

EXAM PREPARATION: BUOYANCY, HEAT AND THERMO

Theory: Answer the questions and explain the concepts by heart

- 1) Vector/scalar
- 2) 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?
- 3) Why do most objects expand when they warm a up?
- 4) Are gases compressible? Give reasons for your answer.
- 5) Are liquids compressible? Give reasons for your answer.
- 6) pressure
- 7) Pascal's principle
- 8) What is a good rule of thumb for water pressure? (in terms of quantity)
- 9) What is a good rule of thumb for atmospheric pressure? (in terms of quantity)
- 10) Vacuum
- 11) Explain how a mercury barometer works (using a given picture)
- 12) Buoyancy
- 13) Archimedes' principle
- 14) What is the condition for a submerged object to sink or to rise in a liquid?
- 15) What is the condition for an object to float at the surface of a liquid?
- 16) Temperature
- 17) How do temperature and the movement of the molecules and atoms relate?
- 18) The Celsius and the Kelvin temperature scales and their corresponding fixed points
- 19) Absolute zero
- 20) 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?
- 21) Internal energy
- 22) Heat
- 23) How do temperature and internal energy relate?
- 24) Give two possibilities of how to increase an object's internal energy.
- 25) Specific heat capacity

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
- Explain the working principle of a mercury barometer

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

Physical quantities: Know these physical quantities by heart (symbol and unit)

	symbol	unit		symbol	unit
time			velocity		
acceleration			acceleration of free fall		
mass			force		
energy			power		
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		

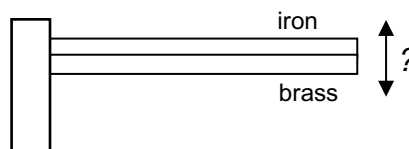
Exercises:

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

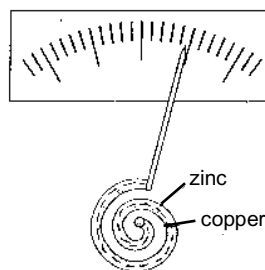
All work sheets plus assignment sheets A35 – A37

Additional problems

1. Convert the melting point of tungsten to K.
2. Complete the following sentences:
 - a) If work is done on an object, the movement of its atoms and molecules becomes intense, and it warms up.
 - b) If an object releases, the energy of the object decreases, and it cools down.
 - c) If the movement of an object's particles becomes less intense, the particles need room for moving about and the object
3. Here's a bimetallic strip of iron and brass. Which side does it bend to when heated? Give reasons for you answer.

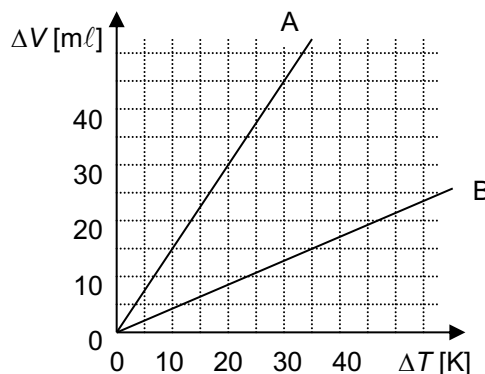


4. Here's a bimetal dial thermometer. The pointer is fixed to one end of a coiled bimetallic strip.
- Explain in a couple of sentences how this thermometer works.
 - Draw in the picture which side on the scale shows warmer temperatures and which side shows cooler temperatures.



5. If the temperature of a copper rod ($m = 0.14$ kg) increases by $\Delta T = 0.86370$ K, its length increases by $\Delta \ell = 0.001305900$ cm. The initial length (at the lower temperature) is to be calculated.
- Place a dot above the significant digits of the values which are needed in the calculation. How many significant figures do they have? How many significant figures does your final answer require?
 - Calculate the rod's initial length (in mm).
 - Round your result (in mm) to the correct number of significant figures and write it in the normalized scientific notation (with a power of ten).

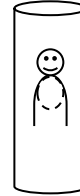
6. This graph shows how the change in volume of two liquids A and B relates to the change in temperature ($V_0 = 1'000$ mL).
- By what amount does the volume of liquid B increase, if the temperature rises by 35 K?
 - What is the coefficient of volume expansion of liquid A?
 - Draw the graph for alcohol ($V_0 = 1'000$ mL).



7. You mount your brand new rocket to go on a trip through space in order to visit a friend who lives on a distant star. At departure ($\vartheta_{\text{Earth}} = 31.0$ °C), the antenna of your space rocket is 5.0000 m long. In space ($T = 4.00$ K), looking out the window, you notice that the antenna has shrunk by 3.57 cm!
- What material is the antenna made of?
 - At landing the antenna's length is 5.0700 m. What is the temperature (in °C) on your friend's star?
8. A spoon of copper ($m = 20.0$ g) and a spoon of aluminium ($m = 20.0$ g) are rubbed vigorously with a cloth, each one a hundred times back and forth.
- Describe what happens to the atoms in the spoons.
 - Which one of the spoons is warmed more? Give reasons for your answer.
 - How much frictional work is needed for each one of the spoons to increase its temperature by 2.00 K (assuming no energy is exchanged with the surroundings)?
9. *difficult* What is the density of silver at 120.0 °C? (the densities given in the table are for 20.0 °C)?
10. An iron cylinder ($m = 0.0706300$ kg) is fully submerged in olive oil. The buoyant force acting on it is 0.081100 N. The volume of the cylinder is to be calculated (in m³).
- Place a dot above the significant digits of the values which are needed in the calculation. How many significant figures do they have? How many significant figures does your final answer require?
 - Calculate the cylinder's volume (in m³).
 - Round your result (in m³) to the correct number of significant figures and write it in the normalized scientific notation (with a power of ten).

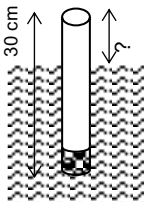
11. Which ones of these sentences are correct, which ones are wrong? Give reasons for your answer and correct the wrong sentences.
- The deeper below the surface of a liquid an object is submerged, the larger is the buoyant force.
 - When submerging a block of aluminium and a block of lead (of equal volume) in a liquid, the buoyant force acting the aluminium block is larger.
 - When submerging a block of aluminium and a block of copper (of equal mass) in a liquid, the buoyant force acting the aluminium block is larger.

12. The toy “Cartesian diver” requires a water filled container which can be squeezed together. In the water there is a little figure with a bubble of air in its belly. The figure is open at the bottom. When exerting pressure by squeezing the container the diver sinks. Explain!



13. An empty glass sphere ($V = 100 \text{ cm}^3$) is suspended at one end of a balance scale and at the other end a small metal block ($V = 2.00 \text{ cm}^3$) is suspended. The scale is at equilibrium in air. Then the air is removed by a vacuum pump. What side does the scale tilt to? Why?

14.



A tube of aluminium ($m = 120.0 \text{ g}$, $A = 12.0 \text{ cm}^2$, $h = 30.0 \text{ cm}$, see picture) is filled with small bullets of lead ($m = 150.0 \text{ g}$). It floats in alcohol.

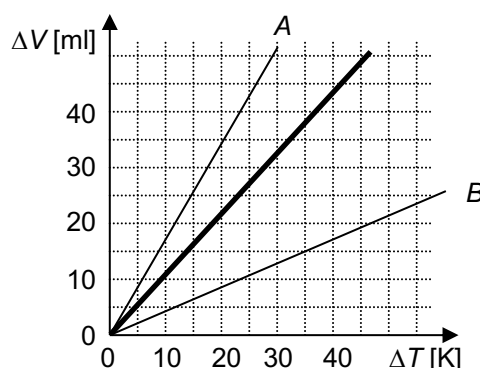
- How far does the tube stick out of the alcohol?
- How much lead needs to be added for the tube to sink in one more centimeter?

Solutions:

- 3390 °C + 273.15 = 3'663.15 K
- If **frictional work** is done on an object, the movement of its atoms and molecules becomes **more** intense, and it warms up.
 - If an object releases **heat**, the **internal energy** of the object decreases, and it cools down.
 - If the movement of an object's particles becomes less intense, the particles need **less** room for moving about and the object **contracts**.
- Upwards. Reason: The coefficient of linear expansion of brass ($\alpha_{\text{brass}} = 18 \cdot 10^{-6} \frac{1}{\text{K}}$) is greater than the coefficient of linear expansion of iron ($\alpha_{\text{iron}} = 12 \cdot 10^{-6} \frac{1}{\text{K}}$).
- Two metal strips of different coefficients of linear expansion are bonded together and rolled up in the form of a coil. If the temperature rises, zinc expands more than copper, which causes the bimetallic strip to bend. The end of the coil is attached to a pointer which then moves to the right or left and the temperature can be read on a scale.
 - left: cool; right: warm
- $m = 0.14$ kg: 2 significant figures (not required), $\Delta T = 0.86370$ K: 5 significant figures, $\Delta l = 0.001305900$ cm: 7 significant figures, $\alpha = 16.8 \cdot 10^{-6} \frac{1}{\text{K}}$: 3 significant figures, result: 3 figures
 - $l_0 = \frac{\Delta l}{\alpha \cdot \Delta T} = \frac{0.0001305900 \text{ m}}{16.8 \cdot 10^{-6} \frac{1}{\text{K}} \cdot 0.86370 \text{ K}} = 0.8999990076 \text{ m} = 0.900 \text{ m} = 900 \text{ mm}$
 - $l_0 = \underline{9.00 \cdot 10^2 \text{ mm}}$

- 15 ml
 - e.g. at $\Delta T = 20$ K, $\Delta V = 30$ ml

$$\gamma = \frac{\Delta V}{V_0 \cdot \Delta T} = \frac{30 \text{ ml}}{1'000 \text{ ml} \cdot 20 \text{ K}} = \underline{0.0015 \frac{1}{\text{K}}}$$
 - e.g. at $\Delta T = 40$ K,
 $\Delta V = \gamma \cdot V_0 \cdot \Delta T =$
 $= 0.00110 \frac{1}{\text{K}} \cdot 1000 \text{ ml} \cdot 40 \text{ K} = \underline{44 \text{ ml}}$



- $\alpha = \frac{\Delta l}{l_0 \cdot \Delta T} = \frac{3.57 \text{ cm}}{500 \text{ cm} \cdot (304 \text{ K} - 4.00 \text{ K})} = 2.38 \cdot 10^{-5} \frac{1}{\text{K}} = 23.8 \cdot 10^{-6} \frac{1}{\text{K}}$ aluminium
 - $\Delta T = \frac{\Delta l}{l_0 \cdot \alpha} = \frac{7.00 \text{ cm}}{500 \text{ cm} \cdot 2.38 \cdot 10^{-5} \frac{1}{\text{K}}} = 588 \text{ K}$ $\vartheta_{\text{star}} = \vartheta_{\text{Earth}} + \Delta T = 31.0 \text{ °C} + 588 \text{ K} = \underline{619 \text{ °C}}$
- By rubbing frictional work is done on the spoons which causes the atoms of the spoons to vibrate more, and the temperature increases.
 - The temperature of copper increases more, because its specific heat capacity is smaller and it needs to absorb less energy for a greater increase in temperature.
 - Copper: $\Delta U = c \cdot m \cdot \Delta T = 0.383 \cdot 10^3 \frac{\text{J}}{\text{kgK}} \cdot 0.0200 \text{ kg} \cdot 2.0 \text{ K} = \underline{15.3 \text{ J}}$
Aluminium: $\Delta U = c \cdot m \cdot \Delta T = 0.896 \cdot 10^3 \frac{\text{J}}{\text{kgK}} \cdot 0.0200 \text{ kg} \cdot 2.0 \text{ K} = \underline{35.8 \text{ J}}$

9. $\rho = \frac{m}{V} = \frac{10'510 \text{ kg}}{1.000 \text{ m}^3}$ at 20 °C.

The edge of the cube at 120.00 °C is $l = l_0 + \Delta l = l_0 + \alpha \cdot l_0 \cdot \Delta T$

$$= l_0 \cdot (1 + \alpha \cdot \Delta T) = 1.000 \text{ m} \cdot (1 + 19.7 \cdot 10^{-6} \frac{1}{\text{K}} \cdot 100 \text{ K}) = 1.00197 \text{ m}$$

The volume of the cube at 120 °C is $V = l^3 = (1.00197 \text{ m})^3 = 1.00592 \text{ m}^3$.

$$\text{The density at 120 °C is } \rho = \frac{m}{V} = \frac{10'510 \text{ kg}}{1.00592 \text{ m}^3} = 10'448 \frac{\text{kg}}{\text{m}^3} = \underline{\underline{10.45 \cdot 10^3 \frac{\text{kg}}{\text{m}^3}}}$$

10. a) $F_B = 0.081100 \text{ N}$: 5 significant figures, $\rho_{\text{olive oil}} = 0.92 \cdot 10^3 \frac{\text{kg}}{\text{m}^3}$: 2 significant figures,
 $g = 9.81 \frac{\text{m}}{\text{s}^2}$: 3 significant figures, $m = 0.0706300 \text{ kg}$: 6 significant figures (not needed),
 result: 2 digits

b) $V_{\text{immersed}} = \frac{F_B}{\rho_{\text{olive oil}} \cdot g} = \frac{0.081100 \text{ N}}{0.92 \cdot 10^3 \frac{\text{kg}}{\text{m}^3} \cdot 9.81 \frac{\text{m}}{\text{s}^2}} = 0.000008986 \text{ m}^3 = 8.986 \cdot 10^{-6} \text{ m}^3$

c) $V_{\text{immersed}} = \underline{\underline{9.0 \cdot 10^{-6} \text{ m}^3}}$

11. a) Wrong: The buoyant force does not depend on the depth.
 b) Wrong: The buoyant force is the same because they have the same volume.
 c) Right: Aluminium is less dense and therefore its volume is larger which accounts for a larger buoyant force.
12. Squeezing the bottle increases the pressure in the water. Water is incompressible, but air is compressible, thus the size of the air bubble is reduced. The volume of the diver decreases and so does the buoyant force. This causes the diver to sink.
13. It tilts to the side of the glass sphere. Reducing the density of air reduces buoyancy. In air the buoyancy acting on the sphere was more than the buoyancy acting on the small metal block. In fact the sphere is a little heavier than the metal block, and without the "help" of buoyancy the truth comes out! ☺
14. a) $F_G = m \cdot g = F_B = \rho_{\text{liquid}} \cdot g \cdot V_{\text{immersed}} = \rho_{\text{liquid}} \cdot g \cdot A \cdot h_{\text{immersed}}$

$$h_{\text{immersed}} = \frac{m \cdot g}{\rho_{\text{liquid}} \cdot g \cdot A} = \frac{m_{\text{tube+lead}}}{\rho_{\text{alcohol}} \cdot A} = \frac{0.2700 \text{ kg}}{789 \frac{\text{kg}}{\text{m}^3} \cdot 0.00120 \text{ m}^2} = 0.285 \text{ m} = 28.5 \text{ cm}$$

 30.0 cm – 28.5 cm = 1.5 cm are sticking out of the liquid.
- b) 1.0 cm deeper: $h_{\text{immersed}} = 29.5 \text{ cm}$; $V_{\text{immersed}} = 29.5 \text{ cm} \cdot 12.0 \text{ cm}^2 = 354 \text{ cm}^3$
 $(m + m_{\text{additional lead}}) \cdot g = \rho_{\text{liquid}} \cdot g \cdot V_{\text{immersed}} = \rho_{\text{liquid}} \cdot g \cdot A \cdot h_{\text{immersed}}$
 $(m + m_{\text{additional lead}}) = \rho_{\text{liquid}} \cdot V_{\text{immersed}} = \rho_{\text{alcohol}} \cdot A \cdot h_{\text{immersed}}$
 $m_{\text{additional lead}} = \rho_{\text{alcohol}} \cdot A \cdot h_{\text{immersed}} - m = 789 \frac{\text{kg}}{\text{m}^3} \cdot 0.00120 \text{ m}^2 \cdot 0.295 \text{ m} - 0.2700 \text{ kg} =$
 $0.0093 \text{ kg} = \underline{\underline{9.3 \text{ g}}}$