensional gel electrophoresis. About 2000 different metabolic reactions are known.

b) Macronutrients: C, H, O, N, S, P. The last three are often taken up as ammonia, sulfate and phosphate respectively.

c) Micronutrients: Inorganic ions. Potassium and magnesium are found in all cells. In contrast sodium and calcium are required by eukaryotes but not by most bacteria which in fact usually excrete them. The following trace elements are found in certain enzymes and cofactors:

Iron (Fe)	Cytochromes & other heme enzymes, Iron-sulfur proteins, FeMo cofactor, some ADH's
Zinc (Zn)	Many enzymes of nucleic acid metabolism, Alcohol dehydrogenase, Structural in cell envelope
Manganese (Mn)	Several enzymes, Photosynthesis
Copper (Cu)	Cytochrome oxidase, Plastocyanin
Cobalt (Co)	Vitamin B12
Nickel (Ni)	Methanogenesis, Hydrogenase
Selenium (Se)	Formate dehydrogenase
Molybdenum (Mo)	Nitrate reductase, Nitrogenase
Vanadium (V)	Alternative N-fixation systems
Tungsten (W)	Replaces Mo in certain organisms

Composition of a Typical Bacterial Cell

Bacteria are about 70% water. The other 30% - the dry weight - consists of:

Molecule	% Dry weight	Constituents
Protein	55	amino acids
Polysaccharide	9-10	sugars
Lipid	9	fatty acids, glycerol, phosphate
RNA	20	purines, pyrimidines, phosphate,
DNA	3	and pentoses
Small molecules	3-4	low molecular weight solutes and inorganic ions

Overall Macromolecular Composition of an Average *E. coli* Cell

Macromolecule	% of dry weight	Weight/cell x 10^{-15}g	Molecular weight	Number per cell	Different kinds of molecule
Protein	55.0	155.0	4.0×10^4	2,360,000	1050
RNA	20.5	59.0			
23 S rRNA		31.0	1.0×10^6	18,700	1
16 S rRNA		16.0	5.0×10^5	18,700	1
5 S rRNA		1.0	3.9×10^4	18,700	1
transfer		8.6	2.5×10^4	205,000	60
messenger		2.4	1.0×10^9	1,380	400
DNA	3.1	9.0	2.5×10^9	2	1
Lipid	9.1	26.0	705	22,000,000	4
Lipopolysaccharide	3.4	10.0	4346	1,200,000	1
Peptidoglycan	2.5	7.0	(904)	1	1
Glycogen	2.5	7.0	1.0×10^6	4,360	1
Total macromolecules Soluble pool	96.1 2.9	273.0 8.0			
building blocks		7.0			
metabolites, vitamins		1.0			
Inorganic ions	1.0	3.0			
Total dry weight	100.0	284.0			

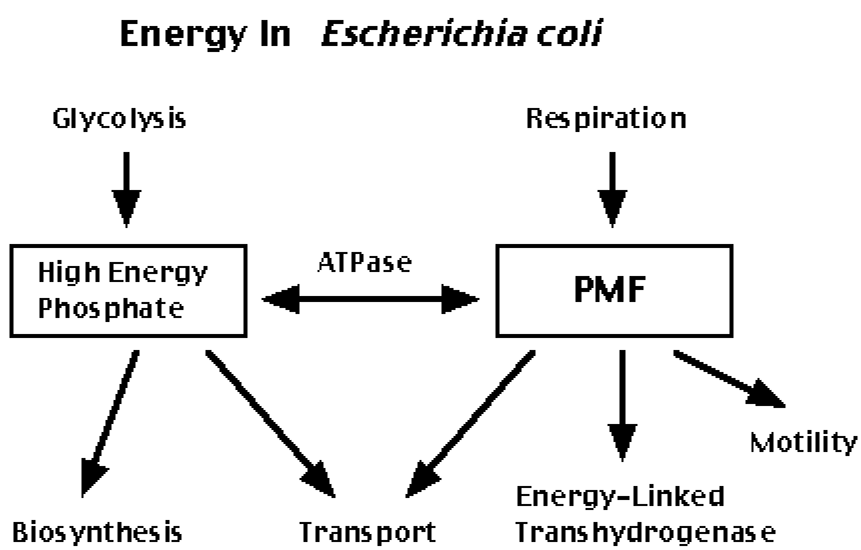
Total dry weight/cell		2.8×10^{-13}g
Water at 70% of cell		6.5×10^{-13}g
Total weight of one cell		9.3×10^{-13}g

*Remember: 10^{-3} gram = milligram, 10^{-6} gram = microgram, 10^{-9} gram = nanogram, 10^{-12} gram = picogram, 10^{-15} gram = femtogram

Strategy of Metabolism

1) Organisms convert raw materials into living matter by using energy from their environment. Chemotrophs oxidize chemical fuel molecules to release useful energy. Phototrophs use sunlight as an energy source. These two classes of organism depend on each other. Phototrophs produce organic material which is the food for chemotrophs. They also produce oxygen which is necessary for the oxidation of food molecules by chemotrophs. The chemotrophs break down organic materials so releasing carbon-dioxide which the phototrophs use during photosynthesis.

2) Biological energy is obtained from redox reactions. Chemotrophic bacteria oxidize organic molecules such as sugars or fatty acids in order to derive energy.



3) The free energy released by redox reactions is conserved either by high energy carrier molecules such as adenosine triphosphate (ATP) or as an energized state of the membrane - the Proton Motive Force (PMF). ATP and the PMF are interconvertible.

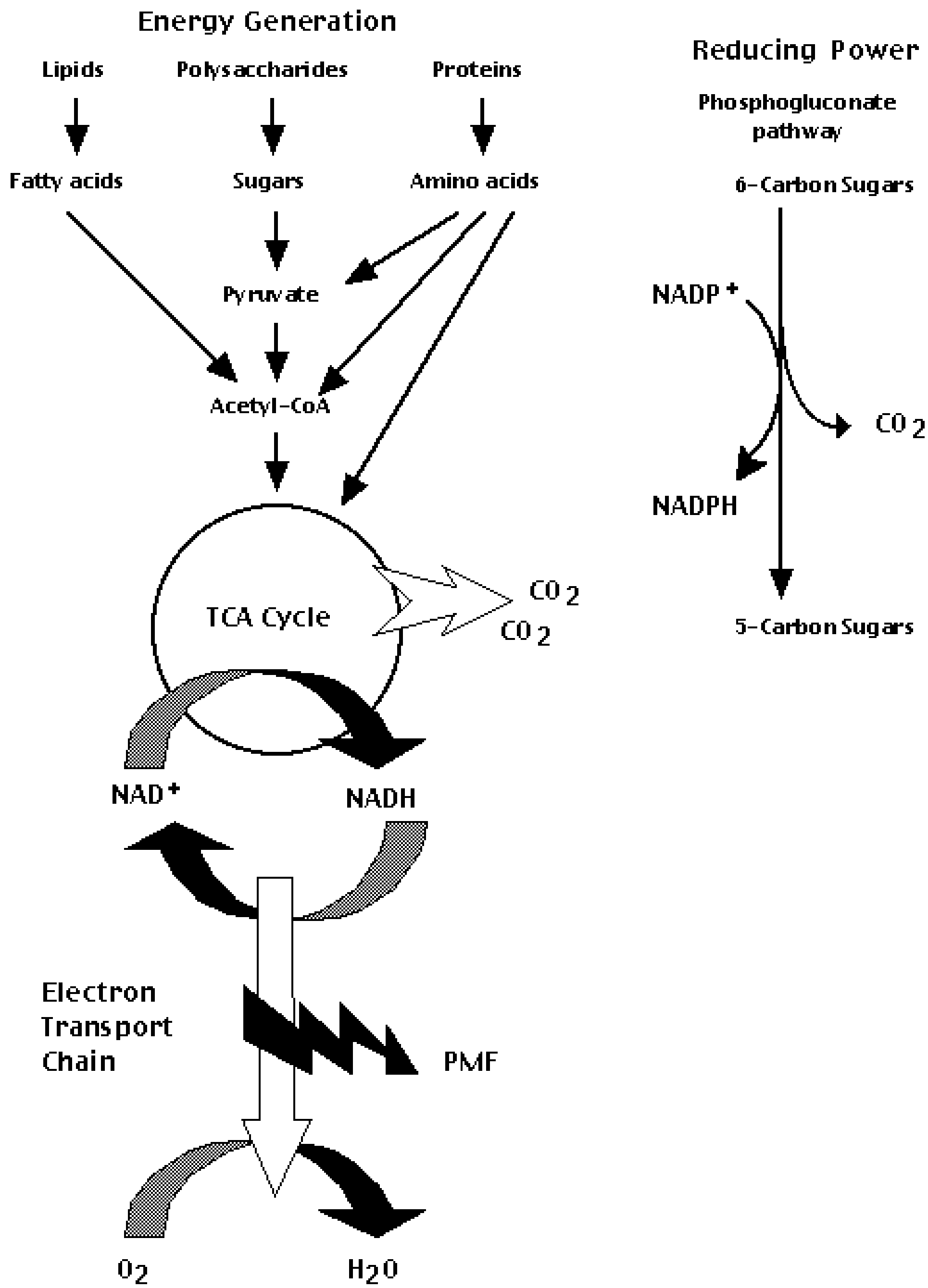
4) Biosynthesis requires reducing power as well as energy. The reducing power is required for the synthesis of many biomolecules as they are often highly reduced. NADH

and NADPH are the universal carriers of reducing power. Reduced NADH is usually oxidized to give energy whereas reduced NADPH is used for reducing power in biosynthetic reactions. In *E. coli* about 80% of the glucose goes down the main, energy yielding pathways and about 20% down the side pathways which generate reducing power as NADPH.

5) Outline of catabolic pathways (see diagram). Energy Metabolism is sometimes divided into four stages:

Stage I	Breakdown of polymers to monomers. Most bacteria cannot take in polymers and require small molecules - i.e. sugars, fatty acids or amino acids.
Stage II	Conversion of monomers to central intermediates - in particular pyruvate and acetyl-CoA. Amino acids are normally only degraded if no sugars or fatty acids are available.
Stage III	a) Conversion of acetyl-CoA to CO2 by Kreb's cycle
	b) Production of reduced NADH by Kreb's cycle
Stage IV	a) Oxidation of NADH by electron transport chain to give PMF
	b) Interconversion of PMF and ATP
In addition we need:	a) Generation of reducing power (NADPH) by side pathways
	b) Anaplerotic pathways to replace essential intermediates consumed in biosynthesis (not shown in diagram)

Note that in the absence of oxygen cells cannot perform respiration so instead pyruvate and acetyl-CoA are converted to fermentation products. ATP is produced from glycolysis alone. (Some bacteria - but not higher organisms - can use alternative oxidising agents to respire anaerobically - discussed later.)


Energy Generation
Lipids
Polysaccharides
Proteins
Fatty acids
Sugars
Amino acids
Pyruvate
Acetyl-CoA
TCA Cycle
CO_2
CO_2
NAD^+
NADH
Electron Transport Chain
PMF
O_2
H_2O
Reducing Power
Phosphogluconate pathway
6-Carbon Sugars
$NADP^+$
CO_2
NADPH
5-Carbon Sugars