BBS2710 Microbial Physiology

Module 5 - Energy and Metabolism

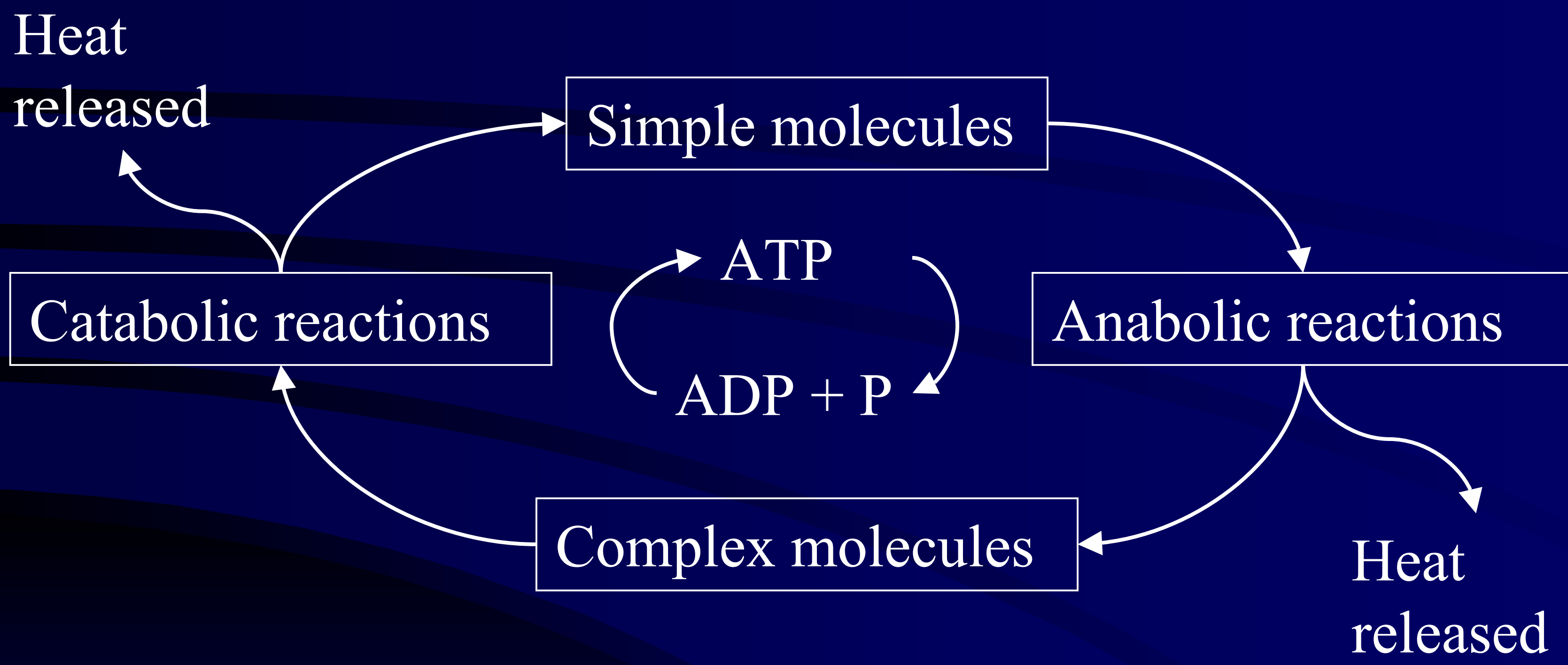
Topics

- Energy production - an overview
- Fermentation
- Aerobic respiration
- Alternative approaches to respiration
- Photosynthesis
- Summary

Introduction

- Microbial cells built from a wide variety of chemical substances
- when a cell grows - all constituents increase in amount
- basic chemical constituents come from the environment (nutrients)
- biosynthesis (anabolism) in an energy requiring process
- energy obtained from two sources - chemicals and light
- most microorganisms obtain energy from oxidation of chemical compounds (catabolism)
- metabolism is the combination of anabolic and catabolic processes

Overview


Heat
released
Simple molecules
ATP
Catabolic reactions
Anabolic reactions
ADP + P
Complex molecules
Heat
released

Oxidation and Reduction

- Oxidation and reduction important in energy and metabolism
- Oxidation - removal of electrons from an atom or molecule - energy released
- Reduction - addition of electrons
- frequently whole hydrogen atoms are transferred
- reactions are usually coupled (Redox) and require an electron donor and electron acceptor
- different substances have different reduction potentials - the greater the difference in reductions potentials the more energy is released

Electron Carriers

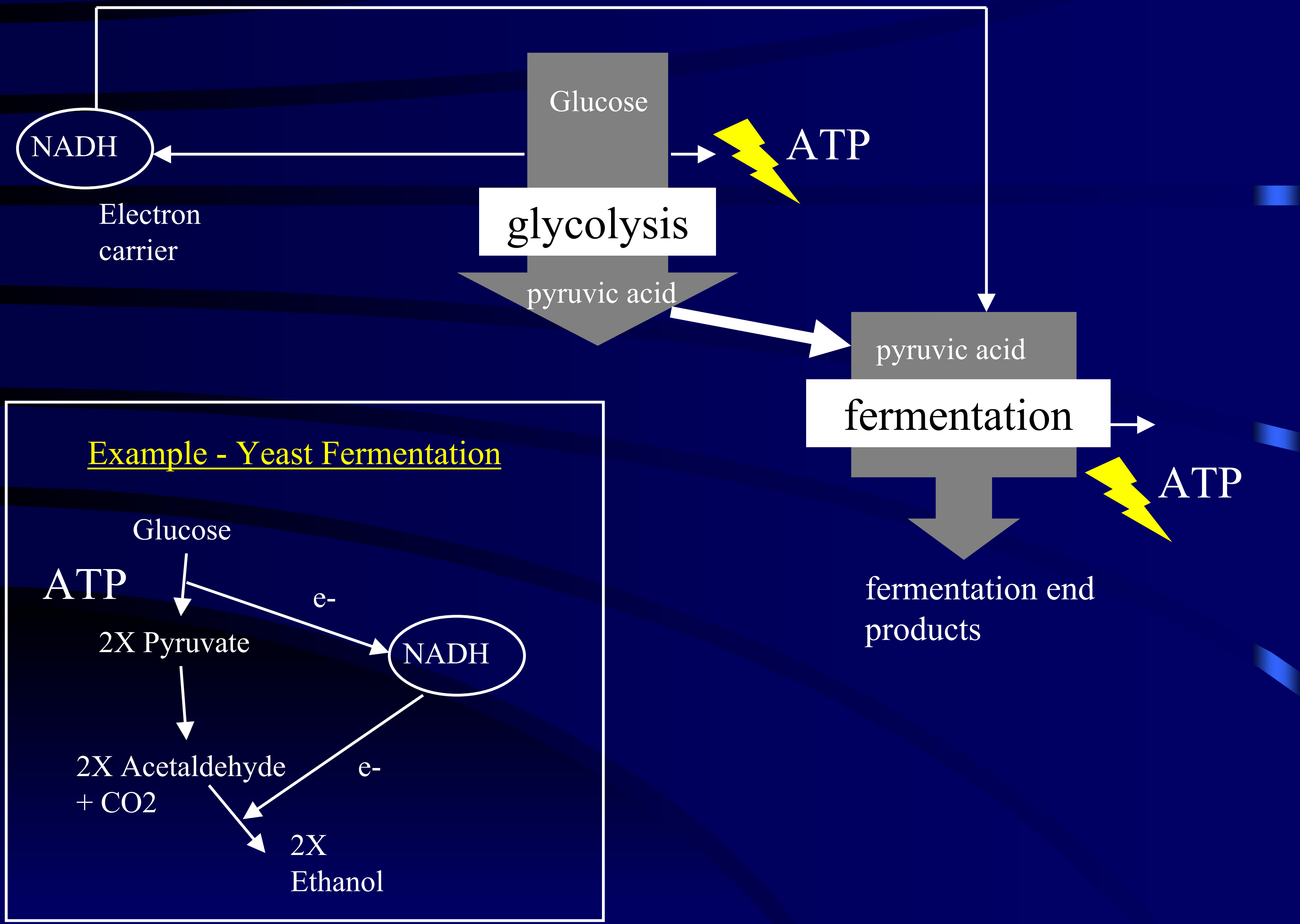
- O-R reactions often involve transfer of electrons through an intermediate
- some are freely diffusible eg. NAD+, NADP+
- others are fixed in the cytoplasmic membrane eg. Electron transport chain
- three stages to most cellular O-R processes -
- 1) removal of electrons from primary donor
- 2) transfer of electrons through electron carriers
- 3) addition of electrons to terminal acceptor

ATP

- Energy from oxidation-reduction reactions must be conserved to be useful in biosynthesis
- most energy generating O-R reactions linked directly or indirectly to ATP synthesis
- ATP is the primary energy carrier in living organisms
- high energy phosphate bonds provide an easily exploited energy source
- ATP synthesised by two major pathways - fermentation and respiration

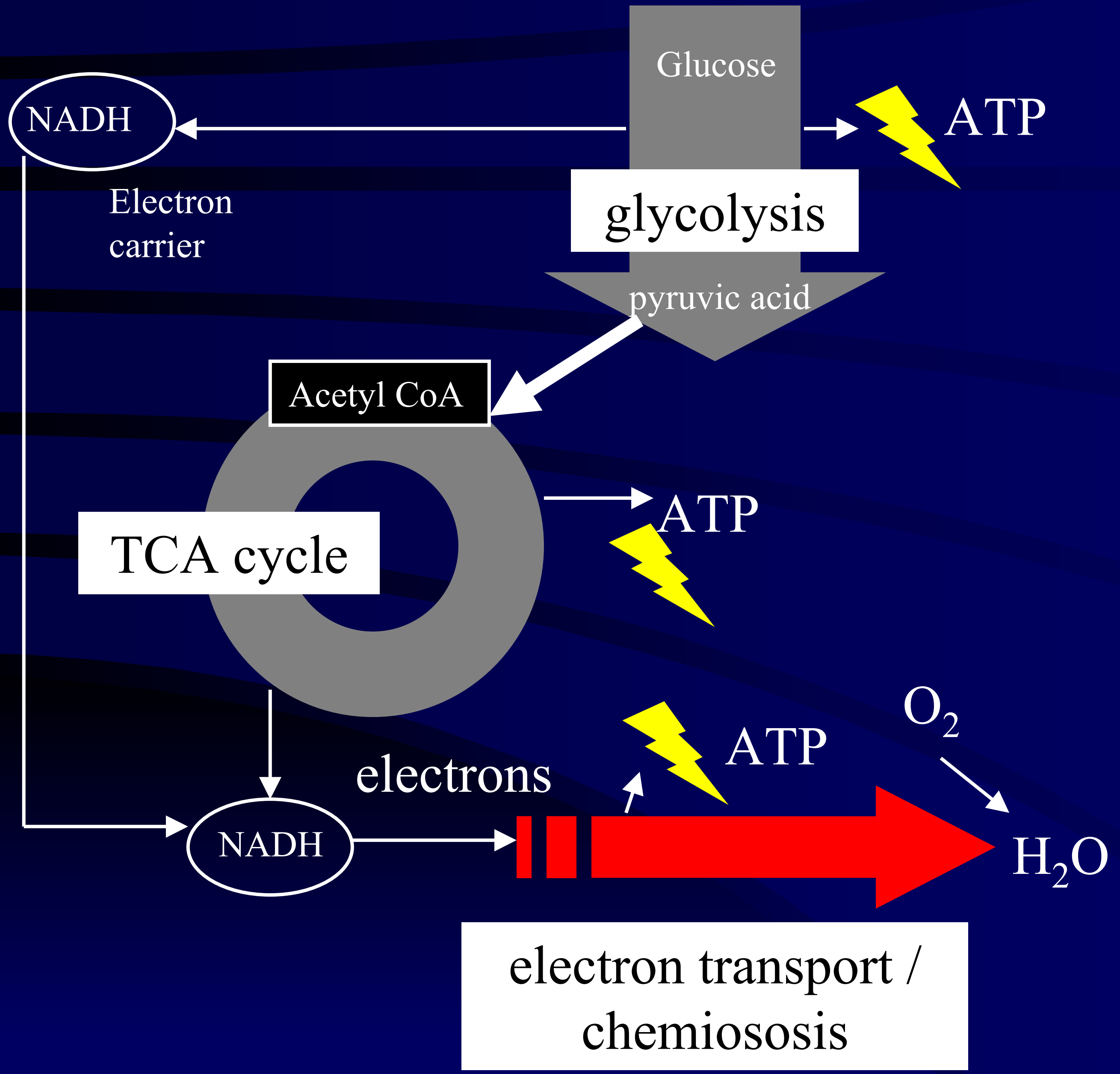
Fermentation

- Internally balanced O-R reactions of organic compounds with energy release
- no externally supplied final electron acceptor
- only partial oxidation of electron donor carbon atoms occurs - only a small amount of potential energy available is actually released
- ATP produced by substrate level phosphorylation (direct ATP synthesis during enzymatic steps of catalysis)
- ATP and reduced electron carriers produced by glycolysis
- electrons in carriers transferred to glycolysis catabolite to produce ATP and fermentation products (eg. ethanol)

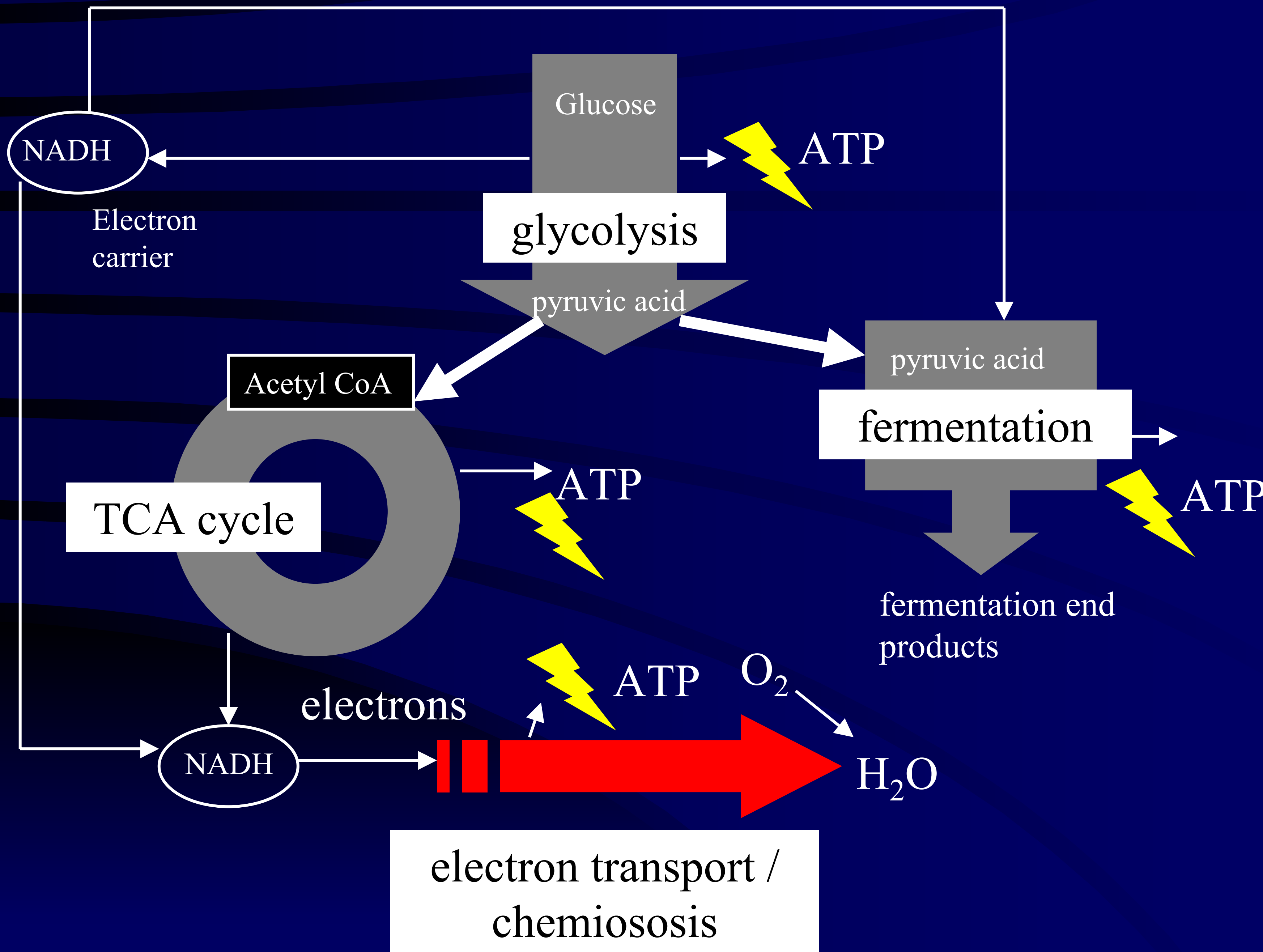

NADH
Electron
carrier
Glucose
ATP
glycolysis
pyruvic acid
pyruvic acid
fermentation
ATP
fermentation end
products
Example - Yeast Fermentation
Glucose
ATP
e-
2X Pyruvate
NADH
2X Acetaldehyde
+ CO2
e-
2X
Ethanol

Respiration

- If an external electron acceptor is used (eg. O_2) all substrate molecules can be oxidised completely to CO_2
- far higher yield of energy is possible
- ATP synthesis in aerobic respiration is performed by both substrate level phosphorylation and chemiosmosis
- reduced electron carriers and ATP generated by glycolysis and TCA cycle
- ATP generated by transfer of electrons along the electron transport chain linked to chemiosmosis



Glucose
ATP
NADH
Electron carrier
glycolysis
pyruvic acid
Acetyl CoA
TCA cycle
ATP
ATP
O_2
electrons
NADH
H_2O
electron transport / chemiosis

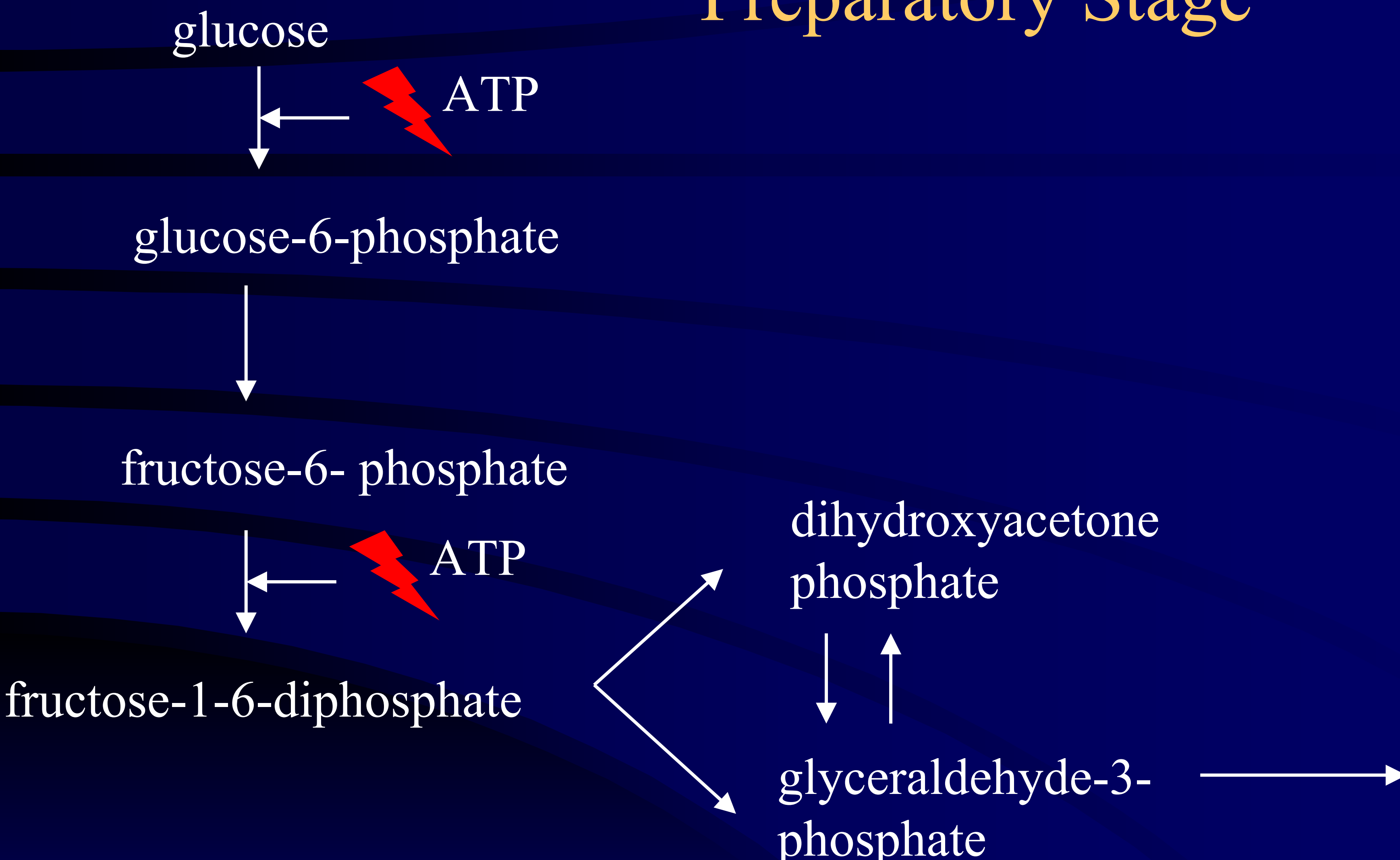


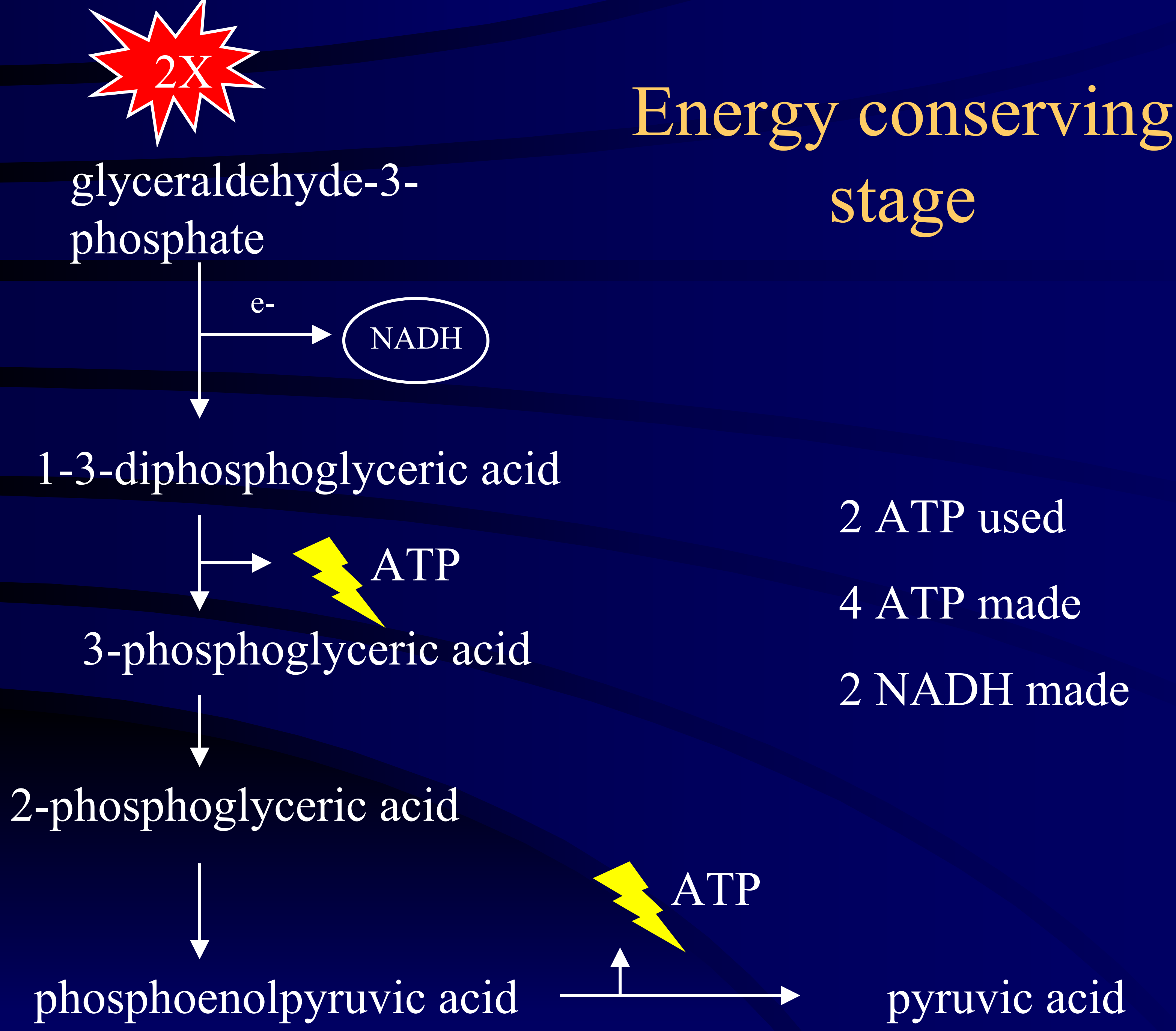
NADH
Electron carrier
Glucose
ATP
glycolysis
pyruvic acid
Acetyl CoA
pyruvic acid
fermentation
ATP
TCA cycle
ATP
fermentation end products
ATP
O_2
electrons
NADH
H_2O
electron transport / chemiososis

Glycolysis

- Embden-Meyerhof pathway
- Glucose (6 carbon) split into two 3 carbon sugars
- 3 carbon sugars oxidised to produce energy and rearranged to form 2 pyruvate molecules
- does not require oxygen (aerobic and anaerobic)
- all 10 steps catalysed by a different enzyme
- two stages - preparatory stage (ATP used), energy conserving stage (ATP, NADH produced)

Preparatory Stage

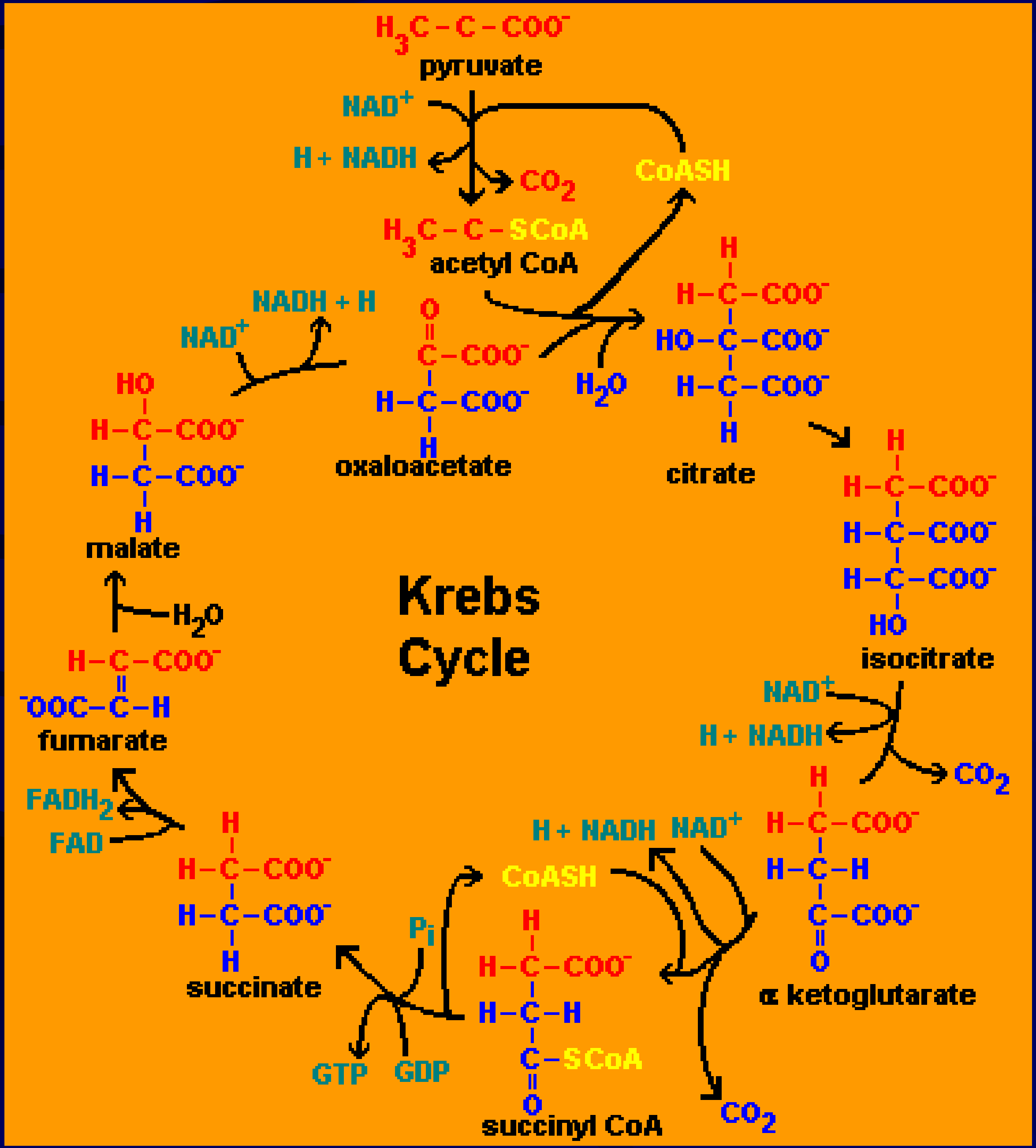




Energy conserving stage
2X
glyceraldehyde-3-phosphate
e-
NADH
1-3-diphosphoglyceric acid
ATP
3-phosphoglyceric acid
2-phosphoglyceric acid
phosphoenolpyruvic acid
ATP
pyruvic acid
2 ATP used
4 ATP made
2 NADH made

TCA Cycle

- two possible fates for pyruvate generated - fermentation or cellular respiration
- three components to aerobic respiration - TCA cycle, electron transport chain and chemiosmosis
- Acetyl-CoA produced from pyruvate
- TCA cycle - involves transfer of Acetyl-CoA electrons (energy) to coenzymes (eg. NAD+) by Redox reactions



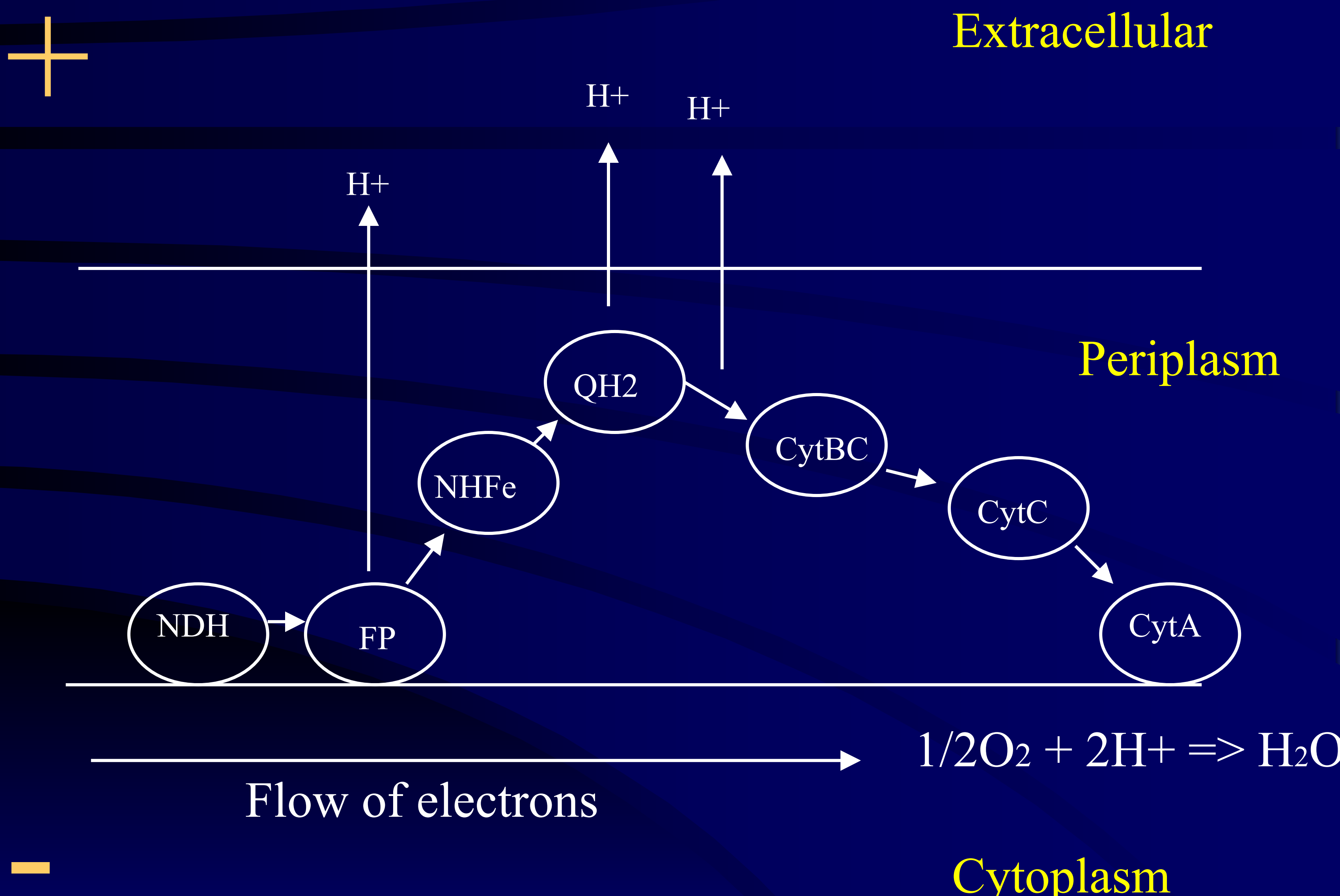
$H_3C-C-COO^-$
pyruvate
NAD^+
H + NADH
CO_2
CoASH
$H_3C-C-SCoA$
acetyl CoA
H_2O
citrate
oxaloacetate
NADH + H
NAD^+
malate
Krebs
Cycle
isocitrate
NAD^+
H + NADH
CO_2
H_2O
fumarate
$FADH_2$
FAD
succinate
H + NADH
NAD^+
CoASH
α ketoglutarate
P_i
GTP
GDP
succinyl CoA
CO_2

Electron transport chain

- Membrane associated electron carriers
- transfer electrons from free electrons carriers (eg. NADH) sequentially
- NADH dehydrogenase - flavoproteins - iron-sulfur proteins - cytochromes
- couple energy released to ATP synthesis via chemiosmosis

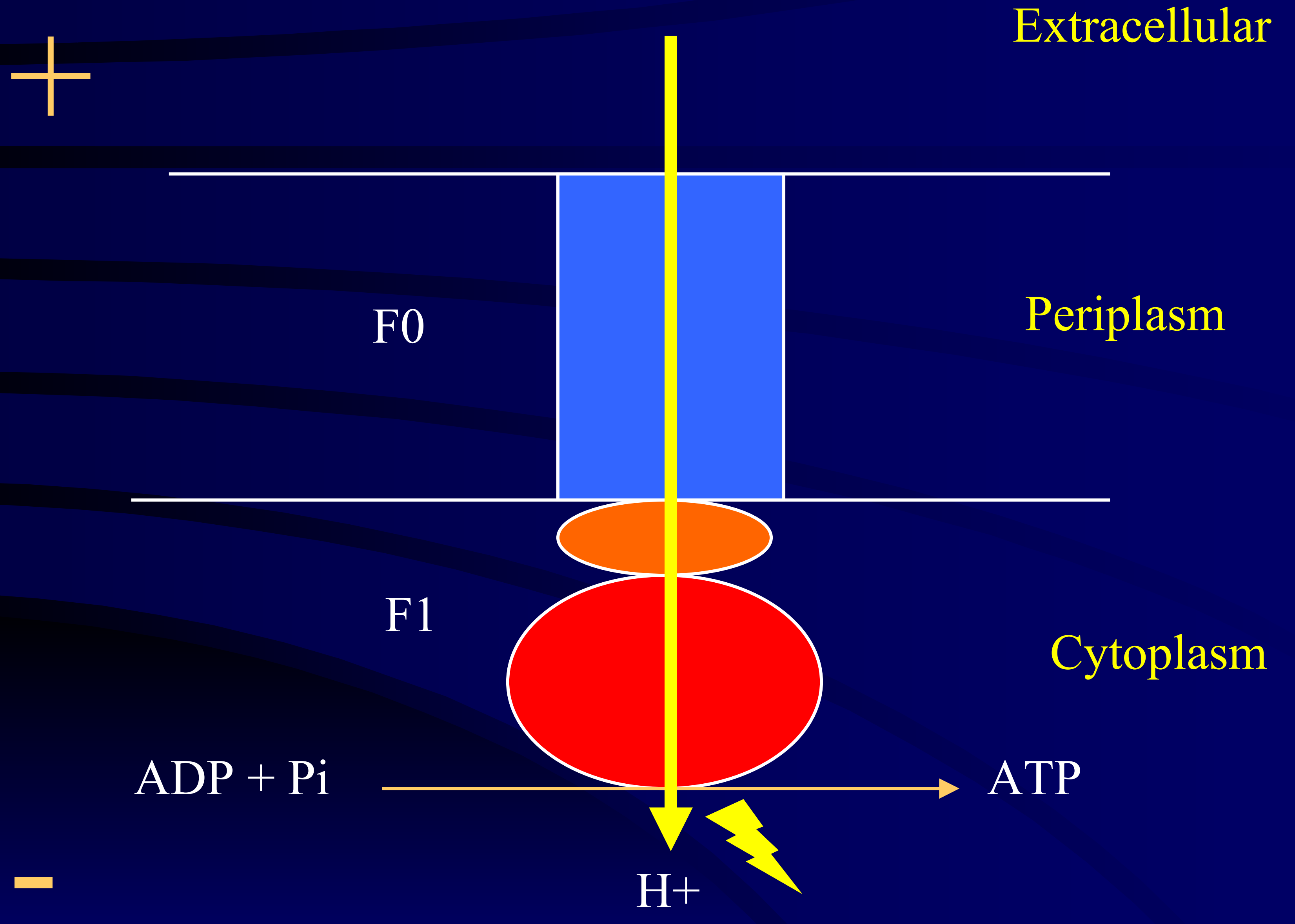
Chemiosmosis

- During electron transfer hydrogen atoms removed from electron carriers are separated into protons (H+) and electrons
- electrons are transferred to terminal electron acceptor (O_2) within the cell and H+ is extruded from the cell
- this generates a pH gradient across the cell membrane as H+ and OH- ions are not membrane diffusable
- known as the proton motive force
- movement of H+ ions back into the cytoplasm releases energy, this energy is used for ATP synthesis by ATPase


+
Extracellular
H+
H+
H+
Periplasm
QH2
NHFe
CytBC
CytC
NDH
FP
CytA
$1/2O_2 + 2H^+ \Rightarrow H_2O$
Flow of electrons
-
Cytoplasm

ATPase

- ATPase is a transmembrane protein
- it allows the controlled re-entry of H+ into the cell through a proton conducting channel
- a multi subunit cytoplasmic headpiece uses the energy released from H+ transfer to catalyse the ADP + P => ATP reaction (ATP synthesis)
- ATPases can also operate in the opposite direction - coupling ATP breakdown with the transfer of H+ outside of the cell


+
Extracellular
F0
Periplasm
F1
Cytoplasm
ADP + Pi
ATP
H+
-

Anaerobic respiration

- usually organic compounds as energy source
- alternative (usually inorganic) electron acceptors used eg. nitrate NO_3-, sulfate SO_4^{2-}, CO_2 (methanogens)
- generally possess typical electron transfer chains
- eg. sulfate reducing bacteria (Desulfovibrio, Desulfobacter)
- obligately anaerobic
- SO_4^{2-} reduced to H_2S
- must first be activated by a reaction with ATP (to form adenosine-5`-phosphosulfate)
- not very energetically efficient process
- electron donors include H_2, acetate, lactate

Alternative energy generation

- most fermentative, aerobic and anaerobic respiratory bacteria are chemoorganotrophs (use organic molecules as energy, electron and carbon source)
- chemolithotrophs use inorganic substrates as electron donors
- chemolithoautotrophs fix CO_2 for carbon
- chemolithoheterotrophs require organic molecules as a carbon source
- energy can be produced via photosynthesis (phototrophs)
- photolithotrophs use CO_2 as a carbon source
- photoheterotrophs require organic molecules as a carbon source

Microbial Metabolism

Physiological Type	Energy Source	Electron Source	Carbon Source
Chemolithotroph	Inorganic molecule	Inorganic molecule	Inorganic CO_2
Photolithotroph	Light	Inorganic molecule	Inorganic CO_2
Photoorganotroph	Light	Organic molecule	Organic molecule
Chemoorganotroph	Organic molecule	Organic molecule	Organic molecule

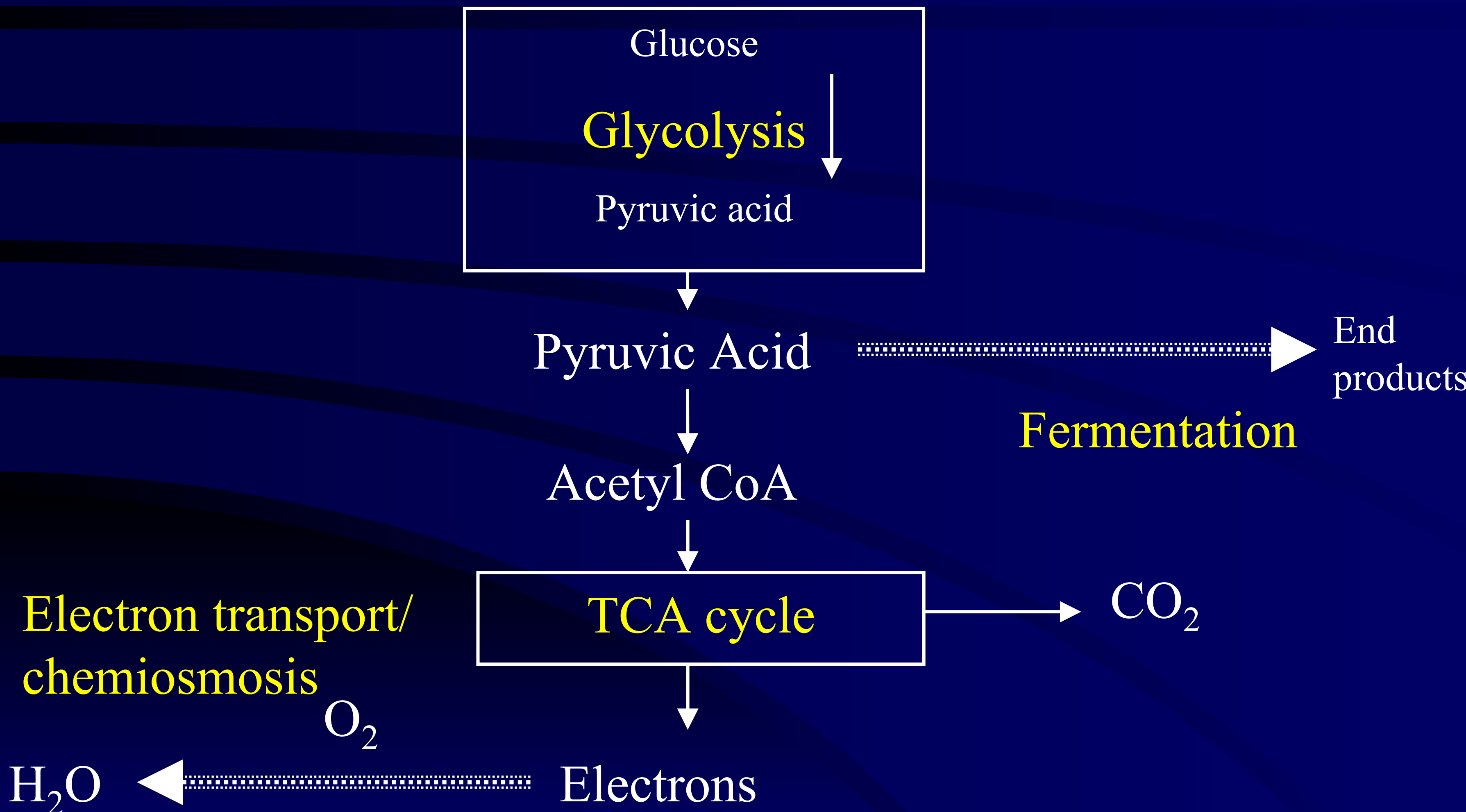
Chemolithotrophs

- chemolithotrophs obtain energy from oxidation of inorganic compounds
- use electron transport chains for energy production
- use either CO_2 or organic molecules as carbon sources
- eg. hydrogen oxidising bacteria
- $6H_2 + 2O_2 + CO_2 => (CH_2O) + 5H_2O$
- eg. sulfur bacteria (*Sulfolobus acidocaldarius*)
- H_2S (sulphide), S^0, $S_2O_3^{2-}$ (thiosulfate) oxidising bacteria
- $H_2S + 2O_2 => SO_4^{2-} = 2H+$
- eg. iron oxidising bacteria (*Thiobacillus ferrooxidans*)

Photosynthesis

- two separate sets of reactions in photosynthesis - light reaction (light converted to chemical energy) and dark reaction (chemical energy used for CO_2 fixation)
- reduced electron carriers required for CO_2 reduction (usually NADPH)
- purple and green bacteria produce NADPH by using reducing material present in the environment (eg. H_2S)
- process is anoxygenic (no oxygen produced)
- plants, algae and cyanobacteria obtain electrons by splitting water into O_2 and H+ (oxygenic)
- anoxygenic bacteria have a modified form of chlorophyll called bacteriochlorophyll

Summary of energy producing mechanisms



Summary of energy producing mechanisms