Catabolism in heterotrophs

Overview of carbon flow through the cell

- **Enters the cell**
  - in heterotrophs as organic compounds
    e.g. glucose, amino acids, fatty acids, glycerol.
  - in autotrophs as CO_2
- **Converted to other compounds**
  - organic compounds: via catabolism (glycolysis; TCA cycle) to small molecular weight intermediate metabolites
  - CO_2: via fixation pathways (Calvin and Hatch-Slack cycles) to glucose
- **Fate of these compounds**
  Used to biosynthesise cell components, storage compounds, excreted as CO_2, wastes and other compounds *e.g.* antibiotics

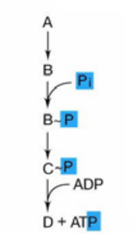
Overview of energy flow through the cell

- Captured
  - as ATP and NADH is cytoplasmic membranes (or mitochondria) from
    - catabolism of organic compounds
    - lithotrophy of inorganic compounds
  - or ATP and NADPH in thylakoids (chloroplasts) from light
- Stored as
  - ATP, ADP
  - other phosphorylated compounds
  - NADH; NADPH
  - organic compounds
- Used for biosynthesis (cell growth and reproduction), motility, nutritent transport into the cell

Energy from organic compounds

Pathways for the oxidation of organic compounds to produce energy fall into 2 groups
(different in phosphorylation)

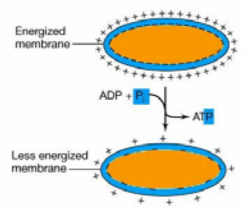
Fermentation



(a) **Substrate-level phosphorylation**

No externally supplied electron acceptor required as oxidation is coupled with reduction of organic compound

Respiration



(b) Oxidative phosphorylation

External electron acceptor is required

Glycolysis

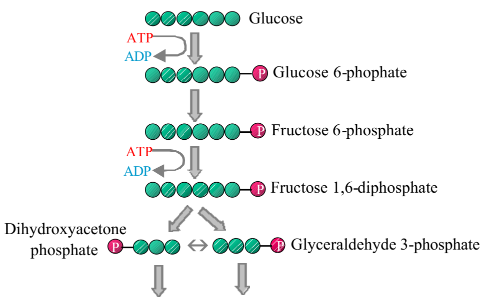
Oxidation of glucose to pyruvate

- Reduces carbon number from 6 to 3
- Releases energy for anabolism and fermentation
- Several amphibolic pathways (catabolic and anabolic) pathways
  - Embden-Meyerhof in eukaryotes and bacteria
  - Others found in bacteria
- Glucose derived from polysaccharides and other sugars
- Carbon compounds derived from amino acids and lipids may enter glycolytic pathways at various stages

The Embden-Meyerhof Pathway

Two stages

1. Preparatory reactions of 6C compounds

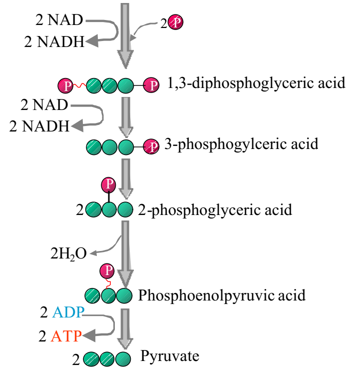


Features

- **Phosphorylation with 2 P**
  To energize 3C intermediate product
- **Isomerization**
  Glucose to fructose
- **Cleavage**
  6C to 3C compounds
- **Net loss of 2 ATP**

The Embden-Meyerhof Pathway 2

2. Oxidative reactions of 3C compounds



Features

- Phosphorylation and oxidation
  (at 1,3-diphosphoglycerate)
- Substrate phosphorylation of ADP
- Dehydration upgrades phosphate bond to high-energy bond
- Net gain of 2 ATP

Overall reaction in glycolysis

Glucose + 2ADP + 2Pi + 2NAD$^+$ → 2 pyruvate + 2ATP + 2NADH + 2H$^+$

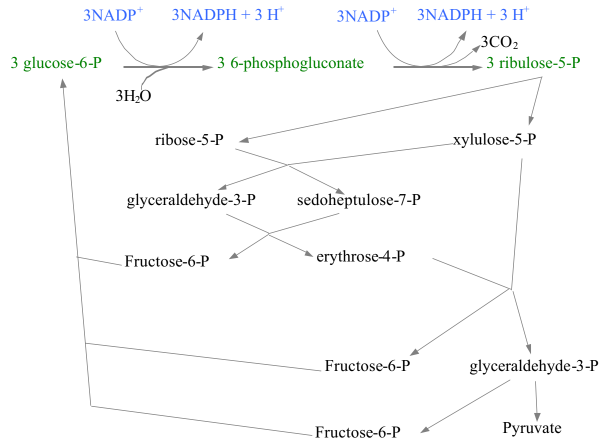
Alternatives to glycolysis

The Pentose Phosphate Pathway

a.k.a the Hexose Monophosphate pathway

- **A sole pathway, or in conjunction with the Embden-Meyerhof or Entner-Doudoroff pathways**
  Important in anabolism as well as catabolism
- **Significance**
  - Source of energy though of greater importance in biosynthesis
    1 ATP (net) per glucose molecule via glycolysis (pyruvate from glyceraldehyde-3-phosphate)
  - NADPH produced is a source of electrons for reduction in biosynthesis;
    12 NADPH per glucose molecule
  - Synthesizes 4 and 5 C sugars various purposes
    e.g. ribose-5-phosphate for nucleic acids; ribulose-1,5-biphosphate is the primary CO_2 acceptor in photosynthesis

The Pentose Phosphate Pathway 2

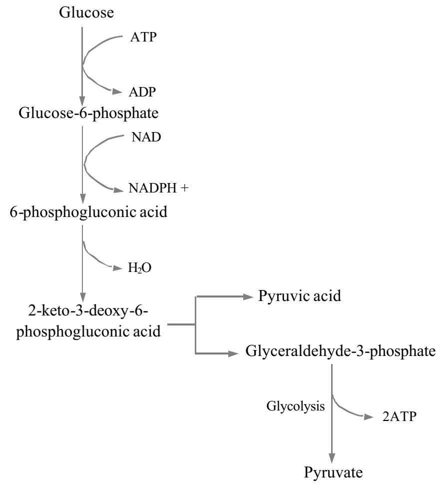


3 Glucose-6-P + 6NADP$^+$ + 3H2O → 2 Fructose-6-P + Glyceraldehyde-3-P + 3CO2 + 6NADPH + 6H$^+$

The Entner-Doudoroff pathway

- **Alternative to the Embden-Meyerhof pathway for glucose catalysis**
  - Found in some G(-) bacteria *e.g. Pseudomonas, Rhizobium.* Generally not found in G(+) bacteria
- **Generates**
  - 2 pyruvate per glucose molecule
  - 1 ATP (net), 1 NADPH, 1 NADH per glucose

The Entner-Doudoroff pathway 2

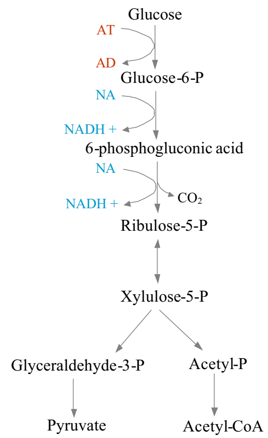


- **Three stages**
  - Oxidation of glucose-6-P to 6-phosphogluconate
  - Dehydration to 2-keto-3-deoxy-6-phosphogluconate
  - cleavage to pyruvate and glyceraldehyde-3-P

The Phosphoketolase pathway

- **An alternative to the Embden-Meyerhof pathway**
  - may be linked to reductive/fermentative pathway from pyruvate
  - present in heterofermentative lactic acid bacteria
- **Generates**
  - pyruvate and acetyl-P during oxidation
    - which ferment (reduce) to lactic acid and ethanol
  - 1 ATP and 3 NADH per glucose molecule

The Phosphoketolase pathway 2



- **Three stages**
  - oxidation of glucose to xylulose-5-P
  - cleavage to acetyl-P and glyceraldehyde-3-P
  - oxidation of glyceraldehyde-3-P to pyruvate

The Krebs/TCA/Citric Acid cycle

- **Oxidation of acetyl groups to CO_2 with production of NADH, $FADH_2$ and some ATP**
  4 NADH+H, 1 FADH+H and 1GTP per pyruvate molecule

- **4, 5 and 6C compounds available for biosynthesis**
  Carbon skeletons supplied for amino acid biosynthesis by α-ketoglutarate, succinate and oxaloacetate
  Glucose biosynthesis (gluconeogenesis) from malate/oxaloacetate

- **Present in organisms with aerobic respiration**
  The cycle is not fully developed in anaerobes (they lack the α-ketoglutarate dehydrogenase complex)