Teaching Thermodynamics - A New Concept

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Thermodynamics is generally considered a difficult science by students. Its historical development has resulted in an unique structure which is generally incompatible with those of other physical sciences thereby making an intuitive understanding difficult.

Characteristics of the New Concept

1. Unified description of mechanical, electric, thermal, substantial, ...systems.
2. Macroscopic and microscopic, reversible and irreversible, static and kinetic systems can be uniformly described.
3. Short calculations which can be easily understood by the students.
4. All quantities used have an intuitively clear physical meaning.
5. Teaching can be easily adapted to all levels of education.
6. Reduced effort in teaching and learning saves time (about 50%).
7. Integration of more than forty simple but impressive demonstration experiments.

1 Unified description ...

All calculations base on a single equation, the "*main equation*" of the system. Example: Falling rain drop

dW = -pdV + TdS + dn + dq + dA + v dp + md

pressure, volume, temperature, entropy, chemical potential, amount of substance, electric potential, charge, surface tension, surface area, velocity, momentum, mass, gravitational pot., total energy

Quantities without a counterpart in other physical disciplines and also their derivatives are omitted from the new concept such as

~~inner energy U, enthalpy H, free energy F, free enthalpy G, fugacity f, activity a~~

The intensive quantity related to a *substance-like quantity* may be regarded as a *potential* acting on this quantity:

m	mass		gravitational potential
q	charge		electric potential
n	amount of subst.		chemical potential
p	momentum	v	"kinetic potential"
S	entropy	T	"thermal potential"

The transport of a substance-like quantity from a low potential to a high potential consumes energy:

m W = m(2- 1), q W = q(2- 1),
n W = n(2- 1), p W = p(v2-v1),
S W = S(T2-T1).

high (2) ↑ low (1)

The reverse process (from high to low potential) releases energy (W < 0 from the point of view of the system). Only a fraction of this energy can be used while the rest is burned up on entropy production:

W = W + (1-)W

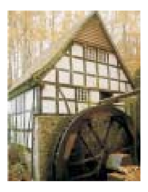
used energy — burned up energy

generated entropy: S_e = -(1-)W/T

An efficiency of 100% (= 1) can be obtained only theoretically. Only these processes are reversible.

The production of S_e always leads to an additional warming of the system and/or its surroundings compared to the reversible process.

To use the released energy special apparatus, machines or devices have to be applied, for example:



Water mill: W = m(2- 1)

Steam engine: W = S(T2-T1)

"Drinking duck" W = n(2- 1)

~~The standard form W = Q (T2-T1)/T1 obscures the analogy~~

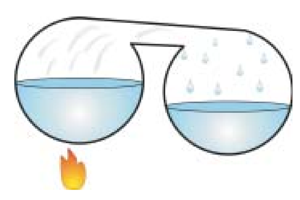
Without any of these machines etc. the efficiency tends to 0 and the generated entropy S_e = -W/T reaches its maximum.

2 Macroscopic and microscopic ...

Macroscopic systems are generally thought to be in the realm of classical thermodynamics, whereas microscopic systems seem to demand the methods of statistical physics. However, it is possible to use classical thermodynamics for the analysis of the properties of atoms or molecules and their interactions (please find more detailed informations on poster 56).

Irreversible thermodynamics which describe the coupling of different transport processes is rarely used by a chemist although these processes are part of his every day life.

An example is the distillation process.



A substance migrates from the left side, a warm place, to the right side, a cold place, although the chemical potential increaseses during the migration.

So, what is the *driving force* of the process?
The migration of the substance is closely linked to the entropy flow from high to low temperatures.

For distillation of 1 mol water at 1 bar we obtain:
W_n n(2 1) 6 kJ W_S S(T_2 T_1) 13 kJ

3 Short calculations ...

The thermodynamic calculus used in the new concept mainly consists of five operations for the transformation of partial differential quotients. Four of them are already well-known.

1. Inverting
(p/ q)r... 1/(q/ p)r...,
2. Inserting a new variable
(p/ q)r... (p/ s)r... (s/ q)r...,
3. Inverting a variable from the index
(p/ q)r... (p/ r)q... (r/ q)p...,
4. Changing a variable within the index
(p/ q)r... (p/ q)s... (p/ s)q... (s/ q)r...

The 5th operation summarizes all reciprocity relations of reversible and irreversible processes.

For example for a system with the following main equation:
dW Pdp Qdq Rdr Sds...

5. "*Overturning*" of the left quotient supplies directly the right one
(Q/ P)qrR (p/ q)PsS.

C_p-C_V is a standard textbook problem and therefore suitable to show the calculating concept:

$$C_p \quad C_V \quad T \quad \frac{S}{T}_p \quad \frac{S}{T}_V \quad T \quad \frac{S}{p}_T \quad \frac{p}{T}_V$$

$$T \quad \frac{V}{T}_p^{2} \Big/ \frac{V}{p}_T \quad T \quad V^{2}.$$

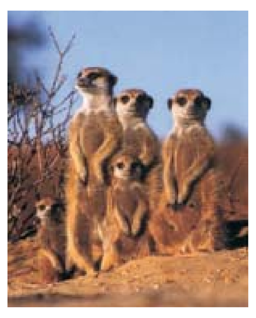
4 ... intuitively clear physical meaning

Two quantities of the main equation usually are difficult to understand: the entropy S and the chemical potential μ. But both quantities are compatible with an average person´s perception.

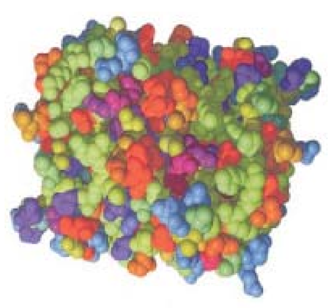
Therefore a phenomenological approach was chosen:

An object or living being is described by its external properties and not by its internal structure.

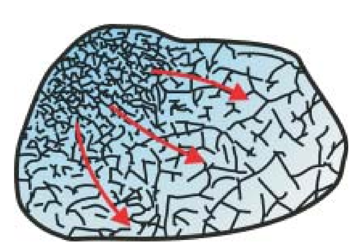
For example: What are - suricates -?



phenomenological



genotypical



Entropy
- visualized as an in matter distributed
- more or less mobile,
- producible but indestructible quantity.

These assumptions allow us to describe entropy as a substance-like quantity which can be taught in a similar fashion like the electrical charge and they form the basis of the phenomenological approach.

For characterizing an object or a person a few informations are often sufficient. But:

What are ***characteristic properties*** of the entropy?

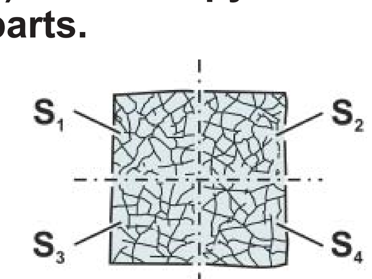
1) Objects of the same kind and in the same state contain equal amount of entropy.

S_1 = S_2 = S_3

"Entropy is a state fuction".

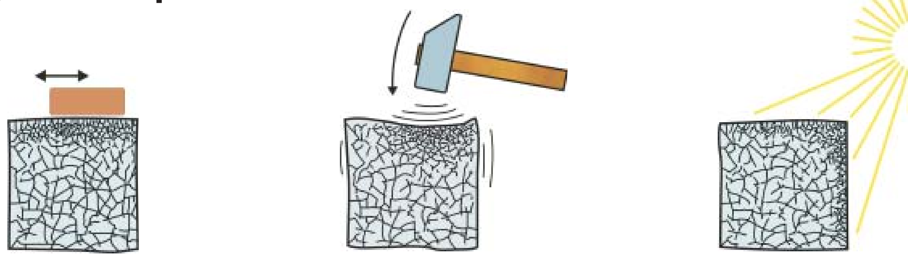
2) The entropy of a composite object equals the sum of the entropies of its parts.

"Entropy is an extensive quantity".

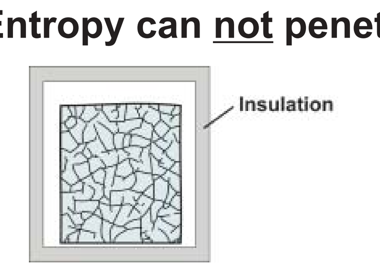


$S = S_1 + S_2 + S_3 + S_4$

3) Entropy can be produced but not destructed.



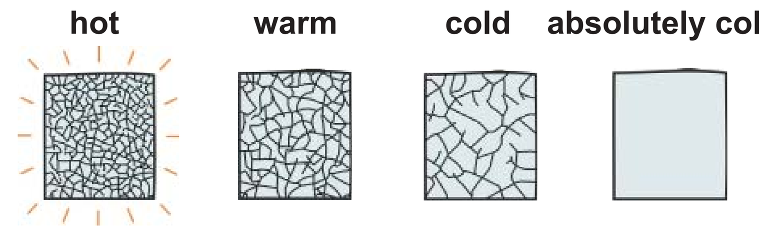
4) Entropy can not penetrate insulating walls.



Therefore, the amount of entropy in an insulated system cannot decrease but only increase.

also known as "2nd law of thermodynamics"

5)The main effect of an entropy increase is the increase in warmth. In a set of identical objects the one without entropy is absolutely cold.



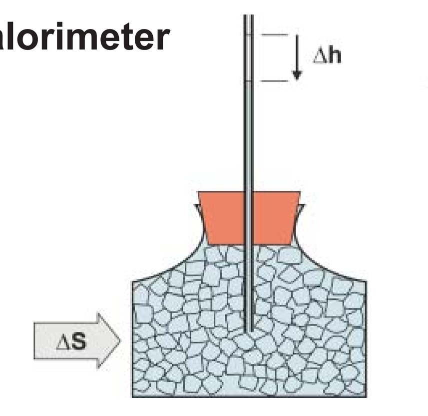
Entropy flows freely from the hottest to the coldest object.

Measuring entropy:

Entropy can be measured directly:
- Entropy streams into the bottle.
- A little bit of ice melts.
- The volume of the mixture decrease.
- The water level falls.

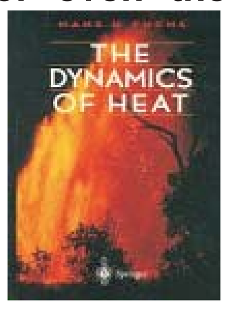
h $\frac{S}{r^2}$ 23.3 $\frac{K\ mm^3}{J}$

Ice-water-calorimeter



5 Teaching ...

The new concept induced other autors to rephrase thermodynamics or even the whole concept of physics. These conceptional changes have a strong impact not only on the education of chemists, physists, or engineers

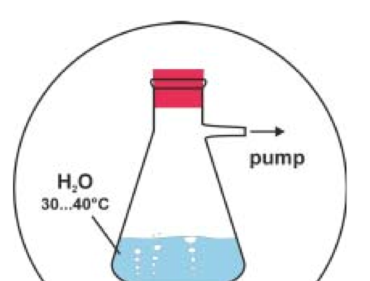


but also on physics classes at every level of education.

7 Integration of ... demonstration experiments

Detailed descriptions of more than forty simple but nevertheless impressive experiments are developped, for example:

Boiling water at low pressure



Materials:
Filtering flask
Vacuum hose
Water-jet vacuum pump

Chemicals
Warm water (30...40°C)

Safety:
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Procedure:
Fill the filtering flask to one third with water and close it with a rubber stopper.
After heating to 30...40°C evacuate the fileting flask by a water-jet vacuum pump.

Observation:
The only warm water is boiling.

Discussion:

$H_2O(l) \rightarrow H_2O(g)$

At room-temperature normally the chemical potential (g) > (l) but … At sufficiently low pressure (g) < (l) because of the pressure dependence of (= 0 + p; (g) very high.

Disposal:
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