Lecture 19 -24

METABOLISM OF CARBOHYDRATE

Introduction

- Carbohydrates are major sources of energy for living organisms.
- The **chief source of carbohydrate** in human food is **starch**, which is the storage form of glucose in plants.
- Plants may store relatively large amounts of starch within their own cells in time of abundant supply, to be used later by the plant itself when there is a **demand for energy production.**
- **Glycogen** is the glucose storage polysaccharide of animals.
- It accounts for upto 10% of the mass of the liver and one percent of the mass of the muscle.
- Glycogen is larger and highly branched than amylopectin.
- By the action of several enzymes, such as **α-amylase, β-amylase, amylo $\alpha(1\rightarrow6)$ glucosidase and $\propto(1\rightarrow4)$ glucosidase,** starch and glycogen from dietary intake are degraded finally to glucose.
- Carbohydrate is utilized by cells mainly in the form of glucose.
- The three principal monosaccharides resulting from the digestive processes are **glucose, fructose and galactose**.
- Both fructose and galactose are readily converted to glucose by the liver.
- Pentose sugars such as xylose, arabinose and ribose may be present in the diet, but their fate after absorption is obscure.
- Since glucose is the compound formed from starch and glycogen, the carbohydrate metabolism commences with this monosaccharide.

The major metabolic processes in carbohydrates are:

i. Glycolysis:

Glycolysis is the sequence of reactions that convert **glucose into pyruvate** with the concomitant trapping of the energy as ATP.

ii. The citric acid cycle:

It is the final **common oxidative pathway for carbohydrates, fats and proteins**. It is also a source of precursors for biosynthesis of various biomolecules. The **acetyl CoA** that enters in this pathway is completely oxidised to **carbon dioxide and water** with concomitant production of reducing equivalents, namely **NADH and $FADH_2$.**

iii. The hexose monophosphate shunt:

It is an **alternative pathway** to the glycolytic pathway and the citric acid cycle for the oxidation of glucose to carbon dioxide and water with the **generation of reduced nicotinamide adenine dinucleotide phosphate (NADPH) molecules and ribose 5-phosphate.**

iv. Gluconeogenesis:

It is a biosynthetic pathway that generates **glucose from non-carbohydrate precursors.**

v. Glycogenesis:

It is a pathway by which **glycogen is synthesised** from glucose.

vi. Glycogenolysis:

Glycolysis

❖ Glycolysis, also called as **Embden-Meyerhof-Parnas pathway (EMP pathway),** consists of a series of reactions through which glucose is converted to pyruvate with the concomitant production of relatively small amounts of adenosine triphosphate (ATP).

❖ It is derived from the Greek stem '**glykys'** meaning sweet and **'lysis'** meaning splitting.

❖ It is the primary pathway occurring in the cytoplasm of all the tissues of biological systems.

❖ All the enzymes responsible for the catalysis are found in the **extra-mitochondrial soluble fraction of the cells (cytoplasm).**

In plants, glucose and fructose are the main monosaccharides catabolised by glycolysis although others are also converted into these sugars.

❖ Glucose entering the glycolysis is derived from **starch or sucrose**, and fructose is derived from **sucrose.**

❖ The starch is either from seeds or chloroplasts of matured plants.

❖ Glycolysis normally takes place in the **presence of O_2** in higher plant cells.

The enzymes in the cytoplasm catalyse the reactions involved in the conversion of **glucose to pyruvate** .

The series of reactions indicated take place in 3 stages.

Stage 1: Conversion of glucose to fructose 1,6-bisphosphate

❖ The formation of fructose 1,6-bisphosphate takes place in three steps catalysed by enzymes.

- The purpose of these reactions is to form a compound that can be readily cleaved into phosphorylated three carbon units from which, through a series of reactions, ATP is formed.
- After the **first phosphorylation** reaction to form glucose 6-phosphate, isomerisation of glucose 6-phosphate to **fructose-6-phosphate** occurs which is conversion of an aldose into a ketose.
- A second phosphorylation reaction follows the isomerization, catalysed by **phosphofructokinase** resulting in the formation of fructose 1,6-bisphosphate.
- **Phosphofructokinase** is the key enzyme in the control of glycolysis.

Stage 2: Conversion of fructose 1,6-bisphosphate to 3-phosphoglycerate.

- The **splitting of fructose 1,6-bisphosphate** occurs in the second stage of glycolysis resulting in the formation of a molecule of glyceraldehyde 3-phosphate and a molecule of dihydroxyacetone phosphate catalysed by **aldolase.**
- The dihydroxyacetone phosphate is isomerised to glyceraldehyde 3-phosphate by **phosphotriose isomerase.** The isomerisation reaction is rapid and reversible.
- In the next step, glyceraldehyde 3- phosphate is oxidised to 1,3-bisphosphoglycerate catalyzed by **glyceraldehyde 3-phosphate dehydrogenase.**
- The product is further converted into 3-phosphoglycerate and a molecule of ATP is formed. The phosphorylation of ADP to ATP is called **substrate level phosphorylation** since the phosphate group from a substrate molecule is transferred to ADP.

Stage 3: Formation of pyruvate

- An intramolecular rearrangement of the phosphoryl group occurs resulting in the formation of 2-**phosphoglycerate from 3-phosphoglycerate catalyzed by phosphoglycerate mutase.**
- The 2-phosphoglycerate formed undergoes **dehydration** forming phosphoenolpyruvate which gives rise to pyruvate and a molecule of ATP (substrate level phosphorylation).
- The reaction is irreversible and catalyzed by **pyruvate kinase.**

The net reaction in the transformation of glucose to pyruvate is

Glucose + 2 Pi + 2ADP + 2 NAD^+ ---→ 2 pyruvate + 2 ATP + 2 NADH + 2 H^+ + H_2O

Once pyruvate is formed, further degradation is determined by the **presence or absence of oxygen.**

Under anaerobic conditions, in one of the pathways, pyruvate undergoes reduction yielding **lactic acid.**

The formation of lactic acid is very rare in plants with exception of potato tubers maintained under anaerobic condition and some green algae.

In the second pathway, pyruvate is converted to **ethyl alcohol and carbon dioxide**. The **alcoholic fermentation** is the basis of the beer and wine-making industries.

Under **aerobic conditions**, pyruvate is **oxidatively decarboxylated to acetyl CoA** which is then completely oxidised to CO_2 and water through the **citric acid cycle**

Energetics of glycolysis

From glucose, two molecules of glyceraldehyde 3-phosphate are formed in the second stage of glycolysis from which two molecules of pyruvate are obtained as end products of glycolysis. Hence energetic of glycolysis is calculated by taking into account two molecules of glyceraldehyde 3-phosphate.

Energetics of glycolysis

Stages/steps	Enzyme	Method of high energy bond formation	No. of ATP formed
Stage 1			
Formation of1,3-bisphospho glycerate from glyceraldehydes 3-phosphate	Glyceraldehyde3-phosphate dehydrogenase	Respiratory chain oxidation of 2 NADH	5
Stage 2			
Formation of 3 phosphoglycerate from 1,3 bisphospho glycerate	Phosphoglycerate kinase	Phosphorylation at subtrate level	2
Stage 3			
Formation of pyruvate from phosphoenol pyruvate	Pyruvate kinase	Phosphorylation at subrate level	2
Allowance for consumption of ATP by reactions catalysed by hexokinase and phosphofructokinase.			2
Number of ATP molecules generated by the catabolism of one molecule of glucose under aerobic conditions.			**7**
Number of ATP molecules generated by the catabolism of one molecule of glucose under anaerobic conditions.			2

Significance of glycolysis

- Glycolysis is an almost **universal central pathway** of glucose catabolism occurring in the cytoplasm of all the tissues of biological systems leading to generation of energy in the form of ATP for vital activities.
- It is the pathway through which the **largest flux of carbon** occurs in most cells.
- Some plant tissues which are modified for the storage of starch such as potato tubers and some plants adapted to growth in inundated water such as water cress derive most of their energy from glycolysis.

❖ In plants, glycolysis is the **key metabolic component of the respiratory process,** which generates energy in the form of ATP in cells where photosynthesis is not taking place.

❖ Many types of **anaerobic microorganisms** are entirely dependent on glycolysis.

❖ Mammalian tissues such as renal medulla and brain solely dependent on glycolysis for major sources of metabolic energy.

The tricarboxylic acid cycle

❖ In 1937, Sir Hans Krebs, an English biochemist proposed a pathway consisting of a cycle of reactions through which acetyl CoA is converted to carbon dioxide and water and hence the cycle was named as Kreb's cycle.

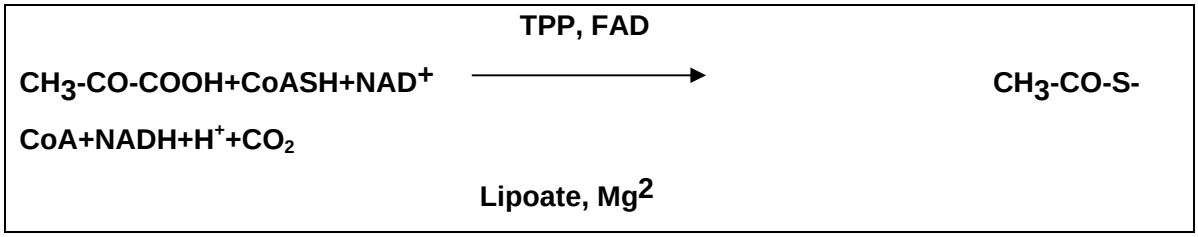
❖ All the enzymes catalyzing the reactions of this cycle occur inside **mitochondria (mitochondrial matrix**) in contrast with those of glycolysis, which occur in the cytosol.

Before pyruvate can enter the citric acid cycle, it must be oxidatively decarboxylated to acetyl CoA (active acetate).

Three different enzymes working sequentially in a multienzyme complex catalyse this reaction.

This formation of acetyl CoA from pyruvate **by alpha-oxidative decarboxylation** occurs in the mitochondrion following the formation of pyruvate in the cytosol during glycolysis.

The reaction involves six cofactors: **coenzyme A, NAD^+, lipoic acid, FAD, thiamine pyrophosphate (TPP) and Mg^{2+}.**



Reactions of the TCA cycle

Acetyl CoA, derived mainly from the oxidation of carbohydrates, lipids and proteins, combines with oxaloacetate to form **citrate** which is the first reaction of the citric acid cycle. Subsequently, citrate is oxidised in a series of reactions liberating carbon dioxide and reducing equivalents (NADH, $FADH_2$).

The oxaloacetate is regenerated and functions therefore in a catalytic manner in the oxidation of acetyl CoA to two molecules of carbon dioxide.

The citric acid cycle has eight steps as described below:

i. Formation of citrate

The first step is the reaction between the four-carbon unit, oxaloacetate and the two-carbon unit, acetyl CoA resulting in the formation of citrate and coenzyme A catalysed **by citrate synthase**. The coenzyme A formed in this reaction is recycled.

ii. Formation of isocitrate via cis-aconitate

The isomerization of citrate to isocitrate catalysed by **aconitase** occurs in two steps with the formation of cis-aconitate as an intermediate. This formation of isocitrate involves both dehydration and hydration. The result is an interchange of hydrogen and a hydroxyl group. In this reaction, **fluoroacetate** acts as an inhibitor to the enzyme, aconitase.

iii. Oxidation of isocitrate to α-ketoglutarate

The enzyme, **isocitrate dehydrogenase** oxidatively decarboxylates isocitrate to α-ketoglutarate with simultaneous liberation of carbon dioxide. The intermediate in this reaction is oxalosuccinate, an unstable β-ketoacid. While bound to the enzyme, it loses carbon dioxide to form α-ketoglutarate. There are two different forms of isocitrate dehydrogenase (isozymes), one requiring NAD^+ and other requiring $NADP^+$.

iv. Oxidation of α-ketoglutarate to succinyl CoA

α-Ketoglutarate, undergoes oxidative decarboxylation forming succinyl-CoA and carbon dioxide in the presence of **α-ketoglutarate dehydrogenase complex,** an assembly consisting of three kinds of enzymes. The mechanism of this reaction is very similar to the reaction catalyzed by **pyruvate dehydrogenase complex**. This reaction is irreversible. **Arsenite** acts as an inhibitor of TCA cycle by inhibiting the action of α-ketoglutarate dehydrogenase complex.

v. Conversion of succinyl CoA to succinate

Succinate is formed in a reversible reaction from succinyl CoA catalysed by the enzyme, **succinyl CoA synthetase or succinate thiokinase** with the simultaneous formation of GTP and coenzyme A. Succinate thiokinase utilises GDP in animal tissues whereas it uses ADP predominantly in plants and bacteria. The **formation of GTP** in this reaction is a **substrate level phosphorylation reaction.**

vi. Formation of fumarate by oxidation of succinate

The succinate formed from succinyl CoA is oxidised to fumarate by **succinate dehydrogenase** with the participation of FAD. **Malonate,** an analogue of succinate being a strong competitive inhibitor of succinate dehydrogenase, blocks the citric acid cycle.

vii. Formation of malate by hydration of fumarate

The reversible hydration of fumarate to L-malate is catalysed by **fumarase.**

viii. Oxidation of malate to oxaloacetate

This reaction forms the last reaction of the citric acid cycle. NAD-linked malate dehydrogenase catalyses the oxidation of L-malate to oxaloacetate.

Energetics of tricarboxylic acid cycle

From one molecule of glucose, two molecules of pyruvate are formed which in turn give rise to two molecules of acetyl CoA. When two molecules of acetyl-CoA undergo oxidation through TCA cycle, the following number of high-energy bonds (ATPs) are produced.

Significance of the TCA cycle

i) The major significance of the citric acid cycle is to act as the **final common pathway for the oxidation of carbohydrates, lipids and proteins,** since glucose, fatty acids and many amino acids are all metabolised to acetyl CoA.

ii) This cycle serves as the mechanism by which much of **the free energy liberated during the oxidation of carbohydrate, lipids and amino acids is made available.**

iii) TCA cycle is of further significance since it has **dual or amphibolic role thus providing precursor compounds for biosynthesis of other biomolecules** (amino acids, fatty acids, and glucose.

Glyoxylate cycle

❖ Plants, especially seedlings, can use acetate as the only source of carbon for all carbon compounds they produce.

❖ Acetyl CoA, which enters the TCA cycle, is completely oxidised to two molecules of CO_2. Thus it would not be possible for the cycle to produce the massive amounts biosynthetic precursors needed for acetate based growth unless alternative reactions were possible.

❖ Plants and bacteria employ a **modification of the TCA cycle** called the glyoxylate cycle to produce four **carbon dicarboxylic acids from acetyl CoA**. The glyoxylate cycle bypasses the decarboxylations of the TCA cycle.

❖ The enzymes of the glyoxylate cycle in plants are present in **glyoxysomes. Isocitrate lyase and malate synthase** are the additional enzymes required for this cycle in addition to TCA cycle enzymes.

❖ Glyoxysomes do not contain all the enzymes needed for the glyoxylate cycle. The enzymes succinate dehydrogenase, fumarase and malate dehydrogenase are absent.

❖ Hence glyoxysomes, with the help of mitochondria run their cycle Succinate molecules formed in glyoxysomes are transported to mitochondria where it is converted to oxaloacetate with the help of TCA cycle enzymes. The oxaloacetate is then converted to asparate and transported to glyoxysomes where it is transaminated to oxaloacetate.

❖ The oxaloacetate is converted to malate through glyoxylate cycle. The malate then enters the cytosol and converted into glucose via gluconeogenesis pathway.

The existence of glyoxylate cycle is important for the **germinating seeds** where photosynthesis is not possible. Triacylglycerols rich in oilseeds are degraded to acetyl CoA. Glyoxysomes formed during germination convert the acetyl CoA to oxaloacetate, which is then utilised for the conversion to glucose through gluconeogenesis. Once the growing seedling begins their photosynthesis to produce carbohydrates, the glyoxysomes disappear.

Electron transport chain and oxidative phosphorylation

❖ The mitochondrion is the aerobic organelle in which the final stage of the oxidation of food occurs.

❖ It is the site of the citric acid cycle, fatty acid oxidation and oxidative phosphorylation, processes that are responsible for the formation of ATP under aerobic condition.

❖ The two most important energy transductions in the biological systems are the **oxidative phosphorylation (ATP synthesis driven by electron transfer** to oxygen) and photophosphorylation (ATP synthesis driven by light).

❖ Oxidative phosphorylation is the process in which ATP molecules are formed as a result of the transfer of electrons from the reducing equivalents, NADH or $FADH_2$ (produced by glycolysis, the citric acid cycle and fatty acid oxidation) to oxygen by a series of electron carriers in the form of a chain located in the inner membrane of mitochondria. This is the final reaction sequence of respiration.

❖ Since the electrons are transferred by a series of electron carriers in the form of a chain, it is known as electron transport chain (ETC).

❖ In plants, ATP is mainly derived through photosynthesis utilizing the energy derived from the sun. In non-photosynthetic tissues, ATPs are derived through respiration.

The electrons are transferred along a set of cytochromes in the form of a chain in steps from the **more electronegative components (NADH/$FADH_2$) to the more electropositive oxygen.**

The respiratory chain consists of a number of protein complexes that are remarkably complicated in nature. They are known as **NADH- ubiquinone reductase, succinate**-ubiquinone reductase, ubiquinone-cytochrome c reductase and cytochrome c oxidase These complexes are also called as **NADH dehydrogenase, succinate dehydrogenase, cytochrome b-c complex and cytochrome c oxidase respectively or as complexes I - IV.**

All the three reductases are also known as iron-sulphur proteins since they contain Fe-S centres as their critical components. Iron in these enzyme complexes can exist in two forms as Fe^{2+} and Fe^{3+}. Each cytochrome in its oxidised form (Fe^{3+}) accepts one electron and becomes reduced to Fe^{2+} form. Fe^{2+} donates electron to the next carrier.

Oxidation of one molecule of NADH results in generation of 2.5 molecules of ATP whereas oxidation of one molecule of $FADH_2$ generates 1.5 molecules of ATP.

Sites of ATP formation

When electrons are transported along the respiratory chain, due to high amount of energy released, ATP molecules are synthesised at the following three sites.

i) **transfer of electrons from NADH to ubiquinone via flavoprotein (FMN).**

ii) **transfer of electrons from cyt b to cyt c.**

iii) **transfer of electrons from cyt a to cyt a_3.**

Mechanism of ATP formation

Two principal hypotheses have been proposed for the mechanism of oxidative phosphorylation.

i. **Chemical hypothesis**

ii. **Chemiosmotic theory**

Chemical hypothesis

Many attempts have been made since 1920 to identify an energy-rich metabolite linking oxidation and phosphorylation. No such intermediates was isolated and in 1960, Peter Mitchell suggested that no possibility of existence of such an intermediate compound. So, the chemical hypothesis has become discredited.

Chemiosmotic theory

The chemiosmotic theory states that the coupling of oxidation to phosphorylation is indirect. According to this, the hydrogen ions (protons) generated by the oxidation of components in the respiratory chain are ejected to the outside (matrix) of the inner membrane. The electrochemical potential difference resulting from the asymmetric distribution of the hydrogen ions (protons or H^+) is used to drive a membrane-located ATP synthase which in the presence of Pi + ADP forms ATP.

Inhibitors of respiratory chain

Inhibitors, which inhibit respiratory chain, may be grouped as follows:

i. **Inhibitors of electron transfer**

ii. **Inhibitors of ATP synthase**

iii. **Uncouplers of oxidative phosphorylation**

Inhibitors that arrest respiration by blocking the respiratory chain act at three sites.

Compounds such as barbiturates, amytal, rotenone prevent the transfer of electron from FeS centre to ubiquinone. Carboxin specifically inhibits transfer of reducing equivalents from succinate dehydrogenase to ubiquinone.

Antimycin A blocks electron transfer from cytochrome b to cytochrome c_1.

Substances such as cyanide (CN^-), azide (N_3^-) and carbon monoxide inhibit cytochrome c oxidase by binding to heme group and are extremely poisonous. Oligomycin inhibits ATP synthase.

In the presence of the uncouplers such as dicoumarol and 2,4-dinitrophenol, oxidation proceeds without phosphorylation (dissociation of oxidation in the respiratory

chain from phosphorylation) releasing energy in the form of heat rather than in the form of ATP.

The hexose monophosphate shunt

The hexose monophosphate shunt (HMP shunt), also called as pentose phosphate pathway (PPP) and phosphogluconate pathway is an alternate pathway for the oxidation of glucose. In 1930, Otto Warburg discovered the first evidence for the existence of this pathway, which was later, elucidated in 1950 by Frank Dickens group.

The pathway is important during the hours of darkness and in non-photosynthetic tissues such as differentiating tissues and germinating seeds. In animal system, it occurs in certain tissues, notably liver, lactating mammary gland and adipose tissue in addition to the Embden - Meyerhof pathway. The enzymes of the shunt pathway are found in the extra mitochondrial soluble portion of the cell. It is in effect, a multicyclic process whereby three molecules of glucose 6-phosphate give rise to three molecules of CO_2 and three 5-carbon residues. The latter are rearranged to regenerate two molecules of glucose 6-phosphate and one molecule of glyceraldehyde-3-phosphate. Since two molecules of glyceraldehyde 3-phosphate can regenerate a molecule of glucose 6-phosphate by reactions, which are essentially a reversal of glycolysis, the pathway can account for the complete oxidation of glucose. Here oxidation is achieved by dehydrogenation using NADP and not NAD as in Embden-Meyerhof's glycolytic pathway. This pathway consists of a series of reactions taking place in three stages

Stage I. Formation of NADPH and ribulose 5-phosphate

The first three reactions of the pathway, catalysed by glucose-6-phosphate dehydrogenase, phosphogluconolactonase and phosphogluconate dehydrogenase ultimately result in **the formation of ribulose 5-phosphate and NADPH.**

Stage II.

In this stage, the ribulose 5-phosphate is converted to ribose 5-phosphate by ribulose 5-phosphate isomerase and then to xylulose-5 phosphate by ribulose 5-phosphate epimerase. The ribose 5-phosphate is essential precursor in the biosynthesis of nucleotides.

Stage III.

In the third stage, three molecules of the 5-carbon sugars are converted to two molecules of 6-carbon sugars and one molecule of 3-carbon sugar, glyceraldehyde 3-phosphate catalysed **by two enzymes, transaldolase and transketolase.**

Transketolase catalyses the transfer of a C_2 unit from xylulose 5-phosphate to ribose 5-phosphate yielding glyceraldehyde 3-phosphate and sedoheptulose 7-phosphate.

Transaldolase catalyses the transfer of a three carbon unit from sedoheptulose 7-phosphate to glyceraldehyde 3-phosphate yielding erythrose 4-phosphate and fructose 6-phosphate.

Control of the HMP shunt

Ribose 5-phosphate and NADPH are the principal products of the HMP shunt. In this pathway, excess amount of ribose 5-phosphate is converted into glycolytic intermediates when the need for NADPH exceeds that of ribose 5-phosphate in nucleotide biosynthesis.

If ribose 5-phosphate is needed more than NADPH, fructose 6-phosphate and glyceraldehyde 3-phosphate are used for the synthesis of ribose 5-phosphate by reversal of the transaldolase and transketolase reactions.

The rate of NADPH formation in the pathway is controlled by the rate of the glucose 6-phosphate dehydrogenase reaction.

Metabolic significance of the HMP Shunt

i.Major function of HMP shunt appears to be the production of reduced NADP (NADPH) required by anabolic (synthetic) processes such as fatty acid synthesis outside the mitochondria .

ii.The pathway provides ribose for nucleotide and nucleic acid synthesis.

iii.It also provides erythrose required for the synthesis of phenolics and other aromatic compounds through shikimate pathway.

Glucose 6-phosphate can be used as a substrate either for glycolysis or for the pentose phosphate pathway. On the basis of the cell's needs, it makes this choice for biosynthesis and for energy from catabolism. If glucose 6-phosphate is channeled into glycolysis, ATP is produced in abundance; but if it is channeled into pentose phosphate pathway. NADPH and ribose 5-phosphate are produced. The fate of glucose 6-phosphate is determined to a large extent of phosphofructokinase and glucose-6 P. There are four principal possibilities in which, depending upon the cell's need, HMP shunt operates.

i. More ribose 5-phosphate than NADPH is required

Most of the glucose 6-phosphate is converted into fructose 6-phosphate and glyceraldehyde 3-phosphate by the glycolytic pathway. Two molecules of fructose 6-

phosphate and one molecule of glyceraldehyde 3-phosphate are converted into three molecules of ribose 5-phosphate by a reversal of reactions catalysed by transaldolase and transketolase reactions.

ii.. **Both ribose 5-phosphate and NADPH are needed by the cell**

In this, the first four reactions of the pentose phosphate pathway predominate. Ribose 5-phosphate is the principal product of the metabolism and NADPH is also produced. The net reaction for these processes is

Glucose 6 P + 2 $NADP^+$ + H_2O --------> Ribose 5-Phosphate + CO_2 + 2 NADPH + H^+

3. More NADPH than ribose 5-phosphate is needed by the cell

Under this situation, glucose 6-phosphate is completely oxidized to carbon dioxide. Three reactions are active. First, two NADPH and one ribose 5-phosphate are formed by the oxidative branch of the pentose phosphate pathway. Then, ribose 5-phosphate is converted into fructose 6-phosphate and glyceraldehyde 3-phosphate by transketolase and transaldolase. In the final reaction, glucose 6-phosphate is resynthesised from fructose 6-phosphate and glyceraldehyde 3-phosphate by the gluconeogenic pathway. The sum of these reactions is

Glucose 6-phosphate + 12 $NADPH^+$ + 7H2O -------> 6 CO_2 + 12 NADPH + 12H^+ + Pi

iv. Both NADPH and ATP are needed by the cell.

In this, fructose 6-phosphate and glyceraldehyde 3-phosphate derived from ribose 5-phosphate enter the glycolytic pathway and form pyruvate. ATP and NADPH are concomitantly generated and five of the six carbons of glucose 6-phosphate emerge in pyruvate.

3 Glucose 6-phosphate + 6 $NADP^+$ + 5NAD^+ + 5 Pi + 10ADP ------> 5 pyruvate + 3 CO_2 + 6NADPH + 5NADH + 10ATP + 2H_2O + 10H^+

Comparative account of glycolysis and HMP shunt

These two major pathways are meant for the catabolism of glucose. They have little in common, e.g. the presence of metabolites like glucose 6-phosphate. The major differences are

i. ATP is not generated in the HMP pathway, whereas in glycolysis, ATP molecules are generated.

ii. Pentose phosphates are generated in the HMP pathway but not in glycolysis.

iii. NADH is produced in glycolytic pathway whereas NADPH is produced in HMP shunt.