Thermodynamics B: 6 hp

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- This course: Thermodynamics B: 6 hp,

  Additional course: Topics in Thermodynamics, 1.5 hp
  Three more lectures,
  More problems on the exam.
  Together 6.0 + 1.5 = 7.5 hp.

- Now: general information
- After the break: Introduction lecture, chapter 1.
- `http://www.tp.umu.se:Thermo/L-notes/L01-Intro.pdf`

General information

- Teaching:
  - Lectures,
  - problem solving,
  - two experimental labs.
- Examination:
  - written exam,
  - labs: one short written report, one oral discussion.
- Book: Schroeder, *An introduction to Thermal Physics*.

Course content

- The course is about **heat** and **temperature** and also **energy**, **work**, and **entropy**.
- Familiar concept except for **entropy** which is something that is difficult to grasp.
  The course introduces entropy from a microscopic viewpoint.
- **Thermodynamics**—Consider *macroscopic* properties like pressure, temperature, energy, entropy.
  Focus on *general rules* that are true for all systems.
- **Statistical physics**—Start from a *microscopic description* to derive the behavior of *macroscopic* quantities.
  Different behavior in different systems. (But still consistent with thermodynamics.)

Lots of applications

- Hot air balloon. (What is the density of air?)
- Meteorology—rising air, how do T and P depend on height?
- Pumping a bicycle tire.
- How does the boiling temperature depend on height?
- Workings of a refrigerator/heat pump.
- How can there be ice on the road when the thermometer shows temperatures above zero?
- Electrolysis and fuel cells?
- Why does one use salt to stabilize ski trails when temperatures are high?

Topics in Thermodynamics

- What happens when you cool/liquefy air?
- Why is the freezing point of a mixture of water and glycol—used for cooling care engines—so low?
- Osmotic pressure.
- $p_H = 7$ for neutral H_2O is not a definition!

Overview—Schroeder, *An introduction to Thermal Physics*

I Fundamentals

1. Energy in thermal physics: The ideal gas. Heat and work.
2. The second law: Why do many processes only happen in one direction and not the reverse? Define entropy.
3. Interactions and implications: What is temperature really? Define T from entropy. The thermodynamic identity.

II Thermodynamics

4. Engines and refrigerators: Maximum efficiency (from the second law).
5. Free energy and chemical thermodynamics: Batteries and, fuel cells. Phase transformations.

III Statistical mechanics

Chapter 6–8, next course...though they now use another textbook

1. Energy in thermal physics

1.1 Thermal equilibrium

Important since thermodynamics only holds for systems in (or close to) equilibrium.

Definition:

After two objects have been in contact long enough they are in thermal equilibrium.

- contact—lets the objects spontaneously exchange energy as heat.
- long enough—the relaxation time—time needed to reach thermal equilibrium.

$$\boxed{T_1 \,|\, T_2} \xrightarrow[\text{time}]{\text{relaxation}} \boxed{T^* \,|\, T^*}$$

$$T_1 < T_2 \qquad\qquad T_1 < T^* < T_2$$

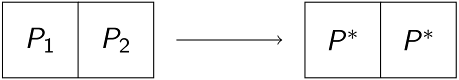
Relaxation time?

How long is a relaxation time?

Cup of coffee in a room	— a few hours
Milk in a cup of coffee	— a few seconds
Coffee in a thermos	— more than a day.

Wider concept: *Thermodynamic equilibrium*

Type of equilibrium	Exchanged quantity
thermal	energy
mechanical	volume
diffusive	particles.



$P_1 < P_2$ $\qquad$ $P_1 < P^* < P_2$

Moving wall equilibrates the pressure.

Temperature (more later in chapter 3)

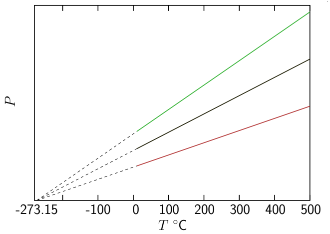
Two kinds of definitions:

1. Operational definition:
   Temperature is what you measure with a thermometer.
2. Theoretical (more later):
   Temperature is the thing that is the same for objects when they have been in contact long enough (objects in thermal equilibrium).

Note:

> *To measure the temperature of something the thermometer needs to have the same temperature, since the thermometer shows the temperature of the substance in the thermometer itself—we need to wait a relaxation time.*

1. Thermometer based on *thermal expansion* of a fluid.
2. Thermometer based on *the change of pressure* of a gas.



- Different amount of air in a bulb.
- The absolute temperature scale.

- Curves extrapolate to zero pressure at $T = -273.15°\mathrm{C}$—the zero point of the absolute temperature scale, Kelvin.
- $T_{\mathrm{Kelvin}} = T_{\mathrm{Celcius}} + 273.15$.
- Room temperature $\approx 300\mathrm{K}$ (27 °C).

Interesting temperatures

He^4 liquid,	4K	$-269°C$
liquid N_2,	77K	$-196°C$
high-T_c superconductor,	138K	$-135°C$
melting of ice,	273.15K	0°C
triple point of H_2O	273.16K	0.01°C
human body,	310K	37°C
boiling of water,	373K	100°C
combustion,	2000–3000K	

Temperatures in Farenheit:

"To convert Fahrenheit to Celsius, subtract 32 from the Fahrenheit value and then divide the result by 1.8."

0 °C	32°F
37.8 °C	100°F
100 °C	212°F

1.2 The ideal gas

$$PV = Nk_B T$$

- Valid for sufficiently dilute gases. We may then neglect the interactions between the atoms/molecules.
- This is a simple example of an *equation of state*,

$$P(V, T, N).$$

- $$\text{Recall: pressure} = P = \frac{dF}{dA}, \text{from the force on a small area.}$$

Here k_B is Boltzmann's constant. Unit?

$$[k_B] = \left[\frac{PV}{NT}\right] = \left[\frac{E}{T}\right] = \mathrm{J/K},$$

since

$$[PV] = [PA \cdot L] = [F \cdot L] = [E].$$

$$k_B = 1.38 \cdot 10^{-23} \mathrm{J/K}.$$

1.2 The ideal gas... cont'd

Also often written

$$PV = nRT,$$

with

- $n =$ number of moles $= N/N_A$,

where $N_A = 6.022 \cdot 10^{23}$ is Avogadro's number,

- $R = N_A k_B = 8.31$ J/mol K.

Units for pressure

SI-unit: Pascal, $\text{Pa} = \text{N}/\text{m}^2$.

Also:
$$
\begin{aligned}
1\ \text{bar} &= 10^5\ \text{Pa (exactly)} \\
1\ \text{atm} &= 1.013 \cdot 10^5\ \text{Pa} \\
&= 1013\ \text{mbar}.
\end{aligned}
$$

Next lecture

- Relation between temperature and kinetic energy.
  What is the typical velocity of an air molecule?
- Equipartition of energy
  How does the above result change for diatomic molecules?
- Heat and Work.
- First law of thermodynamics.