Exam Preparation: Heat and Thermo

<u>Theory:</u> Answer the questions and explain the concepts by heart

a) Vector/scalar
b) Describe the three states of matter on the molecular level. Pay attention to the following:
   - Do the atoms and molecules have fixed positions?
   - What are the attractive forces between atoms/molecules like?
   - Are the atoms/molecules close together or far apart?
c) Why do most objects expand when they warm up?
d) Temperature
e) How do temperature and the movement of the molecules and atoms relate?
f) The Celsius and the Kelvin temperature scales and their corresponding fixed points
g) Absolute zero
h) Describe the anomalous behavior of water below 4°C, compared to a “normal” substance. What happens in the liquid state between 0 °C and 4 °C, and what happens when freezing?
i) Internal energy
j) Heat
k) How do temperature and internal energy relate?
l) Give two possibilities of how to increase an object’s internal energy.
m) Specific heat capacity
n) Latent heat of fusion
o) Latent heat of vaporization
p) How does the boiling point of a substance depend on external pressure?
q) vaporize/boil/evaporate

<u>Physical quantities:</u> Know these physical quantities by heart (symbol and unit)

	symbol	unit		symbol	unit
time			velocity		
acceleration			acceleration of free fall		
mass			force		
volume			density		
length			pressure		
temperature (Celsius scale)			temperature (Kelvin scale)		
coefficient of linear expansion			coefficient of volume expansion		
work			internal energy		
heat			specific heat capacity		
latent heat of fusion			latent heat of vaporization		

Skills:

- Transform equations, insert numbers with units into the equation, calculate results correctly
- Round your results to the correct number of significant digits and write your answer with a power of ten in the normalized scientific format
- Draw and read scientific graphs
- represent vectors graphically by drawing them as arrows and solve problems by using this method
- Draw a free-body-diagram to show all the forces acting on an object (representing the forces as arrows)
- Determine the resultant of several vectors, as well as the components of a vector, using their graphical representation as arrows
- Convert the units of angle *degrees* to *radians* and vice versa
- Convert the units of pressure *Pascal* to *bar* and vice versa
- Convert units of area and volume
- Convert the units of temperature *Kelvin* to *degree Celsius* and vice versa
- Describe and explain the working principles of a refrigerator. Label its parts correctly.

Formulae: A formula sheet will be handed out. Please find the formula sheet on ga.perihel.ch.

Exercises:

An algebraic solution and all values used in calculations are required to get the full mark.

All work sheets plus assignment sheets A38 – A41

Additional problems

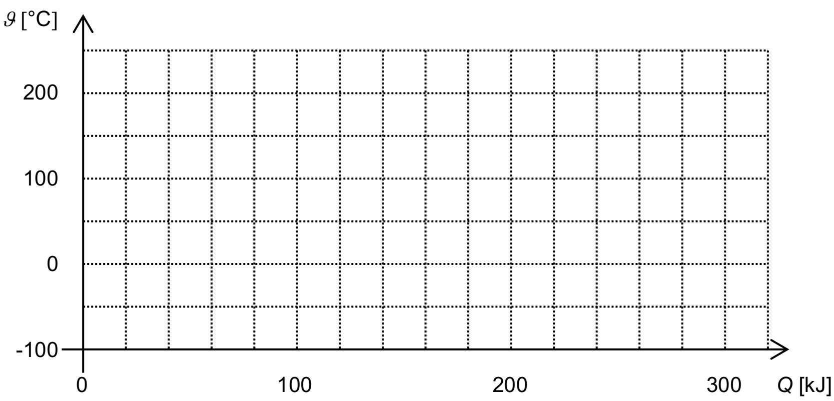
1. The internal energy of a brass ball (m = 0.148830 kg, r = 4.5 cm, ϑ = 0.0 °C) increases by ΔU = 0.011310 MJ. The increase in temperature is to be calculated.

a) Place a dot above the significant figures of the values which are required in the calculation. How many significant digits do they have? How many significant figures does your final answer require?

b) Calculate the increase in temperature.

c) Round your result to the correct number of significant figures and write it in the normalized scientific notation (with a power of ten).

2. 80.0 g of water, which initially is frozen as ice at – 100 °C, is supplied with heat while the temperature is measured, until the temperature reaches + 200 °C.
How does the temperature change while heat is supplied to the water? Determine the required values, using the table, and draw the corresponding graph in the diagram below.



3. When water vapor condenses to liquid water, is the surrounding air warmed or cooled?

4. Why is a steam burn more damaging than a burn from boiling water at the same temperature?

5. The human body can maintain its temperature of 37 °C on a day when the temperature is above 40 °C. How is this done?

6. You can determine the wind direction by wetting your finger and holding it up in the air. Discuss why.

7. A rod of gold (ℓ_0 = 0.067430 m, ϑ = 1‘063 °C) is being melted. The energy required for melting the entire rod of gold is 0.127500 kJ. The mass of the gold rod is to be calculated.
a) On the values which are required in the calculation, place a dot above the digits which are significant. How many significant digits do they have? How many significant figures does your final answer require?
b) Calculate the initial mass of the gold rod (in kg). in mm and
c) Round your result to the correct number of significant figures and write it in the normalized scientific notation (with a power of ten).

8. A bathtub holds 222 ℓ (= 222 kg) of water at a temperature of 65.0 °C. The water is to be cooled down to 37.0 °C by adding cold water of 14.0 °C.
How many liters of cold water need to be added?

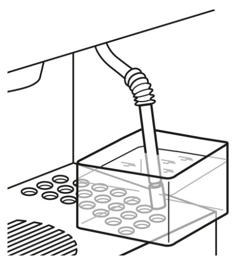
9. An unknown substance (m = 546 g, ϑ = 60.0 °C) is submerged in 300.0 g of water of temperature 25.0 °C. After a while equilibrium is reached and the final temperature is 30.0 °C. What is the specific heat capacity of the unknown substance?

10. A hot iron nail (m = 4.0 g) is submerged in 100.0 g of water of 18.0 °C. After a while, the water’s (and the nail’s) temperature is 22.0 °C.
What was the nail’s initial temperature?

11. Dan has a certain amount of water of 22.0 °C which he wishes to cool. He takes an ice cube (m = 11.0 g) of 0.0 °C and drops it into in the water. After a while, the temperature at equilibrium is 5.00 °C (no energy exchange with the surroundings ☺).
Calculate the total mass of the final mixture consisting of melted ice and water.

12. “Bleigiessen” is a New Year’s Eve tradition where a drop of molten lead is poured into a bowl of cold water. The produced shapes are then used for fortune telling.
50.0 g of lead is melted over a flame and then poured into 1.00 dℓ of water at room temperature (ϑ = 23.0 °C).
a) How much heat is needed to heat the lead to melting point and then melt it?
b) *difficult* What is the final temperature at equilibrium after the liquid lead was poured into the water?

13. Direct steam injection is a fast and efficient way of heating water for tea, for example. Claire is heating water, using the steam wand of her espresso maker (see picture).
Steam of 100.0 °C is injected into 260 g of water of 8.0 °C. The final temperature at equilibrium is 35 °C.
a) What are the two processes that the steam goes through?
b) Explain why this method is so efficient.
c) Calculate the mass of the steam required.
d) *difficult* What would be the final temperature at equilibrium, if 16.5 g of steam were injected into the water?

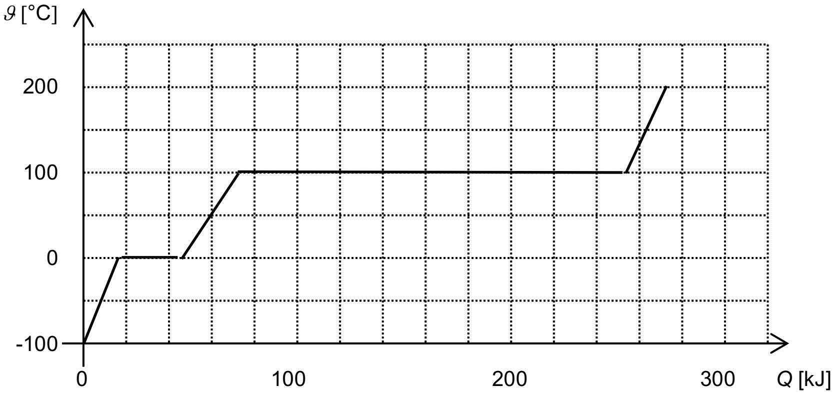


14. *difficult* A closed container holds 98.0 g of water vapor of 100 °C. How many grams of ice of 0.0 °C do you need to add in order to get water of 0.00 °C as a final product?

Solutions:

1. a) $m = 0.\dot{1}\dot{4}\dot{8}\dot{8}\dot{3}\dot{0}$ kg: 6 significant figures, $\Delta U = 0.0\dot{1}\dot{1}\dot{3}\dot{1}\dot{0}$ MJ: 5 significant figures,
$c_{\text{brass}} = 0.\dot{3}\dot{8}\dot{0} \cdot 10^3 \frac{\text{J}}{\text{kg}\cdot\text{K}}$:3 significant figures, result: 3 significant figures
(*r* and ϑ are not required)
b) $\Delta T = \dfrac{\Delta U}{c_{\text{brass}} \cdot m_{\text{brass}}} = \dfrac{11'310 \text{ J}}{380 \frac{\text{J}}{\text{K}\cdot\text{kg}} \cdot 0.148830 \text{ kg}} = 199.98 \text{ K} = 200 \text{ K}$
c) <u>$2.00 \cdot 10^2$ K</u>

2. Melting point is at 0.0 °C, boiling point is at 100 °C
Heating the ice: $Q_{\text{ice}} = c_{\text{ice}} \cdot m \cdot \Delta T_{\text{ice}} = 2.09 \cdot 10^3 \frac{\text{J}}{\text{kg}\cdot\text{K}} \cdot 0.080 \text{ kg} \cdot 100 \text{ K} = 16'720 \text{ J} =$ <u>17 kJ</u>
Melting the ice: $Q_{\text{melting}} = L_f \cdot m = 3.34 \cdot 10^5 \frac{\text{J}}{\text{kg}} \cdot 0.080 \text{ kg} = 26'720 \text{ J} =$ <u>27 kJ</u>
Heating the water: $Q_{\text{water}} = c_{\text{water}} \cdot m \cdot \Delta T_{\text{water}} = 4.182 \cdot 10^3 \frac{\text{J}}{\text{kg}\cdot\text{K}} \cdot 0.080 \text{ kg} \cdot 100 \text{ K}$
$= 33'456 \text{ J} =$ <u>33 kJ</u>
Vaporizing the water: $Q_{\text{vaporization}} = L_v \cdot m = 2.257 \cdot 10^6 \frac{\text{J}}{\text{kg}} \cdot 0.080 \text{ kg} = 180'560 \text{ J} =$ <u>181 kJ</u>
Heating the vapor: $Q_{\text{steam}} = c_{\text{steam}} \cdot m \cdot \Delta T_{\text{steam}} = 1.863 \cdot 10^3 \frac{\text{J}}{\text{kg}\cdot\text{K}} \cdot 0.080 \text{ kg} \cdot 100 \text{ K}$
$= 14'904 \text{ J} =$ <u>15 kJ</u>



3. The change of state is from vapor to liquid, which releases energy, so the surrounding air is warmed. The water molecules that condense are the slower ones. Removing the slower molecules from the water vapor increases the average speed of the molecules remaining in the gaseous state which results in an increase in temperature.

4. Steam at 100 °C contains more energy than water at 100 °C. When condensing at 100 °C to become water of 100 °C, steam releases a lot of energy in the form of heat.

5. The body maintains its temperature at a normal 37 °C by the process of evaporation. When the body tends to overheat, perspiration occurs, which cools the body if the perspiration is allowed to evaporate.

6. When a wet finger is held to the wind, evaporation is greater on the windy side, which feels cool. The cool side of your finger is windward.

7. a) $\ell_0 = 0.0\dot{6}\dot{7}\dot{4}\dot{3}\dot{0}$ m: 5 significant figures (not required), $\vartheta = \dot{1}\dot{0}\dot{6}\dot{3}$ °C: 4 significant figures (not required), $Q = 0.\dot{1}\dot{2}\dot{7}\dot{5}\dot{0}\dot{0}$ kJ: 6 significant figures, $L_f = 0.\dot{6}\dot{4} \cdot 10^5 \frac{\text{J}}{\text{kg}}$: 2 significant figures,
result: 2 figures
b) $m = \dfrac{Q}{L_f} = \dfrac{127.500 \text{ J}}{0.64 \cdot 10^5 \frac{\text{J}}{\text{kg}}} = 0.0019922 \text{ kg} = 0.0020 \text{ kg}$
c) $m =$ <u>$2.0 \cdot 10^{-3}$ kg</u>

8. The heat lost by the warmer water equals the heat gained by the cold water:
$Q = \Delta U = c_{water} \cdot m \cdot \Delta T = 4'182\ \frac{J}{kg \cdot K} \cdot 222\ kg \cdot (65.0\ °C - 37.0\ °C) = 25'995\ kJ$

$m = \frac{\Delta U}{c \cdot \Delta T} = \frac{25'995'312\ J}{4'182\ \frac{J}{kg \cdot K} \cdot (37°\ C - 14\ °C)} = 270\ kg$, that is <u>270 ℓ</u> of cold water.

9. The internal energy of the water increases by:
$\Delta U_{water} = c_{water} \cdot m_{water} \cdot \Delta T_{water} = 4'182\ \frac{J}{kg \cdot K} \cdot 0.300\ kg \cdot (30.0\ °C - 25.0\ °C) = 6'273\ J$
The required heat was lost by the unknown substance, thus its internal energy decreases by 6'273 J:

$c_{unknown\ substance} = \frac{c_{water} \cdot m_{water} \cdot \Delta T_{water}}{m_{unknown\ substance} \cdot \Delta T_{unknown\ substance}} = \frac{4.182 \cdot 10^3\ \frac{J}{kg \cdot K} \cdot 0.300\ kg \cdot 5.00\ K}{0.546\ kg \cdot 30.0\ K}$
$= \underline{\underline{383\ \frac{J}{kg \cdot K}}}$ (copper)

10. The internal energy of the water increases by:
$\Delta U_{water} = c_{water} \cdot m_{water} \cdot \Delta T_{water} = 4'182\ \frac{J}{kg \cdot K} \cdot 0.100\ kg \cdot (22.0\ °C - 18.0\ °C) = 1'673\ J$
This is the heat lost by the nail; the nail's internal energy decreases by $\Delta U_{nail} = 1'673\ J$
$\Delta T_{nail} = \frac{\Delta U_{nail}}{c_{iron} \cdot m_{nail}} = \frac{1673\ J}{450\ \frac{J}{kg \cdot K} \cdot 0.0040\ kg} = 929\ K$
$\vartheta_{initial(nail)} = \Delta T_{nail} + \vartheta_{final} = 929\ K + 22\ °\ C = \underline{951\ °C}$

11. $Q_{water} = Q_{ice} = \Delta U_{ice} + Q_{melting(ice)}$
$c_{water} \cdot m_{water} \cdot \Delta T_{water} = c_{ice} \cdot m_{ice} \cdot \Delta T_{ice} + L_{f(ice)} \cdot m_{ice} = m_{ice} \cdot (c_{ice} \cdot \Delta T_{ice} + L_{f(ice)})$
$Q_{ice} = m_{ice} \cdot (c_{ice} \cdot \Delta T_{ice} + L_{f(ice)}) = 0.011\ kg \cdot (2.09 \cdot 10^3\ \frac{J}{kg \cdot K} \cdot 5.00\ K + 3.34 \cdot 10^5\ \frac{J}{kg}) = 3'789\ J$
$m_{water} = \frac{Q_{ice}}{c_{water} \cdot \Delta T_{water}} = \frac{3'789\ J}{4'182\ \frac{J}{kg \cdot K} \cdot 17.0\ K} = 0.0533\ kg = 53.3\ g$
$m_{total} = m_{water} + m_{ice} = 53.3\ g + 11.0\ g = \underline{64.3\ g}$

12. a) Heat required to heat the solid lead from room temperature (23 °C) to the boiling point (327 °C):

$Q_{heating} = c_{lead} \cdot m_{lead} \cdot \Delta T_{lead} = 129\ \frac{J}{kg \cdot K} \cdot 0.050\ kg \cdot (327\ °C - 23\ °C) = 1'961\ J$

Heat required to melt the lead at boiling point:

$Q_{melting} = L_{f(lead)} \cdot m_{lead} = 0.23 \cdot 10^5\ \frac{J}{kg} \cdot 0.050\ kg = 1'150\ J$

$Q_{total} = Q_{heating} + Q_{melting} = 1'961\ J + 1'150\ J = 3'111\ J = \underline{3.1\ kJ}$

b) ① As the liquid lead becomes solid at boiling point, it releases heat. The released heat is absorbed by the water: $\Delta U_{water①} = Q_{freezing(lead)}$

$c_{water} \cdot m_{water} \cdot \Delta T_{water①} = L_{f(lead)} \cdot m_{lead}$

$$\Delta T_{water①} = \frac{L_{f(lead)} \cdot m_{lead}}{c_{water} \cdot m_{water}} = \frac{0.23 \cdot 10^5\ \frac{J}{kg} \cdot 0.50\ kg}{4182\ \frac{J}{kg \cdot K} \cdot 0.100\ kg} = 2.75\ K$$

$\vartheta_{water①} = \vartheta_{water(initial)} + \Delta T_{water①} = 23.0\ °C + 2.75\ K = 25.75\ °C = \underline{26\ °C}$

② As the lead cools down, it releases heat. The released heat is absorbed by the water:

$\Delta U_{water②} = \Delta U_{lead}$

$c_{water} \cdot m_{water} \cdot \Delta T_{water②} = c_{lead} \cdot m_{lead} \cdot \Delta T_{lead}$

$c_{water} \cdot m_{water} \cdot (\vartheta_{final} - \vartheta_{water①}) = c_{lead} \cdot m_{lead} \cdot (\vartheta_{lead(boiling\ point)} - \vartheta_{final})$

$$\vartheta_{final} = \frac{c_{lead} \cdot m_{lead} \cdot \vartheta_{lead(boiling\ point)} + c_{water} \cdot m_{water} \cdot \vartheta_{water①}}{c_{lead} \cdot m_{lead} + c_{water} \cdot m_{water}} =$$

$$= \frac{129\ \frac{J}{kg \cdot K} \cdot 0.050\ kg \cdot 327\ °C + 4'182\ \frac{J}{kg \cdot K} \cdot 0.100\ kg \cdot 25.75\ °C}{129\ \frac{J}{kg \cdot K} \cdot 0.050\ kg + 4'182\ \frac{J}{kg \cdot K} \cdot 0.100\ kg} = \underline{\underline{30\ °C}}$$

or (faster solution, all in one big equation ☺):

$\Delta U_{water} = Q_{freezing(lead)} + Q_{cooling(lead)}$

$c_{water} \cdot m_{water} \cdot \Delta T_{water} = L_{f(lead)} \cdot m_{lead} + c_{lead} \cdot m_{lead} \cdot \Delta T_{lead}$

$c_{water} \cdot m_{water} \cdot (\vartheta_{final} - \vartheta_{water(initial)}) = L_{f(lead)} \cdot m_{lead} + c_{lead} \cdot m_{lead} \cdot (\vartheta_{lead(boiling\ point)} - \vartheta_{final})$

$$\vartheta_{final} = \frac{L_{f(lead)} \cdot m_{lead} + c_{lead} \cdot m_{lead} \cdot \vartheta_{lead(boiling\ point)} + c_{water} \cdot m_{water} \cdot \vartheta_{water(initial)}}{c_{lead} \cdot m_{lead} + c_{water} \cdot m_{water}} =$$

$$= \frac{0.23 \cdot 10^5\ \frac{J}{kg} \cdot 0.050\ kg + 129\ \frac{J}{kg \cdot K} \cdot 0.050\ kg \cdot 327\ °C + 4'182\ \frac{J}{kg \cdot K} \cdot 0.100\ kg \cdot 23.0\ °C}{129\ \frac{J}{kg \cdot K} \cdot 0.050\ kg + 4'182\ \frac{J}{kg \cdot K} \cdot 0.100\ kg}$$

$= \underline{\underline{30.3\ °C}}$

13. a) Steam condenses to water - condensed water cools down to 35 °C
b) While the steam bubbles condense at 100 °C, they release heat. The heat is absorbed by the tea water and the water's internal energy increases and thus the temperature rises.
c) $Q_{tea} = c_{water} \cdot m_{tea} \cdot \Delta T_{tea} = 4'182 \ \frac{J}{kg \cdot K} \cdot 0.260 \text{ kg} \cdot 27 \text{ K} = 29'358 \text{ J} = 29 \text{ kJ}$

$Q_{tea} = Q_{steam} = Q_{condensation} + Q_{cooling\ (condensed\ steam)}$

$c_{water} \cdot m_{tea} \cdot \Delta T_{tea} = L_{v(water)} \cdot m_{steam} + c_{water} \cdot m_{steam} \cdot \Delta T_{condensed\ steam}$
$= m_{steam} \cdot (L_{v(water)} + c_{water} \cdot \Delta T_{condensed\ steam})$

$$m_{steam} = \frac{Q_{water}}{L_{v(water)} + c_{water} \cdot \Delta T_{condensed\ steam}} = \frac{c_{water} \cdot m_{tea} \cdot \Delta T_{tea}}{L_{v(water)} + c_{water} \cdot \Delta T_{condensed\ steam}} =$$

$$= \frac{4'182 \frac{J}{kg \cdot K} \cdot 0.260 \text{ kg} \cdot 27 \text{ K}}{2.257 \cdot 10^6 \frac{J}{kg} + 4'182 \frac{J}{kg \cdot K} \cdot 65 \text{ K}} = 0.0116 \text{ kg} = \underline{11.6 \text{ g}}$$

d) $Q_{tea} = Q_{steam} = Q_{condensation} + Q_{cooling\ (condensed\ steam)}$

$c_{water} \cdot m_{tea} \cdot \Delta T_{water} = L_{v(water)} \cdot m_{steam} + c_{water} \cdot m_{steam} \cdot \Delta T_{condensed\ steam}$

$c_{water} \cdot m_{tea} \cdot (\vartheta_{final} - \vartheta_{initial(tea)}) = L_{v(water)} \cdot m_{steam} + c_{water} \cdot m_{steam} \cdot (\vartheta_{initial(steam)} - \vartheta_{final})$

$$\vartheta_{final} = \frac{L_{v(water)} \cdot m_{steam} + c_{water} \cdot m_{steam} \cdot \vartheta_{initial(steam)} + c_{water} \cdot m_{tea} \cdot \vartheta_{initial(tea)}}{c_{water} \cdot m_{tea} + c_{water} \cdot m_{steam}} =$$

$$= \frac{2.257 \cdot 10^6 \frac{J}{kg} \cdot 0.0165 \text{ kg} + 4'182 \frac{J}{kg \cdot K} \cdot 0.0165 \text{ kg} \cdot 100.0 \text{ °C} + 4'182 \frac{J}{kg \cdot K} \cdot 0.260 \text{ kg} \cdot 8.0 \text{ °C}}{4'182 \frac{J}{kg \cdot K} \cdot 0.0165 \text{ kg} + 4'182 \frac{J}{kg \cdot K} \cdot 0.260 \text{ kg}}$$

$= \underline{46 \text{ °C}}$

14. ① Steam releases heat while condensing, ② then the condensed water (from steam) cools down and releases more heat
The released heat is absorbed by the ice while melting at 0.0 °C
$Q_{melting} = Q_{condensing} + Q_{cooling}$
$L_f \cdot m_{ice} = L_v \cdot m_{steam} + c_{water} \cdot m_{steam} \cdot \Delta T_{steam}$

$$m_{ice} = \frac{L_v \cdot m_{steam} + c_{water} \cdot m_{steam} \cdot \Delta T_{steam}}{L_f}$$

$$= \frac{2.257 \cdot 10^6 \frac{J}{kg} \cdot 0.0980 \text{ kg} + 4'182 \frac{J}{kg \cdot K} \cdot 0.0980 \text{ kg} \cdot 100 \text{ K}}{3.34 \cdot 10^5 \frac{J}{kg}} = 0.785 \text{ kg} = \underline{\underline{785 \text{ g}}}$$