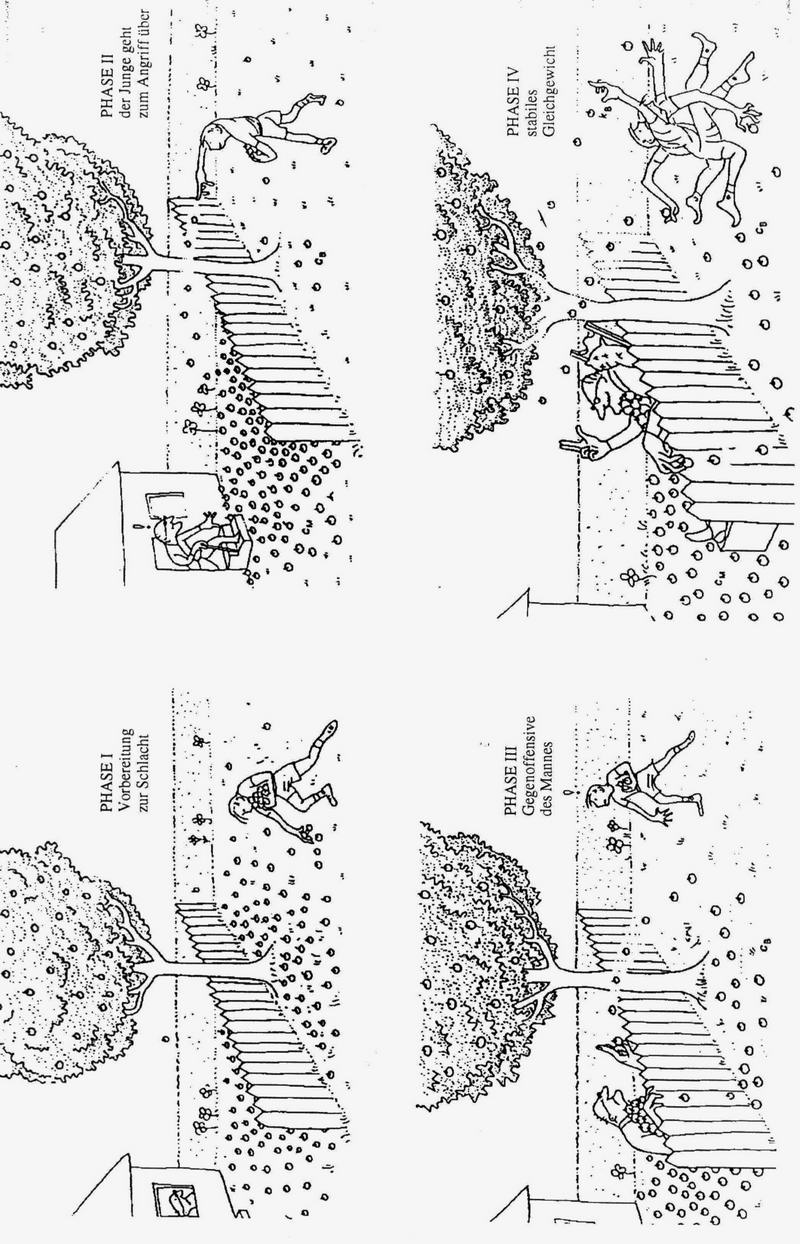
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| --- | --- |
| Equilibrium, -ia /ˌiːkwɪˈlɪbriəm/ | Gleichgewicht |
| dynamic | dynamisch, nicht statisch sondern "in Bewegung"" |
| prerequisites | Voraussetzungen |
| ratio | Verhältnis |
| carbonic acid | Kohlensäure, E290, H2CO3 |
| position of the equilibrium | Lage des Ggw |
| to shift | verschieben |
| to oppose | bekämpfen, dagegen wehren |
|  |  |
| table salt | Kochsalz |
| yield | Ausbeute |
| nitrogen fertiliser | Stickstoffdünger |
| nitric acid | Salpetersäure |
| limestone cave | Kalksteinhöhle |
| Law of mass action / equilibrium Law | Massenwirkungsgesetz |
|  |  |
|  |  |

**Allgemeines:**

|  |  |
| --- | --- |
| Script, handout | Skript |
| Nach vorne kommen (Schüler) | Come up (front) |
| allotrope | Modifikation |
| alloy | Legierung |
| bent line | „gewinkeltes Molekül“ The shape of a moleculae that contains two bonding pairs and two lone pairs. |
| co-ordinate bond | Komplexbindung |
| bidentate (🡪 multidentate) | zweizähnig (Ligand) |
| diatomic | zweiatomig (-es Molekül) |
| displayed formula | Lewis-Formel A chem. formula showing all the atoms in a compound and their bonds. |
| emperical formula | Verhältnisformel  a formula that gives the simplest whole number ratio of atoms of each element in a compound |
| molecular formula | Molekülformel  A formula that gives the actual number of atoms of each element in a molecule |
| shortened structural formula | Abbreviated structual formula in which the arrangement of atoms and group is shown without drawing bonds.  e.g. hexane = CH3(CH2)4)CH3 |
| E-Z-isomer | E/Z-Isomer |
|  |  |
| full equation | Stoffgleichung |
| ionic equation | +/- Teilchengleichung |
| feedstock | Rohstoff, Rohmaterial |
| lattice /ˈlætɪs/ | (Kristall-)gitter |
| malleable /ˈmæliəb(ə)l/ | formbar, verformbar, plastisch |

# Dynamic Chemical Equilibria



**Task: answer the following questions**

1. Why does the above story result in an equilibrium?
2. At which point is the equilibrium reached?
3. Why is it a ‘dynamic’ equilibrium?
4. Think of other non-chemical dynamic equilibria!
5. Can all chemical reactions be called dynamic equilibria?

## Prerequisites for dynamic chemical equilibria

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*Example:* C6H12O6 + 6 O2 🡪 6 CO2 + 6 H2O

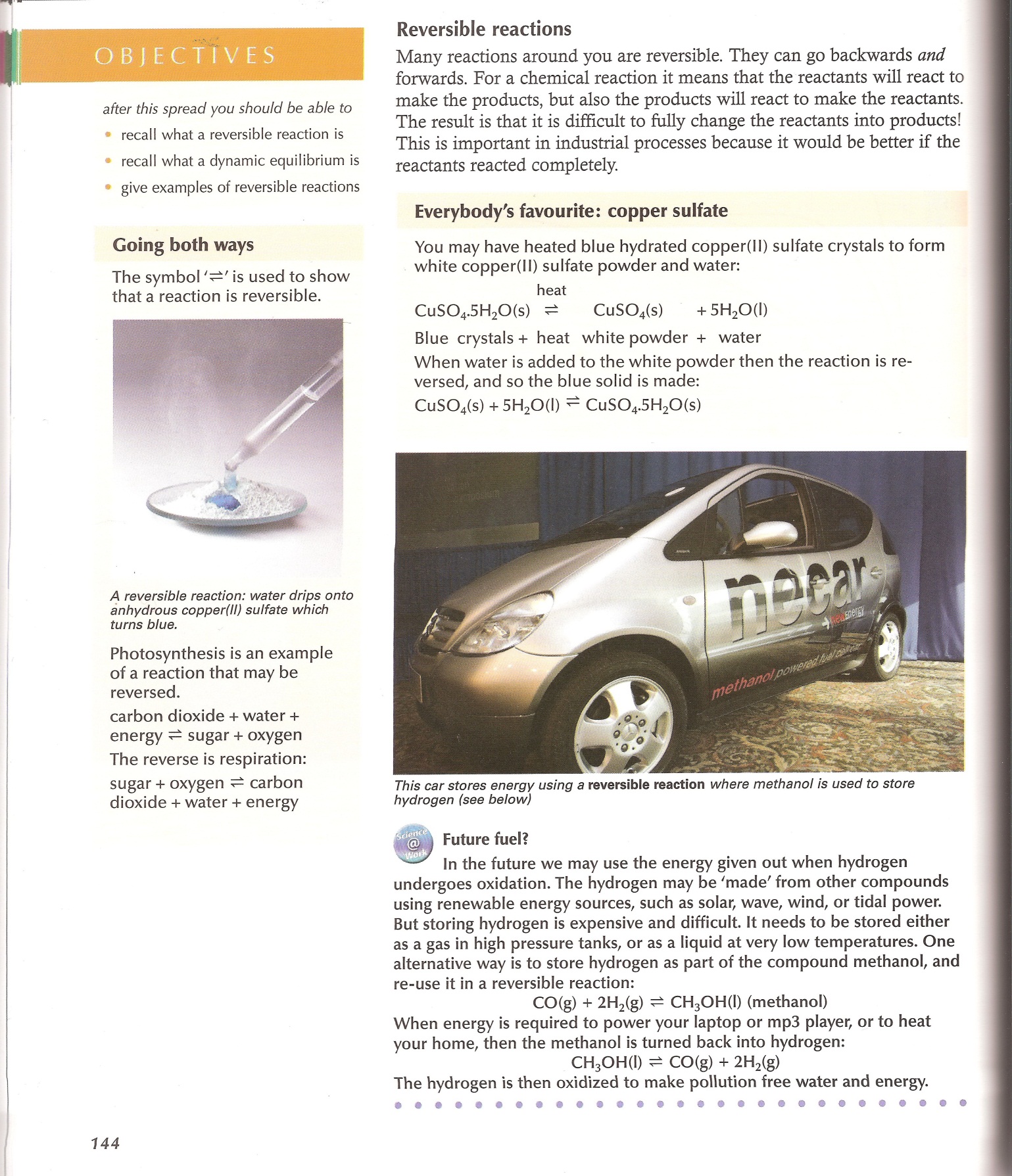
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**Important remarks**

„Equilibrium“ does not mean that the concentrations of the substances involved are equal. A system can easily contain the hundredfold concentration of products than reactants and still be at equilibrium.

At equilibrium the concentrations do not change any more. Both the forward and the reverse reaction still take place but there is no overall reaction. Consequently, the rate of the forward reaction equals the rate of the reverse reaction.

## Reversible reactions



## Class experiment: A dynamic chemical equilibria going to completion

Actions according to the dice: 1 + 2: sit down

3 - 5: no reaction

6: stand up

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| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **t=0** | **t=1** | **t=2** | **t=3** | **t=4** | **t=5** | **t=6** |
| **High energy level** |  |  |  |  |  |  |  |
| **Low energy level** |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  | **t=0** | **t=1** | **t=2** | **t=3** | **t=4** | **t=5** | **t=6** |
| **High energy level** |  |  |  |  |  |  |  |
| **Low energy level** |  |  |  |  |  |  |  |
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Percentage of students in

high energy state

## The equilibrium law

## Exercises

1. Write down the equilibrium laws for the following reactions:

a.) O2 (g) + 2 H2 (g)  2 H2O (g)

b.) 2 NH3 (g)  N2 (g) + 3 H2(g)

2. For the reaction

H2 (g) + I2 (g)  2 HI (g)

the equilibrium constant at a given temperature is K= 50.5.

a.) Considering this value, what can you say about the reaction? What does the value mean for the concentrations of the involved substances at equilibrium?

b.) The above reaction is carried out starting with the reactants. After some time the concentrations of all involved substances is measured:

c(H2) = 15.78·10-3 mol/l, c(I2) = 4.93·10-3 mol/l und c(HI) = 20.17·10-3 mol/l.

Is this reaction at equilibrium?

3. The value of the equilibrium constant K can never have a value equal or smaller than zero.

1. Why is that so? Study the expression of the equilibrium law for this reaction.
2. In what range of values lies K if the equilibrium is on the left, the right or in the middle?

4. Determine what influence a catalyst has on the position of an equilibrium. Do it as follows:

* + Draw one graph that shows the energy change for the forward and one that shows the reverse reaction.
  + In these graphs show how a catalyst influences the forward and the reverse reaction respectively.
  + Now determine what influence a catalyst has on the overall reaction and the position of the equilibrium.

## Affecting an equilibrium

## Experiment 1:

## Experiment 2:

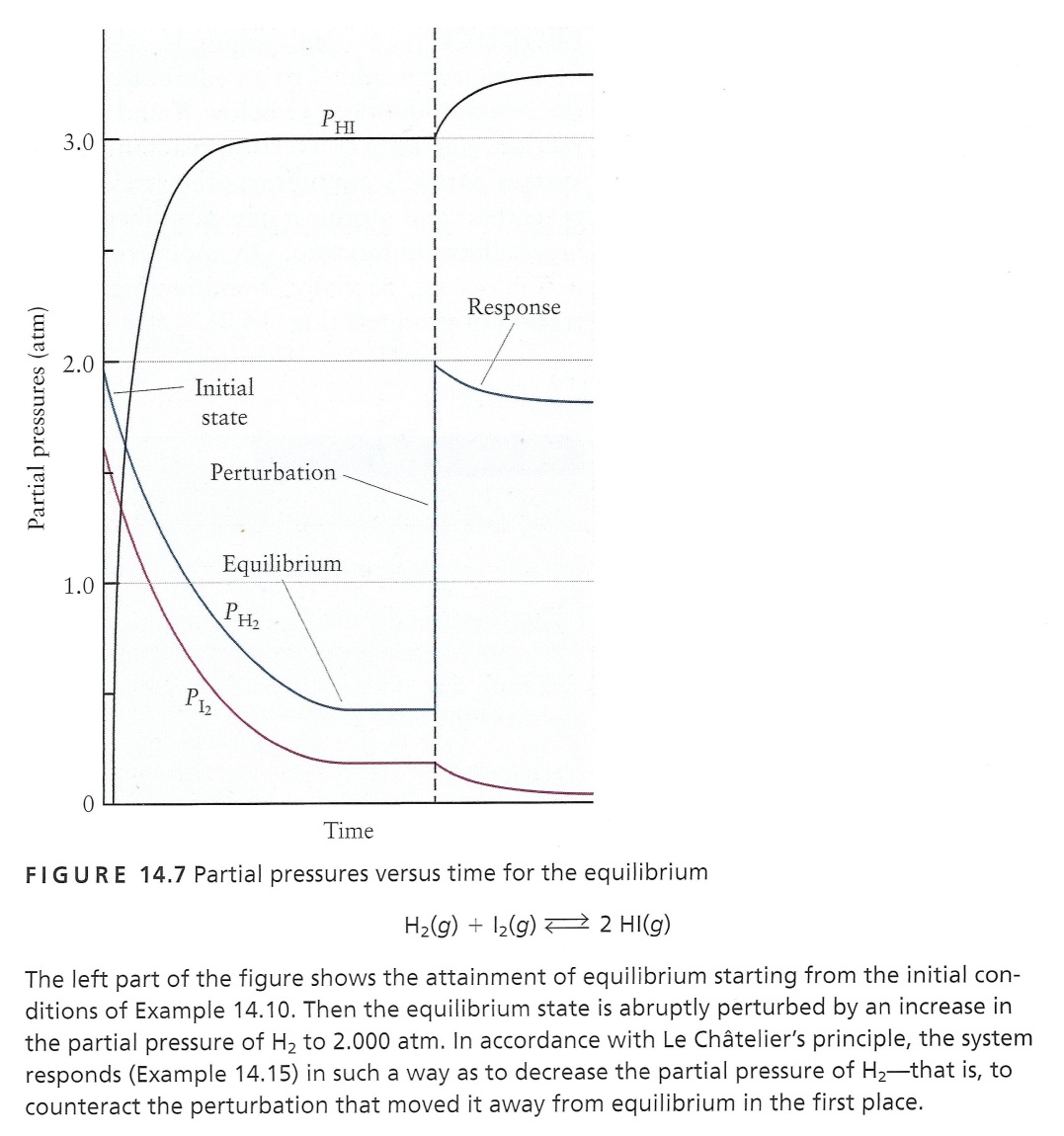
### Le Chatelier’s principle: “Opposing outward influence“

The French chemist Henri Le Chatelier observed how the position of equilibria is affected. He put forward a general rule, known as Le Chatelier’s principle:

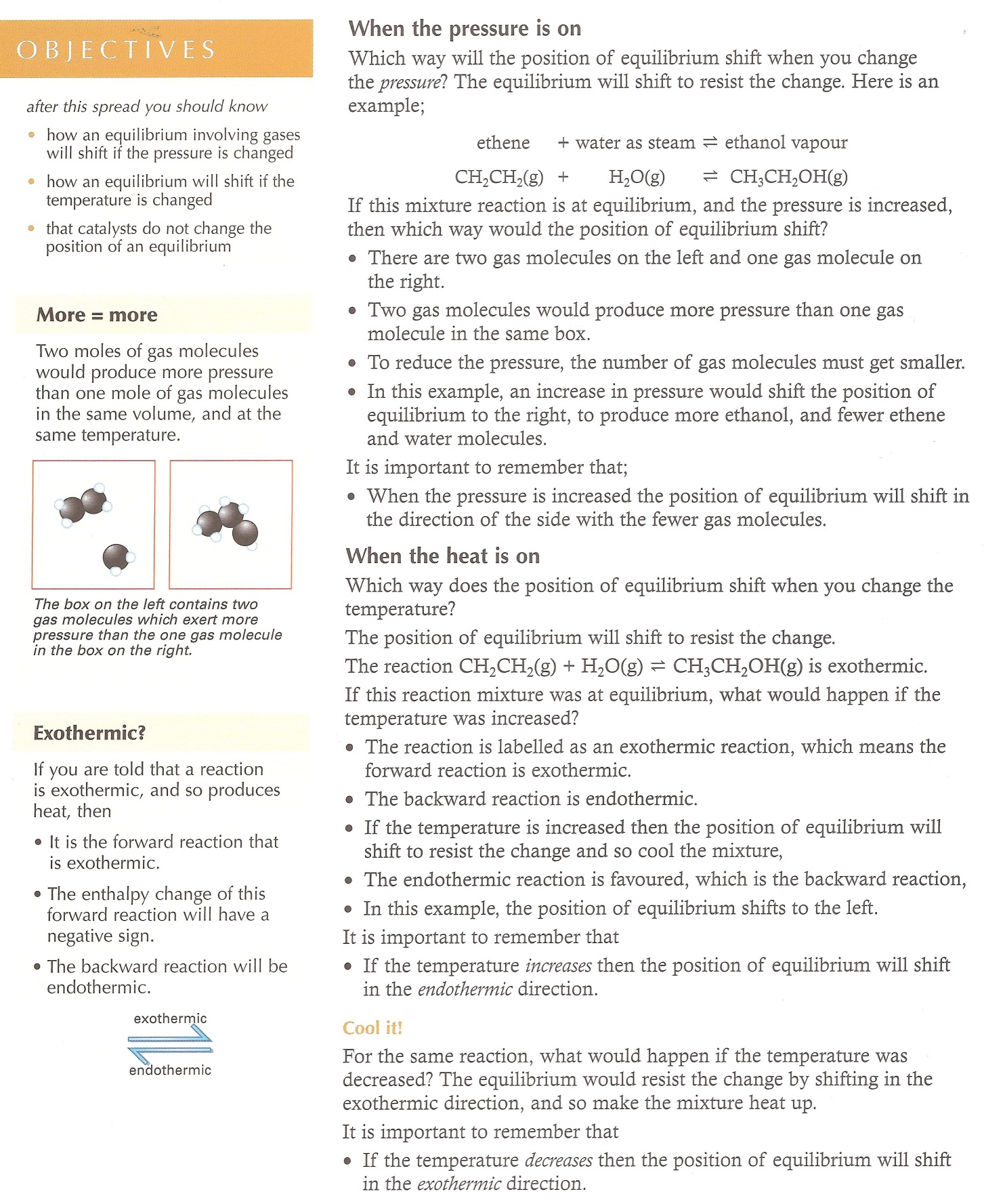
***“If one or more factors that affect an equilibrium is changed, the position of   
equilibrium shifts in the direction which reduces (opposes) the change.”***

**Task**

The graph and text below and on the next page explain how Le Chatelier’s principle counteracts changes in temperature or pressure. Read the text and highlight the most important parts only. Discuss in pairs how the principle of Le Chatelier works when changing the concentrations of products or reactants. Then sum it up in the text box given.



*From: “Principles of Modern Chemistry” by Oxtoby&Gills*



*From: “AS Chemistry for AQA” by Nigel and Angela Saunders*

### Explain here how the principle of Le Chatelier counteracts a change in concentrations of products or reactants:

## Exercises to Le Chatelier’s principle

The following reactions are all carried out in a closed system and are in the state of a dynamic equilibrium. In what directions does the equilibrium shift, if the following measures are applied: *(Exercise from: U. Wuthier, Zug)*

➀ N2 (g) + O2 (g) 2 NO (g) ΔH = +181 kJ/mol

a) raising the temperature: ......................................................................................................................

b) raising the overall pressure: ......................................................................................................................

c) increasing the volume: ......................................................................................................................

➁ 2 NO (g) + O2 (g) 2 NO2 (g) ΔH = -113 kJ/mol

a) adding O2: ......................................................................................................................

b) decreasing the overall pressure: ......................................................................................................................

c) decreasing the temperature: ......................................................................................................................

➂ C (s) + CO2 (g) 2 CO (g) ΔH = +172 kJ/mol

a) dividing the volume by two: ......................................................................................................................

b) increasing the temperature: ......................................................................................................................

c) taking away CO: ......................................................................................................................

➃ 2 NO2 (g) N2O4 (g) ΔH = -62 kJ/mol

a) decreasing the overall pressure: ......................................................................................................................

b) raising the temperature: ......................................................................................................................

c) adding NO2: ......................................................................................................................

➄ AgCl (s) + n H2O (l) Ag (aq) + Cl (aq) ΔH = ?

a) adding table salt: ......................................................................................................................

b) increasing overall pressure: ......................................................................................................................

c) decreasing the temperature: ......................................................................................................................

**states of matter**: **(s)**=solid= **(l)**=liquid= **(g)**=gaseous, **(aq)**=solved in water

## Ammonia and other important nitrogen compounds

Ammonia is the basic material for the production of almost all compounds that contain nitrogen, the by far most important one being nitrogen fertiliser. About 85% of the produced

ammonia is used for that purpose. The reason ammonia has to be produced first lies in the incredible stability of the triple-bond of the N2-Molecule. Cracking it needs a lot of energy and before it was managed produce ammonia from Nitrogen out of the air, loads of sodium nitrate

(“Chile saltpetre“ = NaNO3) was imported as fertiliser from Chile to Europe. In addition, it had an important strategic value during World War I, because it is needed to make explosives.

### _Nitrogen cycle (big)

### *Picture: the nitrogen cycle (from Encyclopaedia Britannica)*

### Task: answer the following questions

### In what way do we humans influence the natural nitrogen cycle?

* What pathways are there to fix N2?
* What interest do bacteria have to fix nitrogen?
* What interest do bacteria have to do nitrification/denitrification?

### Experiment: Bonding of nitrogen by lightning

### Synthesis of Ammonia: a dynamic equilibrium



***Fritz Haber*** *was the first to find appropriate conditions for the reaction below and therefore was awarded the Nobel Prize for Chemistry in 1918.*

**Basic Knowledge**

Ammonia is produced in a chemical dynamic equilibrium reaction, out of the elementary substances nitrogen and hydrogen as follows:

**N2  +  3 H2  aagl  2 NH3   Δ*H = -92 kJ/mol***

As you can see at the negative reaction energy, the reaction is **exothermal**. All substances involved are **gaseous**.

You know the principle of le Chatelier: every change in outside conditions makes the reaction shift in such a manner that it counteracts that change.

**Task: Find the appropriate conditions for this reaction and award yourself the Nobel Prize!**

* + - 1. What conditions are there (in general) to influence the position of an equilibrium?  
         Write down keywords only.

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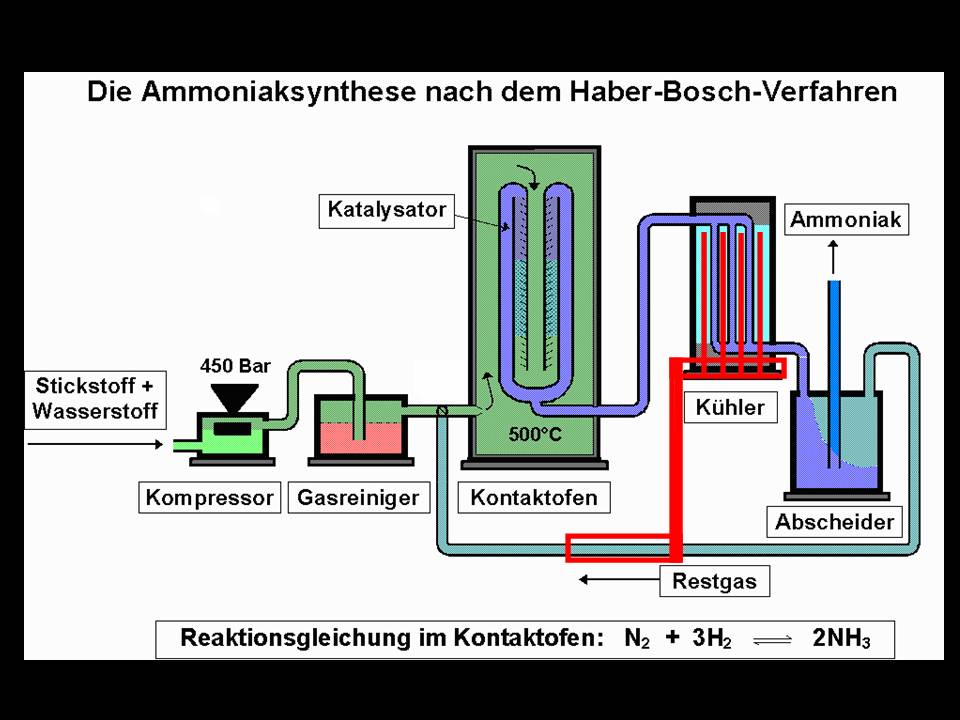
2. How do this conditions have to be chosen so that the equilibrium is shifted in the way to produce the best yield of ammonia?

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* + 1. Unfortunately the catalyst does not work at room temperature but instead needs about 450°C. Therefore we cannot use the temperature to shift the reaction. What does that mean for the other reaction conditions?

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### Industrial ammonia-synthesis in the Haber-Bosch process



**Schematic view of a heat exchanger**



Thanks to heat exchangers more than 90% of the thermal energy can be recaptured. All modern office buildings use this system to save energy.

### From ammonia to nitric acid (nitrification)

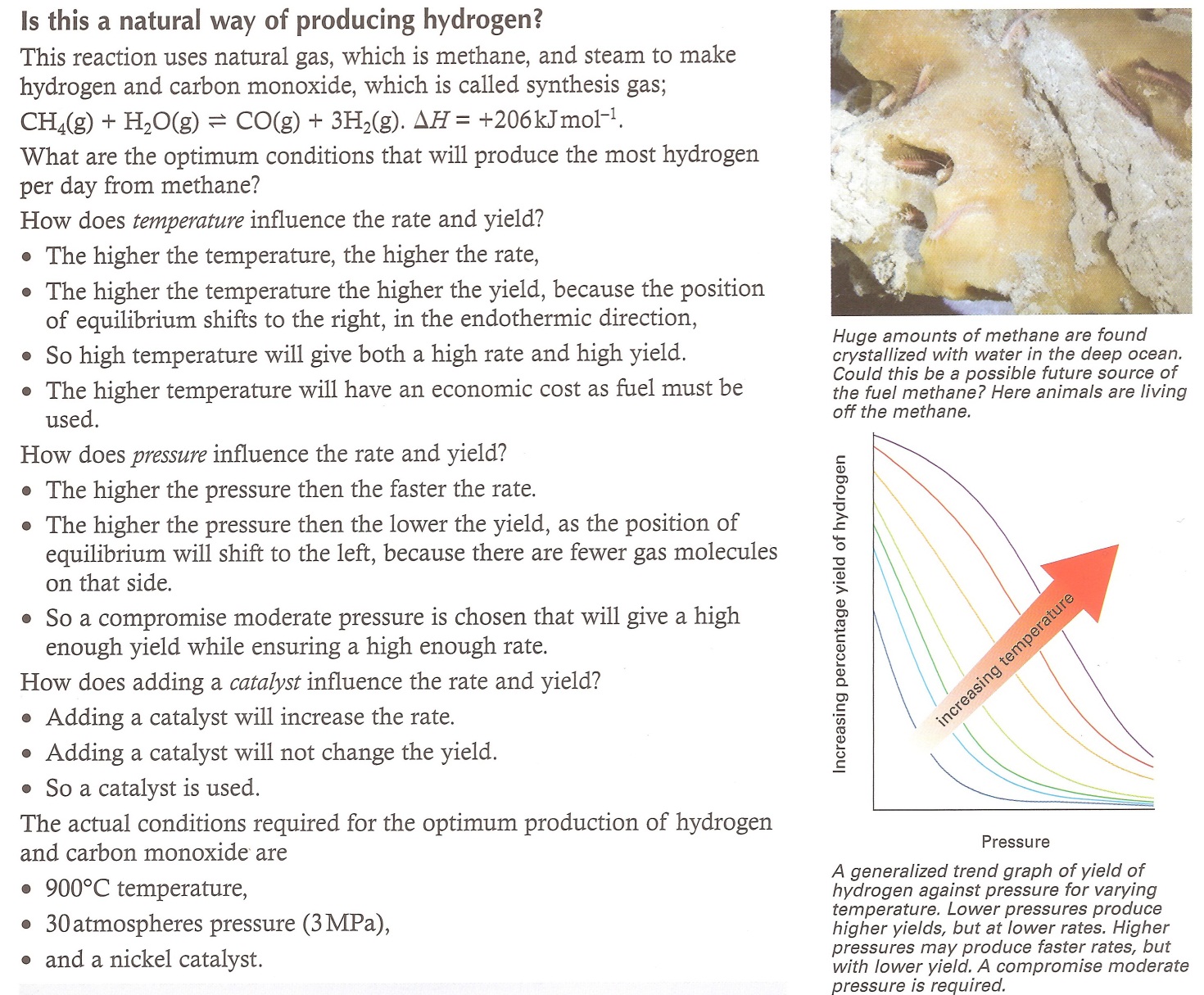
The oxidation of ammonia to nitrate is called nitrification, but only if it is carried out by bacteria. These bacteria are therefore called nitrogenic bacteria and the reaction is carried out under aerobic conditions (that is in the presence of oxygen). It is a two-step process:

1. Formation of nitrite: 2 NH3 + 3 O2 🡪 2 NO2 + 2 H3O

2. Formation of nitrate: 2 NO2 + O2 + 2 H3O 🡪 2 HNO3 + 2 H2O

### The equilibrium of methane and hydrogen

The Haber-Bosch process needs large amounts of hydrogen for the synthesis of ammonia. Unfortunately, there is no natural source of hydrogen hence it has to be produced either by electrolysing water or from methane as shown in the text below. Since electrolysis is much more expensive it is not widely used.



*From: “AS Chemistry for AQA” by Nigel and Angela Saunders*