

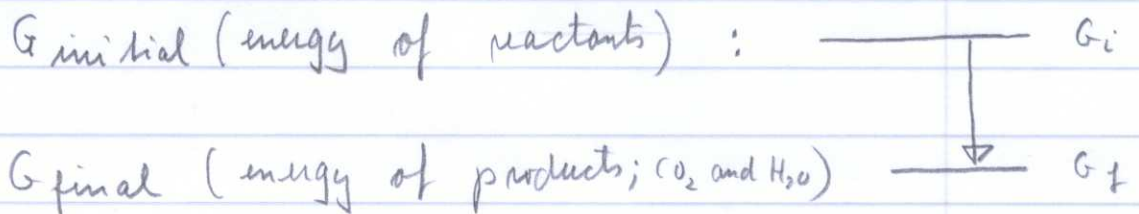
BIOENERGETICS

We consider the breakdown of glucose:



The standard free (Gibbs) energy of the reaction is:

$$\Delta G^\circ = G_{\text{fin}} - G_{\text{ini}} = -2868 \text{ kJ/mol}$$



The minus sign means that energy is released in the reaction (exergonic)

We compare the above reaction to a general reaction written in the following way:



for which we had the following free energy:

$$\Delta G = \sum_i (\mu_0^i \cdot \nu_i + RT(\ln c_i) \cdot \nu_i) \cdot \Delta \xi$$

$$\equiv A \cdot \Delta \xi, \text{ where}$$

A is the affinity of the reaction and $\Delta \xi$ the amount of mol converted in the reaction.

When the reaction proceeds at stand conditions ⁽²⁾
($p = 1 \text{ atm}$, $T = 273^\circ \text{K}$, $C = 1 \text{ M}$), one will have:

$$\Delta G = \Delta G^\circ \cdot \Delta \xi$$

The reaction rate (R) is defined as:

$$R = \frac{\Delta \xi}{\Delta t} \quad (\text{amount of mol converted per time unit})$$

and often reactions proceed at a rate which is constant in time. The combustion reactions in a living organism is nearly constant in time, and our daily need for energy is:

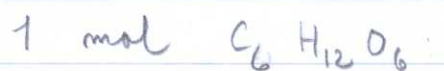
$$\Delta G = 2000 \text{ kcal} = 2000 \cdot 4.2 \text{ kJ} = 8400 \text{ kJ}$$

When we use glucose as energy source, it means:

$$\Delta G = \Delta G^\circ \cdot \Delta \xi$$

$$8400 \text{ kJ} = 2868 \text{ kJ} \cdot \Delta \xi \Rightarrow \Delta \xi \approx \underline{\underline{3 \text{ mol}}}$$

How many grams of glucose is that?
Then we need to the molecular weight (M.W.) of glucose:



$$6 C = 6 \cdot 12 = 72$$

$$12 H = 6 \cdot 1 = 12$$

$$6 O = 6 \cdot 16 = 96$$

$$\underline{\underline{180 \text{ g}}}$$

1 mol glucose is 180 g

Then we need 3 mol = 3 · 180 g = 540 g a day, and the rate of glucose combustion is then:

$$R = \frac{\Delta \xi}{\Delta t} = \frac{3 \text{ mol}}{24 \text{ day} \cdot 60 \text{ s}} = \frac{3 \text{ mol}}{24 \cdot 60 \cdot 60 \text{ s}} \approx 3.5 \cdot 10^{-5} \text{ mol/s}$$

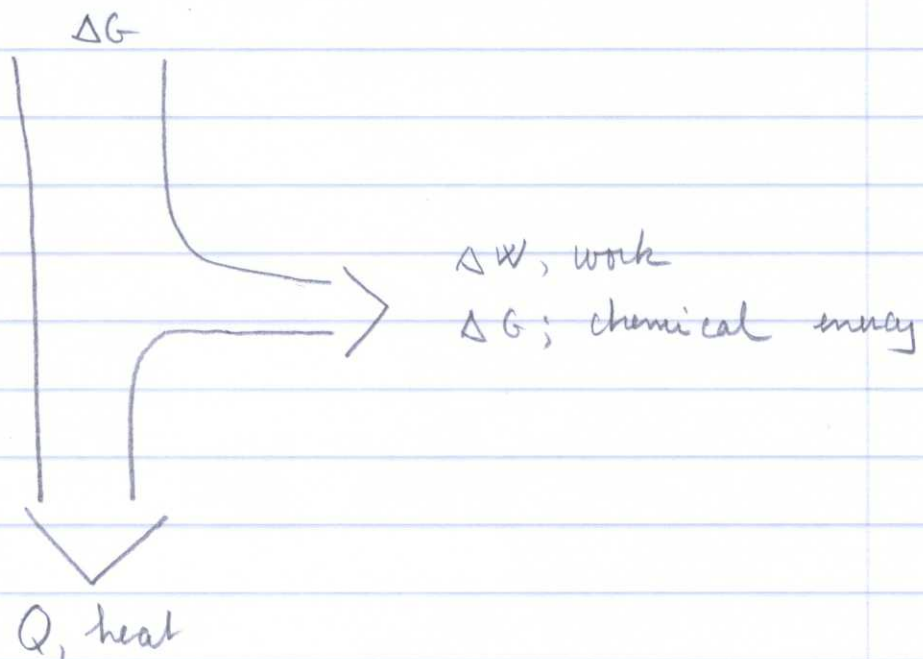
and the energy released per second in our organism is:

$$\frac{\Delta G}{\Delta t} = \Delta G_0 \cdot R = 8.4 \cdot 10^3 \frac{\text{kJ}}{\text{mol}} \cdot 3.5 \cdot 10^{-5} \text{ mol/s} \\ \approx 285 \text{ W}$$

This is only a fraction of a horsepower (750 W).

ENERGY CONVERSION

In a combustion reaction the free energy is released as heat, however it can be converted to other forms of energy as well:



In living systems the energy stored in glucose is converted into a molecule

called adenosin tri phosphate (ATP), in the reaction:

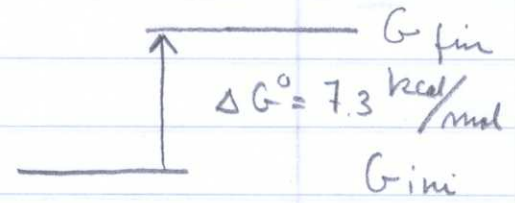


A phosphate group, $PO_4^{--} \equiv \textcircled{P}$, reacts with adenosin-di-phosphate, the create ATP.

The energy of the reactants and the product is:

Product (= final state)

Reactants (= initial state)



$$\Delta G^\circ = G_{fin} - G_{ini} = 7.3 \text{ kcal/mol}$$

ATP is an "energy rich" molecule, and is a general energy source in most cases (mechanical work, chemical reactions, ion pumps..).

In the complicated respiration processes altogether 36 ATP molecules are formed from one glucose molecule, so the efficiency of energy conversion is:

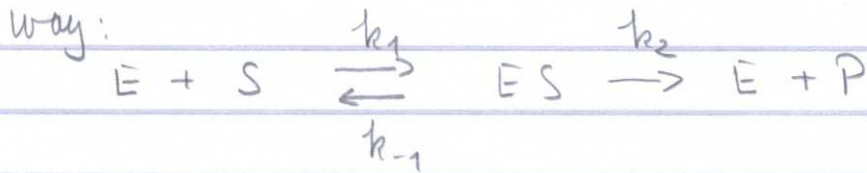
$$\eta (\text{efficiency}) = \frac{\Delta G_{ATP}}{\Delta G_{glu}} = 36 \cdot \frac{7.3 \text{ kcal/mol}}{682 \text{ kcal/mol}}$$

$$\approx 0.4$$

This efficiency might be even higher, when the reactions proceed at non-standard concentrations.

ENZYMES AND ENZYME KINETICS

For almost every chemical reaction in an organism there is an enzyme controlling the reaction rate. The reaction mechanism is universal, and is written in the following way:



E is the enzyme, which is a protein, and S the reactant, called the substrate. When a S molecule moves and meet an E, an enzyme-substrate complex can be formed (ES). In the complexed state the activation energy for forming P from S is lowered, which is one of two outcomes of the enzyme substrate complex. It might also disintegrate back into a free E and S, with a rate constant k_{-1} .

The formation rate of ES is:

$$\frac{d[\text{ES}]}{dt} = k_1 [\text{E}] \cdot [\text{S}] - k_{-1} [\text{ES}] - k_2 [\text{ES}]$$

The number of ES molecules formed per sec. is in proportion to concentration of both E and S (they must meet in a collision), and the number of ES that vanishes is in proportion to ES molecules already present.

- The condition of stationary tells that the number of ES molecules is constant in time; $\frac{d[\text{ES}]}{dt} \stackrel{!}{=} 0$.
- Furthermore, the amount of enzyme, either free or complexed, is constant

The first condition will give:

$$[ES] \cdot (k_{-1} + k_2) = k_1 [E] \cdot [S] \quad (\text{eq. 1})$$

The second condition will give:

$$[E_0] = [E] + [ES], \quad [E_0] \text{ is the total enzyme concentration, } \Rightarrow$$
$$[E] = [E_0] - [ES] \quad (\text{eq. 2})$$

Combining eq. 1 and eq. 2 will give:

$$[ES] \cdot (k_{-1} + k_2) = k_1 ([E_0] - [ES]) \cdot [S]$$

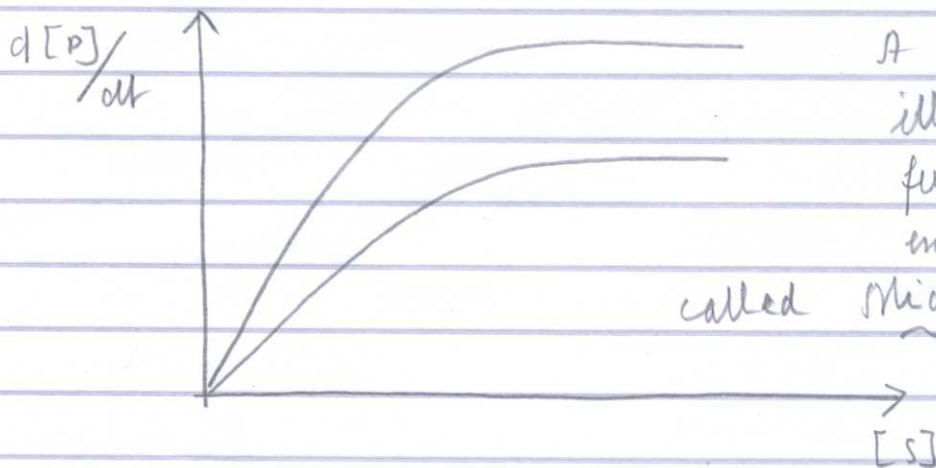
$$[ES] \cdot (k_{-1} + k_2) = k_1 [E_0] \cdot [S] - k_1 [ES] \cdot [S]$$

which gives

$$[ES] = \frac{k_1 [E_0] \cdot [S]}{(k_{-1} + k_2) + k_1 [S]} = \frac{k_1 [E_0] \cdot [S]}{\frac{k_{-1} + k_2}{k_1} + [S]}$$

and the rate of product formation is finally:

$$\frac{d[P]}{dt} = k_2 [ES] = \frac{k_2 [E_0] \cdot [S]}{K_m + [S]}, \quad K_m \equiv \frac{k_{-1} + k_2}{k_1}$$



A graphical illustration of the function for enzyme kinetics, called Michaelis-Menten law