Aerobic Metabolism

Glycolysis

↓

Transition

↓

Kreb's

↓

ETC

METABOLISM

1) Glycolysis ☆

(Anaerobic)

2ana) Fermentation

☆ (Aerobic)

Transition / Prep

2aero) Krebs

3aero) ETC

(AEROBIC)
METABOLISM - CELLULAR RESPIRATION (3 major steps + Transition)

* 1) 1) Glycolysis (both aerobic & anaerobic processes)

→ 2a) Transition (Pyruvate Oxidation - Preparatory Step)

2) 2) Kreb's (The Citric Acid - TCA) Cycle

3) 3) ETC (Electron Transport Chain - Oxidative Phosphorylation)

(Kreb's - aerobic
TCA cycle)

Glycolysis (Thru the cell membrane and into the cytoplasm)

↓

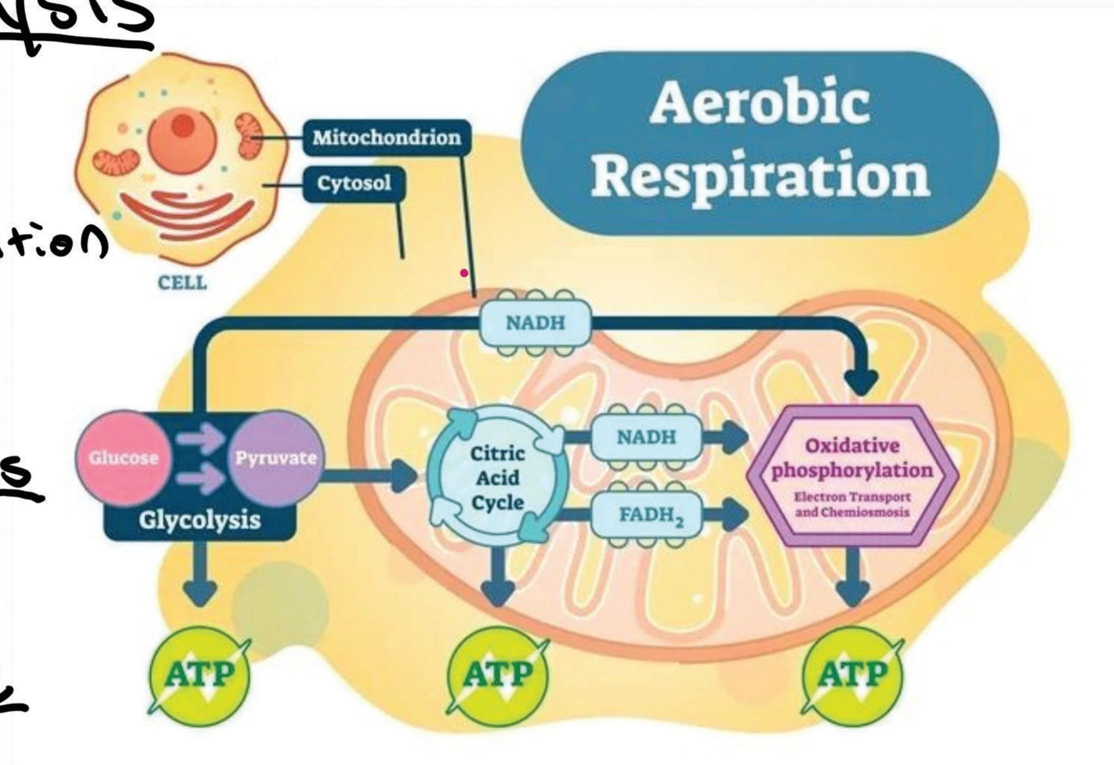
Transition (Thru the mitochondrial membrane to enter the mitochondria)

↓

Kreb's (Inside mitochondria)

↓

ETC (Thru the mitochondrial membrane to exit the mitochondria)



GLYCOLYSIS (entering the cell's cytoplasm)

- Glucose is water soluble, 6-carbon chain molecule
  = can't get into the cell thru membrane

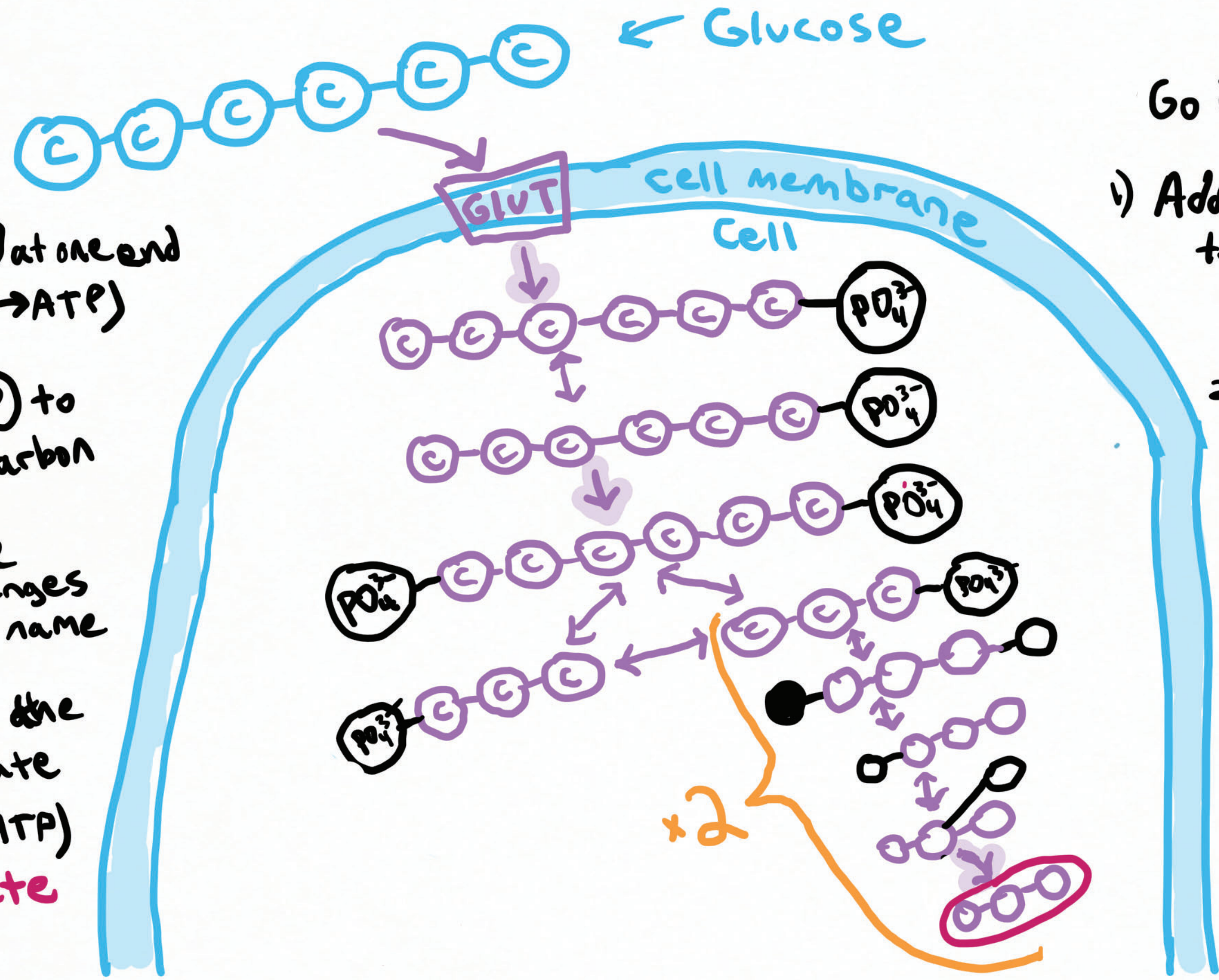
  C–C–C–C–C–C

- Glycolysis
  - 1) GLUT → Glucose Transporters — brings glucose into cell cytoplasm thru cell membrane
  - Rest of steps in cell's cytoplasm
    - ★ enzymes drive reactions
    - ★ energy transporters ATP, NADH

IN	OUT
2 ATP	4 ATP

NET
2 ATP

1 molecule glucose = Result is 2 molecules of Pyruvate in cell's cytoplasm



Go in via GluT

1) Add phosphate group to lock it inside (ATP → ADP)

2) Molecule rearranges + changes name

3) Add phosphate group to other end (ATP → ADP)

4) Divide in half = now, 2 molecules

5) Add phosphate (Pi) to other ends (NAD → NADH+)

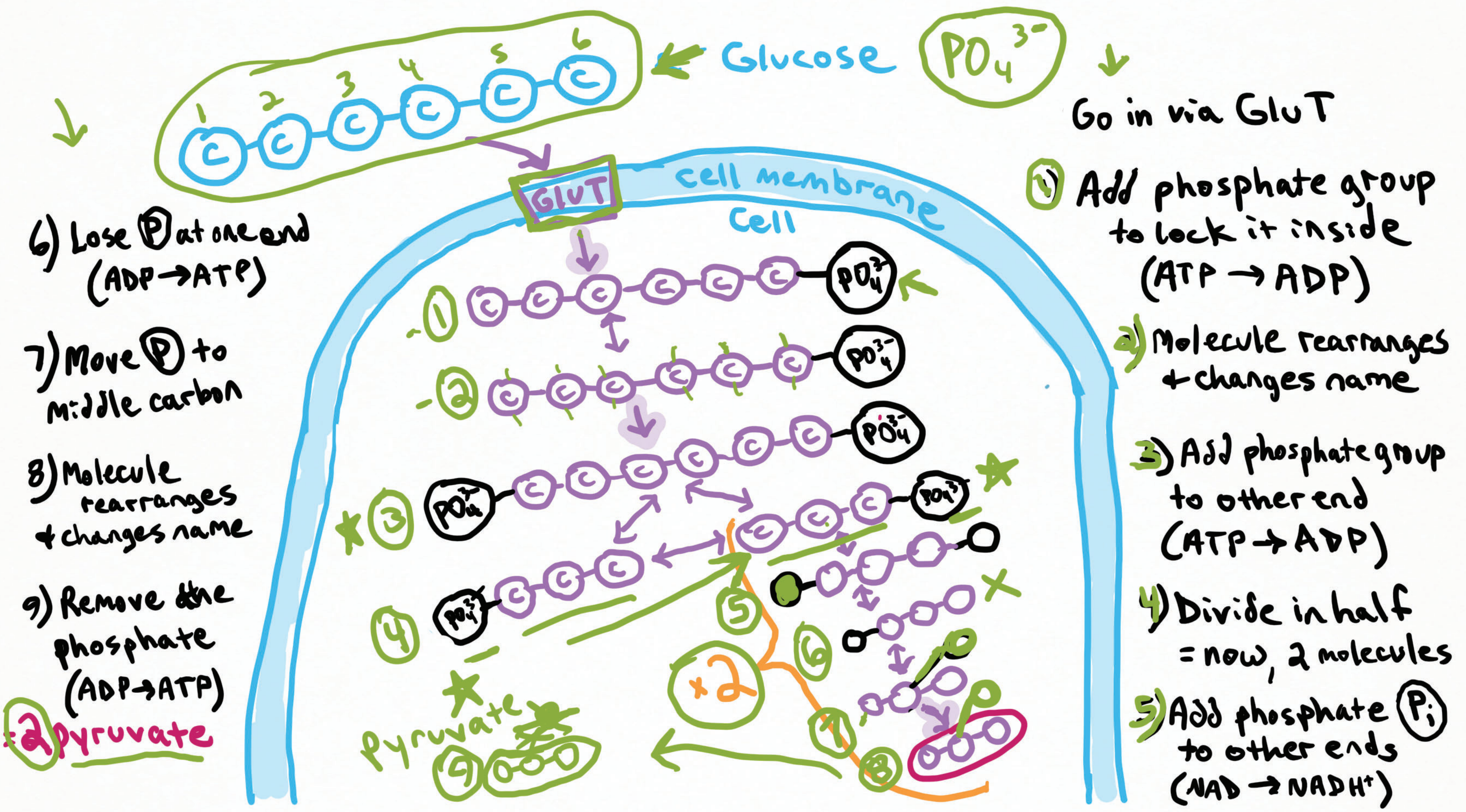
6) Lose (P) at one end (ADP → ATP)

7) Move (P) to middle carbon

8) Molecule rearranges + changes name

9) Remove the phosphate (ADP → ATP)

= 2 pyruvate


Glucose
1 2 3 4 5 6
C C C C C C
PO_4^{3-}
Go in via GluT
1) Add phosphate group to lock it inside (ATP → ADP)
2) Molecule rearranges + changes name
3) Add phosphate group to other end (ATP → ADP)
4) Divide in half = now, 2 molecules
5) Add phosphate P_i to other ends (NAD → $NADH^+$)
6) Lose P at one end (ADP → ATP)
7) Move P to middle carbon
8) Molecule rearranges + changes name
9) Remove the phosphate (ADP → ATP)
=2 pyruvate
GluT
cell membrane
Cell
x2
Pyruvate

Energy Carriers (Transporters)

ATP / ADP — Energy in phosphate bonds

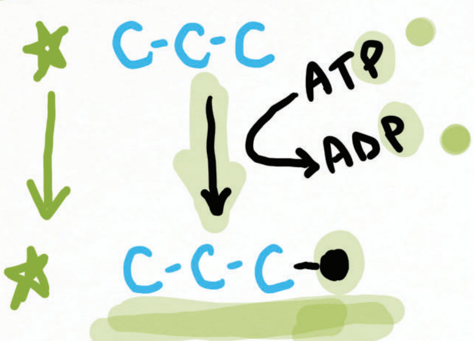
NAD^+ / NADH — Energy in hydrate bonds

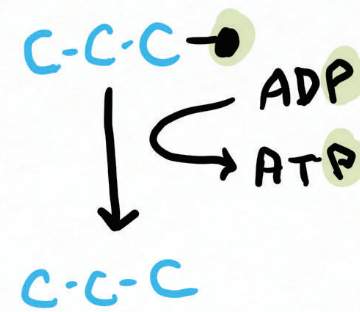
3Ⓟ **ATP** – Adenosine Triphosphate

"tri" – three (3) = 3 Phosphates Ⓐ–●–●–● (1 2 3)

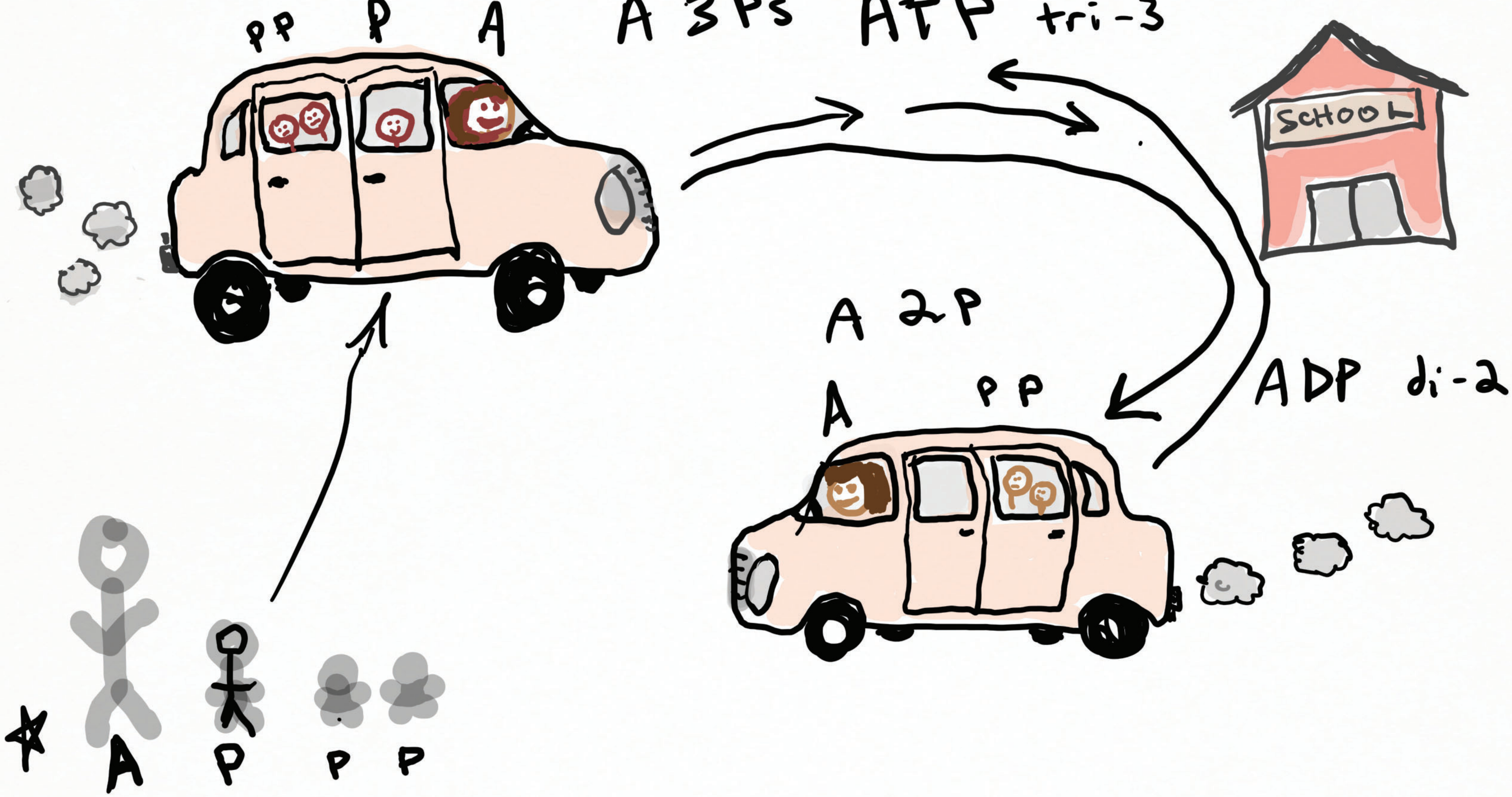
2Ⓟ **ADP** – Adenosine Diphosphate

"di" – two (2) = 2 Phosphates Ⓐ–●–● (1 2)





Phosphate: PO_4^{3-}

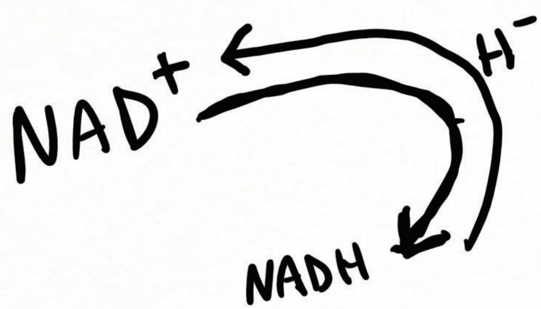


PP P A
A 3Ps ATP tri-3
SCHOOL
A 2P
A PP
ADP di-2
A P P P

NAD^+ — Nicotinamide Adenine Dinucleotide

NADH — 1,4- Dihydro NAD

<u>hydrate</u> (hydro) – H^- — 1 Hydrogen + extra e^-



Enzymes end in "-ase"

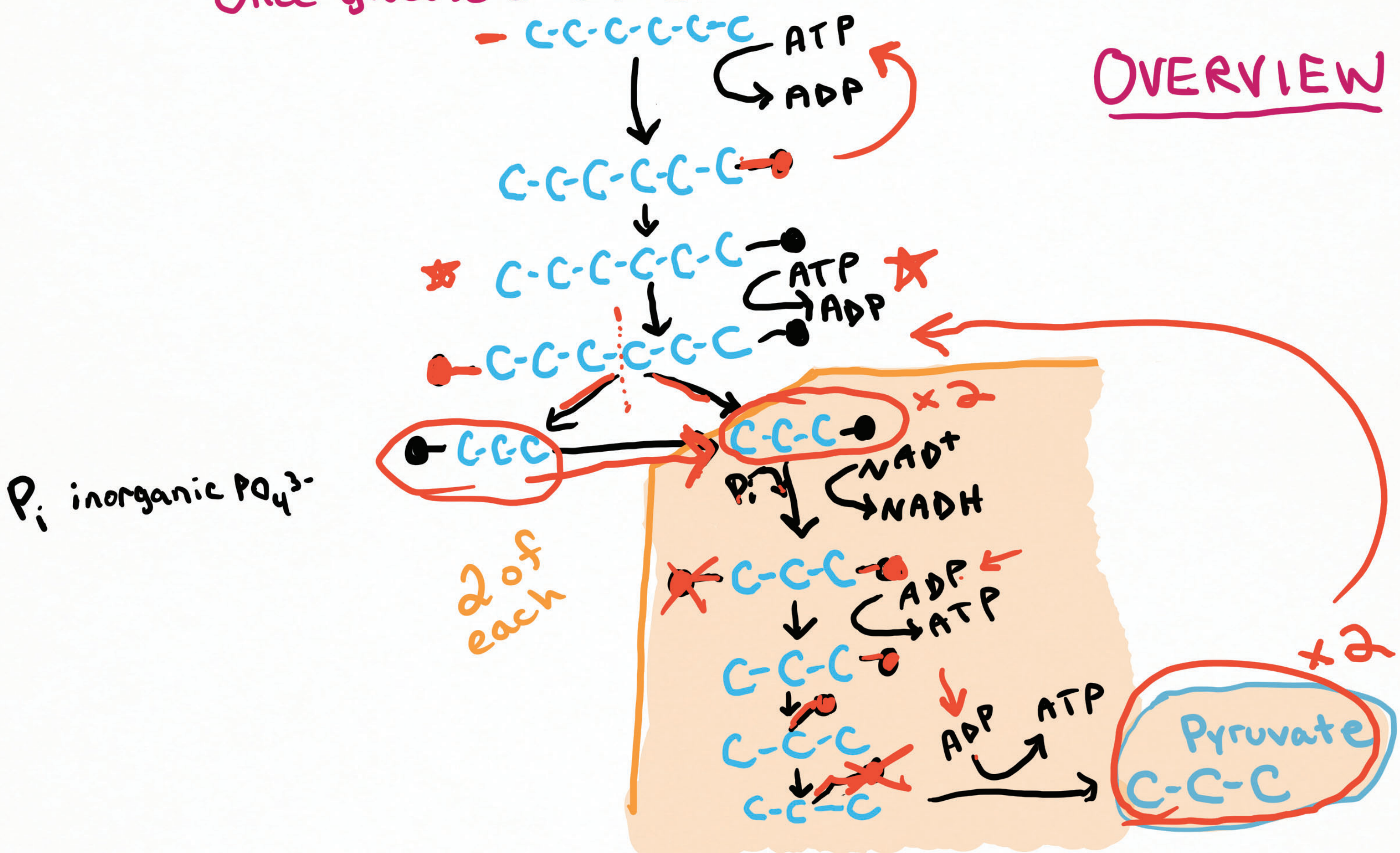
When ADP / ATP involved: enzymes: "___ kinase"

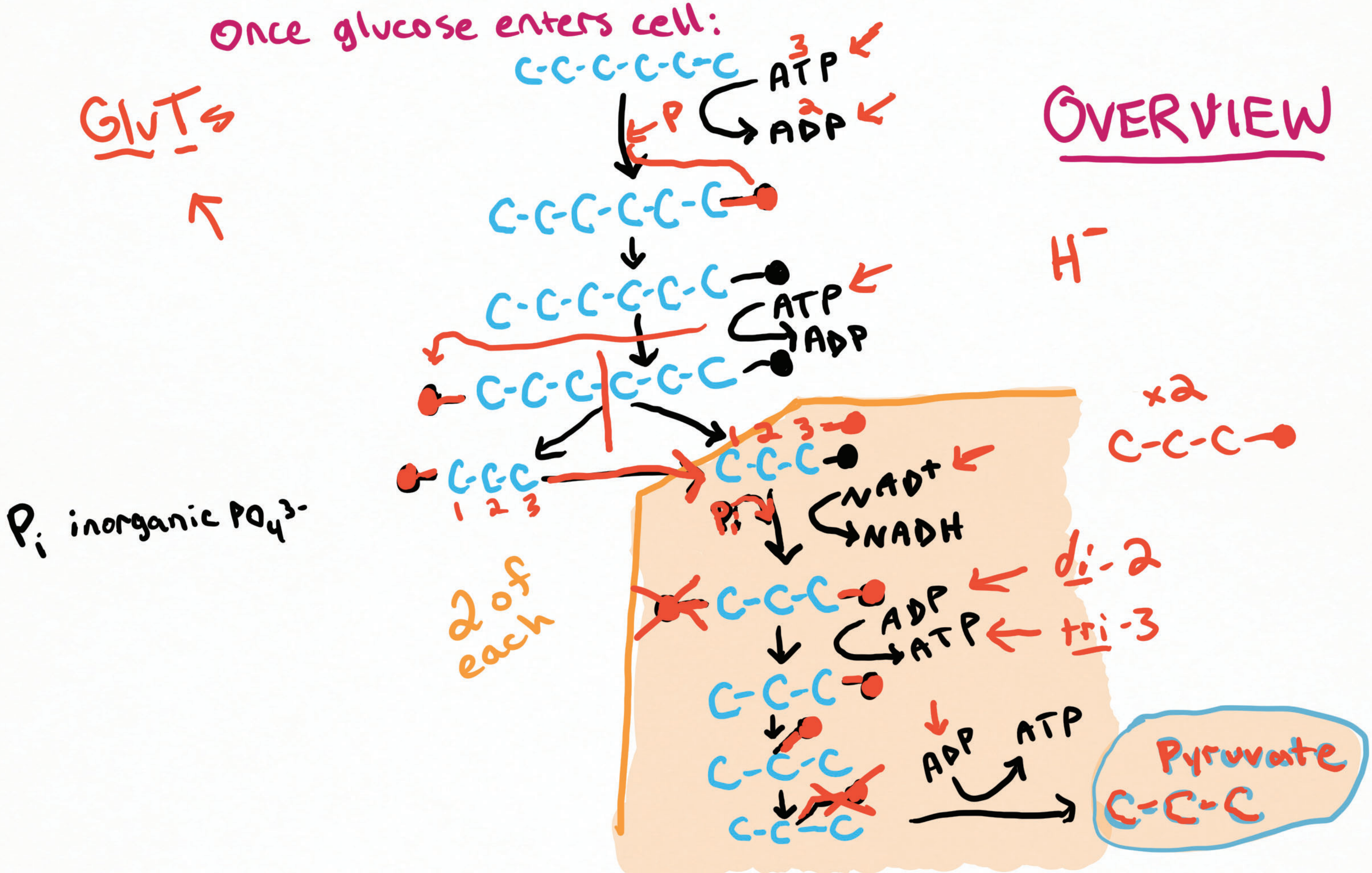
When NAD^+ / NADH involved: enzymes: "___ dehydrogenase"

When molecule gets rearranged (→ isomer or → enol): enzymes: "___ isomerase" or "___ enolase"

OVERVIEW

Once glucose enters cell:





OVERVIEW
Once glucose enters cell:
GluTs
C-C-C-C-C-C
ATP
ADP
P
ATP
ADP
C-C-C
1 2 3
2 of each
P_i inorganic PO_4^{3-}
H⁻
x2
NAD⁺
NADH
di-2
tri-3
ADP
ATP
Pyruvate
C-C-C

Glycolysis - Step 1

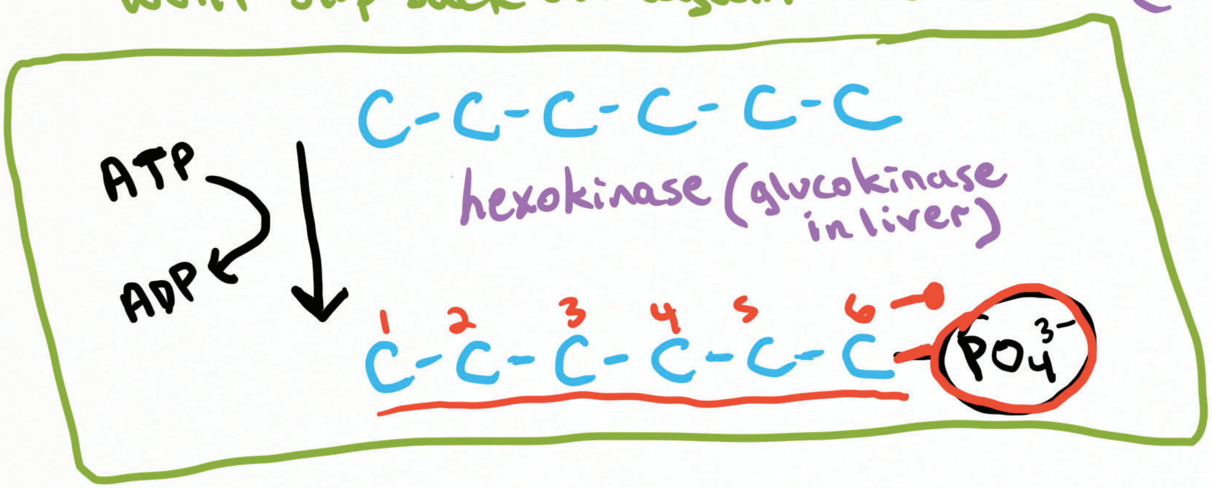
(START: Outside of cell)

C-C-C-C-C-C Glucose (6-carbon chain) $C_6H_{12}O_6$

★ Thru GluT in cell membrane into cell.

(Rest: takes place in cytoplasm inside cell)

★ Add on a PO_4^{3-} (phosphate) to keep it trapped inside cell, so it won't slip back out again thru GluT (enzyme: hexokinase)



IN: ATP

STICKS: PO_4^{3-}

OUT: ADP

Glycolysis - Step ②

1 2 3 4 5 6
C-C-C-C-C-C-PO_4^{3-} **Glucose-6-phosphate** ☆

Rearrange the other atoms in the molecule, changes name
(enzyme: phosphohexase isomerase)

= C-C-C-C-C-C-PO_4^{3-} **Fructose-6-phosphate**

Glycolysis - Step (3)

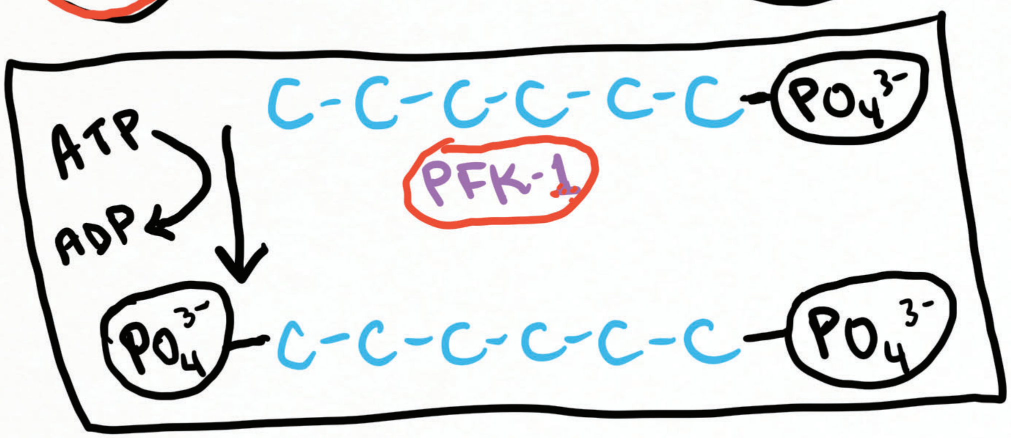
C-C-C-C-C-C-PO_4^{3-} Fructose-6-phosphate

↓

★ Add another phosphate to other end of molecule so it won't slip back into Glucose-6-phosphate (enzyme: phosphofructokinase-1 (PFK1))

1 2 3 4 5 6

PO_4^{3-}-C-C-C-C-C-C-PO_4^{3-} = Fructose-1,6-bizphosphate

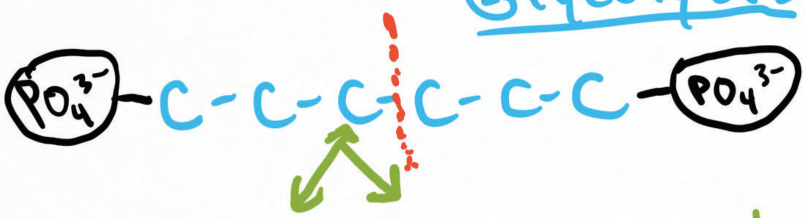


In: ATP

Sticks: PO_4^{3-}

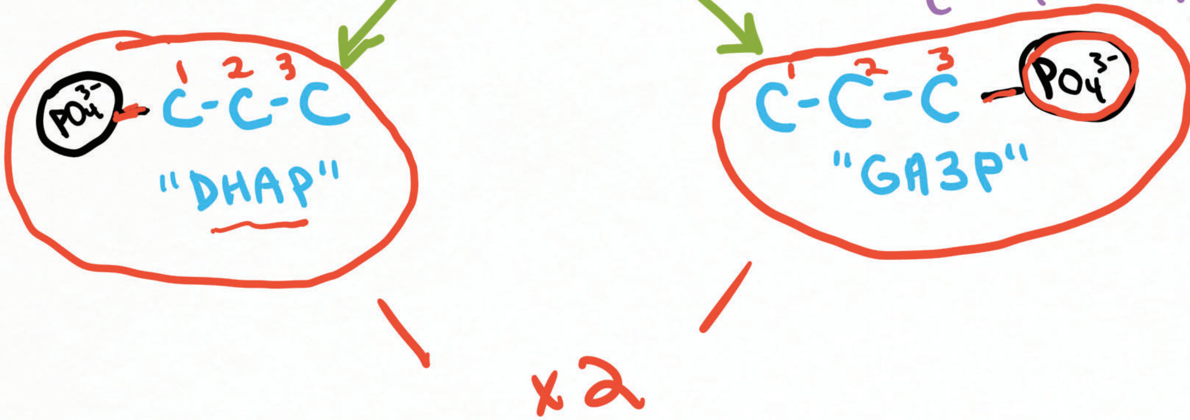
Out: ADP

Glycolysis - Step (4a)



Split in 1/2: now you have 2 molecules that everything happens to, so everything is doubled from now on

(enzyme: Aldolase)



Glycolysis – Step 4b

(● – for PO_4^{3-})

●–C–C–C DHAP (carbons numbered 1, 2, 3)

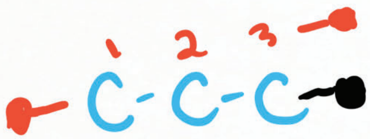
C–C–C–● GA3P

Convert DHAP to GA3P (so they're both GA3P)

(enzyme: Triose-phosphate Isomerase)

x2 GA3P G3P

Glycolysis - Step (5)

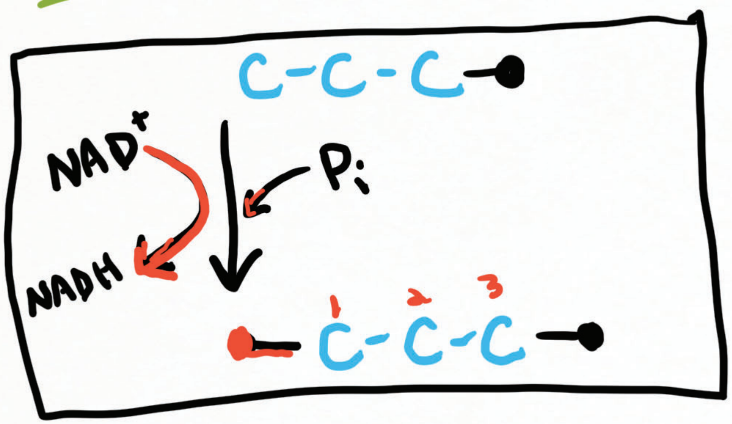


"GA3P" ×2

Adds inorganic phosphate to other end so it won't slip back into DHAP

(enzyme: GA3P Dehydrogenase)

AND Removes a hydride (H^-)



IN: NAD^+

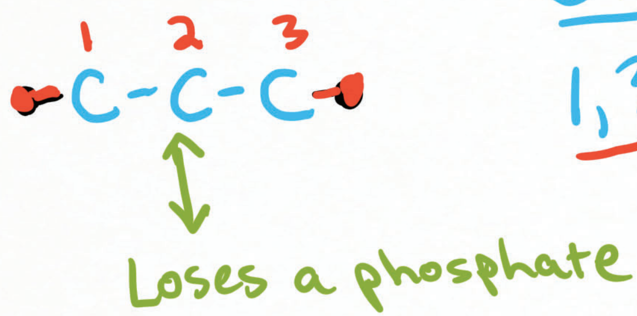
Removes: H^-

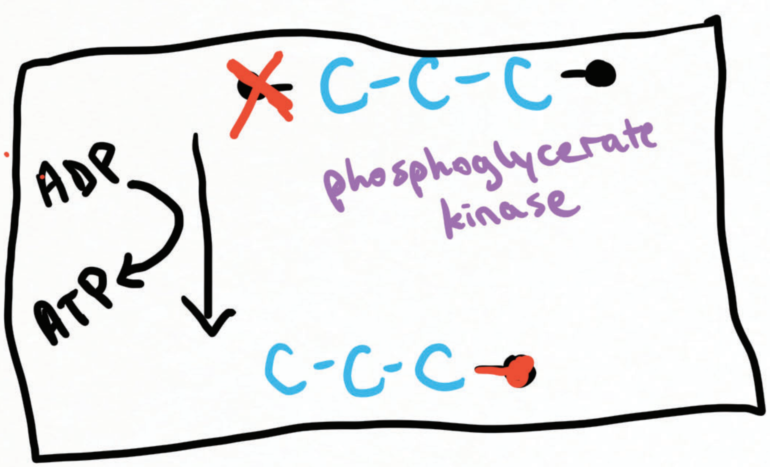
OUT: NADH

Glycolysis- Step 6

1,3- Bisphosphoglycerate

(enzyme: phosphoglycerate kinase)





IN: ADP
Takes: phosphate
Out: ATP

Glycolysis - Step 7

* C-C-C   3-phosphoglycerate

↕

Rearrange phosphate to center of molecule

(enzyme: phosphoglycerate mutase)

C-C-C   2-phosphoglycerate

Glycolysis- Step 8

C-C-C 2- phosphoglycerate

Rearrange phosphate on molecule to C-C=C

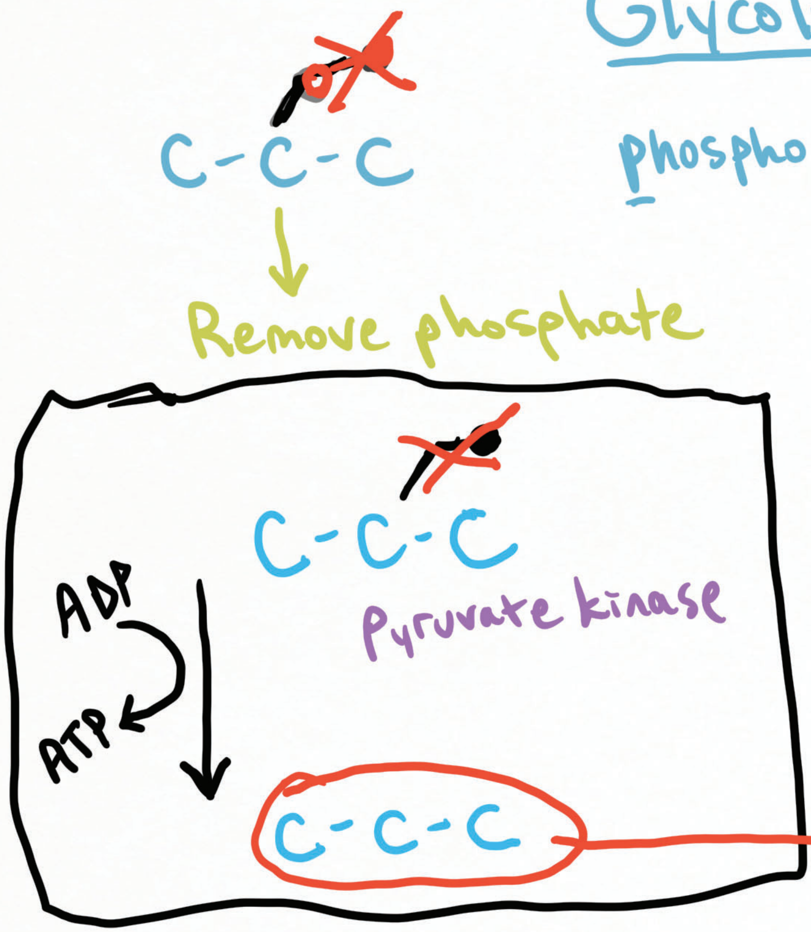
(enzyme: enolase)

C-C-C "PEP" (phospho enol pyruvate)

Glycolysis - Step 9

phospho enol pyruvate "PEP"

(enzyme: Pyruvate kinase)



IN: ADP

REMOVE: PO_4^{3-}

OUT: ATP

Pyruvate

x2

★ GLYCOLYSIS RESULTS

(include BOTH molecules 1/2)

2 ATP = generate 2

2 NADH = 2

2 Pyruvates = 2

GLYCOLYSIS

Steps:

1. Enter cell, add phosphate — 1 ATP used → ~~1 ADP gained~~ — -1 ATP
2. Rearrange
3. Add phosphate — 1 ATP used → ~~1 ADP gained~~ — -1 ATP
4. Split in 2
5. Add phosphate — NAD^+ used → NADH × 2 gained
6. Remove phosphate — ADP → ATP × 2 gained — 2 ATP
7. Rearrange ✓
8. Rearrange ✓
9. Remove phosphate — ADP → ATP × 2 gained — 2 ATP

= 2 pyruvates

2 ATPs gained

Aerobic Metabolism

Glycolysis

↓

Transition ☆

↓

Kreb's

↓

ETC

METABOLISM

1) Glycolysis

(Anaerobic)

2ana) Fermentation

★ (Aerobic)

Transition / Prep

2aero) Krebs

3aero) ETC

(Thru the cell membrane and into the cytoplasm)

Glycolysis

↓

(Thru the mitochondrial membrane to enter the mitochondria)

Transition

↓

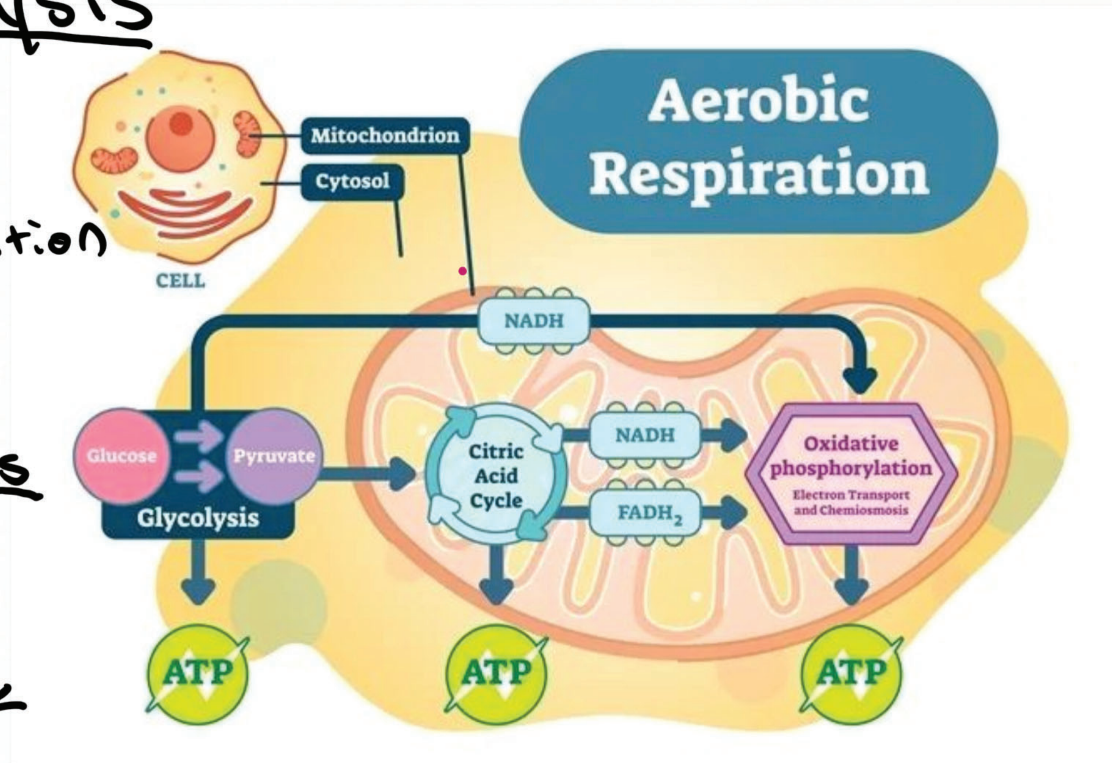
(Inside mitochondria)

Kreb's

↓

(Thru the mitochondrial membrane to exit the mitochondria)

ETC

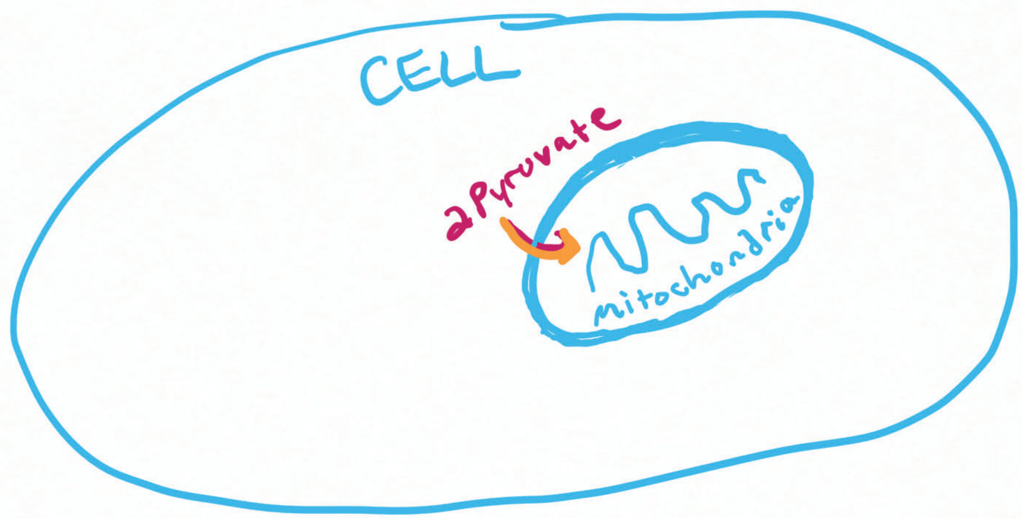


TRANSITION STAGE

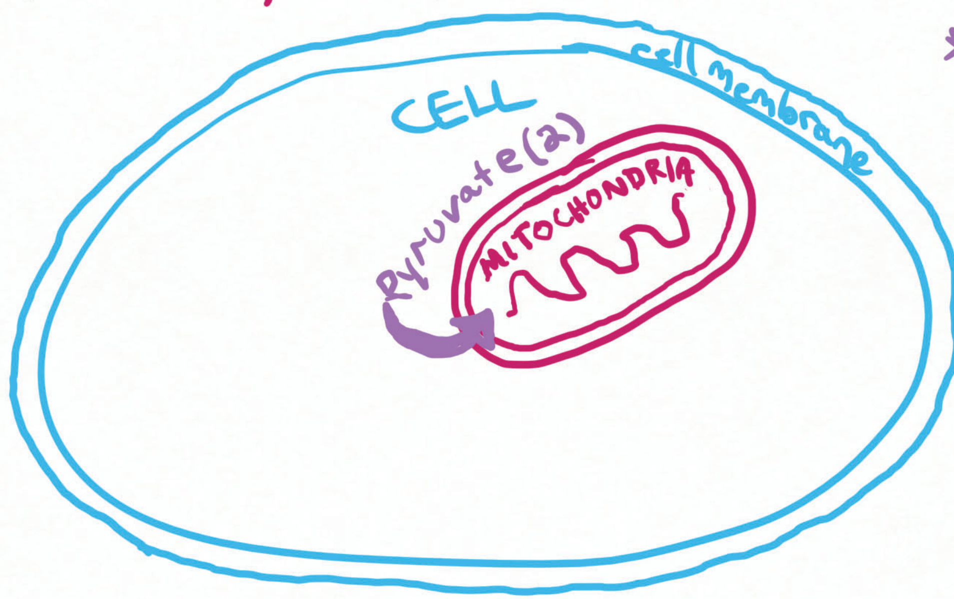
(aka "Pyruvate Oxidation")
aka "Preparatory Phase"

Brings the 2 molecules of pyruvate into the mitochondria

(pyruvate can't cross the mitochondrial membrane by itself)

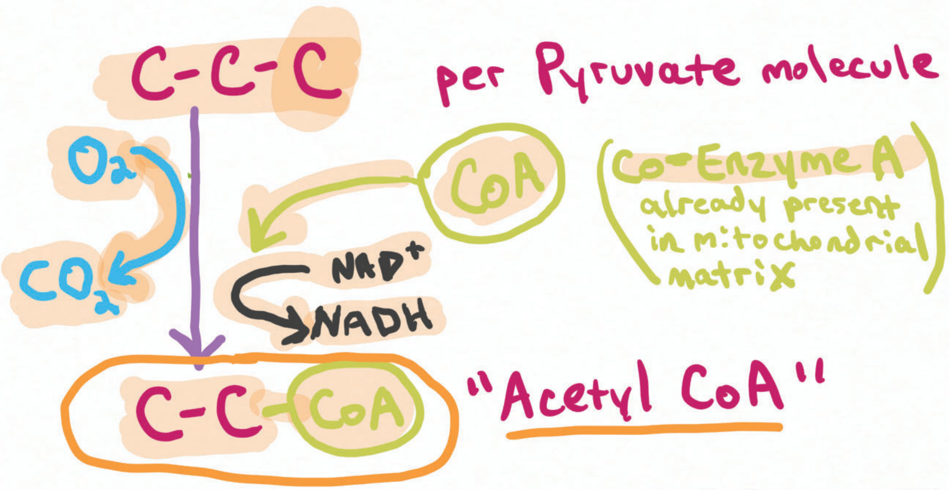


- **MUST have OXYGEN present!**
  (Otherwise, goes to Fermentation pathway
  Can't cross mitochondrial membrane w/o Oxygen)
  ↳ therefore, can't get in to mitochondria



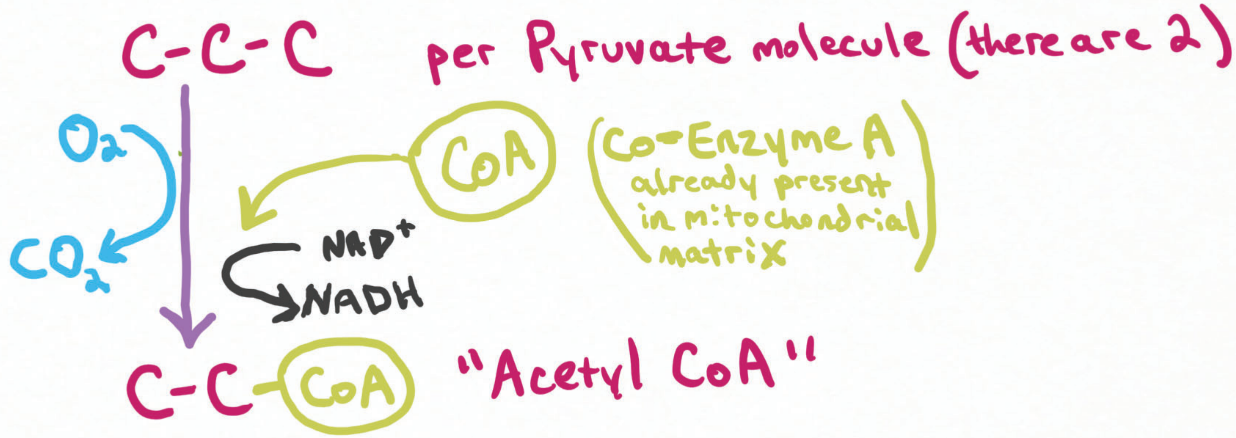
*Remember: Count for 2 molecules of Pyruvate!

per Pyruvate molecule (there are 2)



enzyme: Pyruvate De-Hydrogenase
(aka "PDH")

IN	OUT	NET × 2
O_2	CO_2	✓ 2 CO_2
CoA	X	X
NAD^+	NADH	✓ 2 NADH
		✓ = 2 Acetyl CoA



enzyme: Pyruvate De-Hydrogenase (aka "PDH")

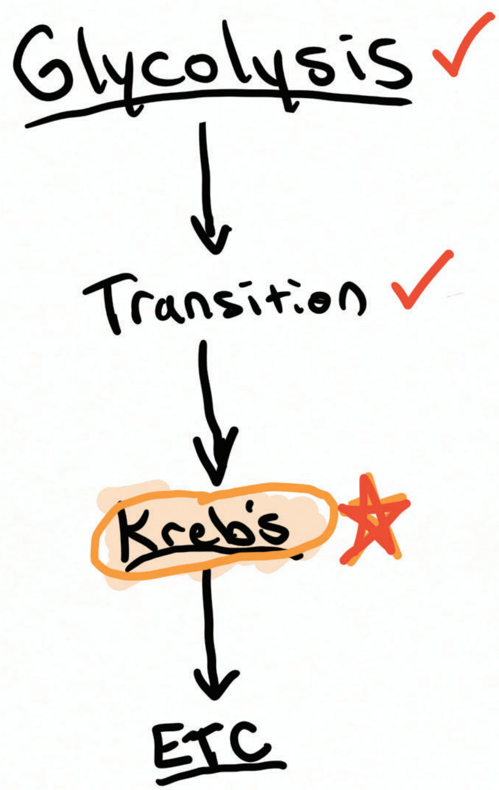
IN	OUT	NET × 2
O_2	CO_2	$2CO_2$
CoA	X	X
NAD^+	NADH	2NADH
		=2 Acetyl CoA

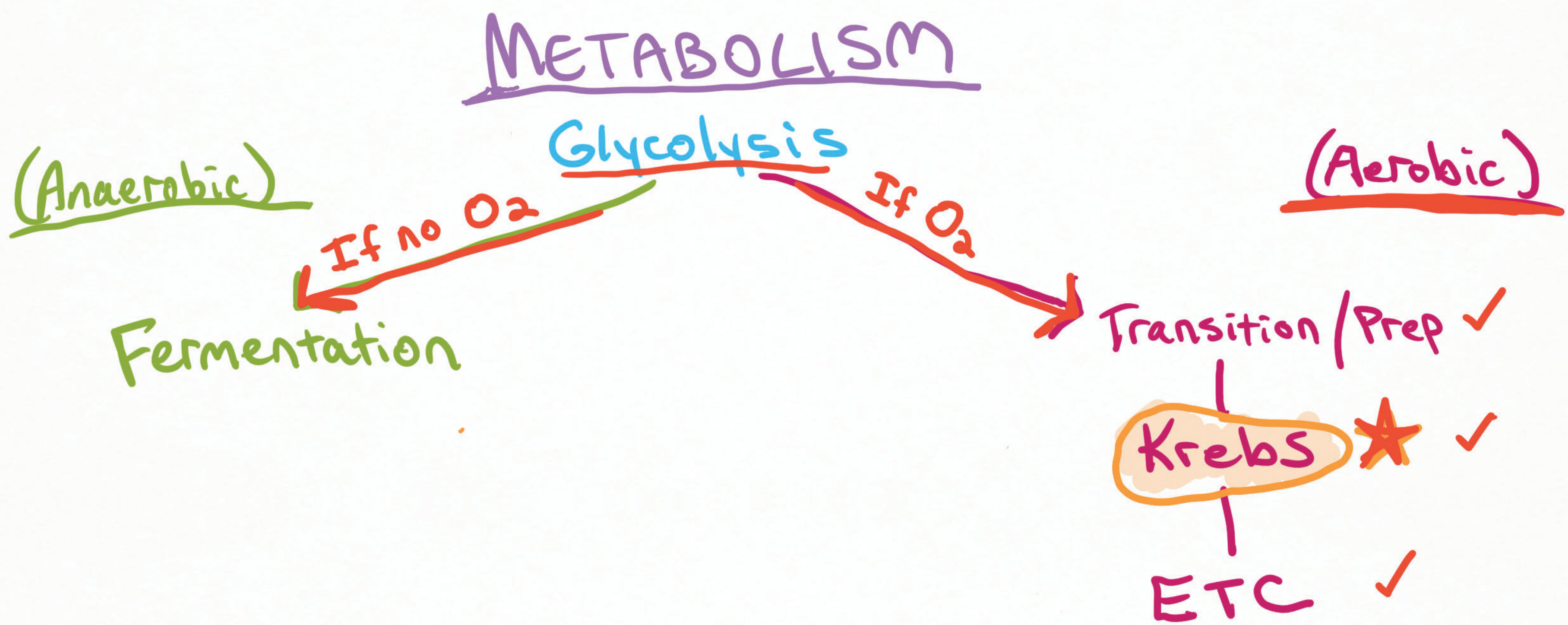
NEXT: Kreb's Cycle

THE KREB`s CYCLE!

EASY and CLEAR

Aerobic Metabolism




METABOLISM
Glycolysis
(Anaerobic)
If no O_2
Fermentation
If O_2
(Aerobic)
Transition / Prep ✓
Krebs ★ ✓
ETC ✓

(Thru the cell membrane and into the cytoplasm) — **Glycolysis**

↓

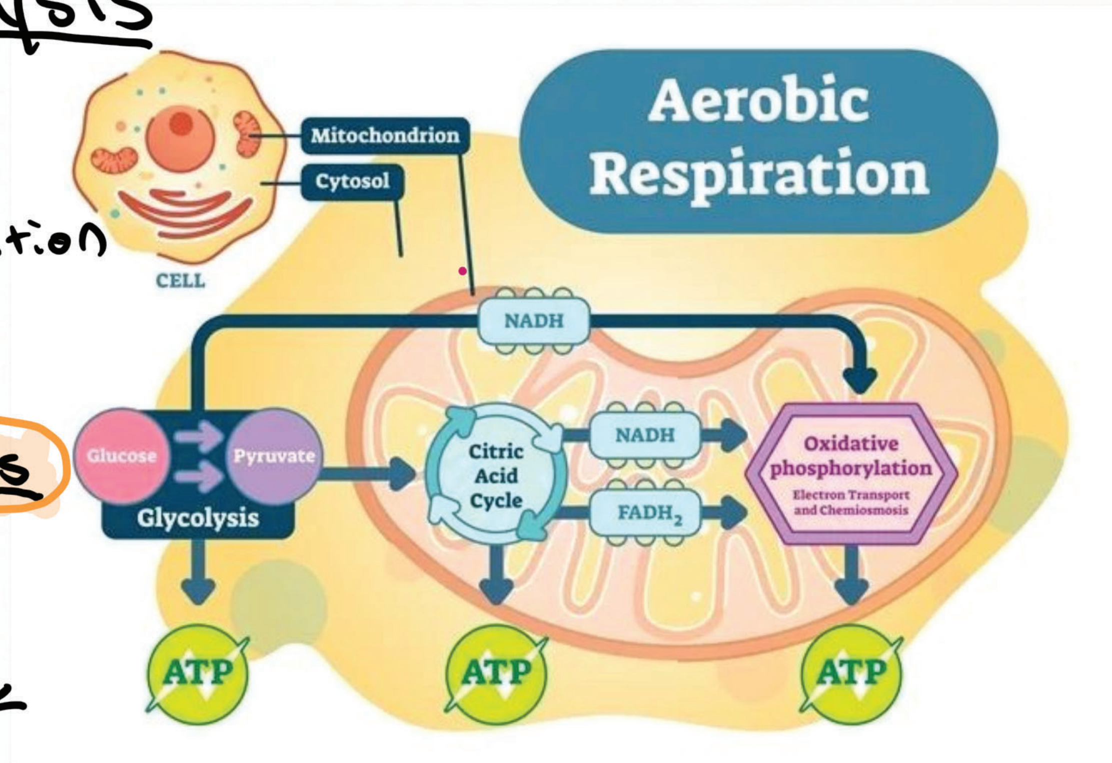
(Thru the mitochondrial membrane to enter the mitochondria) ✓ — Transition

↓

★ (Inside mitochondrial matrix) — **Kreb's**

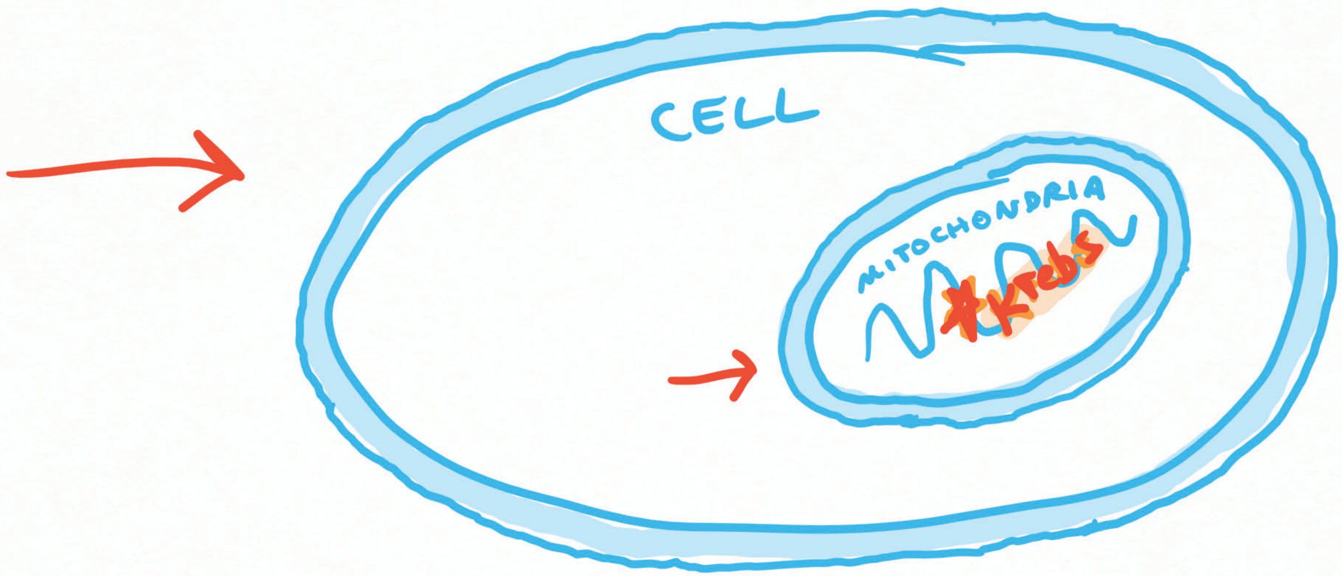
↓

(Thru the mitochondrial membrane to exit the mitochondria) — **ETC**



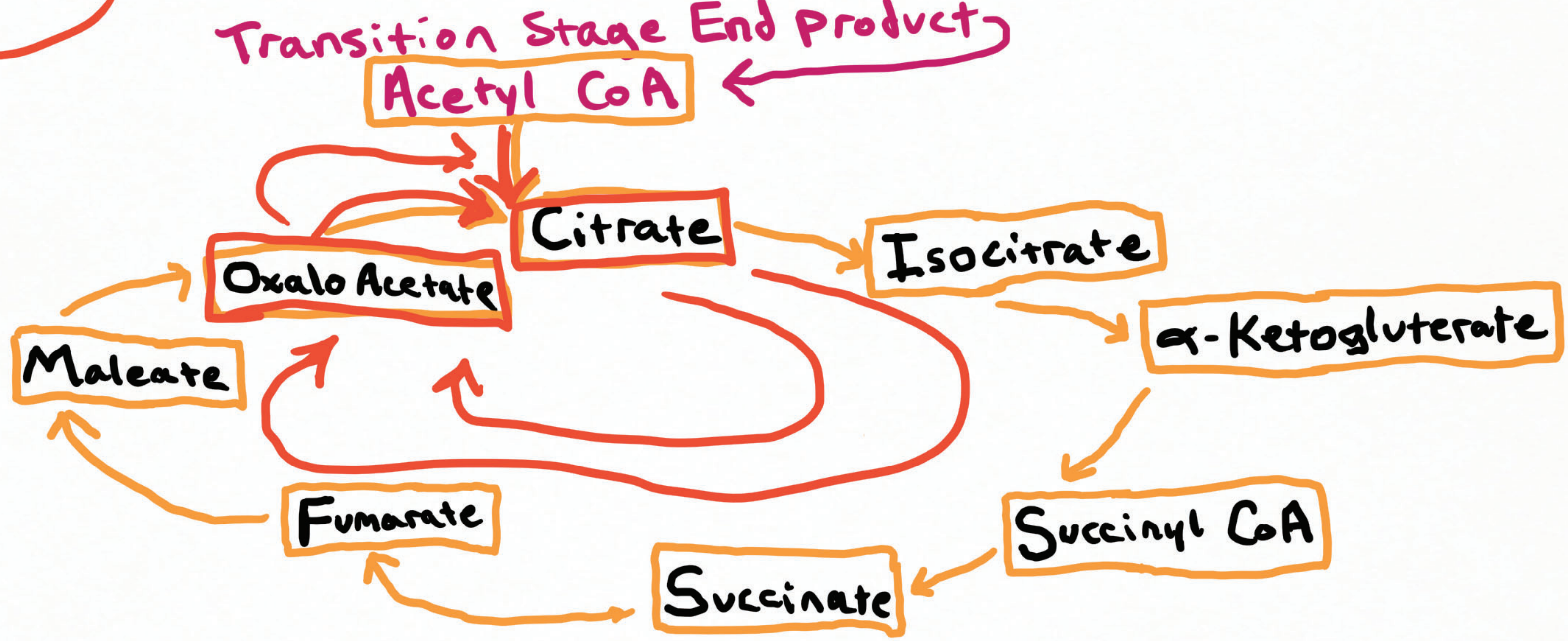
Kreb's Cycle (aka The Citric Acid Cycle or TCA or Tri-Carboxylic Acid Cycle) ✓

- x2 molecules
- Happens in mitochondrial matrix
- Middle step in AEROBIC RESPIRATION (Oxygen)



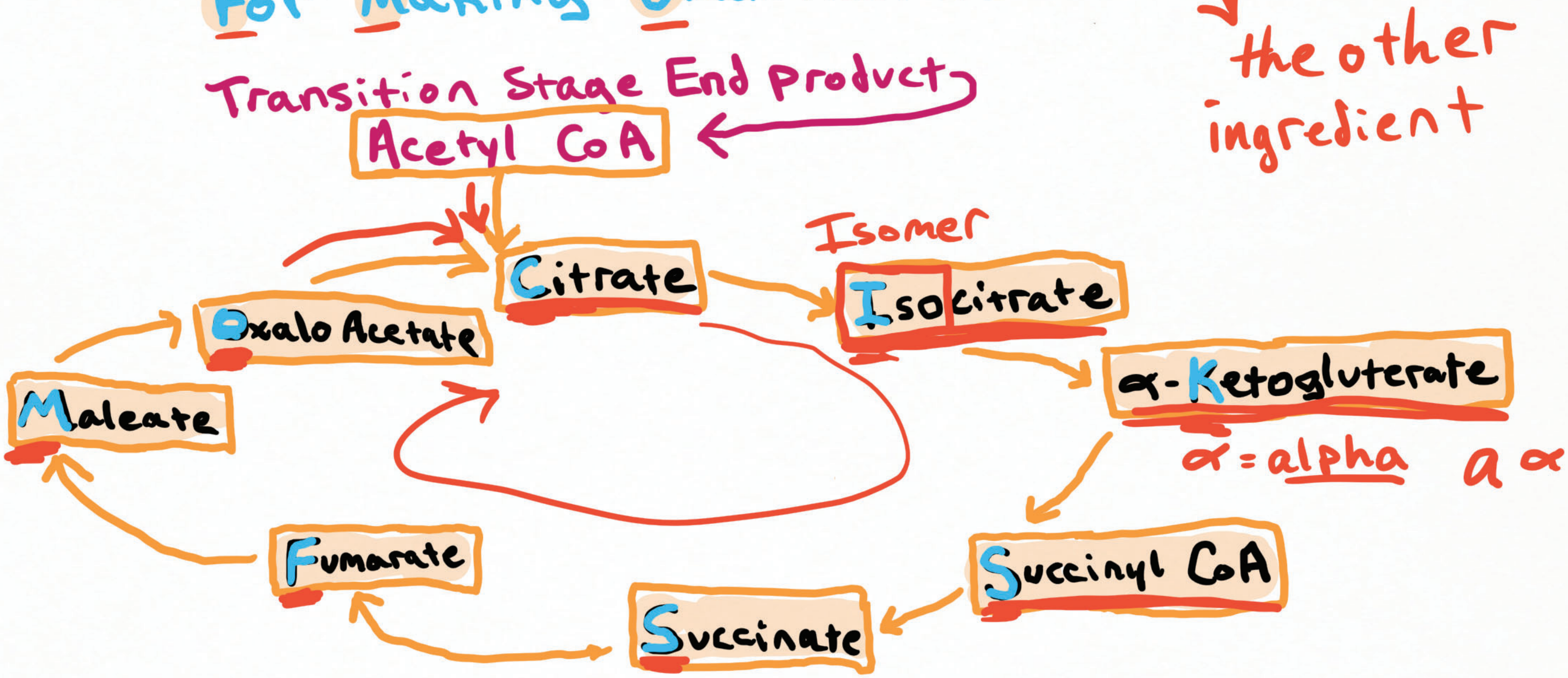
Kreb's

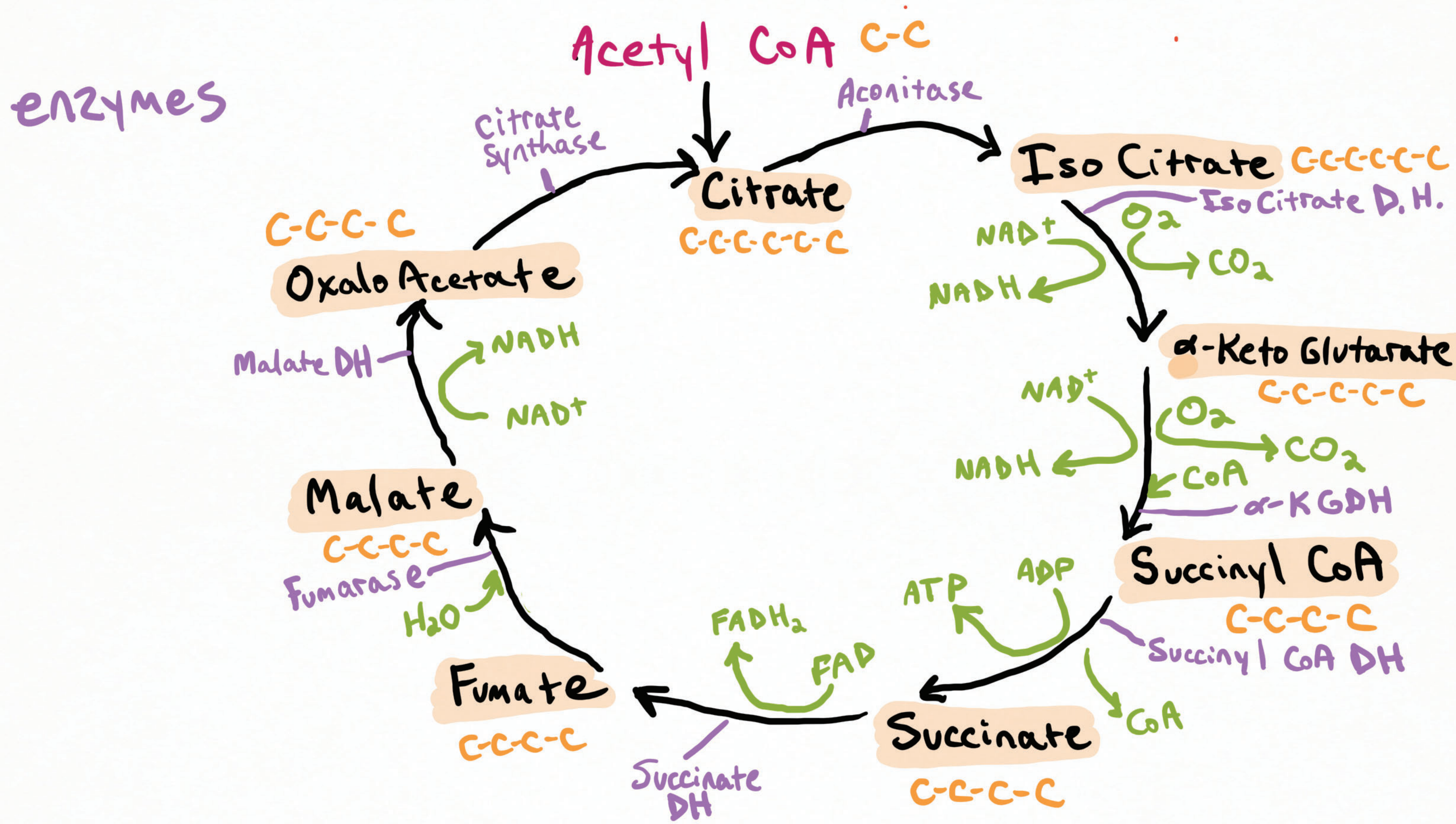
- "Cycle" because beginning Acetyl CoA (from Transition stage) fuses with end product Oxalo Acetate and starts cycle again

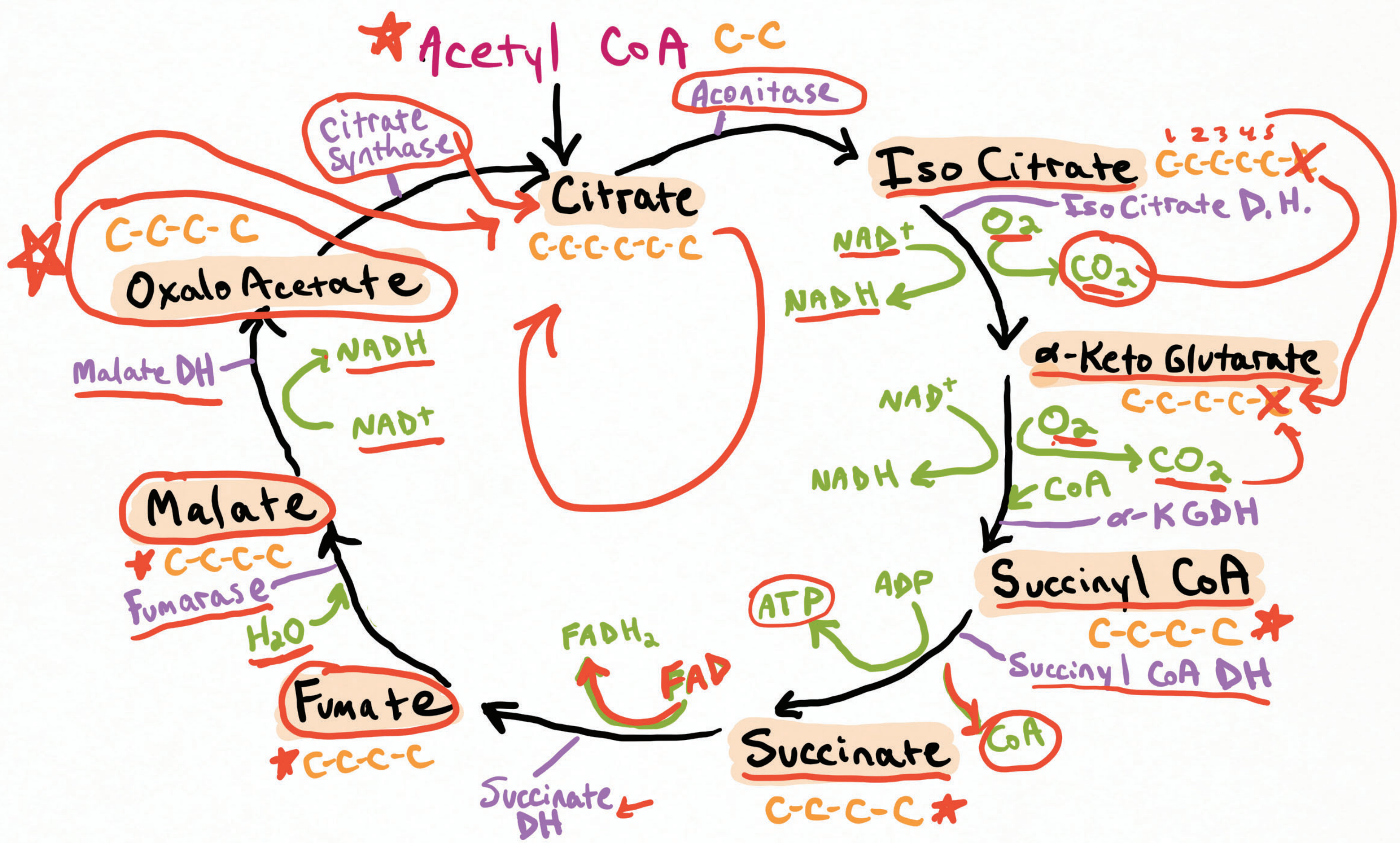


Kreb's

Mnemonic: Citrate Is Kreb's Starting Substrate For Making Oxalo Acetate




enzymes
Acetyl CoA C-C
Citrate Synthase
Aconitase
Citrate
C-C-C-C-C-C
Iso Citrate C-C-C-C-C-C
Iso Citrate D.H.
NAD+
NADH
O2
CO2
α-Keto Glutarate
C-C-C-C-C
NAD+
NADH
O2
CO2
CoA
α-KGDH
Succinyl CoA
C-C-C-C
Succinyl CoA DH
ADP
ATP
CoA
Succinate
C-C-C-C
FAD
FADH2
Succinate DH
Fumate
C-C-C-C
H2O
Fumarase
Malate
C-C-C-C
NADH
NAD+
Malate DH
Oxalo Acetate
C-C-C-C


Acetyl CoA
C-C
Citrate Synthase
Aconitase
Citrate
C-C-C-C-C-C
Iso Citrate
1 2 3 4 5
C-C-C-C-C-X
Iso Citrate D. H.
NAD+
NADH
O2
CO2
α-Keto Glutarate
C-C-C-C-X
NAD+
NADH
O2
CO2
CoA
α-KGDH
Succinyl CoA
C-C-C-C
Succinyl CoA DH
ADP
ATP
CoA
Succinate
C-C-C-C
FAD
FADH2
Succinate DH
Fumate
C-C-C-C
H2O
Fumarase
Malate
C-C-C-C
NADH
NAD+
Malate DH
Oxalo Acetate
C-C-C-C

KREB's Step 1

Transition's end product Acetyl CoA   C–C–CoA

\+ Kreb's end product Oxalo Acetate   C–C–C–C

= Citrate   C–C–C–C–C–C

Synthesize Citrate

enzyme: Citrate Synthase (enzymes)

KREB's Step ②

Turns Citrate into Iso-Citrate ("isomer" of, aka (rearrangement of Citrate))

C-C-C-C-C-C C-C-C-C-C-C
(both 6-carbons)

enzyme: **Aconitase**

KREB's Step ③

Iso-Citrate is decarboxylated (loses a Carbon) C-C-C-C-C-C

removed

↳ in form of CO_2

= α-Ketoglutarate C-C-C-C-C

1 2 3 4 5

enzyme: Iso Citrate Dehydrogenase

IN	OUT
NAD^+	NADH
O_2	CO_2

NET

2 NADH

2 CO_2

KREB's Step (4)

α-Keto-Glutarate is De-Carboxylated, CoA added

↳ loses a Carbon

turns into Succinyl CoA

C-C-C-C-~~C~~ → C-C-C-C-CoA

enzyme: α-KetoGlutarate DeHydrogenase

IN	OUT
CoA	X
O_2	CO_2
NAD^+	NADH

NET

2 CO_2

2 NADH

KREB's Step 5

Succinyl CoA loses CoA   C-C-C-C-~~CoA~~

= turns into Succinate C-C-C-C

enzyme: Succinyl CoA Synthetase

Synthetase → Synthesizing Succinate

IN	OUT
ADP	ATP
	CoA

NET

2 ATP

KREB's Step 6

Succinate
= turns into Fumarate
Fumate

C-C-C-C ★
C-C-C-C ★

enzyme: Succinate DeHydrogenase

IN		OUT
→ FAD	→	$FADH_2$

NET
2 $FADH_2$

KREB's Step 7

H_2O → Fumarate

= turns into Malcate

C-C-C-C 4Cs

C-C-C-C 4Cs

enzyme: Fumarase (enzyme)

IN	OUT	NET
H_2O	X	X

KREB's Step 8

Malate

= turns into OxaloAcetate

C-C-C-C

C-C-C-C

enzyme: Malate Dehydrogenase

IN	OUT
NAD^+	NADH

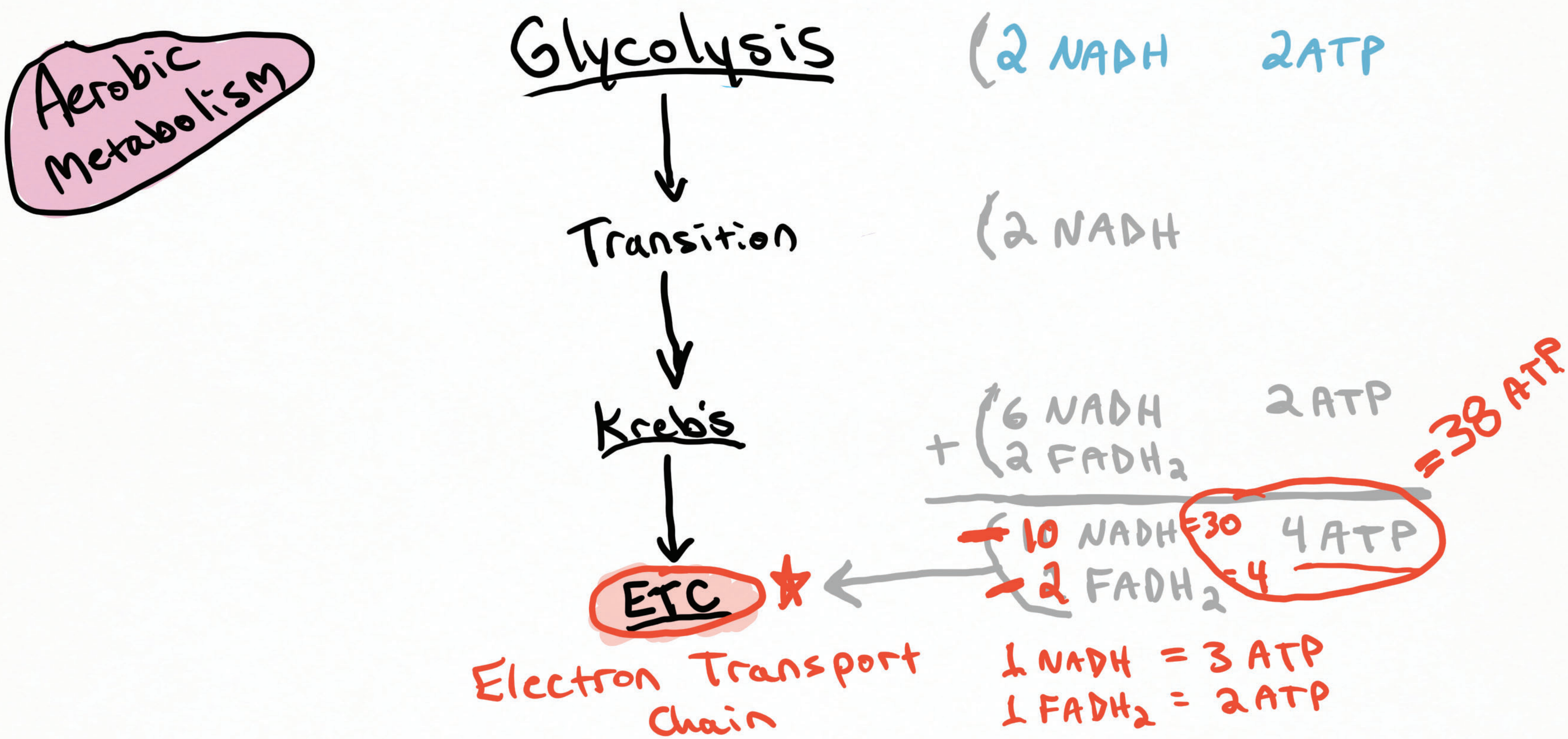
NET

2 NADH

KREB'S CYCLE PRODUCTS

- ✓ 2 ATP
- ✓ 6 NADH
- ✓ 2 $FADH_2$
- ✓ 4 CO_2

Including BOTH molecules (divided in Glycolysis)


Aerobic Metabolism
Glycolysis
2 NADH
2ATP
Transition
2 NADH
Kreb's
6 NADH
2 FADH2
2 ATP
+
10 NADH =30
4 ATP
2 FADH2 =4
=38 ATP
ETC
Electron Transport Chain
1 NADH = 3 ATP
1 FADH2 = 2 ATP

(AEROBIC)
METABOLISM - <u>CELLULAR RESPIRATION</u> (3 major steps + Transition)

Glycolysis (both aerobic & anaerobic processes)

Transition (Pyruvate Oxidation - Preparatory Step)

Krebs (The Citric Acid - TCA) Cycle

★ ETC (Electron Transport Chain - Oxidative Phosphorylation)

(Thru the cell membrane and into the cytoplasm) — **Glycolysis** ✓

↓

(Thru the mitochondrial membrane to enter the mitochondria) — Transition ✓

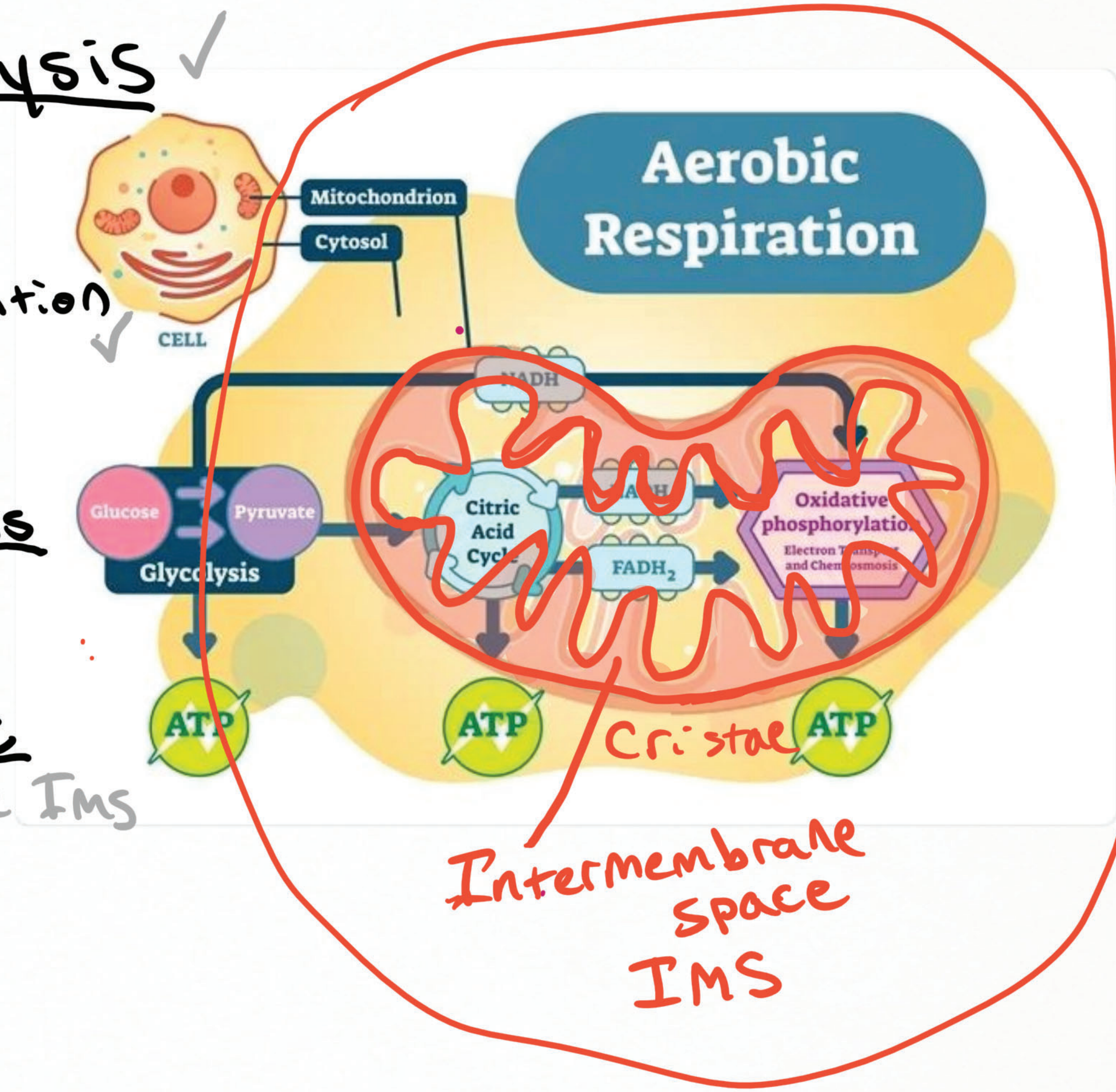
↓

(Inside mitochondria) — ✓ **Kreb's**

↓

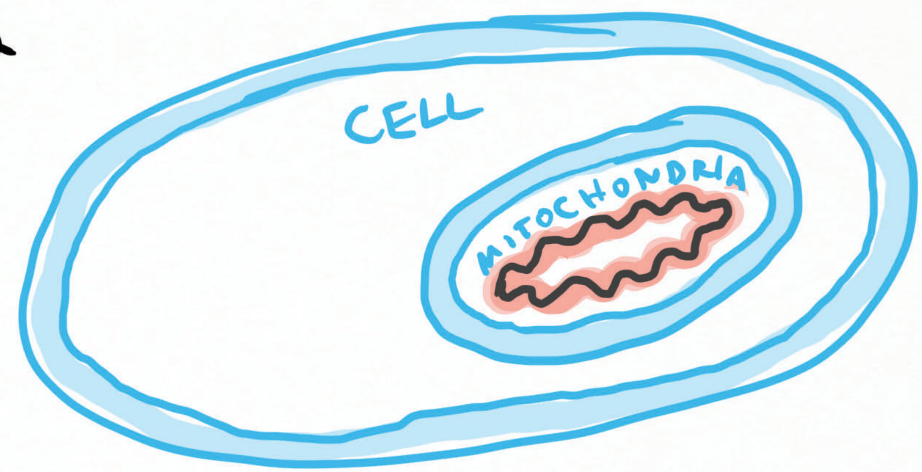
(Thru the mitochondrial membrane to exit the mitochondria) — **ETC**

Cristae IMS



ELECTRON TRANSPORT CHAIN

- In mitochondrial matrix's "<u>cristae</u>" (folds in matrix)
- Produces the most ATP
- Final step: converting original Glucose molecule into ATP + O_2

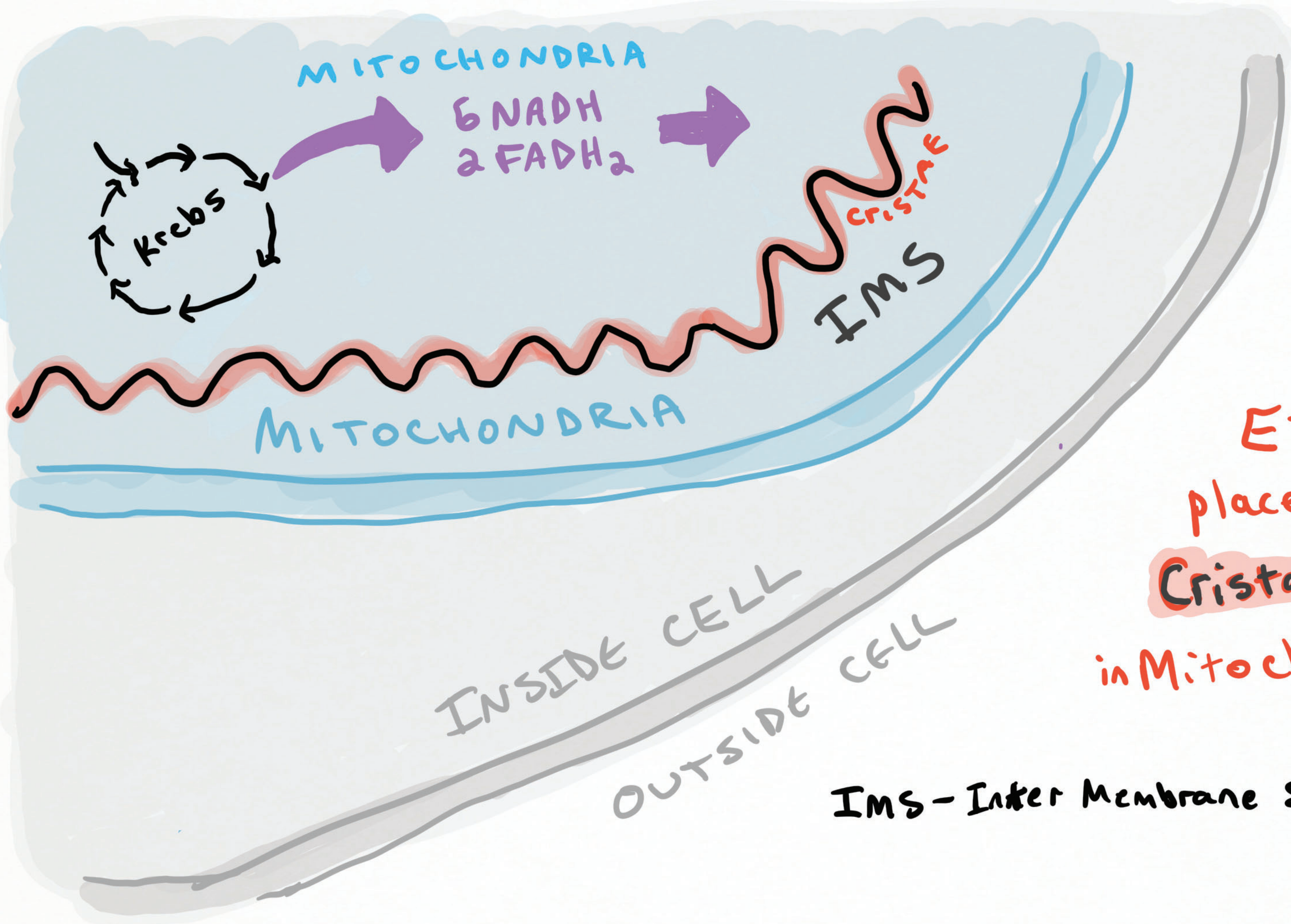


ELECTRON TRANSPORT CHAIN

- The NADHs and $FADH_2$s from the Kreb's Cycle are taken up into the ETC after being generated in the previous cycles
- The H^- ions ($1 H + 1$ extra e^-) carry electrons

= Why it's called "Electron Transport"

= 1 NADH → 3 ATP
1 FADH → 2 ATP



ETC takes place in the Cristae and IMS in Mitochondria

IMS - Inter Membrane Space

→ $NADH = NAD^+ + H^+ + 2e^-$

H^+ = proton

→ $FADH_2 = FAD + H_2^+ + 2e^-$

(extra electron)

... because $H^- = H^+ + 2e^-$

... because $H = H^+ + e^-$ (proton)

H^+s pumped out into INNERMEMBRANE SPACE IMS

- e^-s passed along down row of complexes

I Q II III C IV

NADH → I takes e^-, pumps out H^+ into IMS (margin), NAD^+ remains

$FADH_2$ → II takes e^-, can't pump out H^+, FAD and H^+ remain

→ hands off to Q → III → C → IV → back inside

$e^- + H_2^+ + O = H_2O$

→ H^+ to III → out to IMS

IV pumps out extra H^+ → IMS in resulting e^-

OXYGEN is "final electron receptor"

★ Test Q

ETC Pump (ATP Synthase)

H^+ from IMS (moves from high → low concentration)

↳ Into rotar of pump

= causes rotar to spin

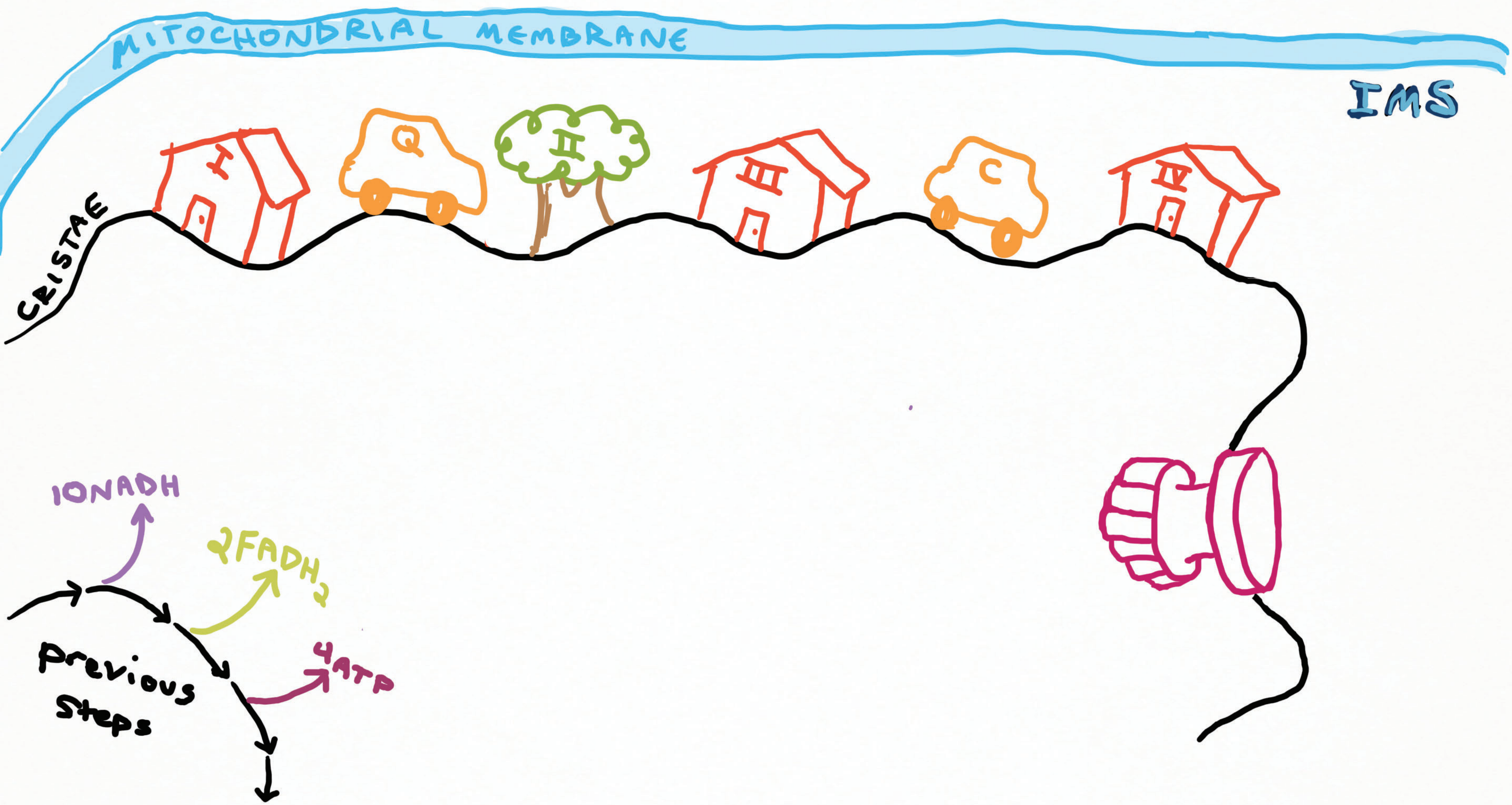
Spinning rotar has kinetic energy

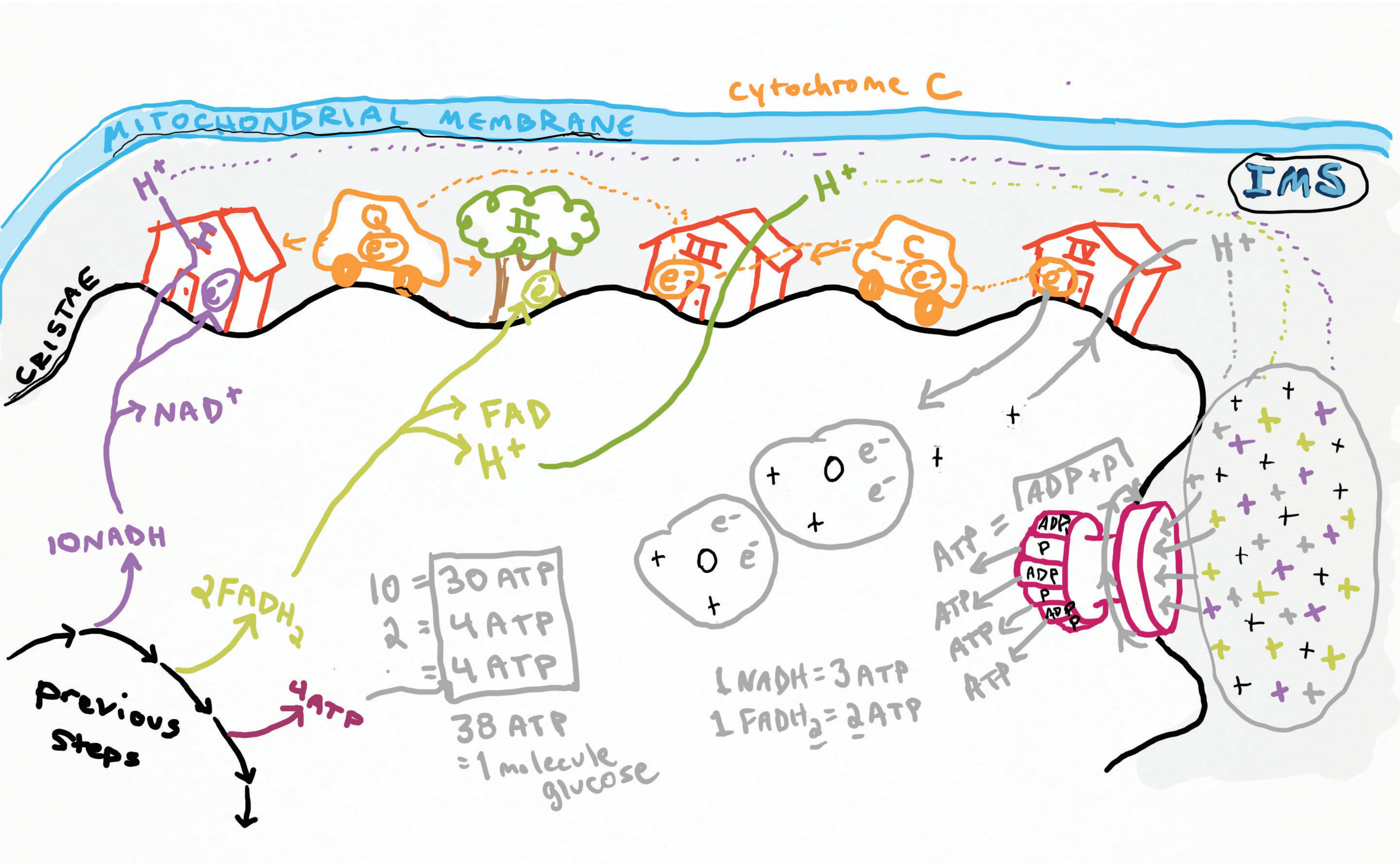
↳ Puts together ADP + P = ATP

= energy stored as potential energy in ATP

1 NADH = 3 ATP

1 $FADH_2$ = 2 ATP


MITOCHONDRIAL MEMBRANE
IMS
CRISTAE
I
Q
II
III
C
IV
10NADH
2FADH2
4ATP
Previous steps



cytochrome C
MITOCHONDRIAL MEMBRANE
IMS
CRISTAE
H+
I
Q
II
III
C
IV
NAD+
FAD
H+
10NADH
2FADH2
4ATP
previous steps
10 = 30 ATP
2 = 4 ATP
= 4 ATP
38 ATP
= 1 molecule glucose
1 NADH = 3 ATP
1 FADH2 = 2 ATP
ADP + P
ATP =
ADP
P
ATP

	NADH	$FADH_2$	ATP	NADH ×3	$FADH_2$ ×2	+ATP
Krebs	6	2	2	18	4	2
Transition	2	×	×	6	×	×
Glycolysis	2	×	2	+ 6	×	2
				30	4	4

=ATP

=38 ATP

www. SuzannesTutoring.com