METABOLISM

بسم الله الرحمن الرحيم

Final – Lecture 2

Pentose Phosphate Pathway (Pt.2)

﴿ وَإِن تَتَوَلَّوْا يَسْتَبْدِلْ قَوْمًا غَيْرَكُمْ ثُمَّ لَا يَكُونُوا أَمْثَالَكُم ﴾

اللهم استعملنا ولا تستبدلنا

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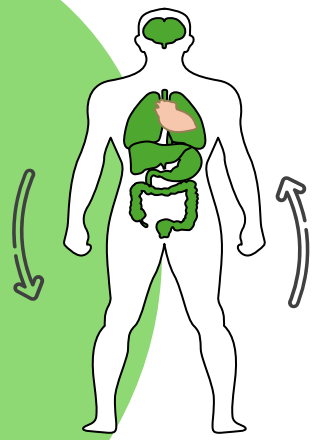


Before starting (;

In the first 10 slides, We will swiftly and thoroughly go through what have been said in the previous lecture or modified that was just before the first exam.
just to refresh your brains, since We have been through a lot in the MID exams!!.
You can skip them safely if you have studied them before.(;

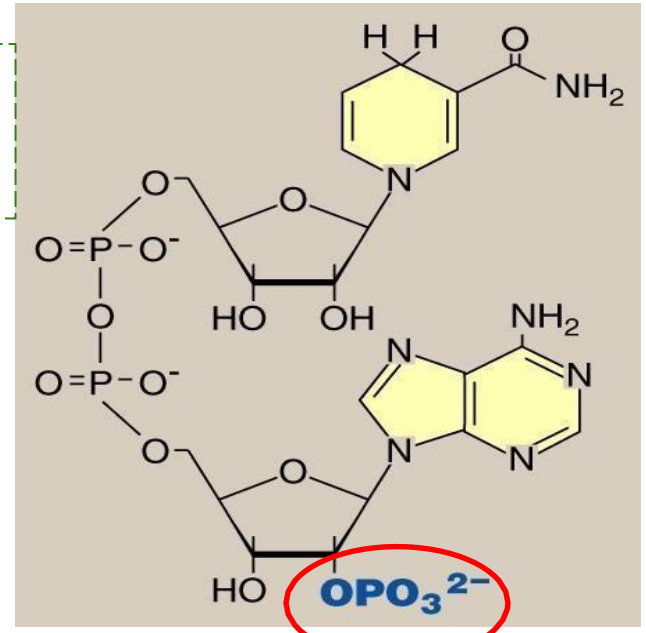
Functions of the PPP

1. Production of NADPH **"the more important."**
   - NADPH dependent biosynthesis of fatty acids
     - Liver, lactating mammary glands, adipose tissue
   - NADPH dependent biosynthesis of steroid hormones
     - Testes, ovaries, placenta, and adrenal cortex
   - Maintenance of Glutathione (GSH) in the reduced form in the RBCs
2. Metabolism of five-carbon sugars (Pentoses) **"the less important."**
   - Ribose 5-phosphate (nucleotide biosynthesis)
   - Metabolism of pentoses

Generally speaking:

- **Degradative pathway: Oxidation of the main substrate and reduction of the coenzyme**
- **Synthetic pathway: reduction of the main substrate and oxidation of the coenzyme**

Sex hormones and adrenocortical hormones; for instance: aldosterone and cortisone ….etc.



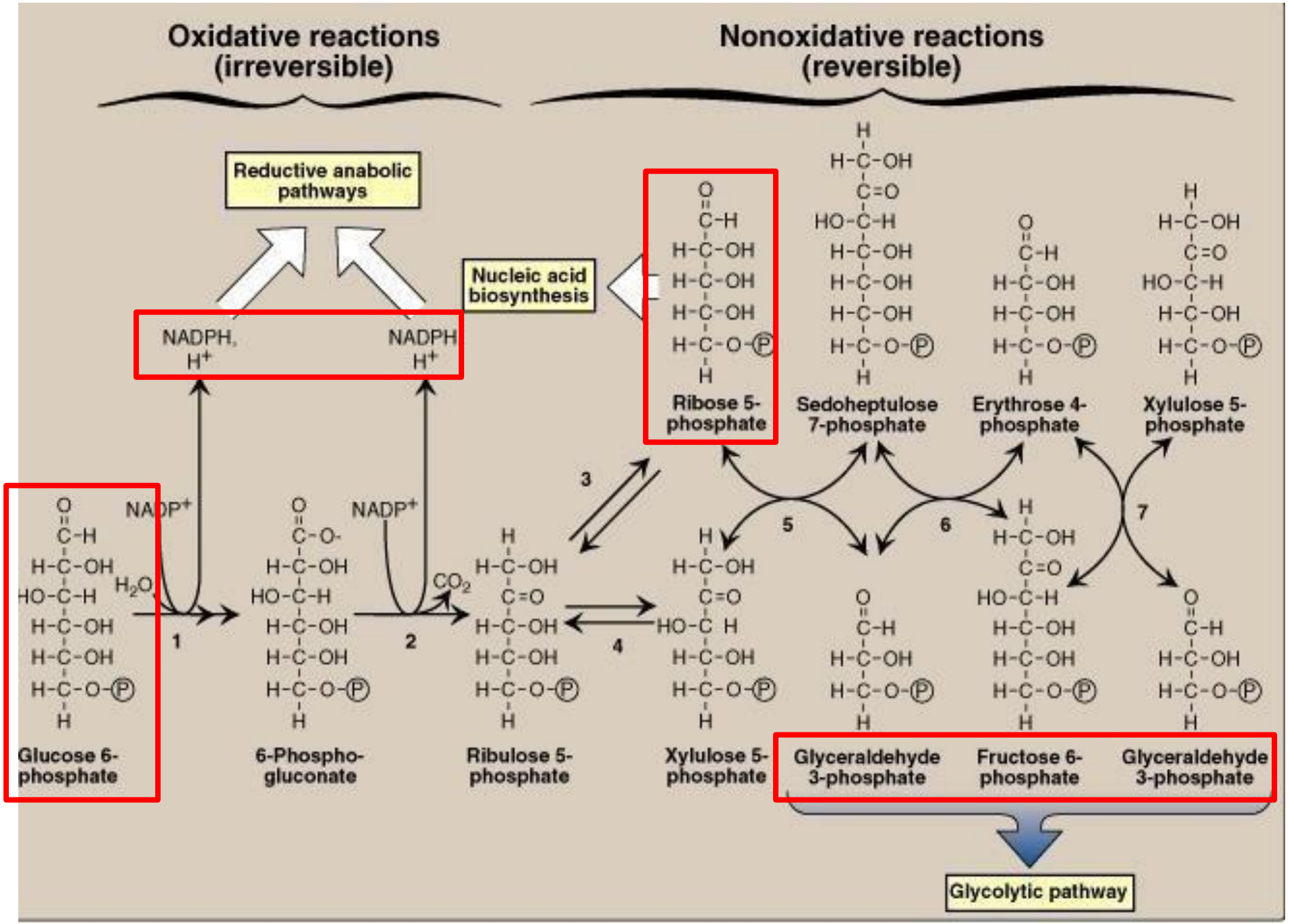
OH in NADH

A simple review of the PPP
Or Hexose Monophosphate Shunt.

- Glucose 6-phosphate, instead of entering glycolysis, can enter this alternative pathway, eventually producing glycolytic intermediate, Hence the name, 'shunt', just like traffic shunt!!.
- The PPP (Pentose Phosphate Pathway) is a pathway that occurs in the well-fed state, and it consists of two phases:
- 1: The Oxidative irreversible phase: 2NADPH are produced per Glucose 6-phosphate.
- 2: Non-Oxidative phase: two fructose 6-phosphate and glyceraldeyhde-3-phosphate.

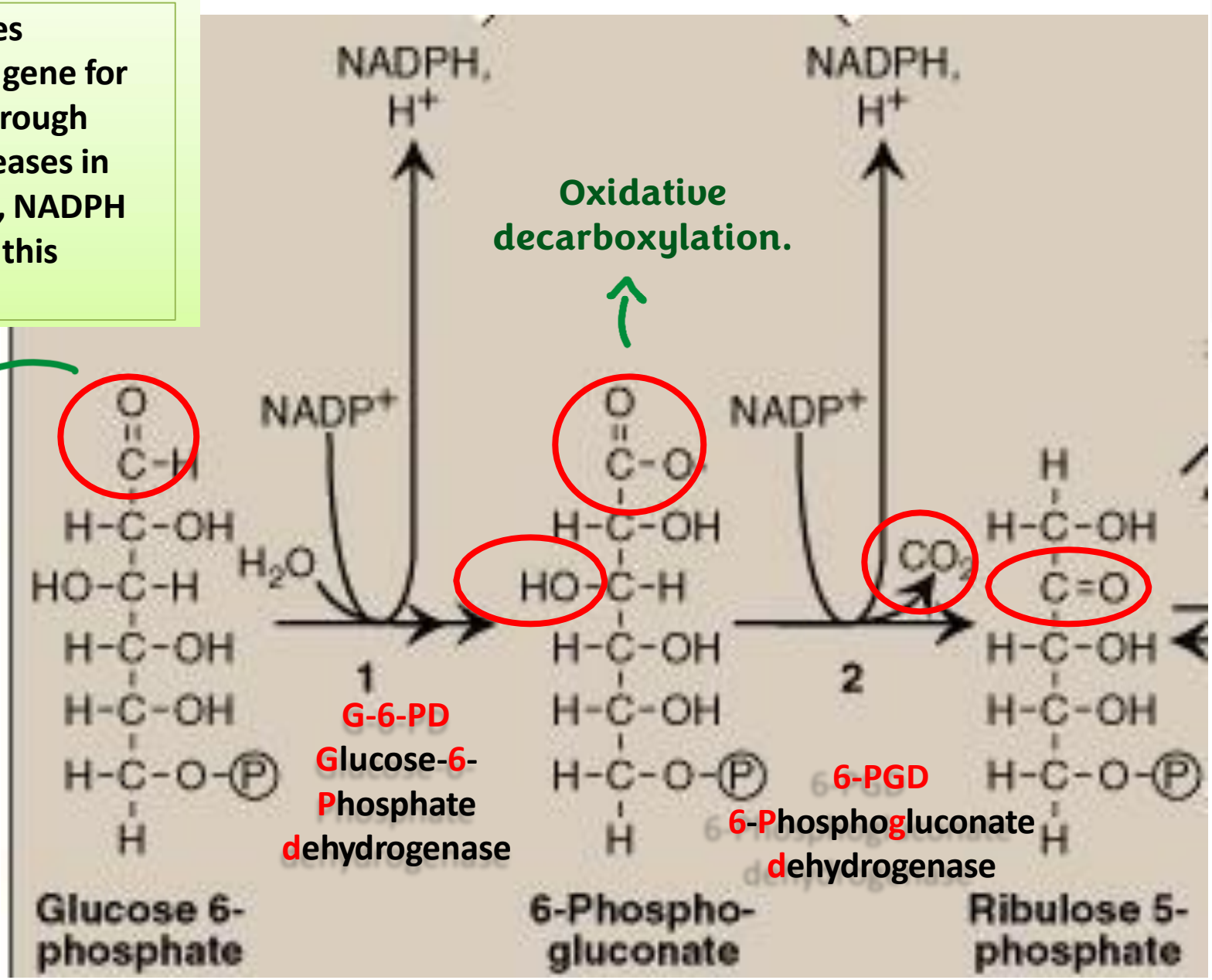
Please See the next few slides for more clarification.

PPP


Oxidative reactions
(irreversible)
Nonoxidative reactions
(reversible)
Reductive anabolic pathways
Nucleic acid biosynthesis
NADPH, H+
NADPH H+
NADP+
NADP+
H2O
CO2
1
2
3
4
5
6
7
Glucose 6-phosphate
6-Phospho-gluconate
Ribulose 5-phosphate
Xylulose 5-phosphate
Ribose 5-phosphate
Sedoheptulose 7-phosphate
Erythrose 4-phosphate
Xylulose 5-phosphate
Glyceraldehyde 3-phosphate
Fructose 6-phosphate
Glyceraldehyde 3-phosphate
Glycolytic pathway

Insulin upregulates expression of the gene for G6PD, and flux through the pathway increases in the well-fed state, NADPH is an inhibitor for this enzyme.

PPP
The oxidative irreversible phase



-Oxidation of the first carbon "the aldehyde carbon" yielding Gluconate.

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note that glucuronate results from oxidation of the last carbon, just for you to know.

Glc. 6 Phosph. +2 $NADP^+$ ⟶ Ribulose 5-Phosph. + CO_2 + 2 NADPH

The oxidative irreversible phase.

Reaction 1:

G-6-PD
Glucose-6- Phosphate dehydrogenase

Glucose 6-Phosphate+ $NADP^+$ ⟶ 6-phospho-gluconate + NADPH

Reaction 2:

6-PGD
6-Phosphogluconate dehydrogenase

6-phospho-gluconate + $NADP^+$ ⟶ Ribulose 5-Phosphate + NADPH + CO_2

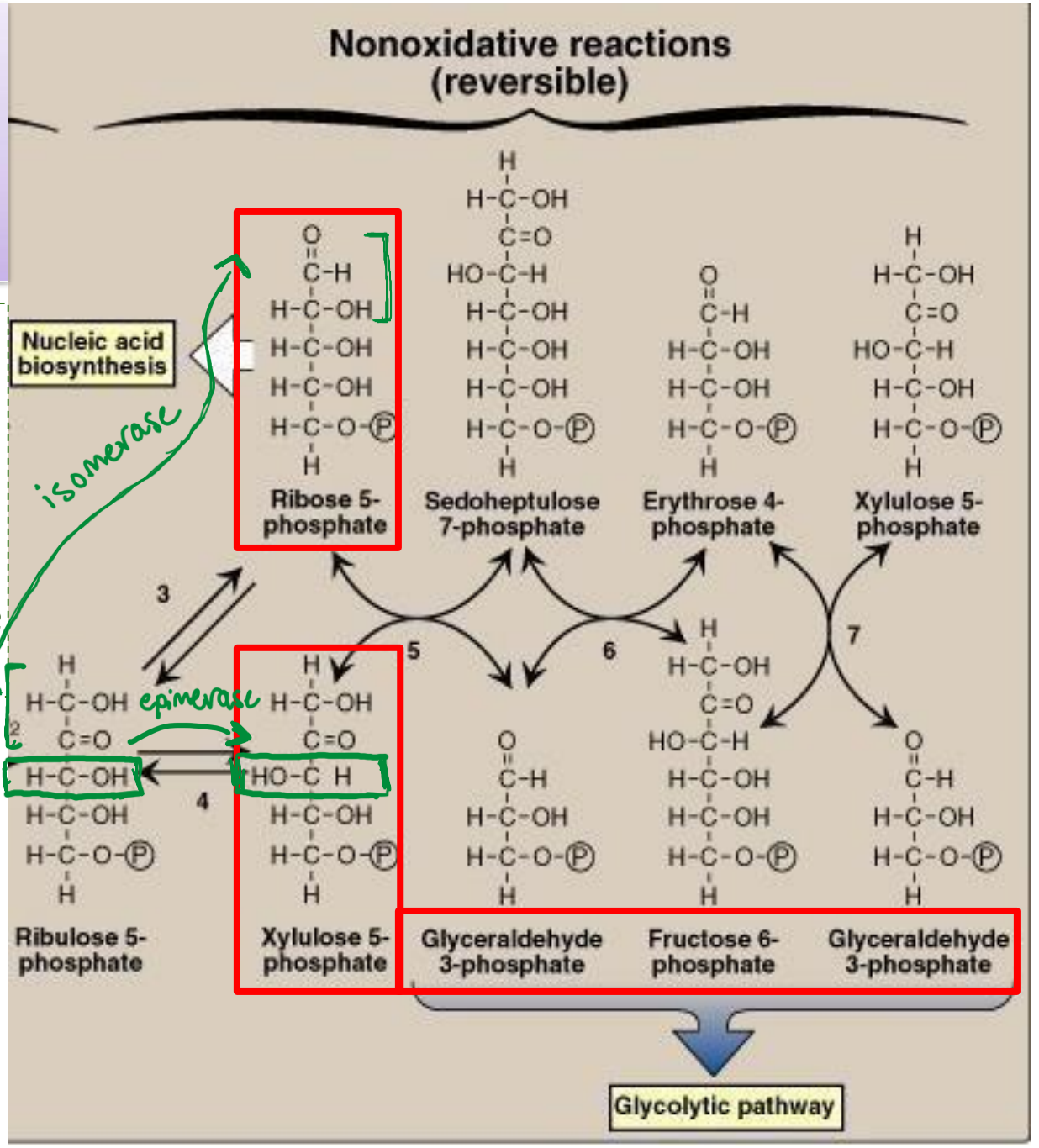
Total:

Glucose 6-Phosphate + $2NADP^+$ ⟶ Ribulose 5-Phosph. + CO_2 + 2 NADPH

PPP
The non-oxidative reversible phase

Once Ribulose 5-Phosphate (ketose) is produced, it can be ***isomerized*** into Ribose 5-phosphate (aldose) by ***isomerase*** enzyme, which continues into Nucleic acid biosynthesis pathways that is mostly activated at the S phase of the cell cycle, where there is high demand of energy. This partially explains why PPP typically occurs in the well-fed state during which anabolic pathways are strongly favored.

Now second molecule of Glucose 6-phosphate must repeat the same steps until Ribulose 5-Phosphate is produced, so that it can be ***epimerized*** into Xylulose 5-phosphate carried out by ***epimerase*** enzyme, only altering the configuration around carbon number 3.



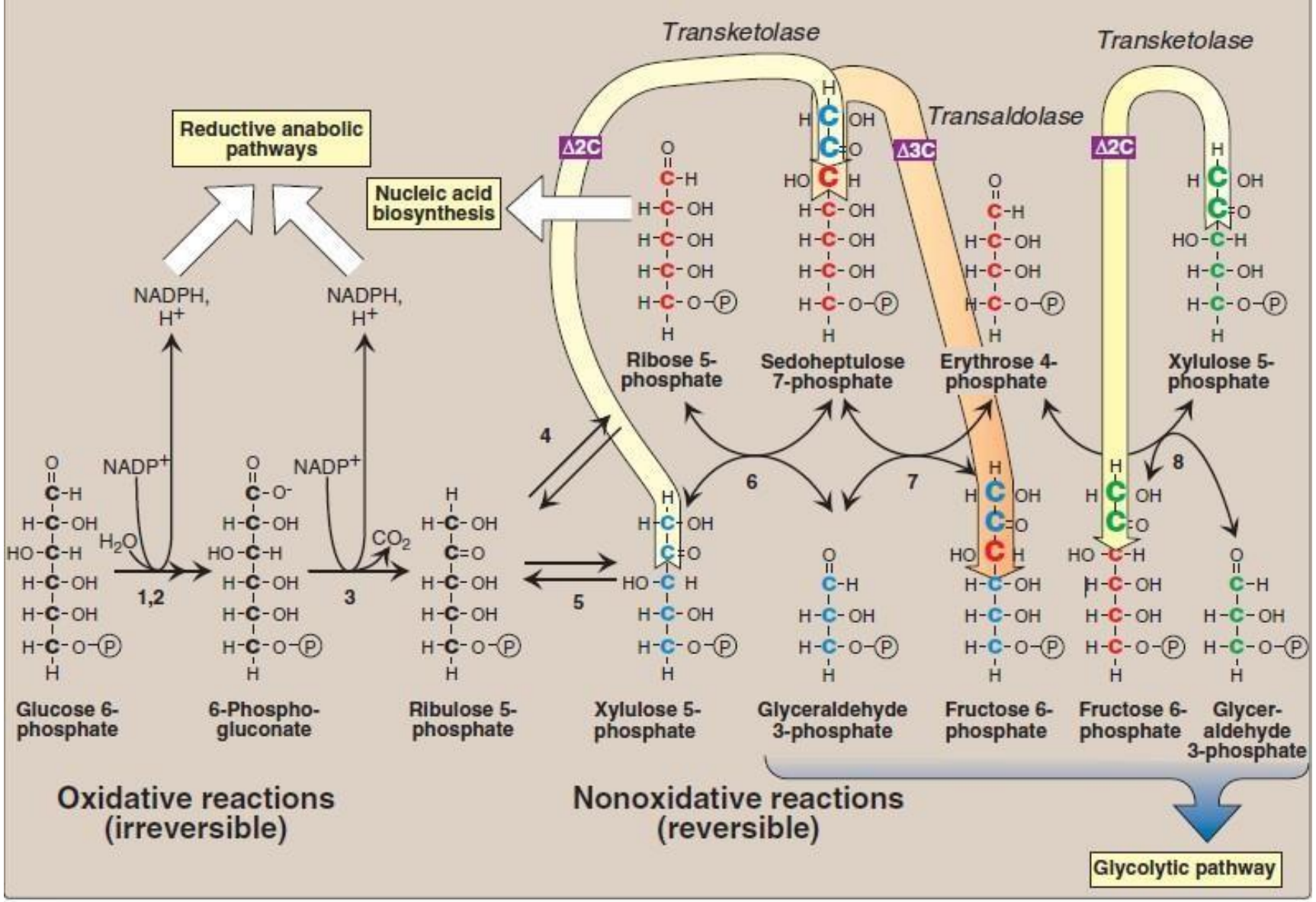


Figure 13.2
Reactions of the hexose monophosphate pathway. Enzymes numbered above are: 1,2) *glucose 6-phosphate dehydrogenase* and *6-phosphogluconolactone hydrolase*, 3) *6-phosphogluconate dehydrogenase*, 4) *ribose 5-phosphate isomerase*, 5) *phosphopentose epimerase*, 6) and 8) *transketolase* (coenzyme: thiamine pyrophosphate), and 7) *transaldolase*. Δ2C = two carbons are transferred in *transketolase* reactions; Δ3C = three carbons are transferred in the *transaldolase* reaction.

The non-oxidative reversible phase.

Reaction 3:

Do not memorize just understand the concept.

Ribulose 5-Phosphate —isomerase→ Ribose 5-phosphate

Reaction 4:

Ribulose 5-phosphate —epimerase→ Xylulose 5-phosphate

Reaction 5:

Xylulose 5-phosphate + Ribose 5-phosphate —transketolase→ Sedoheptulose 7-phosphate + Glyceraldehyde 3-phosphate

Reaction 6:

Sedoheptulose7-phosphate + Glyceraldehyde3-phosphate —transaldolase→ Fructose 6-phosphate + Erythrose 4-phosphate

Reaction 7:

A third molecule of G6P must enter to give this Xylulose. ↑

Erythrose 4-phosphate + Xylulose 5-phosphate —transketolase→ Fructose6-phosphate +Glyceraldehyde3-phosphate

Carbon movements in non-oxidative reactions

Do not memorize just understand the concept.

Ketose + Aldose ⇌ Aldose + Ketose

The whole concept is that each aldose becomes a ketose, and each ketose becomes an aldose by the transfer of 3C or 2C, catalyzed by transaldolase or transketolase enzymes respectively.

C5 + C5 ⇌ C3 + C7

C7 + C3 ⇌ C4 + C6

C5 + C4 ⇌ C3 + C6

Summary of the non-oxidative reactions

NO NET CARBON LOSS

- Reversible reactions
- Transfer of 2 or 3 carbon fragment
- Transketolase (2C), Transaldolase (3C)
- Ketose + aldose  ketose + aldose
- From ketose to aldose

- Rearrangment of sugars
- 3 pentose phosph..  2 hexose phosph + 1 triose phosph.

Ribulose 5-P

Fructose 6-P

Glyceraldeyhde 3-P

The net non-oxidative reaction

Do not memorize just understand the concept.

- 3 Ribulose 5-phosph. ⇌ { 2 Fructose 6-phosph. + Glyceraldehyde 3-phosph. }
- Multiply by 2
- 6 Ribulose 5-phosph. ⇌ { 4 Fructose 6-phosph. + 2 Glyceraldehyde 3-phosph. }

6 molecules of Ribulose (5 carbons), a total of 30 carbons, The final yield of this pathway is 5 fructose molecules (6 carbons) giving a total of 30 carbons.. NO NET CARBON LOSS

↓

↓

↓

The two G3P turn into one F6P as if they were in the glycolysis.

5 Fructose. 6-Phosph.

Net Products of the 2 Phases

Do not memorize just understand the concept.

Now indeed here the actual yield is Fructose 6-phoshphate not Glucose 6-phosphate, however we desire to unify the compounds for a purpose.

$$3\ \text{Glc. 6-P} + 6\ \text{NADP}^+ \longrightarrow 2\ \text{Glc. 6-P} + \text{GA3P} + 3\ CO_2 + 6\ \text{NADPH}$$

MULTIPLY BY 2

$$6\ \text{Glc. 6-P} + 12\ \text{NADP}^+ \longrightarrow 4\ \text{Glc. 6-P} + 2\ \text{GA3P} + 6\ CO_2 + 12\ \text{NADPH}$$

$$\text{GA3P} \downarrow$$

$$\text{Glc. 6-P}$$

$$6\ \text{Glc. 6-P} + 12\ \text{NADP}^+ \longrightarrow 5\ \text{Glc. 6-P} + 6\ CO_2 + 12\ \text{NADPH}$$

- **The whole concept is that there will be loss of one Glucose 6-phosphate in the form of six CO2 molecules for each six G6P molecules that enter this pathway, instead of all the six Glucose 6-phosphate typically entering the glycolytic pathway.**
- **The importance of this pathway in NADPH production and Nucleic acid biosynthesis comes at the cost of this loss of carbons.**

NADPH vs NADH

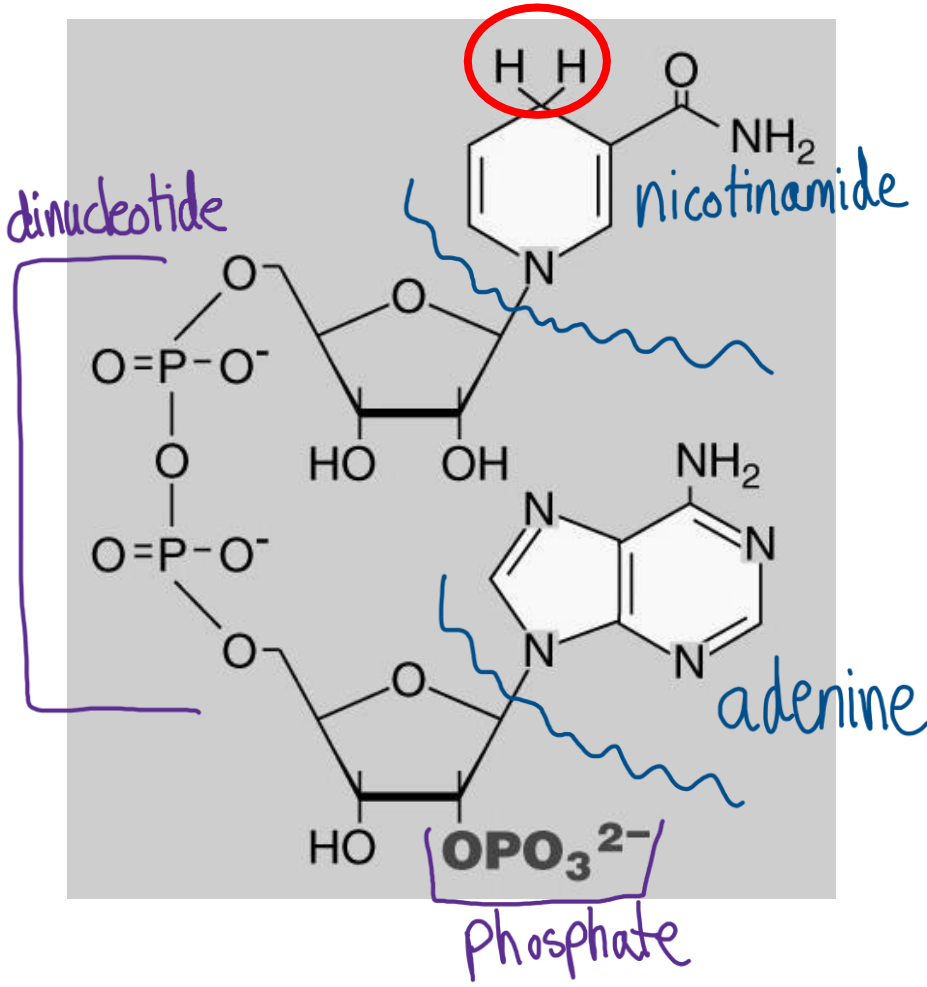
Since NADPH is primarily oxidized in the biosynthetic pathways reducing the main substrate.

On the other hand, NAD+ is primarily reduced in the degradative pathways oxidizing the main substrate.

Therefore, there are two pools, one is more oxidized while the other is more reduced, this facilitates REDOX reaction inside the cell, whether oxidation or reduction reaction is carried out.

- Enzymes can specifically use one NOT the other
- NADPH and NADH have different roles
- NADPH exists mainly in the reduced form (NADPH)
- NADH exists mainly in the oxidized form (NAD^+)
- In the cytosol of hepatocyte
  - $NADP^+/NADPH \approx 1/10$
  - $NAD^+/NADH \approx 1000/1$

Site of oxidation/ reduction



What are the uses of NADPH?

1. Reductive Biosynthesis

- Some biosynthetic reactions require high energy electron donor to produce reduced product
- Examples: Fatty acids, Steroids

+ cholesterol (precursor of steroids).

- …

Reduction of H2O2 indirectly by reduction of Glutathione directly for the recycling. to be discussed.

2. Reduction of Hydrogen Peroxide

- H_2O_2 one of a family of compounds known as Reactive Oxygen Species (**ROS**)
- Other: Super oxide, hydroxyl radical,
- Formed continuously
  - As by products of aerobic metabolism
  - Interaction with drugs and environmental toxins

ROS are normally produced as byproduct of the metabolism.

- Can cause chemical damage to proteins, lipids and DNA
  ➔cancer, inflammatory disease, cell death

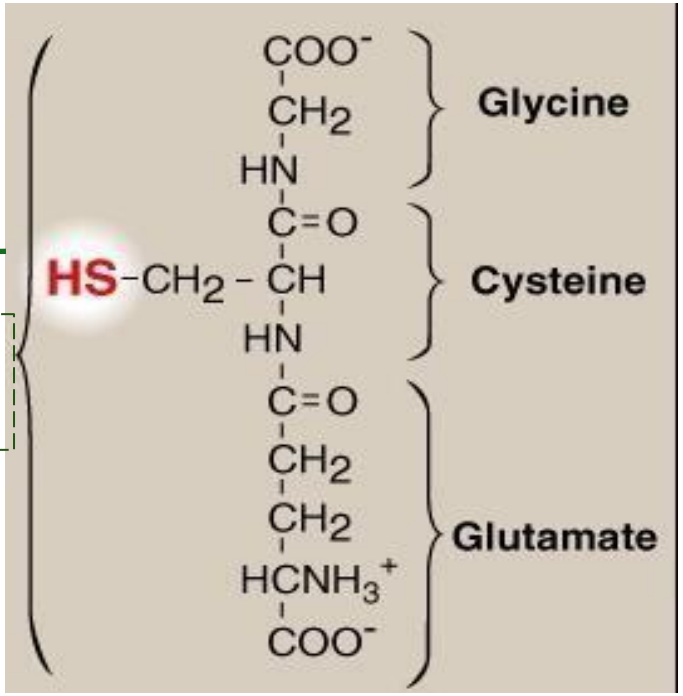
They are hazardous if present in large amounts

Enzymes that catalyze antioxidant reactions

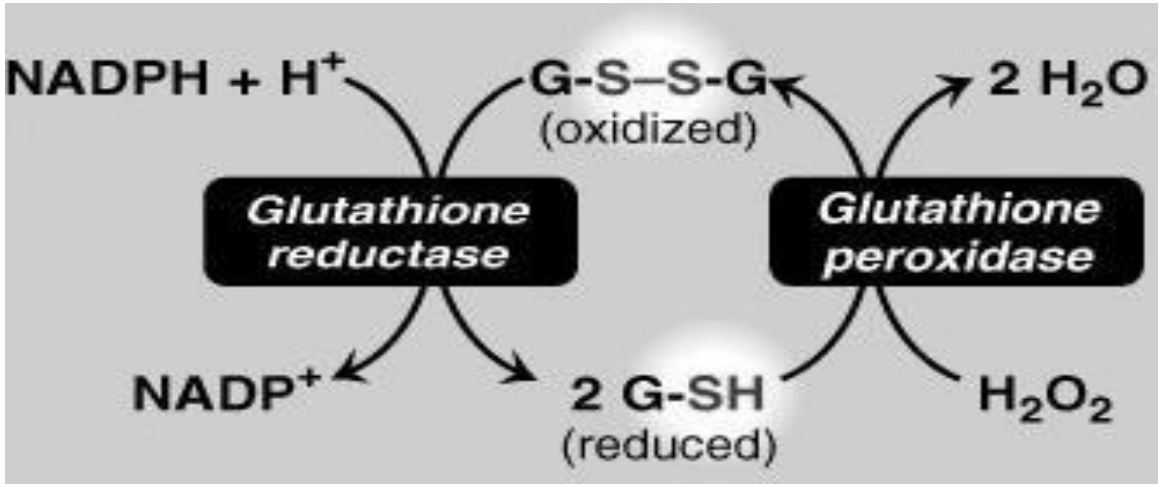
Please See next slide for more clarification.

1. Glutathione peroxidase

- Glutathione is a reducing agent
- Tripeptide
- GSH is the reduced form
- Oxidation ➔two molecules joined by disulfide (GSSG)
- reduction: GSH ⟶ GSSG



Glutathione peroxidase is Selenium requiring Enzyme. RBCs are totally dependent on PPP for NADPH production.



Glutathione peroxidase mechanism.

- H_2O_2 reacts with two reduced Glutathione molecules (free sulfhydryl groups "GSH"), and by the activity of ***Glutathione peroxidase***, H_2O_2 will be reduced to water alongside the oxidation of two GSH yielding disulfide bridge (GS-SG).

- Now the oxidized Glutathione (GS-SG) must be recycled back to two (GSH) by *glutathione reductase* which oxidizes NADPH to NADP+, breaking up the disulfide bond and ensuring that Glutathione is mostly present in the reduced form so that it can function in the clearance of ROS again.

- This reaction is particularly essential in the erythrocytes for several reasons, their internal environment is highly saturated with O_2, the raw material from which ROS are primarily generated, besides the absence of mitochondria in RBC, which partially aid in the removal of these hazardous products in other cells other than RBC.

$$H_2O_2 + 2GSH \longrightarrow GS\text{-}SG + 2H_2O$$

$$GS\text{-}SG + NADPH + H^+ \longrightarrow 2GSH + NADP^+$$

Enzymes that catalyze antioxidant reactions

2. Superoxide dismutase (**SOD**)

Can be removed by either Glutathione peroxidase or catalase enzymes.

3. Catalase

Heme protein present in peroxisomes.

Antioxidant chemicals

- Vitamin E, Vitamin C, Carotenoids (source of Vitamin A)

Many of these chemicals are present in the cosmetics for their antioxidant characteristics.

Clinical Hint: G6PD Deficiency

- A common disease
- characterized by hemolytic anemia
- 200 – 400 millions individuals worldwide
- Highest prevalence in Middle East, S.E. Asia, Mediterranean
- X-linked inheritance
- > 400 different mutations
- Deficiency provides resistance to falciparum malaria.

It is X-linked recessive ,so Males are more susceptible than females, as they only need one copy of the abnormal allele.

Mutations are usually point mutations (missense mutation), however frame shift, addition or deletion mutations are not observed.

Precipitating Factors in G6PD Deficiency

- Oxidant drugs
  - Antibiotics e.g. Sulfomethxazole
  - Antimalaria Primaquine
  - Antipyretics Acetanalid

Please See next slide for more clarification.

التفوّل

- Favism due to vicine and covicine in fava beans in some G6PD deficient patients
- Infection

During infection or inflammation there will be excessive ROS formation.

- Neonatal Jaundice

This is actually another clinical manifestation of G6PD Deficiency, in addition to hemolytic anemia, besides being a Precipitating factor. During the degradation of heme groups, typically as a part of the renewal process of erythrocytes, a toxic byproduct, Bilirubin, is normally produced. in the case of G6PD deficiency, there is premature death of RBC, that is, unusual rapid turn over of these cells occurs, producing excessive amounts of Bilirubin that exceed the functional capacity of our body to detoxify and eliminate these highly toxic compounds, giving the clinical outcome of patient yellowing, mostly affecting neonates and damaging their central nervous system.

Precipitating Factors in G6PD Deficiency and how RBC are affected

- A deficiency in this enzyme hinders the PPP, resulting in decrease in the concentration of NADPH reducing the cellular ability to function against ROS, And Eventually accumulation of these harmful compounds and excessive oxidative stress that can not be handled any longer, leading to senescence or premature death of the affected cells.

- Erythrocytes are particularly most affected since they are more vulnerable and sensitive to the oxidative stress, for several reasons mentioned in slide 18, in addition, RBC do not have any other pathway to produce NADPH unlike other tissues. Therefore, this results in rapid turn over of RBC and early death before 120 days. they as well have no nucleus nor ribosomes so they can not replenish their supply of this enzyme and, moreover, other tissues have alternative pathways like *$NADP^+$-dependent malate dehydrogenase* to produce NADPH. This additionally accounts for the vulnerability of erythrocytes to this condition.

- Precipitating factors are the factors that aggravate the problem by contributing to the oxidative stress or at least making patients more susceptible to it. avoidance of which, besides antioxidants supplementation are essential for the patient to prevent crisis, due to the acute hemolytic anemia that would otherwise result from the exposure to these factors.

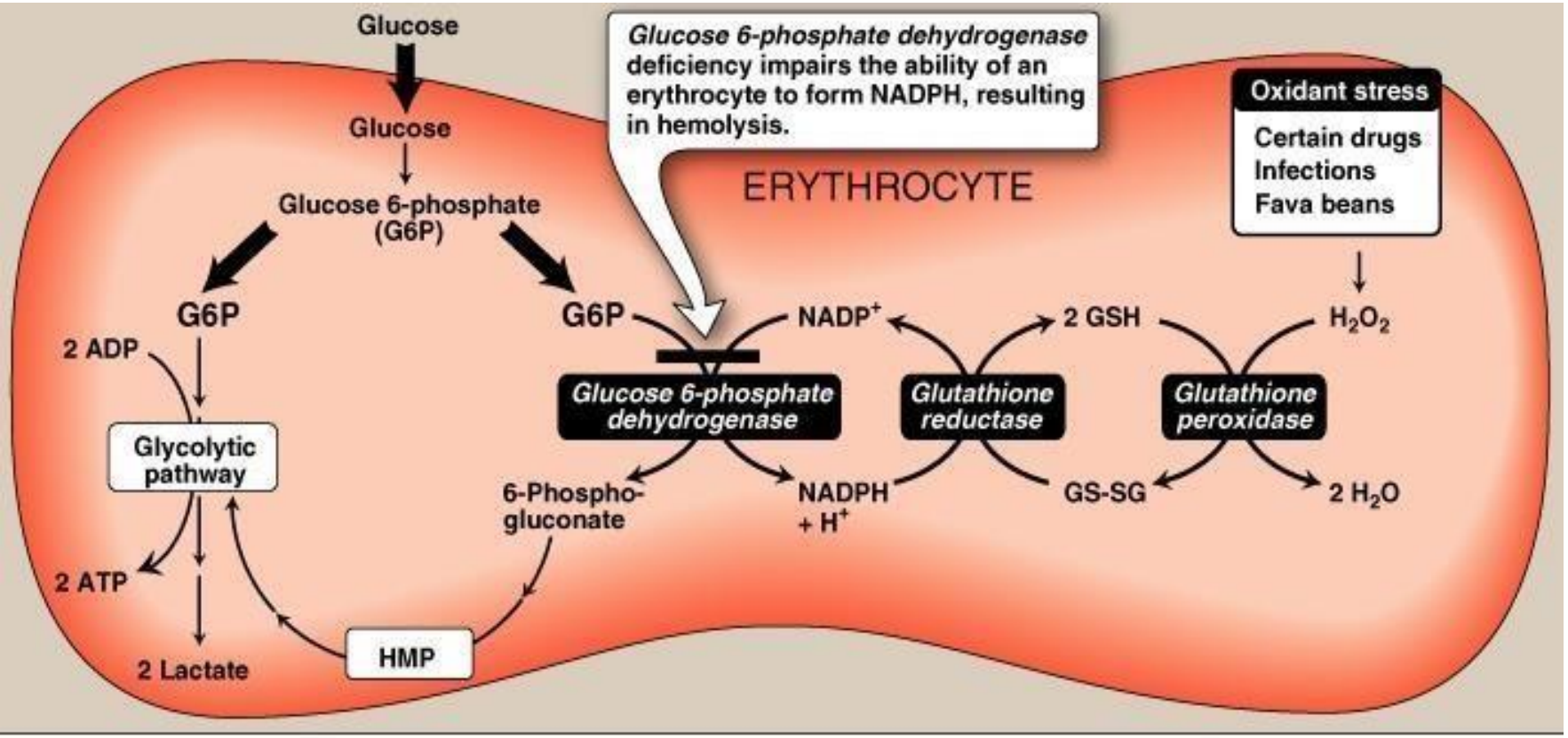
Role of G6PD in red blood cells

$$H_2O_2 + GSH \longrightarrow G\text{-}S\text{-}S\text{-}G + 2H_2O$$

$$G\text{-}S\text{-}S\text{-}G + NADPH \longrightarrow 2GSH + NADP+$$

GSH helps maintain the SH groups in proteins in the reduced state

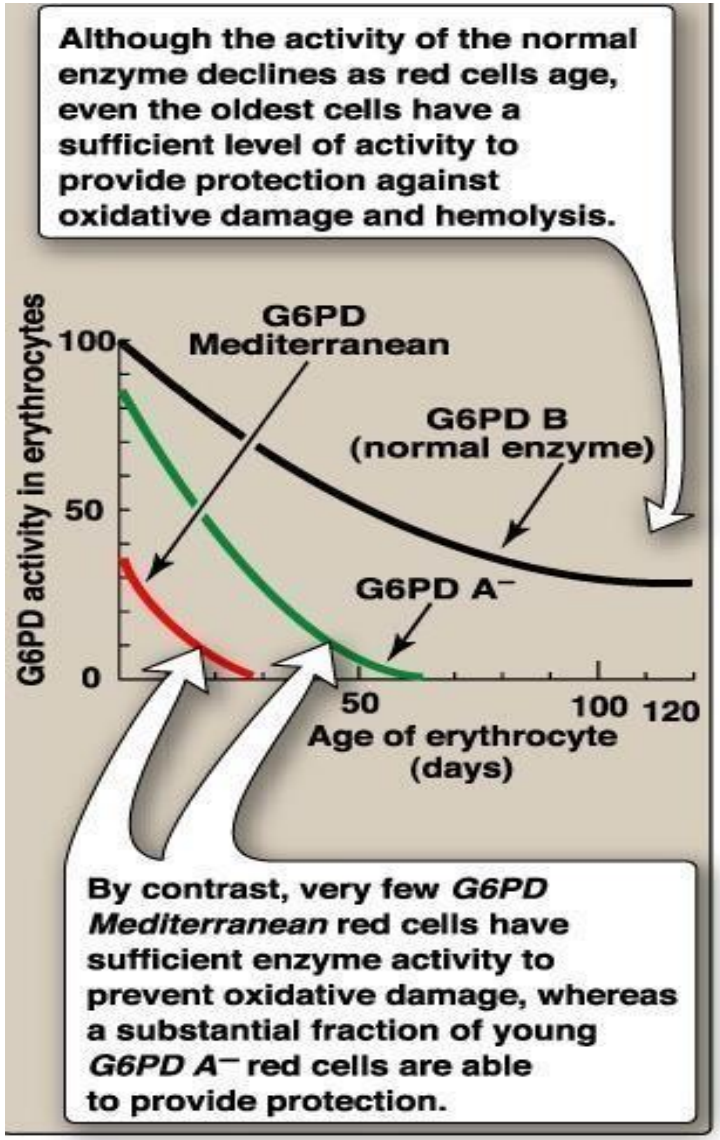
Oxidation ➔ denaturation of proteins and rigidity of the cells



Decreasing the NADPH/NADP⁺ pool in erythrocytes would ultimately reduce GSH/GS-SG pool which in turn increases the ROS. those highly reactive molecules can oxidize sulfhydryl groups of the cellular proteins including hemoglobin, leading to the formation of denatured proteins. Oxidation of the membrane proteins by ROS results in rigid membrane.

Classification of G6PD Deficiency Variants

Please Take a closer look at the figure

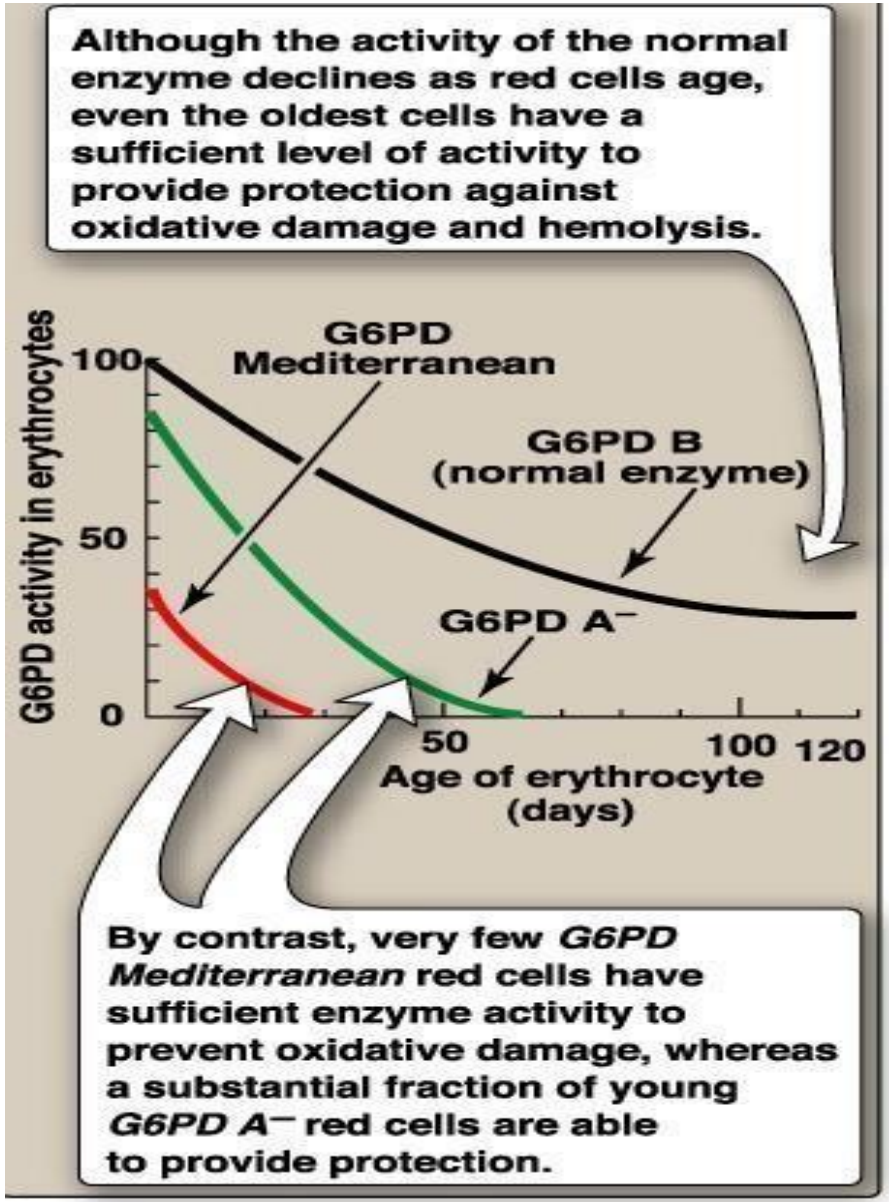


Class	Clinical symptoms	Residual enzyme activity
I	Very severe	<2% **Almost deficient**
II	Severe	<10%
III	Moderate	10–50%
IV	None	> 60%

Different mutations dictates different severities and classes.

- Wild type B: **Normal type**
- Mediterranean Variant B^- (Class II) : 563C → 563T
- African Variant A^- (Class III); two point mutation
- Majority missense mutation, point mutation
- Large deletions or frame shift; Not Observed

elucidation of the diagram



- This graph represents the decrease of G6PD activity during the life span of the erythrocyte with the wild type B, Mediterranean variant B^- and African variant A^-.
- The Black curve: represents the normal erythrocyte (wild type B) with 120 days life span, G6PD activity declines with time but never approaches zero, this means that the cell dies, and the enzyme still has some activity.
- The Green curve: represents African variant A^-, erythrocyte lives only for 60 days, the enzyme has no activity at the time of death, and interestingly notice how the enzymatic activity of variant A^- after 30 days resembles that of normal cell (Wild-type) at death!.
- The Red curve: represents Mediterranean variant B^- (class), erythrocyte lives only for 30 days, the enzyme has no activity at the time of death, also notice how the enzymatic activity of variant B^- early in its life span resembles that of normal cell (wild-type) at death!.

Sources of ROS in the cell

- Oxidases

  e- + O_2

Most oxidases produce H_2O_2 (peroxidase) **Superoxide also.**

Oxidases are confined to sites equipped with protective enzymes

- Oxygenases
  - Mono oxygenases (hydroxylases) **Mono-oxygenase incorporates one Oxygen atom into the substrate while the other oxygen atom becomes reduced to water.**
  - Dioxygenases in the synthesis of prostaglandins, thromboxanes, leukotrienes **Di-oxygenase incorporates complete molecular oxygen O_2 into the substrate.**
- Coenzyme Q in Respiratory chain

- Respiratory Burst (during phagocytosis) $O_2^{\cdot}$, $OH^{\bullet}$, NO, HOCl, H_2O_2

- Ionizing Radiation $OH^{\bullet}$ **By X-Ray or UV, etc...**

Cytochrome P450 Mono-oxygenase

- Mixed function oxygenase
- Super family of structurally related enzymes

✓ Mitochondrial system

Synthesis by hydroxylation of steroids, bile acids, active form of Vit. D

Cholesterol also.

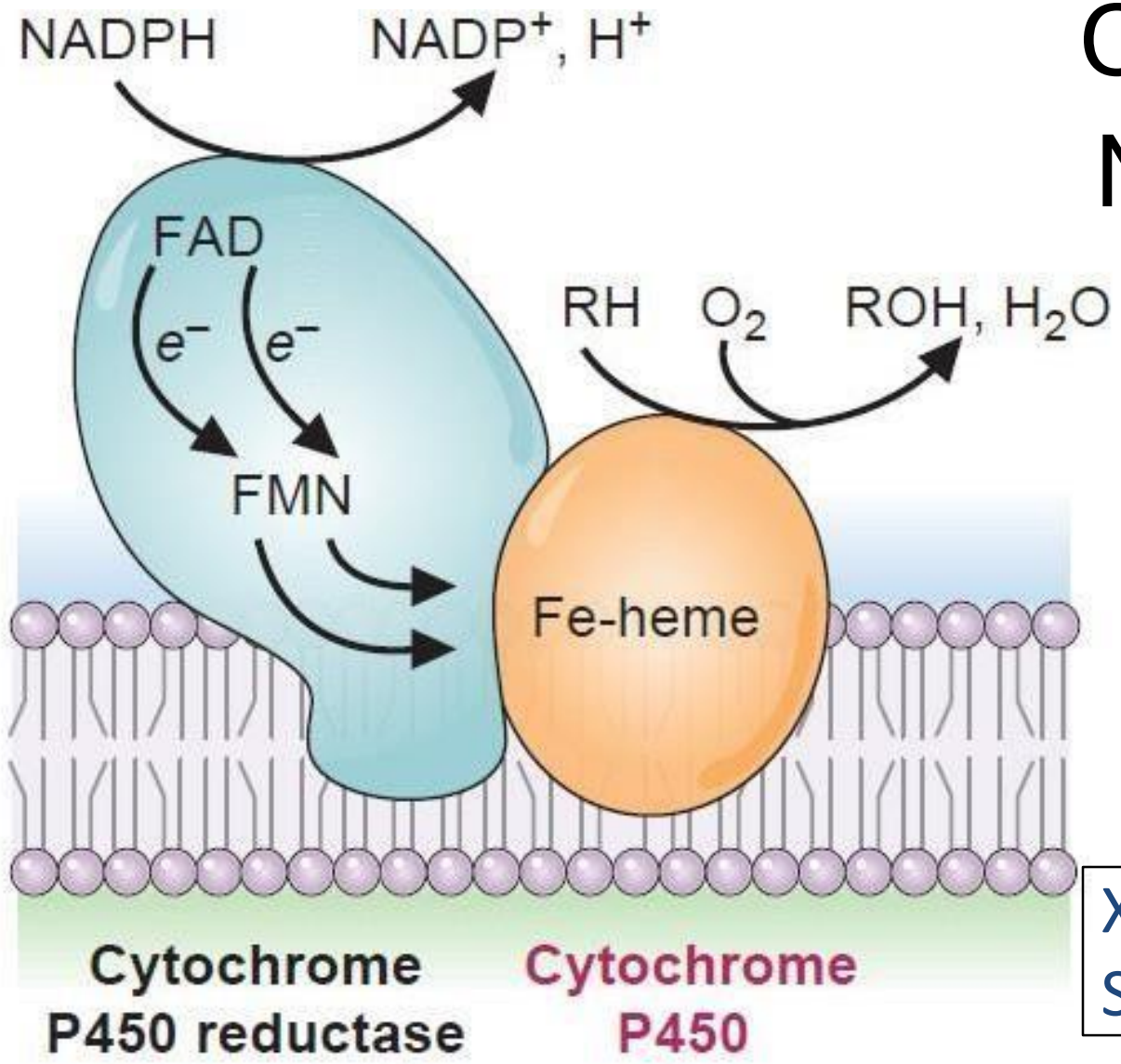
✓ Microsomal system

Detoxification of foreign compounds

Activation or inactivation of Drugs

Solublization to facilitate excretion in urine or feces

Cytochrome P450 Mono-oxygenase



Accidental release of free radical intermediates may occur

XH2: electron donor
S: substrate

$$O_2 + S + XH_2 \longrightarrow H_2O + SOH + X$$

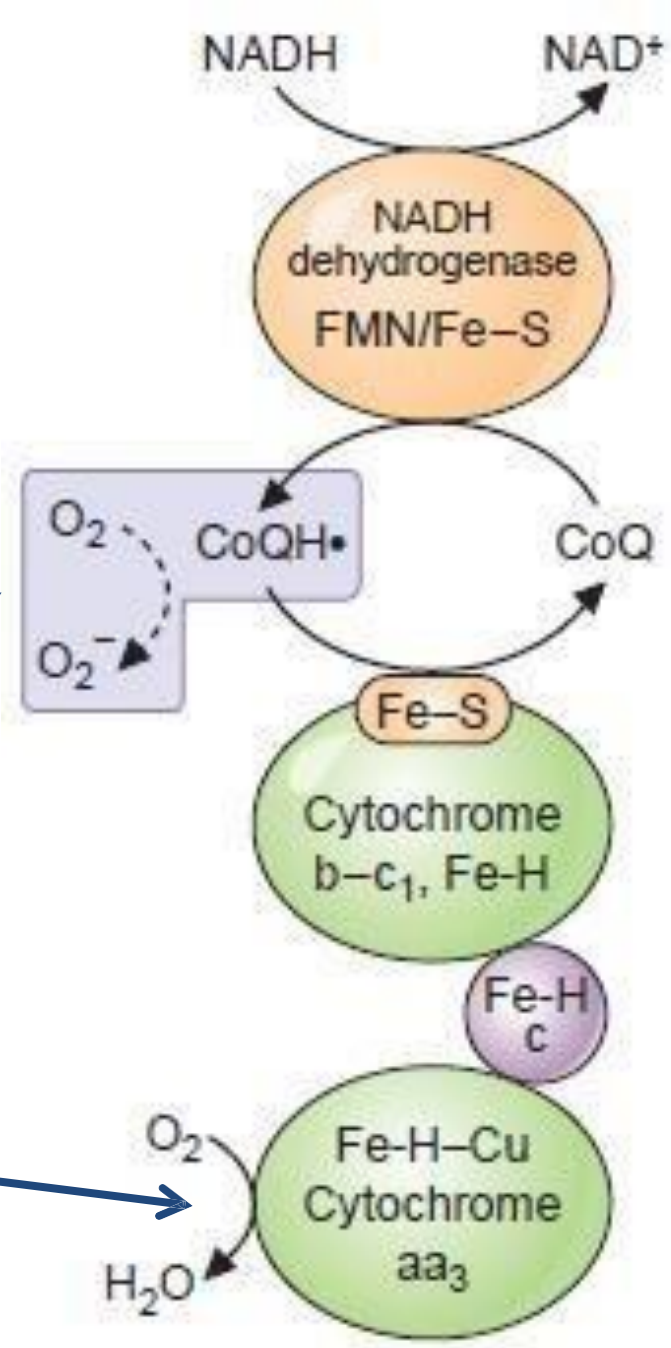
The substrate and NADPH is oxidized, O_2 is reduced to water.

Generation of O_2^- by the respiratory chain

Accidental non-specific interaction

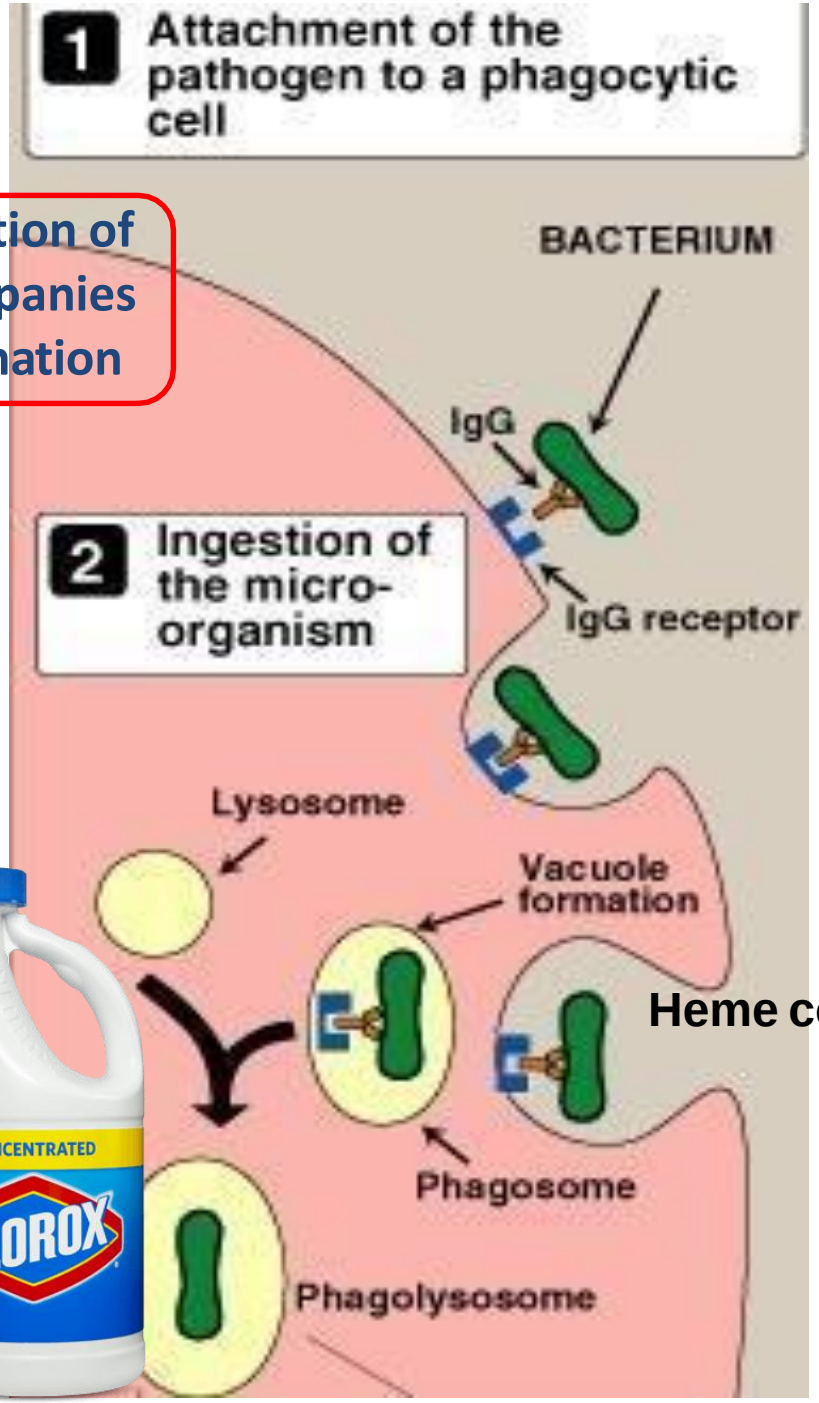
Major source of free radicals

Binuclear center prevents release of free O_2 radicals.

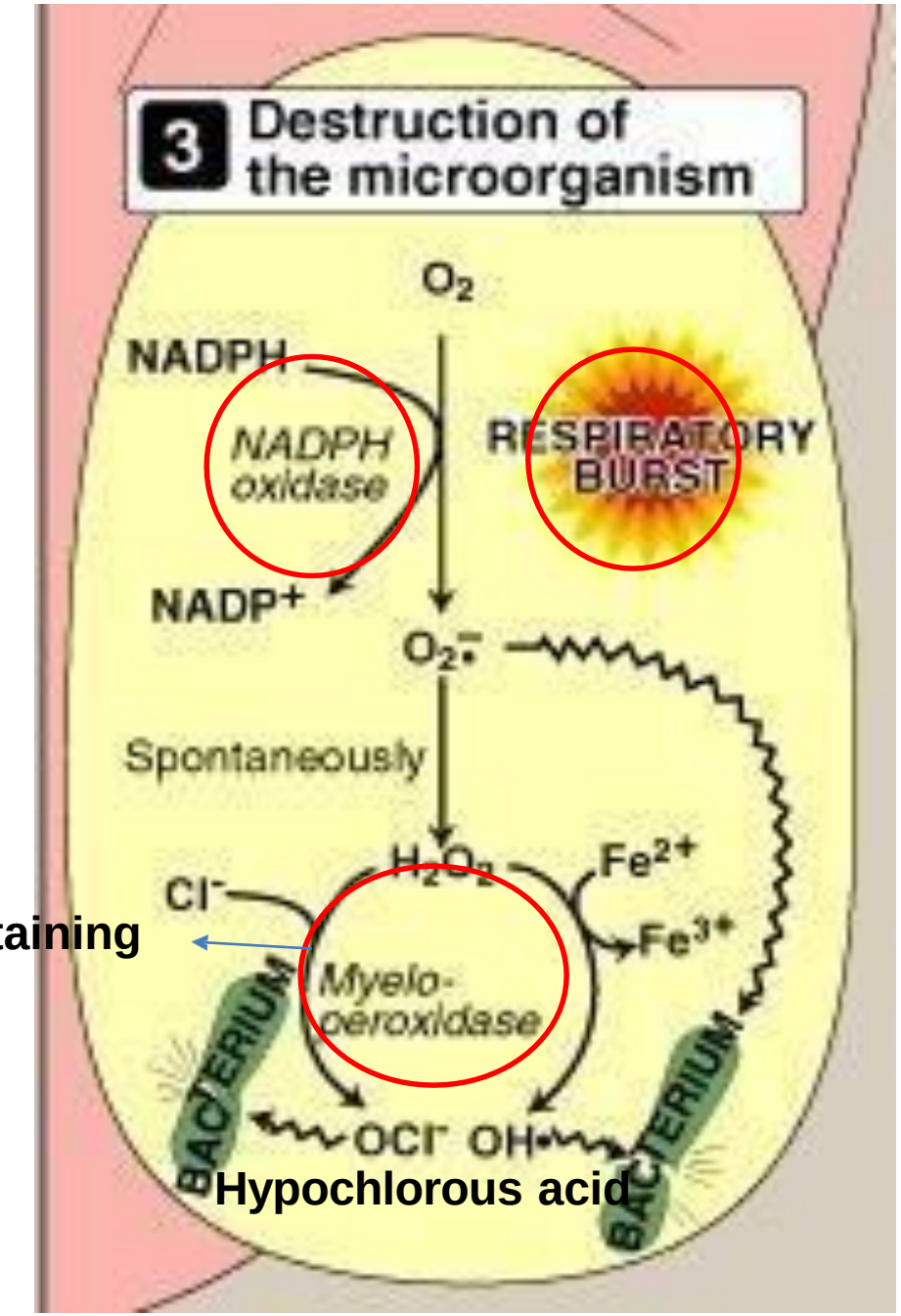


Rapid consumption of O^2 that accompanies superoxide formation

Phagocytosis is the oxygen-dependent pathway of microbial killing by phagocytes.



Heme containing



Hypochlorous acid

H2O2 can also be reduced to water by catalase or glutathione peroxidase

The respiratory burst in phagocytes

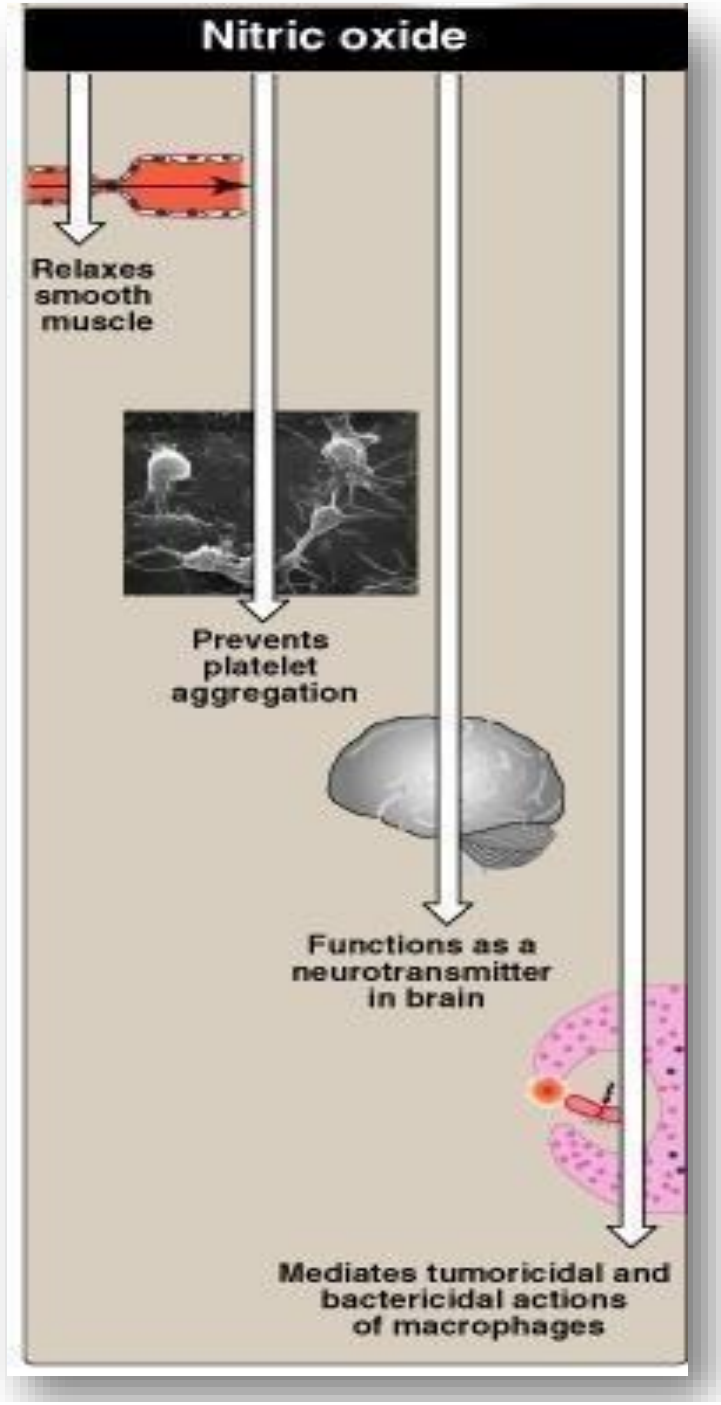
- ***Respiratory burst*** **is the rapid consumption of O_2 that accompanies superoxide formation.**
- ***Phagocytosis*** **is the oxygen-dependent pathway of microbial killing by phagocytes.**

- **The microbe must attach at specific phagocytic receptors (IgG receptors) on the cell surface, and then be internalized or endocytosed into the inside forming phagosome, the latter fuses with the lysosomes giving phagolysosome. Now molecular oxygen O_2 will be reduced to superoxide, oxidizing NADPH into $NADP^+$ by the activity of *NADPH oxidase* enzyme. Superoxide can be, spontaneously or by *superoxide dismutase* enzyme, converted into H_2O_2, both can act on the microbe. H_2O_2 Can be further converted into hydroxyl radical, oxidizing Fe+2 to Fe+3, or into hypochlorite by the activity of *myeloperoxidase enzyme* (heme-containing emzyme).**

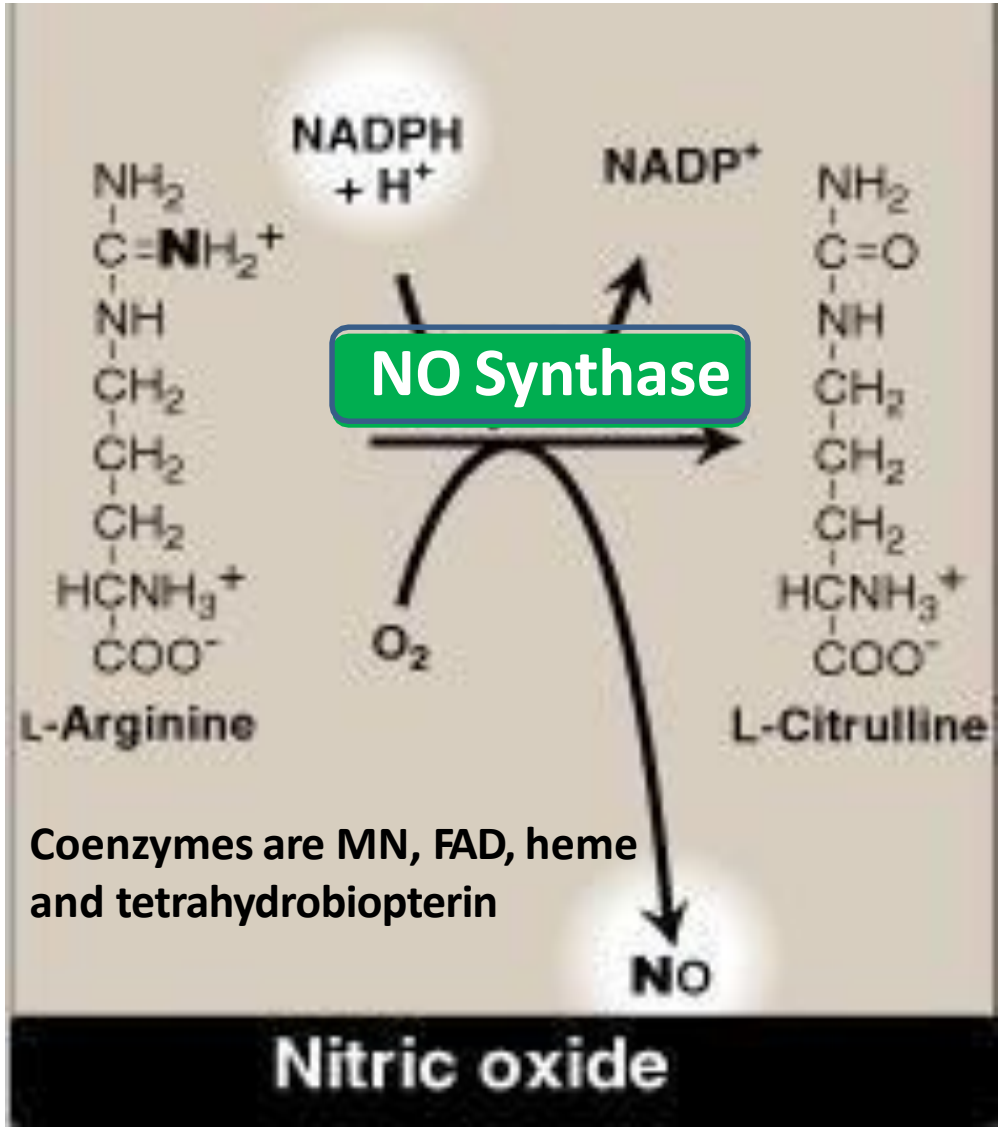
NO and Reactive Nitrogen Oxygen Species (RNOS)

- Diffuses readily
- Essential for life and toxic
- Neurotransmitter , vasodilator
- ↓Platelet aggregation
- At high concentration combines with $O_2\bullet^-$ or O_2 to form **RNOS**
- **RNOS** are involved in neurodegenerative diseases and inflammatory diseases

- **Nitric Oxide is the father molecule of RNOS.**
- **It is an endogenous gaseous signaling molecule that can diffuse passively exerting its effect locally.**



NO Synthesis



NO Synthase
Three isoforms
nNOS neural
eNOS endothelial
Both are constitutive

- **Constitutive means that they are always expressed and synthesized without the need for a stimuli.**
- **iNOS is inducible, meaning its synthesis can be activated by stimulants like infection in Ca^{+2} – independent manner.**

iNOS inducible Ca+2 independent
Induction of transcription in many cells of immune system➔↑↑ NO ➔ RNOS to kill invading bacteria

Action of NO on vascular endothelium

- **NO diffuses into the smooth muscle activating *guanylyl cyclase* producing cGMP from GTP, cGMP activates *protein kinase G*, which in turn phosphorylates Ca^{+2} channels ,inhibiting their entry into smooth myocytes → inducing relaxation.**

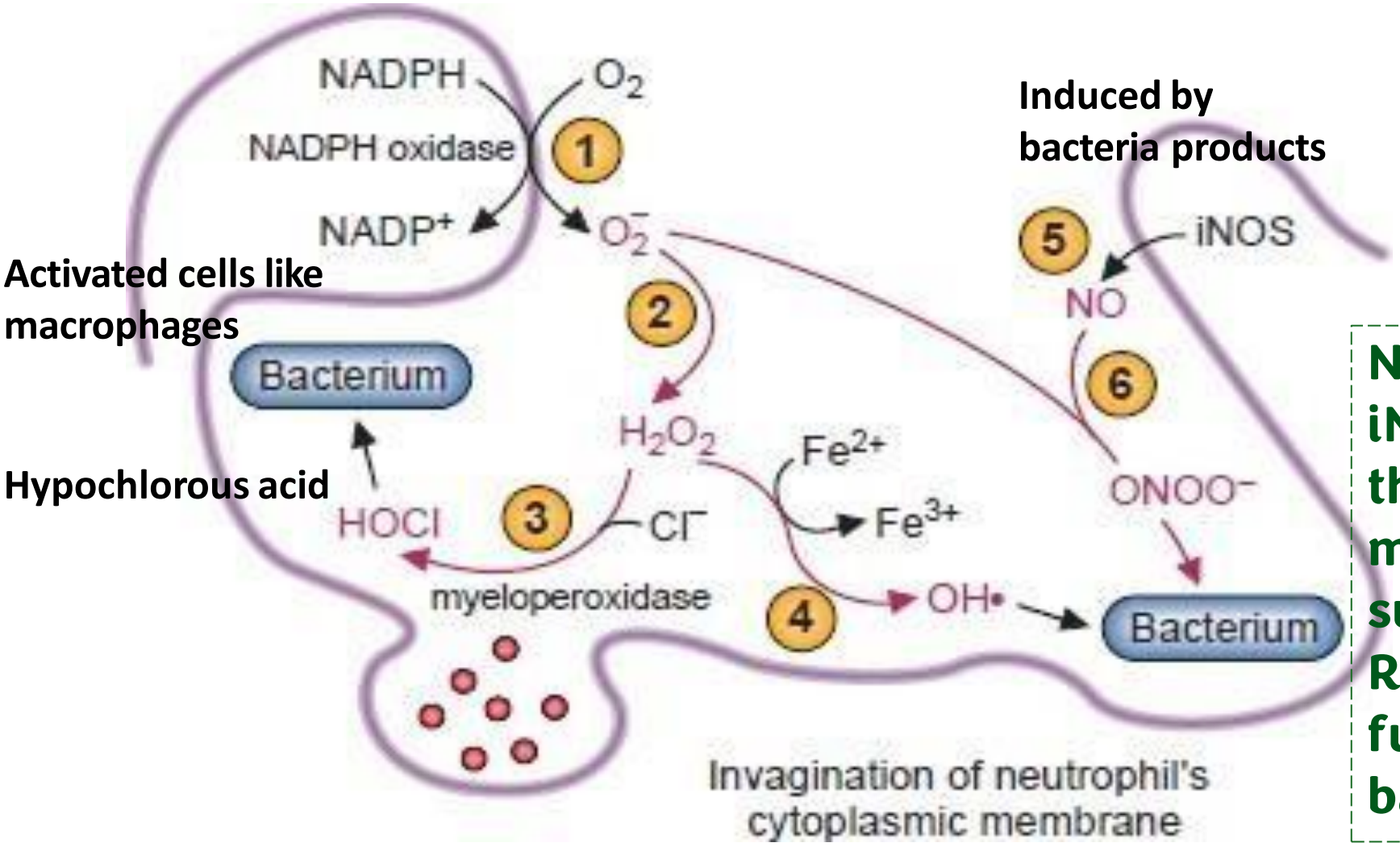
Synthesis by endothelia cells → smooth muscle

Protein Kinase G

Phosphorylation of Ca^{2+} channels

↓↓Ca^{2+} entry into smooth muscle cells and causes muscle relaxation and lowers blood pressure

NO role during bacterial infections



NO is synthesized by iNOS, which diffuses through phagolysosomal membrane reacting with superoxide to produce RNOS ($ONOO^-$) which furthermore aids in bacterial killing.

Test your knowledge:

What are the differences between NADPH and NADH in terms of their roles in the cell? Q.1

A. NADPH is used for energy production, while NADH is for biosynthesis.

B. NADPH is primarily used in the Krebs cycle, while NADH is used in the electron transport chain.

C. NADPH is for biosynthesis; NADH is for energy production.

D. NADPH is found in the mitochondria, while NADH is in the cytosol.

What is the relationship between NADPH and reactive oxygen species (ROS)? Q.2

A. NADPH promotes the formation of reactive oxygen species.

B. NADPH has no relationship with reactive oxygen species.

C. NADPH is converted to NADH in the presence of ROS.

D. NADPH reduces reactive oxygen species, preventing damage.

What is the impact of oxidative stress on red blood cells? Q.3

A. It leads to increased production of hemoglobin, improving oxygen transport.

B. It promotes the regeneration of antioxidants, protecting red blood cells.

C. It enhances the flexibility of red blood cells, allowing better circulation.

D. It causes protein denaturation and hemolysis in red blood cells.

What are the main products generated by the oxidative phase of the PPP?

Q.4

A. Ribose-5-phosphate and CO2

B. ATP and NADH

C. NADH and CO2

D. NADPH and CO2

What role does NADPH play in maintaining glutathione in red blood cells?

Q.5

A. NADPH is involved in the synthesis of hemoglobin in red blood cells

B. NADPH helps in the formation of reactive oxygen species (ROS)

C. NADPH reduces oxidized glutathione (G-S-S-G) to GSH

D. NADPH is used to synthesize ATP in red blood cells

A 30-year-old woman presents with fatigue and jaundice. Blood tests reveal hemolytic anemia and elevated levels of oxidative stress markers. She has a history of consuming fava beans and is concerned about her health.

Q.6

What is the primary metabolic pathway affected in this patient?

A. Glycolysis is unaffected

B. Beta-oxidation is not involved

C. Krebs cycle remains intact

D. Pentose phosphate pathway is impaired

A 30-year-old man of Mediterranean descent presents with sudden fatigue, pallor, and dark urine after consuming fava beans during a family gathering. He reports a history of similar episodes triggered by certain medications.

Q.7

What is the most likely cause of his symptoms?

A. Thalassemia

B. Sickle Cell Anemia

C. G6PD Deficiency

D. Iron Deficiency Anemia

What is the significance of the ratio of NADP+/NADPH in hepatocytes?

Q.8

A. It reflects the energy status of the hepatocyte.

B. It influences the synthesis of ATP in the mitochondria.

C. It indicates the level of oxidative stress in the cell.

D. It supports biosynthesis and detoxification processes.

Which tissues primarily utilize NADPH for fatty acid biosynthesis?

Q.9

A. Brain tissue

B. Muscle tissue

C. Kidney tissue

D. Liver, adipose tissue, lactating mammary glands

How does G6PD deficiency provide resistance to malaria?

Q11

A. It increases oxidative stress, impairing malaria survival.

B. It leads to increased levels of hemoglobin, which is toxic to malaria.

C. It enhances the immune response against malaria parasites.

D. It increases the production of red blood cells, reducing parasite load.

A 30-year-old woman is undergoing treatment for a chronic inflammatory disease. Her physician notes that her red blood cells are struggling to maintain reduced glutathione levels, which could lead to oxidative stress. The doctor discusses the role of NADPH in protecting against reactive oxygen species.

Q.13

How does NADPH contribute to maintaining red blood cell health?

A. It directly reduces hydrogen peroxide into water.

B. It converts NADH to NAD+ for energy production.

C. It helps keep glutathione in its reduced form.

D. It increases the production of superoxide radicals.

How does nitric oxide synthase contribute to the production of nitric oxide?

Q.10

A. Nitric oxide synthase converts L-arginine to nitric oxide using coenzymes.

B. Nitric oxide synthase breaks down nitric oxide into reactive nitrogen species.

C. Nitric oxide synthase converts L-citrulline to nitric oxide using oxygen.

D. Nitric oxide synthase synthesizes nitric oxide from glucose and regulates blood sugar levels.

What is the importance of the respiratory burst in phagocytic cells?

Q.12

A. It helps in the attachment of pathogens to phagocytic cells.

B. It reduces inflammation during the immune response.

C. It promotes the production of antibodies against pathogens.

D. It generates reactive oxygen species to kill pathogens.

How does the structure of glutathione contribute to its function as an antioxidant?

Q.14

A. Glutathione's structure allows it to bind to metal ions, enhancing its antioxidant capacity.

B. The tripeptide structure of glutathione prevents it from being oxidized easily, making it a stable antioxidant.

C. Glutathione's amino acid composition allows it to form stable complexes with free radicals, neutralizing them.

D. The thiol group in cysteine allows glutathione to act as a reducing agent.

Answers:

1. C
2. D
3. D
4. D
5. C
6. D
7. C
8. D/C
9. D
10. A
11. A
12. D
13. C
14. D

For any feedback, scan the code or click on

Corrections from previous versions:

Versions	Slide # and Place of Error	Before Correction	After Correction
V0 → V1	Test your knowledge Slide 17, text box, figure on the far right	--- Site of oxidation and reduction	Q15 is omitted Q8 has two possible answers Site of oxidation
V1 → V2			

Additional Resources:

رسالة من الفريق العلمي:

Extra References for the Reader to Use:

1. **Lippincott Illustrated Reviews 18th edition chapter 13.**

دمشق يا أم العواصم.

M.Z.