A SURVEY OF METABOLISM

1. Basically, metabolism is the synthesis and degradation of cell components. It involves pathways that are promoted by a sequence of enzyme systems. Enzymes participate sequentially in a consecutive, linked fashion so that the product of the 1st enzyme becomes the substrate of the 2nd enzyme and so on.

The pathway may be linear or circular or cyclic.

$$A \xrightarrow[E_1]{} B \xrightarrow[E_2]{} C \xrightarrow[E_3]{} D \xrightarrow[E_4]{} E$$

Precursor

B, C and D are metabolic intermediates (metabolites)

Product

A → B → C → D → E → (cycle with E₁, E₂, E₃, E₄)

Each enzymatic step brings about a small, specific chemical change – either by removal, addition or transfer of an atom, molecule or functional group.
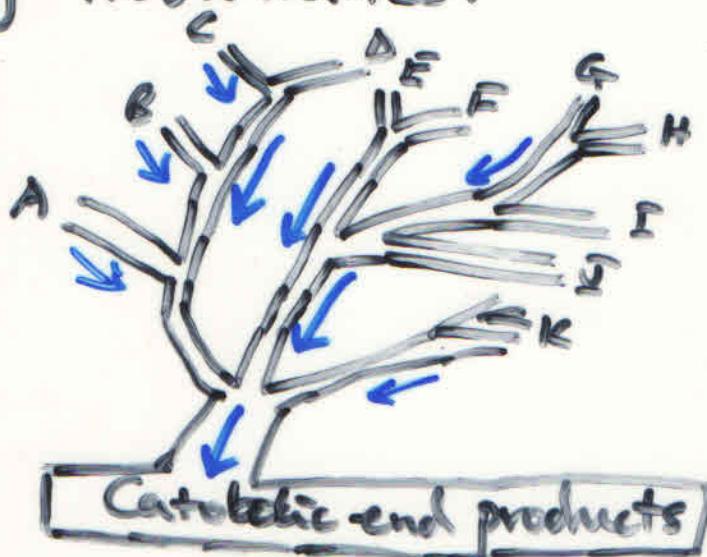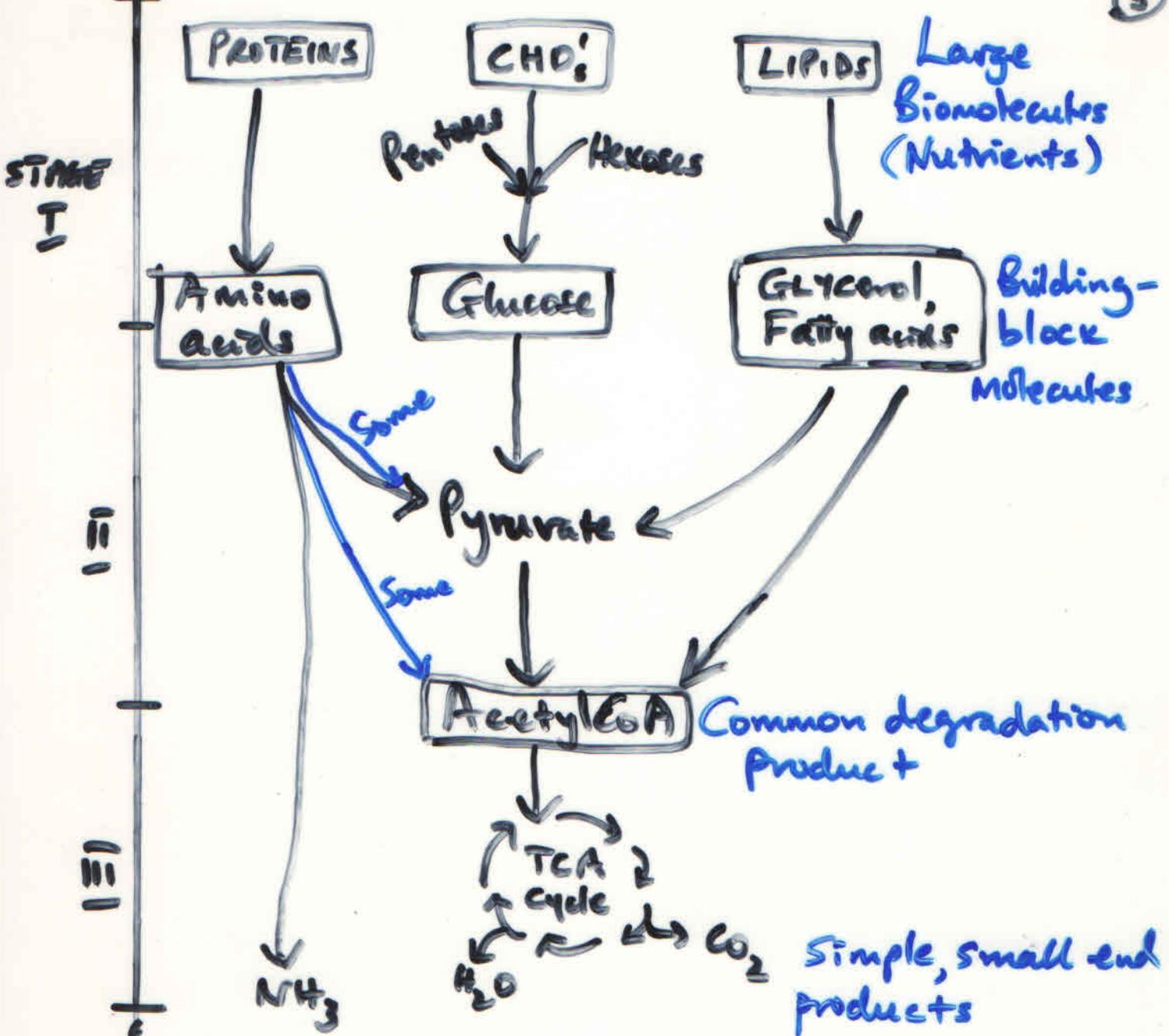
2. Metabolism consists of catabolic and anabolic pathways.

(a) Catabolism

It is the degradative phase in which organic nutrients e.g CHO_s, lipids and proteins are broken down into smaller, simpler end products e.g. CO_2, NH_3, H_2O. Nutrients come from the environment or from the cell's storage. Catabolism is accompanied by release of free energy arising from the organic molecule. Catabolic pathways converge to a few end products. The final pathway resembles a widening river, fed by many tributaries.

The major energy-yielding nutrients are catabolized via 3 stages.

| PROTEINS | CHO's | LIPIDS | **Large Biomolecules (Nutrients)** |

STAGE I

Pentose → Hexoses

| Amino acids | Glucose | Glycerol, Fatty acids | **Building-block Molecules** |

II

Some

Some

Pyruvate

AcetylCoA — **Common degradation Product**

III

TCA Cycle → CO_2

H_2O

NH_3

Simple, small end products
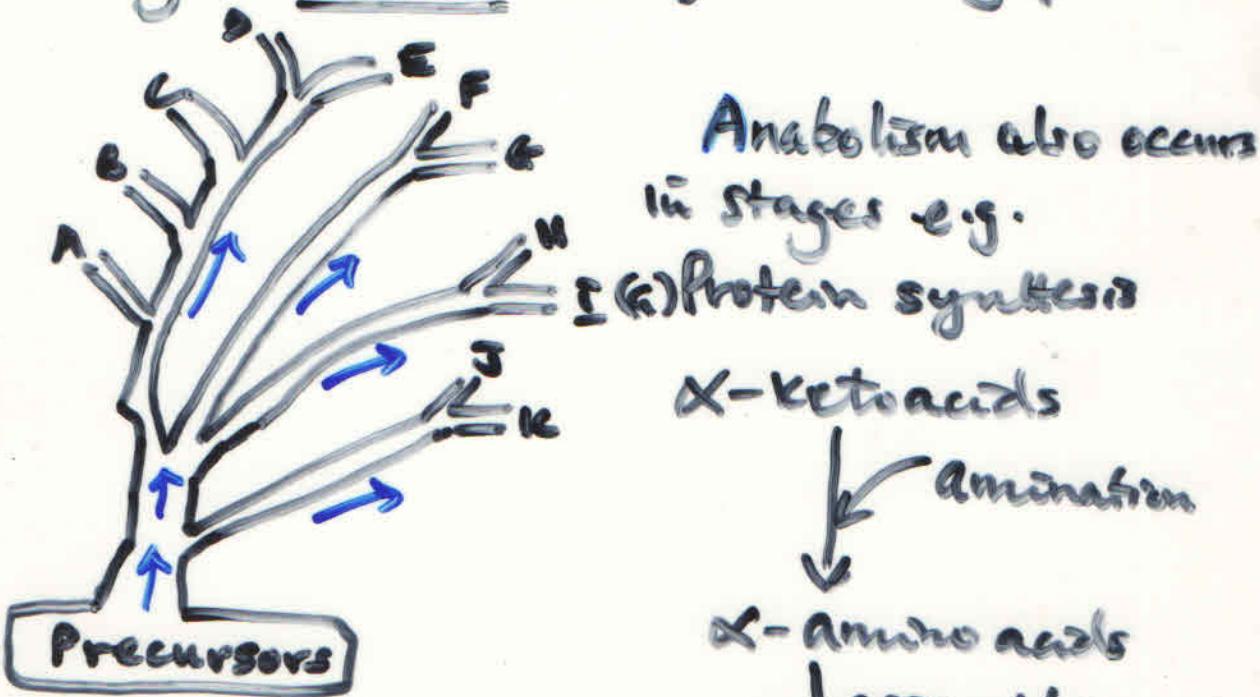
At certain steps in a catabolic pathway, some of the free energy is conserved by means of coupled enzymatic reactions in the form of ATP or NADPH.

Catabolism — It is a "downhill" process that is accompanied by loss of "free" energy — energy that can do work at constant temp. and pressure.

(b) Anabolism

It is the biosynthetic phase of metabolism. Small precursors or building-block molecules are built up into large macromolecules e.g. Proteins, Nucleic acids. Anabolism usually results in increased size and complexity of structure. It involves input of free energy furnished by ATP and/or NADPH.

Pathways diverge to yield many products.

Precursors
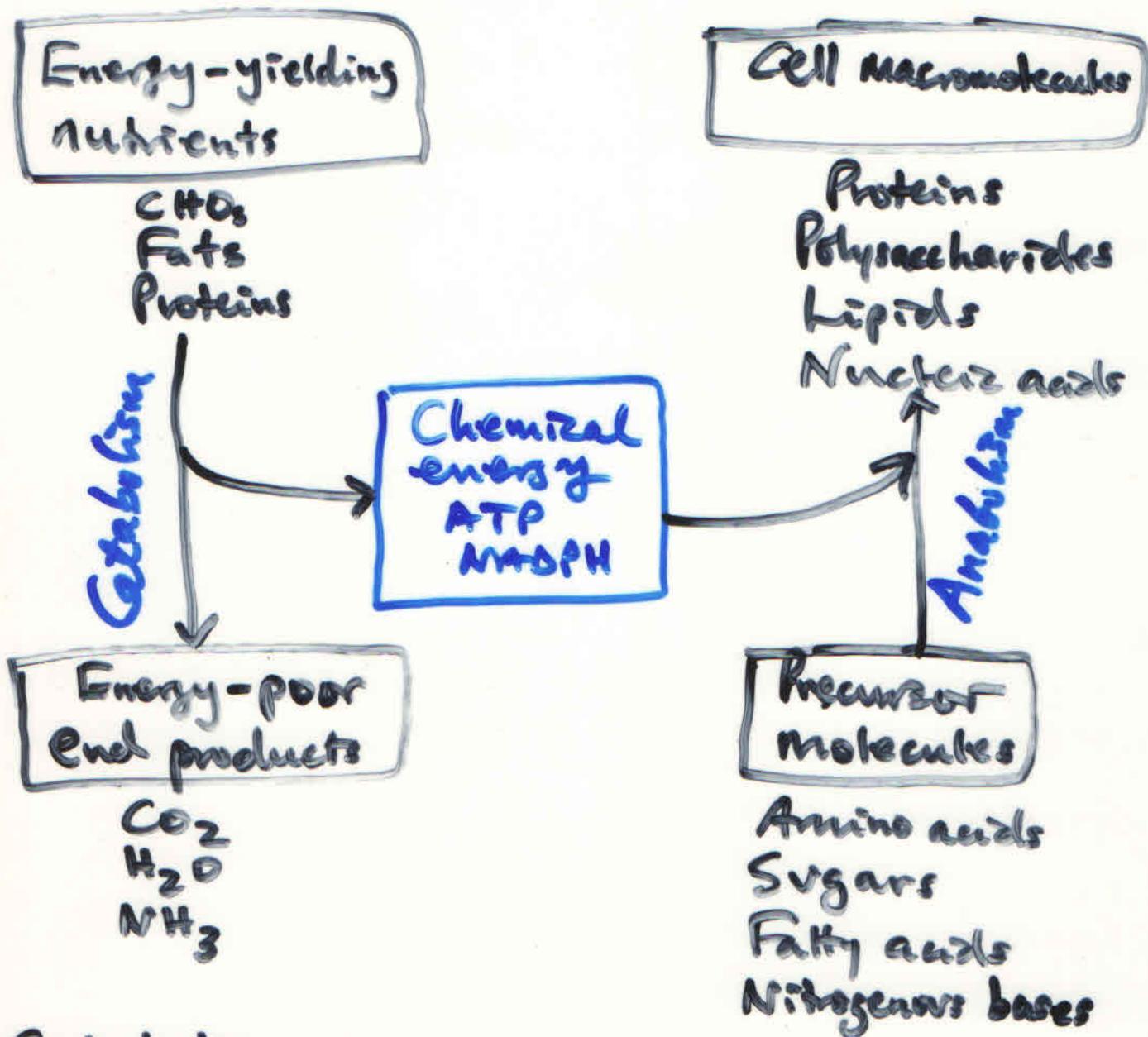
b) Lipid synthesis

Anabolism also occurs in stages e.g.

(a) Protein synthesis

α-Ketoacids

↓ amination

α-Amino acids

↓ assembly

Polypeptide chain (Protein)

Acetyl groups → Fatty acids → Lipids
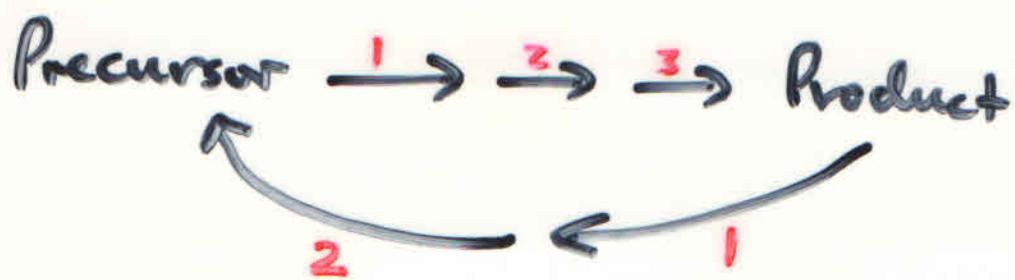
Anabolism — It is a ~~downhill~~ Uphill process requiring input of free energy or gain of free energy.
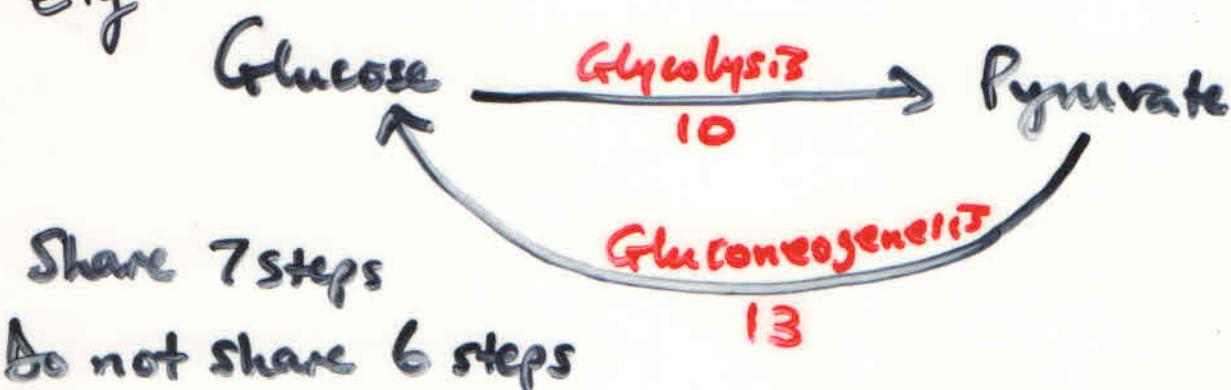
There is an energy-relationship between Catabolic and anabolic pathways. It is linked by chemical energy in form of ATP and NADPH.

Energy-yielding nutrients

CHO₃
Fats
Proteins

Catabolism →

Chemical energy ATP NADPH

Cell macromolecules

Proteins
Polysaccharides
Lipids
Nucleic acids

Anabolism →

Energy-poor end products

CO_2
H_2O
NH_3

Precursor molecules

Amino acids
Sugars
Fatty acids
Nitrogenous bases

— Catabolism and Anabolism take place simultaneously in cells and their rates are regulated independently.
※ There are important differences between Corresponding Catabolic and anabolic pathways;

Precursor $\xrightarrow{1}$ $\xrightarrow{2}$ $\xrightarrow{3}$ Product

$\longleftarrow$ 2 $\longleftarrow$ 1

e.g.

Glucose $\xrightarrow[\text{10}]{\text{Glycolysis}}$ Pyruvate

$\xleftarrow[\text{13}]{\text{Gluconeogenesis}}$

Share 7 steps

Do not share 6 steps

∴ Oppositely directed catabolic and anabolic pathways are not identical. Why?

a) Pathway taken in Catabolism may be energetically impossible in anabolism. "Hill and Boulder Analogy"

b) The two pathways must be independently regulated otherwise slowing one would also slow the other.

$A \underset{E_1}{\overset{E_{10}}{\rightleftharpoons}} B \underset{E_2}{\rightleftharpoons} C \underset{E_3}{\rightleftharpoons} D \underset{E_4}{\rightleftharpoons} E \underset{E_5}{\rightleftharpoons} P$
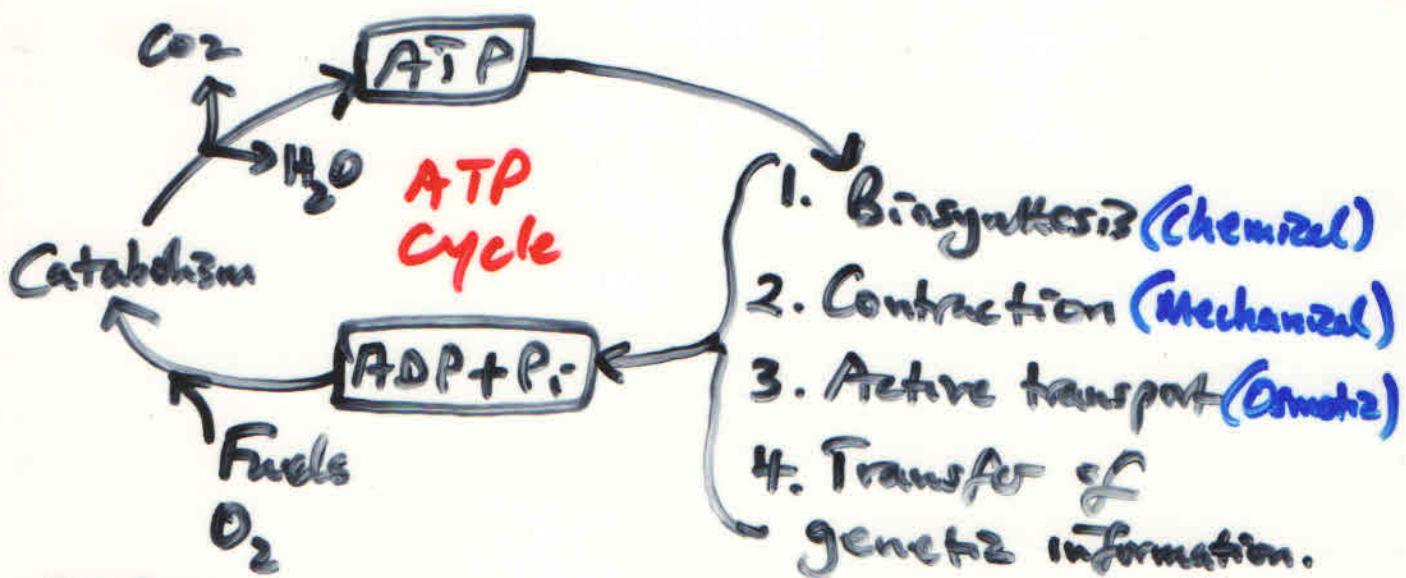
A → B and B → A are regulated steps — Regulatory enzymes.

c) Opposite catabolic and anabolic routes take place in different parts of the cell. e.g. FA metabolism in liver.
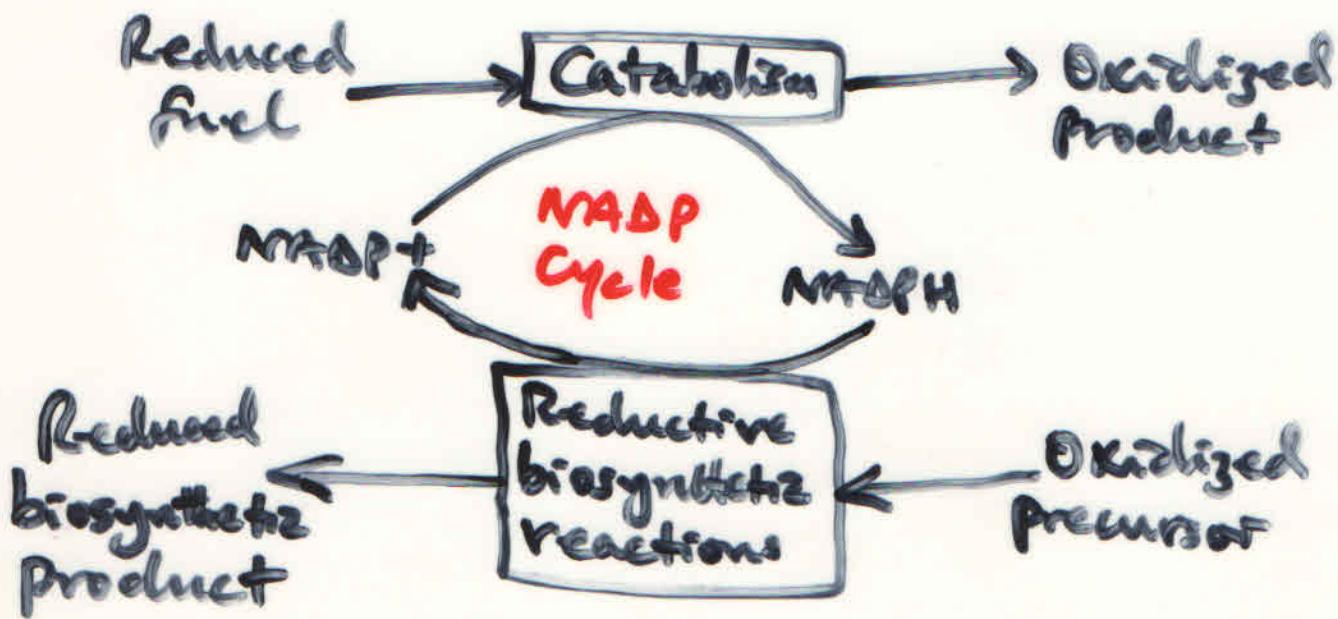
Q. What is the role of ATP and NADPH?

1. ATP carries energy from cataboliz to anaboliz reactions.

ATP Cycle

CO_2 → H_2O → Catabolism ← Fuels O_2 ← ATP → ADP + P_i

1. Biosynthesis (Chemical)
2. Contraction (Mechanical)
3. Active transport (Osmotic)
4. Transfer of genetic information.

ATP serves as the energy-carrying link between energy-yielding and energy-requiring cellular processes.

2. NADPH carries energy in form of reducing power. In form of hydrogen atoms or electrons.

NADP Cycle

Reduced fuel → Catabolism → Oxidized Product

NADP⁺ ← NADPH

Reduced biosynthetic Product ← Reductive biosynthetic reactions ← Oxidized Precursor

Remember:

Cell metabolism is an economical, tightly regulated process. Energy is produced as per cell requirements and not by availability or concentration of fuels.

Regulation is at 3 Levels:

1) ~~Allosteric~~ Regulatory enzymes – Catalyse irreversible steps.

e.g. Catabolic – ATP acts as a regulator or inhibitor of an early step.

Anabolic – end product acts as an inhibitor of an earlier step.
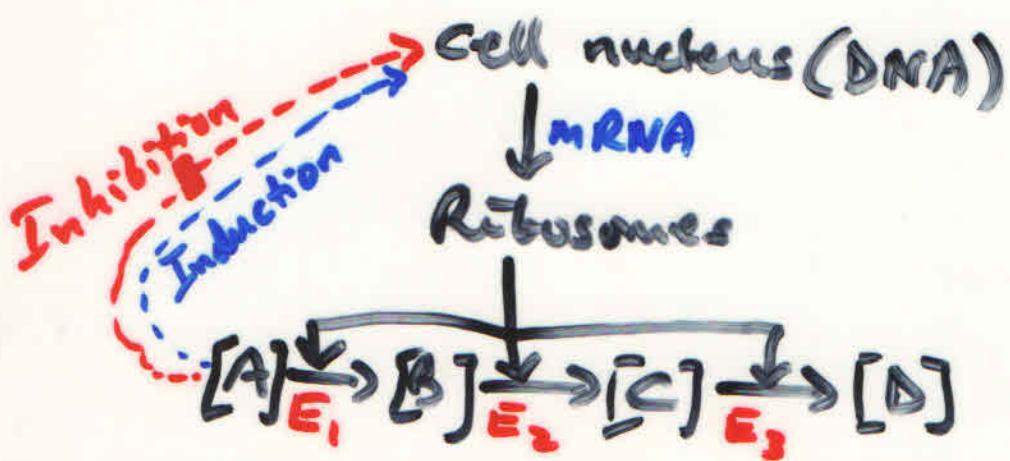
2) Hormonal

e.g. Epinephrine → Liver → Stimulation of glycogen to glucose raising blood glucose level.

3) $[E]$ in the cell – Induction
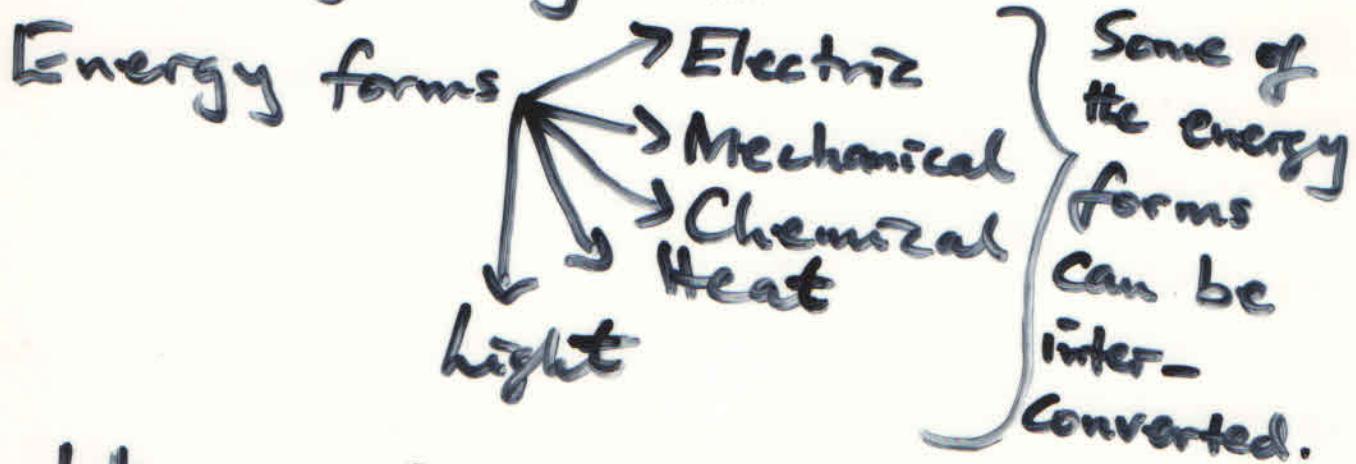
e.g. Low protein diet → ↓$[Enzymes]$

High " " → ↑$[E]$

Cell nucleus (DNA)

↓ mRNA

Ribosomes

↓

Inhibition

Induction

$[A] \xrightarrow{E_1} [B] \xrightarrow{E_2} [C] \xrightarrow{E_3} [D]$

CELL BIOENERGETICS

Is the field of Biochemistry concerned with the transformation and use of energy by living cells.

Energy forms → Electric
→ Mechanical
→ Chemical
→ Heat
Light

} Some of the energy forms can be inter-converted.

When one form is converted into another, there is always some loss of energy -e.g. Electric motor -due to friction, the motor generates heat which is lost.

⇒ Thermodynamics — a branch of physical science that deals with energy changes.

Ist Law — In any physical or chemical change, the total amount of energy in the Universe remains constant.

"Conservation of energy"- Energy can note be created or destroyed but can only be changed from one form to another.

2nd Law — All physical or chemical Changes tend to proceed in such a direction that useful energy undergoes irreversible degradation into a random, disordered form called entropy. The changes come to a stop at an equilibrium point at which the entropy formed is the maximum possible under existing Conditions.

Q. What is useful energy?
1) Free energy
2) Heat energy — Can do work only thru' a change in/of temp or pressure.

Q. What is 'useless' energy?
Entropy — energy in state of randomness or disorder.

e.g.

1. Analogy of the Teakettle and the randomization of heat.

2. Oxidation of Glucose

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

$\underbrace{\phantom{C_6H_{12}O_6 + 6O_2}}$ $\underbrace{}$

7 molecules   12 molecules

Increase in molecular disorder. ↑ Entropy.

System = An animal / a cell or
2 reacting compounds

System
Surroundings ← Universe / outer space

Surroundings = with which the system
can exchange energy.

In biological systems, chemical reactions take place at constant Temp. and Pressure. Changes in free energy and entropy are related quantitatively by the equation:

$$\Delta G = \Delta H - T \Delta S \quad \text{where}$$

ΔG = Change in free energy of the reacting system.

ΔH = Change in its heat content or enthalpy.

T = Absolute temp. at which the process is taking place.

ΔS = Change in entropy of the Universe.

NB When any chemical reaction proceeds to its equilibrium point, entropy of the Universe always increases.
∴, ΔS has a + sign.

Q. What energy changes take place in aerobic cells?

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

STD Conditions { Temp. = 25°C (298K)

Pressure = 1.0 atm (760 mm Hg)

$$\Delta G = -686,000 \text{ cal/mol}$$

$$\Delta H = -673,000 \quad "$$

$$\therefore \Delta S = \frac{\Delta H - \Delta G}{T}$$

$$= \frac{-673,000 - (-686,000)}{298}$$
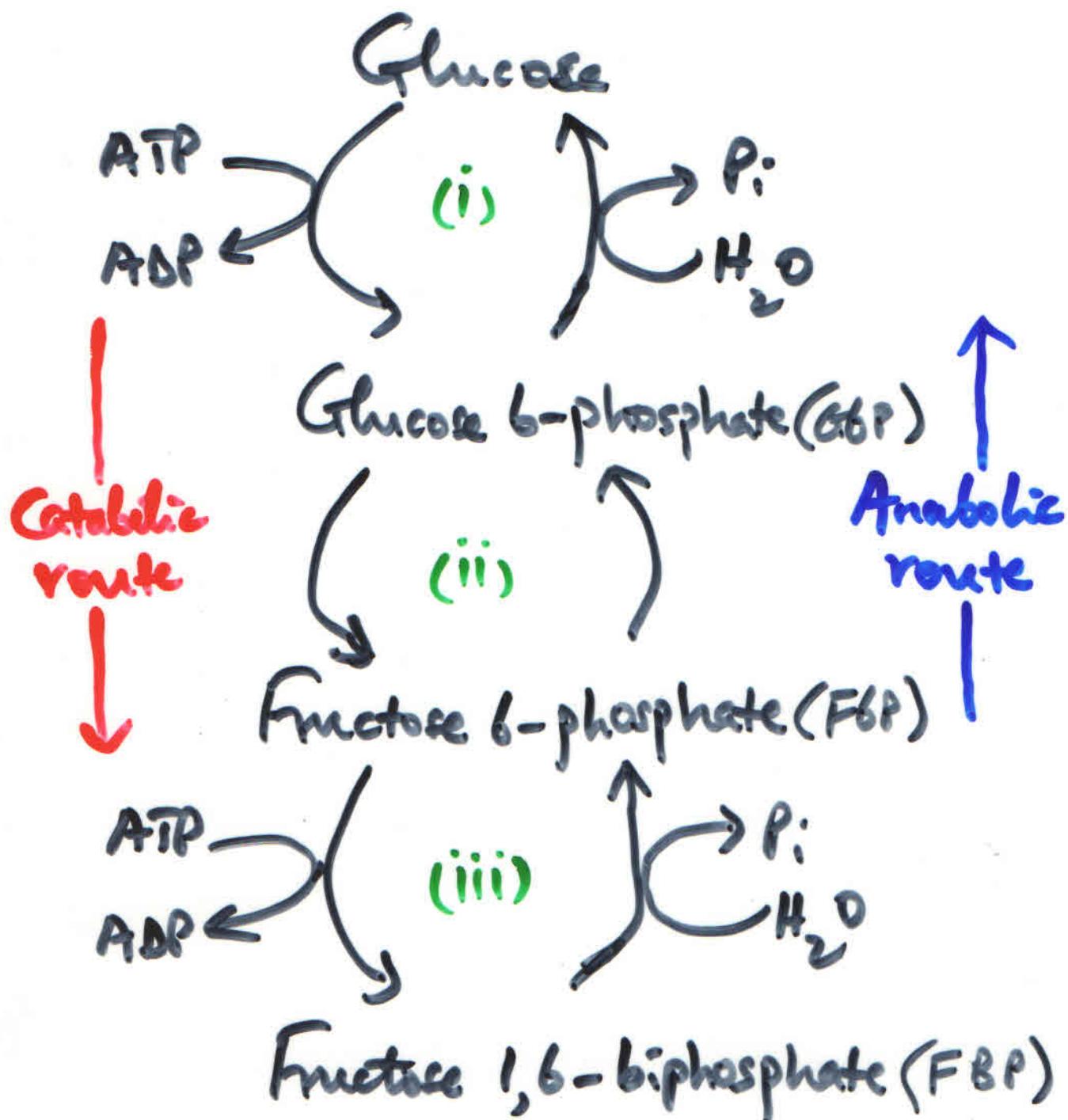
$$\approx +44 \text{ cal/mol} = \text{The entropy of the Universe has increased.}$$

Q. How is the free energy of chemical reactions measured and expressed in quantitative terms?

Every reaction has a characteristic Standard free energy change ($\Delta G°$) which can be calculated. It is a <u>constant</u> for any given reaction.

25°C / 1.0 atm

HOMEWORK

Glucose

ATP
ADP
(i)
Pi
H_2O

Glucose 6-phosphate (G6P)

Catabolic route

(ii)

Anabolic route

Fructose 6-phosphate (F6P)

ATP
ADP
(iii)
Pi
H_2O

Fructose 1,6-biphosphate (FBP)
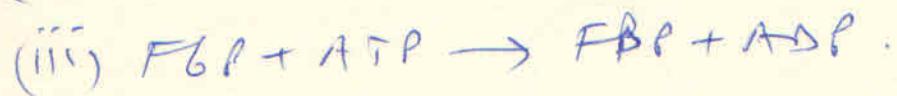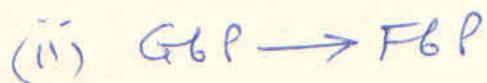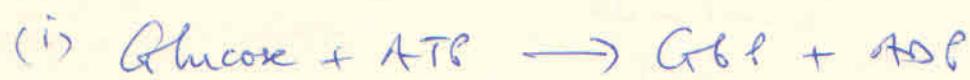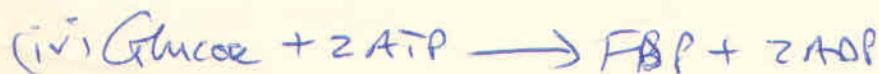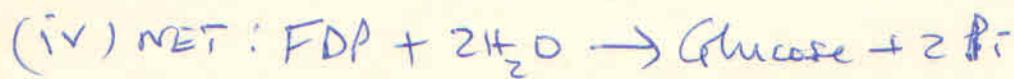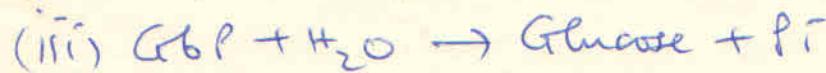
(a) Write a balanced equation for ~~the~~ each step in the catabolic route.

   (i) Glucose + ATP $\longrightarrow$ G6P + ADP

   (ii) G6P $\longrightarrow$ F6P

   (iii) F6P + ATP $\longrightarrow$ FBP + ADP.

(b) ~~NET~~ Write ~~the~~ net equation that results when the individual steps are added:

   (iv) Glucose + 2 ATP $\longrightarrow$ FBP + 2 ADP

(c) Repeat parts (a) and (b) for the anabolic route.

   (i) FBP + H_2O $\longrightarrow$ F6P + P_i

   (ii) FBP $\longrightarrow$ G6P

   (iii) G6P + H_2O $\longrightarrow$ Glucose + P_i

   (iv) NET: FBP + 2H_2O $\longrightarrow$ Glucose + 2P_i

(d) What are the distinguishing differences, based on the **net** reactions between the catabolic and anabolic routes? Are ~~the~~ 2 pathways simply ~~the~~ reverse of each other?

   1. Catabolic 2 ATP's used
      Anabolic 2H_2O used

                          No!

(e) Could the Glucose – G6P interconversions in the catabolic and ~~catabolic~~ anabolic routes be catalysed by the same enzyme?

   – No. There are 2 different ~~enzyme~~ reactions requiring different inputs.

(f) Could the G6P – F6P interconversion in the catabolic and anabolic ~~route~~ routes be catalyzed by the same enzyme?

   YES: Why? No inputs differences.
     Phosphoglucoisomerase.

ΔG° can be calculated from the equilibrium constant (K'_{eq}).

e.g. $A + B \rightleftharpoons C + D$

$$K'_{eq} = \frac{[C][D]}{[A][B]}$$ where all are in Molar Concentrations at the point of equilibrium under STD conditions.

When,

$$aA + bB \rightleftharpoons cC + dD$$

$$K'_{eq} = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

When K'_{eq} is calculated, ΔG° is Calculated ~~Called~~ using the equation;

$$\Delta G^\circ = -2.303 \, RT \log K'_{eq}$$ where

$R = 1.987$ cal /moll K (Gas Constant)

ΔG° = Units of Calories per mole of reactant.

Calorie = Amount of energy which in the form of heat can raise the temp. of 1 gram of H_2O at $15^\circ C$ by $1^\circ C$.

When K'eq is;	ΔG° is;	Starting with 1M components, the reaction;
>1.0	Negative	Proceeds forward
1.0	Zero	Is at equilibrium
<1.0	Positive	Proceeds in reverse

When K'eq is;	ΔG° (Cal/mol) is;
0.001	+4089
0.01	+2726
0.1	+1363
1.0	0
10.0	−1363
100.0	−2726
1000.0	−4089

In biochemical reactions, $\Delta G°$ is written as $\Delta G°'$ because reactions take place near pH 7.0 = std pH.

$$1.0 \text{ cal} = 4.184 \text{ J}$$

In Biology and Medicine, the Cal is usually used.

$\Delta G°' =$ Characteristic values for different chemical reactions.

e.g. $G1P \rightleftharpoons G6P$

If we start reaction with either 0.02M G1P or 0.02M G6P, the final equilibrium mixture will contain 0.001M G1P and 0.019M G6P at $25°C$ and pH 7.0.
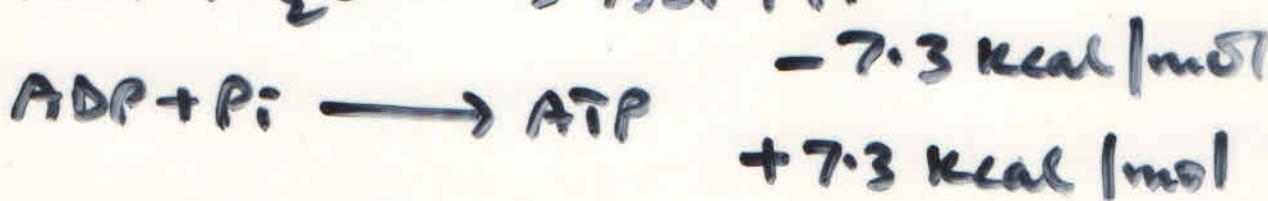
$$K'_{eq} = \frac{[G6P]}{[G1P]} = \frac{0.019}{0.001} = 19.0$$

$$\Delta G^{0'} = -2.303 \ RT \log K'_{eq}$$
$$= -2.303 (1.987)(298) \log 19.0$$
$$= -1364 (1.28)$$
$$\simeq -1745 \ cal/mol$$
$$\simeq -1.74 \ kcal/mol$$

∴ G1P ⟶ G6P is favored as it proceeds with loss of free energy. It has a $-$ sign!

If $+$ sign, $\equiv$ input of free energy

Others

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$
$$-686 \ kcal/mol$$

$$ATP + H_2O \longrightarrow ADP + Pi$$
$$-7.3 \ kcal/mol$$

$$ADP + Pi \longrightarrow ATP$$
$$+7.3 \ kcal/mol$$

Q. What is the difference between $\Delta G^{o'}$ and ΔG ?

$\Delta G^{o'}$ = under STD conditions $\longleftarrow$ PH 7.0
$\quad$ 25°C
$\quad$ 1 atm
$\quad$ I M Cones.

ΔG = a function of the actual conditions of pH, Cone, temp. prevailing during the reaction — which are not necessarily the STD conditions.

ΔG of any reaction proceeding towards its equilibrium is always <u>negative</u> and becomes <u>less</u> negative as reaction proceeds and <u>is</u> <u>zero</u> at point of equilibrium.

Relationship between ΔG and $\Delta G^{o'}$:

$\Delta G = \Delta G^{o'} + 2 \cdot 303 \, RT \log K'_{eq}$

$\underbrace{\qquad\qquad\qquad\qquad}_{\text{Terms actually prevailing}}$

$\longrightarrow$ $\Delta G^{o'}$ = Constant for every reaction / Unchanging

$\longrightarrow$ $\Delta G^{o'}$ values of chemical reactions are additive e.g.

$\quad A \longrightarrow B \quad \Delta G^{o'}_1 \quad B \longrightarrow C \quad \Delta G^{o'}_2$

Overall is $A \longrightarrow C$

$\Delta G^{o'}_s = \Delta G^{o'}_1 + \Delta G^{o'}_2$

1) Calculation of $\Delta G^{\circ\prime}$ from K_{eq}

Calculate the $\Delta G^{\circ\prime}$ of the following metabolically
important enzyme-catalyzed reactions at 25°C
from the K_{eq} given (pH 7.0).

(a) $K'_{eq} = 6.8$ −1.14 kcal/mol

(b) $K'_{eq} = 0.0475$ +1.82 "

(c) $K'_{eq} = 254$ − 3.30 "

2) Calculation of K'_{eq} from $\Delta G^{\circ\prime}$

Calculate the K'_{eq} for the following reactions at pH 7.0
and 25°C using the given $\Delta G^{\circ\prime}$ values.

(a) $\Delta G^{\circ\prime} = -3.3$ kcal/mol   ≈ 250
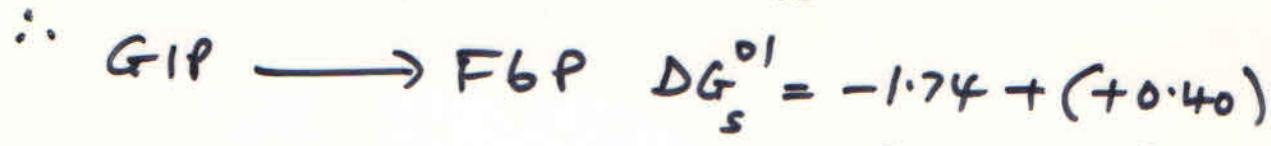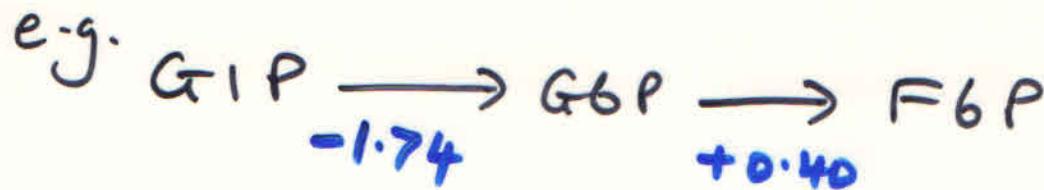
    " = − 3.8   "   ≈ 590

    " = + 0.75 "   ≈ 0.28

3) The $\Delta G^{\circ\prime}$ for coupled reactions.

Using the given $\Delta G^{\circ\prime}$ values, calculate the K'_{eq}
for the sum of the two reactions at 25°C.
i.e. G1P $\longrightarrow$ F6P. $K'_{eq} = 8.9$

e.g. G1P $\longrightarrow$ G6P $\longrightarrow$ F6P

$\quad\quad\quad$ -1.74 $\quad\quad\quad$ +0.40

∴ G1P $\longrightarrow$ F6P $\quad DG_s^{ol} = -1.74 + (+0.40)$
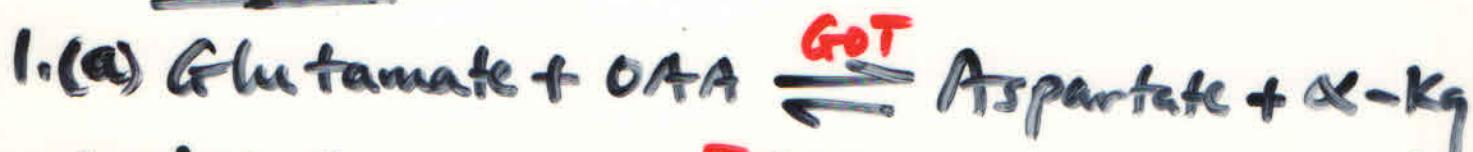
$$= -1.34 \text{ kcal/mol}$$

- A thermodynamically unfavorable reaction can be driven by a favorable one coupled to it.

- The overall free energy change for a chemically coupled series of reactions is equal to the sum of the free-energy changes of the individual steps.

Problems

1. (a) Glutamate + OAA $\underset{}{\overset{GoT}{\rightleftharpoons}}$ Aspartate + α-Kg

(b) Dihydroxyacetone Phosphate $\underset{Isomerase}{\overset{Triose\ phosphate}{\rightleftharpoons}}$ Glyceraldehyde 3-phosphate

(c) F6P + ATP $\underset{}{\overset{PFK}{\rightleftharpoons}}$ Fructose 1,6 Diph. + ADP

2.

(a) G6P + H_2O $\xrightarrow{G6Pase}$ Glucose + Phosphate

(b) Lactose + H_2O $\xrightarrow{\beta\text{-galactosidase}}$ Glucose + galactose

(c) Malate $\xrightarrow{fumarase}$ fumarate + H_2O

3. G1P $\xrightarrow{}$ G6P $\xrightarrow{}$ F6P

$\quad\quad$ -1.74 $\quad\quad\quad$ +0.40
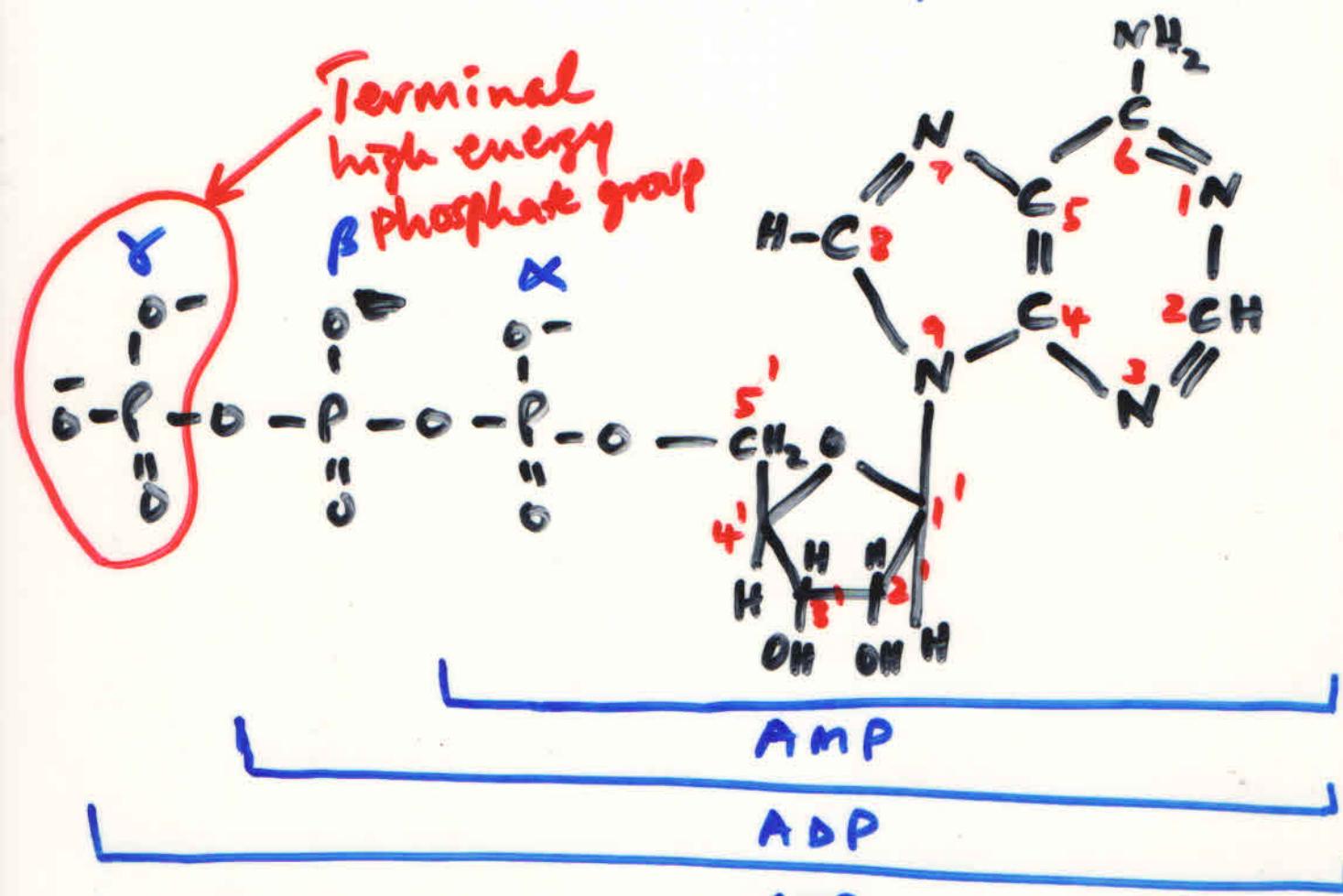
ATP = ADENOSINE TRIPHOSPHATE
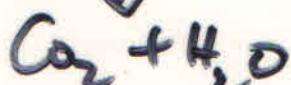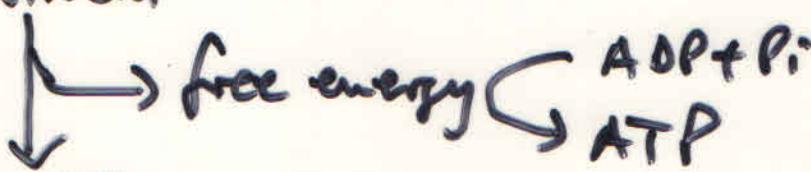
It is a nucleotide consisting of an adenine base, a D-ribose and 3 phosphate groups.

CHEMISTRY

Terminal high energy phosphate group

AMP

ADP

ATP

At pH 7.0 = ATP^{4-} Fully ionized

Nutrient → free energy ⟷ $ADP + P_i$ / ATP

↓

$CO_2 + H_2O$

In cells, ATP and ADP exist as $MgATP^{2-}$ and $MgADP^{-}$ respectively. This is their active forms.

Q. How is ATP able to function as a link between energy-yielding reactions and energy-requiring reactions?

1. ATP has a high and characteristic standard free energy of hydrolysis.

$$ATP + H_2O \longrightarrow ADP + Pi + H^+$$
$$DG^{o'} = -7.3 \text{ kcal/mol}$$

$$ADP + H_2O \longrightarrow AMP + Pi + H^+ \quad -7.3$$

$$AMP + H_2O \longrightarrow Adenosine + Pi \quad -3.4$$

Others:

Compound	$DG^{o'}$ (kcal/mol)
Phosphoenolpyruvate (PEP)	−14.8
3-Phosphoglycerol phosphate	−11.8
Phosphocreatine	−10.3
* ATP	− 7.3
G1P	−5.0
G6P	−3.3

$$ATP^{4-} + H_2O \longrightarrow ADP^{3-} + HPO_4^{2-} + H^+ \quad 1M$$

At pH 7.0, the $[H^+] = 10^{-7} M$ Concs. at STD Conditions.

By law of Mass action, the forward reaction is favored i.e. Compare $[H^+]$ and the Concs. of others.

$10^{-7} M$ Vs $1.0 M$ Concs. of ATP, ADP and Pi at STD conditions.

But;

$$G6P^{2-} + H_2O \longrightarrow Glucose + HPO_4^{2-}$$

No extra H^+ is formed.

2. At pH 7.0, ATP molecules have 4 closely spaced negative charges which <u>repel</u> each other.

$$G6P \longrightarrow Glucose \text{ (no charge) so can}$$
"easily" recombine.

3. ADP^{3-} and HPO_4^{2-} are more stable with less free energy. The products have a <u>smaller</u> free energy content than the reactants ($ATP + H_2O$).

<u>In cells</u>, $\Delta G^{o'}$ is about -12 to -16 kcal/mol because the actual concs. of ATP, ADP and Pi are different (not 1M) and are much <u>lower</u> than in STD conditions.

$$\Delta G_p = \Delta G \text{ in intact cells}$$
$$\nwarrow \text{phosphorylation potential}$$

e.g. Human RBCs
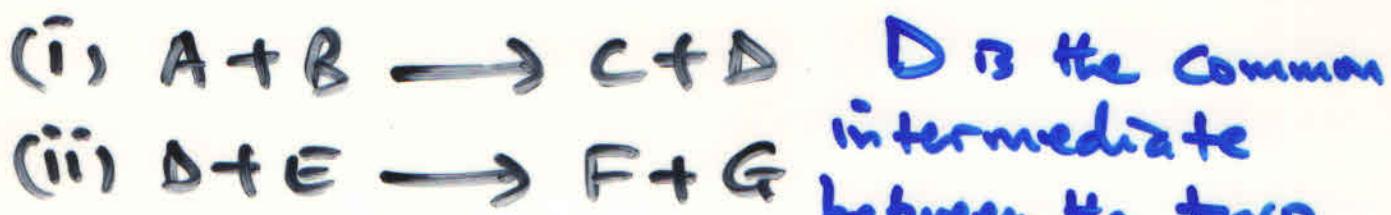
$[ATP] = 2.25\,mM$, $[ADP] = 0.25\,"$

$[Pi] = 1.65$ Assume pH 7.0 / 25°C

$$\Delta G = \Delta G^{o'} + 2.303\, RT \log \frac{[ADP][Pi]}{[ATP]}$$

$\Delta G / \Delta G_p = -12.4$ kcal/mol

2 reactions;

(i) $A + B \longrightarrow C + D$ D is the common intermediate between the two reactions. It can

Serve as the means of energy transfer from the first to the second reaction.

(ii) $D + E \longrightarrow F + G$

(i) $X-\text{\textcircled{P}} + ADP \xrightarrow{\text{Kinase 1}} X + ATP$

Super high energy compound

(ii) $ATP + Y \xrightarrow{\text{Kinase 2}} ADP + Y-\text{\textcircled{P}}$
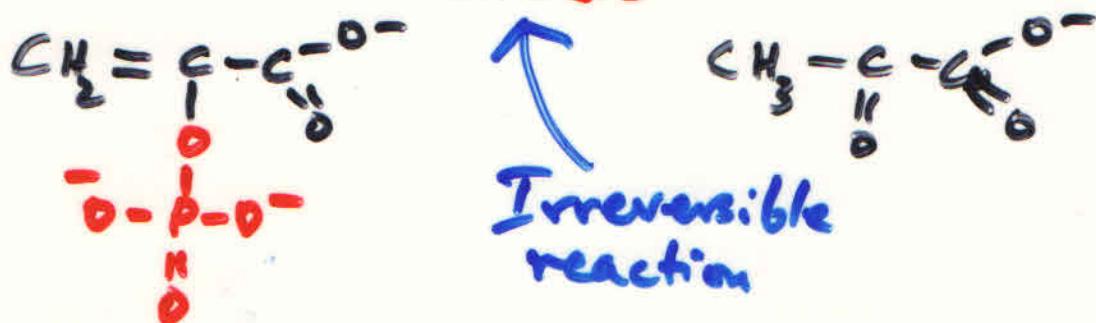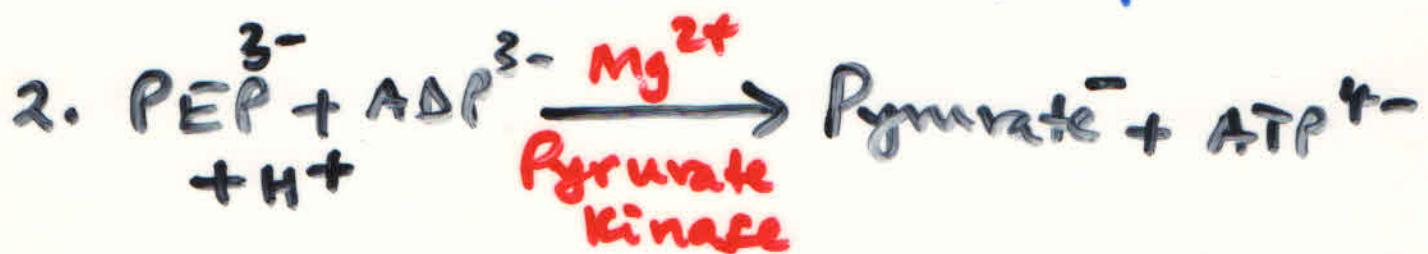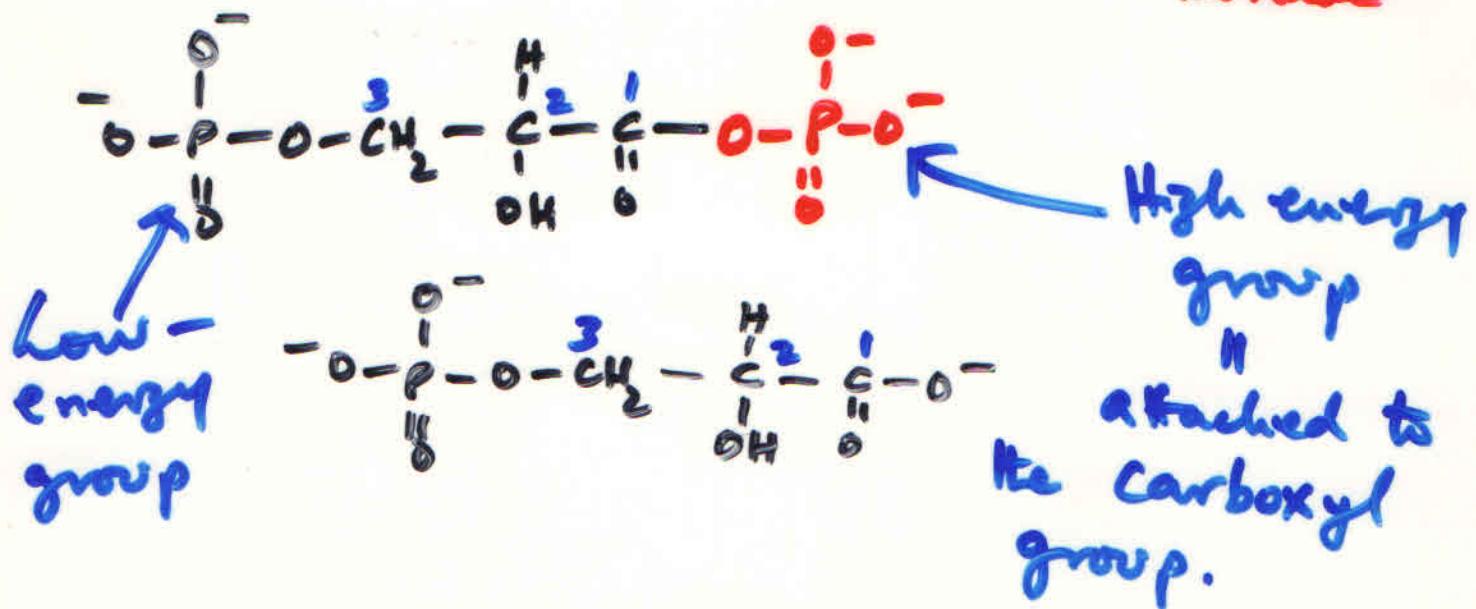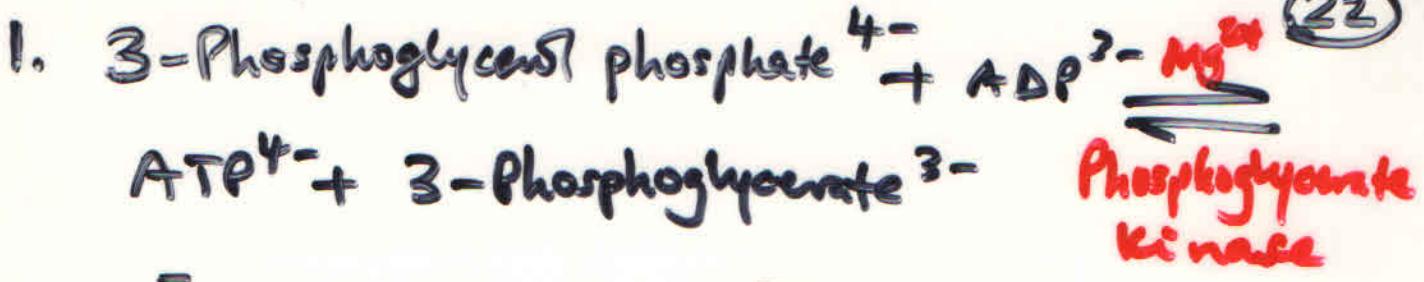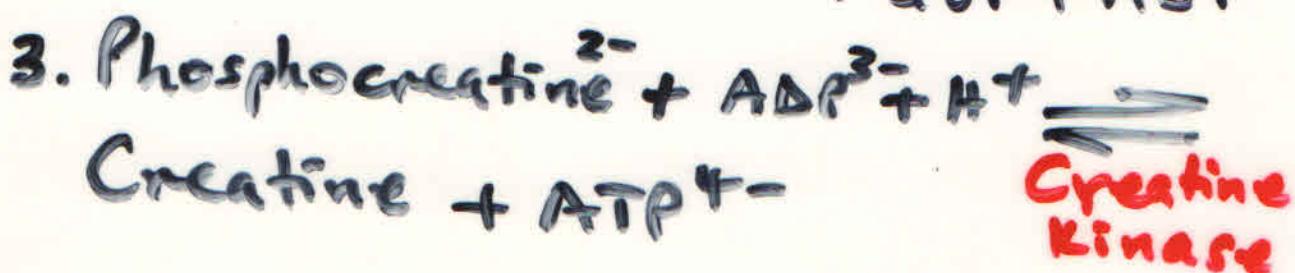
acceptor molecule

NB. Transfer of phosphate group from $X-\text{\textcircled{P}}$ to Y via ATP.
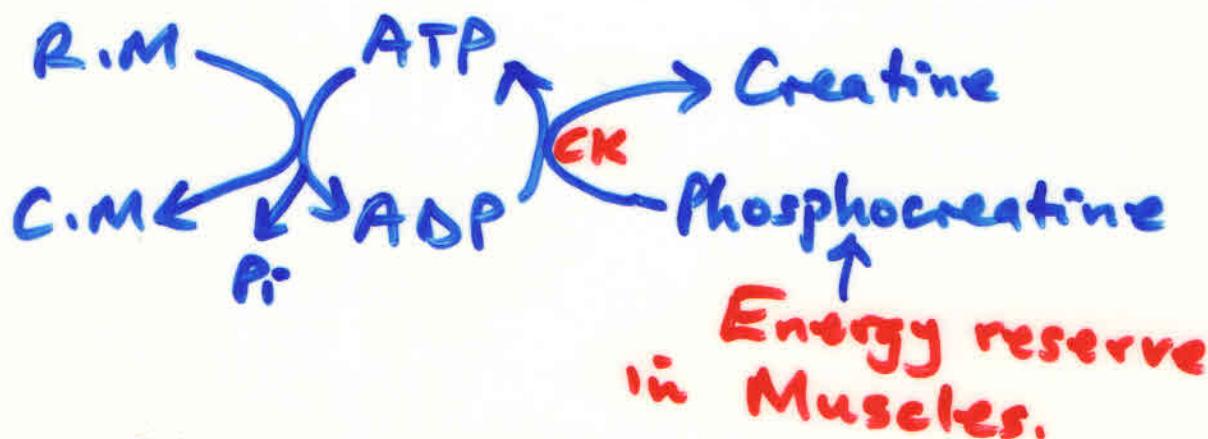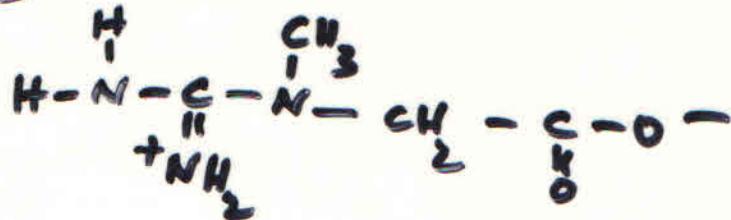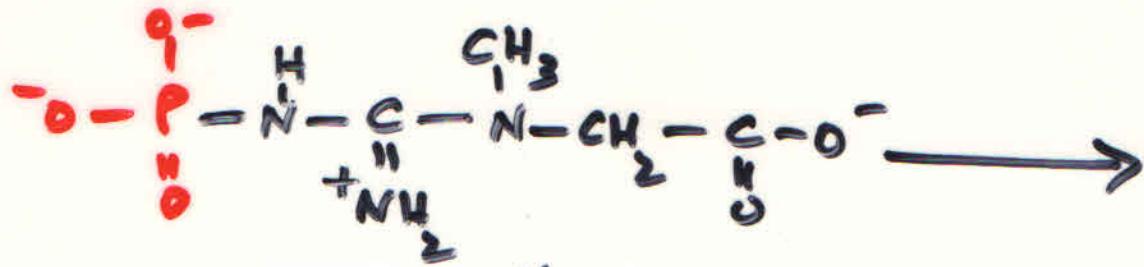
* Cells do not have kinases that directly transfer $\text{\textcircled{P}}$ from high energy phosphate compounds to an acceptor molecule e.g. Y.

Examples of super high energy phosphate compounds and their role in cells;

1. 3-Phosphoglyceroyl phosphate^{4-} + ADP^{3-} $\underset{\text{Phosphoglycerate kinase}}{\overset{Mg^{2+}}{\rightleftharpoons}}$

ATP^{4-} + 3-Phosphoglycerate^{3-}

low-energy group

High energy group $\parallel$ attached to the carboxyl group.

2. PEP^{3-} + ADP^{3-} + H^{+} $\underset{\text{Pyruvate kinase}}{\overset{Mg^{2+}}{\longrightarrow}}$ Pyruvate^{-} + ATP^{4-}

Irreversible reaction
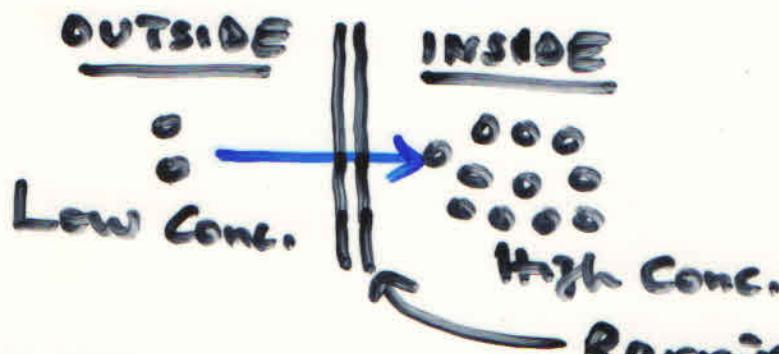
ATP^{4-} $\longrightarrow$ Can be used to transfer a phosphate group to an acceptor molecule eg Glucose.

ATP + Glucose $\longrightarrow$ G6P + ADP

3. Phosphocreatine^{2-} + ADP^{3-} + H^{+} $\underset{\text{Creatine kinase}}{\rightleftharpoons}$

Creatine + ATP^{4-}

$$\overset{-}{O}-\overset{O^-}{\underset{O}{\overset{|}{P}}}-\overset{H}{\underset{}{N}}-\underset{\overset{|}{NH_2^+}}{\overset{CH_3}{\overset{|}{C}}}-N-CH_2-\overset{|}{\underset{O}{C}}-O^- \longrightarrow$$

$$H-\overset{H}{\underset{}{N}}-\underset{\overset{|}{NH_2^+}}{\overset{|}{C}}-\overset{CH_3}{\underset{}{N}}-CH_2-\overset{|}{\underset{O}{C}}-O^-$$

R.M, C.M, ATP, ADP, Pi, **CK**, Creatine, Phosphocreatine

Energy reserve in Muscles.

ATP is used to transport molecules, ions across membranes and against a Conc. gradient = Active transport.

OUTSIDE   INSIDE

Low Conc.

High Conc.

Barrier = membrane

$$DG = 2.303 \, RT \log \frac{c_2}{c_1} \quad \begin{array}{l} \leftarrow \text{inside} \\ \leftarrow \text{outside} \end{array}$$
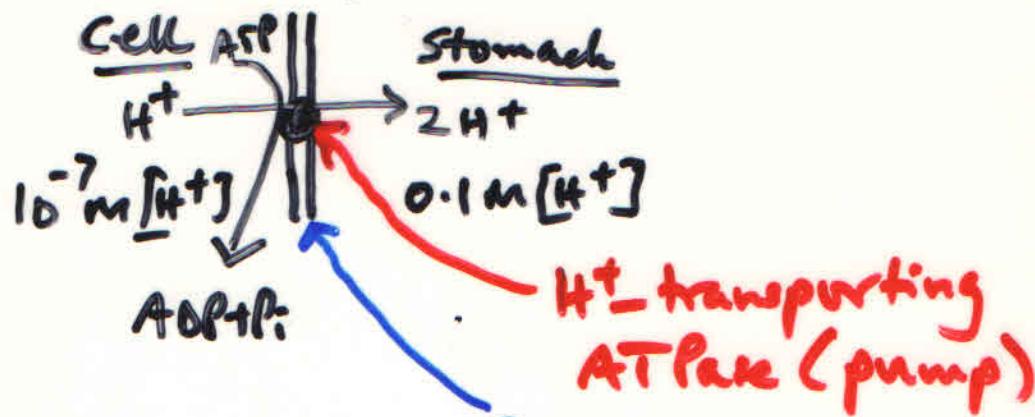
e.g. Glucose transport

Outside 1 mM   Inside 100 mM
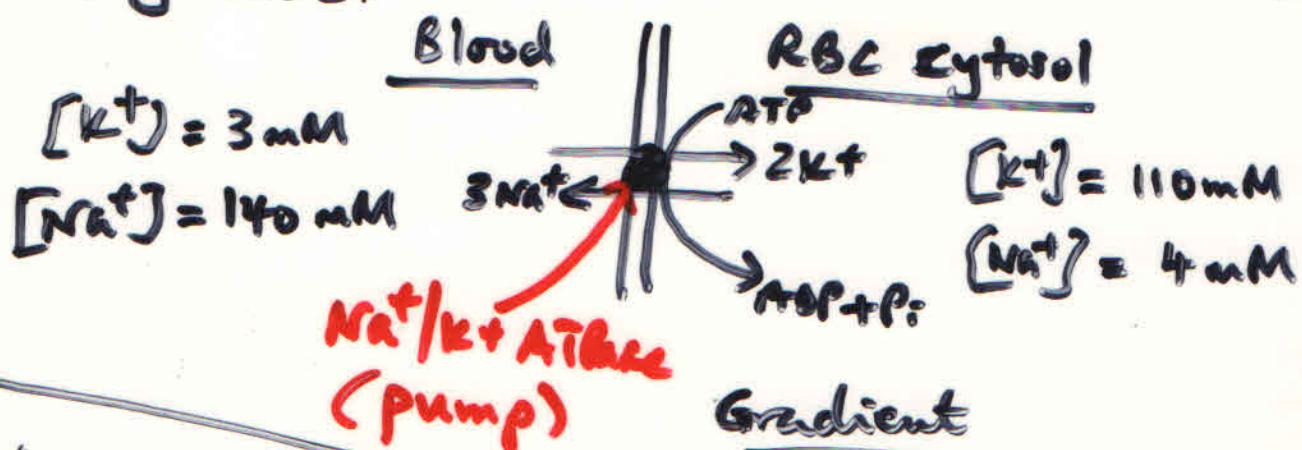
$$DG = 2.303 \times (1.98)(298) \log 100$$

$$= +2.7 \text{ kcal/mol} = \text{Energy required}$$

to transport glucose against Conc. gradient.

e.g. Parietal cells of Stomach

Cell ATP | | | Stomach

H^+ → $2H^+$

$10^{-7}M [H^+]$ | $0.1M [H^+]$

↓ ADP+Pi

H^+-transporting ATPase (pump)

Stomach wall

e.g. Transport of Na^+ and K^+ across the membrane by RBC.

Blood | | | RBC Cytosol

$[K^+] = 3mM$ ATP → $2K^+$ $[K^+] = 110mM$

$[Na^+] = 140mM$ $3Na^+$ ← $[Na^+] = 4mM$

→ ADP+Pi

Na^+/K^+ ATPase (pump)

Gradient
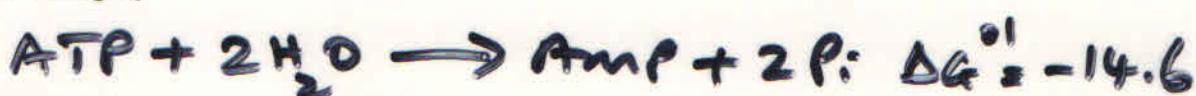
Read on; The enzymatic Cycle of the Na^+/K^+ ATPase
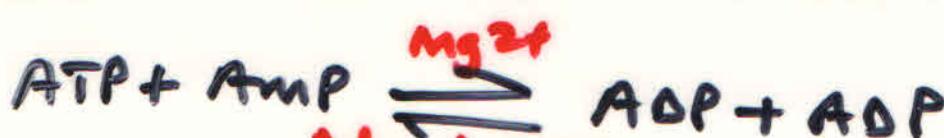
1) Controls cell volume
2) Nerve impulses
3) Drives the active transport of sugars and amino acids.

ATP can also be broken down to AMP and PPi.

(i) $ATP + R-\overset{O}{\underset{||}{C}}-OH + CoA-SH \rightleftharpoons R-\overset{O}{\underset{||}{C}}-S-CoA + AMP + PPi$ $\Delta G^{o1} = +0.2$ $\Delta G^{o1} = -6.9$ kcal/mol

(ii) $PPi + H_2O \longrightarrow 2Pi$

(iii) Overall

$ATP + 2H_2O \longrightarrow AMP + 2Pi$ $\Delta G^{o1} = -14.6$
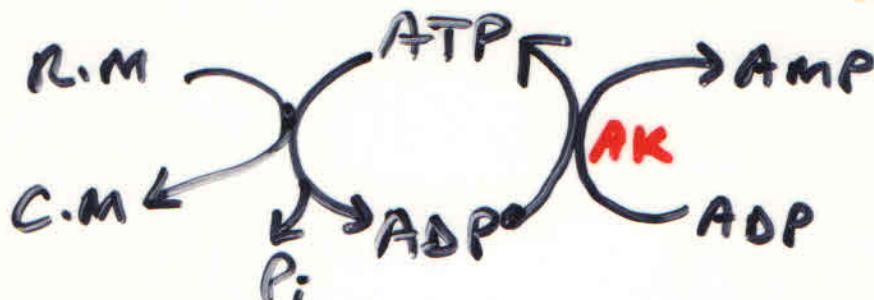
Q. What is the fate of AMP?

$$ATP + AMP \underset{}{\overset{Mg^{2+}}{\rightleftharpoons}} ADP + ADP$$

Adenylate kinase (ADK) = Myokinase

R.M → ATP → AMP

C.M ← Pi → ADP → AK → ADP
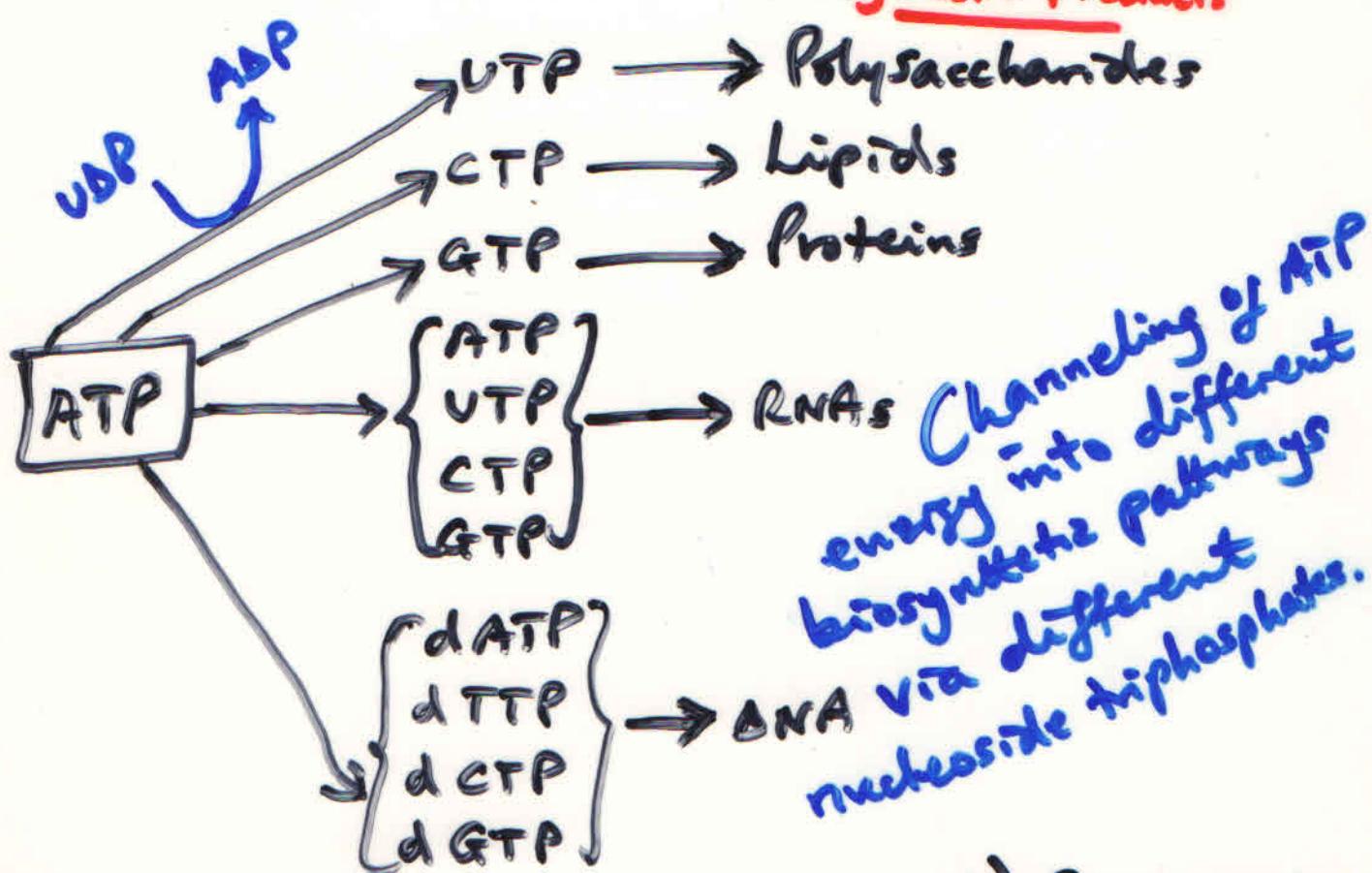
AK acting on ADP can supplement phosphocreatine as a source of ATP during muscle contraction.

Other uses of ATP

Biosynthetic Products

UDP, ADP

ATP → UTP → Polysaccharides

ATP → CTP → Lipids

ATP → GTP → Proteins

ATP → { ATP, UTP, CTP, GTP } → RNAs

ATP → { dATP, dTTP, dCTP, dGTP } → DNA via different nucleoside triphosphates

Channeling of ATP energy into different biosynthetic pathways via different nucleoside triphosphates.

5) Coenzymes

Functions of Nucleotides:

1) Source of energy - ATP
2) Specific carriers of building-blocks
3) Precursors of Nucleic acids
4) Regulators e.g. cAMP, cGMP