1) Consider an aluminum bar with α_1 and Y_1, and a steel bar with α_2 and Y_2, being their coefficient of linear expansion and Young's modulus, respectively. These two bars are bolted together at one end, and bolted to two rigid walls at the other end. The distance between the walls is D and the rods are surrounded by a rigid material (so they can not bend). See fig. 1. If there is no tension the length of the bars are L_0 at T_0 and their area is A. We call the joint point position x, so the aluminum bar's length is x and the steel bar's length is $D - x$. Remember the force formula for a change in length ΔL and a change in temperature ΔT is given by, $F/A = Y(\Delta L/L_0 - \alpha\Delta T)$. Assume that $\alpha\Delta T \ll 1$ and $\Delta L \ll L_0$, so take A to be constant. The walls will not move with temperature change.

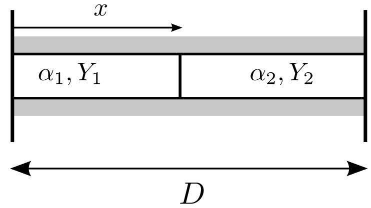

Figure 1: Two bars between solid walls.

a) Use $\Delta T = 0$ and write down mechanical equilibrium condition for the bars and find x at T_0.
b) Write the equilibrium condition at temperature T and find $x(T)$. In what condition x will be independent of T, i.e. $x(T) = x(T_0)$?

2) A steel rod is bolted to two rigid walls at both ends, at temperature T_0. The walls are at a distance D from each other and the ultimate tensile stress of this steel material is F_{C}. In what temperature this rod would rapture?

3) pendulums
A pendulum clock is sensitive to the temperature, because the length of the pendulum rod changes as temperature changes.

a) The Gridiron pendulum uses the idea that one can use two different materials, with the coefficients of expansion α_1 and α_2. See fig. 2. Take the total length of the first material to be L_1 and the second to be L_2 at some temperature. The hanging mass is a point mass and all the connections are bolted other than the pivot. Find the condition so that the pendulum's period does not change with temperature change.
b) The mercury pendulum uses the expansion of mercury to compensate the rod getting longer. Consider a rod with length L_0 and the coefficient of expansion α, connected to a container which has some mercury in it, with height h_0. The mass of the mercury is m. Neglect any change in the container with temperature change and take its mass to be zero. The mass of the uniform rod is M. Find the condition so that the period of this pendulum does not depend on the temperature.

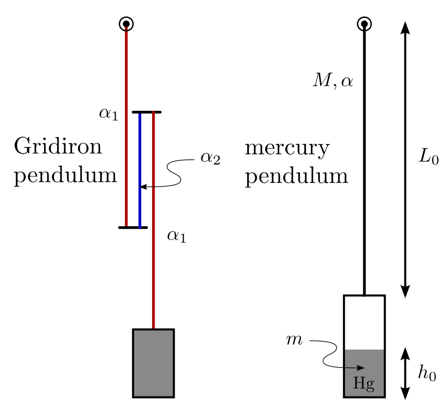

Figure 2: The pendulum clock temperature compensation.

4) [quiz related] An aluminum tea kettle with mass $m_{\text{Al}} = 1.5$ kg and containing $m_{\text{W}} = 1.8$ kg of water is placed on a stove. The specific heat capacity of water, ice, and aluminum are $c_{\text{W}} = 4.2$ kJ/kg · K, $c_{\text{I}} = 2.1$ kJ/kg · K, and $c_{\text{Al}} = 0.91$ kJ/kg · K, respectively. The latent heat of fusion for water is $L_{\text{f}} = 334$ kJ/kg.
a) If no heat is lost to the surrounding, how much heat must be added to raise the temperature from 20°C to 85°C?
b) Now that the temperature is 85°C, if we throw a piece of ice with mass $m_{\text{I}} = 0.5$ kg and temperature −20°C inside this hot water, what would be the final temperature of the system?

5) There is a lake in the neighborhood with a layer of ice on top. You are interested to know how the ice thickness changes with time. So instead of actually measuring it, you come sit in this class and try to see if you can use a simple model. You take the lake to be a cylinder, i.e. the cross-section does not change with the depth. See the fig. 3. You assume that there is only one way the system of ice and water transfer heat, which is conduction through ice, between the water and air. There is no other heat transfer. We know ice density ρ, ice conductivity κ, and the latent hear for fusion of water is L_{f}.

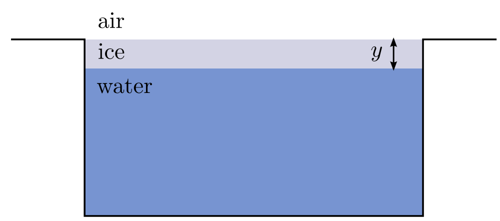

Figure 3: The ice layer on top of the lake.

a) Call the ice thickness y. Assume that the air temperature outside is constant T in degrees Celsius. Find $\mathrm{d}y/\mathrm{d}t$, where t is time. Then, show that,

$$y(t) = \left[\frac{2\kappa}{\rho L_{\text{f}}}(-T)t + y(0)^2\right]^{1/2}, \tag{1}$$

where $y(0)$ is the ice thickness at $t = 0$.
b) If the temperature outside changes with time as $T(t)$, write an expression for $y(t)$.
c) [fun] Get $T(t)$, during couple of freezing months, from a weather channel. Do the integration and find $y(t)$. Go check if it matches with the ice layer thickness.

6) Leidenfrost effect
The water drops can survive for a long time on top of a really hot pan with temperature T_{p}. The reason, known as Leidenfrost effect, is that the drops hover over a thin layer of air and water vapor, with thickness d (assume d is constant). To make the estimation easier, assume a water drop which is a cylinder with height h_0 and area A_0. While evaporating, the water drop shrinks and stays similar to its initial shape. The temperature of the water drop is $T_{\text{w}} = 100$°C. Take the thermal conductivity of the air and water vapor underneath the water drop to be κ.
a) Find the energy conducted from the pan to the drop.
b) If this heat conduction from the pan is the only heat exchange of the water drop with its environment, find $h(t)$ as a function of time t. How long will the water drop last?

7) Consider N layers of material, stuck together in series from left to right, with the same cross-section area A, the thermal conductivities $k_1, \ldots, k_N$, and the thicknesses $l_1, \ldots, l_N$. The temperature on the left of the leftmost layer is T_0, and on the right of the rightmost layer it is T_N. The energy transfer through these layers are steady.
a) Find the rate of energy transfer.
b) Find T_j, the temperature at the right side of j-th layer.

8)
a) Explain why there is no polar mouse but there are polar bears.
b) Explain the penguin huddling and how it helps in sever cold weather of the Antarctic.

9) The pV-diagram in fig. 4 shows a cycle of a heat engine that uses 0.250 mole of an ideal gas having $\gamma = 1.40$. The curved part ab of the cycle is an adiabatic process.

a) Find the pressure of the gas at point a.
b) Find Q_{ab}, Q_{bc}, and Q_{ca}, the heat in each one of the processes.
c) Find W_{ab}, W_{bc}, and W_{ca}, the work done by gas in each one of the processes.
d) Find E_a, E_b, and E_c, the internal energy of the states a, b, and c.

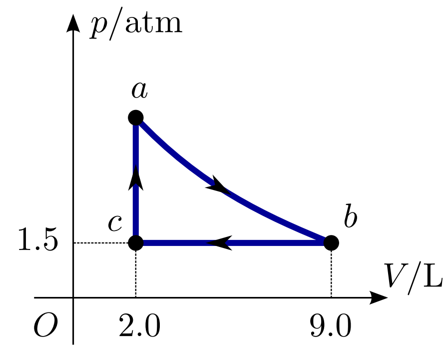

Figure 4: pV-diagram.

10) One mole of a monatomic ideal gas goes through the states by the paths or processes shown as curves with directions in fig. 5. For each one of the diagrams, find work and heat for any process, and find internal energy for any state. The needed information for each diagram are given. If the information is not enough to find a parameter, discuss it.

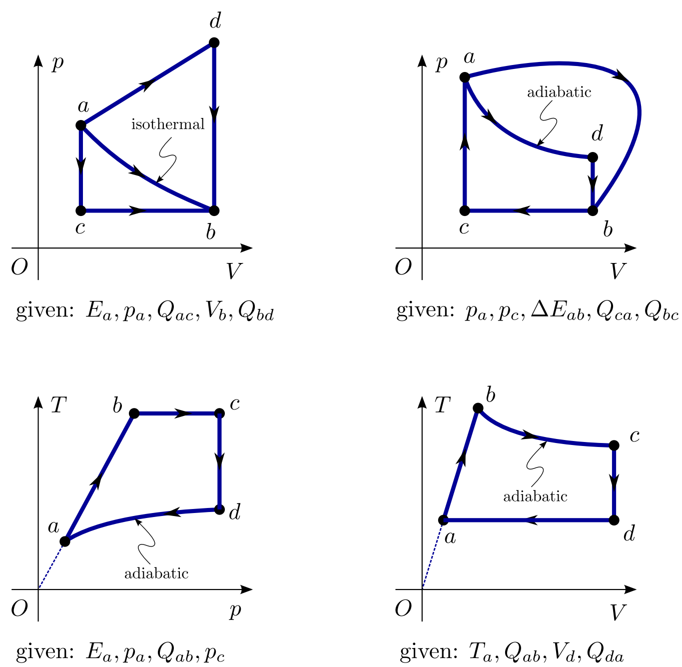

Figure 5: Some diagrams.