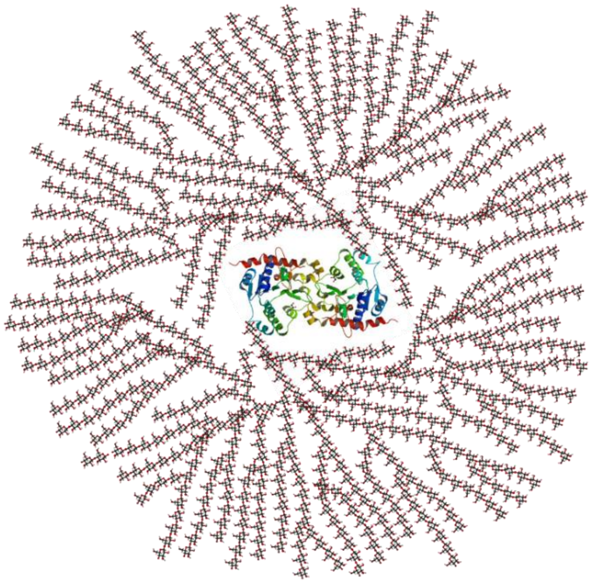
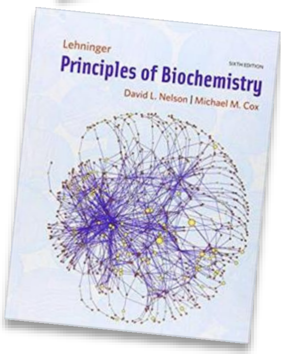
Carbohydrate metabolism



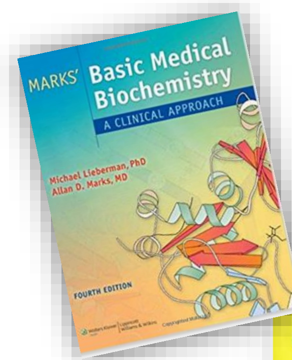
Chadamas Sakonsinsiri
Department of Biochemistry, MD, KKU

References

- Voet D, Pratt CW and Voet JG. Principles of Biochemistry. 4th ed. New Jersey: John Wiley & Sons, 2012

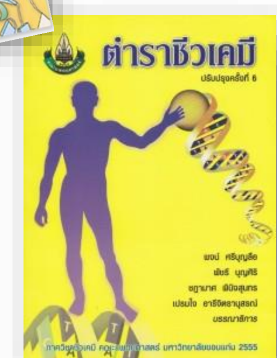


- Nelson DL. and Cox MM. Lehninger Principles of Biochemistry. 6th ed. New York : W.H. Freeman and Company, 2013



- Michael Lieberman, *et al.*, Marks' Essential Medical Biochemistry, Lippincott Williams & Wilkins, 2007

- พจน์ ศรีบุญลือ และคณะ. “ตำราชีวเคมี” ภาควิชาชีวเคมี คณะแพทยศาสตร์ มหาวิทยาลัยขอนแก่น. พิมพ์ครั้งที่ 6. โรงพิมพ์คลังนานาวิทยา, ขอนแก่น, 2555



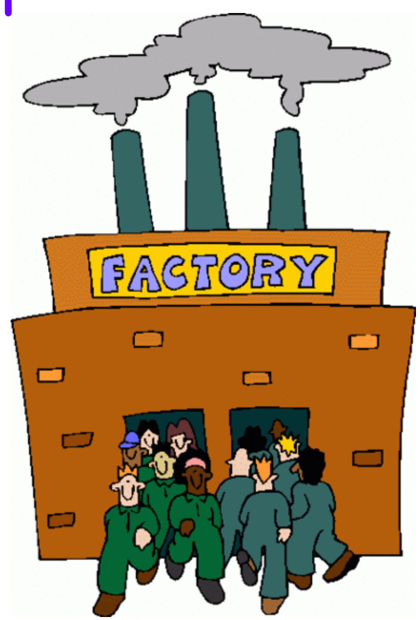
Outline

- Energy production from carbohydrates: glucose
  - Glycolysis
  - Krebs cycle (TCA, citric acid cycle)
  - Electron transport system (ETS)
  - Cellular respiration : aerobic vs. anaerobic
  - Products of glucose breakdown
- Gluconeogenesis
- Pentose phosphate pathway & G6PD deficiency
- Glycogen metabolism: glycogenesis & glycogenolysis

ย่อยเป็น
น้ำตาล
โมเลกุลเดี่ยว

ดูดซึม เข้ากระแสเลือด
เข้าเซลล์

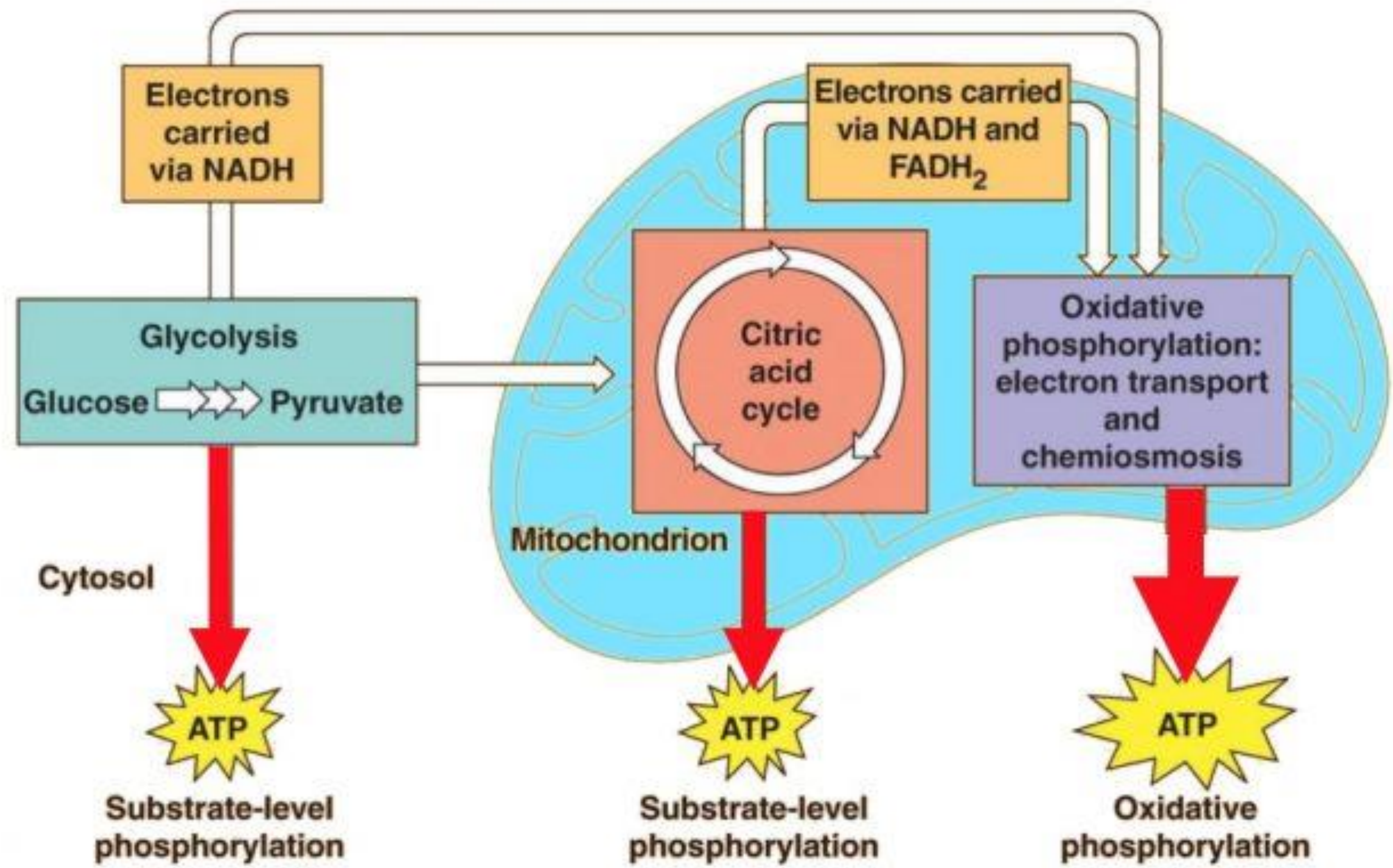
ATP ATP ATP



ชุดของปฏิกิริยาเคมีที่
เกิดขึ้นในเซลล์ =
metabolic pathways
**มีการควบคุม

Enzymes & coenzymes

Metabolic reactions occur in specific sites within cells



Major pathways of glucose utilization

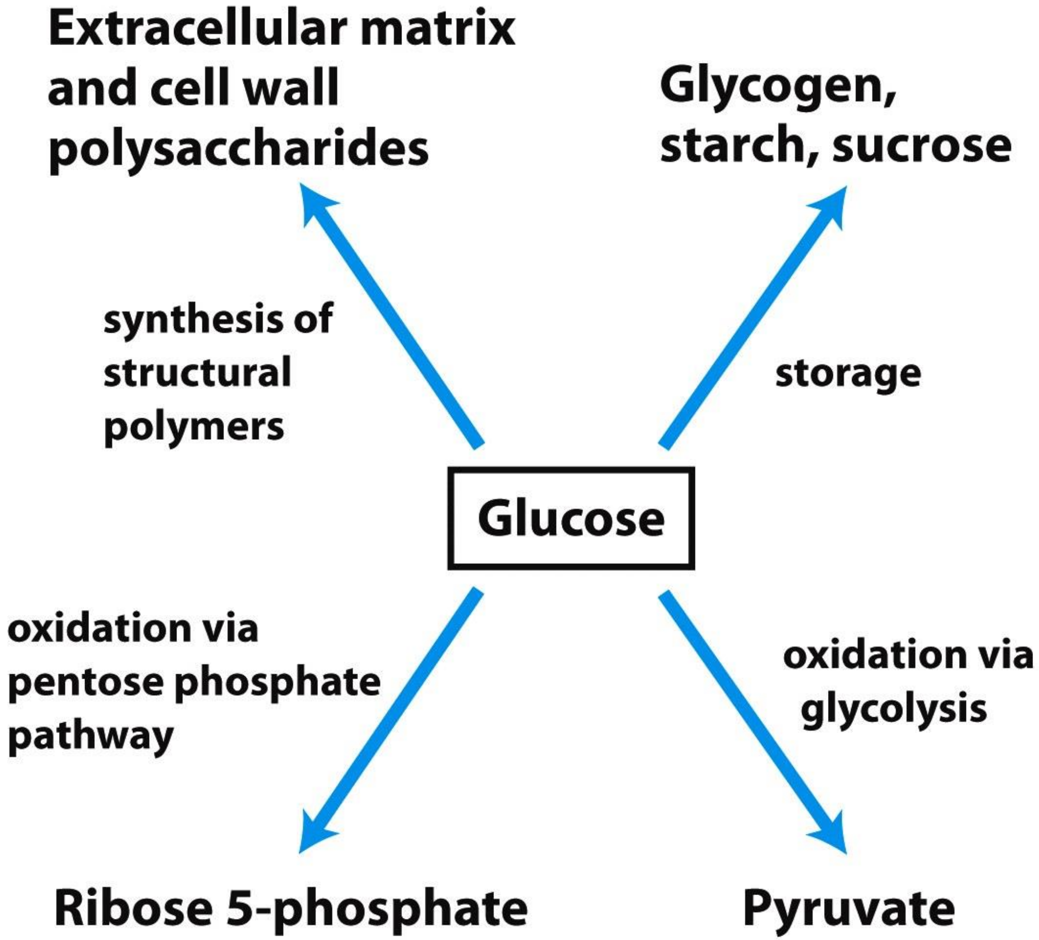
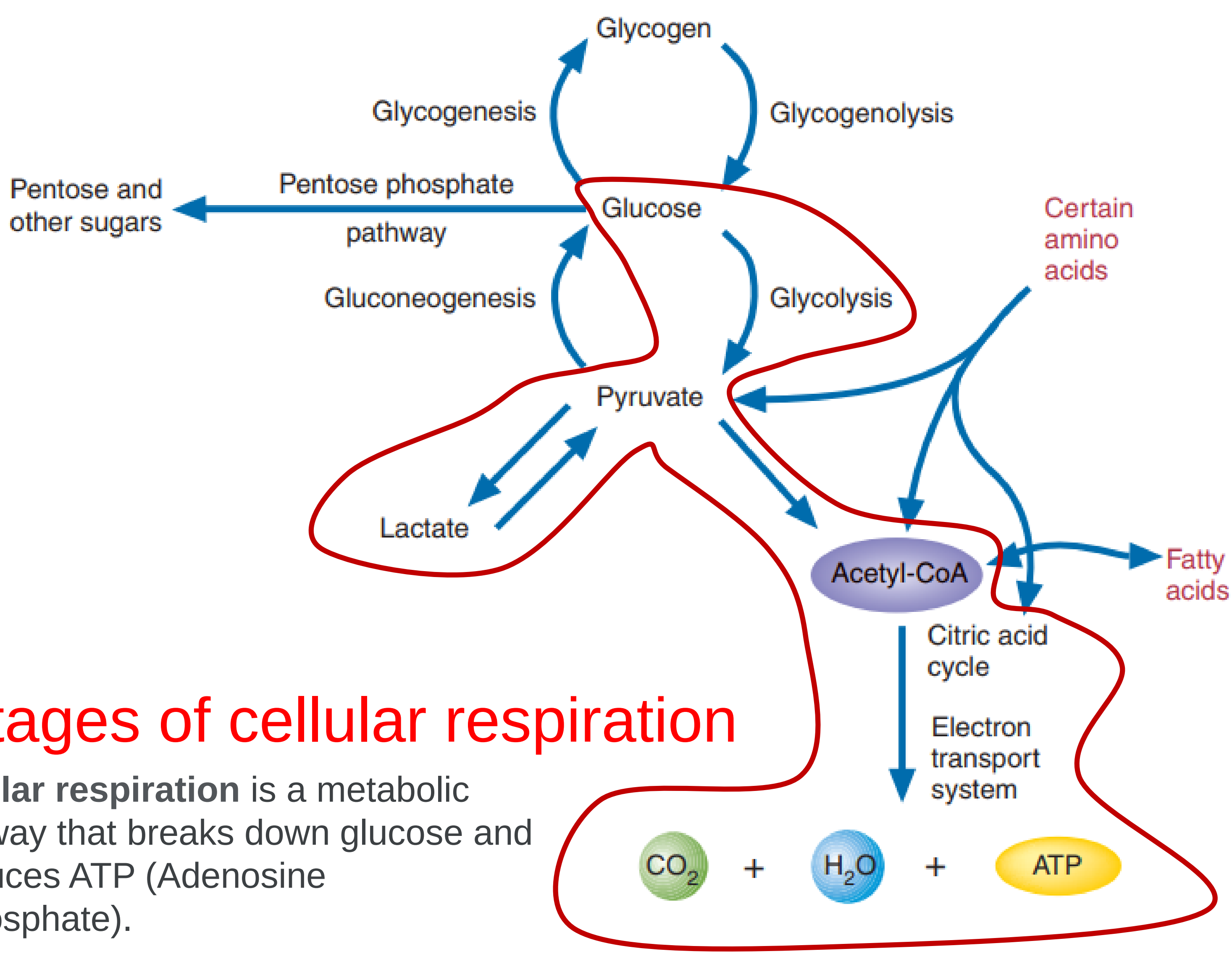


Figure 14-1
Lehninger Principles of Biochemistry, Fifth Edition

Major Pathways in Carbohydrate Metabolism



3 stages of cellular respiration

Cellular respiration is a metabolic pathway that breaks down glucose and produces ATP (Adenosine triphosphate).

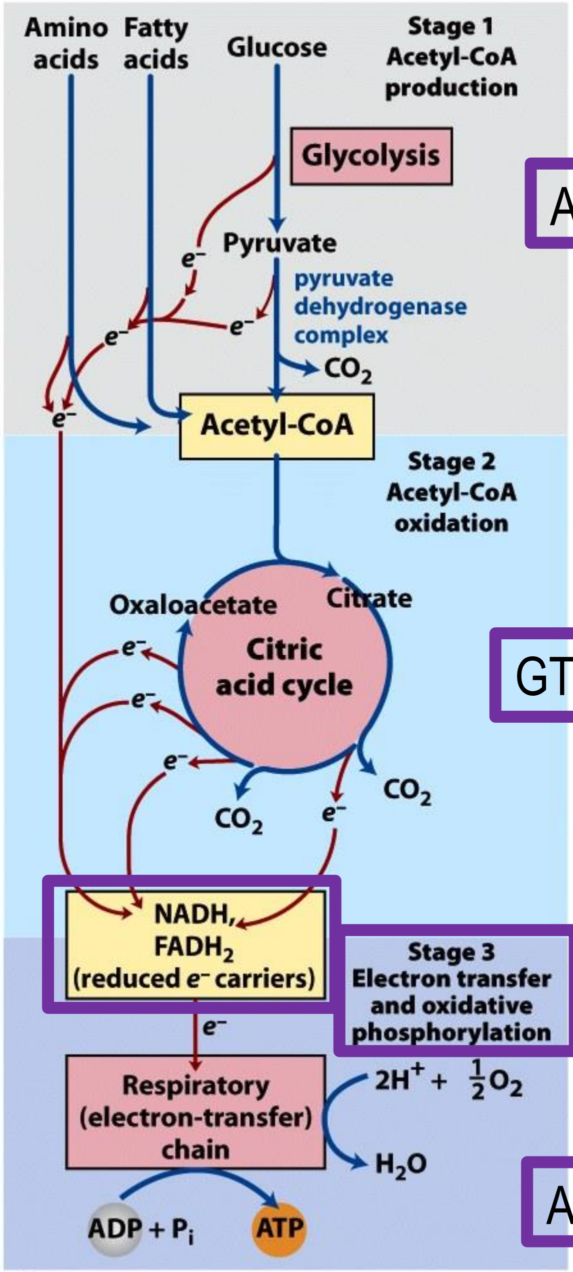
การหายใจระดับเซลล์

3 stages of cellular respiration

Cytoplasm —— **Glycolysis**

Mitochrondria

- **Krebs cycle**
- **ETS (electron transport system)**



ATP

GTP

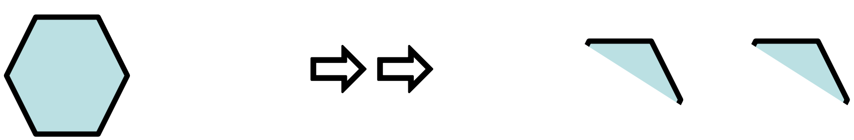
ATP

Figure 16-1
Lehninger Principles of Biochemistry, Fifth Edition

Glycolysis

- *Glyco* = sugar, *lysis* = breaking
- เกิดใน cytoplasm ของเซลล์
- 1 glucose ถูกออกซิไดส์เป็น 2 pyruvate และได้ 2 NADH + H^+ และ 2 ATP
- มี 10 ปฏิกิริยา และ 3 ใน 10 ปฏิกิริยา เป็น irreversible reaction
- แบ่งเป็น 2 ระยะ (Phase I and Phase II)

1 Glucose (C6) ⇨⇨ 2 pyruvate (C3)



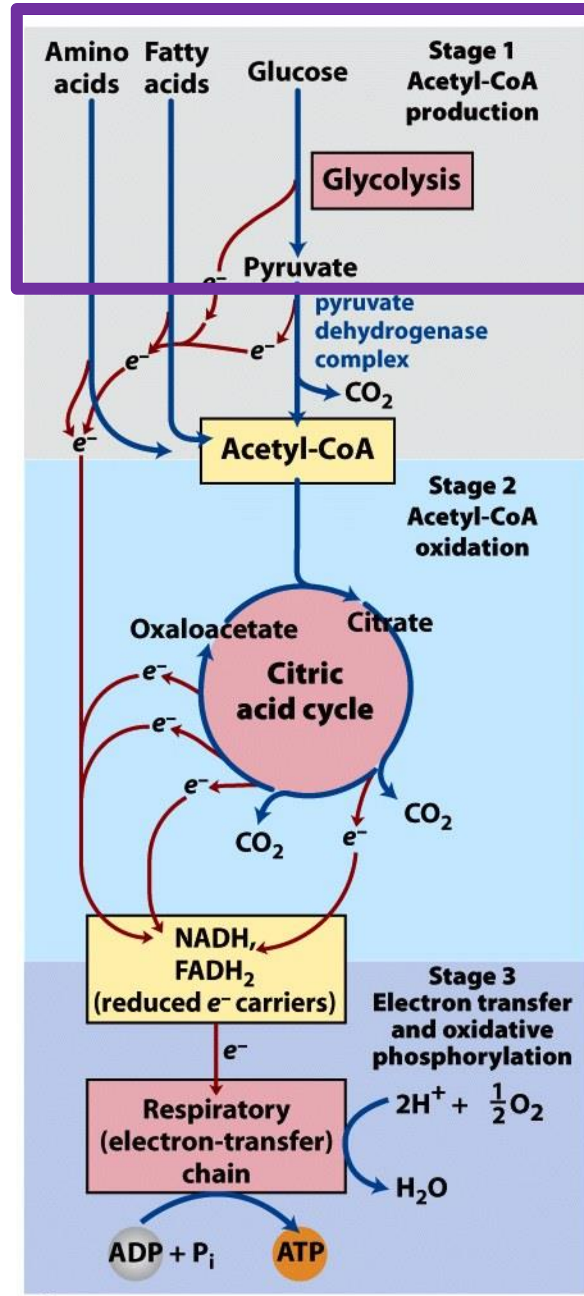


Figure 16-1
Lehninger Principles of Biochemistry, Fifth Edition

• Phase I preparatory phase (ต้องการ ATP)

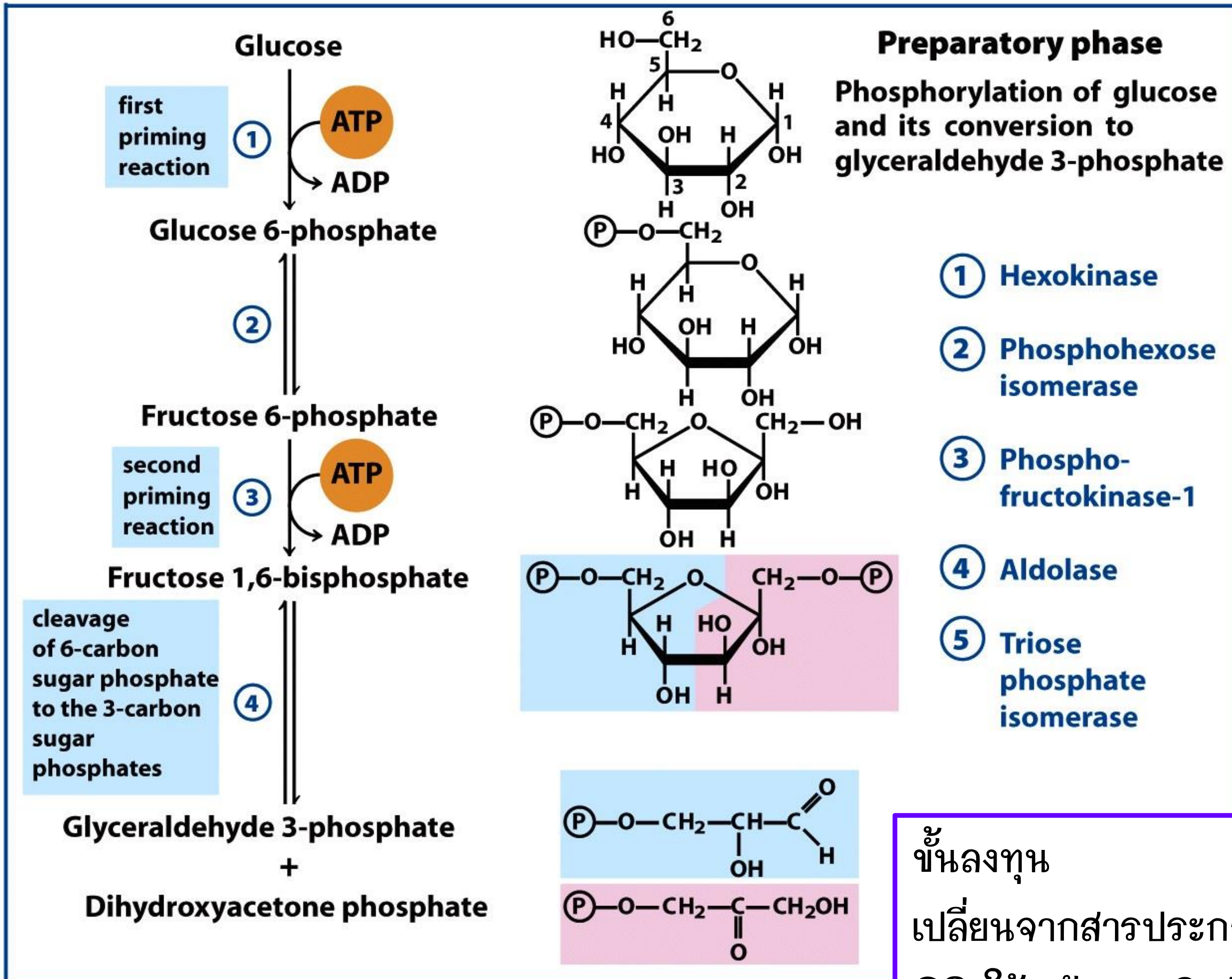


Figure 14-2a
Lehninger Principles of Biochemistry, Fifth Edition

G-3-P
DHAP

ขั้นลงทุน
เปลี่ยนจากสารประกอบ C6 เป็น C3 ใช้พลังงาน 2 ATP/1 Glc

• Phase II Payoff phase (ให้ ATPs and NADHs)

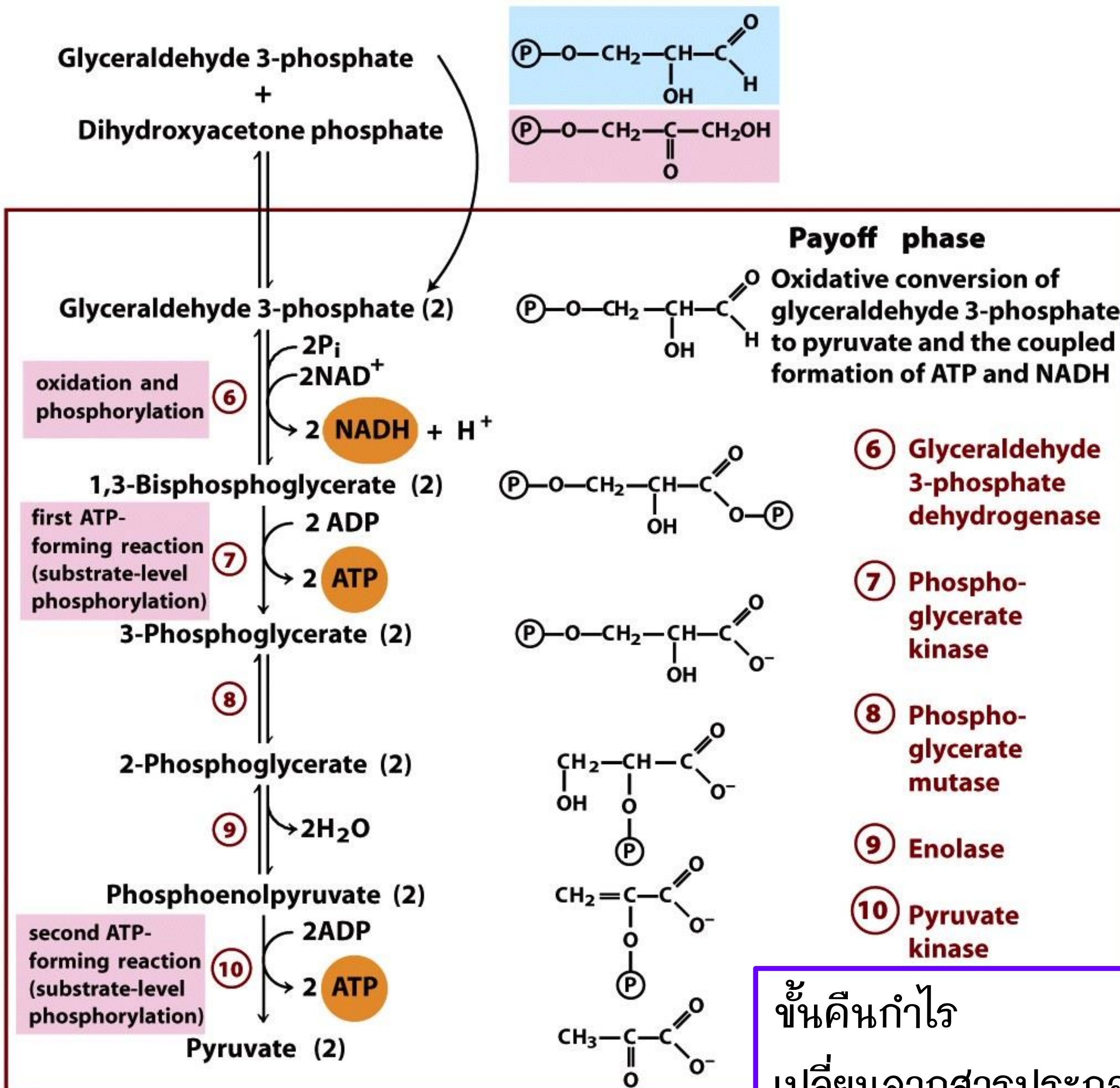


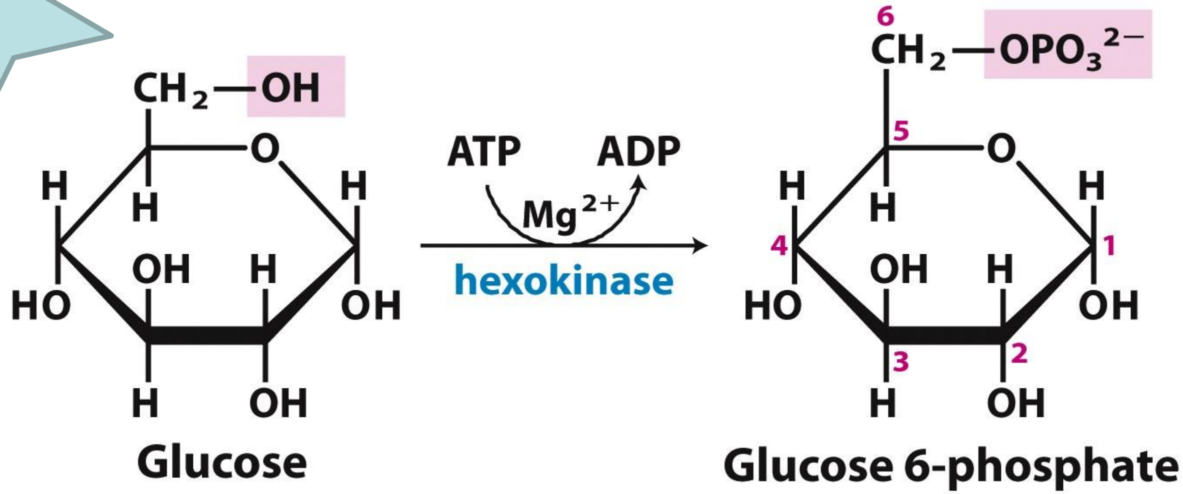
Figure 14-2b
Lehninger Principles of Biochemistry, Fifth Edition

ขั้นคืนกำไร

เปลี่ยนจากสารประกอบ C3 เป็น pyruvate ได้ ATP

Rnx 1 - Phosphorylation of glucose to glucose-6-phosphate

Phase II



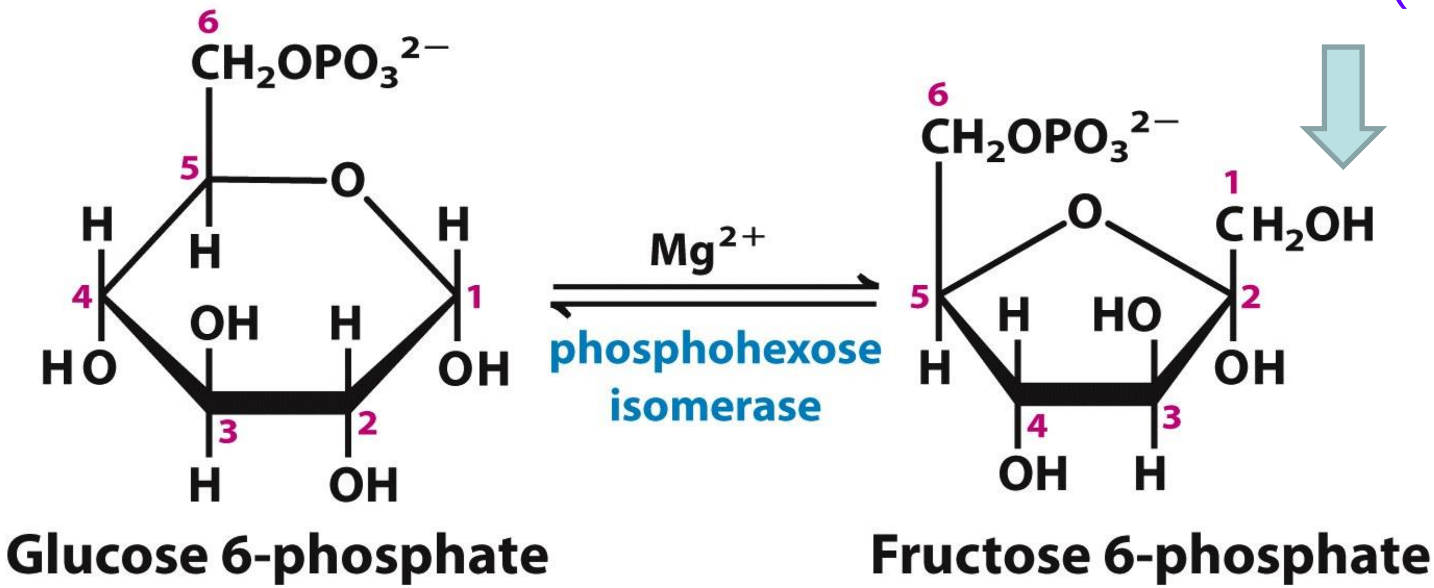
$$\Delta G'^{\circ} = -16.7 \text{ kJ/mol}$$

Unnumbered 14 p532a
Lehninger Principles of Biochemistry, Fifth Edition

- ใช้ ATP (Phosphate มาจาก ATP)
- เร่งปฏิกิริยาโดย hexokinase โดยการช่วยของ Mg^{2+}
- Irreversible reaction ผันกลับไม่ได้
- Phosphate group (มีขั้ว) ทำให้ออกนอกเซลล์ไม่ได้

Rnx 2 - Conversion of G-6-P to F-6-P

Primary OH
Reacts w/ other ATP to form FBP (next step)

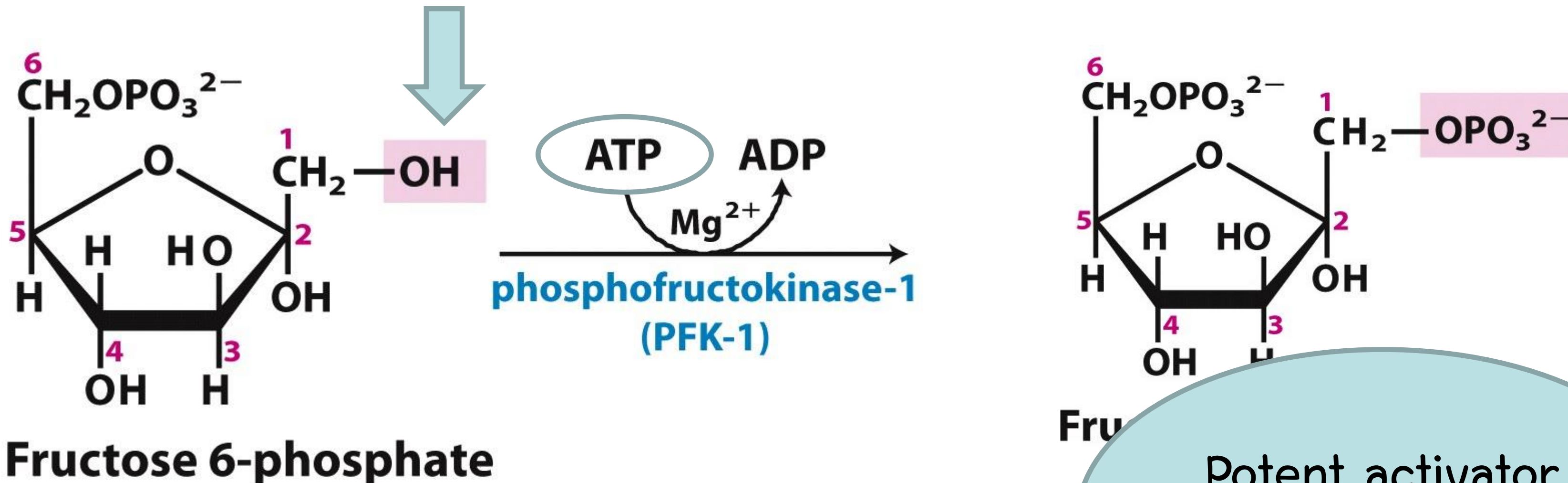


$\Delta G'^{\circ} = 1.7$ kJ/mol

Unnumbered 14 p532b
Lehninger Principles of Biochemistry, Fifth Edition

- Isomerization of an aldose to a ketose (G6P to F6G)
- Reversible reaction

Rnx 3 – Phosphorylation of F-6-P to FBP or F1,6P



Potent activator

สร้างจาก PFK-2

- ใช้ ATP ซึ่งเหมือน step แรก (hexokinase)
- Key point! PFK-1 ควบคุม วิถี glycolysis (Irreversible reaction & rate-determining reaction)

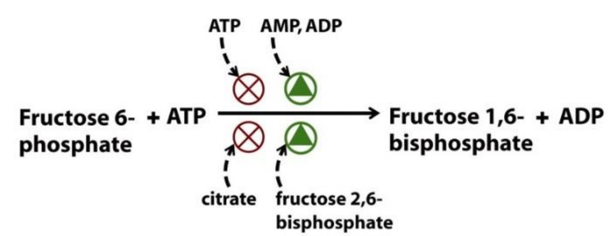
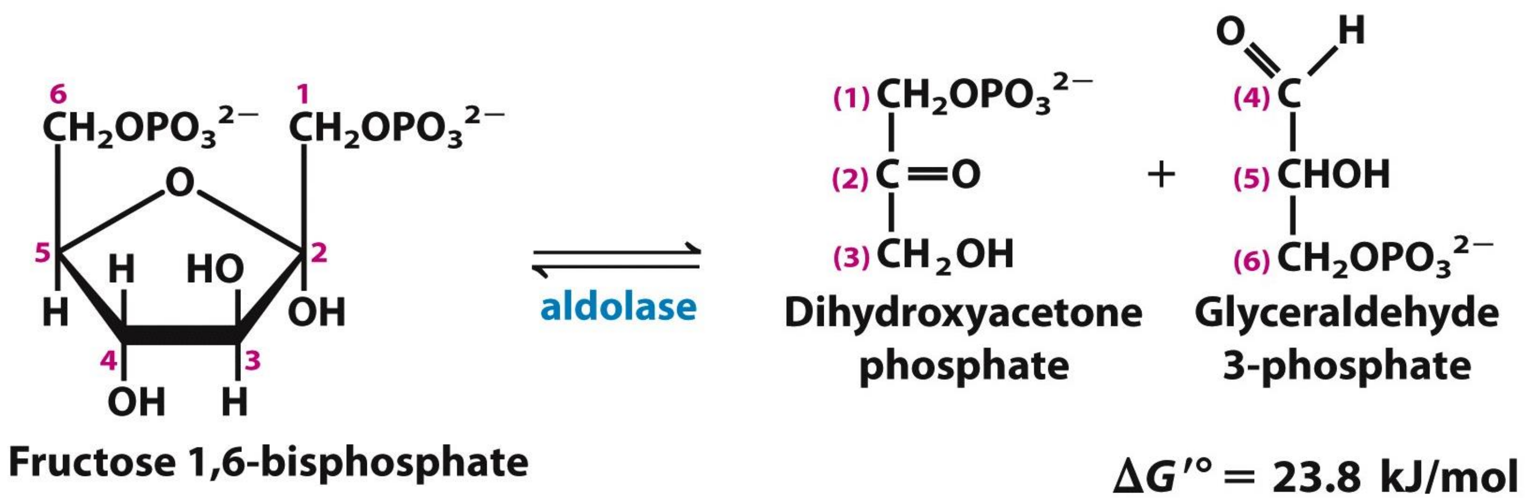


Figure 15-14c
Lehninger Principles of Biochemistry, Fifth Edition
© 2008 W.H. Freeman and Company

Effectors: Fructose-2,6-bisphosphate (F-2,6-BP), ATP/ADP, citrate

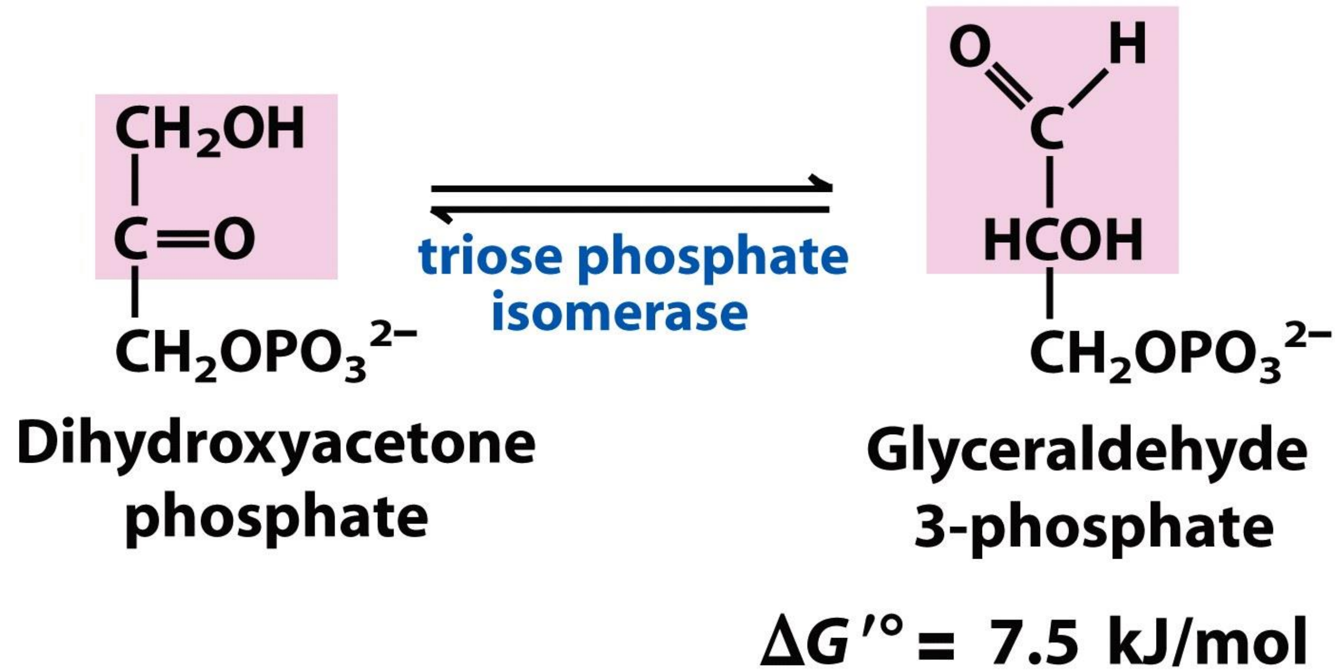
(Effectors = ตัวที่มีบทบาทในการควบคุม กระตุ้นหรือยับยั้ง

Rnx 4 – Cleavage of F-1,6-bis P



- Aldolase enzymatically cleaves a 6-carbon compound to two 3-carbon compounds (2 triose phosphates: DHAP and GAP).
- To complete Phase I, DHAP isomerises to GAP (Next reaction).

Rnx 5 – Inter-conversion of triose phosphates

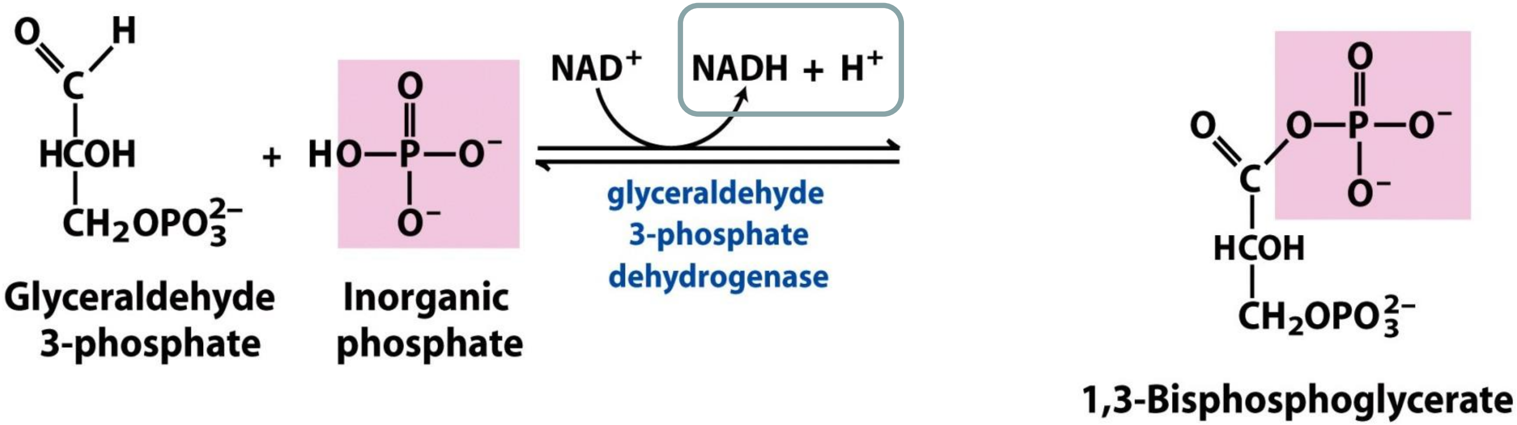


Unnumbered 14 p534
Lehninger Principles of Biochemistry, Fifth Edition

- DHAP and GAP are ketose-aldose isomers.
- Isomerization reaction.
- Convert DHAP to Glyceraldehyde-3-phospahte for the next reaction

Rnx 6 – Oxidation and phosphorylation of GAP by NAD^+ and Pi to 1,3-Bisphosphoglycerate

Phase II



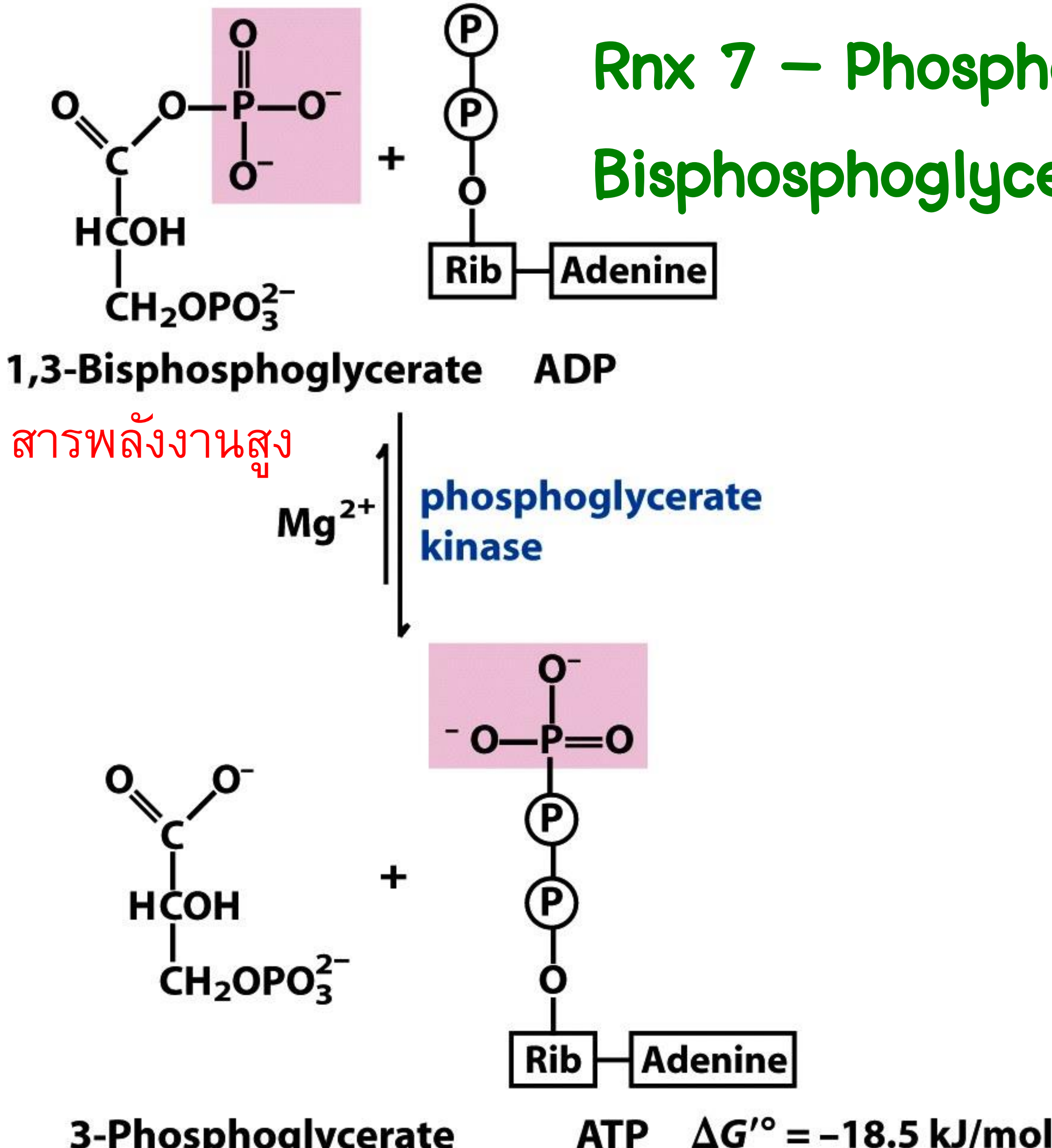
$\Delta G'^{\circ} = 6.3$ kJ/mol

สารพลังงานสูง

Unnumbered 14 p535
Lehninger Principles of Biochemistry, Fifth Edition

- Catalyzed by glyceraldehyde-3-phosphate DH.
- NAD^+ is the coenzyme and oxidizing agent (NAD+ reduces to NADH).
- Pi is the source of the phosphate.
- From the first "high energy phosphate compound" (1,3-BPG).

Rnx 7 – Phosphoryl transfer from 1,3-Bisphosphoglycerate to ADP

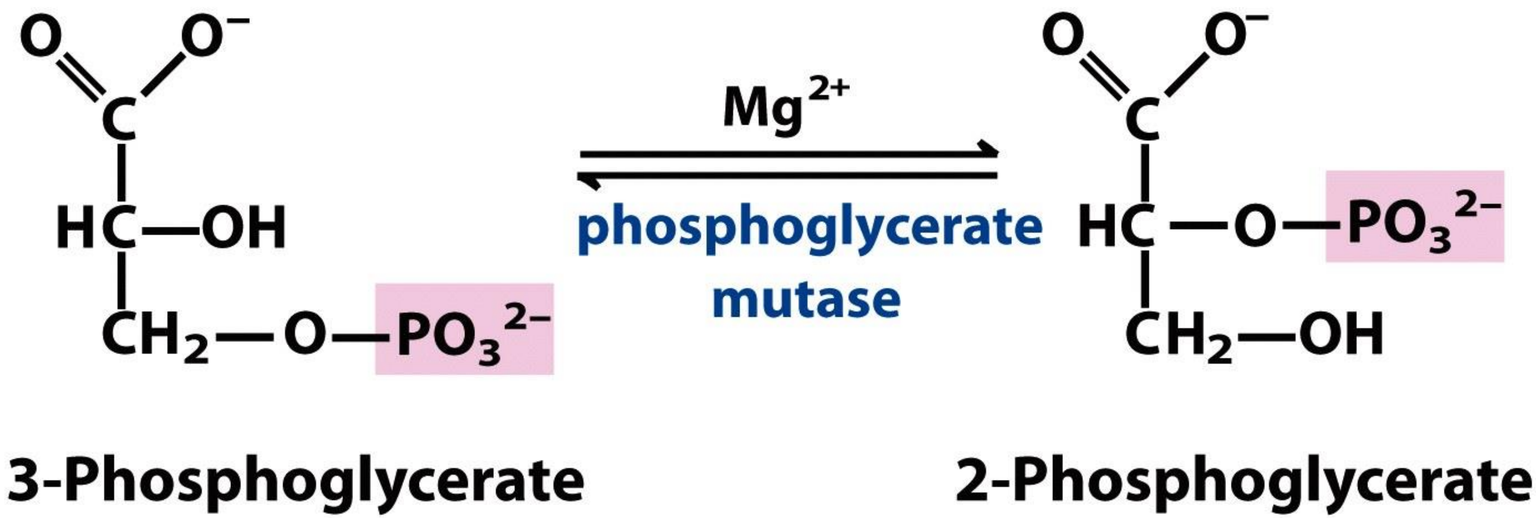


Unnumbered 14 p536

Lehninger Principles of Biochemistry, Fifth Edition

- Produces ATP and 3-phosphoglycerate
- Direct phosphate transfer; Substrate level phosphorylation (Differs from oxidative phosphorylation ซึ่งเกิดใน Electron Transport System)

Rnx 8 – Conversion of 3-PG to 2-PG

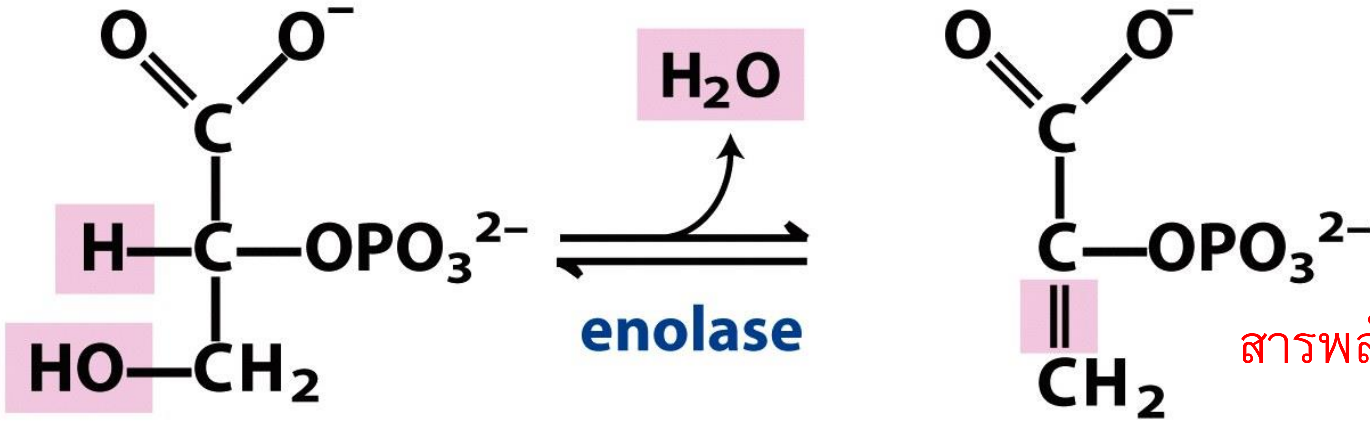


$\Delta G'^{\circ} = 4.4$ kJ/mol

Unnumbered 14 p537
Lehninger Principles of Biochemistry, Fifth Edition

- Phosphoglycerate mutase catalyzes the transfer of a phosphate group from C-3 to C-2

Rnx 9 – Dehydration of 2-PG to PEP



2-Phosphoglycerate

Phosphoenolpyruvate

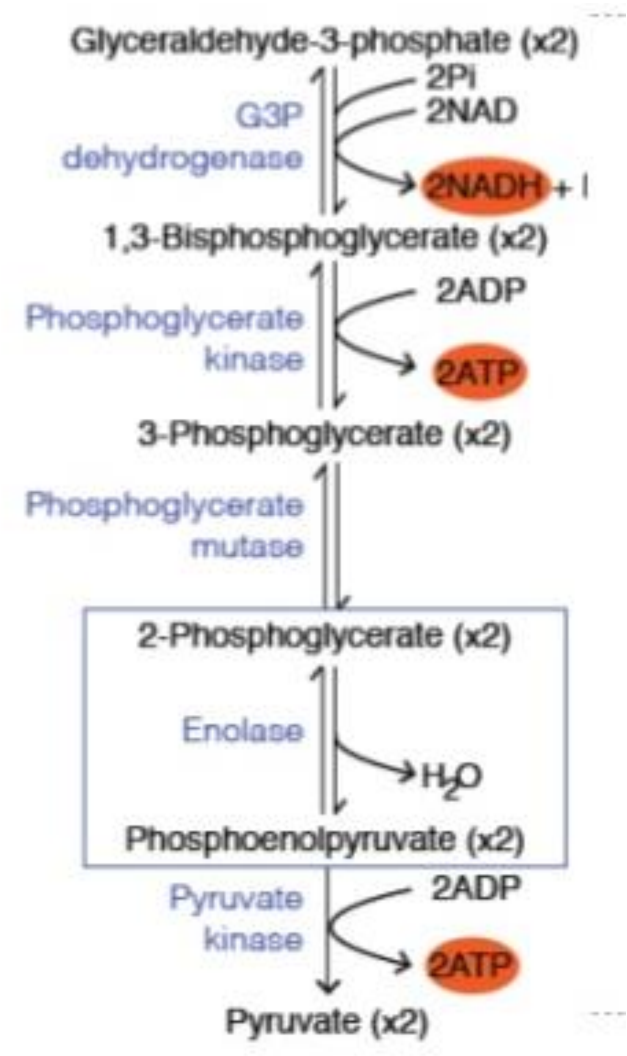
สารพลังงานสูง

$\Delta G'^{\circ} = 7.5$ kJ/mol

Unnumbered 14 p538a
Lehninger Principles of Biochemistry, Fifth Edition

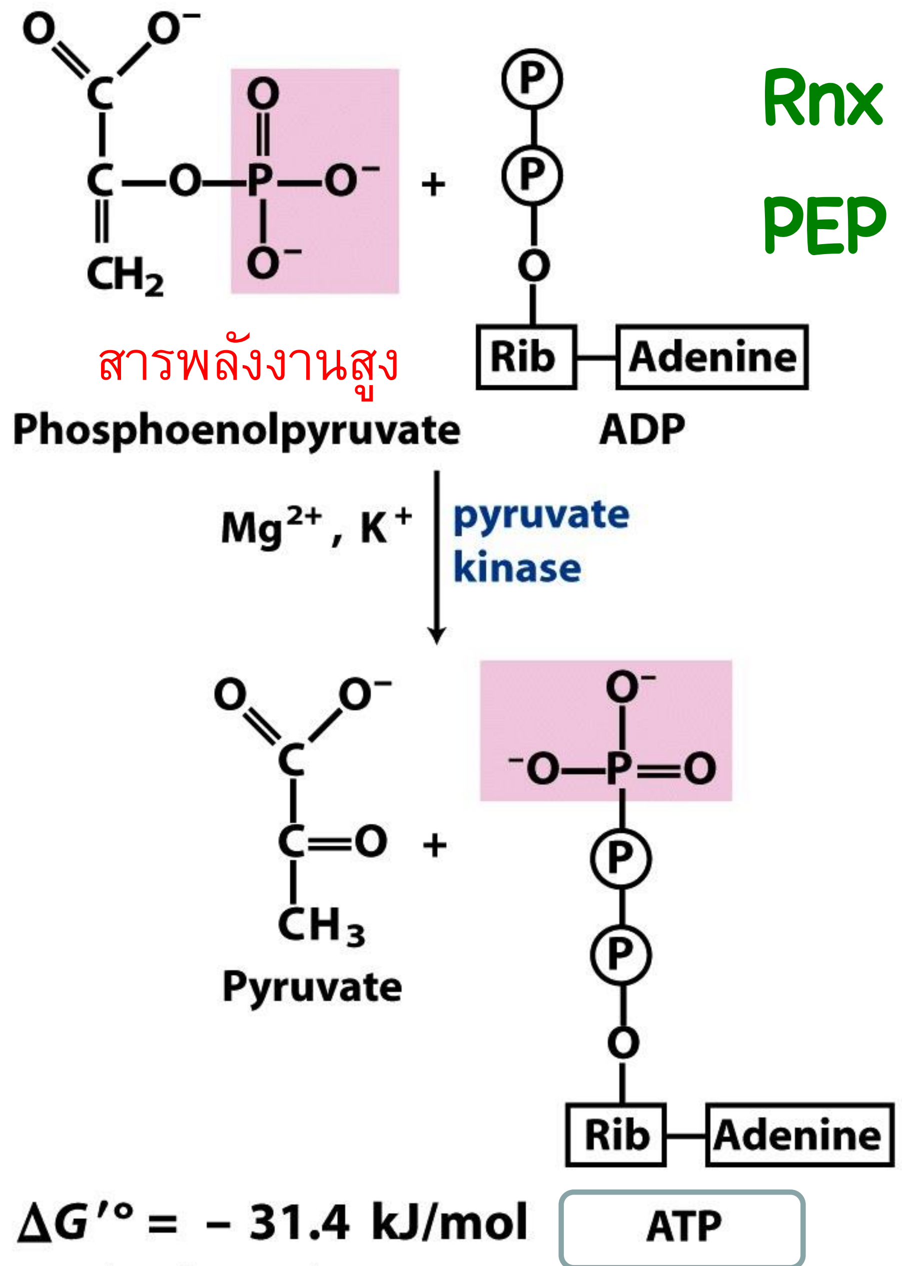
- Formation of a second "high energy" intermediate
- F^- เป็นตัวยับยั้ง Enolase

Fluoride blocks glycolysis by inhibiting the Mg^{2+}-dependent enzyme enolase



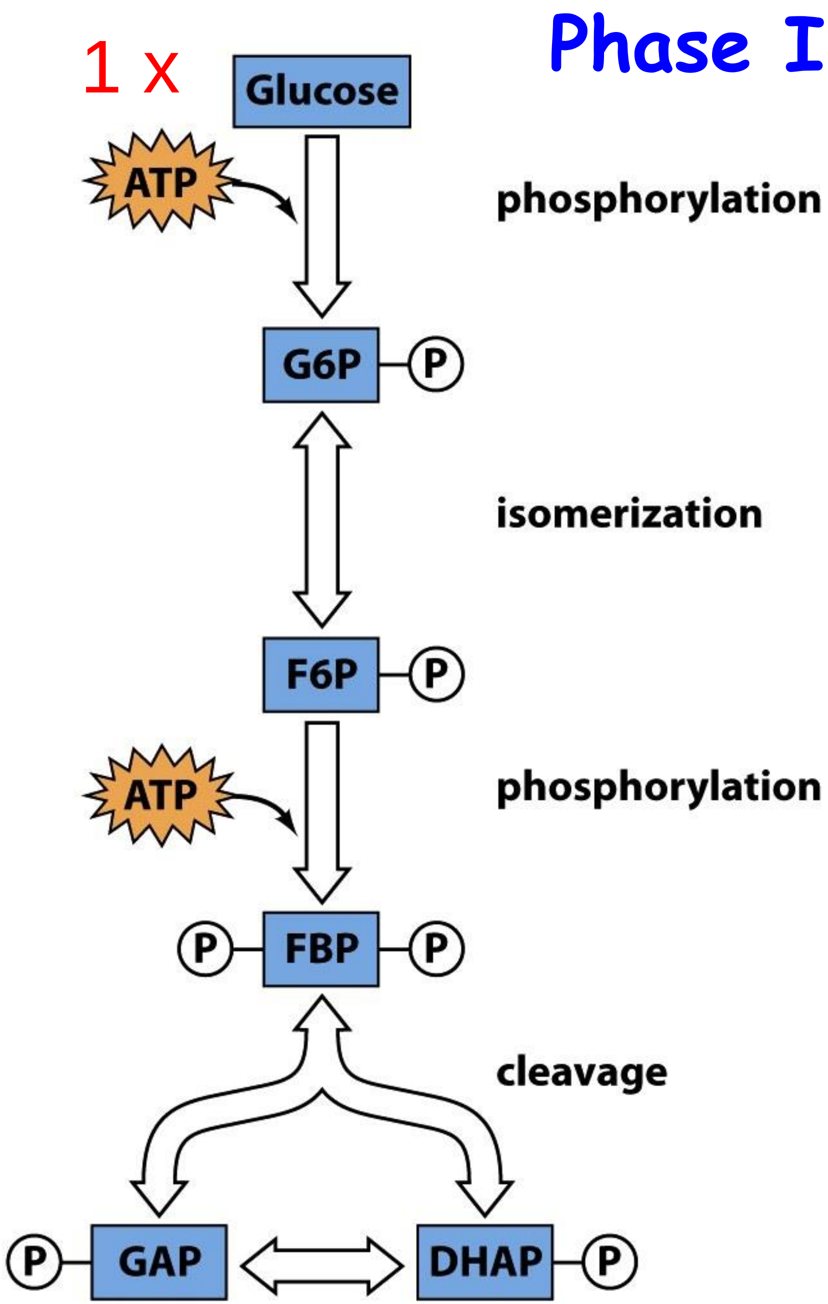
- Adding fluoride to toothpaste can prevent tooth decay
  - Common pathogens produce lactic acid
  - Inhibiting enolase → 2PG cannot get access to active site of enzyme

Rnx 10 – transfer of P from PEP to ADP

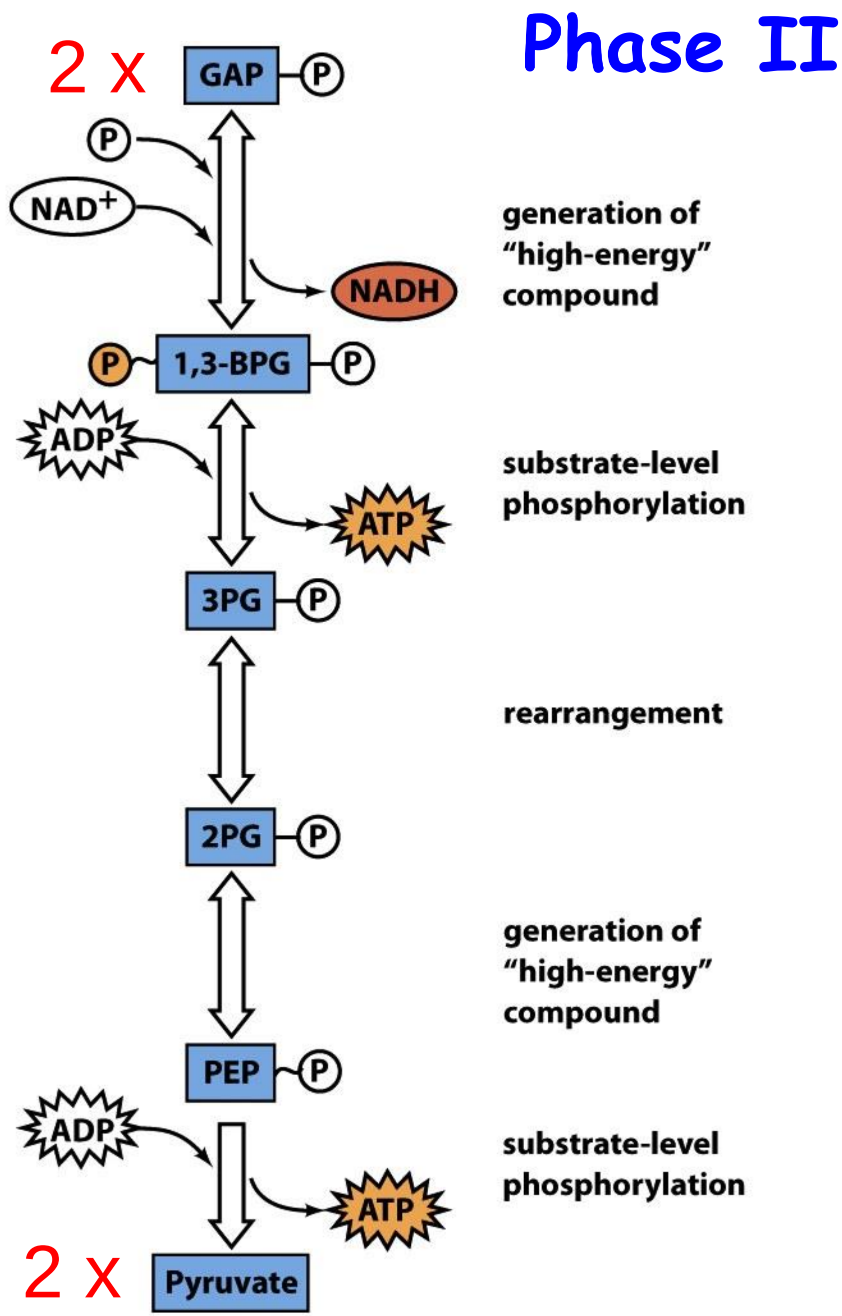


Unnumbered 14 p538b
Lehninger Principles of Biochemistry, Fifth Edition

- Formation of second ATP
- Irreversible (Secondary control point in glycolysis)
- Second substrate-level phosphorylation (ADP receives a phosphate group from the PEP)
- Pyruvate formed.



Phase I
1 x
Glucose
ATP
phosphorylation
G6P
P
isomerization
F6P
P
ATP
phosphorylation
P
FBP
P
cleavage
P
GAP
DHAP
P



Phase II
2 x
GAP
P
P
NAD+
NADH
generation of
“high-energy”
compound
P
1,3-BPG
P
ADP
ATP
substrate-level
phosphorylation
3PG
P
rearrangement
2PG
P
generation of
“high-energy”
compound
PEP
P
ADP
ATP
substrate-level
phosphorylation
2 x
Pyruvate

The net overall equation for the process of glycolysis:

$$\text{Glucose} + 2\,NAD^+ + 2\,ADP + 2\,P_i \longrightarrow 2\ \text{Pyruvate} + 2\,NADH + 2\,H^+ + 2\,ATP$$

Table 24-1 ATP Production and Consumption During Glycolysis

Step	Reaction	ATP Change per Glucose
1	Glucose → glucose 6-phosphate	−1
3	Fructose 6-phosphate → fructose 1,6-bisphosphate	−1
7	2(1,3-Bisphosphoglycerate → 3-phosphoglycerate)	+2
10	2(Phosphoenolpyruvate → pyruvate)	+2
		Net +2

NOTE: NAD^+ must be regenerated!

Fructose and galactose are converted into glycolytic intermediates

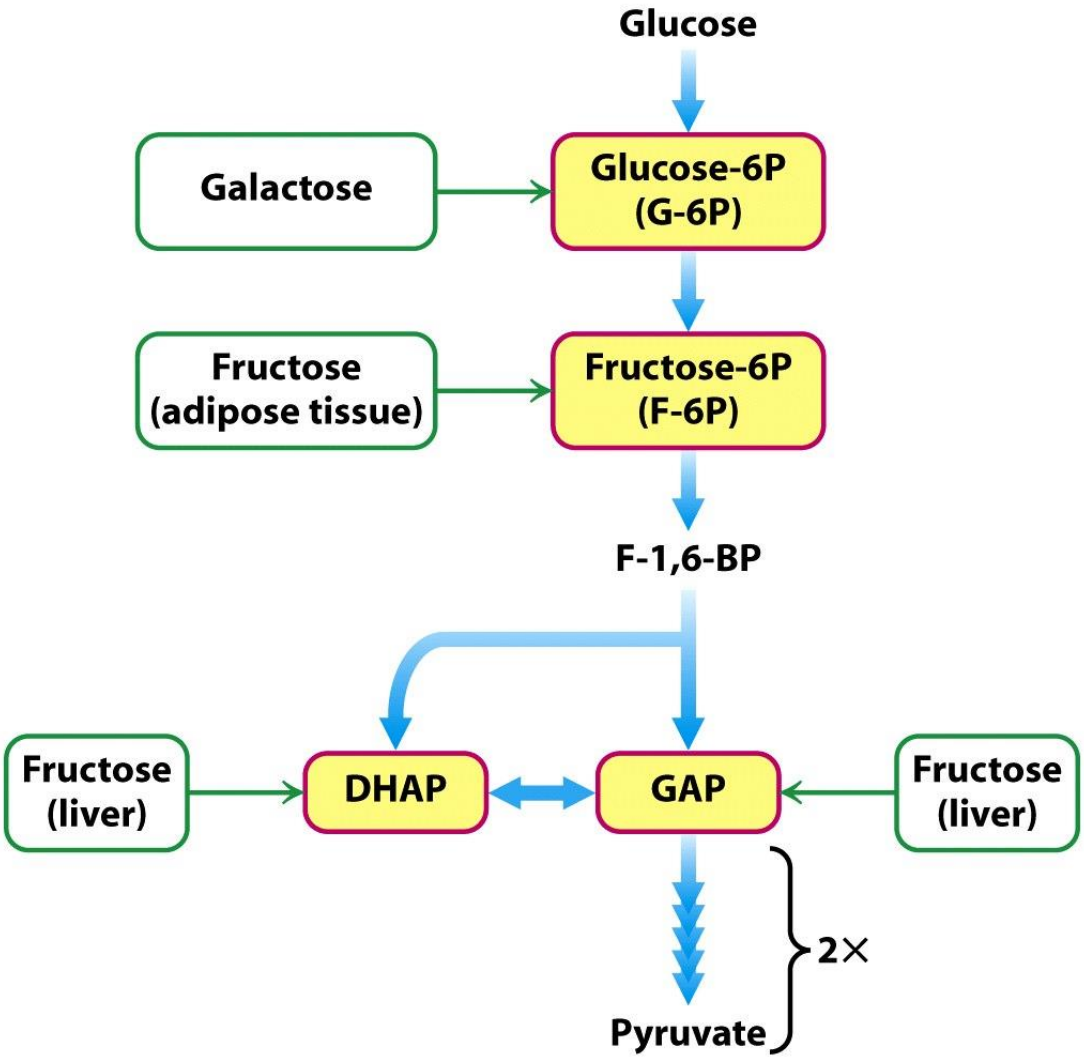


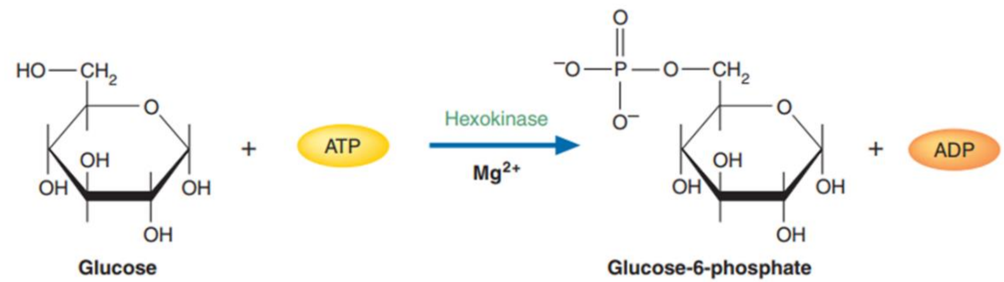
Figure 16-13
Biochemistry, Sixth Edition

Control of Glycolysis

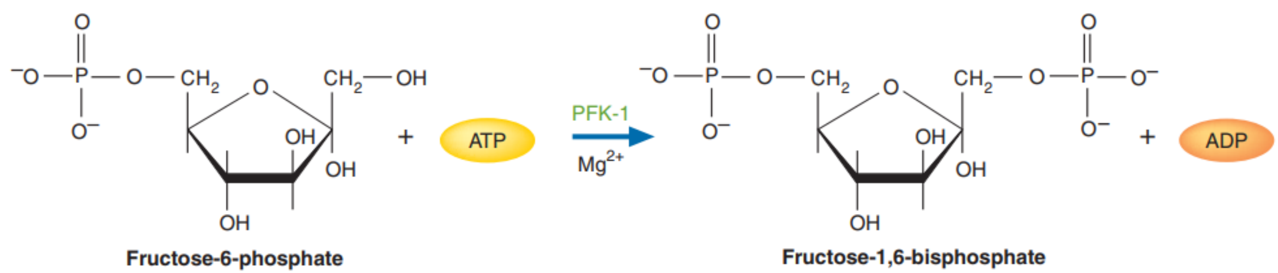
Local control involves dependence of enzyme-catalyzed reactions on concentrations of pathway substrates or intermediates within a cell.

3 key enzymes:

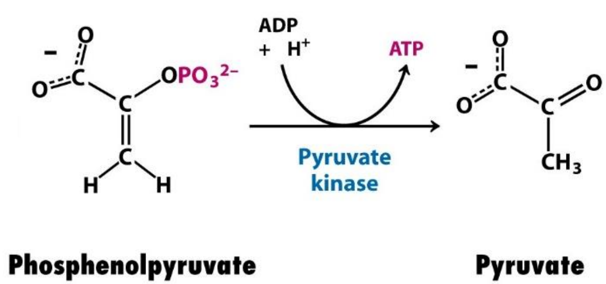
- Hexokinase
  - Rxn 1

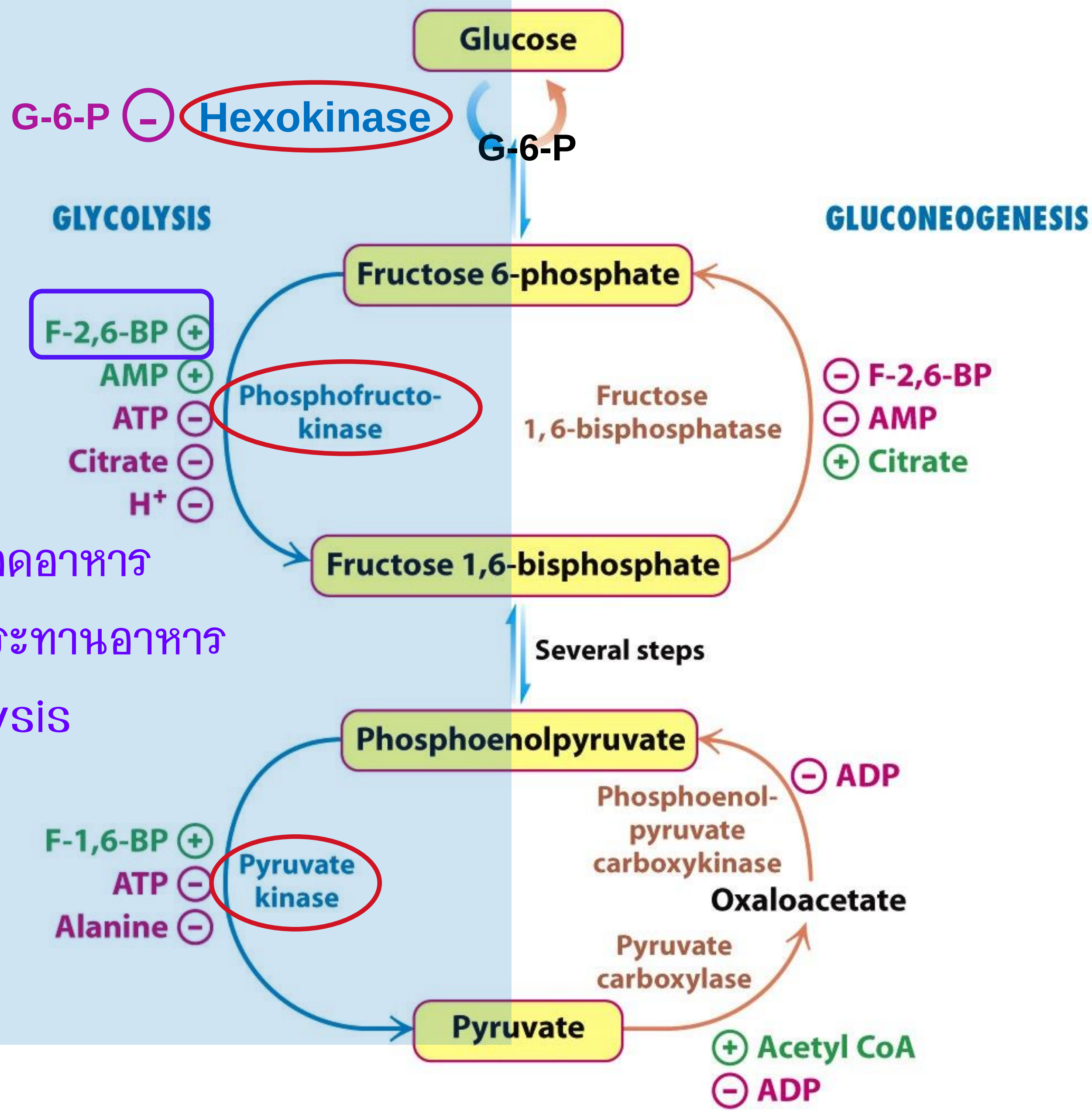


- Phosphofructokinase
  - Rxn 3



- Pyruvate kinase
  - Rxn 10





- ต่ำในภาวะอดอาหาร
- สูงเมื่อรับประทานอาหาร

เพิ่ม glycolysis

Figure 16-28
Biochemistry, Sixth Edition

Fates of pyruvate

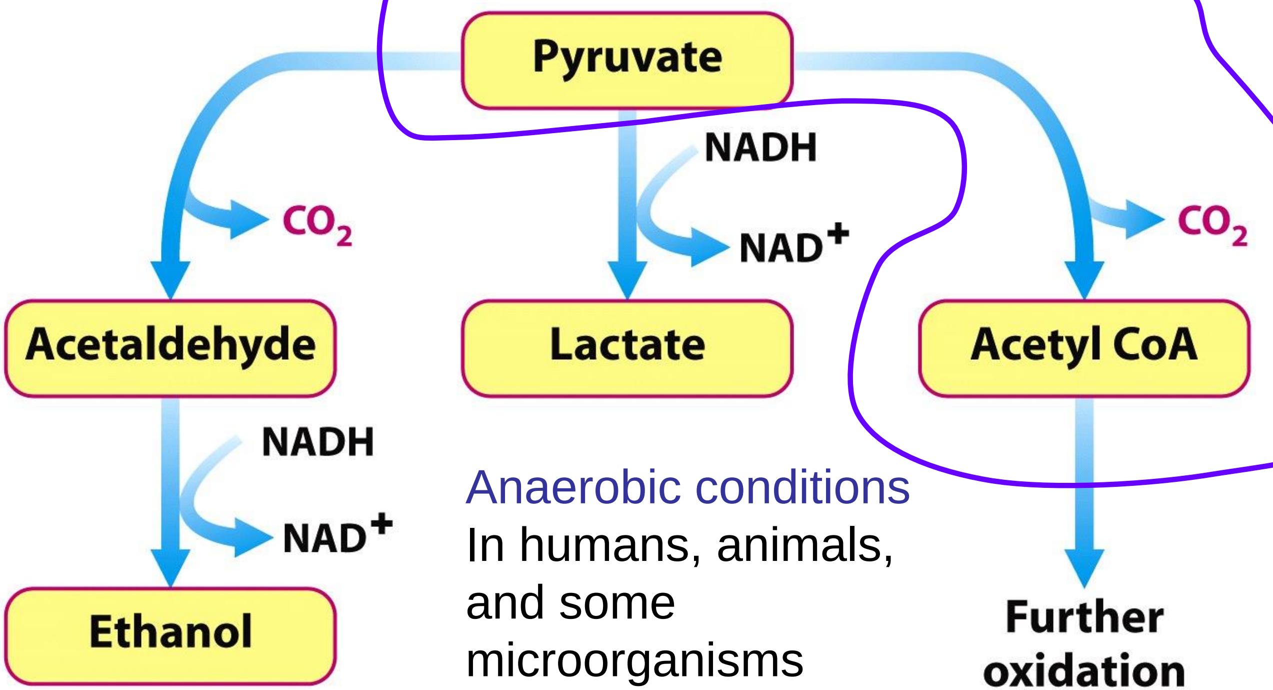


Figure 16-9
Biochemistry, Sixth Edition

Anaerobic conditions
In humans, animals, and some microorganisms

Anaerobic conditions
In some microorganisms

Aerobic conditions
In humans, animals, and some microorganisms

Hexokinase *versus* Glucokinase

- **Hexokinase** (all tissues)
  - Non-specific
  - K_M = ~100 μM
  - Inhibited by glucose-6-P (G-6-P)
- **Glucokinase** (primarily in liver)
  - Specific
  - K_M = ~10 mM
  - Not inhibited by glucose-6-P

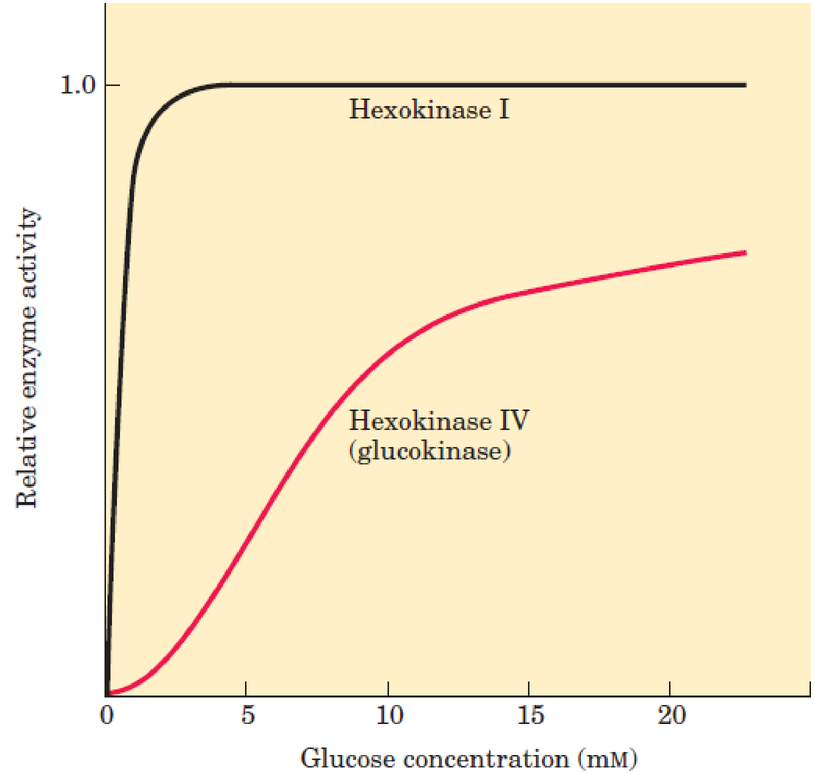
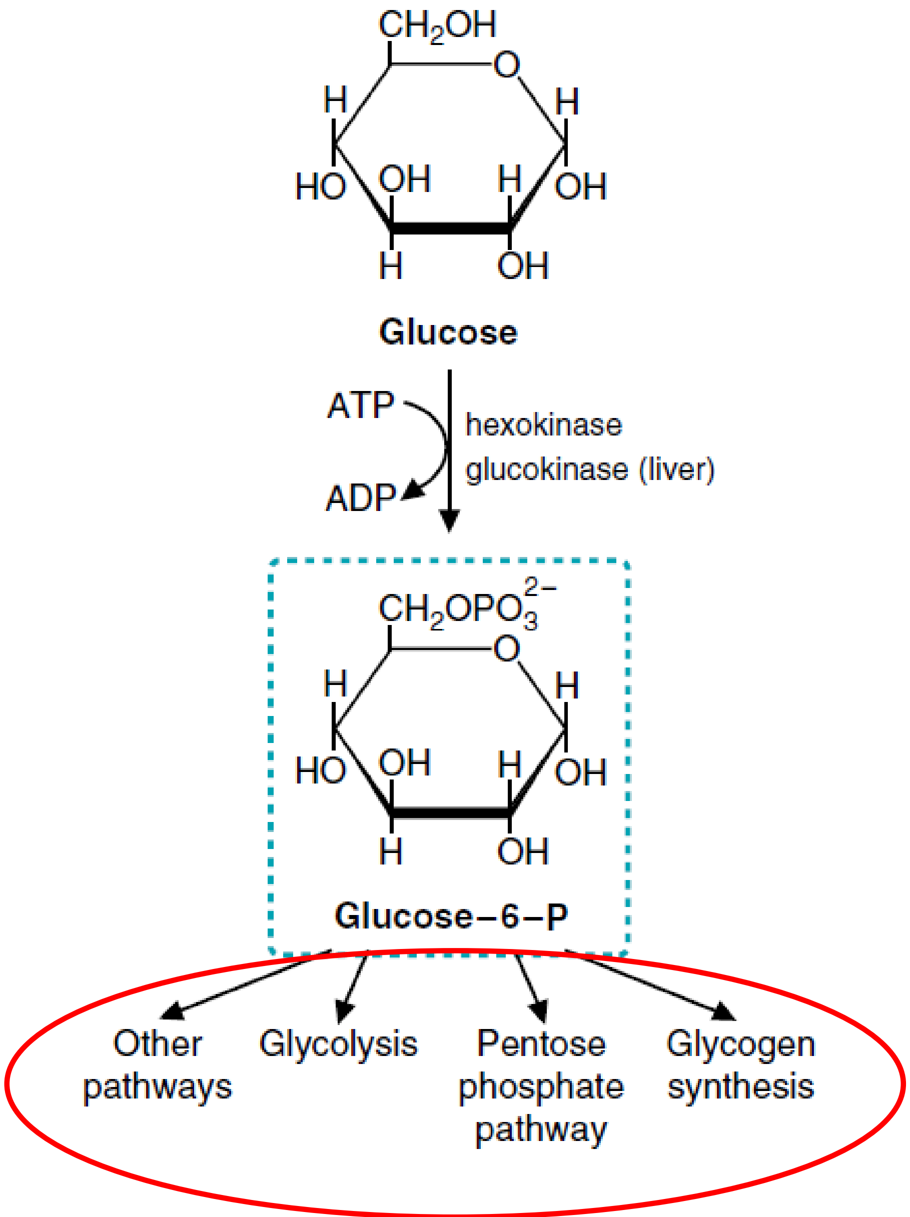


FIGURE 15–16 Comparison of the kinetic properties of hexokinase IV (glucokinase) and hexokinase I. Note the sigmoidicity for hexokinase IV and the much lower K_m for hexokinase I. When blood glucose rises above 5 mM, hexokinase IV activity increases, but hexokinase I is already operating near V_{max} at 5 mM glucose and cannot respond to an increase in glucose concentration. Hexokinase I, II, and III have similar kinetic properties.

Functional Rationale

- Most tissues: metabolize blood glucose which enters cells
  - Glc-6-P impermeable to cell membrane
  - Product inhibition
- Liver: maintain blood glucose
  - High blood glucose: glycogen
  - Low blood glucose: glycolysis

Metabolism of Glucose-6-P



Regulation!

Oxidation of pyruvate to Acetyl-CoA

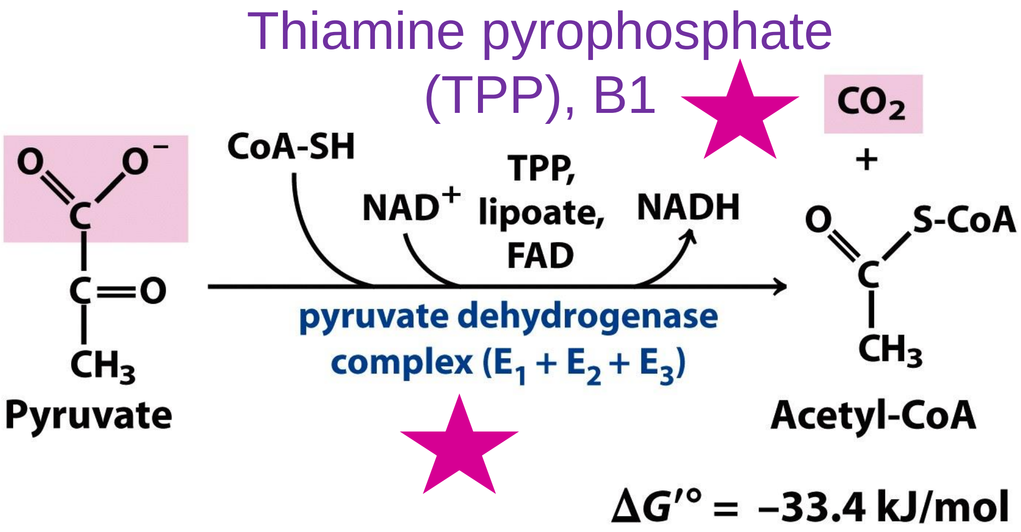
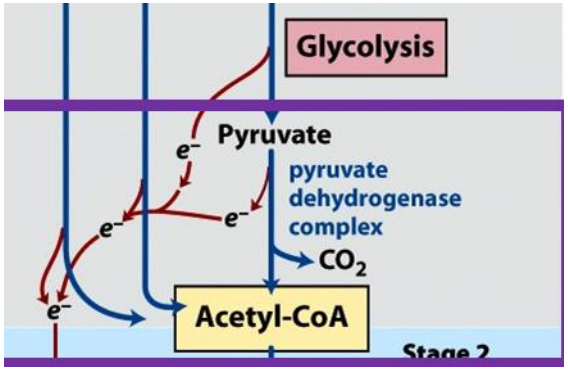


Figure 16-2
Lehninger Principles of Biochemistry, Fifth Edition



- Oxidation and decarboxylation
- เอนไซม์ที่ใช้คือ pyruvate dehydrogenase complex มีหลาย subunits และ active sites.
- ต้องการ coenzyme 5 ชนิด CoA-SH, NAD+, FAD, lipoic acid and TPP
- Acetyl-CoA เข้าสู่ TCA cycle

3 stages of cellular respiration

Glycolysis

Krebs cycle

ETS (electron transport system)

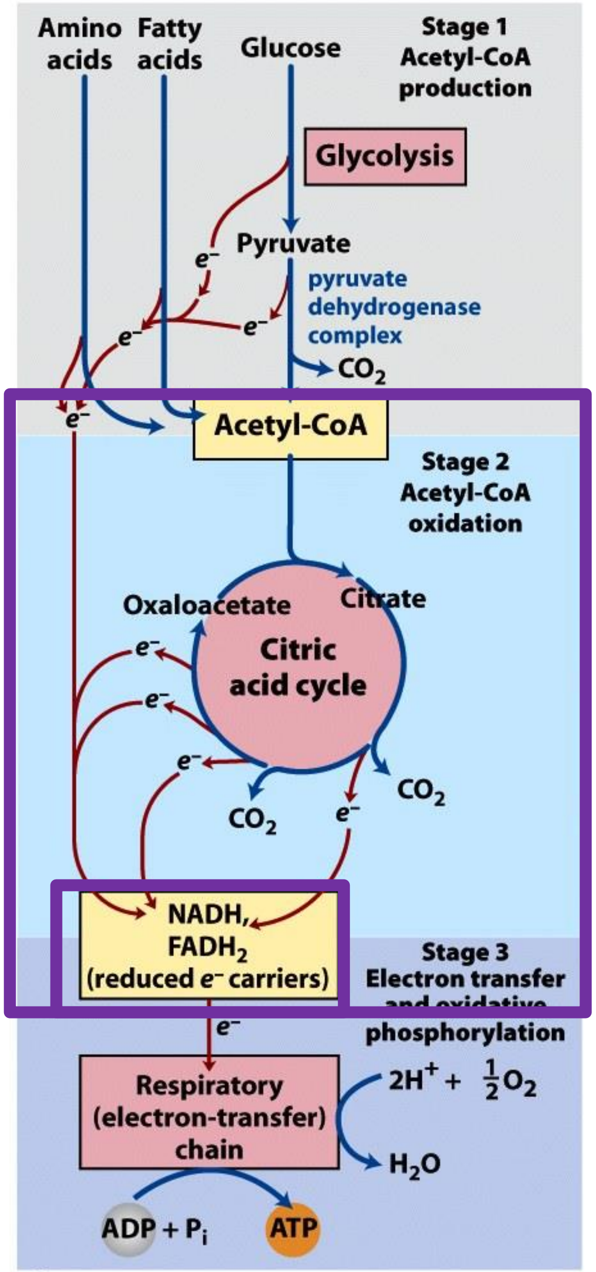
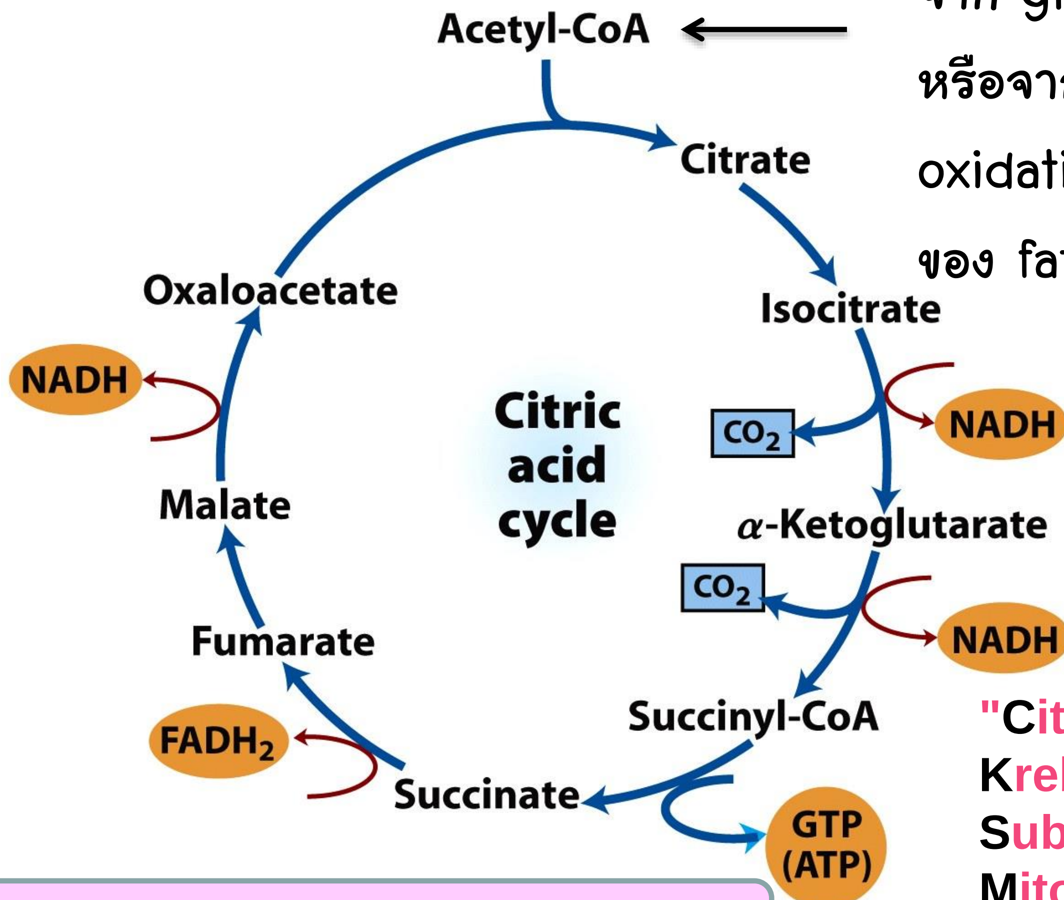


Figure 16-1
Lehninger Principles of Biochemistry, Fifth Edition

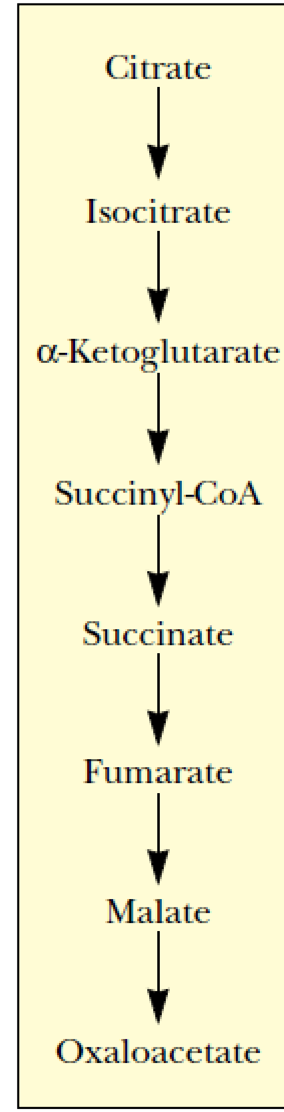
GTP, CO_2

Overview of the citric acid cycle



จาก glycolysis หรือจาก β-oxidation ของ fatty acids

"**C**itric Acid **I**s **K**reb's **S**tarting **S**ubstrate **F**or **M**itochondrial **O**xidation"

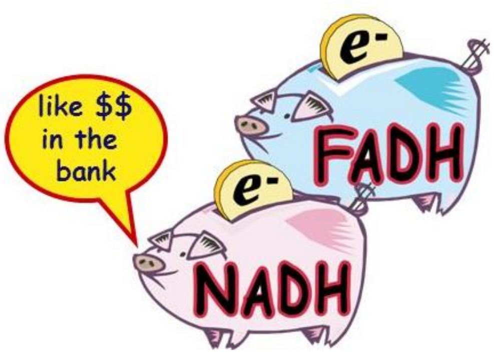


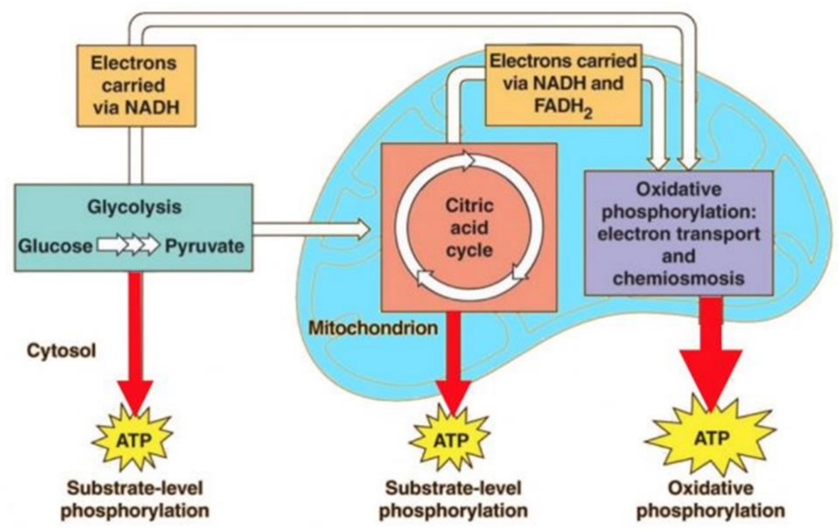
Reducing equivalents for ETS

→ $2\ CO_2 + \boxed{3\ NADH} + 1\ GTP + \boxed{1\ FADH_2}$

Citric acid (TCA & Krebs) cycle

- Final common pathway for the oxidation of carbohydrates, lipids and proteins
- Take place in the mitochondria.
- 5 in 8 reactions are oxidation-reduction reactions.
- Electron carriers: NADH & $FADH_2$ to be used in electron transport chain/system (ETC/ETS)





TCA cycle & control

3 enzymes control the rate of the TCA cycle:

- Citrate synthase
- Isocitrate dehydrogenase
- α-ketoglutarate dehydrogenase complex

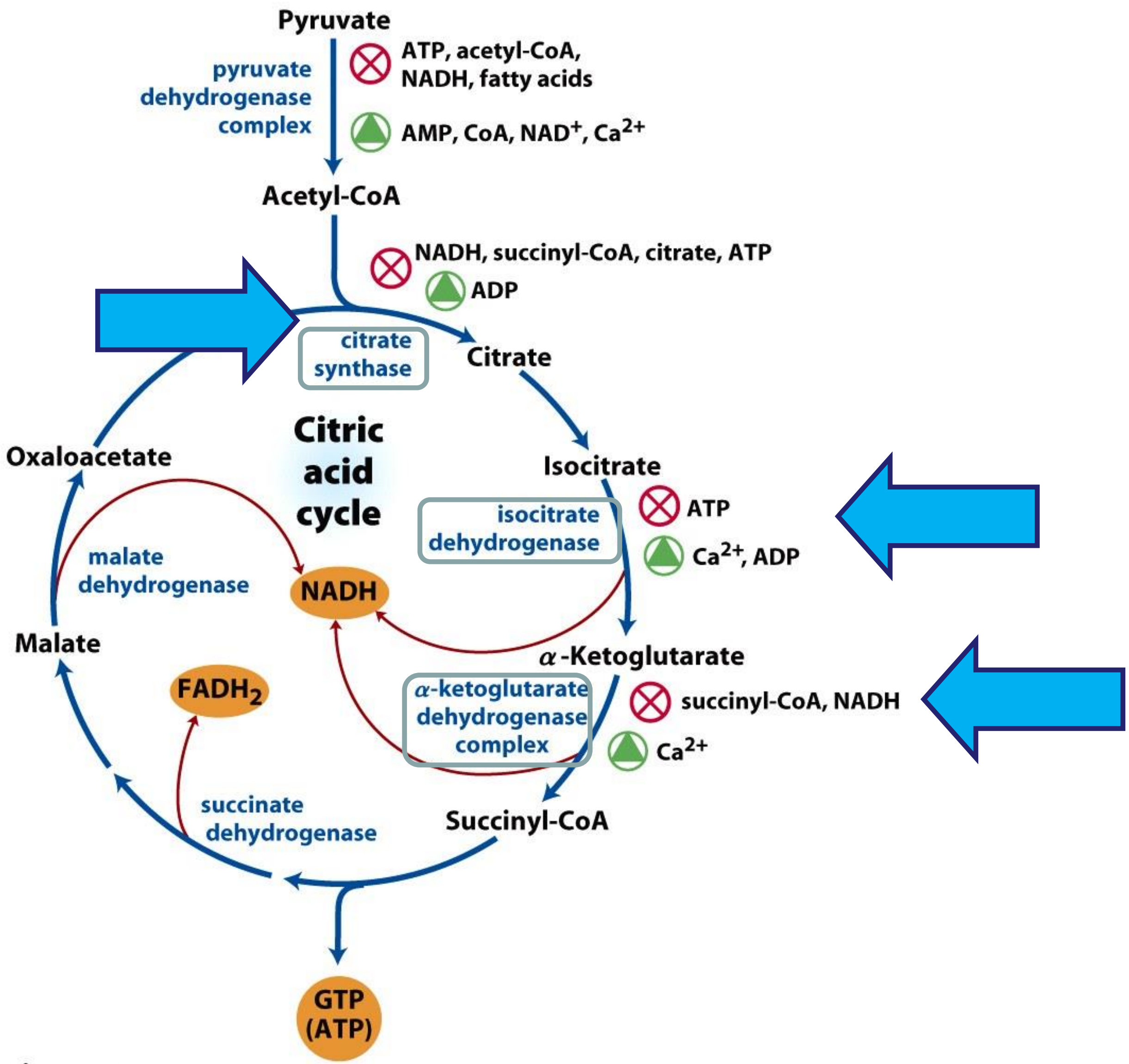
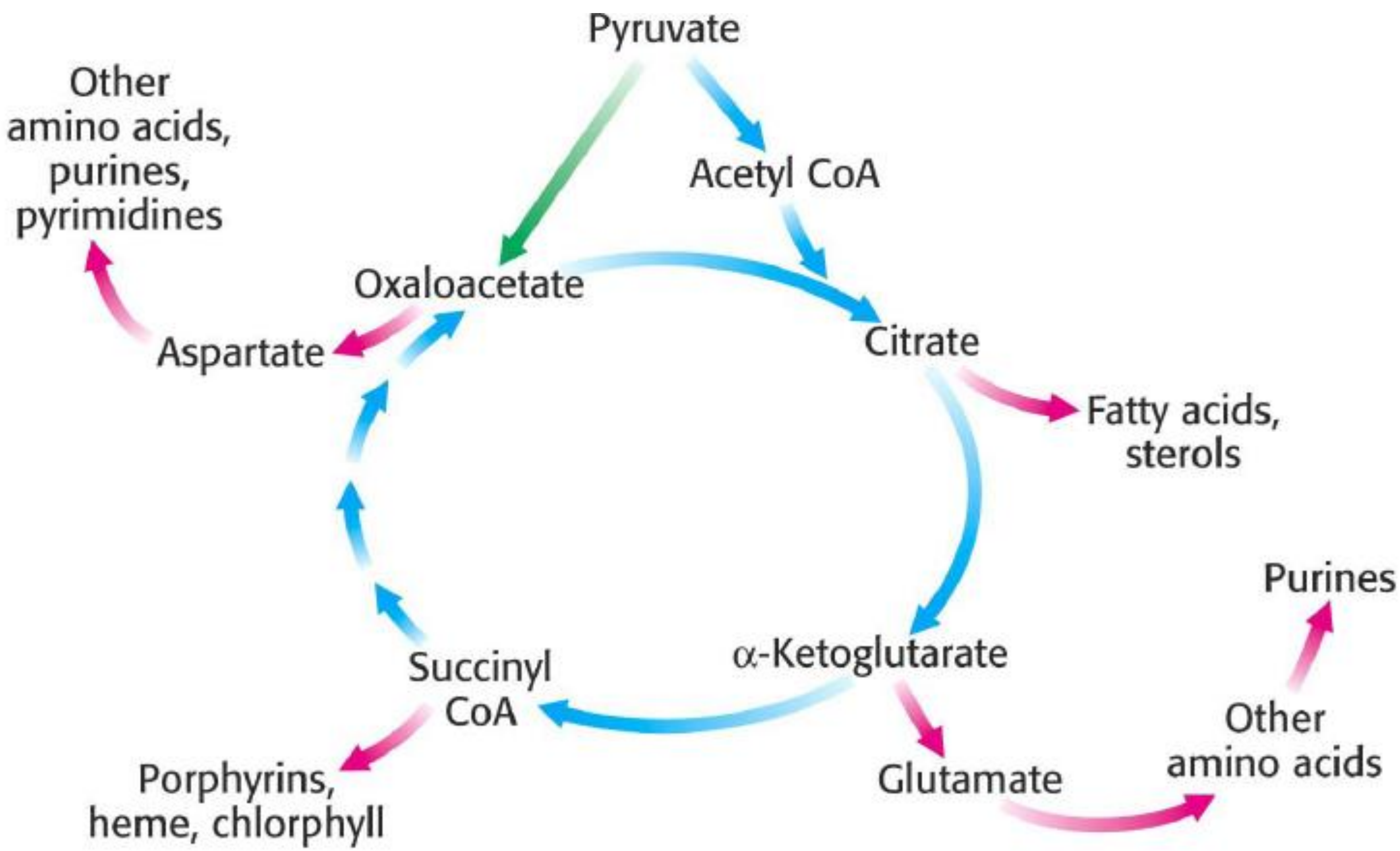


Figure 16-18
Lehninger Principles of Biochemistry, Fifth Edition

TCA Cycle as Source of Biosynthetic Precursors



3 stages of cellular respiration

Glycolysis

Krebs cycle

ETS (electron transport system)

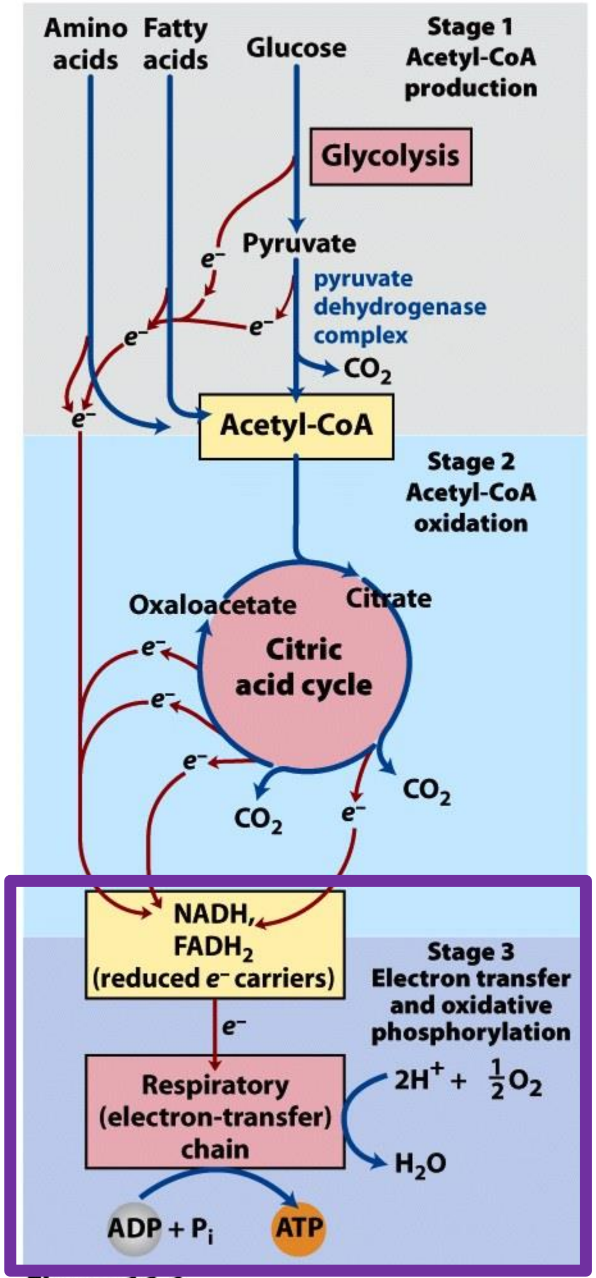
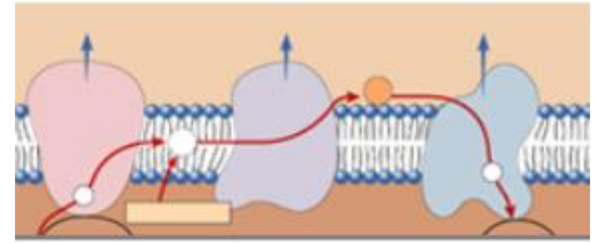
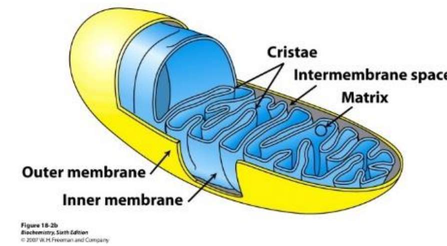


Figure 16-1
Lehninger Principles of Biochemistry, Fifth Edition

Electron transport chain/system



- เกิดขึ้นที่เยื่อหุ้มชั้นในของไมโทคอนเดรีย
- เกิดขึ้นเป็นทอด ๆ ผ่าน protein complexes



- ลำดับของการถ่ายทอดอิเล็กตรอน

NADH → Cpx1 → CoQ → Cpx3 → Cpx4 ➡ 3 ATP

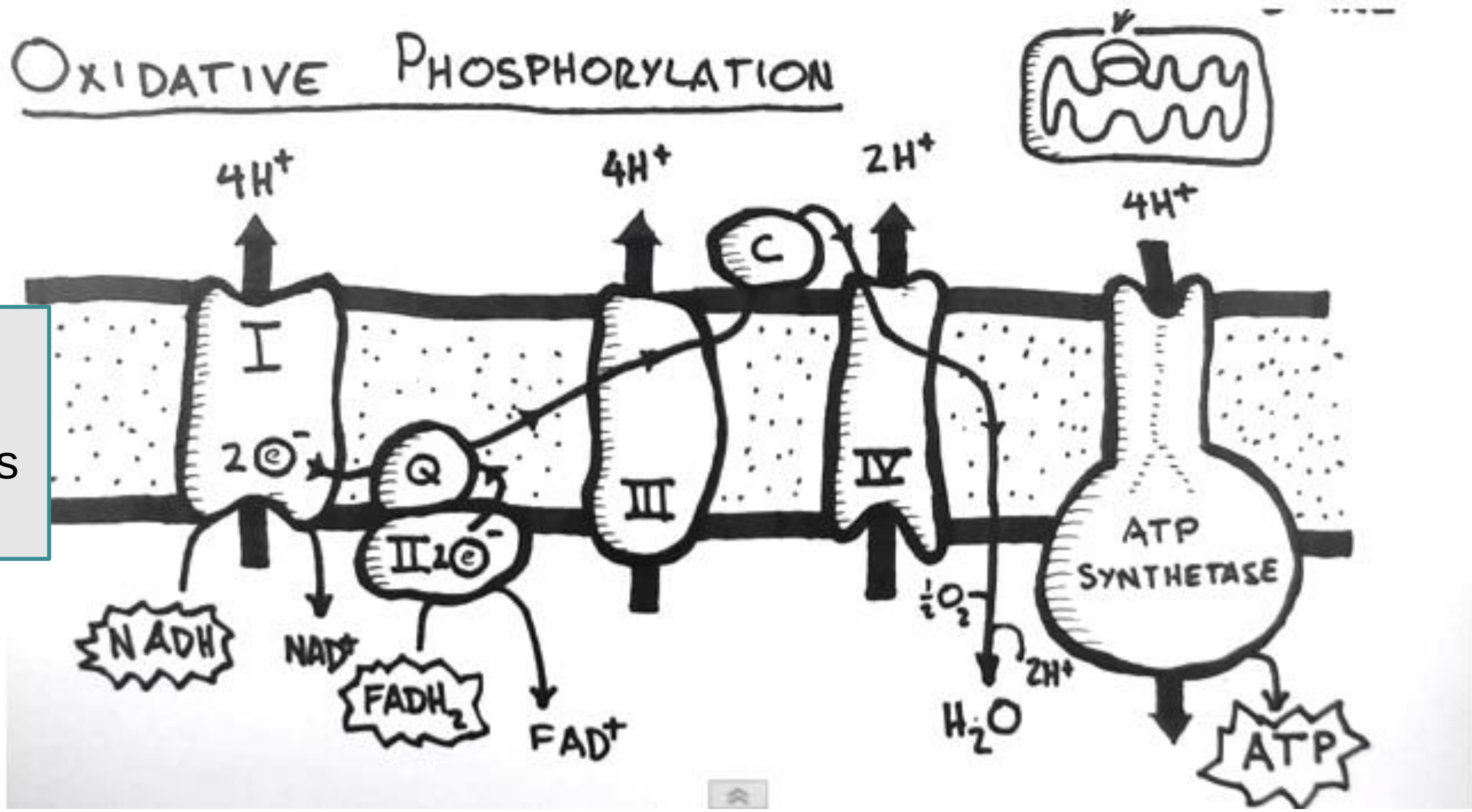
$FADH_2$ → Cpx2 → CoQ → Cpx3 → Cpx4 ➡ 2 ATP

- Oxidative phosphorylation: concentration gradient of H^+
- ตัวรับ electron ตัวสุดท้ายคือ O_2
- Inhibitors of ETS: CO, cyanine (CN^-) ยับยั้ง complex IV

ELECTRON TRANSPORT SYSTEM AND ATP SYNTHESIS

http://www.youtube.com/watch?v=vZz-KLK-X40

NADH from glycolysis, β-oxidation, Kreb's cycle



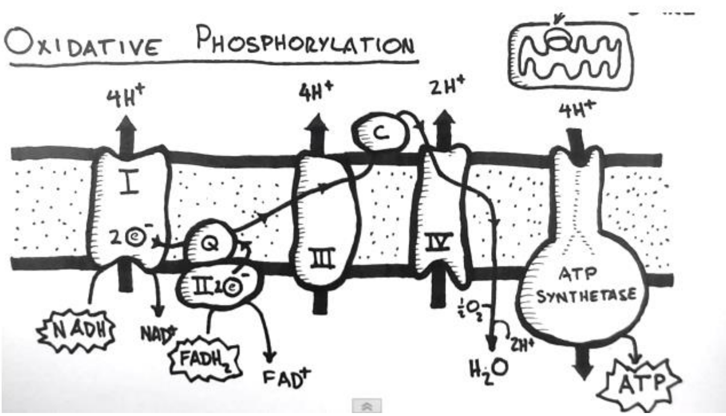
NADH dehydrogenase
Complex I

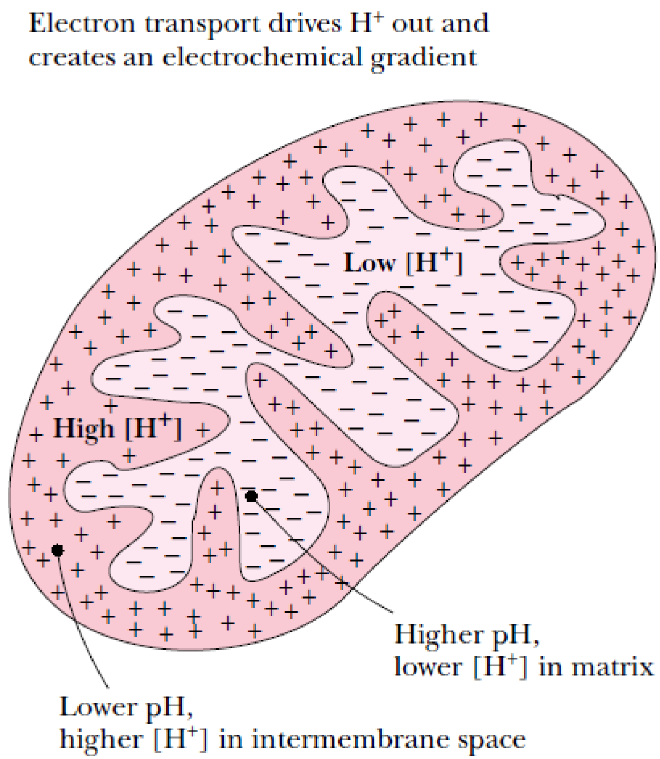
Cytochrome b-c1
Complex III

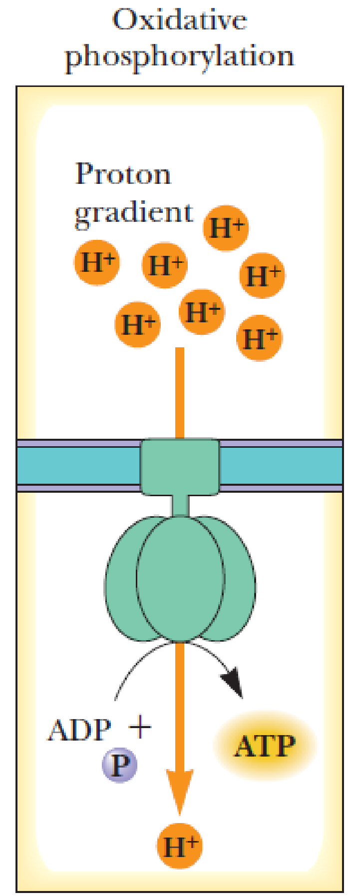
Cytochrome oxidase
Complex IV

Oxidative phosphorylation

the process in which ATP is formed as a result of the transfer of electrons from NADH or $FADH_2$ to O_2 by a series of electron carriers.







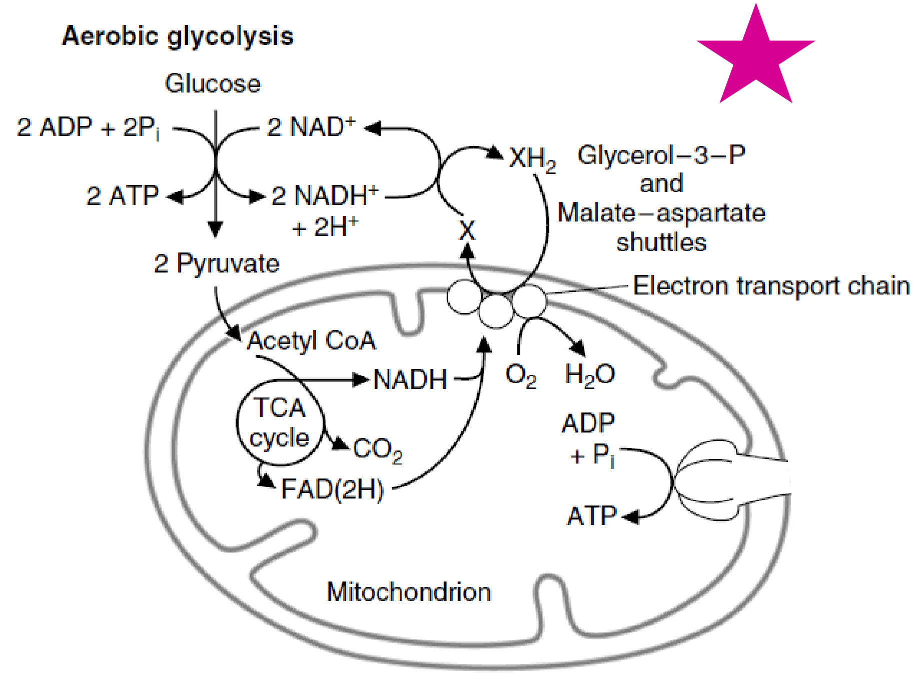
1 NADH	➡	2.5 ATP
1 $FADH_2$	➡	1.5 ATP

How does NADH cross the mitochondrial inner membrane?

NADH ที่เกิดจาก glycolysis ใน cytoplasm ไม่สามารถผ่านเข้าออก mitochondrial membrane ได้ แต่จะมีกลไกที่เกิดขึ้นเสมือนมีการนำโมเลกุลขนาดใหญ่ผ่าน membrane ได้ กลไกดังกล่าวคือ

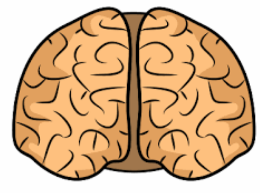
- Glycerol phosphate shuttle
- Malate-aspartate shuttle

NAD+ regeneration



Glycerol 3-phosphate shuttle

Active in skeletal muscles and brain.



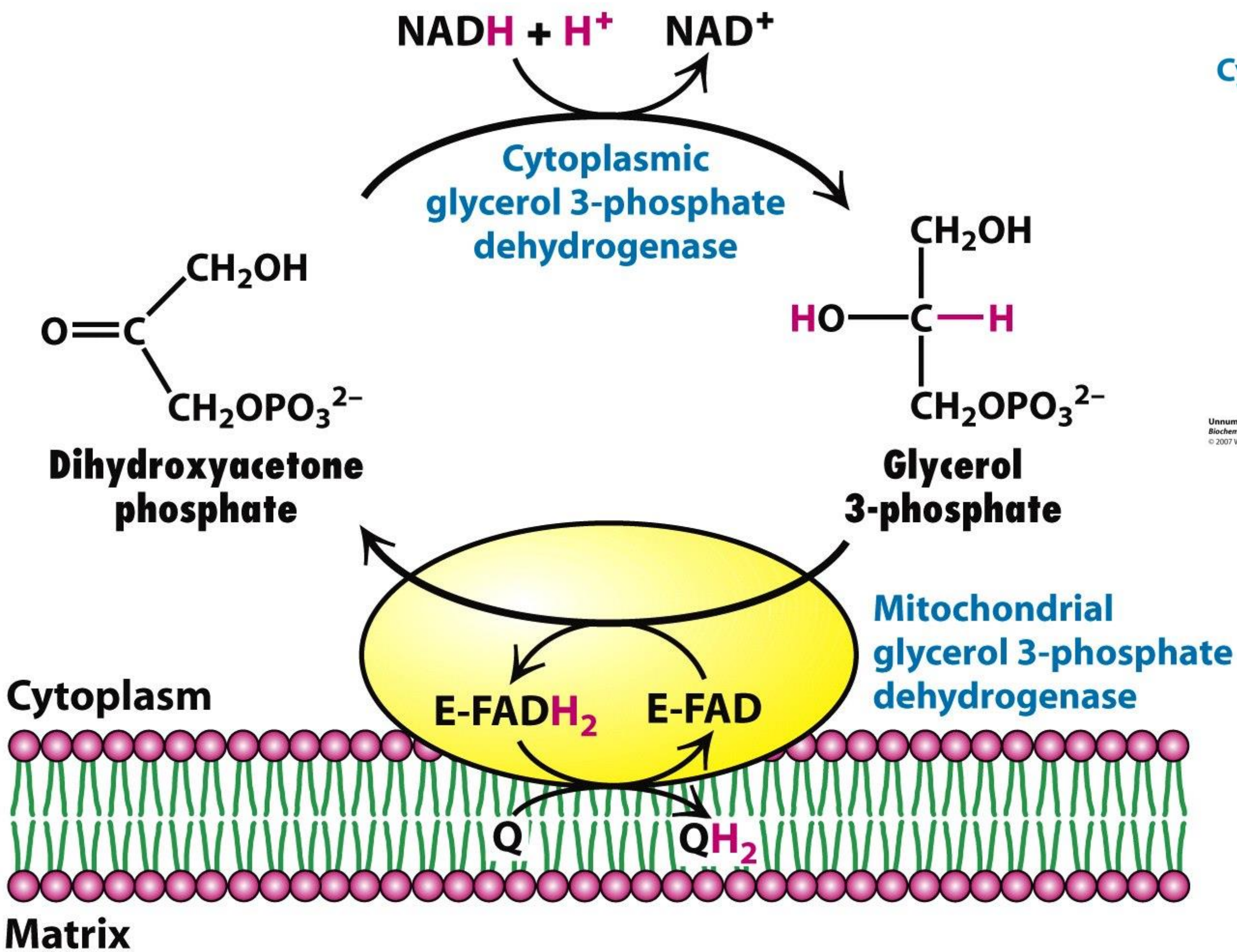
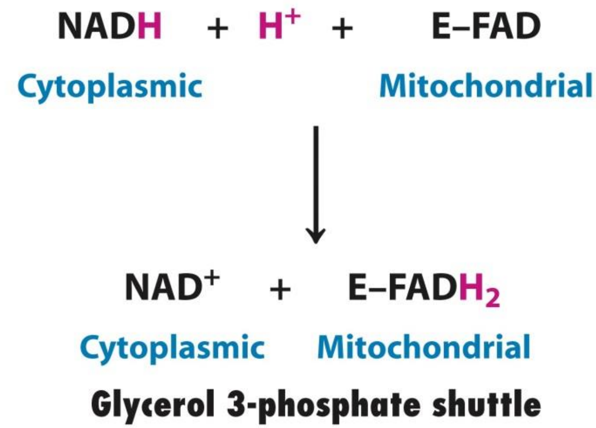
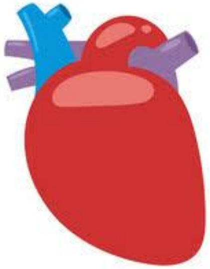


Figure 18-35
Biochemistry, Sixth Edition

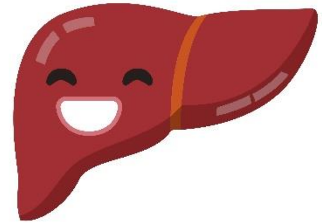


Unnumbered figure pg 527
Biochemistry, Sixth Edition

Electrons enter the ETS via complex II, therefore only 1.5 molecules of ATP are produced.



Malate-aspatate shuttle



Active in heart and liver.

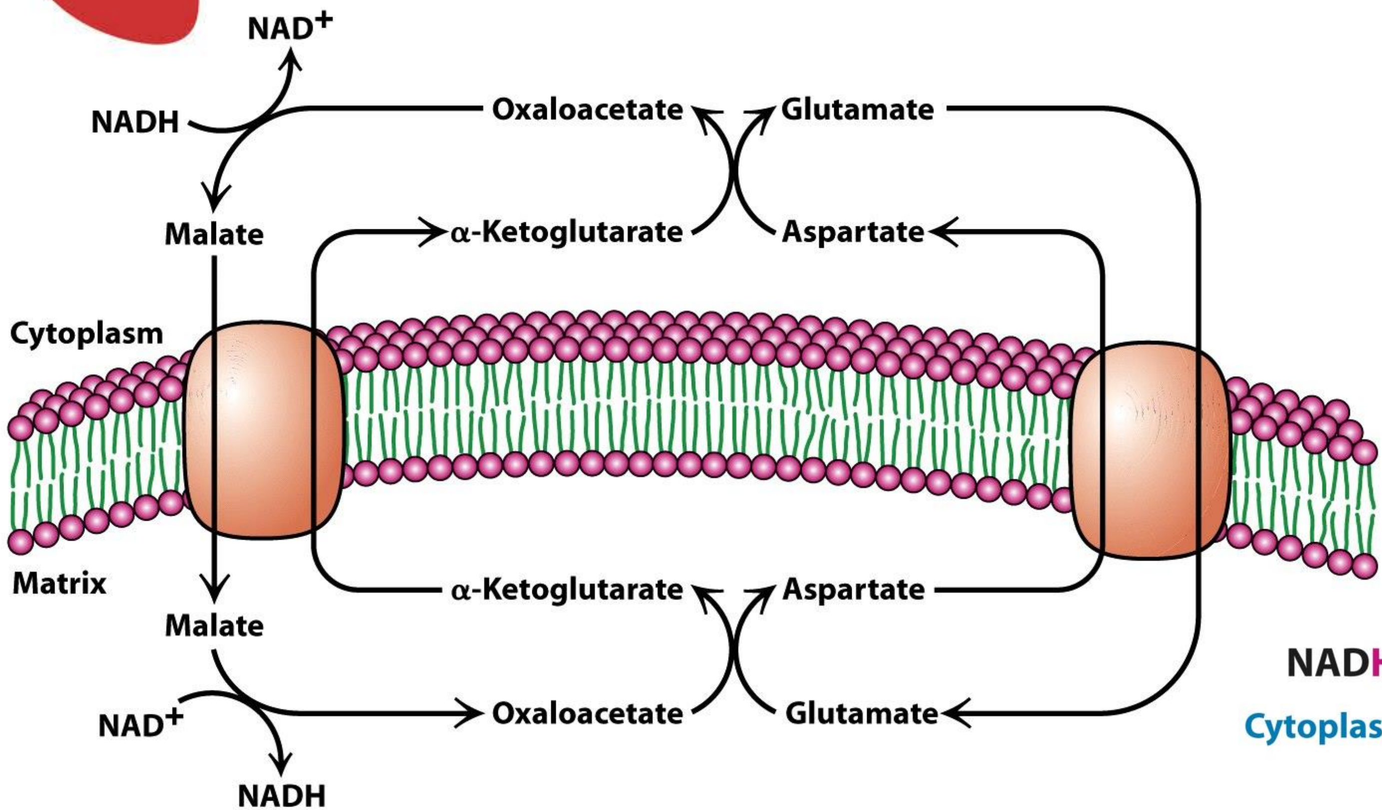
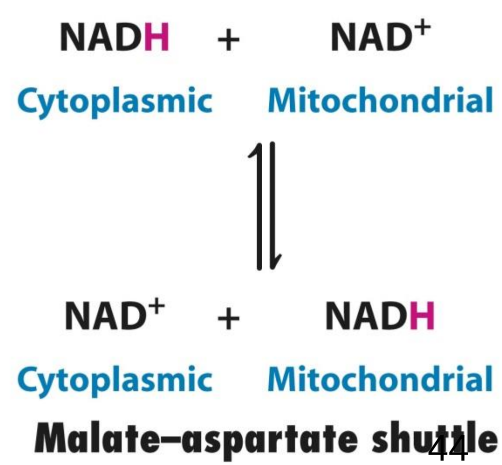


Figure 18-36
Biochemistry, Sixth Edition



Unnumbered figure pg 528
Biochemistry, Sixth Edition

2.5 molecules of ATP are produced.

ATP ที่เกิดจากการสลายกลูโคสอย่างสมบูรณ์

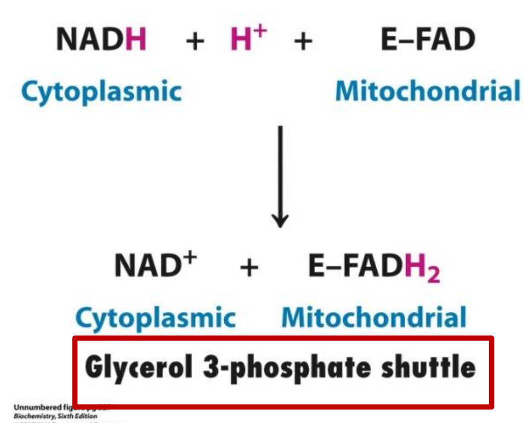
หัวใจและตับ 32 ATP; สมองและกล้ามเนื้อลาย 30 ATP

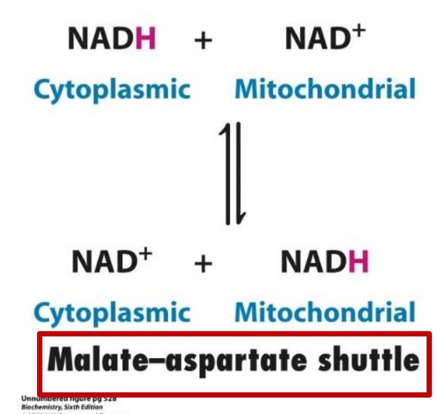
TABLE 19-5 ATP Yield from Complete Oxidation of Glucose

Process	*Direct product*	*Final ATP*
Glycolysis	2 NADH (cytosolic)	3 or 5*
	2 ATP	2
Pyruvate oxidation (two per glucose)	2 NADH (mitochondrial matrix)	5
Acetyl-CoA oxidation in citric acid cycle	6 NADH (mitochondrial matrix)	15
(two per glucose)	2 $FADH_2$	3
	2 ATP or 2 GTP	2
Total yield per glucose		30 or 32

NADH → Cpx I → CoQ → Cpx III → Cpx IV ➡ 2.5 ATP

$FADH_2$ → Cpx II → CoQ → Cpx III → Cpx IV ➡ 1.5 ATP





Fates of pyruvate

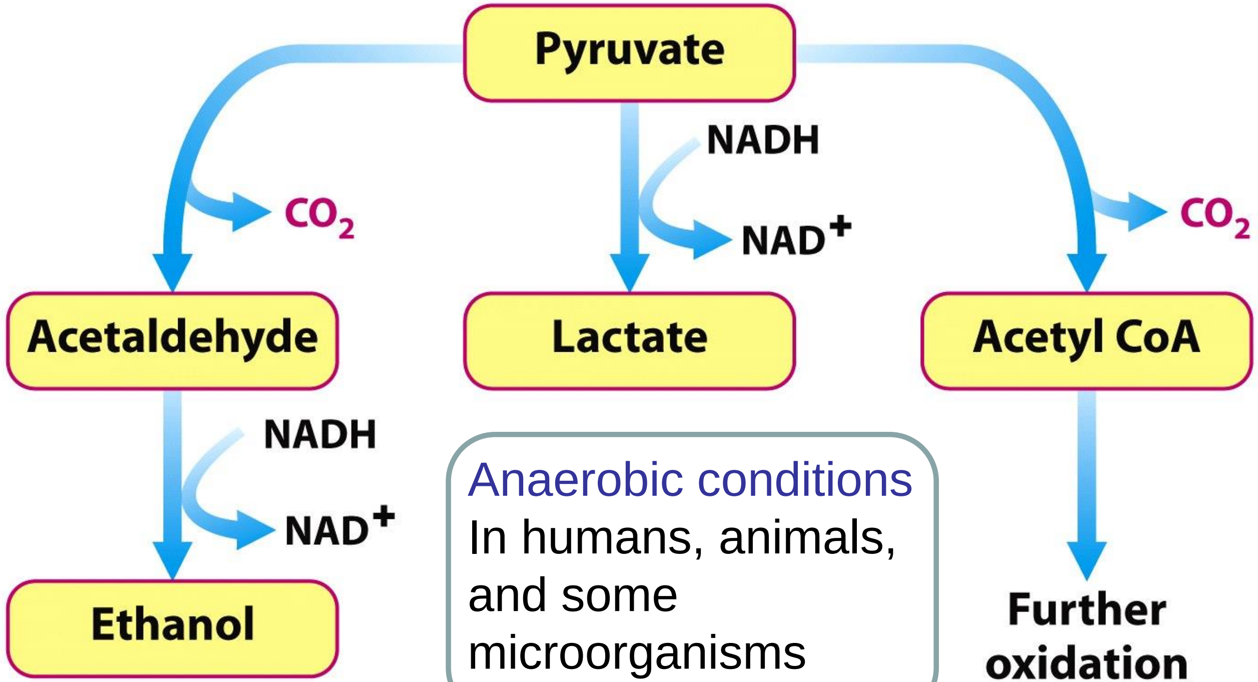


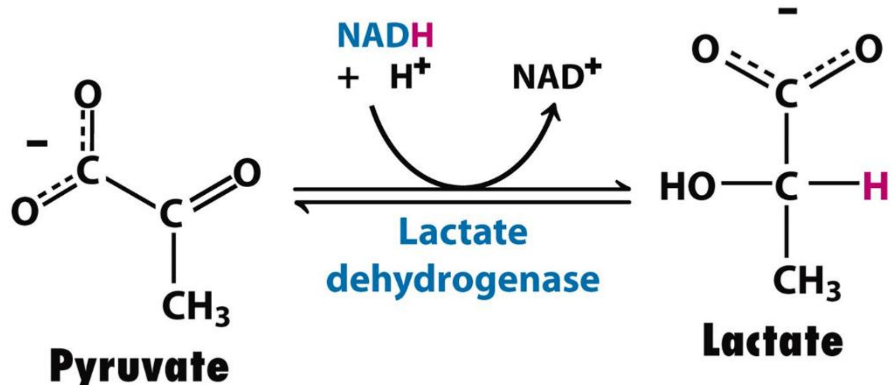
Figure 16-9
Biochemistry, Sixth Edition

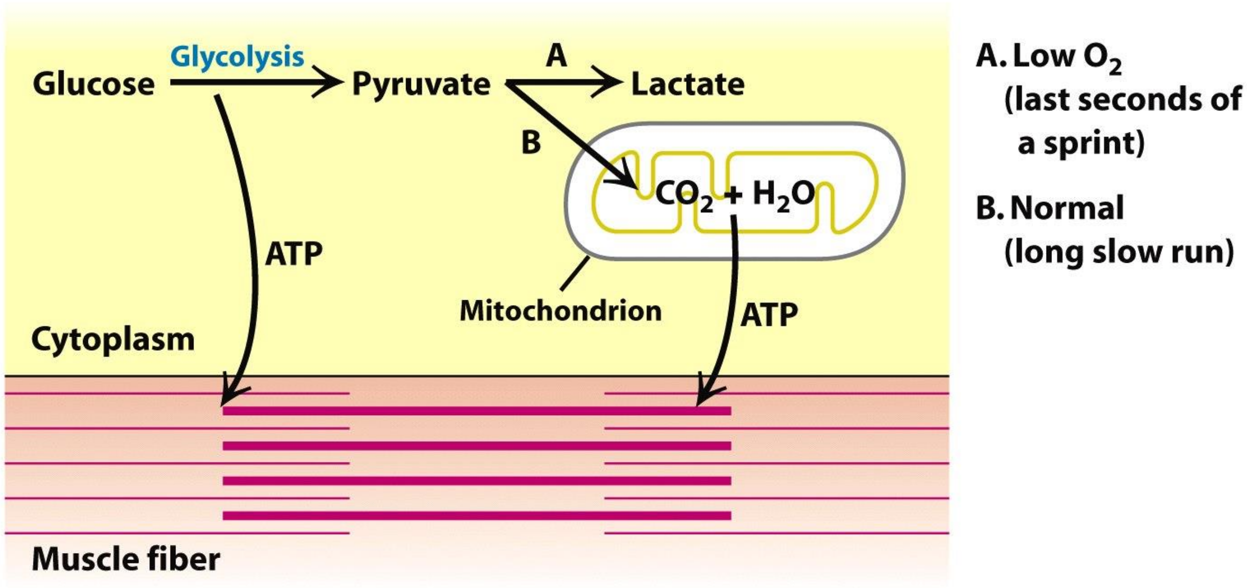
Anaerobic conditions
In humans, animals, and some microorganisms

Anaerobic conditions
In some microorganisms

Aerobic conditions
In humans, animals, and some microorganisms

When O_2 is not available, cells use anaerobic respiration to obtain energy

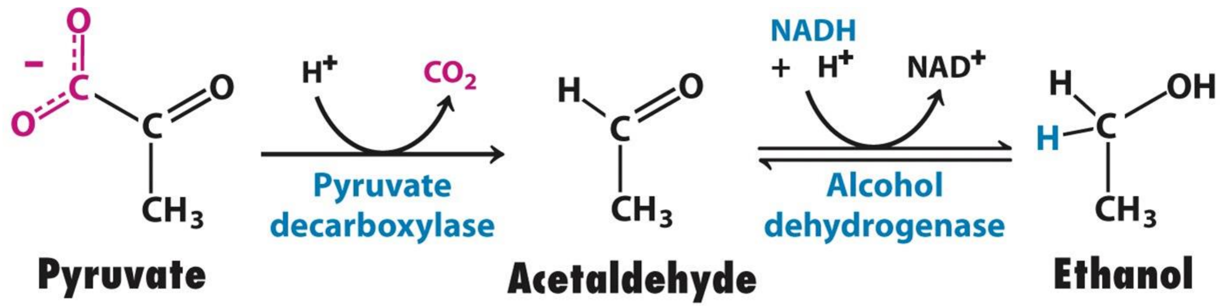


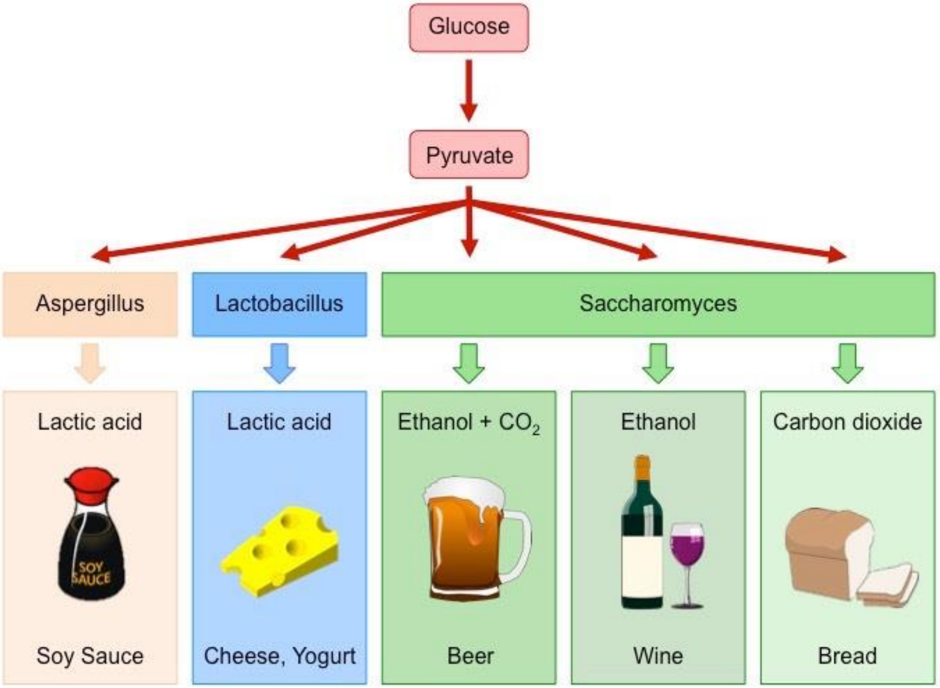


Chapter 16 Opener part 2
Biochemistry, Sixth Edition

Fermentation

In yeast and certain bacterial species, pyruvate is decarboxylated to form acetaldehyde, which is then reduced by NADH to form ethanol.





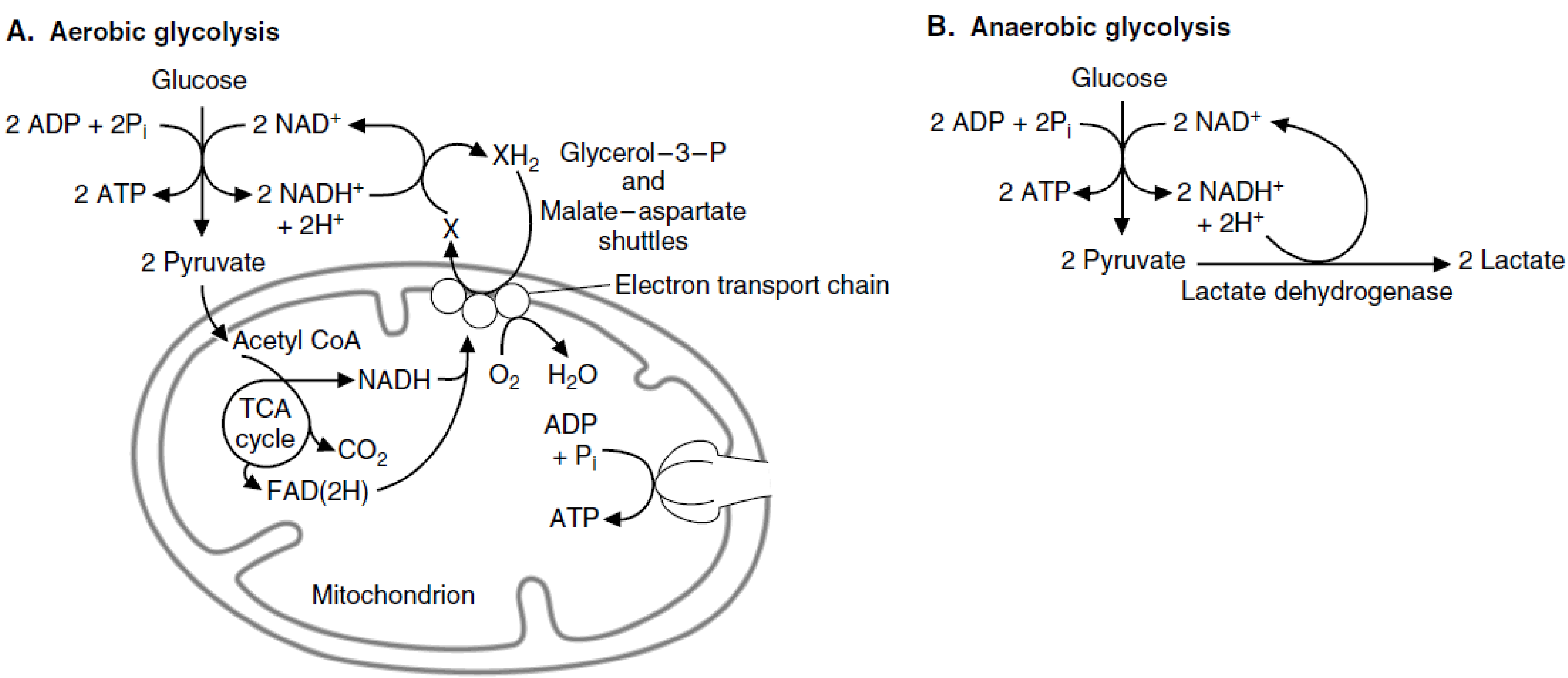
Fermentation products

Aerobic cellular respiration:

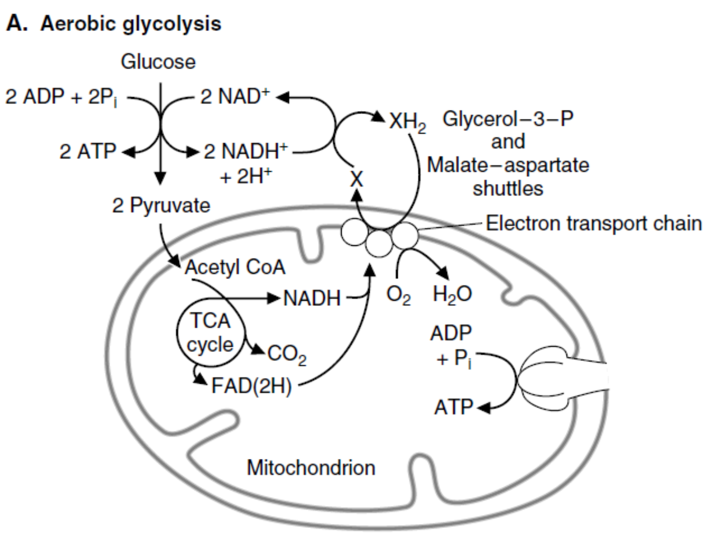
- Glycolysis ⇨ acetyl CoA formation ⇨ Krebs cycle ⇨ ETS

Anaerobic cellular respiration (eg. during exercise, in RBCs):

- **Pyruvate** เปลี่ยนเป็น lactate โดย lactate dehydrogenase ★



• Glucose เป็นเชื้อเพลิง (metabolic fuel) ของทุกเซลล์ ถ้า O_2 เพียงพอ จะมีการสลาย glucoseผ่าน aerobic cellular respiration:



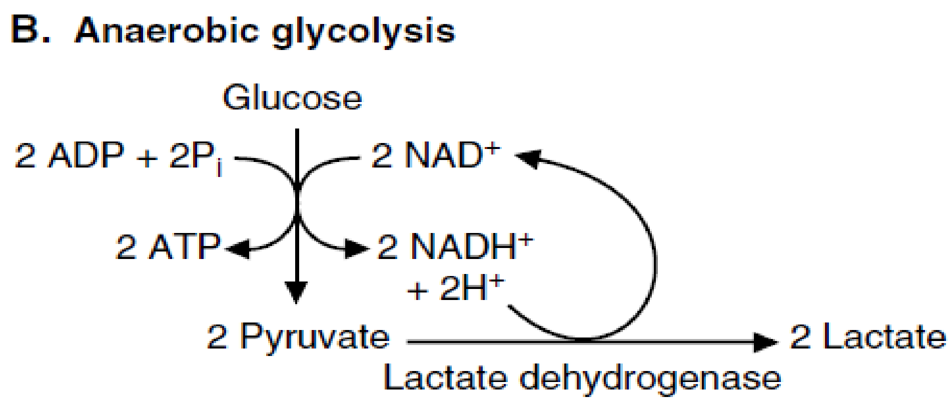
Glycolysis ⇨ acetyl CoA formation ⇨ Krebs cycle ⇨ ETS/ETC

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

ucose + oxygen -> carbon dioxide + water)

- CO_2 ถูกกำจัดออกทางเลือด ผ่านระบบบัพเฟอร์ที่ควบคุม pH ของเลือด คือ carbonic/bicarbonate buffer
- NAD^+ regeneration ผ่าน Malate-aspartate shuttle และ Glyceral-3-phosphate shuttle

• หาก O_2 ไม่เพียงพอกับความต้องการของเซลล์ จะมีการผลิตพลังงานแบบ anaerobic cellular respiration และ regenerate NAD^+ โดยเปลี่ยน pyruvate → lactic acid → lactate + H^+



- Lactate → Liver เพื่อเปลี่ยนกลับเป็น glucose ตามวิถี gluconeogenesis
- H+ ทำให้ pH ของเลือดลดลง และเปลี่ยนเป็น H_2CO_3 โดย

$$H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$

Gluconeogenesis

the generation (genesis) of new (neo) glucose

- กระบวนการสร้างกลูโคสขึ้นมาใหม่จากสารประกอบที่ไม่ใช่คาร์โบไฮเดรต
- Substrates for gluconeogenesis:

  Lactate, glycerol and

  glucogenic amino acids
- เกิดในภาวะที่ร่างกายต้องการกลูโคสและได้รับสารอาหารคาร์โบไฮเดรตไม่เพียงพอ
- เกิดมากในตับ พบในไต ลำไส้เล็ก

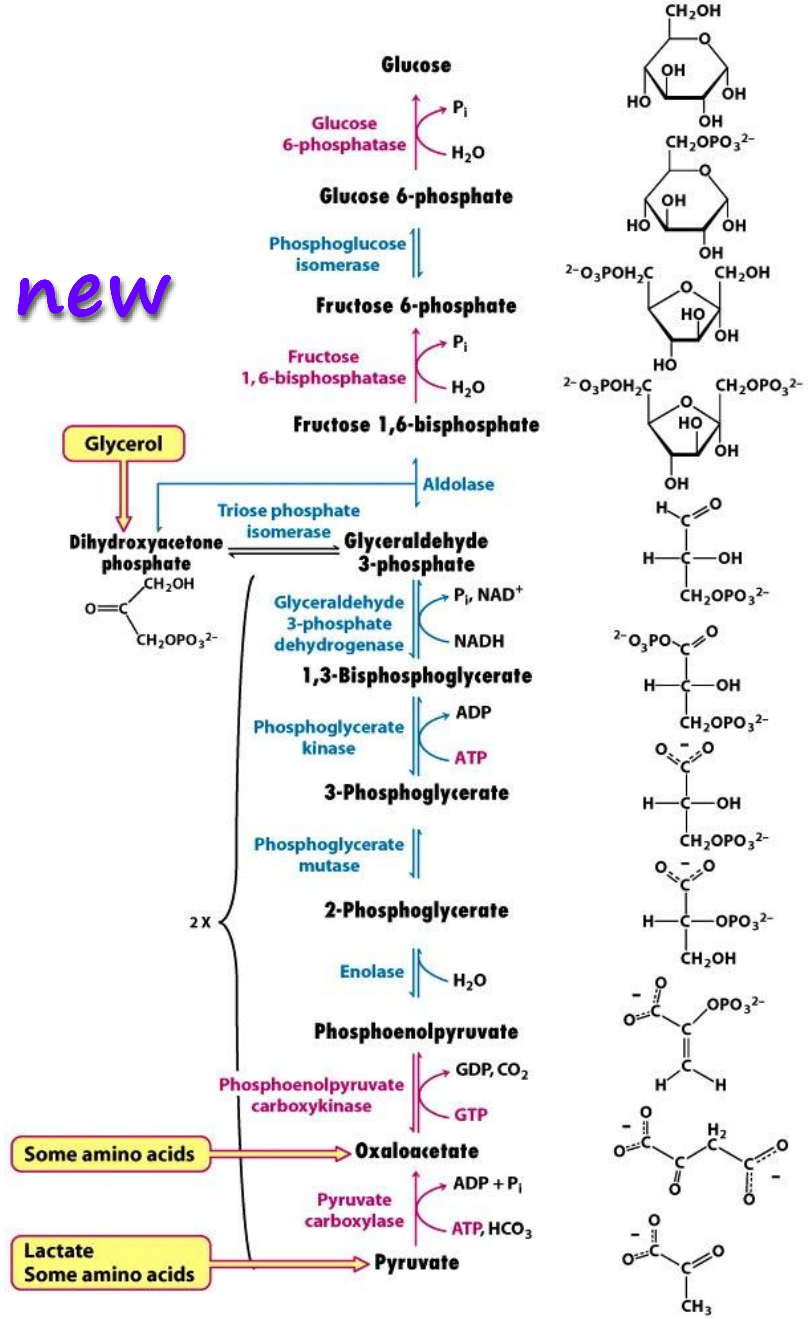


Figure 16-22
Biochemistry, Sixth Edition

Glycolysis and gluconeogenesis are repiprocally regulated

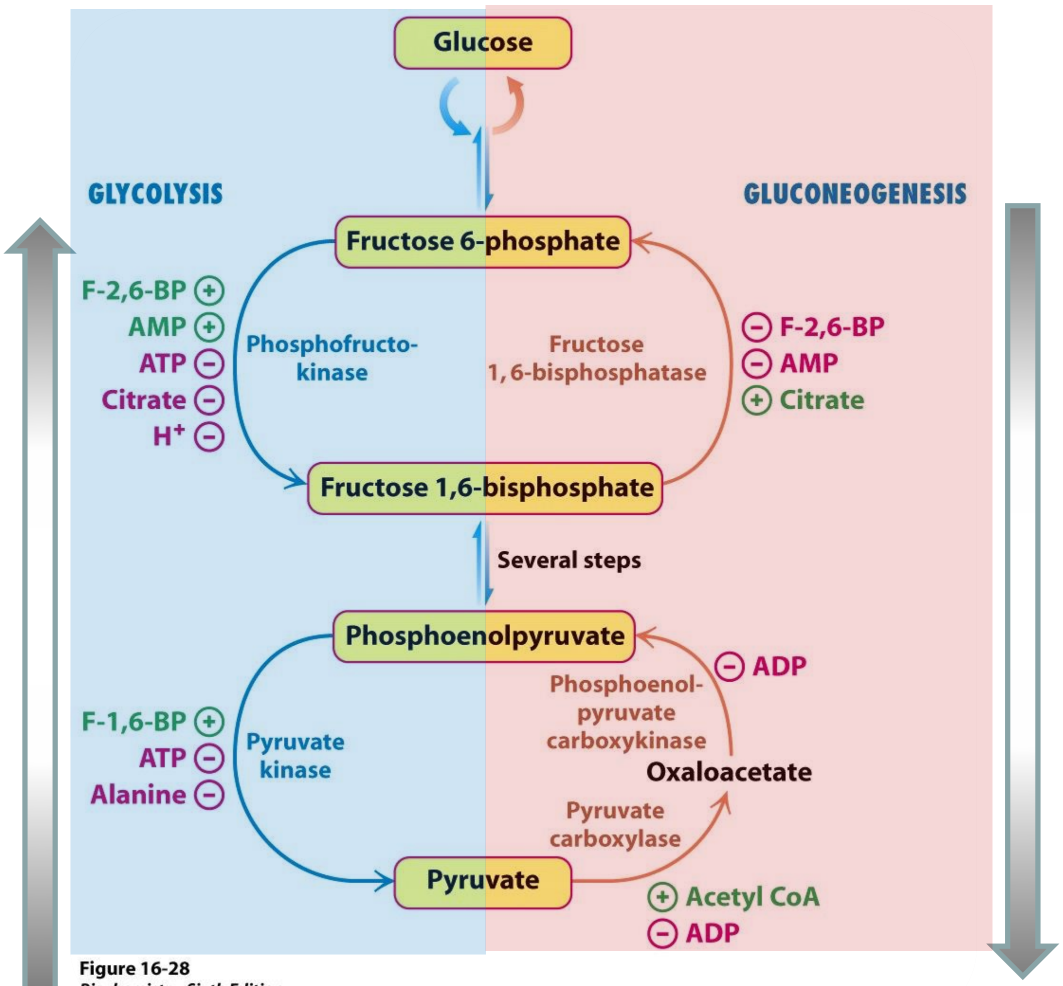
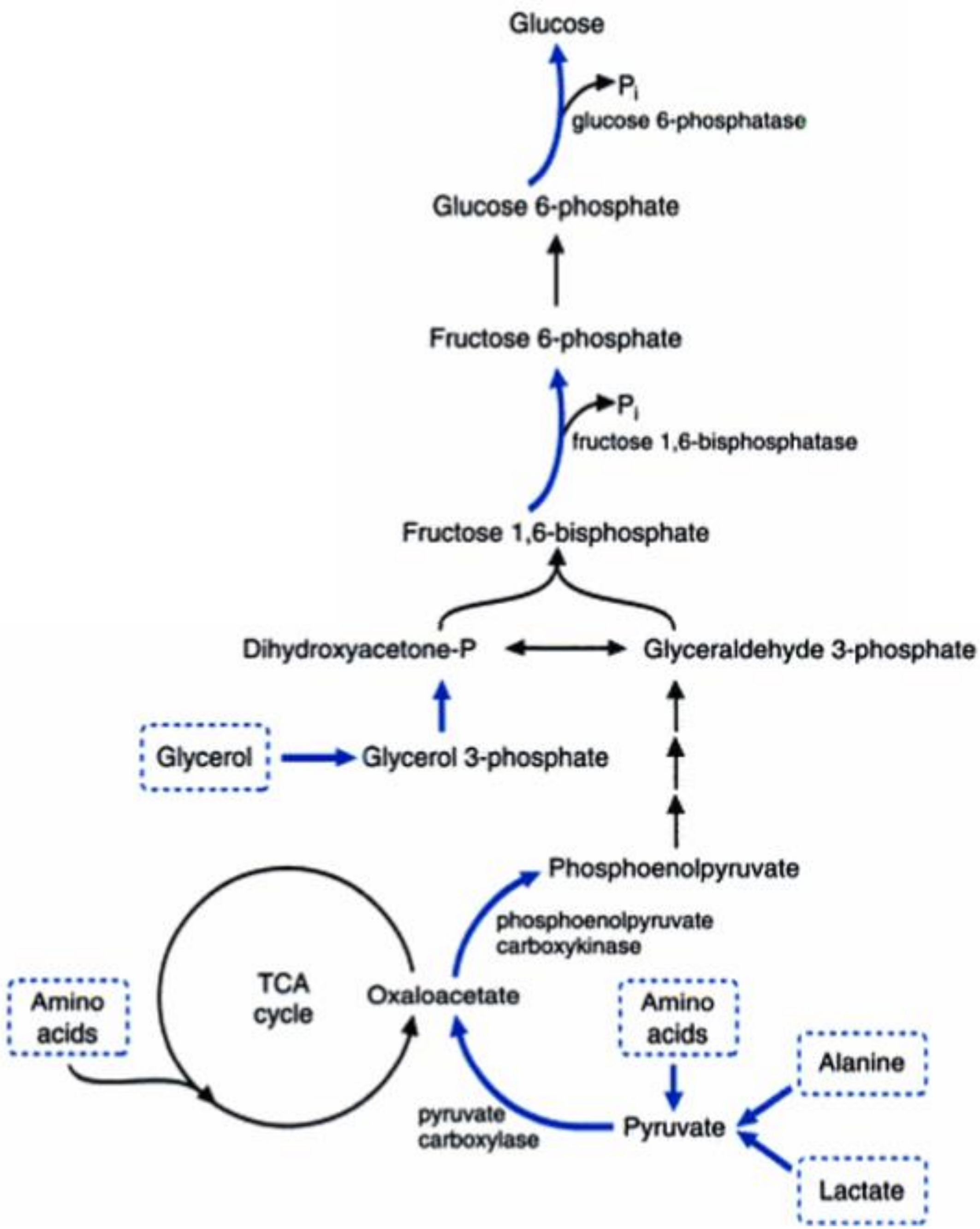
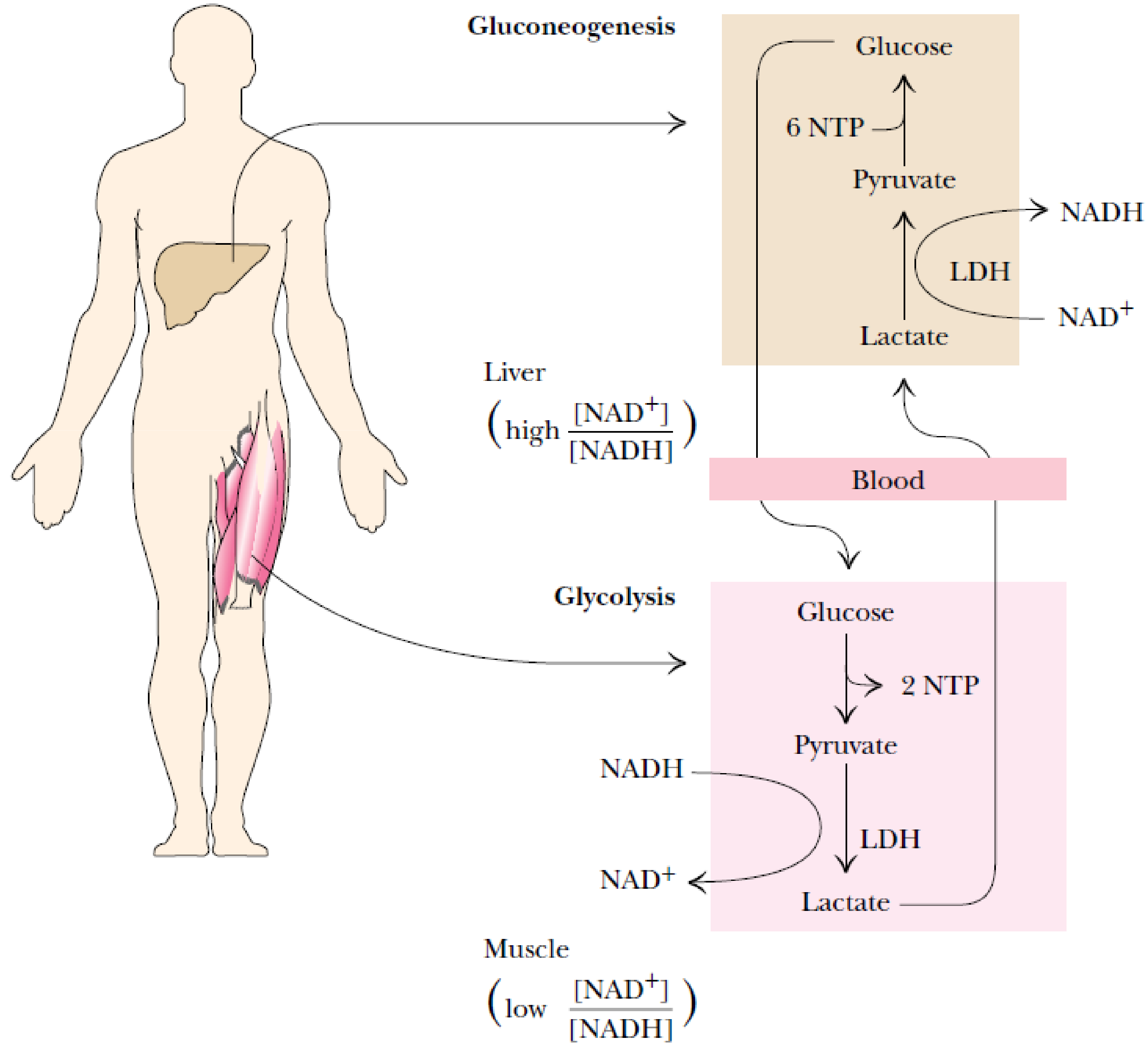


Figure 16-28
Biochemistry, Sixth Edition
©2007 W. H. Freeman and Company

- Pathways not active at the same time.
- Regulated by products of reaction and precursors
- Inhibitors in glycolysis could be activators in gluconeogenesis ex. F-2,6-BP, AMP, citrate.



Substrates for gluconeogenesis คือ Lactate, glycerol, some amino acids ★

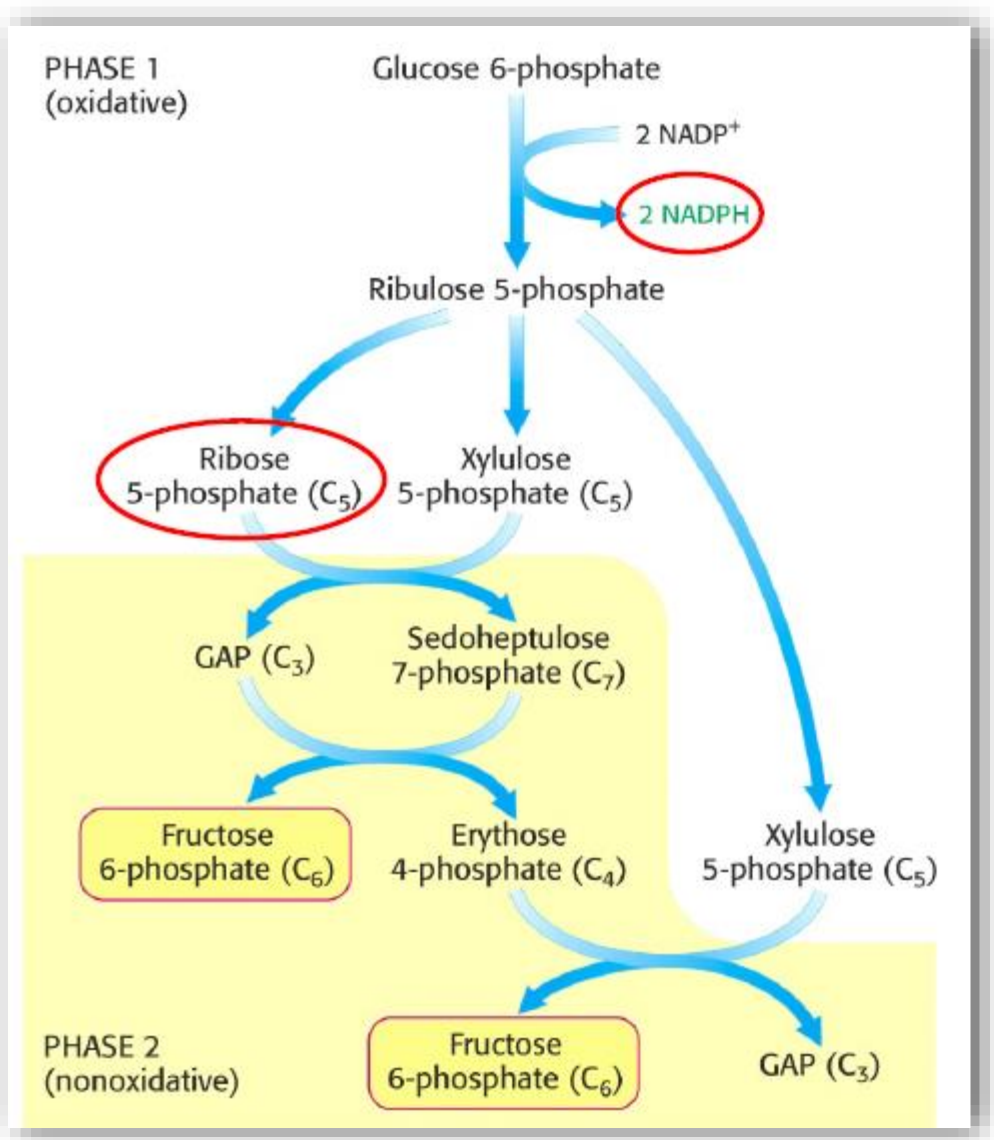


Glucose is synthesized from lactate (the Cori cycle)

Pentose phosphate pathway (PPP)/ hexose monophosphate shunt

1. เป็น shunt ("ทางแยก") ของ glycolysis ซึ่ง supply NADPH และ Ribose-5-P
    - NADPH เป็นที่ต้องการของ biosynthetic pathways เช่น FA biosynthesis, cholesterol synthesis เป็นต้น และยังเป็นที่ต้องการของ detoxification เช่น reduction of oxidized glutathione
    - Ribose-5-P เป็น precursor ของการสังเคราะห์ nucleotides
2. Regulatory enzyme คือ gluclose-6-phosphate DH (ขาดเอนไซม์นี้เกิดภาวะ G6PD deficiency)

Pentose phosphate pathway (PPP)



เกิดใน cytoplasm

แบ่งเป็น 2 phases

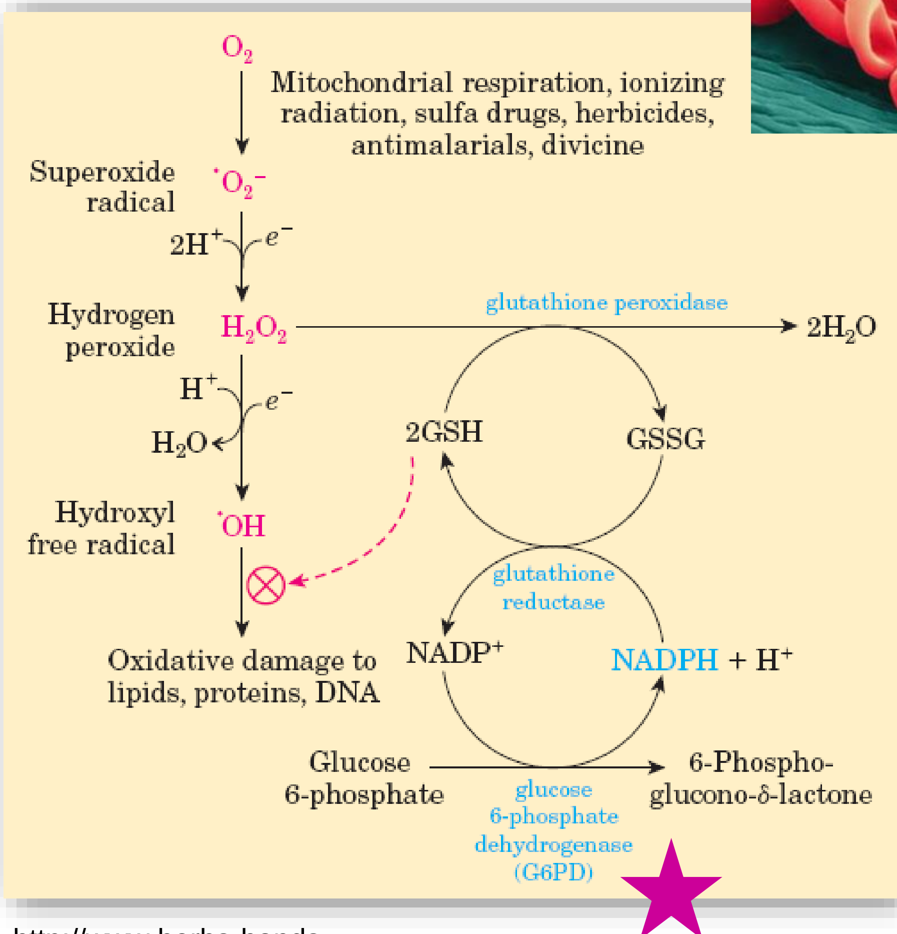
- **Oxidative phase:**

Oxidation of G-6-P เพื่อสร้าง NADPH

- **Nonoxidative phase:**

ได้ phosphorylated 5 carbon sugars (pentoses) GAP สามารถเข้า glycolysis ได้

G6PD deficiency

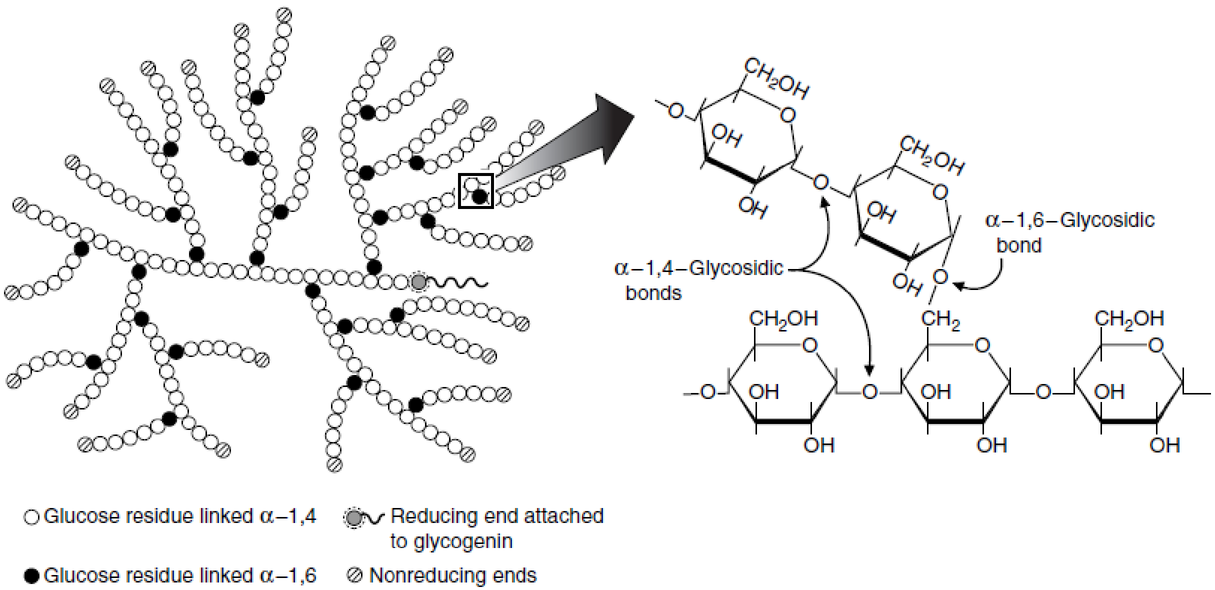


http://www.herbs-hands-healing.co.uk/pictures/superfood/redbloodcells.jpg

- เซลล์เม็ดเลือดแดง (RBC) ตัวแก่ ไม่มีนิวเคลียส ไมโตคอนเดรีย พลังงานงานจึงมาจาก glycolysis และ Pentose phosphate pathway (PPP)

- PPP สร้าง NADPH สำหรับใช้เปลี่ยน glutathione ที่เยื่อหุ้มเซลล์ของ RBC ปกป้องเซลล์จากภาวะเครียดออกซิเดชัน (oxidative stress) จาก H_2O_2 และ free radicals อื่นๆ
- ถ้ามีความบกพร่องเอ็นไซม์ใน G6PD ใน PPP จำให้เม็ดเลือดแดงไม่แข็งแรง แตกง่าย เป็นโลหิตจาง (anemia)

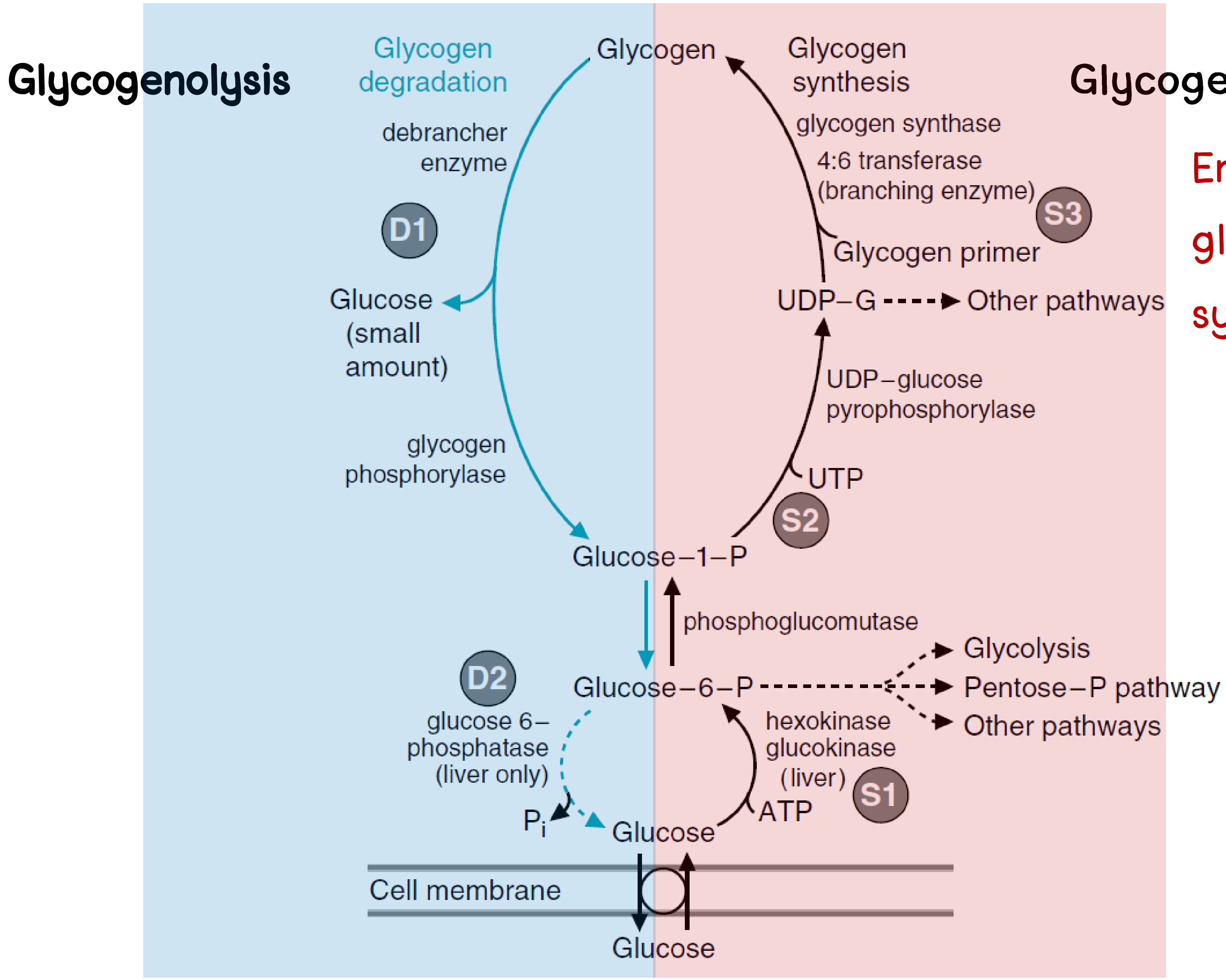
Glycogen metabolism: glycogenesis & glycogenolysis



Glycogen: expanding from a core sequence bound to a protein (glycogenin).

- Glycogen: a storage form of glucose, very large and branched
- It is mainly stored in liver and muscle.
- Glycogenesis is the synthesis of glycogen from glucose; mainly occurs in muscle and liver.
- Glycogenolysis is the breakdown of glycogen (n) to glucose-1-phosphate and glycogen (n-1).

Glycogenesis & glycogenolysis



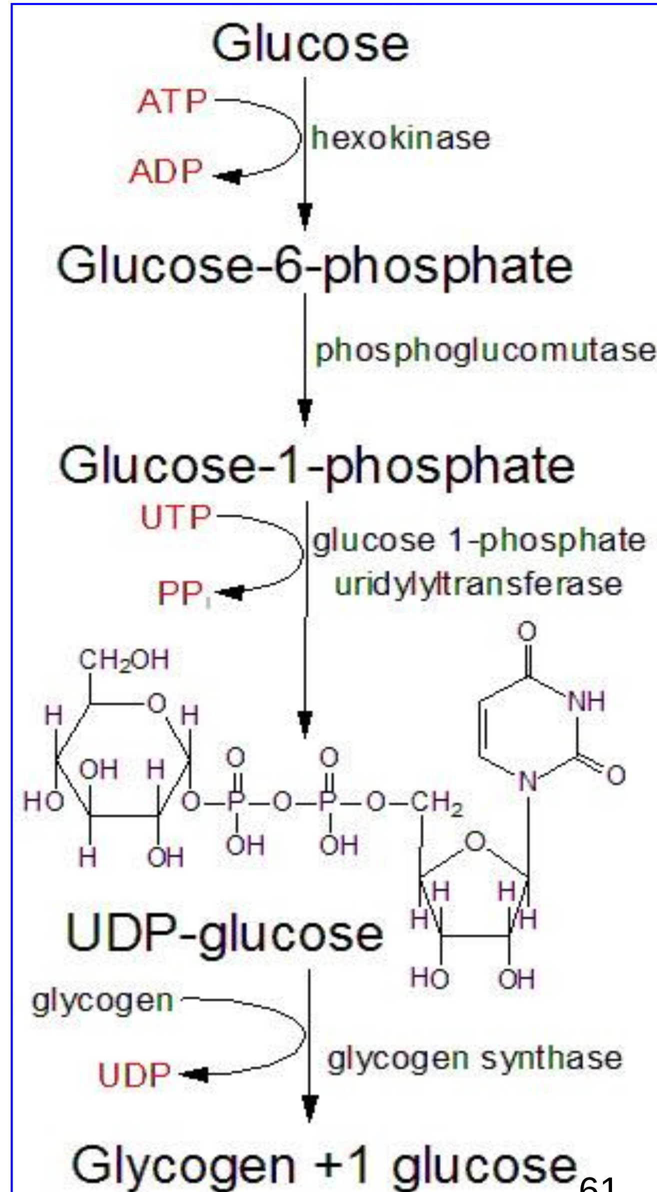
Enzyme:

glycogen

synthase

Glycogen synthesis (glycogenesis)

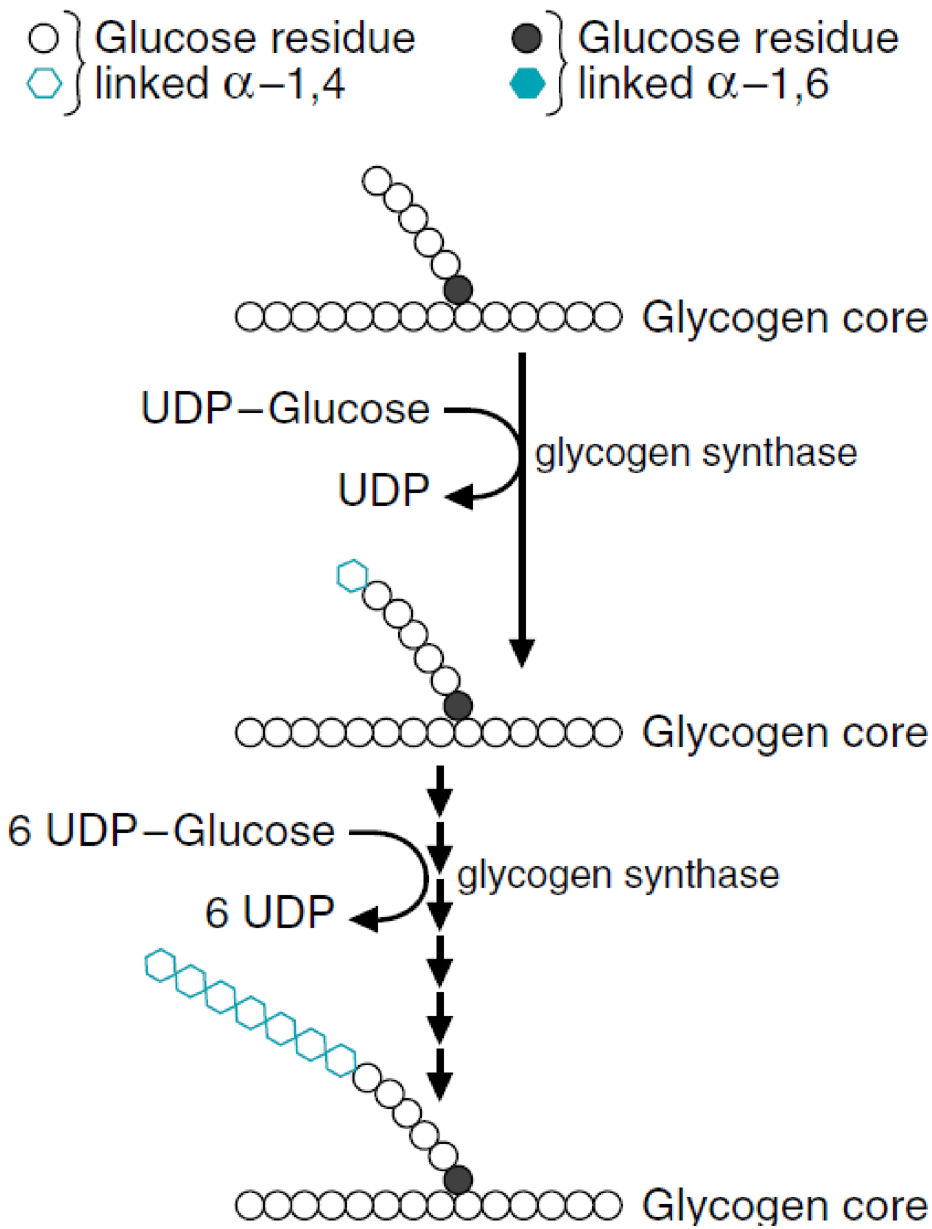
- Glycogen is synthesized when blood glucose levels and ATPs are high.
- This occurs in liver and muscle cells.
- Stimulated by the hormone insulin.
- Uridine diphosphate glucose (UDP-glucose): activated form of glucose; building block for glycogen synthesis.
- The rate-determining enzyme of glycogenesis is glycogen synthase!

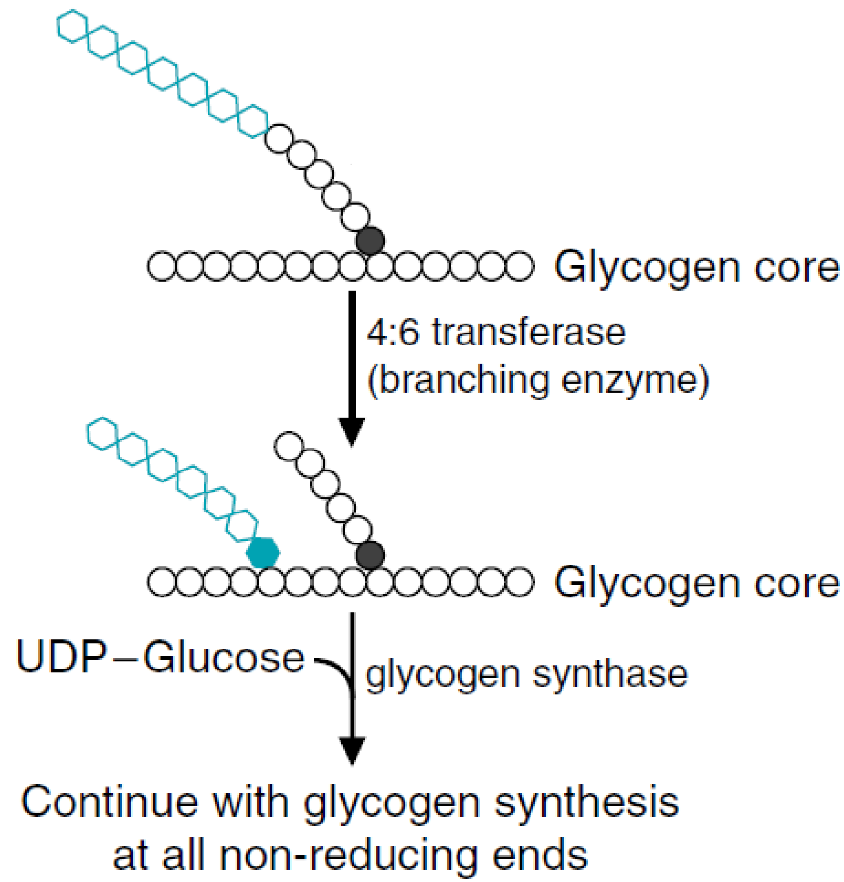


http://themedicalbiochemistrypage.org/glycogen.php

Glycogen branches formation

การเกิดแขนงของไกลโคเจน

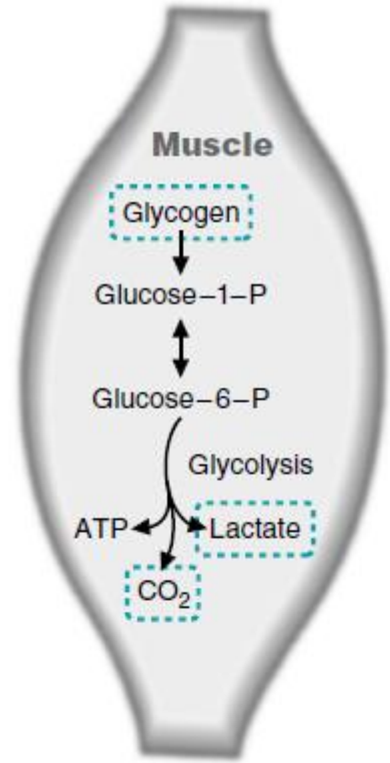


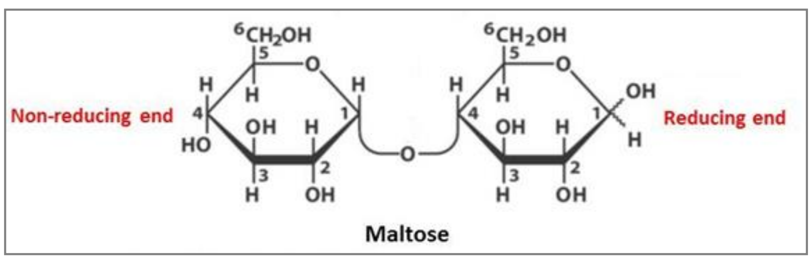


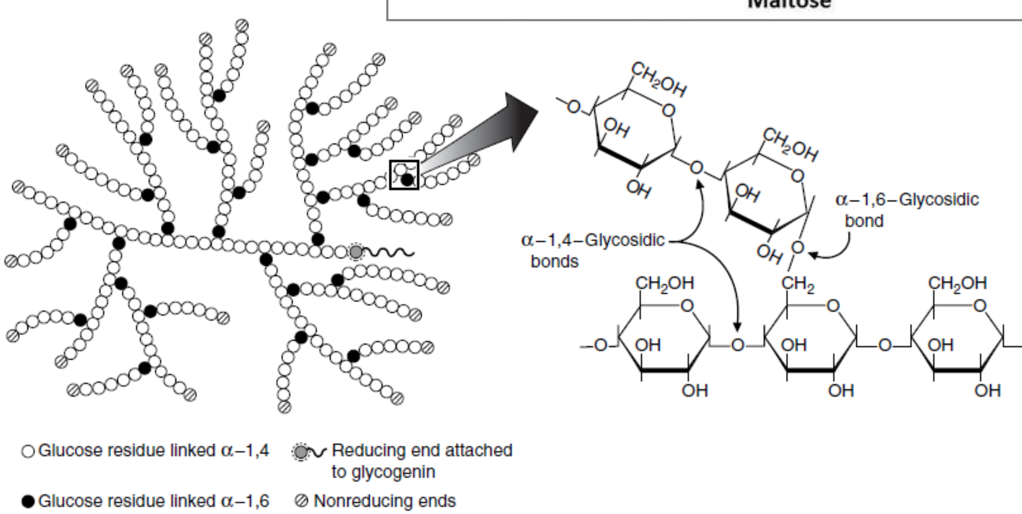
Glycogenolysis

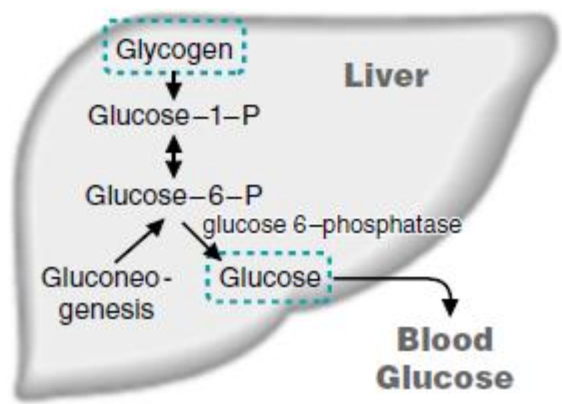
= glycogen breakdown

- only the nonreducing ends are shortened.
- nonreducing ends = the ends lacking a C1-OH group.
- there is a nonreducing end in every branch.

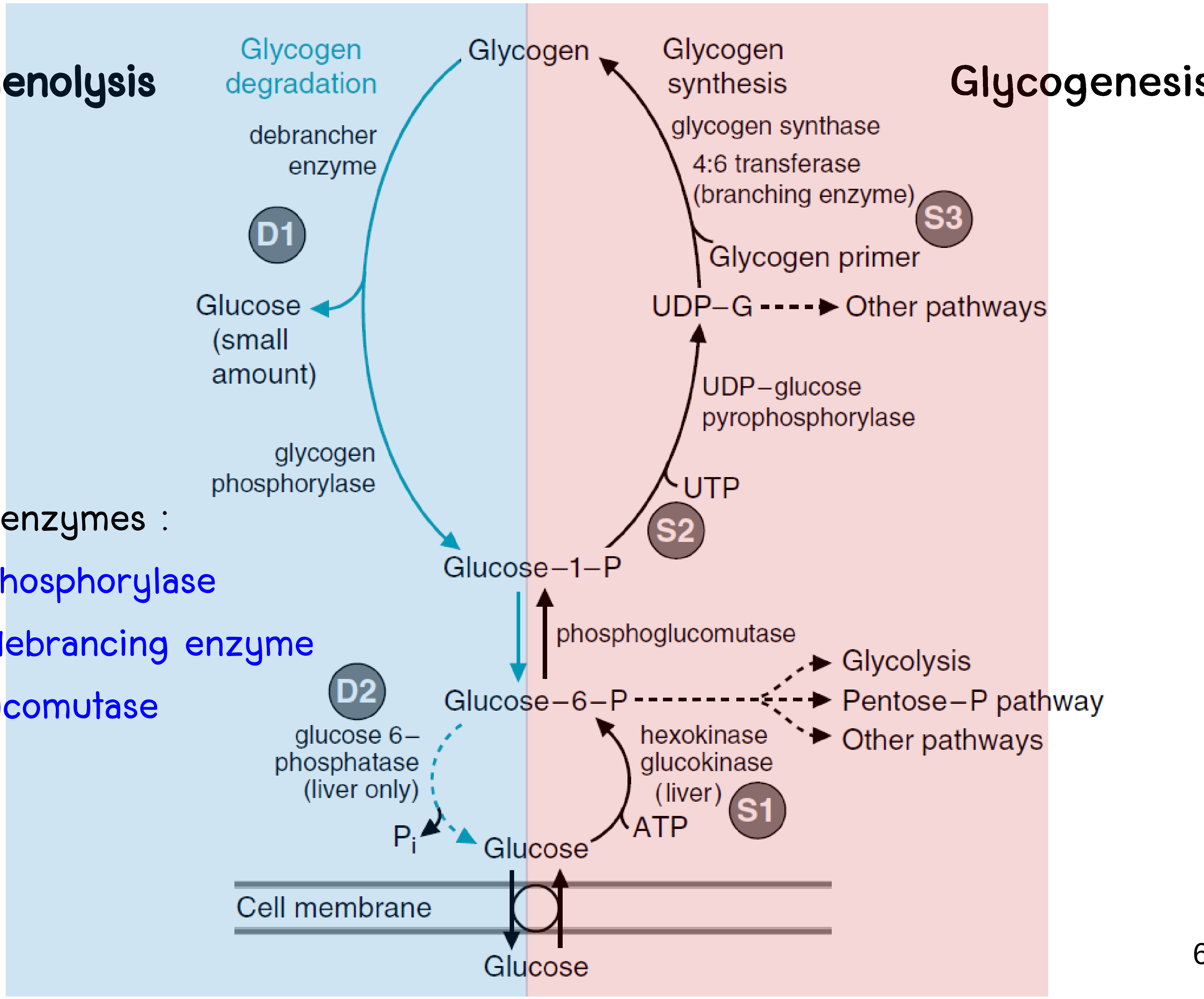








Glycogenesis & glycogenolysis



- Requires 3 enzymes :

1. Glycogen phosphorylase
2. Glycogen debrancing enzyme
3. Phosphoglucomutase

Glycogen breakdown

1. Glycogen phosphorylase catalyzes glycogen phospholysis (bond cleavage by the substitution of a phosphate gr.)

Glycogen + Pi → Glycogen + G1P

This enz. leave 4 residues along each branch.

2. Glycogen debranching enzyme has active sites:

- Transferease shifts a block of 3 residues from one outer branch to the other.
- α-1,6-Glucosidase removes the rest residue, leaving linear chain.

3. Phosphoglucomutase converts G1P to G6P

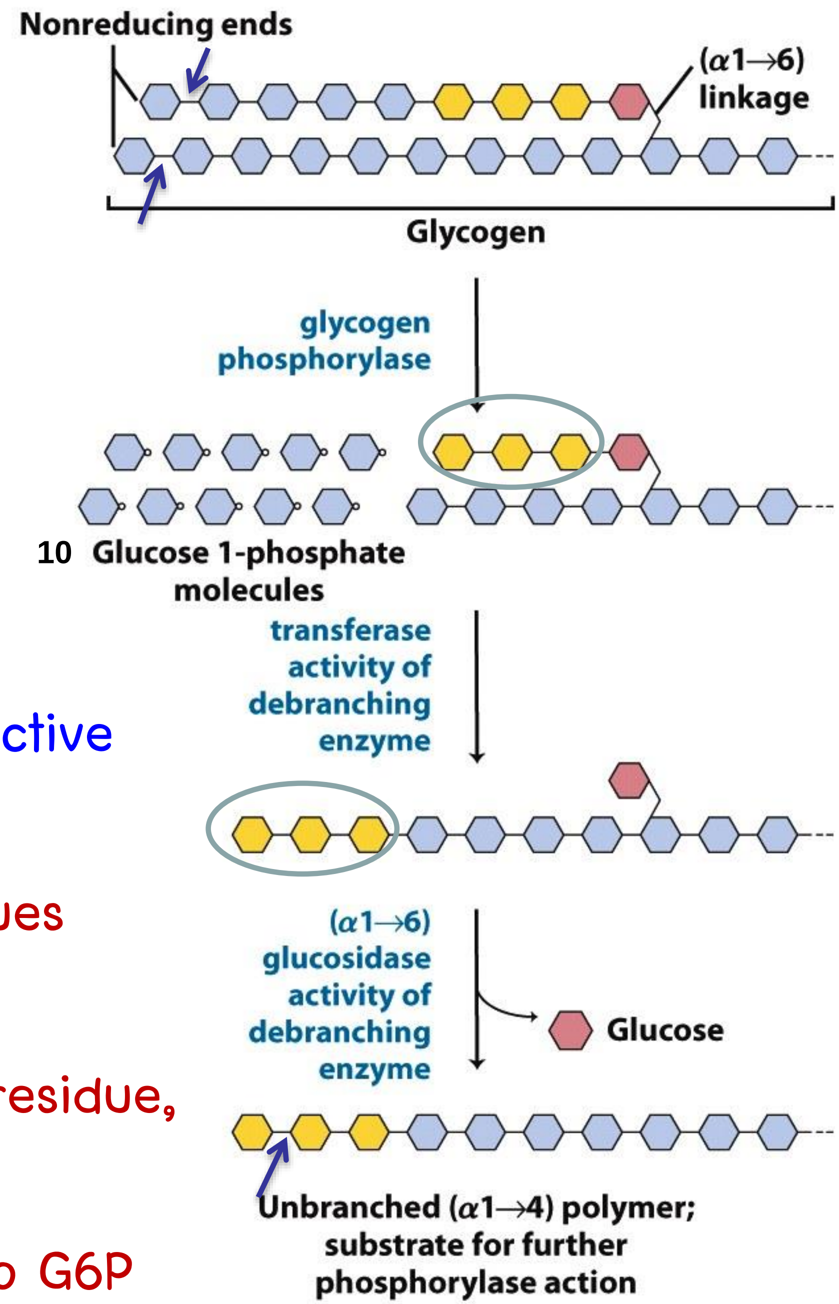
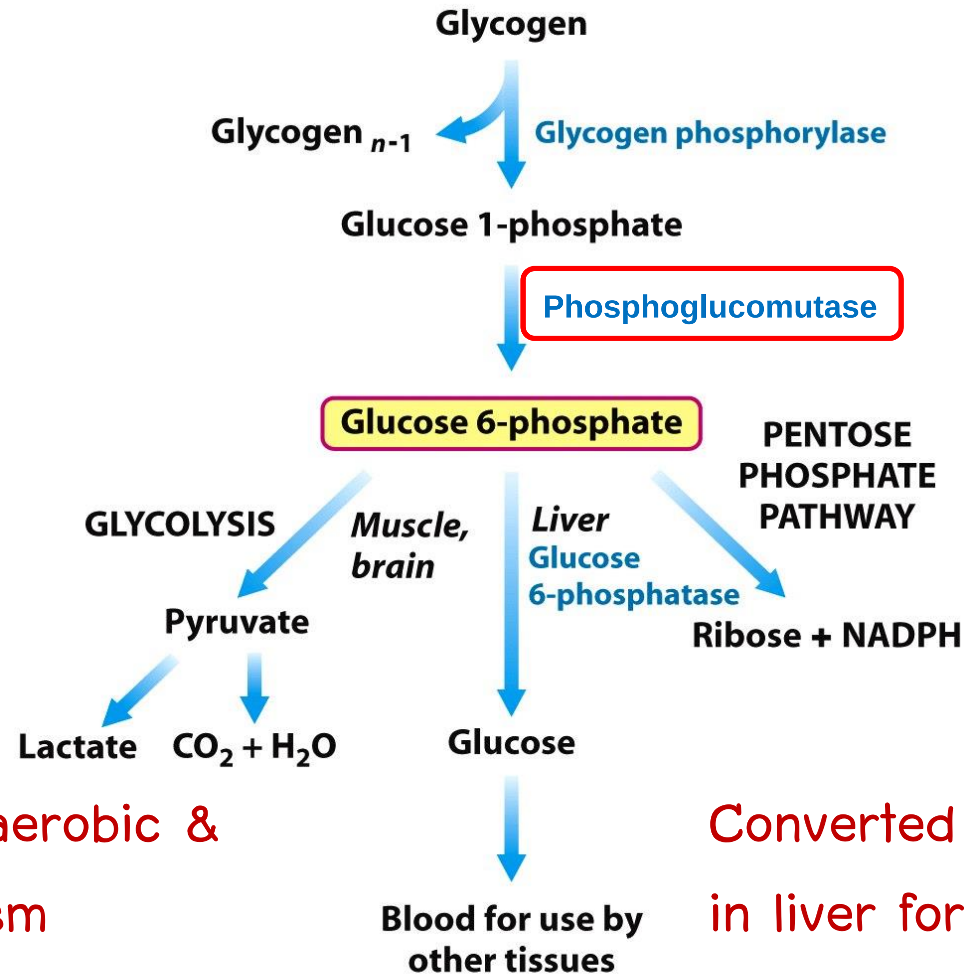


Figure 15-26
Lehninger Principles of Biochemistry, Fifth Edition

Fates of glucose-6-phosphate



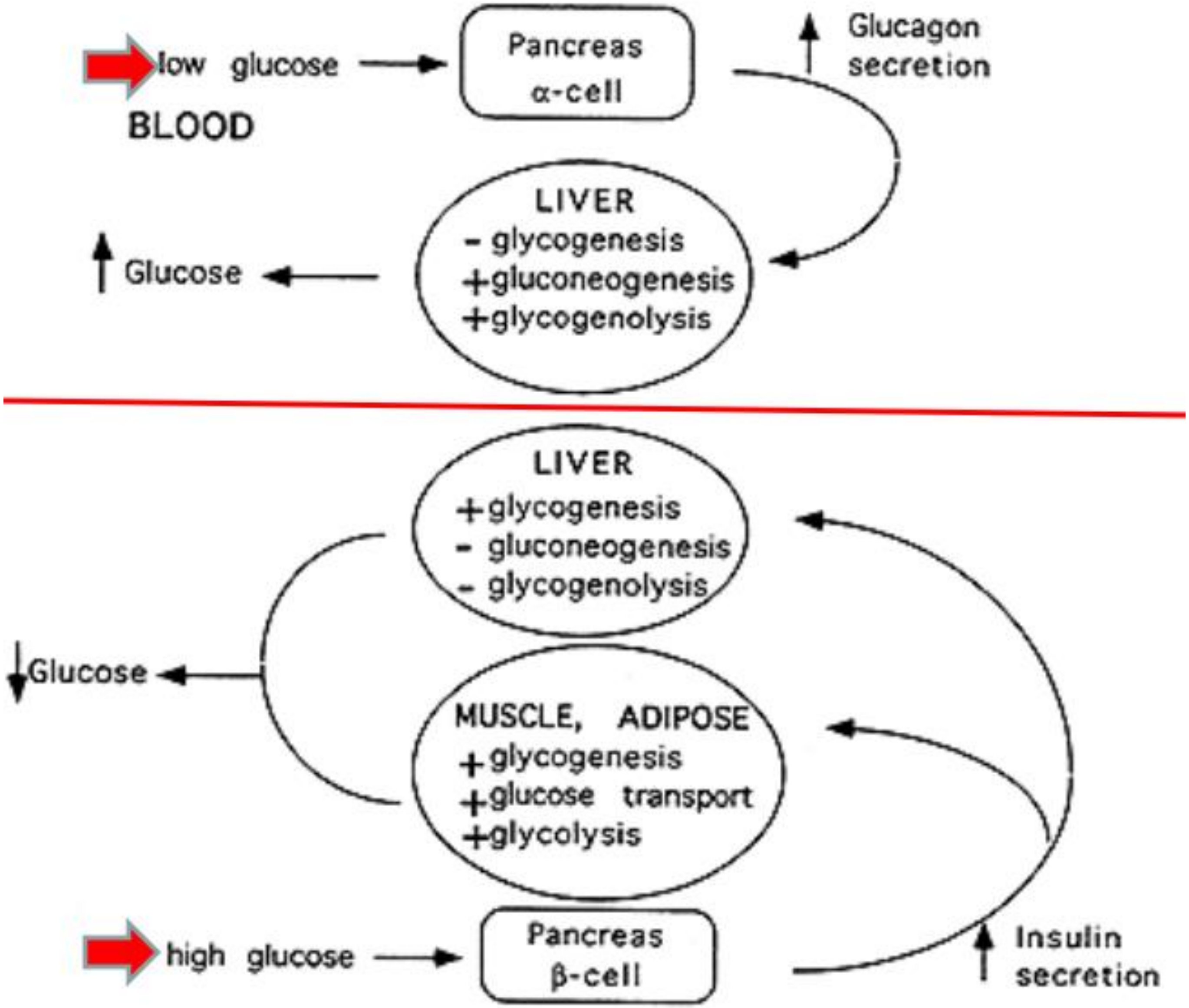
Be processed by PPP

Used as a fuel for aerobic & anaerobic metabolism

Converted to free glc in liver for release into blood.

Figure 21-3
Biochemistry, Sixth Edition

Insulin and glucagon



http://chemistry.gravitywaves.com/CHE450/19_Insulin%20&%20Glucagon.htm