Lecture 16 : biochemical reactions cont'd.

- Rates of reactions
- Enzymes
- Overview of cellular respiration
  - ↳ Finish on Monday.

→

Example Questions

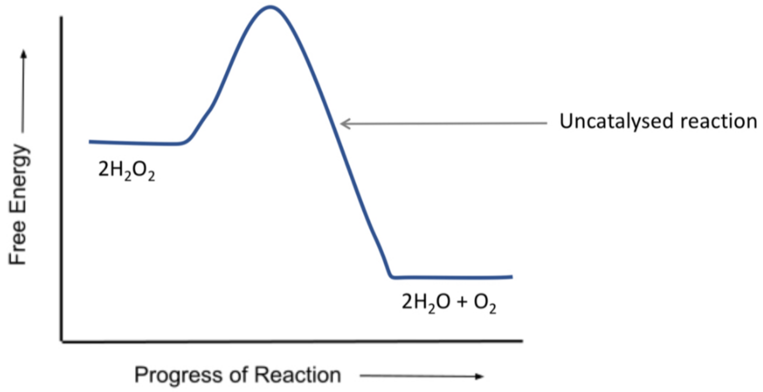
2017 S1

41) Enzymes are biological catalysts. The enzyme 'catalase' catalyses the following reaction of H_2O_2 (hydrogen peroxide) in cells:

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

a. The reaction co-ordinate diagram below shows the uncatalysed breakdown of hydrogen peroxide to water and oxygen. Draw in the curve for the catalysed reaction and label the activation energy for both the catalysed and uncatalysed reactions.

(2 marks)



2018 S5.

36) The Gibbs free energy provides the potential energy available for chemical reactions. Describe the role played by enzymes in chemical reactions and illustrate this with a labelled diagram.

(3 marks)

Answer:

37) Name two factors affecting enzyme activity

(1 marks)

Answer:

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39) Approximately how many ATP molecules are produced during the Electron Transport stage of cellular respiration?

(1 mark)

Answer: ________________

L16

3.6.1 Rate of reaction

The **rate of reaction** is defined as the rate at which **product** is formed, unless otherwise specified.

Rate of reactions

$\boxed{\text{Rate} = \Delta\,\text{amount} / \Delta\,\text{time}}$ eg $\underbrace{\frac{1}{\text{Vol}} \cdot \frac{\Delta n}{\Delta t}}$ $[=]$ $\frac{\text{mol}}{\text{m}^3 \cdot \text{s}}$ = conc./s.

$\frac{\Delta\,\text{conc}}{\Delta t}$ for fixed volume

Relative rates: how many 'per step'

(just conservation of mass)

per 'step' rate

$\boxed{\text{eg. } 2A + B \xrightarrow{R} C \quad \Big\} \quad \underbrace{\frac{dC}{dt} = +R}_{\text{product}}, \quad \frac{dA}{dt} = -2R, \quad \frac{dB}{dt} = -R}$ use 2 A per step

*

Example Problems 6: Reaction rates

1. What is the rate of *consumption* of hydrogen gas in the following reaction when its concentration decreases by 0.2 mol/L in 10 s?

$$H_2 + I_2 \rightarrow 2HI$$

2. Is the rate the same if expressed in terms of HI? What is this latter quantity called?

mol/min

3. The average rate of combustion of a candle made of paraffin is 8.33×10^{-4}. The molar mass of paraffin is 352.6 g/mol. You want the candle to burn for 4h. The candle is only sold in four sizes: 25, 50, 75 or 100 g. Which one is the smallest that you could use?

* $\boxed{\text{Common constitutive model for } R: \text{"law of mass action"}}$

actually (how fast → ~~not~~ conservation)

$aA + bB \xrightarrow{R}$

$R = [A]^a \cdot [B]^b$, where [ ] means concentration.

} 'Chance of collision'

actual rates = f(conc. of reactants)

Answers

1. Rate of consumption is $\frac{0.2\ mol/L}{10\ s} = \boxed{0.02 \frac{mol\ of\ H_2}{L \cdot s}}$

2. Rate of product formation = rate of reaction

$= 2 \times$ consumption rate of H_2

(get $2HI$ for one H_2)

$\Rightarrow$ Rate $= 2 \times 0.02 \frac{mol}{L \cdot s} = \boxed{0.04 \frac{mol\ of\ HI}{L \cdot S}}$

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3. Burn rate $= 8.33 \times 10^{-4}$ mol/min (Δamount/Δtime)

Required time $= 4h = 4\cancel{h} \times \frac{60\ min}{\cancel{h}} = \underline{240\ min}$

Amount required $= 8.33 \times 10^{-4} \frac{mol}{\cancel{min}} \times 240\ \cancel{min}$

$\simeq 0.2$ mol $= 0.2\ \cancel{mol} \times \left(\frac{352.6g}{\cancel{mol}}\right)$

$\approx \underline{70.2g}$

$\Rightarrow$ smallest that is $\underline{> this}$ is $\underline{75g}$

Biological reactions, as opposed to combustion etc, tend to be

1. Slow (naturally)
2. Efficient
3. Highly controlled

How can we speed up reactions? One idea is motivated by the (kinetic) **collision theory**: a reaction requires high energy collisions to break bonds. So, for example,

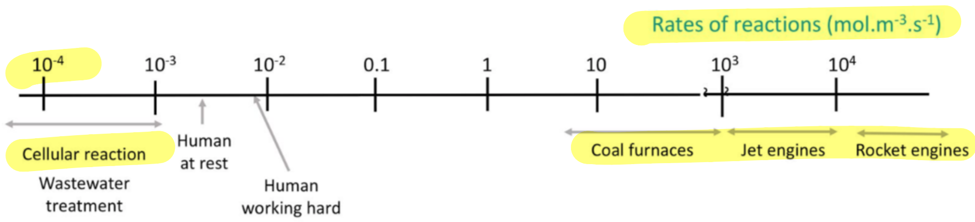


Figure 24: Typical rates of reactions. (From notes by Thor Besier.)

we might suppose that higher temperature → more high energy collisions → faster reaction. } k ↑

While this is in fact true, we have an issue: body temperature is stable at around 37 °C. We can't boil cells!

Instead, we turn to enzymes, a kind of biological catalyst.

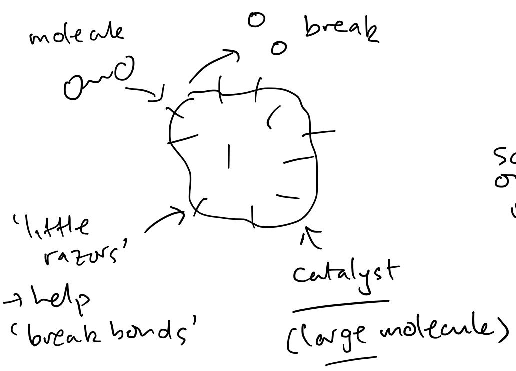
3.6.2 Catalysts and enzymes

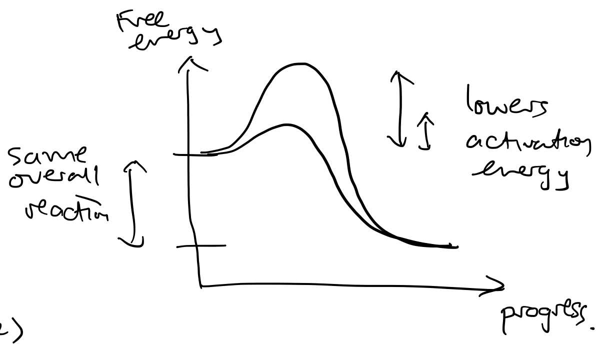
'helper'

A catalyst is a molecule that **speeds up a reaction, without being consumed itself**. It functions to **lower the activation energy** of the reaction.

Nearly all cellular reactions are catalysed by enzymes. These enable increased speed, control and efficiency. Details are given below.

Enzymes





not scientific!

→ see over page.

Enzyme:

Biological catalyst

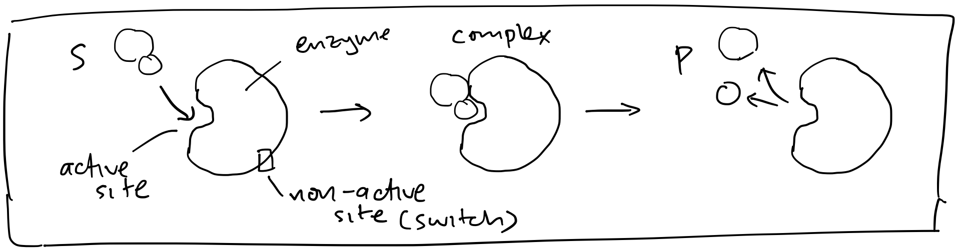
$$\boxed{S + E \rightleftharpoons S:E \longrightarrow P + E}$$

substrate enzyme 'complex' product enzyme

overall is still

$$\boxed{S \longrightarrow P}$$

(E not used up, ΔG same, rate is faster)

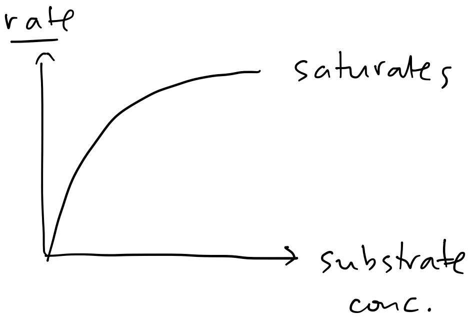


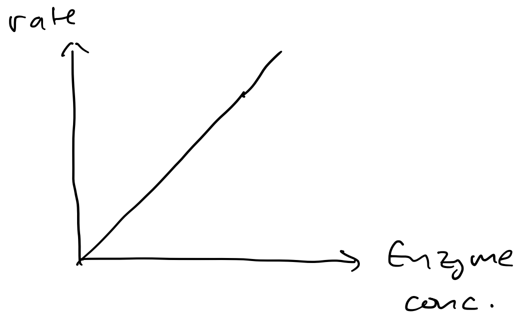
Enzymes are affected by

1. Temperature (best at body temperature)
2. pH (usually best at 7.4 but can vary)
3. Substrate concentration (↑)
4. Enzyme concentration (↑)
5. Enzyme inhibition (↓)
   (a) Competitive inhibition is when two or more molecules attempt to simultaneously bind to the active site.
   (b) Non-competitive inhibition is when a molecule binds to another, non-active, site leading to a modification of the substrate's ability to bind to the active site.

'switch off'

Enzyme activity





Example Problems 7: Enzymes

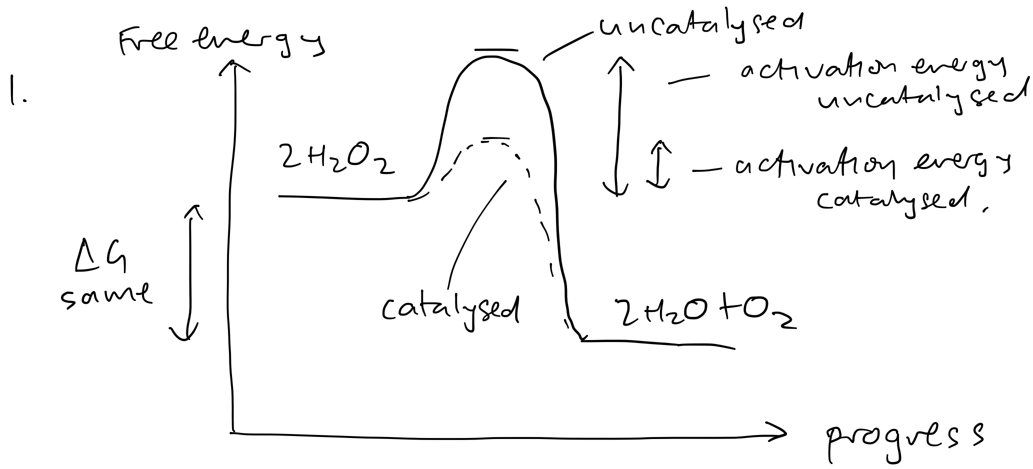
Enzymes are biological catalysts. The enzyme 'catalase' catalyses the following reaction of H_2O_2 (hydrogen peroxide) in cells:

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

1. Draw a diagram showing free energy vs reaction progress for the above reaction. Include both uncatalysed and catalysed reactions, activation energies, reactants and products.
2. Various factors affect the activity of enzymes. Explain how surrounding temperatures of 20°C, 37°C and 50°C would affect the activity of catalyse.

Answers

1.



2. 20°C ↓ (too cold – not enough energy)
37°C (good – body temp)
50°C (too hot – 'denature'/'cook'!)

3.7 Cellular respiration } preview/overview today.

Here we return to

today & next.

$$\text{Food/Light} \xrightarrow{\text{`bank'/store energy}} \text{ATP} \xrightarrow{\text{`spend'/use energy}} \text{Useful Processes.}$$

In particular, we focus on the **first step of Food → ATP via a particular metabolic pathway** known as **cellular respiration**. This 'pathway' consists of a *series of enzyme catalysed reactions*. Cellular respiration is one of the most important ways of extracting energy from food, but not the only way.

The more general term **metabolism** is used to refer to *all reactions involved in maintaining the living state* of an organism. Within this, **catabolism** refers to the *breakdown* of molecules for energy while **anabolism** refers to the *synthesis* of useful molecules.

While cellular respiration can make use of e.g. fats and proteins, here we focus on the key process of **conversion of glucose to ATP**.

This reaction takes the form:

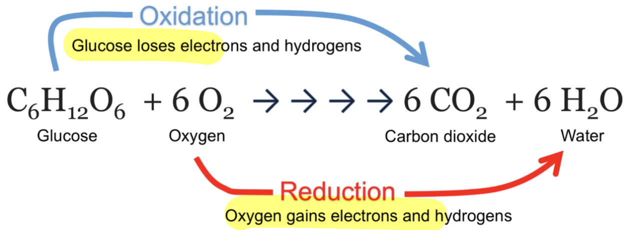
$$\underbrace{C_6H_{12}O_6}_{\text{glucose}} + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

store in ATP.

Some terminology: a **redox reaction** (reduction-oxidation) concerns reactions involving the **transfer of elections**. A key mnemonic is OIL-RIG: Oxidation Is Losing Elections, Reduction is Gaining Electrons.

During cellular respiration:

1. Glucose is **oxidised** (loses electrons and hydrogen).
2. Oxygen is **reduced** (accepts elections and hydrogen).



Cellular respiration as a redox reaction.

There are **three key stages of cellular respiration**:

1. **Glycolysis**: breakdown of glucose started.
2. **Krebs Cycle**: breakdown of glucose completed and carbon dioxide formed.
3. **Electron Transport**: energy from breakdown of glucose converted to ATP.

An overview is shown below; we will consider each of these in detail.

└ today

NAD and FAD?

1 & 2: load buses

Think "electron shuttles/buses" NAD, FAD (unloaded form)

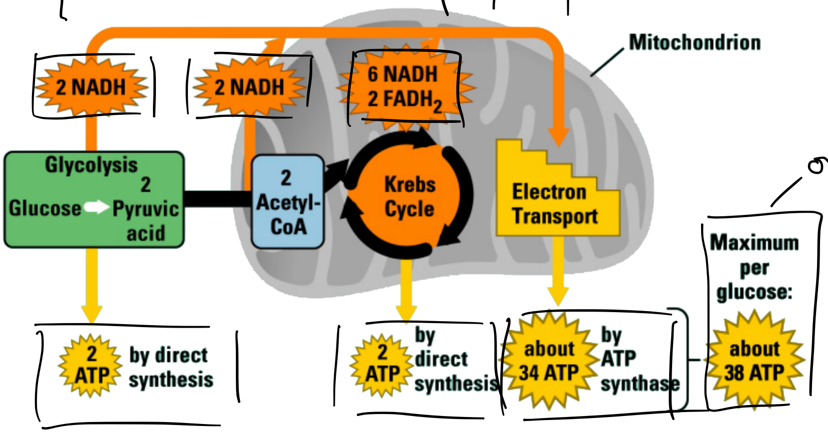
→ NADH & FADH$_2$ are loaded forms

3: unload

→ unload to get energy

unload buses → fill ATP

Load buses



overall: 38 ATP

2 in
4 out
2 net.

Figure 25: Stages of cellular respiration. During cellular respiration, 1 molecule of glucose creates ~38 molecules of ATP. One cell can have 1000-2000 mitochondria producing many energy-rich ATP molecules.

1. 2 ATP (Net) + 2 NADH
↓ [+ 2 NADH (1→2)]
2. 2 ATP + 6 NADH + 2 $FADH_2$
↓
3. 34 ATP

38 ATP

Key: ATP input/outputs

End L16

3.7.1 Glycolysis

Glycolysis is a series of nine reactions in the cytosol of the cell that **begins the breakdown of glucose**. It took about 100 years to discover and elaborate the full pathway!

The **inputs and outputs** are illustrated below.