Cellular aerobic respiration

When cells obtain energy to make ATP by using oxygen to break down glucose into CO_2 and H_2O

$C_6H_{12}O_6$ (glucose)	+	$6O_2$	$\longrightarrow$	$6CO_2$	+	$6H_2O$

(+ energy)

- Requires oxygen
- Yield = 32 ATP per glucose
- Fatty acids and amino acids can be used instead of glucose
- Animals **and plants** use aerobic respiration to make their ATP

Cellular anaerobic respiration

When cells obtain energy to make ATP by breaking down glucose into lactic acid (or into alcohol and CO_2)

$C_6H_{12}O_6$ (glucose)	$\longrightarrow$	lactic acid (or alcohol + CO_2)

(+ energy)

- No oxygen is required
- Yield = only 2 ATP per glucose

Mitochondria

A double membrane organelle where most (but not all) parts of cellular aerobic respiration reactions occur.

- The mitochondria's inner membrane is highly folded

  √ Cristae = The folds of inner membrane

  √ Matrix (inner compartment) = The space enclosed by inner membrane

  √ Intermembrane space (outer compartment) = The space between inner and outer membranes

Fig 6.17

Cellular aerobic respiration takes place in 4 separate stages:

	Glycolysis	Transition step	Kreb's cycle	Electron transport system
Location:	cytoplasm	outer membrane of mito.	inner compartment of mito.	inner membrane of mito.
Substrate changes:	Glucose ↓ 2 Pyruvates (C_3)	Pyruvate ↓ Acetyl (C_2) + CO_2	Acetyl ↓ 2 CO_2	–
NADH and $FADH_2$ yield:	2 NADH	2 NADH	6 NADH 2 $FADH_2$	–
ATP yield:	2 ATP	–	2 ATP	28 ATP

Fig 9.6

Glycolysis

A metabolic pathway that takes place in the cytoplasm. Each molecule of glucose is converted by a series of 10 enzymes into 2 molecules of pyruvate (C_3)

- The first half of the pathway converts glucose (a C_6 molecule) into two molecules of PGAL (a C_3 molecule)

  √ This part requires 2 ATP

- The second half of the pathway converts the two PGAL molecules into two pyruvate molecules (also C_3 molecules)

  √ This part produces 4 ATP and two NADH

- The **net** energy yield from glycolysis is 2 ATP and 2 NADH per glucose

- No O_2 is required

Figs 9.6 and 9.9

Transition step

From each pyruvate, an acetyl (a two-carbon molecule) enters the mitochondria

• Outside the mitochondria, each pyruvate loses 1 carbon as CO_2

• The 2 remaining carbons become an acetyl (C_2) molecule (attached to coenzyme A)

√ Acetyl CoA = the acetyl group attached to coenzyme A

• Yield = 1 NADH per pyruvate (2 per glucose)

Citric acid cycle (Krebs cycle)

A circular metabolic pathway in the inner compartment of the mitochondria. Eight enzymes break down each acetyl into two CO_2

• Yield = 1 ATP, 3 NADH, and 1 $FADH_2$ per acetyl (twice that per glucose)

• Amino acids and fats can enter Kreb's cycle or glycolysis as various intermediates

Mitochondrial electron transport system

An electron transport system in the inner mitochondrial membrane that generates ATP from the energy in NADH and $FADH_2$

- NADH and $FADH_2$ donate high energy electrons to the electron transport system

- Most of the electron carriers are complexes (clusters) of cytochrome proteins.

  √ Three of the complexes are H^+ pumps. They use part of the electron's energy to actively transport H^+ from the matrix to the outer compartment. This creates an H^+ gradient in the outer compartment.

  √ The only non-protein electron carrier is Ubiquinone. It shuttles electrons between the first and the second complexes.

- ATP is made by ATP Synthase, a membrane transport protein that couples facilitated diffusion of H^+ back into the matrix with ATP synthesis

  √ 2.5 ATPs are made per NADH

  √ 1.5 ATP are made per $FADH_2$

  - $FADH_2$ produces one fewer ATP because its donates its electrons directly to ubiquinone, bypassing the first H^+ pump

- The final H^+ pump passes the electrons to oxygen, which combines with H^+ to make water

  $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

- Yield = 28 ATP per glucose

Figs 9.6, 9.15, and 9.19

Cellular anaerobic respiration (fermentation)

When cells obtain energy to make ATP by breaking down glucose into lactic acid (or into alcohol and CO_2)

$C_6H_{12}O_6$ (glucose)	$\longrightarrow$	2 lactic acid molecules (or 2 alcohol molecules + $2CO_2$)	(+ energy)

- Anaerobic respiration begins with the glycolysis metabolic pathway

  √ Due to lack of oxygen, the two pyruvates from glycolysis can **not** enter the mitochondria and can **not** go through the rest of aerobic respiration

  √ The pyruvates are converted into lactic acid (C_3) or alcohol (C_2) + CO_2

- In animals, anaerobic respiration is used to supply muscle with ATP during for short bursts of activity

- No oxygen is required

  √ Cells use anaerobic respiration when there is too little oxygen for aerobic respiration

- Yield = only 2 ATP per glucose

- In yeast and other micro-organisms, alcohol and carbon dioxide (not lactic acid) are the products of fermentation

Figs 9.17 and 9.18